# Stellarium 25.4 User Guide

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# Foreword for Stellarium 25.2

Only a few months ago, in the previous foreword, we could announce big updates with the new Gaia-based star catalog and the new file format for Skycultures. But there are more surprises!

Just as we prepared version 24.4 last December and had first trials with the new star catalog, a new contributor presented his plugin. Josh Meyers has developed a *Stellarium plugin for* his *commissioning work at the new Vera C. Rubin observatory's Simonyi Survey Telescope*[1].

Some messages have to be read more than once to sink in. *Stellarium is used during commissioning of the survey telescope at the Vera C. Rubin observatory.* This is doubtlessly one of the most jaw-dropping astronomical instruments to become operational in this decade, capturing repeated surveys of the whole sky that take only 3 days with its gigantic 3.2 Gigapixel sensor array, and scheduled to producing 20 Terabytes of data. Per night! Josh's plugin just didn't make it into 25.1, but is now integrated in version 25.2 (see 16.4), just in time as first-light images have been announced for the week after our June 2025 solstice release. It is great to see that Stellarium is used in the control room of this magnificent telescope!

You may not run your own survey telescope, but with this plugin you can display several preconfigured sensor areas, and even configure your own dream system. I can imagine it can help in outreach, when the fields of view for professional telescopes can be demonstrated in Stellarium's sky rendition.

Another new plugin that certainly more of you have been waiting for: Wang Siliang has made integrating your own astrophotos into Stellarium so much easier! In his NebulaTextures plugin (see 13.9), just upload an image to Astrometry.net and receive its accurate location within seconds, then display and finetune, and store in your private collection for running in future Stellarium sessions. You can also manually adjust positions, which might be useful to integrate your sketches and paintings (which Astrometry.net may not like). We would like to see a collection of sketches that more represent what observers can see to use as alternative to the ever more stunning photos.

While these new plugins will certainly find friends soon, the core team and our tireless translators were busy in continuing what was first visible in version 25.1. Stellarium has become the de-facto most relevant simulation environment for cultural astronomy, be it archaeoastronomical simulation of old standing stone rows under simulated skies of yesteryear, or explaining the constellations and how they can be used in the lives of the many cultures living on our planet.

The new skyculture file format has grown far, closing the deficiencies of the old system that we and some of you had identified in the last years. Stellarium can now display multiple linguistic variants of constellation and star labels, can show "single star constellations" and "dark constellations" formed by dust clouds in the Milky Way, can properly identify Morning and Evening star, and for those cultures where it is relevant, illustrate the zodiac and lunar stations or lunar mansions in various culture-dependent versions, and some more. All details of the new format can be found in chapter 9.

If something about star names is not found in a skyculture description, chances are such data are or will soon be available in a new online project by Susanne M. Hoffmann, the All Skies Encyclopaedia (ASE). Stellarium's OnlineQueries plugin (13.7) can now retrieve data for stars and constellations from ASE into its

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[1]Wording clarified since the 25.2 User Guide.

integrated web browser.

So, Stellarium is going strong as we approach the 25th anniversary of this project! Twenty-five years ago, in summer of 2000, Fabien Chéreau typed the first lines of code of this desktop planetarium to try something with astronomy and computer graphics. What has grown from these first lines is just awesome.

However, developing and maintaining a project of this size needs dedication, especially when done as unpaid side occupation. Large progress needs funding which is sometimes hard to find. We want to thank all sponsors and backers of the project as meanwhile we had collected substantial funds to support this development also in work hours. We like working on this project, but also must pay our bills, so please keep up your kind support!

In the name of all prior and current developers we wish you much enjoyment with this and future versions of the Stellarium desktop planetarium!

Georg Zotti and Alexander Wolf, June 2025

## . . . and on to V25.3. . .

Over the summer we have further refined many details around skycultures. Contributors have provided and updated many details especially in Arab, Chinese and even Mesopotamian skycultures. Don't imagine, just see Cuneiform labels in the sky!

We have also updated the DSO catalog and further enhanced the AstroCalc module. And we dare to increase the maximum range of dates to ±200.000 years to observe stellar proper motion. (Please note that planet positions by far cannot be modelled in that long time range!)

Clear skies!

Georg Zotti and Alexander Wolf, September 2025

## . . . and V25.4

Our refinements around skycultures continued. Our skyculture researcher, Susanne M. Hoffmann, and her international peers and students have created no less than 4 new skycultures and refined several more. One is a remarkable Chinese adaptation of the standard IAU constellations which replaces the internationally known constellations by characters from the *Journey to the West*, a well-known story from classical Chinese literature. While we cannot provide the whole story and surely all of us not familiar with the story will miss a lot, the cute artwork alone, together with the standard names available in the "Byname" labels, may bring a fresh view to the old figures.

Some time ago, a user asked why our speech output was so bad. To be honest, I was not even aware of the current state of operating system support to output audibly whatever text is shown in the user interface. But indeed there are places where speech output may be helpful even for users without visibility problems. When you have selected a constellation, you may now hear whatever the skyculture author had to say about it. Spoken Information is also available for stars, planets and deep-sky objects. Also the introductory sections of skycultures, and landscape descriptions can be read out. Of course this needs texts translated to your user language, so our thanks again go to our team of translators, we know the amount of text in the sky cultures is quite a challenge. It also needs support of your language by the speech engines, this is out of our hands. Some details may still sound a bit rough, we are also still learning here, so further improvements are likely. And: If you are expert in the field of accessibility and want to redesign and extend this to become fully functional, we welcome your support!

You may also see this User Guide has fewer pages than the last. We have slightly redesigned the appearance and reduced font size, but the actual content has again grown.

Clear skies!

Georg Zotti and Alexander Wolf, December 2025

# Basic Use

# 1. Introduction

*Stellarium* is a software project that allows people to use their home computer as a virtual planetarium. It calculates the positions of the Sun and Moon, planets and stars, and draws how the sky would look to an observer depending on their location and the time. It can also draw the constellations and simulate astronomical phenomena such as meteor showers or comets, and solar or lunar eclipses.

Stellarium may be used as an educational tool for teaching about the night sky, as an observational aid for amateur astronomers wishing to plan a night's observing or even drive their telescopes to observing targets, or simply as a curiosity (it's fun!). Because of the high quality of the graphics that Stellarium produces, it is used in some real planetarium projector products and museum projection setups. Some amateur astronomy groups use it to create sky maps for describing regions of the sky in articles for newsletters and magazines, and the exchangeable sky cultures feature invites its use in the field of Cultural Astronomy research and outreach.

Stellarium is under continuous development, and by the time you read this guide, a newer version may have been released with even more features than those documented here. Check for updates to Stellarium at the Stellarium website[1].

If you have questions and/or comments about this guide, or about Stellarium itself, visit the Stellarium site at GitHub[2] or our Google Groups forum[3].

## 1.1 Historical notes

Fabien Chéreau started the project during the summer 2000, and throughout the years found continuous support by a small team of enthusiastic developers.

Here is a list of past and present major contributors sorted roughly by date of arrival on the project:

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[1] `https://stellarium.org`
[2] `https://github.com/Stellarium/stellarium`
[3] `https://groups.google.com/forum/#!forum/stellarium`

**Fabien Chéreau**  original creator, maintainer, general development

**Matthew Gates**  maintainer, original user guide, user support, general development

**Johannes Gajdosik**  astronomical computations, large star catalogs support

**Johan Meuris**  GUI design, website creation, drawings of our 88 Western constellations

**Nigel Kerr**  Mac OSX port

**Rob Spearman**  funding for planetarium support

**Barry Gerdes**  user support, tester, Windows support. Barry passed away in October 2014 at age 80. He was a major contributor on the forums, wiki pages and mailing list where his good will and enthusiasm is strongly missed.  RIP Barry.

**Timothy Reaves**  ocular plugin

**Bogdan Marinov**  GUI, telescope control, other plugins

**Diego Marcos**  SVMT plugin

**Guillaume Chéreau**  display, optimization, Qt upgrades, HiPS surveys

**Alexander Wolf**  maintainer, DSO catalogs, AstroCalc module, user guide, general development

**Georg Zotti**  astronomical computations, Scenery 3D plugin, ArchaeoLines and Calendars plugins, general development, user guide, user support

**Marcos Cardinot**  MeteorShowers plugin

**Florian Schaukowitsch**  Scenery 3D plugin, Remote Control plugin, RemoteSync plugin, OBJ rendering, Qt/OpenGL internals

**Teresa Huertas Roldán**  Planetary nomenclature

**Jocelyn Girod**  Observing Lists

**Ruslan Kabatsayev**  ShowMySky Skylight model (based on Bruneton's model)

**Worachate Boonplod**  Eclipse computations

Unfortunately time is evolving, and most members of the original development team are no longer able to devote most of their spare time to the project (some are still available for limited work which requires specific knowledge about the project).

As of 2017, the project's maintainer is Alexander Wolf, doing most maintenance and regular releases. He has also introduced the AstroCalc module. Other new features are contributed mostly by Georg Zotti and his team focusing on extensions of Stellarium's applicability in the fields of historical and cultural astronomy research (which means Stellarium is getting more accurate) and outreach (making it usable for museum installations), but also on graphic items like comet tails, light pollution artwork or the Zodiacal Light.

A detailed track of development can be found in the `ChangeLog` file in the installation folder.  A few important milestones for the project:

**2000**  first lines of code for the project

**2001-06**  first public mention (and user feedbacks!) of the software on a French amateur astronomy news-group[4]

**2003-01**  Stellarium reviewed by Astronomy magazine

**2003-07**  funding for developing planetarium features (fisheye projection and other features)

**2005-12**  use accurate (and fast) planetary model

**2006-05**  Stellarium "Project Of the Month" on SourceForge

**2006-08**  large stars catalogs

**2007-01**  funding by ESO for development of professional astronomy extensions (VirGO)

**2007-04**  developers' meeting near Munich, Germany

**2007-05**  switch to the Qt4 library as main GUI and general purpose library

**2009-09**  plugin system, enabling a lot of new development

**2010-07**  Stellarium ported on Maemo mobile device

**2010-11**  artificial satellites plugin

**2014-06**  high quality satellites and Saturn rings shadows, normal mapping for moon craters

**2014-07**  v0.13.0: adapt to OpenGL evolutions in the Qt5 framework, now requires more modern graphic hardware than earlier versions

**2015-04**  v0.13.3: Scenery 3D plugin

**2015-10**  v0.14.0: Accurate precession

**2016-07**  v0.15.0: Remote Control plugin

**2016-12**  v0.15.1: DE430&DE431, AstroCalc, DSS layer, and Stellarium acting as SpoutSender

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[4]`https://groups.google.com/d/topic/fr.sci.astronomie.amateur/OT7K8yogRlI/discussion`

**2017-06** v0.16.0: Remote Sync plugin, polygonal OBJ models for minor bodies, RTS2 telescope support
**2017-09** v0.16.1: Standard and extended DSO catalog, new subcatalogues for DSO
**2017-12** v0.17.0: Nomenclature labels for planets and moons, INDI telescope support
**2018-03** v0.18.0: Multiple image surveys
**2019-12** v0.19.3: ASCOM telescope support
**2020-09** v0.20.3: Accurate seasons' beginnings
**2021-03** v0.21.0: Accurate planet rotation (Libration, central meridians, subsolar points, . . . )
**2021-09** v0.21.2: Annual aberration, DE440&441. Accuracy goals reached.
**2022-10** **Stellarium 1.0**: Switch to Qt6, ShowMySky skylight model, Eclipse details.
**2025-03** v25.1: New star catalog, parallax and revolving binary stars, new Skyculture file format.

## 1.2 Version Numbers

Since its inception, Stellarium's version number had started with 0 to indicate "work in progress". The numbers after that have followed a year.release convention with approximately seasonal releases since 2018. (For example, 0.18.2 was the third release in 2018 which appeared around autumn equinox, after 0.18.0 and 0.18.1.) If needed urgently, there can be additional releases which however break the simple season count.

A software version number of 1.0 signifies a milestone of some sort, like completion of a particular original feature set, usability, or stability. With the completion of the original accuracy issues in 2021 we felt it was time to finally change version number to 1. However, a major technical update in the underlying Qt framework also forced some technical changes upon us to ensure Stellarium will remain working in the later 2020s, and therefore we decided to base the 1.* series on the new version of Qt.

Qt6 does not support old hardware, particularly 32-bit systems will not be able to run 1.* versions. Therefore, we are going to keep both series alive for those with older hardware. Thanks to only minor differences in the underlying frameworks, both series should retain feature equivalence. The only notable difference for now lied in the Scripting functionality (see chapter 17). Our "internal" version numbers therefore indicated which version of Qt was used: series 0.* continued to be based on Qt5, and series 1.* was based on Qt6.

In 2023 we've changed the numbering scheme again to avoid new misunderstandings. Our "internal" version has a standard of 3 components[5], where the first indicates the two last digits of the year of release, the second is the release within that year (0 is used before first release, from January to March) and the last one can be 0 for releases, or the day number of the current year for snapshots. Our short ("public") version has 2 components: year and number of the release. Example: the first release in year 2023 has version 23.1.0 and short (public) version 23.1, the series has number 23.0.

In addition to the version number we are adding the name component qtX, where X is 5 or 6 respectively and marks the major version of Qt which is used as the base for the package.

## 1.3 Acknowledgements

Stellarium has been kindly supported by ESA in their Summer of Code in Space initiatives, which so far has resulted in better planetary rendering (2012), the Meteor Showers plugin (2013), the web-based remote control and an alternative solution for planetary positions based on the DE430/DE431 ephemeris (2015), the RemoteSync plugin and OBJ models (2016), and the planet nomenclature labels (2017). Some of Georg's work of 2015–2023 was supported by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Vienna, Austria.

Stellarium receives funding on OpenCollective. We thank all our sponsors and backers who help us maintaining the software and expanding it with yet more features to come.

## 1.4 Scientific use

Stellarium has gained wide popularity in the research areas of cultural astronomy. Please note limitations of Stellarium mentioned in Appendix F. If you used Stellarium in scientific work, please cite our overview paper (Zotti, S. Hoffmann, et al., 2021) or those mentioned in the respective feature descriptions.

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[5]On Windows it has 4 components, where the last one is always 0.

## 1.5    About this User Guide

This guide is based on the user guide written by Matthew Gates for version 0.10 around 2008. The guide was then ported to the Stellarium wiki and continuously updated by Barry Gerdes and Alexander Wolf up to version 0.12. Unfortunately, some new features were not properly documented in the wiki, and generally, without Barry the wiki started to fall out of sync with the actual program. In late 2015 we (Alexander and Georg) started porting the texts back to LaTeX and updated and added information where necessary, or wrote new chapters for the features which were introduced in the last years. We feel that a single book is the better format for offline reading. The PDF version of this guide has a clickable table of contents and clickable hyperlinks.

These new editions of the Guide (since v0.15) do not contain notes about using earlier versions than 0.13 or using very outdated hardware. Some references to previous versions may still be made for completeness, but if you are using earlier versions of Stellarium for particular reasons, please use the older guides.

# 2. Getting Started

## 2.1 System Requirements

Stellarium has been seen to run on most systems where Qt5 is available, from tiny ARM computers like the Raspberry Pi 2/3/4 or Odroid C1 to big museum installations with multiple projectors and planetaria with fish-eye projectors. The most important hardware requirement is a contemporary graphics subsystem.

### 2.1.1 Minimum

- Linux/Unix; Windows 7 and later; macOS 10.15 and later[1]
- 3D graphics capabilities which support OpenGL 3.0 (2008 GeForce 8xxx and later, ATI/AMD Radeon HD-2xxx and later; Intel HD graphics (Core-i 2xxx and later)) or OpenGL ES 2.0 (e.g., ARM SBCs like Raspberry Pi 2/3/4). On Windows, some older cards may be supported via ANGLE when they support DirectX9.
- Screen resolution $1024 \times 768$[2]
- 512 MB RAM
- 250 MB free on disk
- Keyboard

### 2.1.2 Recommended

- Linux/Unix; Windows 10 and later; macOS 11.0 and later
- 3D graphics card which supports OpenGL 3.3 or higher
- FullHD ($1920 \times 1080$ or $1920 \times 1200$) or larger screen.[3]
- 1 GB RAM or more
- 1.5 GB free on disk (About 3GB extra required for the optional DE430/DE431 files).
- Keyboard and mouse or equivalent device (e.g. touchpad)
- A dark room for realistic rendering — details like the Milky Way, Zodiacal Light or star twinkling can't be seen in a bright room.

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[1]Windows 10 and macOS 11.0 is minimal for Qt6-based Stellarium.

[2]On Linux, an $800 \times 600$ screen can still be used by scaling the desktop e.g. to $1200 \times 900$:

```
xrandr --output HDMI-1 --scale 1.5x1.5
```

To reset after running Stellarium, run

```
xrandr --output HDMI-1 --scale 1x1
```

[3]HiDPI screens may work, but show occasional platform-dependent issues.

## 2.2  Downloading

Download the correct package for your operating system directly from the main page,
`https://stellarium.org`. An archive of all available versions is available at our GitHub page —
`https://github.com/Stellarium/stellarium/releases`.

## 2.3  Installation

### 2.3.1  Windows

1. Double click on the installer file you downloaded:
   - `stellarium-25.4-qt6-win64.exe` for 64-bit Windows 10 and later.
   - `stellarium-25.4-qt6-arm64.exe` for Windows 10 and later on ARM64 device.
   - `stellarium-25.4-qt5-win64.exe` for 64-bit Windows 7 and later.
2. Follow the on-screen instructions.

#### 2.3.1.1  Unattended Install/Uninstall

The installation program allows for unattended installation (e.g., for lab setups) following official documentation[4].

You can uninstall the program like any other program from the Applications list in the system control panel. The uninstaller asks if you want to remove (delete) all your Stellarium user data. Be sure to answer NO when you plan to re-use landscapes, 3D sceneries and the like. For unattended uninstallation in larger setups, also the uninstaller can be called with additional options, which will keep the user data.

```
"C:\Program Files[ (x86)]\Stellarium\unins000.exe" /VERYSILENT /SUPPRESSMSGBOXES
```

### 2.3.2  macOS

1. Locate the downloaded `Stellarium` file in Finder (Stellarium will be automatic unpack from archive by operating system after downloading).
2. Drag `Stellarium` to the Applications folder.

### 2.3.3  Linux

Check if your distribution has a package for Stellarium already — if so you're probably best off using it. If not, you can download and build the source.

For Ubuntu Linux we provide a package repository with the latest stable releases. Open a terminal and type:

```
sudo add-apt-repository ppa:stellarium/stellarium-releases
sudo apt-get update
sudo apt-get install stellarium
```

You can also download and run universal binary packages for linux systems: *flat*[5] or *snap*[6].

#### 2.3.3.1  Raspberry Pi 2/3/4

These tiny ARM-based computers are very popular for small and energy-efficient applications like controlling push-to Dobsonians. Stellarium requires Mesa 17 or later, available in the current Raspbian OS. To set up a Raspberry Pi 2 or 3 with Raspbian Buster for use with Stellarium, activate the OpenGL driver in **raspi-config**. The latest Raspberry Pi 4 comes with this driver by default and can even drive two HiDPI screens.

You must build Stellarium from sources. Please follow instructions from the wiki[7].

For Ubuntu 16.04 LTS, follow instructions[8].

Note that as of December 2019 the 3D planets do not work on Raspberry Pi 2/3, and DSS or HiPS surveys seem to cause issues after a while.

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[4]`https://documentation.help/Inno-Setup/topic_setupcmdline.htm`

[5]`https://flathub.org/apps/details/org.stellarium.Stellarium`

[6]`https://snapcraft.io/stellarium-daily`

[7]`https://github.com/Stellarium/stellarium/wiki/Raspberry-Pi`

[8]`https://ubuntu-mate.community/t/tutorial-activate-opengl-driver-for-ubuntu-mate-16-0`
`4/7094`

### 2.3.4 *BSD/Solaris/OpenIndiana

Check if your operating system has a package or port for Stellarium already — if so you're probably best off using it. If not, you can download and build the source.

### 2.3.5 Haiku

Please use **HaikuDepot** or open **Terminal** and type:

```
pkgman install stellarium
```

to install the Stellarium.

## 2.4 Running Stellarium

### 2.4.1 Windows

The Stellarium installer creates a whole list of items in the **Start Menu** under the **Programs/Stellarium** section. The list evolves over time, not all entries listed here may be installed on your system. Select one of these to run Stellarium:

**Stellarium**  OpenGL version. This is the most efficient for modern PCs and should be used when you have installed appropriate OpenGL drivers. Note that some graphics cards are "blacklisted" by Qt to immediately run via ANGLE (Direct3D), you cannot force OpenGL in this case. This should not bother you.

**Stellarium (ANGLE mode)**  Uses Direct3D translation of the OpenGL rendering via ANGLE library. Forces Direct3D version 9.[9]

**Stellarium (ANGLE WARP mode)**  Uses DirectX3D 11 software rendering via ANGLE library. This should work on any PC without dedicated graphics card.[9]

**Stellarium (MESA mode)**  Uses software rendering via MESA library. This should work on any PC without dedicated graphics card.

**Stellarium (200%)**  On some systems with 4k screens, Stellarium appears too small. This link forces an upscaling.

If for some reason Stellarium's dialogs and buttons appear too large, and you want to scale them down, edit the link and change the scaling parameter.

On startup, a diagnostic check is performed to test whether the graphics hardware is capable of running. If all is fine, you will see nothing of it. Else you may see an error panel informing you that your computer is not capable of running Stellarium ("No OpenGL 2 found"), or a warning that there is only OpenGL 2.1 support. The latter means you will be able to see some graphics, but depending on the type of issue you will have some bad graphics. For example, on an Intel GMA4500 there is only a minor issue in Night Mode, while on other systems we had reports of missing planets or even crashes as soon as a planet comes into view. If you see this, try running in Direct3D 9 or MESA mode, or upgrade your system. The warning, once ignored, will not show again.

When you have found a mode that works on your system, you can delete the other links.

### 2.4.2 macOS

Double click on the *Stellarium* application. Add it to your **Dock** for quick access.

### 2.4.3 Linux

If your distribution had a package you'll probably already have an item in the **GNOME** or **KDE** application menus. If not, just open a terminal and type `stellarium`.

### 2.4.4 *BSD/Solaris/OpenIndiana

If your operating system had a package or port you'll probably already have an item in the **GNOME** or **KDE** application menus. If not, just open a terminal and type `stellarium`.

### 2.4.5 Haiku

If you had installed a package you'll already have an item in the **Applications** menus.

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[9]Stellarium series 0.* and Qt5-based builds only

## 2.5   Troubleshooting

Stellarium writes startup and other diagnostic messages into a logfile. Please see section 5.3 where this file is located on your system. This file is *essential* in case when you feel you need to report a problem with your system which has not been found before.

At startup also a few pop-up windows may appear with information about possible troubles or warnings to make those messages more visible for users.

On some Intel UHD systems users may see the screen blanking when Stellarium is working — the startup of the program with **--single-buffer** parameter can help here. The same option also helps when on an Nvidia system tooltips don't appear in fullscreen mode.

On some older or weak systems, the option **--low-graphics** may be required. This forcefully disables advanced graphics features of OpenGL 3.3 which otherwise would slow down or cause other issues on such systems.

If you don't succeed in running Stellarium, please see the online forum[10]. It includes FAQ (Frequently Asked Questions, also Frequently Answered Questions) and a general question section which may include further hints. Please make sure you have read and understood the FAQ before asking the same questions again.

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[10]`https://github.com/Stellarium/stellarium`

# 3. A First Tour



Figure 3.1: Stellarium main view. (Combination of day and night views.)

When Stellarium first starts, we see a green meadow under a sky. Depending on the time of day, it is either a day or night scene. If you are connected to the Internet, an automatic lookup will attempt to detect your approximate position.[1]

At the bottom left of the screen, you can see the status bar. This shows the current observer location, vertical field of view (FOV), graphics performance in frames per second (FPS) and the current simulation date and time. If you move the mouse over the status bar, it will move up to reveal a tool bar which gives quick control over the program.

The rest of the view is devoted to rendering a realistic scene including a panoramic landscape and the sky. If the simulation time and observer location are such that it is night time, you will see stars, planets and

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[1]See section 4.2 if you want to switch this off.

the moon in the sky, all in the correct positions.

You can drag with the mouse on the sky to look around or use the cursor keys. You can zoom with the mouse wheel or the $\boxed{\text{Page↑}}$ or $\boxed{\text{Page↓}}$ keys.

Much of Stellarium can be controlled very intuitively with the mouse. Many settings can additionally be switched with shortcut keys (hotkeys). Advanced users will learn to use these shortcut keys. Sometimes a key combination will be used. For example, you can quit Stellarium by pressing $\boxed{\text{Ctrl}}$+$\boxed{\text{Q}}$ on Windows and Linux, and $\boxed{\text{⌘}}$+$\boxed{\text{Q}}$ on Mac OS X. For simplicity, we will show only the Windows/Linux version. We will present the default hotkeys in this guide. However, almost all hotkeys can be reconfigured to match your taste. Note that some listed shortkeys are only available as key combinations on international keyboard layouts, e.g., keys which require pressing $\boxed{\text{AltGr}}$ on a German keyboard. These must be reconfigured, please see 4.8 for details.

The way Stellarium is shown on the screen is primarily governed by the menus. These are accessed by dragging the mouse to the left or bottom edge of the screen, where the menus will slide out. In case you want to see the menu bars permanently, you can press the small buttons right in the lower left corner to keep them visible.

## 3.1  Time Travel

When Stellarium starts up, it sets its clock to the same time and date as the system clock. However, Stellarium's clock is not fixed to the same time and date as the system clock, or indeed to the same speed. We may tell Stellarium to change how fast time should pass, and even make time go backwards! So the first thing we shall do is to travel into the future! Let's take a look at the time control buttons on the right hand ride of the tool-bar. If you hover the mouse cursor over the buttons, a short description of the button's purpose and keyboard shortcut will appear.

| *Button* | *Shortcut key* | *Description* |
|---|---|---|
| ◀◀ | $\boxed{\text{J}}$ | Decrease the rate at which time passes |
| ▶ | $\boxed{\text{K}}$ | Make time pass as normal |
| ▶▶ | $\boxed{\text{L}}$ | Increase the rate at which time passes |
| ▼ | $\boxed{\text{8}}$ | Return to the current time & date |

Table 3.1: Time Travel

OK, so lets go see the future! Click the mouse once on the increase time speed button $\boxed{\text{▶▶}}$. Not a whole lot seems to happen. However, take a look at the clock in the status bar. You should see the time going by faster than a normal clock! Click the button a second time. Now the time is going by faster than before. If it's night time, you might also notice that the stars have started to move slightly across the sky. If it's daytime you might be able to see the sun moving (but it's less apparent than the movement of the stars). Increase the rate at which time passes again by clicking on the button a third time. Now time is really flying!

Let time move on at this fast speed for a little while. Notice how the stars move across the sky. If you wait a little while, you'll see the Sun rising and setting. It's a bit like a time-lapse movie.

Stellarium not only allows for moving forward through time – you can go backwards too! Click on the real time speed button $\boxed{\text{▶}}$. The stars and/or the Sun should stop scooting across the sky. Now press the decrease time speed button $\boxed{\text{◀◀}}$ once. Look at the clock. Time has stopped. Click the decrease time speed button four or five more times. Now we're falling back through time at quite a rate (about one day every ten seconds!).

## Time Dragging, Time Scrolling

Another way to quickly change time is *time dragging*. Press Ctrl, press the left mouse button, and slide the mouse along the direction of daily motion to go forward, or to the other direction to go backward.

Similarly, pressing Ctrl and scrolling the mouse wheel will advance time by minutes, pressing Ctrl + ⇧ and scrolling the mouse wheel will advance time by hours, Ctrl + Alt by days, and finally Ctrl + ⇧ + Alt by calendar years.

Enough time travel for now. Wait until it's night time, and then click the real time speed button ▶ . If all works as intended you will now be looking at the night sky.

## 3.2 Moving Around the Sky

| Key | Description |
| --- | --- |
| Cursor keys ← → ↑ ↓ | Pan the view left, right, up and down |
| Page↑/Page↓, Ctrl + ↑ /Ctrl + ↓ | Zoom in and out |
| Left mouse button | Select an object in the sky |
| Right mouse button, Ctrl + ☐ | Clear selected object |
| Centre mouse button (wheel press) | Centre selected object and start tracking |
| Mouse wheel | Zoom in and out |
| ☐ | Centre view on selected object |
| Forward-slash ( / ) | Auto-zoom in to selected object |
| Backslash ( \ ) | Auto-zoom out to original field of view |
| ⇧ + N | Look towards North (keep altitude) |
| ⇧ + E | Look towards East (keep altitude) |
| ⇧ + S | Look towards South (keep altitude) |
| ⇧ + W | Look towards West (keep altitude) |
| ⇧ + Z | Look towards Zenith (south down) |
| Alt + ⇧ + N | Look towards North Celestial Pole |
| Alt + ⇧ + S | Look towards South Celestial Pole |

Table 3.2: Moving Around the Sky

As well as travelling through time, Stellarium lets you look around the sky freely, and zoom in and out. There are several ways to accomplish this, listed in table 3.2.

Let's try it. Use the cursors to move around left, right, up and down. Zoom in a little using the Page↑ key, and back out again using the Page↓. Press the \ key and see how Stellarium returns to the original field of view (how "zoomed in" the view is), and direction of view.

If you prefer stepwise zooming to fixed values for field of view, table 3.3 lists the keys to reach a certain field of view.

Most users prefer to move around using the mouse. If you left-click and drag somewhere on the sky, you can pull the view around.

| Hotkey | Field of view | Hotkey | Field of view |
| --- | --- | --- | --- |
| Ctrl + Alt + 1 | 180° | Ctrl + Alt + 6 | 10° |
| Ctrl + Alt + 2 | 90° | Ctrl + Alt + 7 | 5° |
| Ctrl + Alt + 3 | 60° | Ctrl + Alt + 8 | 2° |
| Ctrl + Alt + 4 | 45° | Ctrl + Alt + 9 | 1° |
| Ctrl + Alt + 5 | 20° | Ctrl + Alt + 0 | 0.5° |

Table 3.3: Hotkeys to set fixed vertical fields of view

Another method of moving is to select some object in the sky (left-click on the object), and press the [Space] key to centre the view on that object. Similarly, selecting an object and pressing the forward-slash key [ / ] will centre on the object and zoom right in on it.

The forward-slash [ / ] and backslash [ \ ] keys auto-zoom in and out to different zoom levels depending on what is selected. If the object selected is a planet or moon in a *sub-system* with a lot of moons (e.g. Jupiter), the initial zoom in will go to an intermediate level where the whole sub-system should be visible. A second zoom will go to the full zoom level on the selected object. Similarly, if you are fully zoomed in on a moon of Jupiter, the first auto-zoom out will go to the sub-system zoom level. Subsequent auto-zoom out will fully zoom out and return the initial direction of view. For objects that are not part of a sub-system, the initial auto-zoom in will zoom right in on the selected object (the exact field of view depending on the size/type of the selected object), and the initial auto-zoom out will return to the initial FOV and direction of view.

If you have a touch screen, you can even use one finger directly to drag the sky around and select objects, and two fingers to zoom. The support for touch screens is incomplete though, and more advanced use of the program requires the classical operation with keyboard and mouse.

## 3.3   The Main Tool Bar



Figure 3.2: Night scene with constellation artwork and moon.

Stellarium can do a whole lot more than just draw the stars. Figure 3.2 shows some of Stellarium's visual effects including constellation line and boundary drawing, constellation art, planet hints, and atmospheric halo around the bright Moon. The controls in the main tool bar provide a mechanism for turning on and off the visual effects.

When the mouse is moved to the bottom left of the screen, a second tool bar becomes visible. All the buttons in this side tool bar open and close dialog boxes which contain controls for further configuration of the program. The dialogs will be described in the next chapter.

Table 3.4 describes the operations of buttons on the main tool bar and the side tool bar, and gives their default keyboard shortcuts.

| Feature | Button | Hotkey | Description |
| --- | --- | --- | --- |
| Constellations | | C | Draw constellations as "stick figures" |
| Constellation Names | | V | Draw name of the constellations |
| Constellation Art | | R | Superimpose artistic representations of the constellations |
| Constellation Boundaries[2] | | B | Draw boundaries of the constellations |
| Asterisms[2] | | C | Draw asterism "stick figures" |
| Asterism Names[2] | | V | Draw name of the asterisms |
| Equatorial Grid | | E | Draw grid lines for the equatorial coordinate system of date (RA/Dec) |
| Azimuth Grid | | Z | Draw grid lines for the horizontal coordinate system (Alt/Azi) |
| Galactic Grid[2] | | | Draw grid lines for the galactic coordinate system (Long/Lat) |
| Equatorial J2000 Grid[2] | | | Draw grid lines for the equatorial coordinate system at standard epoch J2000.0 (RA/Dec) |
| Ecliptic Grid[2] | | | Draw grid lines for the ecliptic coordinate system of date (Long/Lat) |
| Toggle Ground | | G | Toggle drawing of the ground. Turn this off to see objects that are below the horizon. |
| Toggle Cardinal Points | | Q | Toggle marking of the North, South, East and West points on the horizon. |
| Toggle Compass Marks[2] | | ⇧ + Q | Toggle degree marks along the horizon. |
| Toggle Atmosphere | | A | Toggle atmospheric effects. Most notably makes the stars visible in the daytime. |
| Deep-Sky Objects | | D | Toggle marking the positions of Deep-Sky Objects. |
| Planet Hints | | P | Toggle indicators to show the position of planets. |
| Nebula images[2] | | I | Toggle "nebula images". |
| Digitized Sky Survey[2] | | | Toggle "Digitized Sky Survey" (TOAST). |
| Hierarchical Progressive Surveys[2] | | Ctrl + Alt + D | Toggle "Hierarchical Progressive Surveys". |
| Coordinate System | | Ctrl + M | Toggle between horizontal (Alt/Azi) & equatorial (RA/Dec) coordinate systems. |

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[2]This button must be enabled first, see section 4.3.5

| Feature | Button | Hotkey | Description |
|---|---|---|---|
| Center | | | Center the view on the selected object |
| Night Mode | | Ctrl + N | Toggle "night mode", which applies a red-only filter to the view to be easier on the dark-adapted eye. |
| Full Screen Mode | | F11 | Toggle full screen mode. |
| Bookmarks[2] | | Alt + B | Toggle bookmarks window. |
| Flip view (horizontal)[2] | | Ctrl + ⇧ + H | Flip the image in the horizontal plane. |
| Flip view (vertical)[2] | | Ctrl + ⇧ + V | Flip the image in the vertical plane. |
| Quit Stellarium | | Ctrl + Q | Close Stellarium. |
| Help Window | | F1 | Show the help window, with key bindings and other useful information |
| Configuration Window | | F2 | Show the configuration window |
| Search Window | | F3 or Ctrl + F | Show the object search window |
| View Window | | F4 | Show the view window |
| Time Window | | F5 | Show the time window |
| Location Window | | F6 | Show the observer location window (map) |
| AstroCalc Window | | F10 | Show the astronomical calculations window |

Table 3.4: Stellarium's standard menu buttons. Those marked [2] must be enabled first, see section 4.3.5.

## 3.4 Taking Screenshots

You can save what is on the screen to a file by pressing Ctrl + S . Screenshots are taken in PNG format, and have filenames like `stellarium-000.png`, `stellarium-001.png` (the number increments to prevent overwriting existing files).

The screenshots are stored to a directory depending on your operating system, see section 5.1 Files and Directories. See also section 4.3.5 for more screenshot options.

## 3.5 Observing Lists (Bookmarks)

You can store your favourite objects or views in observing lists. Press Alt + B or [star button] to call up the dialog. A bookmarks file from previous versions will be imported and converted to the new format. You can however create an arbitrary number of lists.

The list display shows all entries from the current list. A double click on an entry selects the object. To add/remove an object to/from the list, press Edit list . This changes the view. Highlight (select) your object in the sky and press Add object . To remove an object from a list, select its entry in the list and press Remove object .

Sometimes storing the object alone is not enough. Interesting views like planet conjunctions or eclipses require at least a time entry, if not a particular location. Likewise, the displayed landscape may be nice to restore. Additionally, the field of view may be relevant. To store these data and later retrieve them, use the respective checkboxes.

You can also export the current list or all lists with the according button, or import such an exported list on another system. To export the current list, keep the default `.sol` file type in the filename dialog. To export all your lists, use the `.ol` file type in the filename dialog. Lists are identified with an Universally Unique Identifier (UUID) which we call OLUD (Observing List Unique Identifier). On importing a list, existing lists with the same OLUD may be replaced after a warning. During editing, storing a list with an existing name is prevented. The list import may however import a list with an existing name as long as the OLUD is different. You may want to change one of the duplicate list names after import. To transfer all your lists to another system, export them as `.ol` file, or copy, rename and import (or just copy, to replace the existing) the full file `observingLists.json` from the `data/` subdirectory of your user directory (see section 5.1).

## 3.6 Custom Markers

You can set temporary markers anywhere in the screen. These may be useful for various purposes but cannot be stored.

| Actions | Description |
|---:|---|
| Shift & left click | Add custom marker |
| Shift & right click | Delete the one closest marker to mouse cursor |
| Alt + ⇧ & right click | Delete all custom markers |

## 3.7 Copy Information

If you have selected an object and want to use the displayed information elsewhere, you may want to copy it to the system clipboard with Ctrl + ⇧ + C . In case you want to use its numbers elsewhere, please see Appendix F for known accuracy limitations.

## 3.8 Speech Output

Sometimes you may have dimmed down your field laptop or the font may be too small. Object information can also be output audibly by a Text-to-Speech engine. After object selection, press Shift + R to let a voice read ot to you. See section 4.3.6 for details and configuration.

v 25.4

# 4. The User Interface

This chapter describes the dialog windows which can be accessed from the left menu bar.

Most of Stellarium's settings can be changed using the view window (press ⬚ or F4 ) and the configuration window ( ⬚ or F2 ). Most settings have short labels. To learn more about some settings, more information is available as *tooltips*, small text boxes which appear when you hover the mouse cursor over a button.[1]

You can drag the windows around, and the position will be used again when you restart Stellarium. If this would mean the window is off-screen (because you start in windowed mode, or with a different screen), the window will be moved so that at least a part is visible.

Some options are really rarely changed and therefore may only be configured by editing the configuration file. See 5.4 The Main Configuration File for more details.

## 4.1 Setting the Date and Time
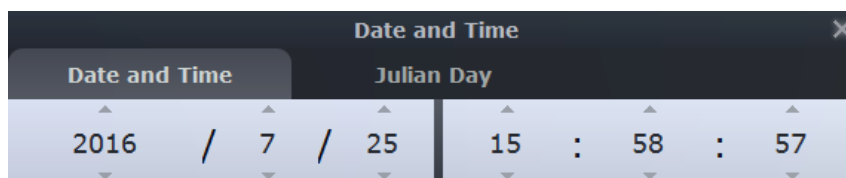


Figure 4.1: Date and Time dialog

In addition to the time rate control buttons on the main toolbar, you can use the date and time window (open with the ⬚ button or F5 ) to set the simulation time. The values for year, month, day, hour, minutes and seconds may be modified by typing new values, by clicking the up and down arrows above and below the values, and by using the mouse wheel.

The other tab in this window allows you to see or set *Julian Day* and/or *Modified Julian Day* numbers (see 18.4.2).
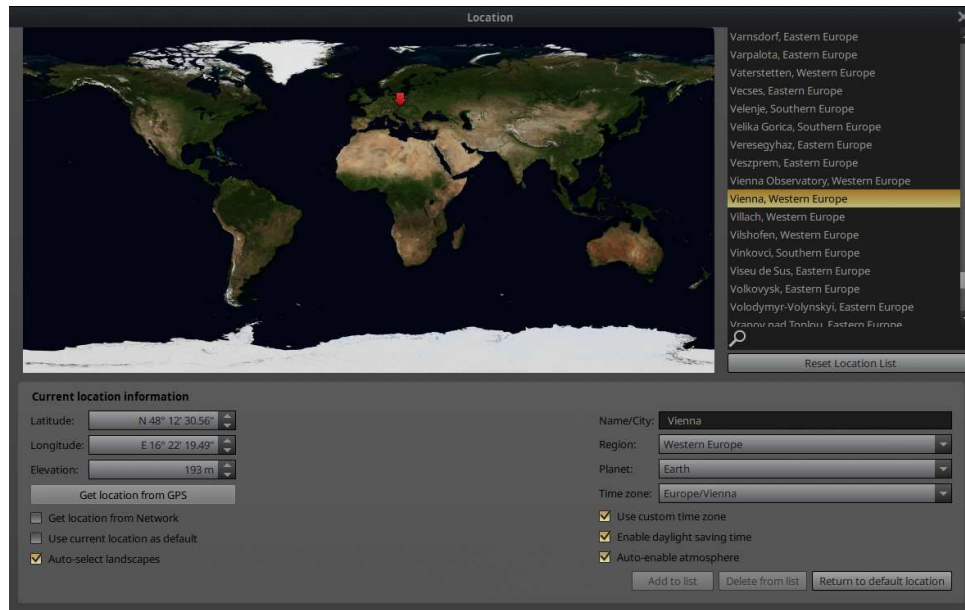
Figure 4.2: Location window

## 4.2 Setting Your Location

The positions of the stars in the sky is dependent on your location on Earth (or other planet) as well as the time and date. For Stellarium to show accurately what is (or will be/was) in the sky, you must tell it where you are. You only need to do this once – Stellarium can save your location so you won't need to set it again until you move.

After installation, Stellarium uses an online service which tries to find your approximate location based on the IP address you are using. This seems very practical, but if you feel this causes privacy issues, you may want to switch this feature off. You should also consider switching it off on a computer which does not move, to save network bandwidth.

To set your location more accurately, or if the lookup service fails, press F6 to open the location window (Fig. 4.2). There are a few ways you can set your location in this dialog:

1. Just click on the map.
2. Search for a city where you live using the search edit box at the top right of the window, and select the right city from the list.
3. Click on the map to filter the list of cities in the vicinity of your click, then choose from the shortlist.
4. Enter a new location using the longitude, latitude and other data.
5. Click on Get Location from GPS if you have a GPS receiver. You activate a periodic request for GPS fixes. After a few seconds, the button should change color and give a textual feedback. Green indicates a good location fix, yellow indicates a 2D-fix only, which means altitudes are not available. (Leave the GPS device running for a few minutes and/or search a place with better sky view.) You could leave it running if you are operating a fast-moving observatory platform, but rather switch it off when you see a good fix, so that other programs can use the serial GPS connection. Red signals an error, and further positions are not retrieved but the button is reset. You may press the button again to start over. Sometimes you have to try several times or let it run for a while to get a green button indicating a valid 3D fix including altitude. See section 5.5.4 for configuration details.

v 1.0                On Windows, if there is no GPS device, a system location service will be queried as fallback.

If you want to use the current location permanently, click on the "use as default" checkbox, disable "Get location from Network", and close the location window.

Two settings may influence the landscape when changing locations:

**Auto select landscapes** When changing the planet, a fitting landscape panorama will be shown when
v 23.2                available. Also, when clicking on the earth map, a zero-altitude landscape is displayed in the

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[1]Unfortunately, on Windows 7 and later, with some Nvidia and AMD GPUs in OpenGL mode, these tooltips sometimes do not work. Sometimes it is enough to leave fullscreen mode to see them.

approximate color of that location (taken from the map).

**Auto-enable atmosphere**  When changing planet during location change, the atmosphere will be switched as required.

As a reverse functionality, loading landscapes may also change location. See section 4.4.5.

### 4.2.1 Time Zones

Locations in Stellarium's location database include their respective time zone. When you click on a location in the list, the time should be shown in the respective time zone. If daylight time rules exist and you have selected "Enable daylight saving time", also this abomination of modern civilisation is respected. Most users will require to have this setting active.

When you select "Use custom time zone", you can select other time zones. Those that start with UTC have no daylight time rules.

Time zones were introduced in the 19th century, originally for purposes of railway traffic synchronization. The first such action was taken in 1847, and therefore Stellarium by default will present Local Mean Solar Time (LMST) for dates before 1847, and ignore all configured time zones unless you deliberately activate "Use custom time zone". The history of time zones and their rules is very complicated, though, and Stellarium should not be expected to find the exact date when time zone use was introduced at a certain location or country. Just be sure to use LMST when replaying historical observations before the 20th century.

For even earlier observations, you can also set Local True Solar Time (LTST), which is the time given by sundials. Here, 12 o'clock is the time when the sun transits the meridian, strictly, daily. The difference between LMST and LTST is called *equation of time*. See section 13.2 for more information.

When you click on the map to set your location, Stellarium has currently no way to guess the timezone of the coordinate pair. In this case, Local Mean Solar Time is presented, which only depends on longitude and was the "normal" time before the development of time zones. Either select a city from the list or manually select a time zone.

### 4.2.2 Geographical Regions

The world is split into political entities called "countries".   Humans have an unappealing tendency of fighting over the question to which country some territories should be counted. Stellarium is an astronomy program which labels coordinates of locations like cities with a name. Earlier editions of Stellarium used countries as further superordinate entities to locations for identification purposes. In consequence to much unnecessary and unfriendly discussion we decided to completely drop the petty-minded assignment of political country names to locations in favour of geographical regions. There is only one known habitable planet, one humankind, and one sky. Stellarium users should overcome borders!

For the "region" classification of sky cultures we use the same regions (see 9.2.1), and we follow the UN M49 geoscheme[2] with extensions for other planets.

### 4.2.3 Observers

In the list of Planets you can find entries called *Solar System Observer*, *Jupiter Observer* and similar for each major planet that has moons: Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. These are specialized locations. When switching to them, you will find yourself looking onto the respective observed object (Sun, Jupiter, … ) from somewhat above the plane of the Solar system. By pressing $\boxed{\text{Alt}}$+$\boxed{\leftarrow}$/$\boxed{\text{Alt}}$+$\boxed{\rightarrow}$ you can rotate around a vertical axis through the observed object. Likewise, by pressing $\boxed{\text{Alt}}$+$\boxed{\uparrow}$/$\boxed{\text{Alt}}$+$\boxed{\downarrow}$ you can change the latitude of observation. Finally, with $\boxed{\text{Alt}}$+$\boxed{\text{Home}}$/$\boxed{\text{Alt}}$+$\boxed{\text{End}}$ you can change the distance from the observed object.

## 4.3 The Configuration Window

The configuration window contains general program settings, and many other settings which do not concern specific display options. Press the tool button $\boxed{\text{🔧}}$ or $\boxed{\text{F2}}$ to open.

### 4.3.1 The Main Tab

The Main tab in the configuration window (Fig. 4.3) provides control for changing the program language.

The next setting group allows to enable using DE430/DE431 and DE440/DE441 ephemeris files. These files have to be installed separately. Most users do not require this. See section 5.5.3 if you are interested.

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[2]https://unstats.un.org/unsd/methodology/m49/
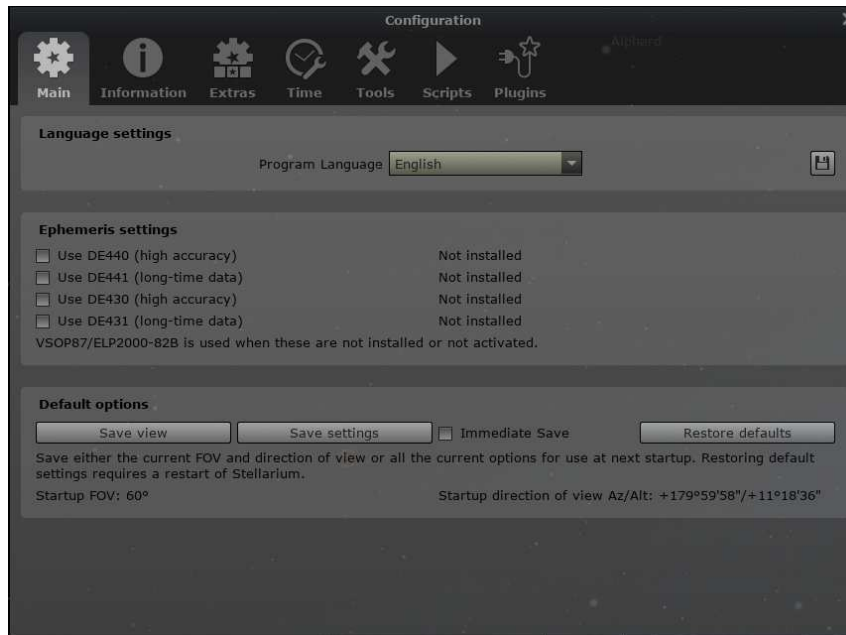
Figure 4.3: Configuration Window: Main Tab

The tab also provides the buttons for saving the current view direction as default for the next startup, and for saving the program configuration: most display settings have to be explicitly stored to make a setting change permanent. If you prefer, you can activate $\boxed{\text{Immediate Save}}$. Then all settings changes will be stored immediately and the program will use them the next time you launch it. Language and font settings have to be stored explicitly with the buttons next to their settings to protect you from unwanted surprises. To permanently set this mode, use $\boxed{\text{Save settings}}$ a final time.

v 24.4

### 4.3.2 The Information Tab
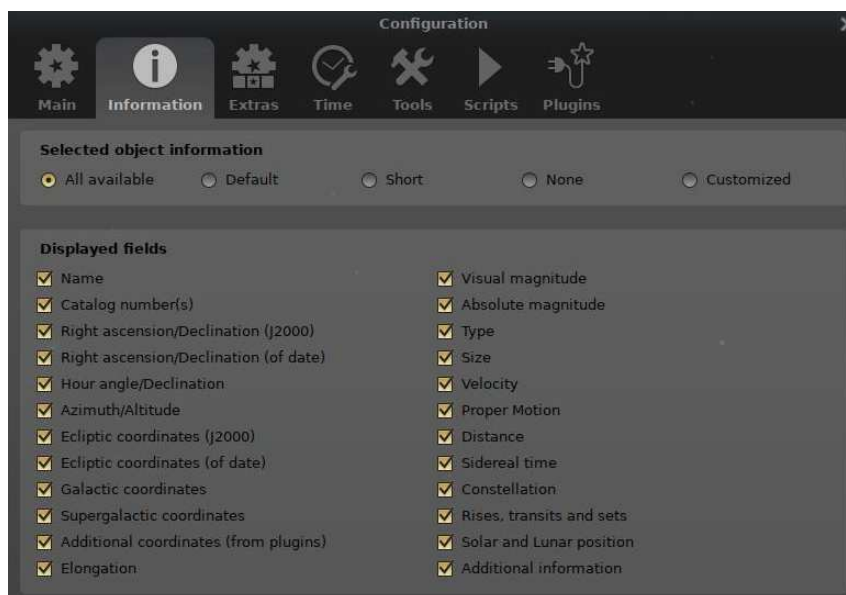


Figure 4.4: Configuration Window: Information Tab

The Information tab (Fig. 4.4) allows you to set the type and amount of information displayed (left column) or output by speech (right column; see 4.3.6) about a selected object. The Radio buttons on the top of the dialog allow quick selection of some useful configurations for display.

v 25.4
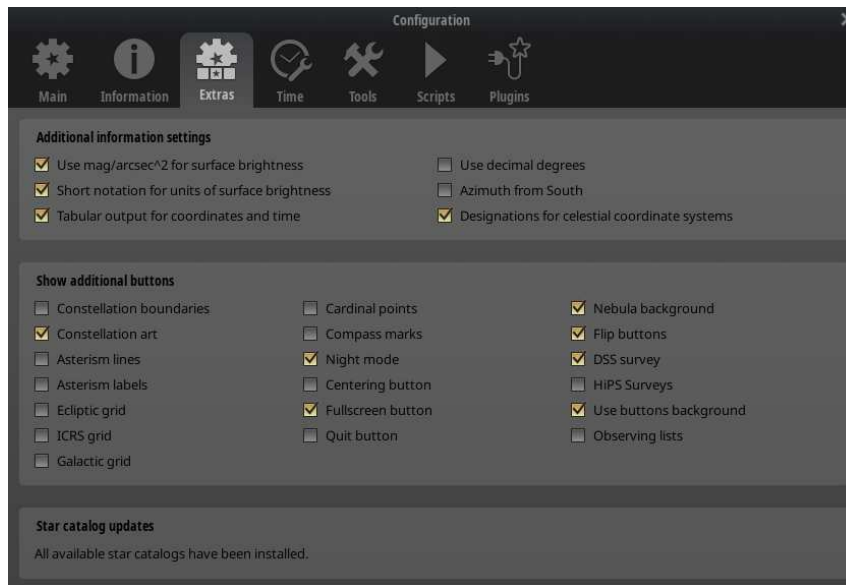
### 4.3.3 The Extras Tab



Figure 4.5: Configuration Window: Extras Tab

The Extras tab (Fig. 4.5) allows you to customize information displayed about a selected object, download more star catalogs and also allows to hide or show additional buttons in the lower button bar.

#### 4.3.3.1 Customization of information displays

The information display can be tweaked a bit with the options found in the GUI section "Additional information settings".

**Use mag/arcsec^2 for surface brightness**  instead of mag/arcmin^2.

**Short notation for units of surface brightness**  symbolic abbreviation.

**Designations for celestial coordinate systems**  Use symbols like $\alpha, \delta$ instead of textual labels.

**Tabular output for coordinates and time**  uses a more eye-friendly layout.

**Use decimal degrees**  You can toggle usage of decimal degree format for coordinates.

**Azimuth from South**  Some users may be used to counting azimuth from south.

**Allow negative hour angles**  Count hour angles $-12h \ldots 12h$ instead of $0h \ldots 24h$.          v 25.4

**Polar distance, not declination**  Used by some telescopes. Using label $p$ or $PD$ instead of $\delta$.          v 25.4

#### 4.3.3.2 Customization of button visibility on bottom toolbar

If your screen is too narrow to show all buttons or you simply don't need them because you prefer the keyboard shortcuts, you can choose your optimal setup. The selection of buttons is stored immediately.

**Constellation boundaries**  You can toggle display of constellation boundaries with this button.

**Asterism lines**  You can toggle display of asterism lines with this button.

**Asterism labels**  You can toggle display of asterism labels with this button.

**Ecliptic grid**  You can toggle display of ecliptic coordinate grid with this button.

**ICRS grid**  You can toggle display of the International Coordinate Reference System (equatorial J2000 coordinate grid) with this button.

**Galactic grid**  You can toggle display of galactic coordinate grid with this button.

**Cardinal points**  You can toggle display of the "Cardinal points" button.

**Compass marks**  You can toggle display of the "Compass marks" button.

**Night mode**  You can toggle display of the nightmode button.

**Centering button**  You can toggle display of the "Center on selected object" button.

**Fullscreen button**  You can toggle display of the fullscreen button.

**Quit button**  You can toggle display of the button to quit Stellarium.

**Nebula background**  You can toggle display of DSO photographs with this button.

**Flip buttons**  When enabled, two buttons will be added to the main tool bar which allow the main view to be mirrored in the vertical and horizontal directions. This is useful when observing through telecopes which may cause the image to be mirrored.

**DSS survey**  You can toggle display of Digitized Sky Survey with this button (see section 10.4).

**HiPS Surveys**  You can toggle display of Hierarchical Progressive Surveys with this button (see section 4.4.7).

**Bookmarks**  You can enable display of Bookmarks (Observing Lists) dialog with this button.

**Use buttons background**  Applies a gray background under the buttons on the bottom bar.

#### 4.3.3.3  Download more star catalogs

Stellarium comes with enough stars for casual stargazing with the unaided eye or binoculars. If you have a telescope and want to see more stars, here you can download more catalogs. (See Appendix C)

### 4.3.4  The Time Tab
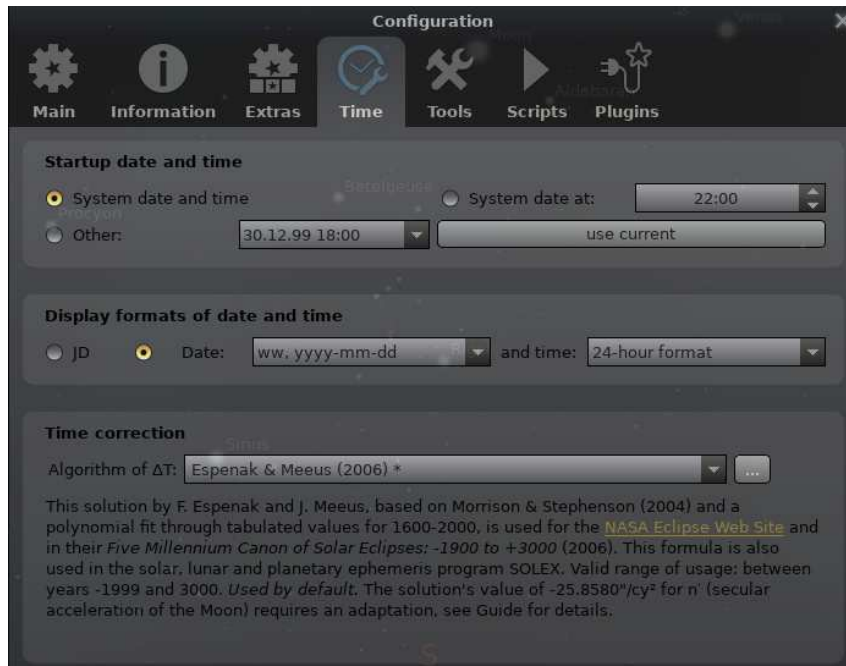


Figure 4.6: Configuration Window: Time Tab

The Time tab (Fig. 4.6) allows to specify what simulation time should be used when the program starts:

**System date and time**  Stellarium will start with the simulation time equal to the operating system clock.

**System date at**  Stellarium will start with the same date as the operating system clock, but the time will be fixed at the specified value. This is a useful setting for those people who use Stellarium during the day to plan observing sessions for the upcoming evening.

**Other**  some fixed time can be chosen which will be used every time Stellarium starts.

The middle field allows specify display formats for date and time on bottom toolbar:

**JD**  Stellarium will display Julian Days (JD).

**Date and time**  Stellarium will display date and time in selected format.

The lowest field allows selection of the correction model for the time correction $\Delta T$ (see section 18.4.3). Default is "Modified Espenak and Meeus (2006, 2014, 2023)". Please use other values only if you know what you are doing.

### 4.3.5  The Tools Tab

The Tools tab (Fig. 4.7) contains planetarium options (like enabling/disabling of keyboard shortcuts for panning and zooming the main view) and options for screenshots.

**Spheric mirror distortion**  This option pre-warps the main view such that it may be projected onto a spherical mirror using a projector. The resulting image will be reflected up from the spherical mirror in such a way that it may shine onto a small planetarium dome (or even just the ceiling of your dining room), making a cheap planetarium projection system.

**Disc viewport**  This option masks the main view producing the effect of a telescope eyepiece. It is also useful when projecting Stellarium's output with a fish-eye lens planetarium projector.
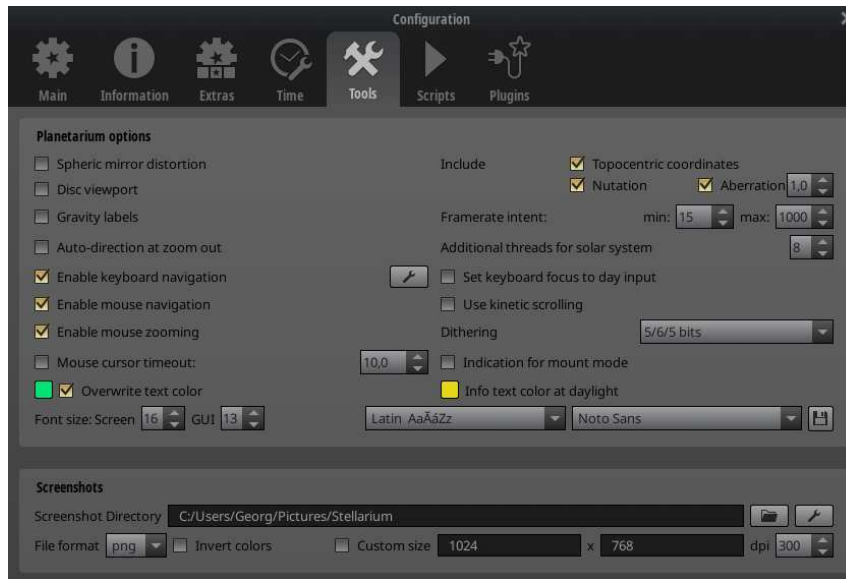
Figure 4.7: Configuration Window: Tools Tab

**Gravity labels**  This option makes labels of objects in the main view align with the nearest horizon. This means that labels projected onto a dome are always aligned properly.

**Auto zoom out returns to initial direction of view**  When enabled, this option changes the behavior of the zoom out key  \  so that it resets the initial direction of view in addition to the field of view.

**Enable keyboard navigation** , i.e. moving the view with cursor keys. The tool button calls the keyboard configuration panel. (See section 4.8.)

**Enable mouse navigation** , i.e. mouse dragging.

**Enable mouse zooming**  use mouse wheel to zoom field of view.

**Mouse cursor timeout**  You can decide whether, and when, the mouse cursor should disappear from view when not moved.

**Include Topocentric coordinates**  If you require planetocentric coordinates, you may switch this off. Usually it should be enabled. (See 18.9.1)

> **Nutation**  Compute the slight wobble of earth's axis. This feature is active only about 500 years around J2000.0.

> **Aberration**  Add effect of annual *aberration of light* to the object's position (see 18.10). Note: This also influences the displayed position in the J2000 frame! For didactic purposes you can exaggerate the effect by up to 5×.

**Overwrite text color** — enabling this option will ignore the color settings for each celestial object and enable one color for text on the info panel for all celestial objects. By default Stellarium uses white color for this option, but you may re-define it through a color chooser.

**Set keyboard focus to day input** — you may use this option to force setting the keyboard focus on the day input field in the Date and Time dialog.

> Important note: the focus in the sky will be lost when you open the Date and Time dialog after enabling this option.

**Use kinetic scrolling**  Text fields in  dialogs can either be moved on sidebar handles (with this switch disabled) or by dragging the text itself (enabled), as it is known from touch-enabled devices like smartphones.

**Dithering**  options to allow select better simulation of sky on different hardware.

**Indication for mount mode**  You can activate the short display of a message when switching type of used mount.

**Info text color at daylight** — this is a color chooser for defining the text color for the info panel at daylight to increase the contrast of the text. By default Stellarium use black color.

### Multithreading

For every frame, the positions of all planets and minor bodies of the Solar system are computed. Most of the other time between frame updates is needed for the actual frame drawing, and waiting for the next frame

v 24.3 cycle if you have deliberately set a low frame rate (useful to conserve energy; see below). If you have many thousands of solar system objects and a moderately new computer, you may feel that Stellarium becomes slow (few frames/second) but see that mostly only one core of your CPU seems to be busy. You can try to distribute the computation of solar system bodies to more CPU cores. But take note, thread synchronization (combining all results ahead of drawing) takes its time, so it pays off only when your solar system is really large. With more than 1000 objects, we recommend starting with 1 additional thread. Even with 25.000 objects, assigning more than 4 additional threads on a 20-core CPU does not show any further gain. Frame drawing is still performed by the main thread, and too many objects still slow down the program. Just try out what works best on your system.

### Framerate intent

The pace of screen updates (frames per second, FPS) depends on several factors: CPU speed, graphics card speed, screen size, number of displayed objects and grids, etc. As is common for interactive programs, the main program thread runs on a single core also on a multicore system. For running Stellarium, a CPU with few but fast cores will appear faster in total than a multicore system at slower CPU cycles. High-end systems may deliver needlessly high framerates, at cost of energy consumption. The maximum FPS setting limits the frame rate when Stellarium is interactively operated (zoomed, panned, settings switched, etc.) After a few seconds, when Stellarium is not interactively operated, it falls back to a minimum FPS setting to conserve energy. Of course, when the system cannot even reach this FPS, the factual FPS will be lower and the system may be overloaded. Keep in mind that the minimum setting also applies to running scripts (non-interactively).

### Font size and font selection

You can change the font sizes for on-screen text and GUI dialogs separately. For some purposes like presentations it may be helpful to enlarge screen font size while keeping GUI font regular, or vice versa. It also depends on your screen size whether all the object info fits on screen. This may also depend on the writing system and installed font. If you are using a non-Western character system and the default font looks bad, you can select another system font. For this, edit `config.ini` (see chapter 5.1): locate the `[gui]` section and set the key `flag_font_selection=true`. On next start of Stellarium, you will find two elements for font selection: one allows you to pre-select a writing system, the other will then allow selection of a font installed in your system that includes the characters used in the selected writing system. When you have found the best font, store your settings here or on the Main tab (see section 4.3.1), and you may edit `config.ini` again to disable the font selection switches.

### Screenshots

You can set the directory where screenshots will be stored, and also whether you want screenshots sized like Stellarium's window or some other, likely larger size. The maximum possible size depends on your hardware. $4096 \times 4096$ should be possible on most PCs, others may even create $16384 \times 16384$ images. The vertical field of view will be the same as in the current view.

You can also set the file format. The exact selection depends on platform and version of the underlying Qt framework. Notable formats are PNG (lossless), JPG (lossy), JPEG (higher quality JPG), BMP (Windows Bitmap), WEBP, TIF (LZW compressed), TIFF (uncompressed), PBM, PGM, PPM, XBM, XPM, and ICO (thumbnails).

Some printing workflows require particular DPI (dots per inch) settings stored in the screenshots. You can configure DPI which will be stored in the image metadata. The intended print size in mm is shown in the tooltip of the dpi spinner.

## 4.3.6  The Speech Tab

v 25.4 The Speech tab (Fig. 4.8) allows configuring speech output.[3] You can select some speech engine, then (hopefully) a list of voices for your user language becomes available from which you can choose. You can influence pitch and speed (Rate) and balance volume against your system volume. Then test the content of the text box with the ▶ Say , or cut this off via ■ Stop .

Speech output is available for data of the currently selected object. In the Information tab (see 4.3.2), the right checkbox colums let you select those information bits which should be output by voice. Most users will keep coordinate readings off, but some physical or morphological data may be interesting to listen to.

The default hotkey for speech output is Shift + R . Pressing it another time will cut off narration.

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[3]This fully depends on capabilities of the operating system and is not available for builds/platforms with Qt version less than 6.4.
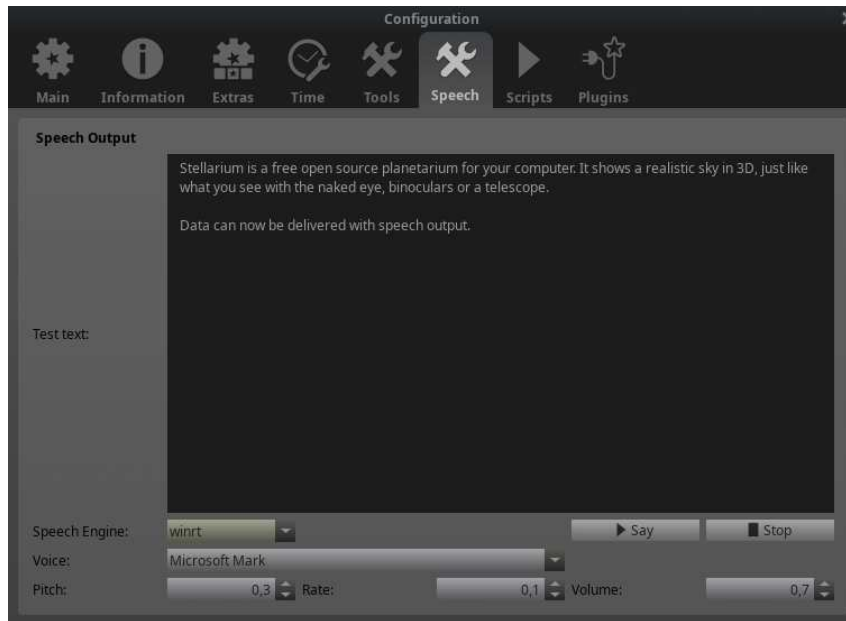
Figure 4.8: Configuration Window: Speech Tab

Also the long texts in the Landscape (see 4.4.5) and Skyculture (4.4.6) tabs of the View Settings dialog can be narrated with the ▶ Read text/■ Stop buttons near the respective text boxes.

### 4.3.7 The Scripts Tab

The Scripts tab (Fig. 4.9) allows the selection of pre-assembled scripts bundled with Stellarium that can be run (See chapter 17 for an introduction to the scripting capabilities and language). This list can be expanded with your own scripts as required. See section 5.2 where to store your own scripts.

When a script is selected it can be run by pressing the arrow button and stopped with the stop button. With some scripts the stop button is inhibited until the script is finished.

Scripts that use sound or embedded videos will need a version of Stellarium configured at compile time with multimedia support enabled. It must be pointed out here that sound or video codecs available depends on the sound and video capabilities of you computer platform and may not work.

### 4.3.8 The Plugins Tab

Plugins (see chapter 12 for an introduction) can be enabled here (Fig. 4.10) to be loaded the next time you start Stellarium. When loaded, many plugins allow additional configuration which is available by pressing the configure button on this tab.

## 4.4 The View Settings Window

The View settings window controls many display features of Stellarium which are not available via the main toolbar.

### 4.4.1 The Sky Tab

The Sky tab of the View window (Fig. 4.11) contains settings for changing the general appearance of the main sky view and projections. Some highlights of sky field:
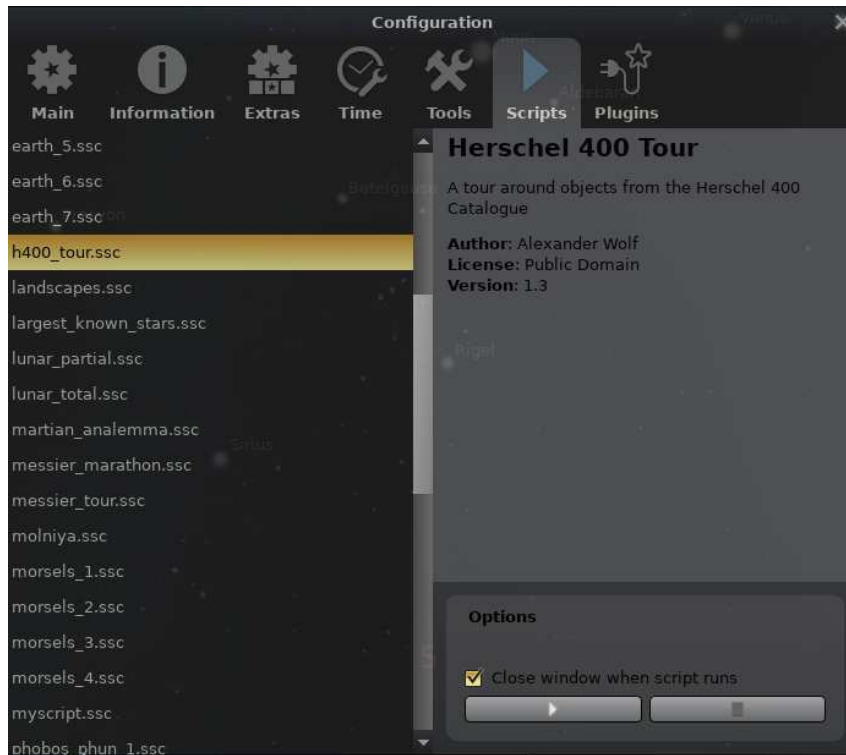
Figure 4.9: Configuration Window: Scripts Tab
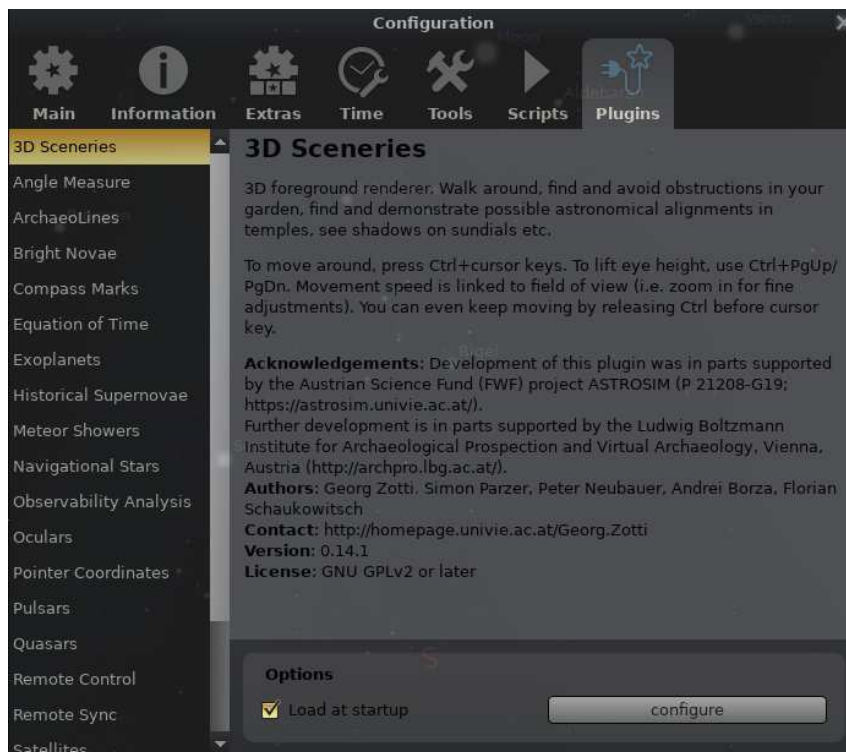


Figure 4.10: Configuration Window: Plugins Tab
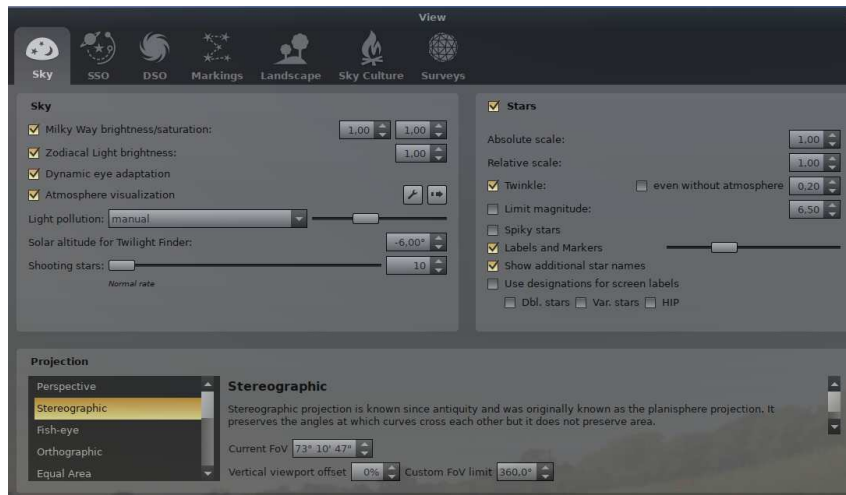
Figure 4.11: View Settings Window: Sky Tab

**Dynamic eye adaptation**  When enabled this feature reduces the brightness of faint objects when a bright object is in the field of view. This simulates how the eye can be dazzled by a bright object such as the moon, making it harder to see faint stars and galaxies.

**Light pollution**  In urban and suburban areas, the sky is brightened by terrestrial light pollution reflected in the atmosphere. Stellarium simulates light pollution and lets the user configure how bright the night sky is. There are several ways to set it up:

**Automatic from locations database**  option makes Stellarium find sky brightness from its locations database and simulate light pollution without any further user input.

**Manual**  mode lets the user choose the amount of light pollution by moving a slider. To make it easier to orient in the resulting amount of light pollution, a tooltip will show the classification of the sky according to the *Bortle Dark Sky Scale* (See Appendix B for more information), as well as the naked-eye limiting magnitude.

**Manual from SQM**  mode lets one enter the reading of a *Sky Quality Meter*. Stellarium can accept it in several units: physical (cd/m$^2$, mcd/m$^2$, $\mu$cd/m$^2$) as well as astronomical, mag/arcsec$^2$. To enter a value, first choose the unit, and then type the number into the spinbox.

**Solar altitude for Twilight Finder**  You can configure  shortcut keys to go to the time when the sun reaches this altitude below the mathematical horizon. See section 4.8.1.

**Shooting stars**  Stellarium has a simple meteor simulation option. This setting controls how many shooting stars will be shown. Note that shooting stars are only visible when the time rate is 1, and might not be visible at some times of the day. Meteor showers can be simulated using a dedicated plugin (see section 14.6).

Some highlights of the stars field:

**Absolute scale**  is the size of stars as rendered by Stellarium. If you increase this value, all stars will appear larger than before.

**Relative scale**  determines the difference in size of bright stars compared to faint stars. Values higher than 1.00 will make the brightest stars appear much larger than they do in the sky. This is useful for creating star charts, or when learning the basic constellations.

**Twinkle**  controls how much the stars twinkle when atmosphere is enabled (*scintillation*, see section 19.13.2.1). Since v0.15.0, the twinkling is reduced in higher altitudes, where the star light passes the atmosphere in a steeper angle and is less distorted.

**Limit magnitude**  Inhibits automatic addition of fainter stars when zooming in. This may be helpful if you are interested in naked eye stars only.

**Labels and markers**  you can independently change the amount of labels displayed for stars. The further to the right the sliders are set, the more labels you will see. Note that more labels will also appear as you zoom in.

**Use designations for screen labels** — when this option is enabled you will see in the sky (on-screen labels) only scientific designations (catalog numbers) of the stars instead of their common names. To

customize the on-screen labels we added 3 additional options[4] — **Dbl. stars**, **Var. stars** and **HIP** — which will show, in this sequence of preference, the first available occurrence of the traditional designations of double stars, variable stars or HIP numbers, respectively.

#### 4.4.1.1 The Projections field

Selecting items in this list changes the projection method which Stellarium uses to draw the sky (Snyder, 1987). Options are:

**Perspective** Perspective projection maps the horizon and other great circles like equator, ecliptic, hour lines, etc. into straight lines. The maximum field of view is 150°. The mathematical name for this projection method is *gnomonic projection*.

**Stereographic** Stereographic projection has been known since antiquity and was originally known as the planisphere projection. It preserves the angles at which curves cross each other but it does not preserve area. Else it is similar to fish-eye projection mode. The maximum field of view in this mode is 235°.

**Fish-Eye** Stellarium draws the sky using *azimuthal equidistant projection*. In fish-eye projection, straight lines become curves when they appear a large angular distance from the center of the field of view (like the distortions seen with very wide angle camera lenses). This is more pronounced as the user zooms out. The maximum field of view in this mode is 180°.

**Orthographic** Orthographic projection is related to perspective projection, but the *point of perspective* is set to an infinite distance. The maximum field of view is 180°.

**Equal Area** The full name of this projection method is *Lambert azimuthal equal-area projection*. It preserves the area but not the angle. The maximum field of view is 360°.

**Hammer-Aitoff** The Hammer projection is an equal-area map projection, described by Ernst von Hammer (1858–1925) in 1892 and directly inspired by the Aitoff projection. The maximum field of view in this mode is 360°.

**Mollweide** The Mollweide projection is a pseudocylindrical equal-area map projection, widely used for whole-sky displays; it preserves relative areas across the sphere while trading off shape and angular fidelity, especially near the poles. The maximum field of view in this mode is 360°.

**Sinusoidal** The sinusoidal projection is a *pseudocylindrical equal-area map projection*, sometimes called the Sanson–Flamsteed or the Mercator equal-area projection. Meridians are mapped to sine curves.

**Mercator** Mercator projection is a cylindrical projection developed by Gerardus Mercator (1512–1594) which preserves the angles between objects, and the scale around an object is the same in all directions. The poles are mapped to infinity. The maximum field of view in this mode is 233°.

**Miller cylindrical** The Miller cylindrical projection is a modified Mercator projection, proposed by Osborn Maitland Miller (1897–1979) in 1942. The poles are no longer mapped to infinity.

**Cylinder** The full name of this simple projection mode is *cylindrical equidistant projection* or *Plate Carrée*. The maximum field of view in this mode is 233°.

Two more settings allow finetuning:

**Vertical viewport offset** If you have a wide screen or like wide-angle views, you may feel that too much of screen space lies below the horizon. This setting can shift the view up or down.

**Custom FoV limit** Some projections allow very wide views, like 180° which covers a complete celestial hemisphere (e.g. the entire skydome) or even more. In some cases like if you are running a planetarium, you may want to limit the vertical field of view so that you won't ever zoom out too far.

#### 4.4.1.2 Atmosphere settings

An auxiliary dialog opens when you select 🔧 and contains detail settings for the atmosphere. Here you can choose visual model of atmosphere, set atmospheric pressure and temperature which influence refraction (see section 19.13.2) and the opacity factor $k_v$ for extinction, *magnitude loss per airmass* (see section 19.13.1).

There are two visual models for the atmosphere available:

**Preetham** This is the legacy model (see section 11.2.1), fallback for the cases when the other one doesn't work.

**ShowMySky** This model is the more realistic visual model of the atmosphere colors (see section 11.2.2). It relies on a precomputed dataset that can be chosen in the user interface after the **ShowMySky** model is enabled.

### 4.4.2 The Solar System Objects (SSO) Tab

The Solar System Objects tab of the View window (Fig. 4.12) contains settings for changing the general appearance of the view of Solar system objects. Some highlights:

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[4]These options are only used if the star does not have Bayer/Flamsted designations.
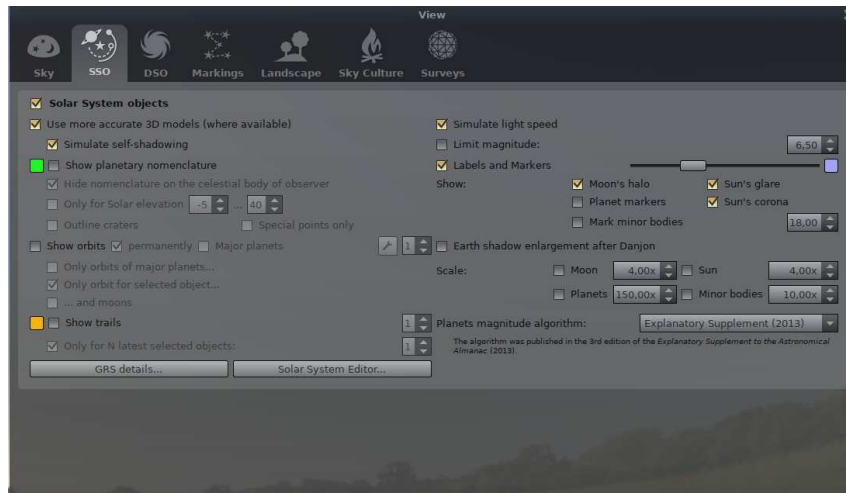
Figure 4.12: View Settings Window: SSO Tab

**Simulate light speed** will give more precise positions for planetary bodies which move rapidly against background stars (e.g. the moons of Jupiter).

**Scale** will increase the apparent size of the selected class of objects:

> **Moon** will increase the apparent size of the Moon in the sky, which can be nice for wide field of view shots.
>
> **Minor bodies** will increase the apparent size of minor bodies: planet satellites, all kinds of asteroids, and comets. Forsome of these 3D models are available, which will be better discernible if enlarged.
>
> **Sun** will increase the apparent size of the Sun in the sky, which can be nice for didactic purposes or demonstrations.
>
> **Planets** will increase the apparent size of major planets.

**Mark minor bodies** Show a little circle at the location of every minor body (comet, asteroid, ...), down to    v 24.3
the configured visual magnitude. The marks are shown regardless of sky brightness, even in daytime. Also, in this mode, markers for objects with highly outdated orbital elements are still plotted (see 13.8 and Appendix D.2.2). This is useful to show the distribution of asteroids and comets on the sky, or especially when viewed from the Solar System Observer (see 4.2.3).

From the "Observer" viewpoints, the visual magnitude for minor bodies is computed as seen from the Sun, so that objects in inferior conjunction ae not dimmed down and filtered away by effects of phase angle, and comet tails are better visible.

**Show orbits** adds a rendition of the orbit or trajectory of an SSO. For efficiency, orbits are not displayed when the object is not inside the screen, unless you set the "permanently" option. You can further fine-tune the selection and appearance (width and colors) of orbits with the additional settings.

**Show trails** plots the apparent path of SSO among the stars as seen from the current planet.

**Show planetary nomenclature** displays positions and names of surface features officially named by the IAU (See Appendix E). When the sun is below the horizon at the location of the feature, the label is attenuated. A few special markers show Centre, North and South poles, east and west points along the equator, and the subsolar point (where the sun is at the zenith as seen from that feature). Features like craters are best visible when they are illuminated by a low sun. You can therefore limit the display to    v 1.2
items along the *terminator* (the border between light and dark on the surface). You can also mark    v 23.3
craters and lunar *maria* (the dark "seas") with circles.

**GRS details...** : The Great Red Spot (GRS) is slowly drifting along Jupiter's System II coordinate system. This button opens a new dialog in which you can adjust the longitude (Jupiter system II) and annual drift rate of this feature at a particular epoch. To help you, another button in this dialog opens a website with relevant data. The central meridian data given in the object information on screen still shows System II longitude.

**Labels and markers** you can independently change the amount of labels displayed for Solar system objects. The further to the right the sliders are set, the more labels you will see. Note that more labels will also appear as you zoom in.

**Planet magnitude algorithm** several ways to compute planet magnitudes have been made available from the literature. Data by Müller (1893) provide visual magnitudes. The other models provide instrumental (Johnson V) magnitudes.

**Earth shadow enlargement after Danjon** Earth's shadow is enlarged by the atmosphere. You can select whether the 2% enlargement used by the Astronomical Almanac should be applied (default), or the formulation of DANJON (see section 19.11.2).

### 4.4.3 The Deep-Sky Objects (DSO) Tab

*Deep-sky objects* or DSO are extended objects which are external to the solar system, and are not point sources like stars. DSO include galaxies, planetary nebulae and star clusters. These objects may or may not have images associated with them. Stellarium comes with a catalog of over 90,000 extended objects containing the combined data from many catalogs, with 500+ images.

The DSO tab (Fig. 4.13) allows you to specify which catalogs or which object types you are interested in. This selection will also be respected in other parts of the program, most notably Search (section 4.5) and AstroCalc/WUT (section 4.6.6) will not find objects from catalogs which you have not selected here.

See chapter 8 for details about the catalog, and how to extend it with your own photographs.

### 4.4.4 The Markings Tab

The Markings tab of the View window (Fig. 4.14) controls plotting various grids and lines on the celestial sphere. Colors for grids, lines and points can be adjusted by clicking on the corresponding colored square. The central column governs lines like equator, ecliptic, meridian etc., where each can optionally be fine-tuned to show partition marks and labels. Color settings are stored immediately, all other flags need explicit saving of the settings (see section 4.3.1).

### 4.4.5 The Landscape Tab

The Landscape tab of the View window (Fig. 4.15) controls the landscape graphics (the horizon which surrounds you). To change the landscape graphics, select a landscape from the list on the left side of the window. A description of the landscape will be shown on the right.

Note that while a landscape can include information about where the landscape graphics were taken (planet, longitude, latitude and altitude), this location does not have to be the same as the location selected in the Location window, although you can set up Stellarium such that selection of a new landscape will alter the location for you.

The controls at the bottom right of the window operate as follows:

**Use this landscape as default** Selecting this option will save the landscape into the program configuration file so that the current landscape will be the one used when Stellarium starts.

**Show ground** This turns on and off landscape rendering (same as the button [icon] in the main tool bar).

**Show fog** This turns on and off rendering of a band of fog/haze along the horizon, when available in this landscape.

**Show illumination** to reflect the ugly developments of our civilisation, landscapes can be configured with a layer of light pollution, e.g., streetlamps, bright windows, or the sky glow of a nearby city. This layer, if present, will be mixed in when it is dark enough.

**Show landscape labels** Landscapes can be configured with a gazetteer of interesting points, e.g., mountain peaks, which can be labeled with this option. Color and font size can also be configured.

**Location from landscape** When enabled, selecting a new landscape will automatically update the observer location. Use this if the landscape is not just decoration, but a true representation of a particular site you wish to visit in the simulation.

**Minimal brightness** Moonless night on very dark locations may appear too dark on your screen. You may want to configure some minimal brightness here.

   **from landscape, if given** Landscape authors may decide to provide such a minimal brightness value in the `landscape.ini` file.

**Draw only polygon** If a polygonal horizon line has been defined for the landscape, only draw this with the given thickness and color.

v 23.3   **Transparency** Allow peeking below the horizon. Note that this may show graphical errors.

Using the button [Add/remove landscapes...], you can also install new landscapes from ZIP files which you can download e.g. from the Stellarium website[5] or create yourself (see ch. 7 Landscapes), or remove these custom landscapes.

---

[5] `https://stellarium.org/landscapes.html`
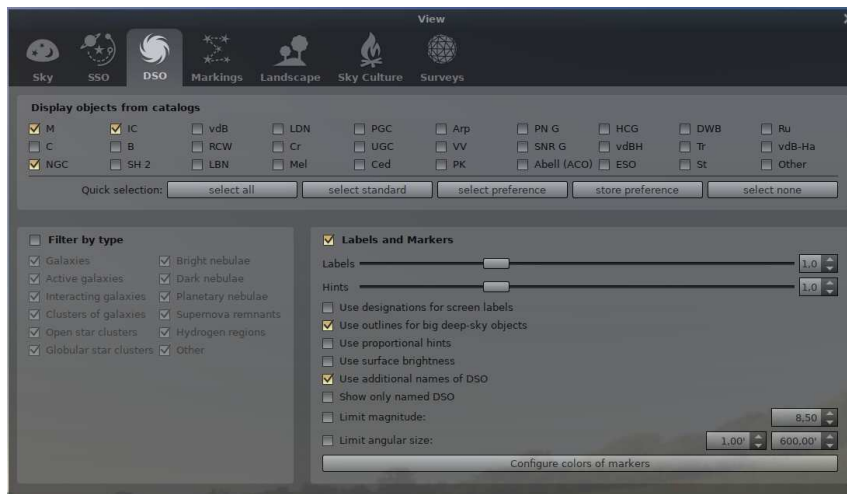
Figure 4.13: View Settings Window: DSO Tab

Figure 4.14: View Settings Window: Markings Tab

Figure 4.15: View Settings Window: Landscape Tab

Loading large landscapes may take several seconds. If you like to switch rapidly between several landscapes and have enough memory, you can increase the default cache size to keep more landscapes loaded previously available in memory. Note that a large landscape can take up 200MB or more! See section D.1.13.

## 4.4.6 The Sky Culture Tab
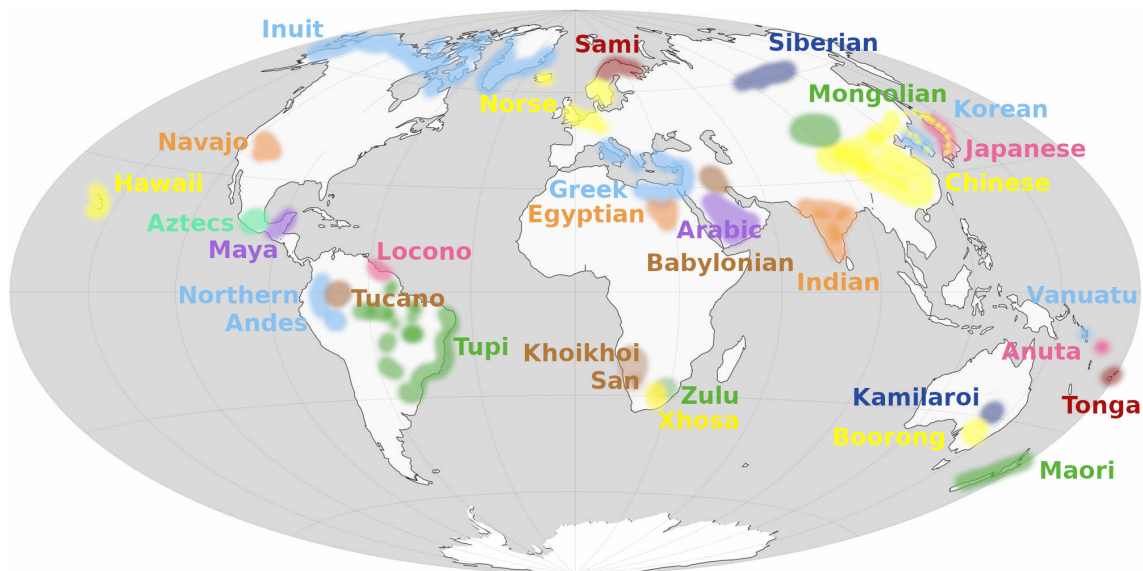


Figure 4.16: World map showing Stellarium's built-in set of sky cultures. To avoid overcrowding, smaller European sky cultures which are mostly derivatives or relatives of the "Modern" sky culture are not shown. (Image: S. M. Hoffmann)

If you want to explore humankind's cultural history, you could also switch to the viewpoint of ancient or other contemporary peoples. Constellations are defined as patterns in the sky shaped from fixed celestial objects, often serving to set calendar marks and to navigate while travelling on Earth. Which patterns are seen depends on the natural environment and the cultural habits of the people, i.e., the Inuit in the arctic area might have seen an Elk where the Chinese have seen a huge spoon or dipper. There cannot be any astrological influence from these patterns as they had been seen differently and, thus, are a product of human's imagination. So, pointing out these cultural differences might have an educational function, too.

> **Caution**
> Some of our native peoples' constellations have been contributed for noncommercial use only. Please respect their heritage holders and check-out the CC licence version in the description before you use sky cultures for broadcasting! See section 9.1.3 for details.

The Sky Culture tab of the View window (Fig. 4.17) controls which culture's constellations and bright star names will be used in the main display. Some cultures have constellation art (e.g., Modern or Inuit), and the rest do not. Configurable options include

**Use this sky culture as default** Activate this option to load this sky culture when Stellarium starts.

v 25.2    **Info and screen label styles** The new skyculture system has introduced a plethora of new name elements, the complete set of which is not required to exist. There are name components that may come in the skyculture's original (*native*) language. If such a culture uses non-Latin glyphs in its writing, non-native users need a *transliteration* that also helps pronunciation, which even depends on user language. Then there are *scientific transliteration* systems for some cases. Finally, a pronunciation aid can be given using the *International Phonetic Alphabet* (IPA). And, for reference, you may want to add the commonly used *modern* name to an object.

There are two sets of settings, for the screen label and for the label used in the information area in the top-left. The currently configured settings are immediately stored per-skyculture and retrieved when you load another skyculture, so that you can adapt the system to your knowledge of languages and character systems. See 9.2.9 for more.

**Abbreviated names** To provide a less cluttered screen in case constellation names are long, you can
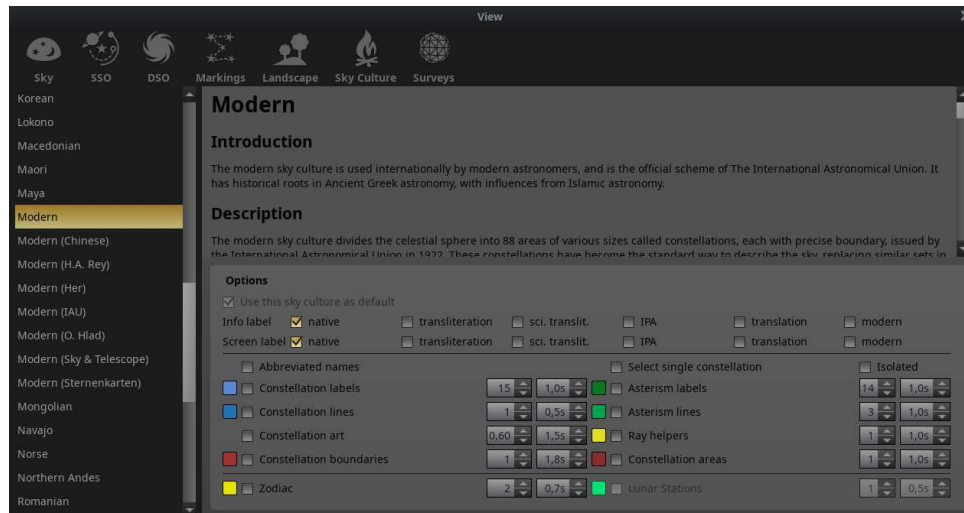
Figure 4.17: View Settings Window: Sky Culture Tab

show abbreviations. The Modern skycultures use the 3-letter codes given by the IAU, for the other skycultures we depend on our skyculture authors to define unique short labels that help memorizing. Some skycultures still just show numbers.

**Select single constellation/Isolated**  See section 4.4.6.1 for details.

**Constellation labels**  Activate display of constellation labels, like $\boxed{\text{⤢}}$ or $\boxed{\text{V}}$.

**Constellation lines**  Activate display of stick figures, like $\boxed{\text{⤬}}$ or $\boxed{\text{C}}$, and you can configure constellation line thickness in the right spinbox.

**Constellation art**  Activate display of constellation art (if available), like $\boxed{\text{⤜}}$ or $\boxed{\text{R}}$. You can also select the brightness here.

**Constellation boundaries**  Activate display of constellation boundaries, like $\boxed{\text{B}}$. Currently, boundaries have been defined only for "Modern" sky cultures.

**Asterism labels**  Activate display of asterism labels, like $\boxed{\text{Alt}}$+$\boxed{\text{V}}$.

**Asterism lines**  Activate display of asterism stick figures (like the shortcut $\boxed{\text{Alt}}$+$\boxed{\text{A}}$), and you can configure asterism line thickness as well.

**Ray helpers**  Activate display of special navigational lines which connect stars often from different constellations (like the shortcut $\boxed{\text{Alt}}$+$\boxed{\text{R}}$), and you can configure thickness of those lines as well.

**Constellation areas**  optional, advanced research feature. See page 115 for details.

**Zodiac**  If this skyculture has a concept of Zodiac (usually a region around the ecliptic split into 12 equal-sized parts), you can enable it here.

**Lunar Stations**  If this skyculture has a concept of Lunar stations or mansions, you can enable them here. For example, Indian skycultures observe 27 *nakshatras* along the ecliptic, and Chinese skycultures have 28 Lunar mansions of unequal width in equatorial coordinates defined by particular stars.

### 4.4.6.1 Select single constellations

Some presenters may want to explain a particular storyline about the constellations of a sky culture, which includes showing single constellations or showing a sequence of appearing constellations. To achieve this, first activate "Select single constellation" mode (see fig 4.17). Then, click on a star which is part of a constellation line set. Click another star which is part of another constellation to show that one in addition. If you really only want to show a single constellation, also add the "Isolated" option.

If you explain a sky culture where constellations also have borders defined, a click anywhere in the constellation area is enough. For other sky cultures, clicking onto a star which is not member of a constellation line will display all constellations.

Press $\boxed{\text{W}}$ to remove all but the last selected constellation. If you had deleted selection (right mouse click) before pressing $\boxed{\text{W}}$, all constellations are hidden. Press $\boxed{\text{W}}$ again to also hide the single displayed one, or click another star to select the next constellation. If you need to keep the single constellation visible, select the currently selected star again to select it again. Press $\boxed{\text{Alt}}$+$\boxed{\text{W}}$ to show all constellations.

With a little training, you will be able to give inspiring constellation tours.

### 4.4.7  The Surveys Tab
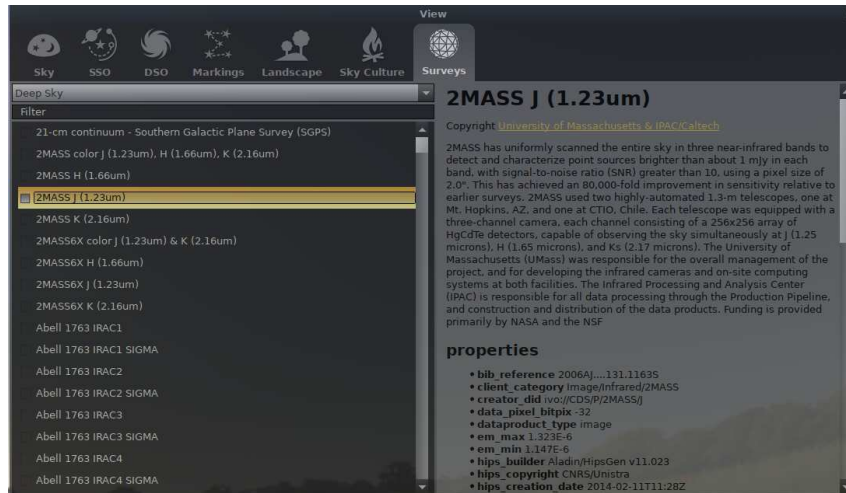


Figure 4.18: View Settings Window: Surveys Tab

The Surveys tab (Fig. 4.18) allows to toggle the visibility of online sky or solar system surveys (see chapter 10 for description of the surveys format). Currently, only HiPS surveys are supported.

On the left side of the window we see the list of available surveys from the configured sources (See section D.1.29 for how to change the default sources). On the right side a description of the selected survey and its properties are displayed.

Surveys are grouped by types. The top combobox allows to filter the listed surveys according to a given type (Deep Sky or Solar System).

You can toggle the visibility of a survey by checking the box on the left of the survey name in the list. (Note that as of v0.18.0, only a single deep sky survey can be rendered at a time, so it makes no sense to select more than one in the list!) Once a survey is visible you should be able to see its loading status in the loading bar area of the sky view.

Deep sky surveys will be rendered aligned with the sky view, while solar system surveys automatically map on the proper body.

## 4.5  The Search Window

### 4.5.1  The Object tab

The Object tab of the Search window provides a convenient way to locate objects in the sky. Simply type in the name of an object to find, and press ↵. Stellarium will point you at that object in the sky.

As you type, Stellarium will make a list of objects which contains what you have typed so far. The first of the list of matching objects will be highlighted. If you press the ⇥ or ↓ key, the selection will change to the next item in the list. Pressing the ↑ key will bring you to the previous item. Hitting the ↵ key will center on the currently highlighted object and close the Search window.

For example, suppose we want to locate Saturn's moon Mimas (SI). Open the Search window ( 🔍 , F3 , or Ctrl + F ). Type the first letter of the name, *m*, to see a list of objects whose name contains *m*:

*M*iranda (UV)
Psa*m*athe (NX)
U*m*briel (UII)
. . .

You may want at this point to have Stellarium rather propose object names which start with the string you enter. Do that in the Options tab of this panel (see section 4.5.5). The search result should update automatically when you navigate back to the Object tab. Now the list is shorter and contains only objects which start with *m*:
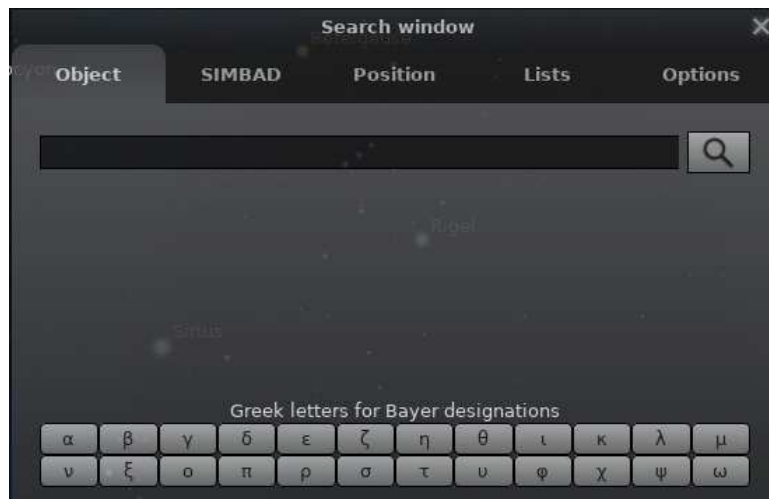
Figure 4.19: The Search Window: Object
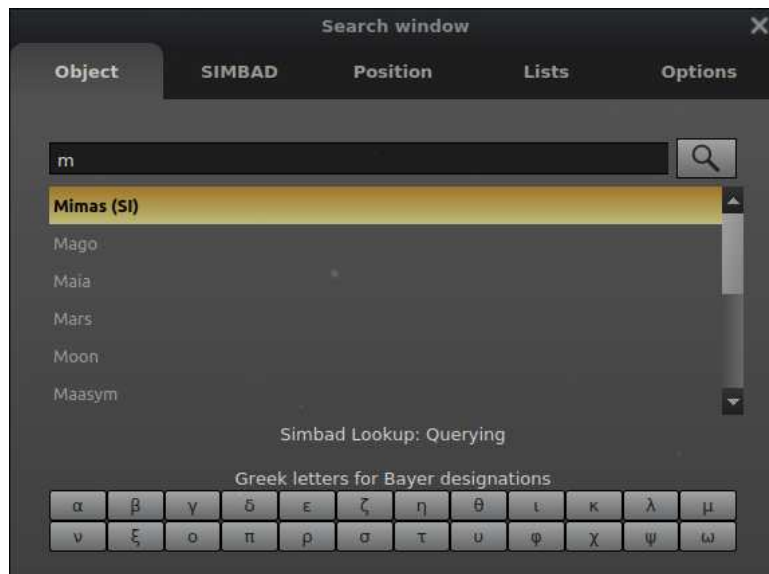


Figure 4.20: The Search Window: Object (Recent Searches)



Figure 4.21: The Search Window: SIMBAD
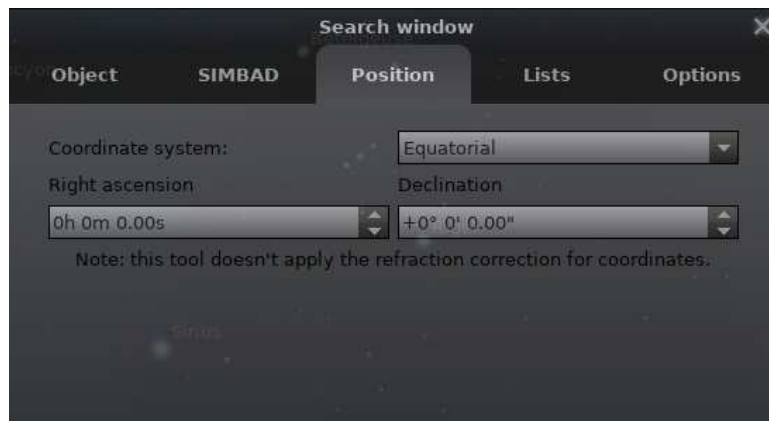
Figure 4.22: The Search Window: Position



Figure 4.23: The Search Window: Lists
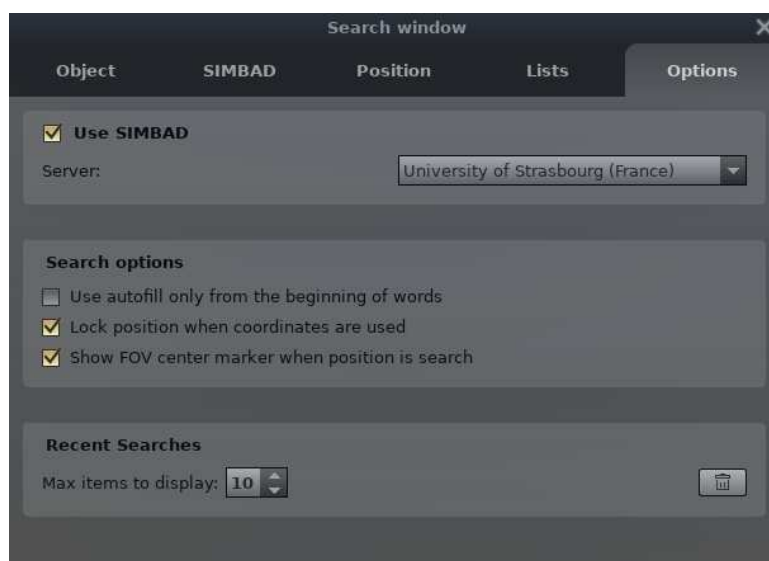


Figure 4.24: The Search Window: Options

$M$ago
$M$aia
$M$ars
$\ldots$

The first item in this list, Mago, is highlighted. Pressing ⌤ now would go to Mago, but we want Mimas (SI). We can either press ⇆ or ↓ a few times to highlight Mimas (SI) and then hit ⌤, or we can continue to type the name until it is the first/only object in the list.

After you searched for an object, the next time the Search window opens, your most recently searched object(s) will automatically appear in the search result of the Object tab. For instance, continuing with our example, re-open the Search window's Object tab. Mimas (SI) should already be populated and highlighted:

**$M$imas (SI)**

The Object tab's search result will now prioritize your most recent searches (which will be shown in **bold**). To modify the search results, see section 4.5.5. From our earlier example, re-enter *m* into the Object tab. Doing so will generate a slightly different list than before. In this case, Mimas (SI) will appear first, as shown in Figure 4.20:

**$M$imas (SI)**
$M$ago
$M$aia
$M$ars
$\ldots$

### 4.5.2 The SIMBAD tab

The SIMBAD tab (Fig. 4.21) provides a convenient way to fetch and show a set of information for selected object from the astronomical online database SIMBAD (Wenger et al., 2000). If some object is only visible in a survey or DSS background (see section 10) and not in Stellarium's catalogs, you can also set a custom marker (see section 3.6), select it and query SIMBAD "tell me what's known about objects at this location".

### 4.5.3 The Position tab

The Position tab (Fig. 4.22) provides a convenient way to enter a set of coordinates.

### 4.5.4 The Lists tab

The Lists tab (Fig. 4.23) allows selection of an object from predefined sets. The number of choices is governed by the loaded DSO catalogs and plug-ins. Scroll down the first window to select the type. Click on the name and Stellarium will center on that object.

### 4.5.5 The Options tab

The Options tab (Fig. 4.24) provides a few settings to fine-tune your search experience.

**Use SIMBAD**  When the name of an object to find is typed in the Object tab and you are connected to the internet and "Use SIMBAD" is ticked, Stellarium will search the SIMBAD on-line databases for its coordinates. You can then click the 🔍 button or press ⌤. Stellarium will point you at that object in the sky even if there is no object displayed on the screen. The SIMBAD server being used can be selected from the scroll window.

      **Server:**  for server selection

**Search Options**  group allows for changes in the search result behaviour.

      **Use autofill only from the beginning of words**  when checked, will search for object names that begins with the same letters as your input. Example provided in section 4.5.1.

      **Lock position when coordinates are used**

      **Show FOV center marker when position is search**

**Recent Searches**  group allows modification to your recent search data. Any changes here will automatically update the search results displayed in the Object tab. Example provided in section 4.5.1.

      **Max items to display**  amount of *recent searches* that can appear in the search result

      🗑 button deletes your recent search history

## 4.6    The Astronomical Calculations Window

This window provides advanced functionality, some of which is still under development. You can call it by

pressing [F10] or the button [icon] on the left menu bar. The Astronomical Calculations window shows eight tabs with different functionality.

Most tabs allow exporting computed data to XLSX (Excel) files in addition to CSV files, and graphs can be exported as PNG files.

### 4.6.1    The Positions Tab

This tab shows equatorial J2000.0 or horizontal positions, magnitudes and additional parameters (e.g. surface brightness for deep-sky objects or angular separation for double stars) for various lists of celestial objects above the horizon at the simulated time, filtered by magnitude. Double-clicking on an entry brings the object into focus (Fig. 4.25). You may also export the list of positions into an XLSX or CSV file.



Figure 4.25: Astronomical Calculations (AstroCalc): Celestial positions / Seen now

This tab is split into 2 subtabs: "Seen now" and "Major planets". The "Major planets" subtab (Fig. 4.26) shows a table with heliocentric ecliptic positions of the major planets and a graphical representation of these positions (in polar coordinates). You may also export the list of positions into an XLSX or CSV file.
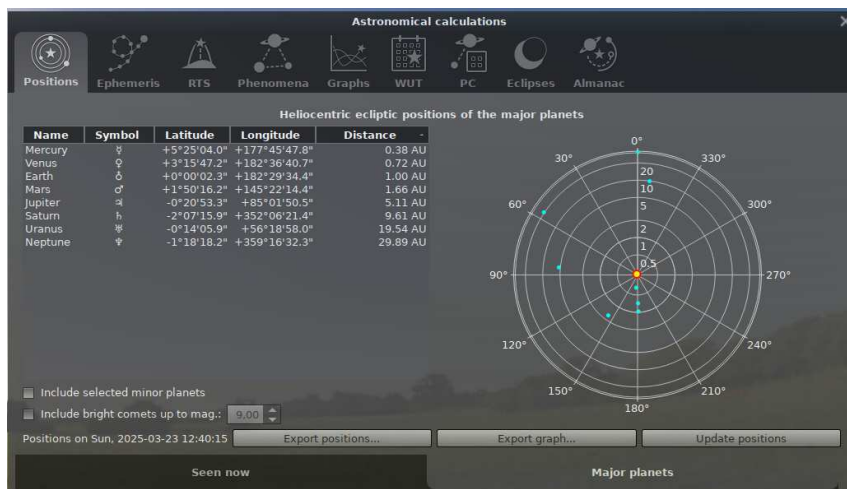


Figure 4.26: Astronomical Calculations (AstroCalc): Celestial positions / Major Planets

### 4.6.2 The Ephemeris Tab

Select an object, start and end time, and compute an ephemeris (list of positions and magnitudes evolving over time) for that object. The positions are marked in the sky with yellow disks (Fig. 4.27).

When you click on a date, an orange disk indicates this date and/or magnitude. Double-clicking sets the respective date and brings the object to focus. Dates and/or magnitudes will show up near position markers when *Show dates* and/or *Show magnitudes* checkboxes are active. To show a line between markers please tick checkbox *Show line*. You may customize the format of displayed data near markers and their frequency in the *Extra options* window (Fig. 4.28). You can also define the color of markers and enable display markers for all naked-eye visible planets.

You can export the calculated ephemeris into an XLSX or CSV file.

Another interesting option in this tool: using horizontal coordinates for plotting traces of the Solar system objects. In this mode, the circle marks are not linked to the sky, but to the horizontal coordinate system. For example, you can get an analemma of the Sun for any location (Fig. 4.29 and 4.30), or observe the visibility of Mercury, Venus or a comet in the twilight sky.

You can draw an ephemeris of two objects at the same time and define custom time step for the ephemeris (Fig. 4.31).

Note: The ephemeris is computed with the current settings for atmosphere, topocentric correction etc. In consequence, e.g. magnitudes may be affected by atmospheric absorption and may show unexpected values. Remember to switch off atmosphere etc. to create extinction free geocentric mean positions as found in almanachs.

### 4.6.3 The "Risings, Transits, and Settings" (RTS) Tab

This tab allows you to compute meridian transits and rising and setting times of selected celestial object (except unnamed stars and artificial satellites) for a specific date range. The tool is useful for planning observations, and it suggests the best time and conditions for visual observations or astrophotography (Fig. 4.32).

You may also export the list of transits into an XLSX or CSV file.

### 4.6.4 The Phenomena Tab

This tab allows you to compute phenomena like conjunctions, oppositions, occultations and eclipses (in special cases) between planetary objects (Fig. 4.33). In addition, it provides computation of greatest elongations for the inner planets and stationary points for all planets, and, for all Solar system bodies except the moons, we also compute perihelia and aphelia.

You can export the calculated phenomena into an XLSX or CSV file.

Four columns in the table may be helpful for planning observation of phenomena:

**solar elongation**  angular distance from the Sun
**lunar elongation**  angular distance from the Moon
**mag. 1**  magnitude of first object
**mag. 2**  magnitude of second object

### 4.6.5 The Graphs Tab

This tab provides on several sub-tabs graphs which are helpful for monthly observation planning of deep-sky objects and analysis of changes between objects or changes of their positions. Clicking in the graph sets the time at that point, and setting the mouse onto a graph displays values at this point. However, most graphs are intended for a rapid overview and are plotted using an interpolating spline through sparse samples, so do not expect highest accuracy.

#### 4.6.5.1 The "Altitude vs. Time" Subtab

On this subtab (the first subtab and default view in the Graphs tab) you can compute the geometrical altitude of the currently selected object on the currently set date and draw it as a graph (Fig. 4.34).

Optional graphs for the Sun (with lines for civil, nautical and astronomical twilight) and the Moon (dashed) are also available.

#### 4.6.5.2 The "Azimuth vs. Time" Subtab

On this subtab you can compute the geometrical azimuth of the currently selected object on the currently set date and draw it as a graph (Fig. 4.35).

#### 4.6.5.3 The "Monthly Elevation" Subtab

This subtab can show a "Monthly Elevation" graph for the current year at the selected time. This tool was introduced for planning yearly observations (Fig. 4.36).

Figure 4.27: Astronomical Calculations (AstroCalc): Plot trace of planet



Figure 4.28: Astronomical Calculations (AstroCalc): Extra options for ephemeris



Figure 4.29: Astronomical Calculations (AstroCalc): Analemma on the Earth

Figure 4.30: Astronomical Calculations (AstroCalc): Analemma on Mars



Figure 4.31: Astronomical Calculations (AstroCalc): Two asteroids nearby to one place



Figure 4.32: Astronomical Calculations (AstroCalc): Risings, transits, and settings of selected celestial object

Figure 4.33: Astronomical Calculations (AstroCalc): Phenomena
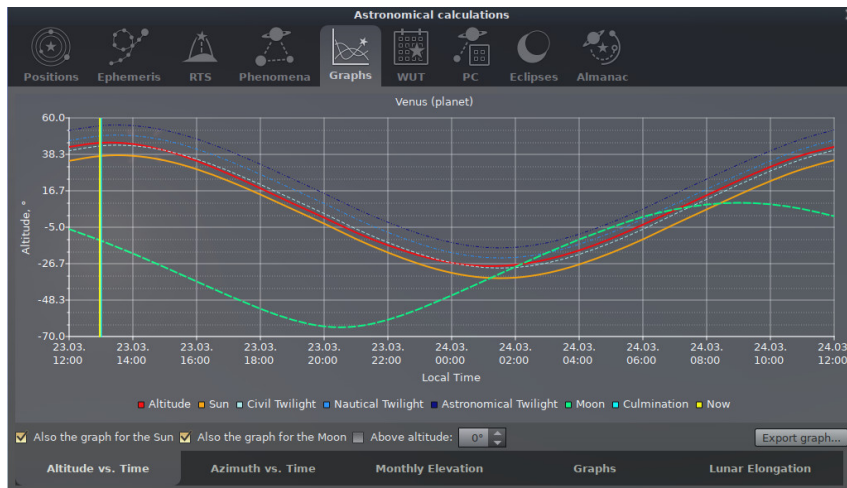


Figure 4.34: Astronomical Calculations (AstroCalc): Graphs / Altitude vs. Time



Figure 4.35: Astronomical Calculations (AstroCalc): Graphs / Azimuth vs. Time

#### 4.6.5.4 The "Graphs" Subtab

This subtab can show two functions over time for the current month or for up to 30 years and draw graphs for them in one screen (Fig. 4.37). You can select from

- Magnitude vs. Time
- Phase vs. Time
- Distance vs. Time
- Elongation vs. Time
- Angular size vs. Time
- Phase angle vs. Time
- Heliocentric distance vs. Time
- Transit altitude vs. Time
- Right ascension vs. Time
- Declination vs. Time

This tool may be very helpful for educational and statistics purposes.[6] For example, the magnitude curve for Jupiter's moons shows occasional dips where the moon is in Jupiter's shadow. However, while for most graphs a sampling interval of 24 hours should be sufficient (i.e., 1 value per day), for this graph you may want to reduce the sampling interval to 1 or 2 hours to avoid missing those eclipses by *undersampling*. Of course, such high density takes much longer to compute, so you should avoid plotting this curve for many years, or expect a long delay where the program may seem unresponsive.

#### 4.6.5.5 The "Lunar Elongation" Subtab

This subtab (Fig. 4.38) can show a "Lunar Elongation" graph — the angular distance between the Moon and the selected object (for example some deep-sky object) for the nearest 30 days. This tool was introduced for planning monthly observations.

### 4.6.6 The "What's Up Tonight" (WUT) Tab

The "What's Up Tonight" (WUT) tool[7] displays a list of objects that will be visible at night for the current date and location.

The objects are organized into type categories. Select an object type in the box labeled *Select a Category*, and all objects of that type which are above the horizon on the selected night will be displayed in the box labeled *Matching Objects*. For example, in the screenshot, the Planets category has been selected, and three planets which are up in the selected night are displayed (Jupiter, Mars and Mercury).

By default, the WUT will display objects which are above the horizon between sunset and midnight (i.e. *in the evening*). You can choose to show objects which are up between midnight and dawn (*in the morning*), *around midnight*, or any time between dusk and dawn (*any time tonight*) using the combobox near the top of the window. You can also choose to see only those objects that are brighter than a certain magnitude by setting a minimum magnitude using the *Show objects brighter than magnitude* spinbox. You may center an object from the right list in the sky map just by selecting it.

Note that only DSO from catalogs which you have selected in the DSO panel (section 4.4.3) will be found.

In version 0.18.3 this tool has been refactored: the tool for searching items from list of *Matching Objects* was removed, the filter for magnitudes was moved to the right, and we added a new filter here to limit the range of acceptable angular sizes of matched objects. In addition to the names we added 5 new sortable columns: magnitude, rising time, transit time, setting time and angular size of object.

### 4.6.7 The "Planetary Calculator" (PC) Tab

The "Planetary Calculator" (PC) tool has been added after user requests. It computes the relations between two Solar system bodies for the current date and location — linear and angular distances, orbital resonances and orbital velocities.

The *Graphs* tab (Fig. 4.41) shows the change in the linear and angular distances between selected celestial bodies over a range of 600 days (centered on the current date) as graphs.

### 4.6.8 The Eclipses Tab

The Eclipses tool has four subtabs: "All Solar Eclipses", "Local Solar Eclipses", "Lunar Eclipses" and "Planetary Transits".

You can export the calculated eclipses and transits into an XLSX or CSV file.

---

[6]The idea for this tool has been obtained from **SkytechX**: http://www.skytechx.eu/

[7]This tool has been partially ported from the **KStars** planetarium: https://edu.kde.org/kstars/
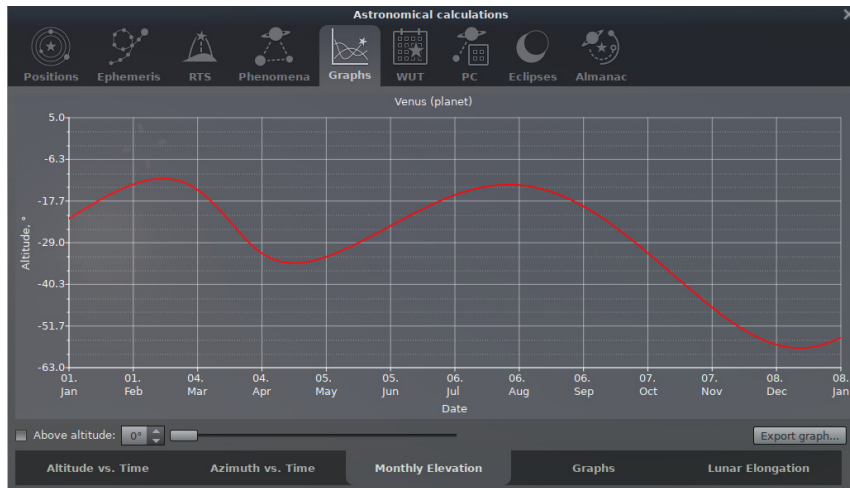
Figure 4.36: Astronomical Calculations (AstroCalc): Graphs / Monthly Elevation
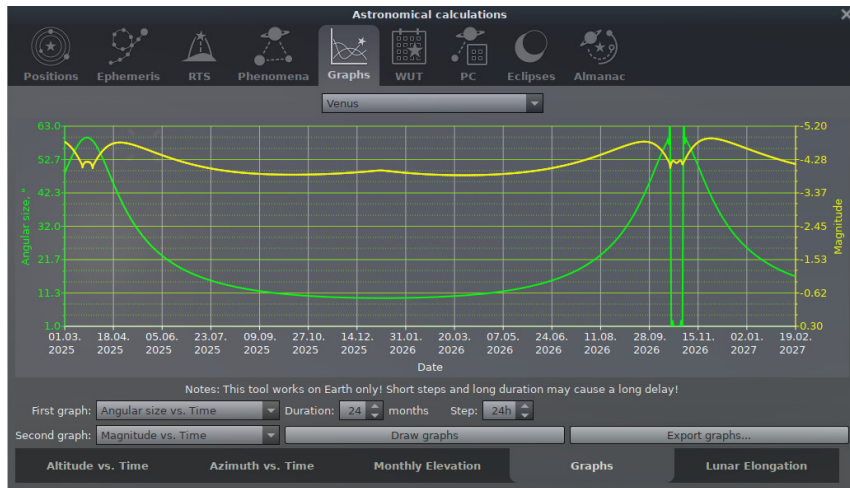


Figure 4.37: Astronomical Calculations (AstroCalc): Graphs



Figure 4.38: Astronomical Calculations (AstroCalc): Graphs / Lunar Elongation
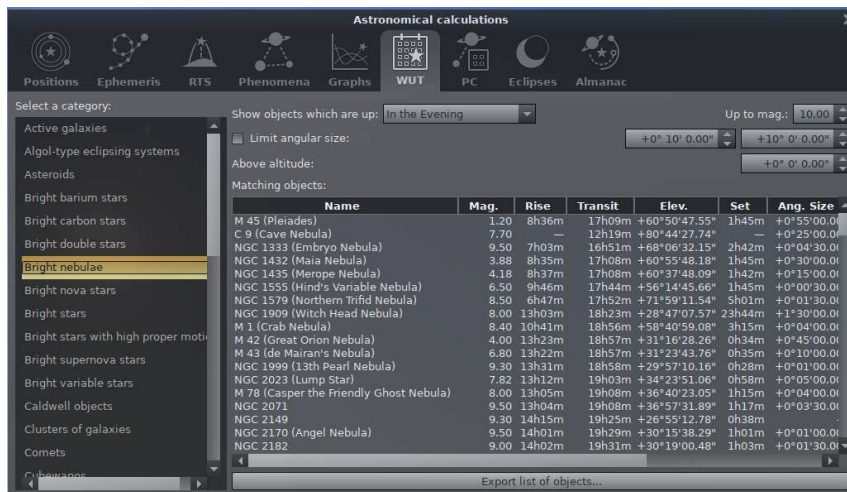
Figure 4.39: Astronomical Calculations (AstroCalc): What's Up Tonight (WUT)



Figure 4.40: Astronomical Calculations (AstroCalc): Planetary Calculator (PC), Data Tab
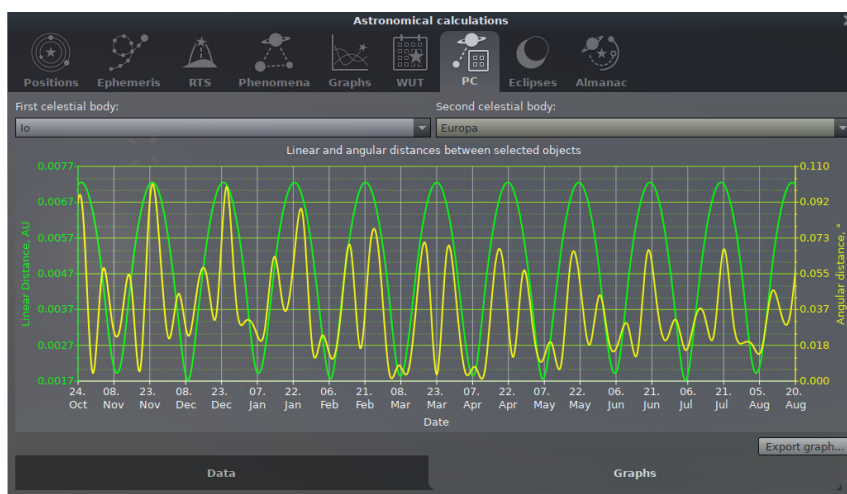


Figure 4.41: Astronomical Calculations (AstroCalc): Planetary Calculator (PC), Graphs Tab

**Caution**

Predicting eclipses and transits, and in particular local circumstances, over thousands of years in the past and future is not reliable due to the principal unpredictability of $\Delta T$, caused by fluctuations of Earth's rotation. (See section 18.4.3 for details.)

### 4.6.8.1 The "All Solar Eclipses" Subtab

This subtab (Fig. 4.42) contains data for all solar eclipses on the Earth in the selected time range. Double click on a line in the table will set location and time of greatest eclipse. Click on the table row will show circumstances of selected eclipse in the lower table.

The quantity Gamma is the minimum distance of the lunar shadow cone axis to the center of the Earth, in units of Earth's equatorial radius. This distance is positive or negative, depending on whether the axis of the shadow cone passes north or south of the Earth's center.

Click the Export KML... button to create a KML file of the selected eclipse. KML is a file format used to display geographic data in Earth browsers, such as **Marble**, **Google Earth** or **Google Maps**. The file can be opened in applications that support KML version 2.2. A description of the lines for solar eclipses is shown in Fig. 4.43. Different colors are used to draw path of central eclipse. Red = total eclipse, blue = annular eclipse, and purple = hybrid eclipse. Limits of penumbral or partial eclipse are green.

### 4.6.8.2 The "Local Solar Eclipses" Subtab

This subtab (Fig. 4.44) contains data for solar eclipses for the current location (on the Earth!) in defined time range.

Double click on a line in the table will set the time of greatest eclipse.

### 4.6.8.3 The "Lunar Eclipses" Subtab

This subtab (Fig. 4.45) contains data for all lunar eclipses on the Earth in defined time range. Double click on the table row will set time of greatest eclipse. Click on the table row will show circumstances of selected eclipse in the lower table.

The quantity gamma is the minimum distance from the center of the Moon to the axis of Earth's umbral shadow cone, in units of Earth's equatorial radius. This distance is positive or negative, depending on whether the Moon passes north or south of the shadow cone axis.

The visibility conditions are based on the altitude of the Moon at greatest eclipse:

**Invisible** — the greatest eclipse is invisible at the current location (altitude is negative);

**Not obs.** — not observable eclipse. Our rule of thumb is that a partial penumbral eclipse is detectable with the unaided eye if penumbral magnitude > 0.7;

**Bad** — bad visibility conditions for current location (altitude range is 0—30°);

**Good** — good visibility conditions for current location (altitude range is 30—45°; i.e., "photometric altitude");

**Perfect** — perfect visibility conditions for current location (altitude range is 45—90°).

### 4.6.8.4 The "Planetary Transits" Subtab

This subtab (Fig. 4.46) contains data for all transits of Mercury and Venus across the Sun as seen from Earth (see 19.11.3) in the defined time range. If an event is not observable because the Sun/planet is below the horizon, its time will be shown in brackets and greyed-out. Further columns show the total duration of the event, and the observable duration at the current location, which takes rising and setting times into account.

Double click on the table row will set time of mid-transit.

## 4.6.9 The Almanac Tab

v 25.1      The Almanac tool has one subtab: "Specific Time".

### 4.6.9.1 The "Specific Time" Subtab

This subtab (Fig. 4.47) contains data for specific time moments in this year (starring and duration seasons) and at today — time for setting and rising the Sun and Moon, time and duration of twilights, and duration of the daytime and astronomical night. You can use buttons to quick set these specific time moments. All dates and times are selectable.
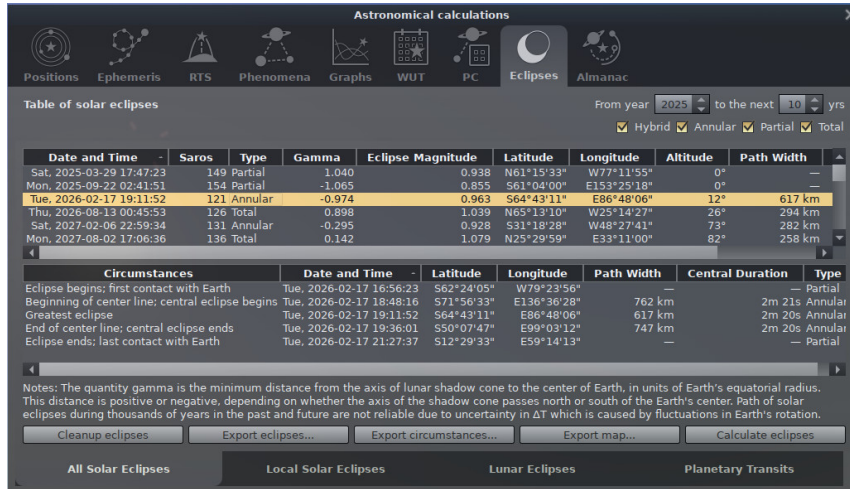
Figure 4.42: Astronomical Calculations (AstroCalc): Eclipses / All Solar Eclipses
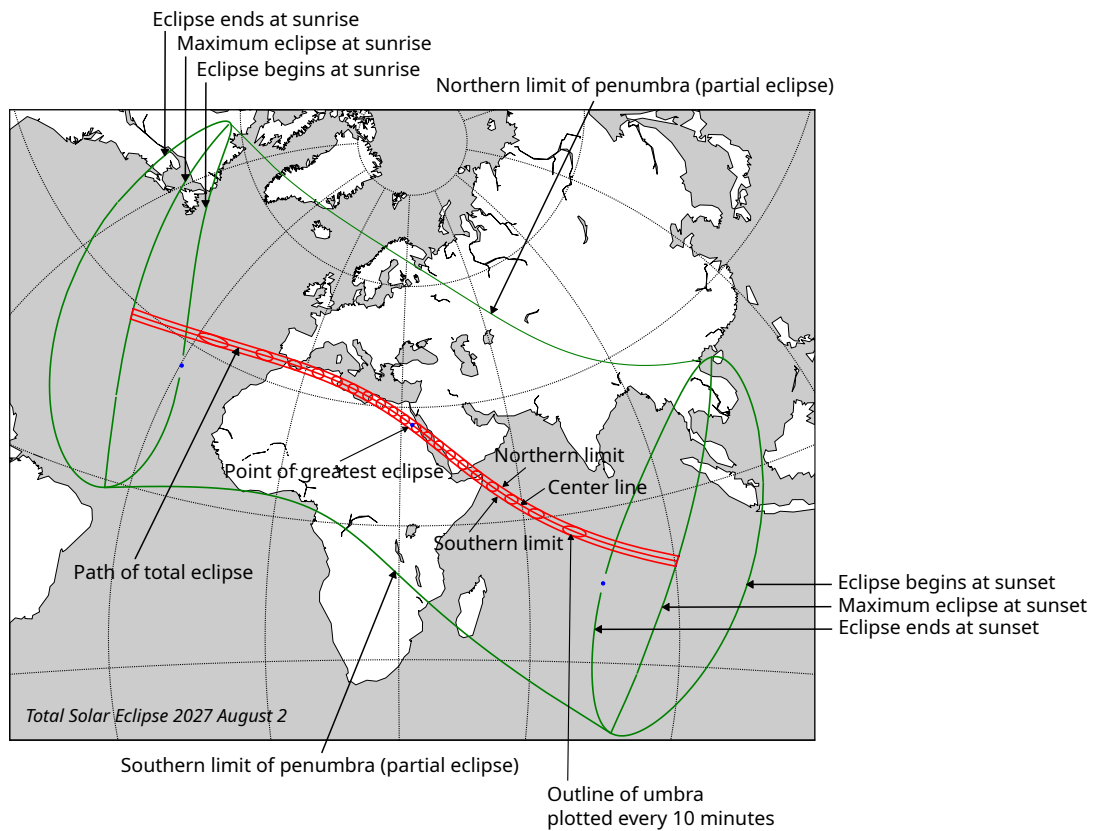


Figure 4.43: Key to solar eclipse map
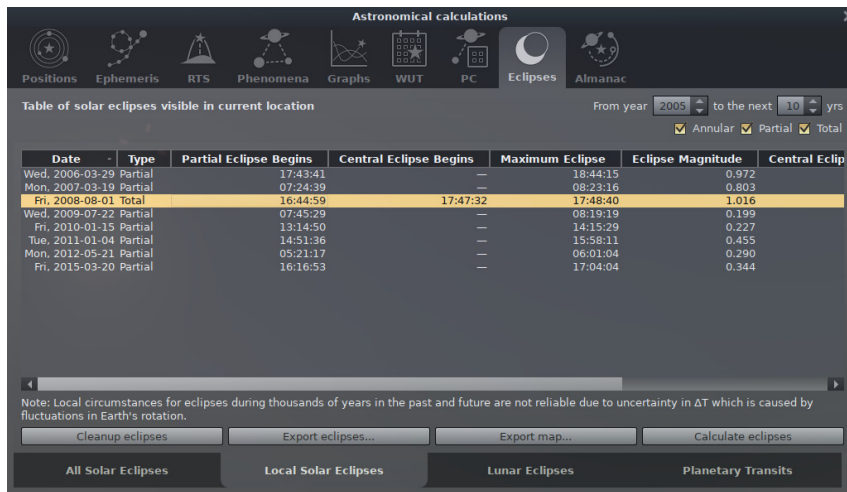
Figure 4.44: Astronomical Calculations (AstroCalc): Eclipses / Local Solar Eclipses
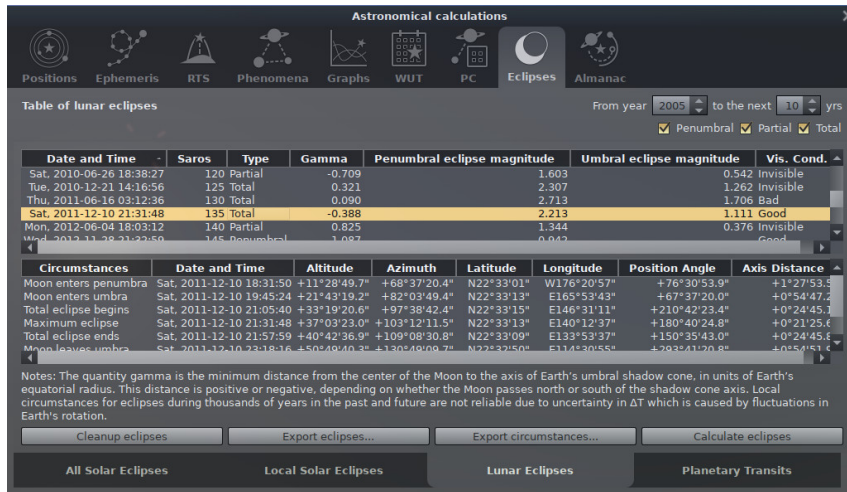


Figure 4.45: Astronomical Calculations (AstroCalc): Eclipses / Lunar Eclipses
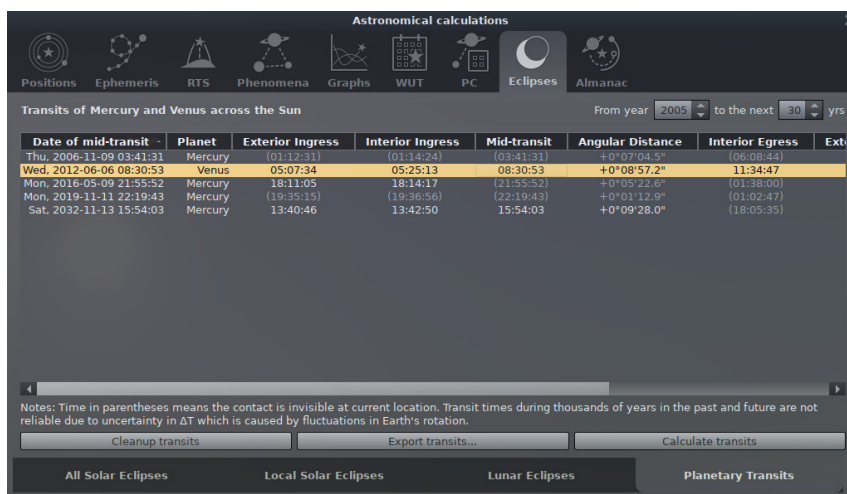


Figure 4.46: Astronomical Calculations (AstroCalc): Eclipses / Planetary Transits
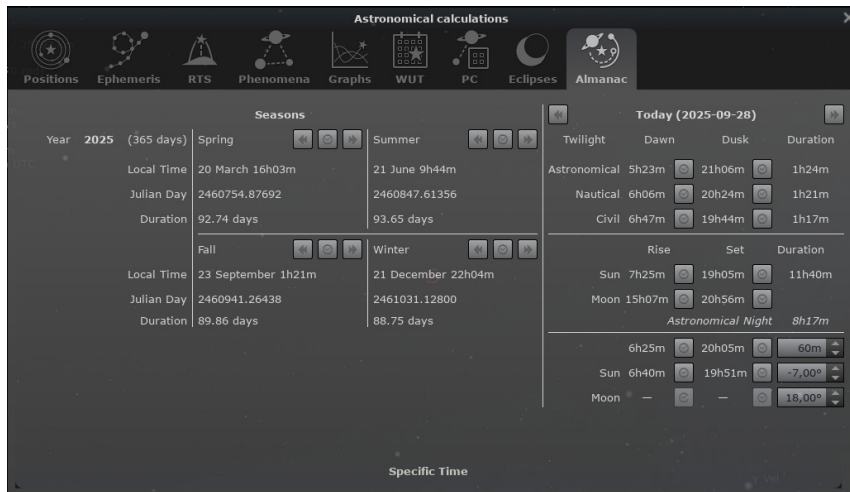
Figure 4.47: Astronomical Calculations (AstroCalc): Almanac / Specific Time

## 4.7   The Help Window

### 4.7.1   The Help Tab
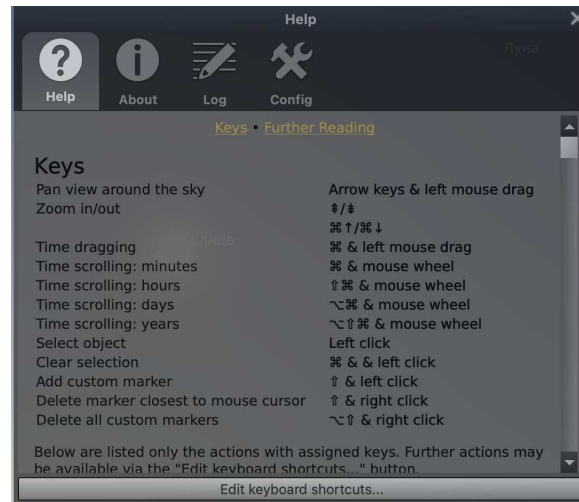


Figure 4.48: Help Window

The Help Tab lists all of Stellarium's keystrokes. Note that some features are only available as keystrokes, so it's a good idea to have a browse of the information in this window.

### 4.7.2   The About Tab

The About Tab (Fig. 4.49) shows version and licensing information, and a list of people who helped to produce the program. This tab  also provides a tool to check for updates of Stellarium.

### 4.7.3   The Log Tab

The Log Tab (Fig. 4.50) shows messages like the loading confirmations carried out when Stellarium runs. It is useful to locate the files that Stellarium writes to your computer. The same information is written to the file `log.txt` that you will find in your user data directory (see 5.1).

### 4.7.4   The Config Tab

The Config Tab (Fig. 4.51) shows configuration data of the Stellarium. It is useful to locate the files that Stellarium writes to your computer. The same information is written to the file `config.ini` that you will find in your user data directory (see 5.1).
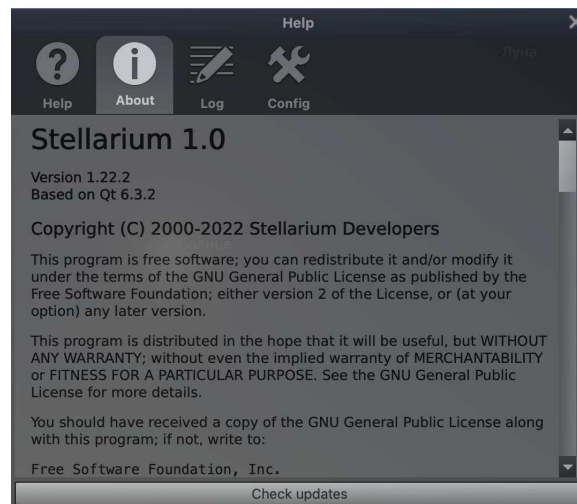
Figure 4.49: Help Window: About
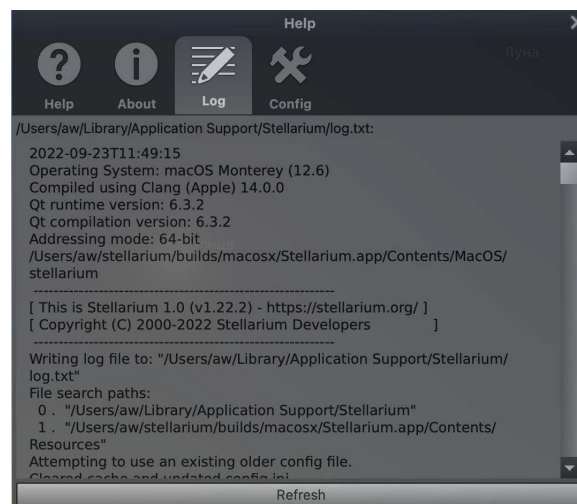


Figure 4.50: Help Window: Logfile
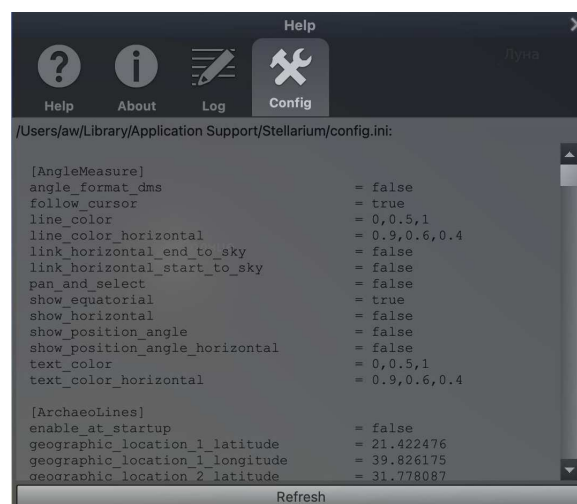


Figure 4.51: Help Window: Config file

## 4.8    Editing Keyboard Shortcuts



Figure 4.52: Keyboard Shortcuts

You can edit the shortcut keys here. Each available function can be configured with up to two key combinations. You may want to reconfigure keys for example if you have a non-English keyboard layout and some keys either do not work at all, or feel unintuitive for you, or if you are familiar with other software and want to use the same hotkeys for similar functions. Simply select the function and click with the mouse into the edit field, then press your key of choice. If the key has been taken already, a message will tell you.

This tool is available through the Help Tab of the Help window (see section 4.7.1) and the Tools Tab of the Configuration window (see section 4.3.5).

### 4.8.1    Example

If you want to follow the sky view each evening with the Sun at the same depth below the horizon, so that the twilight is of equal darkness, you may want to assign some actions to intuitive shortcut keys. In the Keyboard Shortcut editor (Fig. 4.52), find the *Date and Time* group and assign, e.g., the keys on your numeric keypad:

|                            |        |
|----------------------------|--------|
| Previous evening twilight  | Ctrl+9 |
| Previous morning twilight  | Ctrl+7 |
| Next evening twilight      | Ctrl+3 |
| Next morning twilight      | Ctrl+1 |
| Today's evening twilight   | Ctrl+6 |
| Today's morning twilight   | Ctrl+4 |

# Advanced Use

# 5. Files and Directories

## 5.1 Directories

Stellarium has many data files containing such things as star catalogue data, nebula images, button icons, font files and configuration files. When Stellarium looks for a file, it looks in two places. First, it looks in the *user directory*[1] for the account which is running Stellarium. If the file is not found there, Stellarium looks in the *installation directory*[2]. Thus it is possible for Stellarium to be installed by an administrative user and yet have a writable configuration file for non-administrative users. Another benefit of this method is on multi-user systems: Stellarium can be installed by the administrator, and different users can maintain their own configuration and other files in their personal user accounts.

In addition to the main search path, Stellarium saves some files in other locations, for example screens shots and recorded scripts.

The locations of the user directory, installation directory, *screenshot save directory* and *script save directory* vary according to the operating system and installation options used. The following sections describe the locations for various operating systems.

### 5.1.1 Windows

**installation directory** By default this is `C:\Program Files\Stellarium\`, although this can be adjusted during the installation process.

**user directory** This is the Stellarium sub-folder in the Application Data folder for the user account which is used to run Stellarium. Depending on the version of Windows and its configuration, this could be any of the following (each of these is tried, if it fails, the next in the list if tried).

```
%APPDATA%\Stellarium\
%USERPROFILE%\Stellarium\
%HOMEDRIVE%\%HOMEPATH%\Stellarium\
%HOME%\Stellarium\
Stellarium's installation directory
```

Thus, on a typical Windows Vista/7/10 system with user "Bob Dobbs", the user directory will be:

```
C:\Users\Bob Dobbs\AppData\Roaming\Stellarium\
```

The user data directory is unfortunately hidden by default. To make it accessible in the Windows file explorer, open an **Explorer** window and select Organize... ⟩ Folder and search options . Make sure folders marked as hidden are now displayed. Also, deselect the checkbox to "hide known file name endings".[3]

---

[1] also called *user data directory*

[2] The installation directory was referred to as the config root directory in previous versions of this guide

[3] This is a very confusing default setting and in fact a security risk: Consider you receive an email with some file

**screenshot save directory**  Screenshots will be saved to the `Pictures/Stellarium` directory, although this can be changed in the GUI (see section 4.3.5) or with a command line option (see section 6.1).

### 5.1.2  macOS

**installation directory**  This is found inside the application bundle, `Stellarium.app`. See *The Anatomy of macOS App Bundles*[4] or *Bundle Programming Guide*[5] for more information.

**user directory**  This is the sub-directory `~/Library/Application Support/Stellarium` of the user's home directory.

**screenshot save directory**  Screenshots are saved to the user's Desktop.

### 5.1.3  Linux

**installation directory**  This is in the `share/stellarium` sub-directory of the installation prefix, i.e., usually `/usr/share/stellarium`.

**user directory**  This is the `.stellarium` sub-directory of user's home directory, i.e., `~/.stellarium/`. This is a hidden folder, so if you are using a graphical file browser, you may want to change its settings to "display hidden folders".

**screenshot save directory**  Screenshots are saved to the user's home directory.

### 5.1.4  *BSD/Solaris/OpenIndiana

**installation directory**  This is in the `share/stellarium` sub-directory of the installation prefix, i.e., usually `/usr/local/share/stellarium/`.

**user directory**  This is the `.stellarium` sub-directory of user's home directory, i.e., `~/.stellarium/`. This is a hidden folder, so if you are using a graphical file browser, you may want to change its settings to "display hidden folders".

**screenshot save directory**  Screenshots are saved to the user's home directory.

### 5.1.5  Haiku

**installation directory**  This is in the `/boot/system/data/stellarium/` sub-directory.

**user directory**  This is in the user's home directory, i.e., `~/config/settings/Stellarium/` or the sub-directory `/boot/home/config/settings/Stellarium/`.

**screenshot save directory**  Screenshots are saved to the user's home directory.

### 5.1.6  Customized Location

Some users may prefer non-standard locations for their own data, for example when the Windows `C:` drive (which usually contains user data), or the Linux `/home` partition has become too small to hold tens of high-resolution landscapes or detailed 3D sceneries. You can move the entire directory elsewhere and use an environment variable `STEL_USERDIR` that contains the pathname.

## 5.2  Directory Structure

Within the *installation directory* and *user directory* defined in section 5.1, files are arranged in the following sub-directories.

`landscapes/`  contains data files and textures used for Stellarium's various landscapes. Each landscape has its own sub-directory. The name of this sub-directory is called the *landscape ID*, which is used to specify the default landscape in the main configuration file, or in script commands.

`skycultures/`  contains constellations, common star names and constellation artwork for Stellarium's many sky cultures. Each culture has its own sub-directory in the `skycultures` directory.

`scripts/`  contains your own scripts. These can be used to create complex demonstrations (see ch. 17).

`nebulae/`  contains data and image files for nebula textures. In the future Stellarium may be able to support multiple sets of nebula images and switch between them at runtime. This feature is not implemented for version 25.4, although the directory structure is in place – each set of nebula textures has its own sub-directory in the nebulae directory.

---

`funny.png.exe` attached. Your explorer displays this as `funny.png`. You double-click it, expecting to open some image browser with a funny image. However, you start some unknown program instead, and running this `.exe` executable program may turn out to be anything but funny!

[4] `https://www.maketecheasier.com/anatomy-macos-app-bundles/`

[5] `https://developer.apple.com/library/archive/documentation/CoreFoundation/Conceptual/CF Bundles/Introduction/Introduction.html`

`stars/`  contains Stellarium's star catalogues. In the future Stellarium may be able to support multiple star catalogues and switch between them at runtime. This feature is not implemented for version 25.4, although the directory structure is in place – each star catalogue has its own sub-directory in the stars directory.

`data/`  contains miscellaneous data files including fonts, solar system data, city locations, etc.

`textures/`  contains miscellaneous texture files, such as the graphics for the toolbar buttons, planet texture maps, etc.

`ephem/`  (optional) may contain data files for planetary ephemerides DE430, DE431, DE440 and DE441 (see 5.5.3).

If any file exists in both the installation directory and user directory, the version in the user directory will be used. Thus it is possible to override settings which are part of the main Stellarium installation by copying the relevant file to the user area and modifying it there.

It is recommended to add new landscapes or sky cultures by creating the relevant files and directories within the user directory, leaving the installation directory unchanged. In this manner different users on a multi-user system can customise Stellarium without affecting the other users, and updating Stellarium will not risk the loss of your own data.

## 5.3   The Logfile

Stellarium reports various events and confirmations to a *logfile*, `log.txt`, in the *user directory*. This has the same content as you can see on the console on Linux when you start Stellarium on the command line. Normally you don't need to bother with its contents, however, if Stellarium behaves unexpectedly, crashes, or shows other problems, a quick look into this file may help to identify the problem. Also when you report a problem to the developers in the hope that they (we) can 'fix' anything, this logfile is an essential ingredient to your report. The logfile can also be displayed within the program: press $\boxed{\text{F1}}$ to call the help panel, and select the Logfile tab.

## 5.4   The Main Configuration File

The main *configuration file* is read each time Stellarium starts, and settings such as the observer's location and display preferences are taken from it. Ideally this mechanism should be totally transparent to the user – anything that is configurable should be configured "in" the program GUI. However, at time of writing Stellarium isn't quite complete in this respect, despite improvements in each version. Some settings, esp. color values for some lines, grids, etc. can only be changed by directly editing the configuration file.[6] This section describes some of the settings a user may wish to modify in this way, and how to do it.

The name of the configuration file is `config.ini`[7]. If the configuration file does not exist in the *user directory* when Stellarium is started (e.g., the first time the user starts the program), one will be created with default values for all settings (refer to section 5 Files and Directories for the location of the user directory on your operating system).

The configuration file is a regular text file, so all you need to edit it is a text editor like **Notepad** on Windows, **Text Edit** on the Mac, or **nano/vi/gedit/emacs/leafpad** etc. on Linux.

A complete list of configuration file options and values may be found in appendix D.1.

## 5.5   Getting Extra Data

### 5.5.1   More Stars

Stellarium is packaged with over 600 thousand stars in the normal program download, but much larger star catalogues may be downloaded in the *Tools* tab of the *Configuration* dialog ( $\boxed{\phantom{x}}$ or $\boxed{\text{F2}}$ ).

---

[6]Color values can be edited interactively by the Text User Interface plugin (see 13.4).

[7]It is possible to specify a different name for the main configuration file using the `--config-file` command line option. See section 6.1 Command Line Options for details.

### 5.5.2 More Deep-Sky Objects

Stellarium is packaged with over 94 thousand deep-sky objects[8] in the normal program download (the *standard edition* of Stellarium DSO catalog[9], see section 8.1), but an *extended edition* of DSO catalog with over one million objects (up to $20.0^m$ for galaxies) may be downloaded from Stellarium's Github website[10]:

| Version; Edition | Filename | MD5 hash | Size |
|---|---|---|---|
| 3.22; extended | `catalog-3.22.dat` | c4820d050791046baf1460b186fa23c6 | 28MB |

The file can be placed in a folder named `nebulae/default` inside the *user directory* (see section 5.2).

### 5.5.3 Alternative Planet Ephemerides: DE430, DE431, DE440, DE441

By default, Stellarium uses the *VSOP87* planetary theory, an analytical solution which is able to deliver planetary positions for any input date (P. Bretagnon and Francou, 1988). However, its use is recommended only for the year range $-4000\ldots+8000$. Outside this range, it seems to be usable for a few more millennia without too great errors, but with degrading accuracy. Likewise for the moon, Stellarium by default uses ELP 2000-82B (Chapront-Touze, 1982; Chapront-Touzé and Chapront, 1983; Chapront-Touzé and Chapront, 1988b).

Since v0.15.0 you can install extra data files which allow access to the numerical integration runs *DE430* and *DE431* (Folkner et al., 2014), and meanwhile also *DE440* and *DE441* (Park et al., 2021), from NASA's Jet Propulsion Laboratory (JPL). The data files have to be downloaded separately, and most users will likely not need them. DE430 and DE440 provide highly accurate data for the years $+1550\ldots+2650$, while DE431 and DE441 covers years $-13000\ldots+17000$, which allows e.g. archaeoastronomical research on Mesolithic landscapes. (But see Appendix F!) Outside these year ranges, positional computation falls back to VSOP87.

Some current approximations may still lead to numerical data which differ slightly from best possible ephemerides. Please at least compare with JPL Horizons[11] for dependable results.

To enable use of these data, download the files from JPL[12]:

| Ephemeris | Filename | MD5 hash | Size |
|---|---|---|---|
| DE430 | `linux_p1550p2650.430` | 707c4262533d52d59abaaaa5e69c5738 | 97.5 MB |
| DE431 | `lnxm13000p17000.431` | fad0f432ae18c330f9e14915fbf8960a | 2.59 GB |
| DE440 | `linux_p1550p2650.440` | 9dc8a9cefd32b0090002407847e718ba | 97.5 MB |
| DE441 | `linux_m13000p17000.441` | 4e3b924463d17b68ec9c4a18240300cd | 2.59 GB |

The files can be placed in a folder named `ephem` inside either the *installation directory* or the *user directory* (see 5.2). Alternatively, if you have them already stored elsewhere, you may add the path to `config.ini` like:

```
[astro]
de430_path = C:/Astrodata/JPL_DE43x/linux_p1550p2650.430
de431_path = C:/Astrodata/JPL_DE43x/lnxm13000p17000.431
de440_path = C:/Astrodata/JPL_DE44x/linux_p1550p2650.440
de441_path = C:/Astrodata/JPL_DE44x/linux_m13000p17000.441
```

For fast access avoid storing them on a network drive or USB pendrive!

You activate use of either ephemeris in the *Configuration* panel ( F2 ). If you activate more than one, preference will be given for DE440 over DE441 if the simulation time allows it. Only if DE44x are not enabled, DE430 is given preference over DE431 if simulation time allows it. Outside of the valid times, VSOP87 will always be used.

**Acknowledgement**

The optional use of DE430/431 has been supported by the ESA Summer of Code in Space 2015 initiative.

---

[8] Over 83 thousand deep-sky objects in version 0.16.0.

[9] The first number in the version of Stellarium DSO catalog means version of catalog structure, and the second number means version of data.

[10] `https://github.com/Stellarium/stellarium-data/releases/tag/dso-3.22`

[11] `https://ssd.jpl.nasa.gov/horizons.cgi`

[12] `https://ssd.jpl.nasa.gov/ftp/eph/planets/Linux/` (Also download from this directory if you are not running Linux!)

### 5.5.4  GPS Position

In the *Location* panel (see section 4.2) you can receive your location from a *GPS* device. The exact way to receive GPS location depends on your operating system.

#### 5.5.4.1  GPSD (Linux, Mac OS X only)

On Linux, Mac-OS X and other Unixoid platforms, Stellarium preferably should not connect directly to a GPS USB device, serial device, bluetooth device, etc., but use a connection to the **gpsd** daemon running on a computer in your network which provides GPS services concurrently for any interested application. In most cases, this will be a **gpsd** running on your localhost, receiving data from some GPS device plugged in via USB. Please follow instructions by the **gpsd** authors[13] to properly configure this system daemon. A few hints:

- On Ubuntu 16.04 and likely other systems, USB hotplug devices are handled by the **udev** daemon which detects newly plugged-in devices and creates device files in the /dev directory. Unfortunately, most GPS devices use the Prolific 2303 chipset in their serial-to-USB converter and are identified as such, without other unique information like serial numbers. This chipset is also used in other Serial-to-USB converter cables, and to avoid conflicts the according rule has been disabled by the release managers of Ubuntu. In /lib/udev/60-gpsd.rules, find the commented line and re-activate it.
- If you have such an USB GPS mouse and USB-to-serial converters for other purposes like for your telescope control, you must solve the "**udev** crisis" in some other way to get **gpsd** running. You may be able to find some property in your device to uniquely identify this device and write an **udev** rule to create the symlink in /dev/gps0 to which **gpsd** can then connect.
- You can also connect to another computer which runs **gpsd**. This could be a little Raspberry Pi computer which happens to be in your WiFi to allow localisation and time service. To configure this, you must manually edit config.ini. Find the [gui] section and edit

```
[gui]
# These values are used on non-Windows systems
# supporting GPSD
gpsd_hostname   = localhost
gpsd_port       = 2947
```

  Also, **gpsd** must be started with the -G parameter to enable this.
- Even your smartphone can be used as GPS data source[14]: Apps like **BlueNMEA** can provide these data for **gpsd**, but you must make sure to configure hostname/IP Address and port number correctly, for example

```
  sudo gpsd -n -D8 -S 1001 tcp://192.168.1.101:4352
```

  which means
  **-n**  to start without a device connection
  **-D8**  maximum debug level. When it works, use what suits you
  **-S 1001**  provide service on port 1001
  **tcp**  Use this address:port combination to receive data from (IP of your smartphone, port shown on **BlueNMEA** screen).
- In case you really don't want to use the **gpsd**, you can use a directly connected device, see below. This is however not recommended when you have **gpsd** available.

#### 5.5.4.2  NMEA Device

This mode is primarily for Windows users, but also for Linux and Mac users who don't want to use **gpsd**.

Virtually all GPS receivers are able to emit the standardized *NMEA*-0183 messages which encode time, position, speed, satellite information and other data. The standard originally required connection settings of 4800 baud, 8 bit, no parity, one stop bit (8N1), however some devices come with faster transfer.

Compatible devices today are connected on a "virtual COM port" via USB. Unfortunately the COM number seems to depend on the USB plug where you attach the receiver. You can identify the port name (COM3, COM4, ... ) in the Windows system configuration (Device Manager) or with the software that came with your device.[15]

---

[13]https://gpsd.gitlab.io/gpsd/index.html
[14]Thanks to user Caysho for this hint.
[15]On Linux, this may read /dev/ttyUSB0, /dev/gps0 or similar.

If this is the only serial device, Stellarium should automatically connect to it regardless of configuration entries. If you have a device with non-standard baudrate or several serial devices on serial ports (e.g., your telescope?), you must find out which serial port is used by the GPS device and manually edit `config.ini`. Find the `[gui]` section and edit

```
[gui]
# These values are used on Windows primarily.
gps_interface     = COM3
gps_baudrate      = 4800
```

From now on, always use the same USB plug configuration to connect GPS and telescope.[16]

If GPS lookup fails, see section 6.2.1 to enable more diagnostic messages in the logfile.

### Bluetooth GPS

Most smartphones provide GPS and Bluetooth hardware. You can install a virtual COM port in your Windows Bluetooth settings and use a smartphone app like **Share GPS**[17] to provide the NMEA strings.

### Windows location service

On Windows devices, you can get your location using the Windows location service. The result depends on available hardware and other settings, e.g. real GPS sensor or network and WiFi detection.[18]

## 5.5.5 Modernized MESA3D libraries (Software OpenGL on Windows)

Stellarium uses hardware-accelerated OpenGL for rendering. On very old Windows systems without dedicated graphics hardware, or in special circumstances like virtual machines, hardware accelerated graphics may not be available, and the **Mesa3D** software implementation of OpenGL is used. This can also be forced by the command-line option `--mesa-mode`. Rendering the graphics without hardware acceleration is of course much slower than accelerated graphics, but it's surely better than nothing.

Qt's default Mesa library (Mesa 11) provides support for OpenGL 3.0 only. This prevents users of all versions from applying dithering in Mesa mode. Also the **ShowMySky** skylight model (see section 11.2.2) is then not available.

v 23.4    We have replaced this by a version of Mesa 20 compiled by Federico Dossena[19] which appears to be even a bit faster.

The **Mesa3D** project [20] meanwhile (2023) provides at least OpenGL 4.5. If you wish to use more "up to date" precompiled binaries and have Administrator privileges on your Windows system, you can replace this library using the following steps to install unofficial builds[21]. Note however that after this upgrade, the program runs with considerably ($\approx$35%?) lower framerate. You must decide whether this is really beneficial in your situation. The libraries don't provide any additional graphics features that Stellarium makes use of.

- Download the latest "release-msvc" package as you need from `https://github.com/pal1000/mesa-dist-win/releases` and unpack it somewhere.
- Copy `(x86|x64)/libglapi.dll,libgallium_wgl.dll,opengl32.dll` to where the executable `stellarium.exe` is.
- Delete the existing `opengl32sw.dll`
- Rename the just-copied `opengl32.dll` to `opengl32sw.dll`.

Now running Stellarium in Mesa mode (with link from program menu or command line) should report to provide OpenGL 4.5.

---

[16] Again, for Linux the port number is defined in order of hotplugging by **udev**. You should develop an **udev** rule which adds a unique name and use this. In this case, you may also need to add your user to the `dialout` group (or whichever group owns your serial port). Better yet, use **gpsd** (see above).

[17] `https://play.google.com/store/apps/details?id=com.jillybunch.shareGPS`

[18] `https://support.microsoft.com/en-us/windows/windows-location-service-and-privacy-3a8eee0a-5b0b-dc07-eede-2a5ca1c49088`

[19] `https://fdossena.com/?p=mesa/index.frag`

[20] `https://www.mesa3d.org/`

[21] `https://github.com/pal1000/mesa-dist-win/`

# 6. Advanced Options

## 6.1 Command Line Options

Stellarium's behaviour can be modified by providing parameters to the program when it is called via the command line. See table for a full list:

| Option | Option Parameter | Description |
| --- | --- | --- |
| --help or -h | [none] | Print a quick command line help message, and exit. |
| --version or -v | [none] | Print the program name and version information, and exit. |
| --config-file or -c | config file name | Specify the configuration file name. The default value is `config.ini`.<br>The parameter can be a full path (which will be used verbatim) or a partial path.<br>Partial paths will be searched for inside the regular search paths unless they start with a ".", which may be used to explicitly specify a file in the current directory or similar.<br>For example, using the option `-c my_config.ini` would resolve to the file `<user directory>/my_config.ini` whereas `-c ./my_config.ini` can be used to explicitly point to the file `my_config.ini` in the current working directory. |
| --log-file or -l | log file name | Specify the log file name. The default value is `log.txt`.<br>The value of parameter can be a simple filename or absolute path to the log file.<br>When a path is specified like `-l my_log.txt`, the file will be written to `<user directory>/my_log.txt`. When a path is specified like `-l /home/user/stellarium.log` `/home/user/stellarium.log` |

| --restore-defaults | [none] | Stellarium will start with the default configuration. Note: The old configuration file will be overwritten. |
|---|---|---|
| --user-dir<br>--screenshot-dir | path<br>path | Specify the user data directory.<br>Specify the directory to which screenshots will be saved. |
| --full-screen | yes or no | Overrides the full screen setting in the config file. |
| --home-planet<br>--latitude<br>--longitude<br>--altitude | planet<br>latitude<br>longitude<br>altitude | Specify observer planet (English name).<br>Specify latitude, e.g. 41.1 or +53d58'16.6" [1]<br>Specify longitude, e.g. 16.2 or -1d4'27.48" [1]<br>Specify observer altitude in meters. |
| --list-landscapes<br>--landscape | [none]<br>landscape ID | Print a list of available landscape IDs and exit.<br>Start using landscape whose ID matches the passed parameter (dir name of landscape). |
| --sky-date<br>--sky-time | date<br>time | The initial date in `yyyymmdd` format.<br>The initial time in `hh:mm:ss` format. |
| --startup-script | script name | The name of a script to run after the program has started. [`startup.ssc`] |
| --fov | angle (degrees) | The initial vertical field of view in degrees. |
| --scale-gui<br>--gui-css style | scale factor<br>name | Scaling the GUI according to scale factor<br>Use `name.css` to define GUI style |
| --projection-type | ptype | The initial projection type: one of<br>`ProjectionPerspective`<br>`ProjectionEqualArea`<br>`ProjectionStereographic`<br>`ProjectionFisheye`<br>`ProjectionCylinder`<br>`ProjectionCylinderFill`<br>`ProjectionMercator ProjectionMiller`<br>`ProjectionOrthographic`<br>`ProjectionHammer`<br>`ProjectionSinusoidal` |
| --spout or -S<br>--spout-name | all or sky<br>name | Act as Spout sender (See section 6.4).[2,3]<br>Use `name` as name of the Spout sender. Default name: `Stellarium`.[2] |
| --dump-opengl-details or -d | [none] | Dump information about OpenGL support to logfile. Use this is you have graphics problems and want to send a bug report. |
| --angle-mode or -a | [none] | Use ANGLE as OpenGL ES2 rendering engine (autodetect Direct3D version).[2,4] |
| --angle-d3d9 or -9 | [none] | Force use Direct3D 9 for ANGLE OpenGL ES2 rendering engine.[2,4] |
| --angle-d3d11 | [none] | Force use Direct3D 11 for ANGLE OpenGL ES2 rendering engine.[2,4] |
| --angle-warp | [none] | Force use the Direct3D 11 software rasterizer for ANGLE OpenGL ES2 rendering engine.[2,4] |

---

[1] You may have to escape the minute/second characters, like +53d58\'16.6\"

[2] On Windows only

[3] This function requires running in OpenGL mode.

[4] Qt5-based Stellarium versions only

| --mesa-mode or -m | [none] | Use MESA as software OpenGL rendering engine.[2] |
| --single-buffer | [none] | Use single-buffering. This reportedly avoids screen blanking problems with some Intel GPUs. |
| --opengl-compat or -C | [none] | Request OpenGL 3.3 Compatibility Profile. Might fix graphics problems in some driver configurations. |
| --low-graphics or -L | [none] | Force low-graphics mode. May be useful on old GPUs that do support OpenGL 3.3 but perform too slowly. |
| --no-audio | [none] | Disable sound output (avoids initialisation problems on Virtual Machines or special builds). |
| --no-screensaver | [none] | Disable screensaver and auto-sleep when in fullscreen mode (Windows only). |

 If you want to avoid adding the same switch every time when you start Stellarium from the command line, you can also set an environment variable `STEL_OPTS` with your default options.

Calling the respective options on the command line overrides settings from environment variables (apart from `STEL_OPTS`).

### 6.1.1 Examples

- To start Stellarium using the configuration file `configuration_one.ini` situated in the user directory (use either of these):

```
stellarium --config-file=configuration_one.ini
stellarium -c configuration_one.ini
```

- To list the available landscapes, and then start using the landscape with the ID "ocean"

```
stellarium --list-landscapes
stellarium --landscape=ocean
```

Note that console output (like `--list-landscapes`) may not be possible on some Windows systems.

## 6.2 Environment Variables

Some command-line options or settings can be set permanently by storing them into environment variables. How to set them depends on the respective operating system.

**Windows** Press the start menu, search for "environment variable". Use the command to change user variables. After setting, you can call Stellarium via its menu entry or desktop links.

This may be especially helpful on Windows systems with older graphics cards which may not fully be compatible with OpenGL. Here we recommend you either use the program links using the ANGLE-related options, or you can set the environment variable once and forget about the problems.

**Linux, macOS** You will usually set such variables at the end of your `~/.bashrc` file. Open this with a text editor and add, near the end,

```
export STEL_OPTS="-platform xcb --single-buffer"
```

This forces use of the X11 platform plugin which may work better than `wayland` on older systems. These environment variables are important:

**STEL_OPTS** may contain a default commandline with options in the syntax of the table above. Also some Qt settings can only be tweaked with this. For example, Windows users of international keyboards with Alt Gr key may want to use

```
STEL_OPTS=-platform windows:altgr,fontengine=freetype --single-buffer
```

The `-platform` parameter is part of Qt. Its second argument, `fontengine`, selects a different font engine (i.e., some fonts may look better with it). The other argument, `--single-buffer`, is a setting that influences Stellarium (see table above).

**STEL_USERDIR** may contain the path to a user data directory deviating from the default (see section 5.1).

**QT_OPENGL** [2] May be one of `desktop` (native OpenGL for your GPU, recommended), `angle`[4] or `software`. The last activates pure software rendering using the MESA OpenGL library. Note that command line options take precedence over this environment variable.

**QT_ANGLE_PLATFORM** [2,4] May be one of `d3d9` (DirectX 9) or `d3d11` (DirectX 11), or `warp` for another software-only solution. Note that command line options take precedence over this environment variable.

### 6.2.1 Logfile tweaks

Qt based programs can write log files where status messages of varying severity can be written[5]. There are categories `debug` (usually only of developer interest), `info` (informational), `warning` (something unexpected), `critical` (usually connected to some real failure) and `fatal` (program fails (usually exits) here). The amount of logging messages can be tuned by setting the environment variable `QT_LOGGING_RULES`. For example, to remove all `debug` messages, set it to `*.debug=false;`. To remove even the `info` messages, add `*.info=false;`. (Close each rule, also the last, with semicolon!) If you experience operating trouble, make sure you allow all messages, i.e., set these entries shown here to `true` (or delete the variable).

v 25.4        Some modules can be individually finetuned with respect to the amount of logging. Most users won't ever want to see the ugly details, so `debug` is deactivated by default for:

`stel.GPS` GPS related issues.
`stel.LocIP` IP-based location queries.
`stel.Texture` Texture handling.
`stel.Atmosphere` Atmosphere related messages.
`stel.Scripting` scripting related messages.
`stel.Media` Multimedia related messages.
`stel.HiPS` HiPS related messages.
`stel.Properties` StelProperty related messages.

If you suspect issues with some features on your computer, add those entries as shown above, e.g., to hunt down issues with a GPS device:

```
QT_LOGGING_RULES =*. debug = false ; stel . GPS . debug = true ;
```

or if you are developing scripts and videos don't play, try if this helps:

```
QT_LOGGING_RULES =*. debug = false ; stel . Media . debug = true ;
```

## 6.3 GUI Customizations

Some users have difficulties to read Stellarium's rather dark user interface. Some screens may be too dark, or environments too bright.

### 6.3.1 Panel transparency

The GUI panels are semitransparent by design. If this impedes your ability to read them, you can make them fully opaque with an entry to `config.ini`.

```
[ gui ]
flag_use_window_transparency = false
```

### 6.3.2 Button brightness

v 24.4    If you only want a bit brighter buttons, these can be tweaked separately in `config.ini`.

```
[ gui ]
pixmaps_brightness =1.25
```

The value is clamped to $[1 \ldots 1.8]$ to avoid making active and inactive buttons equally bright.

### 6.3.3 Text shadow

v 24.4    Some users complain the infotext is badly visible when there are trees or the Milky Way in the background. This can also be mitigated in `config.ini`.

```
[gui]
flag_info_shadow=true
```

### 6.3.4 User interface colors

Others users still find the GUI too bright, and they would prefer a real "dark mode". To allow this, you can create and load your own alternative style files.

The appearance of the windows, buttons etc. is governed by a CSS (Cascaded Style Sheet) file. It certainly requires some knowledge and guessing to edit your own, but there is enough general help on CSS available online. You can find the CSS files in Stellarium's Github site[6].

Copy them into your user directory and rename to e.g. `myOwnGreatStyle.css`. Edit numbers, but do not change the item names! Then you can either launch Stellarium with the added command line option like

```
stellarium --gui-css myOwnGreatStyle
```

or you could also use the scripting option (see chapter 17):

```
core.setGuiStyle("MyOwnGreatStyle");
```

To go back to Stellarium's default, just use

```
core.setGuiStyle("default");
```

If link colors in text panels are now difficult to read, copy `normalHtml.css` from Github to your own `MyOwnGreatStyleHtml.css` and modify to your taste.

Note that, as Stellarium evolves, these files also may change from version to version. We cannot give any guarantees that one customized file will work without adaptation on later or earlier versions of Stellarium.

## 6.4 Spout

Apart from stand-alone use, Stellarium can be used as multimedia source in larger installations, in museums or science exhibitions. **Spout**[7] is a technology which enables use of Stellarium's output window as texture in DirectX applications on Windows. Simply start Stellarium with the `--spout=sky` command line option. (Currently **Spout** output is limited to the main window without GUI panels, but this may change in future versions.) Your master application must obviously embed a **Spout** receiver. The default name of the **Spout** sender is `Stellarium`. If you need more than one instance of Stellarium acting as source, you can use option `--spout-name=StelSpout2` in addition to create another **Spout** sender without a name conflict. In such cases, it may be useful to also have separate user data directories and use option `--user-dir`.

This mode does not work in ANGLE mode and requires reasonably modern graphics hardware with the `WGL_NV_DX_interop` driver extension running in OpenGL mode. Some Nvidia GPUs work without this extension listed explicitly. On a notebook with Nvidia Optimus technology, make sure to launch Stellarium *and* **SpoutReceiver** (or your target application) on the Nvidia hardware. For permanent setting, use the Nvidia configuration dialog to configure Stellarium and the target application explicitly to run always on the Nvidia card.

Note that Spout use disables any multisampling setting (see Appendix D.1.25).

## 6.5 Spherical Mirror Mode for Planetarium Use

IMMERSIVE-THEATRES.COM

With Stellarium it's very easy to project the sky on a dome and create your own planetarium.

---

[5] `https://doc.qt.io/qt-6/qloggingcategory.html`, `https://doc.qt.io/qt-6/debug.html`

[6] `https://github.com/Stellarium/stellarium/blob/stellarium-stable/data/gui/normalStyle.css` and `https://github.com/Stellarium/stellarium/blob/stellarium-stable/data/gui/normalHtml.css`

[7] `https://spout.zeal.co/`

### 6.5.0.1  360° Projection

You can use either a very expensive fisheye lens projector – or a standard projector with a spherical mirror. Not only is spherical mirror projection less expensive, but it produces a higher resolution image on the dome[8], and it's very easy to upgrade the projector.

A planetarium spherical mirror is curved like a security mirror (convex safety mirror) – with the important difference that its 'first surface', i.e., the reflective silver, is not protected by a transparent acrylic or polycarbonate layer. This allows light to be reflected without being refracted. Spherical mirrors are therefore very delicate and should never be touched with fingers or wiped with a cloth. A powerful dust blower is all you need to keep it clean.

There are two types of spherical mirror projection boxes: compact 'Newtonians' (spherical mirror with an additional small mirror)[9]; or full-length boxes (spherical mirror only)[10]. The former take up less space in the planetarium (but a little less light reaches the dome); whereas the latter produce a slightly brighter image (but require more space in the planetarium).

Although commercial projection boxes are quite expensive (mainly due to the cost of the first-surface spherical mirror); it's quite easy to build your own[11] – and you can use a cheap convex safety mirror for testing before investing in a first-surface mirror.

### 6.5.0.2  Projector Specifications

A major challenge with digital planetariums (360° cinemas) is the cross-reflection of light on the dome. This is why projector *contrast ratio* and *colour saturation* are more important than brightness (lumens). Light 'bouncing' around the dome causes the planetarium image to 'wash out' (lose colour) – so the higher the projector colour saturation, the better. Similarly, the higher the contrast ratio, the sharper and crisper the planetarium image will be, especially the night sky.

4K projectors are now very affordable, allowing you to deliver the same high-quality visuals in your small dome as large planetariums!

### 6.5.0.3  Computer Configuration

The best way to operate a planetarium is with a dual display arrangement, i.e., computer screen as the primary (main) display, and projector as the secondary (extended) display.

This way the Stellarium remote control window, desktop shortcuts, other applications, etc., will only be visible to you. The audience will only see what you want them to see. To ensure there's always something nice on the dome (even with no application open), use a high-resolution image of stars as your desktop wallpaper.

To function as a planetarium, Stellarium should be configured to open in full screen mode on the extended display (see below).

### 6.5.0.4  System Configuration

To minimise image distortion at the back of the dome, it's worth carrying out the slightly complex **Meshmapper** configuration[12]. This creates a custom distortion file for your specific system (i.e., your dome diameter, stand height, spherical mirror dimensions); and the image improvement will be remarkable[13]. This custom distortion file ('warp mesh data file') can then be used with dome applications like Stellarium.

### 6.5.0.5  Stellarium Configuration

To enable planetarium spherical mirror projection, the `config.ini` file needs to include the following:

```
[navigation]
init_fov = 180
[projection]
type = ProjectionFisheye
auto_zoom_out_resets_direction = true
[video]
fullscreen = true
viewport_effect = sphericMirrorDistorter
```

---

[8]`https://domeclub.com/#PxComp`

[9]`https://www.eplanetarium.com/projector_newtonian.php`

[10]`https://myplanetarium.com/projection-dome-system`

[11]`https://docs.worldwidetelescope.org/diy-planetarium-dome/1/dome/#setting-up-the-projector-and-mirrors`

[12]`https://paulbourke.net/dome/meshmapper`

[13]`https://domeclub.com/images/Meshmapper-1152w.jpg`

```
screen_number = 1
[spheric_mirror]
distorter_max_fov = 180
dome_radius = 5.0 (note: regardless of your actual dome radius)
image_distance_div_height = 2.67
mirror_position_x = 0
mirror_position_y = 5
mirror_position_z = 0
mirror_radius = 0.37 (regardless of your actual mirror radius)
```

Stellarium also has built-in options to help you project the best possible planetarium night sky. In a planetarium, removing the Stellarium atmosphere results in a much darker (and more beautiful) night sky. Yet without the atmosphere, the stars stop twinkling and meteors (shooting stars) disappear – which is correct for the real sky, but not what you may desire in the planetarium. To maintain twinkling and meteors even without the atmosphere, manually add the following lines to the config.ini file:

```
[stars]
flag_forced_twinkle = true
[astro]
flag_forced_meteor_activity = true
```

Another useful configuration for planetariums is to completely hide the vertical and horizontal toolbars on the dome:

```
[gui]
flag_show_gui = false
```

The following are also recommended (adjust the values to your preference):

```
[viewing]
flag_moon_scaled = true
moon_scale = 8.00
[astro]
meteor_zhr = 3000
[landscape]
flag_fog = false
[stars]
absolute_scale = 6.00
flag_star_twinkle = 1.00
flag_star_spiky = false
relative_scale = 0.70
star_twinkle_amount = 0.50
```

#### 6.5.0.6  Further notes

This feature is rarely used by the current developers and cannot be tested on standard hardware. See ongoing discussion on Github[14] and get involved.

---

[14] https://github.com/Stellarium/stellarium/issues/1914 and
https://github.com/Stellarium/stellarium/issues/3535

# 7. Landscapes

GEORG ZOTTI

Landscapes are one of the key features that make Stellarium popular. Originally just used for decoration, since version 10.6 they can be configured accurately for research and demonstration in "skyscape astronomy", a term which describes the connection of landscape, the sky above, and the observer (D. Brown, 2015). Configured properly, they can act as reliable proxies of the real landscapes, so that you can take e.g. measurements of sunrise or stellar alignments (Zotti and Neubauer, 2015), or prepare your next moonrise photograph, as though you were on-site.

In this chapter you can find relevant information required to accurately configure Stellarium landscapes, using panoramas created from photographs taken on-site, optionally supported by horizon measurements with a theodolite.

Creating an accurate panorama requires some experience with photography and image processing. However, great open-source tools have been developed to help you on the job. If you already know other tools, you should be able to easily transfer the presented concepts to those other tools.

While you are editing a landscape, you may want to reload it frequently. Turn off caching by editing the `config.ini`:

```
[landscape]
cache_size_mb = 0
```

## 7.1 Stellarium Landscapes

As of version 0.15, the available landscape types are:

**polygonal** A point list of measured azimuth/altitude pairs, used to define a sharp horizon polygon. The area below the horizon line is colored in a single color (Section 7.1.2).

**spherical** The simple form to configure a photo-based panorama: A single image is used as texture map for the horizon (Section 7.1.3).

**old_style** The original photo panorama. This is the most difficult to configure, but allows highest resolution by using several texture maps (Section 7.1.4).

**fisheye** Another 1-texture approach, utilizing an image made with a fisheye lens. This landscape suffers from calibration uncertainties and can only be recommended for decoration (Section 7.1.5).

A landscape consists of a `landscape.ini` plus the data files that are referenced from there, like a coordinate list or the textures. Those reside in a subdirectory of the `landscape` folder inside the Stellarium program directory, or, for own work, in a subdirectory of the `landscape` folder inside your Stellarium user data directory (see section 5.1).

Let us assume we want to create a landscape for a place called Rosenburg. The location for the files of our new custom landscape *Rosenburg* depends on the operating system (see 5.1). Create a new subdirectory, and for maximum compatibility, use small letters and no spaces:

Windows    `C:/Users/YOU/AppData/Roaming/Stellarium/landscapes/rosenburg`
Linux      `~/.stellarium/landscapes/rosenburg`
Mac        `$HOME/Library/Application Support/Stellarium/landscapes/rosenburg`

### 7.1.1 Location information

This optional section in `landscape.ini` allows automatic loading of site coordinates if this option is activated in the program GUI (see 4.4.5). For our purposes we should consider especially the coordinates in the location section mandatory!

```
[location]
planet = Earth
country = Austria
name = KGA Rosenburg
latitude = +48d38'3.3"
longitude = +15d38'2.8"
altitude = 266
timezone = Europe/Vienna
light_pollution = 1
atmospheric_extinction_coefficient = 0.2
display_fog = 0
atmospheric_temperature = 10.0
atmospheric_pressure = 1013.0
```

Where:

`planet`  Is the English name of the solar system body for the landscape.

`latitude`  Is the latitude of site of the landscape in degrees, minutes and seconds. Positive values represent North of the equator, negative values South of the equator.

`longitude`  Is the longitude of site of the landscape. Positive values represent East of the Greenwich Meridian on Earth (or equivalent on other bodies), Negative values represent Western longitude.

`altitude`  Is the altitude of the site of the landscape in meters.

`country`  (optional) Name of the country the location is in.

`state`  (optional) Name of the state the location is in.

`timezone`  (optional) IANA Timezone code

`name`  (optional) Name of the location. This may contain spaces, but keep it short to have it fully visible in the selection box.

Since v0.11.0, there are a few more optional parameters that can be loaded if the according switch is active in the landscape selection panel. If they are missing, the parameters do not change to defaults.

`light_pollution`  (optional) Light pollution of the site, given on the Bortle Scale (1: none … 9: metropolitan; see Appendix B). If negative or absent, no change will be made.

`atmospheric_extinction_coefficient`  (optional, no change if absent.) Extinction coefficient (mag/airmass) for this site.

`atmospheric_temperature`  (optional, no change if absent.) Surface air temperature (Degrees Celsius). Used for refraction. Set to -1000 to explicitly declare "no change".

`atmospheric_pressure`  (optional, no change if absent.) Surface air pressure (mbar; would be 1013 for "normal" sea-level conditions). Used for refraction. Set to -2 to declare "no change", or -1 to compute from altitude.

`display_fog`  (optional, -1/0/1, default=-1) You may want to preconfigure setting 0 for a landscape on the Moon. Set -1 to declare "no change".

### 7.1.2 Polygonal landscape

This landscape type has been added to allow the use of measured horizons. Users of **Cartes du Ciel**[1] will be happy to hear that the format of the list of measurements is mostly compatible.

---

[1]SkyChart / Cartes du Ciel planetarium: `https://www.ap-i.net/skychart/en/start`

This is the technically simplest of the landscapes, but may be used to describe accurately measured horizon profiles. The file that encodes horizon altitudes can also be used in all other landscape types. If present there, it will be used to define object visibility (instead of the opacity of the landscape photo textures) and, if `horizon_line_color` is defined, will be plotted.

There are a few little caveats:

- If you create a polygonal line with vertex azimuths 0, 90, 180, 270 (exactly), the horizon may not show up at all. Add a tiny nonzero value to the global rotation, like

```
polygonal_angle_rotatez = 0.0000001
```

- Sometimes, there may appear vertical lines from some corners towards the zenith or the mathematical horizon, e.g. if there is a vertex including azimuth 0 or 180. If this irritates you, just offset this azimuth minimally (e.g., 180.00001).
- As technical requirement, the zenith is always assumed to remain free and uncovered. It is not possible to define a "dome cutout" or similar restricted views out of a window. Such effect can be achieved with a Spherical Landscape (see section 7.1.3).

The `landscape.ini` file for a polygonal type landscape looks like this (this example is based on the *Geneve* landscape which was borrowed from **Cartes du Ciel** and comes with Stellarium):

```
[landscape]
name = Geneve
type = polygonal
author = Georg Zotti; Horizon definition by Patrick Chevalley
description = Horizon line of Geneve.
              Demonstrates compatibility with
              horizon descriptions from Cartes du Ciel.
polygonal_horizon_list = horizon_Geneve.txt
polygonal_angle_rotatez = 0
ground_color = .15,.45,.45
```

Where:

`name` appears in the landscape tab of the configuration window.

`type` identifies the method used for this landscape. `polygonal` in this case.

`author` lists the author(s) responsible for images and composition.

`description` gives a short description visible in the selection panel. The text can be superseded by optional `description.<lang>.utf8` files.

`polygonal_horizon_list` is the name of the horizon data file for this landscape.

`polygonal_horizon_list_mode` (optional) the two first columns in the list are numbers: azimuth and altitude or zenith distance, in either degrees or radians or gradians(gon). The value must be one of `azDeg_altDeg`, `azDeg_zdDeg`, `azRad_altRad`, `azRad_zdRad`, `azGrad_altGrad`, `azGrad_zdGrad`. Default: `azDeg_altDeg`

`polygonal_angle_rotatez` (optional, default=0) Angle (degrees) to adjust azimuth. This may be used to apply a (usually) small offset rotation, e.g. when you have measured the horizon in a grid-based coordinate system like UTM and have to compensate for the meridian convergence.

`ground_color` (optional, default=0,0,0, i.e., black) Color for the area below the horizon line. Each R,G,B component is a float within 0..1.

`minimal_brightness` (optional) Some minimum brightness to keep landscape visible. Default=-1, i.e., use `minimal_brightness` from the `[landscape]` section in the global `config.ini`.

`minimal_altitude` (optional, default=-2) Some sky elements, e.g. stars, are not drawn below this altitude to increase performance. Under certain circumstances you may want to specify something else here. (since v0.14.0)

`polygonal_horizon_inverted` (optional, default=false; only required in v0.15.0–0.20.2) In rare cases like horizon lines for high mountain peaks with many negative horizon values this should be set to true.

No longer used:

`horizon_line_color` (optional, default: invisible) used to draw a polygonal horizon line. This is now a global setting, `config.ini:landscape/polygon_color`.

#### 7.1.2.1 Artificial Polygonal Panoramas

The online service **HeyWhatsThat**[2] allows an SRTM-based analysis of the viewshed (the visible topographic area) for an observing location which also gives names for the mountain peaks visible at a given location. In summer of 2020 a dedicated landscape download option for **Stellarium** was added (see upper-right corner), so that you can install a custom landscape. Its package/directory name is `stellarium-landscape`. If you create more than one, you must rename the directory. You may also want to extend the scene description in `landscape.ini`.

A data download option provides users inclined to do some programming with the necessary data to create a polygonal landscape for Stellarium. From this, BRIAN DOYLE has created another online service, **horiZONE**[3], which does just this work for you.

1. When your viewshed analysis has been created in **HeyWhatsThat**, enter the "all panoramas" tab, and on the map click the marker associated with the panorama. Select "make public".
2. Then, take the landscape key given to you by **HeyWhatsThat**[4], add a few lines of description and other details that will become visible and used in Stellarium, and you receive a ZIP file ready for installation in Stellarium (see section 4.4.5).

A similar web service, **PeakFinder**[5], meanwhile also allows downloading the horizon polygon as installable landscape for Stellarium. A great feature of this service is the excellent gazetteer (peak identification) also visible on the website.

### 7.1.3 Spherical landscape

This method uses a more usual type of panorama – the kind which is produced directly from software such as **autostitch** or **Hugin**[6]. The *Moon* landscape which comes with Stellarium provides a minimal example of a `landscape.ini` file for a spherical type landscape:

```
[landscape]
name = Moon
type = spherical
maptex = apollo17.png
```

A more elaborate example is found with the *Grossmugl* landscape:

```
[landscape]
name = Grossmugl
type = spherical
author = Guenther Wuchterl, Kuffner-Sternwarte.at;
         Lightscape: Georg Zotti
description = Field near Leeberg, Grossmugl (Riesentumulus),
              Austria - Primary Observing Spot of the Grossmugl
              Starlight Oasis - http://starlightoasis.org
maptex = grossmugl_leeberg_crop11.25.png
maptex_top=11.25
maptex_fog = grossmugl_leeberg_fog_crop22.5.png
maptex_fog_top = 22.5
maptex_fog_bottom = -22.5
maptex_illum = grossmugl_leeberg_illum_crop0.png
maptex_illum_bottom = 0
angle_rotatez=-89.1
minimal_brightness = 0.0075
polygonal_horizon_list = horizon_grossmugl.txt
polygonal_angle_rotatez=0
minimal_altitude = -1
```

---

[2] https://www.heywhatsthat.com/

[3] https://briandoylegit.github.io/horiZONE/

[4] in the line https://www.heywhatsthat.com/?view=N15ABXY

[5] https://www.peakfinder.com

[6] http://hugin.sourceforge.net/

Where:

name appears in the landscape tab of the configuration window. This name may be translated.

type identifies the method used for this landscape. spherical in this case.

author lists the author(s) responsible for images and composition.

description gives a short description visible in the selection panel. The text will be superseded by optional description.<lang>.utf8 files.

maptex is the name of the image file for this landscape.

maptex_top (optional; default=90) is the altitude angle of the top edge.

maptex_bottom (optional; default=-90) is the altitude angle of the bottom edge. Usually you will not require this, or else there will be a hole at your feet, unless you also specify

bottom_cap_color (optional; default=-1.0,0.0,0.0 to signal "no color"). If set, this is used to close any hole in the nadir area (if maptex_bottom higher than -90).

maptex_fog (optional; default: no fog) is the name of the fog image file for this landscape.

maptex_fog_top (optional; default=90) is the altitude angle of the top edge of the fog texture. Useful to crop away parts of the image to conserve texture memory.

maptex_fog_bottom (optional; default=-90) is the altitude angle of the bottom edge.

maptex_illum (optional; default: no illumination layer) is the name of the nocturnal illumination/light pollution image file for this landscape.

maptex_illum_top (optional; default=90) is the altitude angle of the top edge, if you have light pollution only close to the horizon.

maptex_illum_bottom (optional; default=-90) is the altitude angle of the bottom edge.

angle_rotatez (optional, default=0) Angle (degrees) to adjust azimuth. If 0, the left/right edge is due east.

tesselate_rows (optional, default=20) This is the number of rows for the maptex. If straight vertical edges in your landscape appear broken, try increasing this value, but higher values require more computing power. Fog and illumination textures will have a similar vertical resolution.

tesselate_cols (optional, default=40) If straight horizontal edges in your landscape appear broken, try increasing.

polygonal_horizon_list (optional) is the name of the (measured) horizon data file for this landscape. Can be used to define the exact position of the horizon. If missing, the texture can be queried for horizon transparency (for accurate object rising/setting times)

polygonal_horizon_list_mode (optional) see 7.1.2

polygonal_angle_rotatez (optional, default=0) see 7.1.2

minimal_brightness see 7.1.2

minimal_altitude (optional, default=-2) Some sky elements, e.g. stars, are not drawn below this altitude for efficiency. Under certain circumstances (e.g. for space station panoramas where you may have sky below your feet, or for deep valleys/high mountains, you may want to specify something else here.

To save texture memory, you can trim away the transparent sky and define the angle maptex_top. Likewise, fogtex_top, fogtex_bottom, maptex_illum_top and maptex_illum_bottom. You should then stretch the texture to a full power of 2 for maximum compatibility, like 4096 × 1024 (but note that some hardware is even limited to 2048 pixels). The easiest method to create perfectly aligned fog and illumination layers is with an image editor that supports layers like the **GIMP** or **Photoshop**. Fog and Light images should have black background.

## 7.1.4 High resolution ("Old Style") landscape

The old_style or multiple image method works by having the 360°panorama of the horizon (without wasting too much texture memory with the sky) split into a number of reasonably small *side textures*, and a separate *ground texture*. This has the advantage over the single-image method that the detail level of the horizon can be increased without ending up with a single very large image file, so this is usable for either very high-resolution panoramas or for older hardware with limited capabilities. The ground texture can be a different resolution than the side textures. Memory usage may be more efficient because there are no unused texture parts like the corners of the texture file in the fish-eye method. It is even possible to repeat the horizon several times (for purely decorative purpose). The side textures are mapped onto curved (spherical ring or cylinder) walls (Fig. 7.1).

On the negative side, it is more difficult to create this type of landscape – merging the ground texture with the side textures can prove tricky. (**Hugin** can be used to create also this file, though. And on the other hand, you can replace this by something else like a site map.) The contents of the landscape.ini

Figure 7.1: Old_style landscape: eight parts delivering a high-resolution panorama. The bottom (ground) texture, drawn on a flat plane, is not shown here.

file for this landscape type is also somewhat more complicated than for other landscape types. Here is the landscape.ini file which describes our *Rosenburg* landscape[7]:

```
[landscape]
name = KGA Rosenburg
author = Georg Zotti, VIAS/ASTROSIM
description = KGA Rosenburg
type = old_style
nbsidetex = 8
tex0 = Horiz-0.png
tex1 = Horiz-1.png
tex2 = Horiz-2.png
tex3 = Horiz-3.png
tex4 = Horiz-4.png
tex5 = Horiz-5.png
tex6 = Horiz-6.png
tex7 = Horiz-7.png
nbside = 8
side0 = tex0:0:0:1:1
side1 = tex1:0:0:1:1
side2 = tex2:0:0:1:1
side3 = tex3:0:0:1:1
side4 = tex4:0:0:1:1
side5 = tex5:0:0:1:1
side6 = tex6:0:0:1:1
side7 = tex7:0:0:1:1
groundtex = grassground.png
ground = groundtex:0:0:1:1
nb_decor_repeat = 1
decor_alt_angle =  82
decor_angle_shift = -62
; Rotatez deviates from -90 by the Meridian Convergence.
```

---

[7]the groundtex grassground.png mentioned here has been taken from the *Guereins* landscape.

```
; The original landscape pano is grid-aligned,
; not north-aligned!
decor_angle_rotatez =  -90.525837223
ground_angle_shift = -62
ground_angle_rotatez =  44.474162777
draw_ground_first = 1
fogtex = fog.png
fog_alt_angle = 20
fog_angle_shift = -3
fog = fogtex:0:0:1:1
calibrated = true
[location]
planet = Earth
latitude = +48d38'3.3"
longitude = +15d38'2.8"
altitude = 266
light_pollution = 1
atmospheric_extinction_coefficient = 0.2
display_fog = 0
atmospheric_temperature = 10.0
atmospheric_pressure = 1013.0
```

Where:

name  is the name that will appear in the landscape tab of the configuration window for this landscape

type  should be `old_style` for the multiple image method.

author  lists the author(s) responsible for images and composition.

description  gives a short description visible in the selection panel. The text will be superseded by optional `description.<lang>.utf8` files.

nbsidetex  is the number of side textures for the landscape.

tex0 ...  tex<nbsidetex-1>  are the side texture file names. These should exist in the `textures / landscapes / landscape` directory in PNG format.

light0 ...  light<nbsidetex-1>  are optional textures. If they exist, they are used as overlays on top of the respective `tex<...>` files and represent nocturnal illumination, e.g. street lamps, lit windows, red dots on towers, sky glow by city light pollution, ... Empty (black) panels can be omitted. They are rendered exactly over the `tex<...>` files even when the PNG files have different size. If you need your light pollution higher in the sky, you must use a spherical or fisheye landscape.

nbside  is the number of side textures

side0 ...side<nbside-1>  are the descriptions of how the side textures should be arranged in the program. Each description contains five fields separated by colon characters (`:`). The first field is the ID of the texture (e.g. `tex0`), the remaining fields are the texture coordinates (`x0:y0:x1:y1`) used to place the texture in the scene. If you want to use all of the image, this will just be `0:0:1:1`.

groundtex  is the name of the ground texture file. (This could also be a diagram e.g. indicating the mountain peaks!)

fogtex  is the name of the texture file for fog in this landscape. Fog is mapped onto a simple cylinder.[8] Note that for this landscape, accurate overlay of fog and landscape is only guaranteed if `calibrated=true` and `tan_mode=true`.

nb_decor_repeat  is the number of times to repeat the side textures in the 360 panorama. (Useful photo panoramas should have 1 here)

decor_alt_angle  (degrees) is the vertical angular extent of the textures (i.e. how many degrees of the full altitude range they span).

decor_angle_shift  (degrees) vertical angular offset of the scenery textures, at which height the bottom line of the side textures is placed.

decor_angle_rotatez  (degrees) angular rotation of the panorama around the vertical axis. This is handy for rotating the landscape so North is in the correct direction. Note that for historical reasons, a landscape with this value set to zero degrees has its leftmost edge pointing towards east.

---

[8]In very wide-angle views, the fog cylinder may become visible in the corners.

ground_angle_shift (degrees) vertical angular offset of the ground texture, at which height the ground
    texture is placed. Values above -10 are not recommended for non-photographic content (e.g., a map)
    due to high distortion.
ground_angle_rotatez (degrees) angular rotation of the ground texture around the vertical axis. When
    the sides are rotated, the ground texture may need to be rotated as well to match up with the
    sides. If 0, east is up. if North is up in your image, set this to 90. Note that adjustments of
    decor_angle_rotatez require adjustments of this angle in the opposite direction!
fog_alt_angle (degrees) vertical angular size of the fog cylinder - how fog looks. Accurate vertical size
    requires calibrated=true.
fog_angle_shift (degrees) vertical angular offset of the fog texture - at what height is it drawn. Accurate
    vertical placement requires calibrated=true.
draw_ground_first if true or 1[9] the ground is drawn in front of the scenery, i.e. the side textures will
    overlap over the ground texture if ground_angle_shift > decor_angle_shift.
calibrated (optional). Only if true, decor_alt_angle etc. really work as documented above. The
    (buggy) old code was left to work with the landscapes already existing. Note that with "uncalibrated"
    landscapes, sunrise computations and similar functionality which requires an accurate horizon line
    will not work.
tan_mode (optional, not used in this file). If true, the panorama image must be in in cylindrical, not
    equirectangular projection. Finding decor_alt_angle and decor_angle_shift may be a bit
    more difficult with this, but now (v0.13.0) works also with calibrated. A fog image created as overlay
    on the pano will be perfectly placed.
polygonal_horizon_list (optional) see 7.1.3
polygonal_horizon_list_mode (optional) see 7.1.2
polygonal_angle_rotatez (optional, default=0) see 7.1.2
minimal_brightness (optional) see 7.1.2
minimal_altitude (optional) see 7.1.2

### 7.1.5 Fisheye landscape

The *Trees* landscape that is provided with Stellarium is an example of the single fish-eye method, and
provides a good illustration. The centre of the image is the spot directly above the observer (the zenith). The
point below the observer (the nadir) becomes a circle that just touches the edges of the image. The remaining
areas of the image (the corners outside the circle) are not used.

The image file (Fig. 7.2) should be saved in PNG format with alpha transparency. Wherever the image is
transparent Stellarium will render the sky.

The landscape.ini file for a fish-eye type landscape looks like this (this example is based on the *Trees*
landscape which comes with Stellarium):

```
[landscape]
name = Trees
type = fisheye
author = Robert Spearman. Light pollution image: Georg Zotti
description = Trees in Greenlake Park, Seattle
maptex = trees_512.png
maptex_illum = trees_illum_512.png
maptex_fog = trees_fog_512.png
texturefov = 210
angle_rotatez = 17
tesselate_rows = 28
tesselate_cols = 60
```

Where:
name appears in the landscape tab of the configuration window.
type identifies the method used for this landscape. fisheye in this case.
author lists the author(s) responsible for images and composition.
description gives a short description visible in the selection panel. The text will be superseded by
    optional description.<lang>.utf8 files.

_____
[9]Boolean values true|false preferred since V0.19.3, but 0|1 are still accepted.

Figure 7.2: Texture for the *Trees* Fisheye landscape.

`maptex` is the name of the image file for this landscape.

`maptex_fog` (optional) is the name of the fog image file for this landscape.

`maptex_illum` (optional) is the name of the nocturnal illumination/light pollution image file for this landscape.

`texturefov` is the field of view that the image covers in degrees.

`angle_rotatez` (optional) Angle (degrees) to adjust azimuth.

`tesselate_rows` (optional, default=20) If straight edges in your landscape appear broken, try increasing.

`tesselate_cols` (optional, default=40) If straight edges in your landscape appear broken, try increasing.

`polygonal_horizon_list` (optional) see 7.1.3

`polygonal_horizon_list_mode` (optional) see 7.1.2

`polygonal_angle_rotatez` (optional, default=0) see 7.1.2

`minimal_brightness` (optional) see 7.1.2

`minimal_altitude` (optional) see 7.1.2

### 7.1.6 Description

The short `description` entry in `landscape.ini` will be replaced by the contents of an optional file `description.<LANG>.utf8`. `<LANG>` is the ISO 639-1 language code, or its extension which contains language and country code, like `pt_BR` for Brazilian Portuguese. The long description requires the file

description.en.utf8, this is en=english text with optional HTML tags for sections, tables, etc. You can also have embedded images in the HTML (Views of sacred landscapes, other informative images, . . . ?), just make them PNG format please. The length of the description texts is not limited, you have room for a good description, links to external resources, whatever seems suitable.

If you can provide other languages supported by Stellarium, you can provide translations yourself, else Stellarium translators *may* translate the English version for you. (It may take years though.) The file ending .utf8 indicates that for special characters like ÄÖÜßáé you should use UTF8 encoding. If you write only English/ASCII, this may not be relevant.

### 7.1.7 Gazetteer

An optional feature for landscapes is a gazetteer function, i.e., labels for landscape features. The *Grossmugl* landscape demonstrates an example and should be self-explanatory. This is again multilingual, so the files are called gazetteer.<LANG>.utf8.

```
# demo gazetteer for Grossmugl landscape.
# Can be used to better describe the landscape,
# i.e. show labels on landscape features.
# Fields must be separated by vertical line,
# label must not have such a vertical line.
# Comments have this hash mark in first column.
# coordinates in degrees from true North.
# line towards zenith draws a single line strictly upward.
# label is centered on line endpoint.
# Azimuth | Altitude | degrees          | azimuth | label
#         |          | towards zenith | shift   |
113.66   | 5.5      |     4            |   -6    | Leeberg
35       | 1.5      |     2.5          |    0    | Grossmugl
335      | 2        |     2            |    0    | Steinabrunn
305      | 2        |     1            |    0    | Ringendorf
180      | 2        |     2            |    0    | Vienna (30km)
135      | 2        |     0.5          |    0    | Wind power plant Strasshof
```

### 7.1.8 Packing and Publishing

You likely have developed your landscape already in your own Stellarium user data directory, but when you are happy with your work, you may consider sharing it with other users. For easy distribution and installation via Stellarium's GUI (see section 4.4.5), you should create a ZIP file. This must contain landscape.ini and any textures and auxiliary files described above (description.en.utf8, gazetteer.en.utf8 and their translations, horizon files, images for the description . . . ) used by your landscape. If you want to release the landscape for download, consider adding a README.txt clarifying license and usage conditions. It does not matter whether the ZIP file contains a directory name inside the ZIP. If not, the directory name (ID) of the landscape will be taken from the ZIP file name.

## 7.2 Creating Panorama Photographs for Stellarium

### 7.2.1 Panorama Photography

Traditional film-based panorama photography required dedicated cameras with curved film holders and specialized lenses (Figure 7.3).

Digital photography has brought a revolution also in this field, and it has become quite easy to create panoramas simply by taking a series of photographs with a regular camera on the same spot and combining them with dedicated software.

A complete panorama photo visually encloses the observer like the mental image that astronomers have been using for millennia: the celestial sphere. If we want to document the view, say, in a big hall like a church, optimal results will be gained with a camera on a tripod with a specialized panorama head (Figure 7.4) which assures the camera rotates around the *entrance pupil*[10] of the lens in order to avoid errors by the parallax shift observed on photographs taken on adjacent but separate positions.

---

[10]In many references you will find "Nodal Point" mentioned here. But see these: https://en.wikipedia.org/wiki/Cardinal_point_%28optics%29#Nodal_points, http://web.archive.org/web/20060513074042/http://doug.kerr.home.att.net/pumpkin/Pivot_Point.pdf, http://www.janrik.net/PanoPostings/NoParallaxPoint/TheoryOfTheNoParallaxPoint.pdf

Figure 7.3: Zenit "Horizon 202" panorama camera with rotating lens for 35mm film. (Source: Wikipedia, "Horizon202" by BillC - Own Work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - `https://commons.wikimedia.org/wiki/File:Horizon202.jpg`)



Figure 7.4: Automated panorama head. (Source: Wikipedia `https://commons.wikimedia.org/wiki/File:Rodeon_vr_head_01.jpg`)

Often however, both the upper half of the observer's environment (the sky) and the ground the photographer is standing on, are regarded of lesser importance, and only a series of laterally adjacent photographs is taken and combined into a cylindrical or spherical ring that shows the landscape horizon, i.e., where ground and sky meet. If the closest object of interest is farther away that a few metres, requirements on parallax avoidance are far less critical, and the author has taken lots of landscape panoramas with a camera on the usual tripod screw, and even more entirely without a tripod. However, any visible errors that are caused by a shifted camera will require more effort in postprocessing.

When you have no tripod, note that *you must not rotate the camera on your outstretched arm!* Rather, the camera's entrance pupil must be rotated, so you should appear to dance around the camera!

The images should match in brightness and white balance. If you can shoot in RAW, do so to be able to change white balance later. If the camera can only create JPG, ensure you have set the camera to a suitable white balance before taking the photos and not to "auto", because this may find different settings and thus give colour mismatches. Exposure brightness differences can be largely removed during stitching, but good, well-exposed original shots always give better results.

As a general recommendation, the images of a panorama should be taken from left to right, else please accordingly invert some of the instructions given below.

There are several panorama making programs. Often they are included in the software that comes with a digital camera and allow the creation of simple panoramas. Other software titles are available for purchase. However, there is one cost-free open-source program that does everything we need for our task, and much more:

### 7.2.2   Hugin Panorama Software

**Hugin**[11], named after one of the ravens that sits on Odin's shoulder and tells him about the world, is a user-friendly catch-all package with graphical user interface that allows creating panoramas with a single application. Actually, **Hugin** is a GUI application which calls several specialized sub-programs with fitting parameters. The instructions are based on **Hugin V2014.0** and **2015.0**.

Typically digital images come in JPG format with information about camera, lens, and settings stored in invisible metadata in the EXIF format. When **Hugin** reads such images, it can automatically derive focal length, field of view, and exposure differences (exposure time, aperture, color balance) to create panoramas as easily as possible.

After starting **Hugin** for the first time, select Interface 〉 Expert to release several options not visible to "beginners". In the Preferences dialog ( Files 〉 Preferences ), edit number of CPU to match the number of cores in your computer and allow parallel processing. E.g., if you have an Intel Core-i7, you usually can set up to 8 cores (4 cores with hyperthreading; but maybe leave one core for your other tasks while you wait for a processing job?). If your PC is equipped with a modern programmable graphics card, you can enable its use in the Programs tab with activating "Use GPU for remapping".

After that, we are ready for creating our panoramas.

### 7.2.3   Regular creation of panoramas

The graphical user interface (GUI) consists of a main menu, symbols, and 4 tabs. We start on the tab Photos.

- Add images... Opens a file browser. Select the images which you want to stitch. Usually, lens data (focal length, horizontal field of view[12], . . . ) are read from the EXIF data. If those are not available (e.g. cheap cameras, images scanned from film), you can enter those data on loading or later. The images are now listed in the file list, and you can edit image parameters by marking one or more, and then choosing from the context menu which you get from pressing the right mouse button. In case you have used different lenses (or inadvertently used different focal lengths of a zoom lens), you can assign separate lenses to the images.
  Caveat: If you have resized the images, or produced copied on your RAW converter with non-native resolution, the horizontal Field of View (FoV) in **Hugin** may be misidentified. You must edit lens parameters and fill in the field of view from a full-size image. Else the first round of optimisation will run into unsolvable trouble.
- Select one image as *position anchor* (usually the center image), and one as *exposure anchor* (this can be the same image). For our purpose, *the anchor image should face south*.

---

[11]http://hugin.sourceforge.net/

[12]contrary to Stellarium, field of view (FoV) in **Hugin** means the *horizontal* extent in degrees.

- Next, we must find common feature points. The next field below provides the required settings. It is recommended to use the **CPFind** command. To avoid finding control points in (moving) clouds, select setting Hugin's CPFind + Celeste [13]. Then press Create control points. This opens a dialog box in which you can see output of the selected feature point extractor. It should finish with a box telling you the number of identified points. In rare cases some images cannot be linked to others, you will have to manually add or edit feature points in those cases.
- Now it's time to start optimisations. On the Geometric Optimimisation combo, start with the button Positions, incremental from anchor, and press Calculate. Moments later, a first rough match is available for inspection.
- First open the Preview window (press Ctrl + P or click the blue icon). Assumed your images cover the full horizon, the window shows an equirectangular area (360 degrees along the horizon and 180 degrees from zenith to nadir). The anchor image should be close to the image center, and the other images should be already well-aligned to both sides. You can set the exact center point by clicking it in the image. If the horizon appears badly warped, use the right mouse key and click on the horizon roughly near −90 or +90 degrees (halfway to the left or right).
- Open the OpenGL preview window (press Ctrl + Shift + P or click the blue icon with GL inside). This panel provides several important views:
  - The Preview tab is similar to the non-OpenGL preview. You can display an overlay of the control points, which are colored according to match quality. Also, with button Identify activated, you see the overlapping image frames when you move the mouse over the image.
  - The Layout tab helps finding links between images.
  - The Move/Drag dialog may help to interactively adjust a panorama.
  
  Sometimes the preview image may however be distorted and unusable.
- Open the *Control Points Table* dialog (press F3 or click the "table" button). Here you see the points listed which link two images. Clicking a column label sorts by this column. It is recommended that only neighboring overlapping images should be included here. If you have very large overlap, it is possible that points are found between two images which are not directly adjacent. In the OpenGL preview window, you can use the Preview or the Layout tabs to identify those image pairs. Such points should be deleted. In the point table, click on columns "Right Img.", then "Left Img.", and then find pairs like 0/2, 1/3, 2/4 etc. Mark those lines, and delete the points.
- To re-run the optimisation, press the double-arrow icon or the calculate button in the Optimise/Geometric area.

### 7.2.3.1 Preliminary Geometric Optimisation

Now the (usually) longest part begins: Iterative optimisation of the photo matchpoints. If your images were taken on a panorama tripod head, there should only be very few bad matchpoints, e.g. those found on persons or clouds[14] which have moved between photos. For handheld photos, the following considerations should be observed.

The most important line which we want to create in all perfection is the visible horizon, where sky and earth meet. The foreground, usually grassy or rocky, is of lesser interest, and stitching errors in those areas may not even be relevant.

Therefore, matchpoints with large errors in the foreground can be safely removed, while, if necessary, points on the horizon should be added manually. Use the Control Points tab, select adjacent images (start with 0 on the left and 1 on the right side), and delete the worst-fitting matchpoints closest to the camera (near the bottom of the images). We now start a long phase of re-optimizing and deletion of ill-matching points as long as those are far from the horizon. When all near matchpoints are deleted, the result should already look not too bad.

For continued optimisation, the number of parameters to optimize can be extended. To begin, I recommend Positions and View (y, p, r, v), which may find a new focal length slightly different from the data in the EXIF tags. Again, delete further foreground points. If after a few rounds you still have bad point distances, try Positions and Barrel Distortion (y, p, r, b) to balance distortion by bad optics, or even go up to Everything without translation. Optimisation can only reach perfect results if you did not move between exposures. Else, find a solution which shows the least error.

In case you took your photos not on a tripod and moved too much, you may even want to play with the translation options, but errors will be increasingly hard to avoid.

---

[13]If you forget this, you can remove cloud points by calling **Celeste** in the control point editor later

[14]You should have created control points with the **Celeste** option!

**Using Straight Edges as Guides**

If the panorama contains straight lines like vertical edges of buildings, these can be used to automatically get a correctly leveled horizon: Vertical lines are mapped to vertical lines in equirectangular panos! In the Control Points tab, select the image with the vertical edge in both subframes, and mark points on the vertical edge. (switch off auto-estimate!). Likewise, horizontal lines may help, but make sure lines like rooves are perpendicular to your line of view, else the perspective effect causes an inclination.

**Multi-ring Panoramas**

If you are trying to create a panorama with several rings (horizon, one or two rings below, and nadir area), you must try to create/keep control points that best give a result without visible seams. In this case, and esp. if you have only used a regular tripod or even dared to go for a free-handed panorama, you may observe that it is best to remove control points in neighboring photos in the lower rings, but keep only the "vertical" links between images with similar azimuth.

In total, and if the foreground is not important but only grassy or sandy, the rule of thumb is that the horizon images must be strongly linked with good quality (small errors), while images in the lower rings should be linked mostly to their respective upper photos, but not necessarily to the images to its sides. The resulting panorama will then show a good horizon line, while stitching artifacts in a grassy or otherwise only decorative ground will usually be acceptable and can, if needed, be camouflaged in post-processing.

This optimization and editing of control points is likely a longish iterative process, and these are the late night hours where you will finally wish you had used a panorama head...

### 7.2.3.2 Masking

If you have images with overlapping areas, you can usually not force **Hugin** to take pixels from the image which you find best. you can however mask off an area from an image which you don't want to see in the output under any circumstances, e.g. a person's arm or foot in one image. Just open the image in the Mask tab and either press Add new mask and draw the mask polygon covering the unwanted area, or use the crop settings to define rectangular areas to use.

### 7.2.3.3 Exposure disbalance

In the Photos tab, select Photometric parameters on the right side. The EV column lists the *Exposure Value*. If you see disbalance here and in the preview window, you can run a photometric optimization with the lowest button on the Photos tab. Simply select Low dynamic range and press Calculate. The preview should now show a seamless image. If all else fails, you can edit the EV values directly.

Advanced photographers may want to correct exposures in their RAW images before creating JPG or TIF images to combine with **Hugin**. This unfortunately may create exposure disbalance because the EXIF tags may not be adjusted accordingly, so based on different exposure/f-stop combinations **Hugin** may think it has to re-balance the values. In these cases, don't run the photometric optimizer. Some image exposure values have to be changed manually, and the effect supervised in the preview window. Usually the smooth blending in the subprogam **enblend** called by **Hugin** will hide remaining differences.

### 7.2.3.4 Stitching

When you are happy with the panorama in the preview window and the match-points promise a good fit, it is time to finally create the panorama image. **Hugin** can create a large number of different projections which all have their application. For Stellarium, we can only use the equirectangular projection. You still have 2 options:

**spherical** landscapes (see 7.1.3) require single equirectangular images, the maximum size depends on your graphics hardware and **Qt** limitations and is likely not larger than $8192 \times 4096$ pixels.

**old_style** landscapes (see 7.1.4) can use several textures for the ring along the horizon, and one image for the nadir zone. If you need high resolution, you should aim for creating this one.

Sometimes, creating the nadir zone is difficult: this is where usually the view is blocked by the tripod, and we are not interested in views of tripod or our own feet. For our purpose it is usually enough to fill in the feet area using the clone stamp, or a monochrome color, or, for old_style landscapes, you can instead insert an oriented site map or wind rose.

There is a button create optimal size in **Hugin**. It may recommend a panorama width around 13.000 pixels for an average camera and photos taken with a wide-angle lens. Increasing this size will most likely not lead to higher optical resolution! The panorama width which you can most usefully create depends on the resolution of the source images (which leads to the result given by **Hugin**) and on your needs. If you need arc-minute resolution, you would aim for $360 \times 60 = 21600$ pixels, which cannot be loaded into graphics memory in a single piece, i.e., is too large for Stellarium, and must be configured as old_style landscape. In this case, 10 or 11 tiles of $2048 \times 2048$ pixels (totalling 20480 or 22528 pixels) is the closest meaningful

setting, i.e., you could create an image of 20480 pixels width and cut this into usable pieces. Usually, a size of $4096 \times 2048$ or $8192 \times 4096$ pixels (for better computers) is enough, and can be used in a `spherical` landscape.

We have to edit the file after stitching, therefore select creation of an image in the TIFF format. LZW compression is non-lossy, so use this to keep file size reasonably small.

For regular images, it is enough to create "Exposure corrected, low dynamic range". If you have a problem with persons that have moved between your images, you may want to post-process the final result with import of the distorted sub-images and manually defining the best blending line. For this, find the "Remapped Images" group and again activate "Exposure corrected, low dynamic range".

Now, press the Stitch! button in the lower right corner. This opens a helper program which supervises the stitching process. Depending on your computer and size of the image, it will require a few minutes of processing.

In case stitching fails with a cryptic error message, try to add the option --fine-mask to the **enblend** options.

Store a copy of the **Hugin** project file to always be able to go back to the settings you used to create the last panorama. We will get back to it when we want to make a truly calibrated panorama (see 7.3.3).

## 7.3 Panorama Postprocessing

The image created has to be further processed to be used in Stellarium. The most obvious change is the need for a transparent sky, which we can easily create in programs like **Adobe Photoshop** or the free and open-source **GIMP**. I will describe only the free and open-source solution.

After that, we have to bring the image into shape for Stellarium, which may include some trimming. While we could also slice an image with interactive tools, higher accuracy and repeatable results can be achieved with command-line programs, which makes the **ImageMagick** suite the tool of our choice.

### 7.3.1 The GIMP

The **GIMP** (GNU Image Manipulation Program) has been developed as free alternative to the leading commercial product, **Adobe Photoshop**. While it may look a bit different, basic concepts are similar. Not everybody can (or wants to) afford **Photoshop**, therefore let's use the **GIMP**.

Like **Photoshop**, the **GIMP** is a layer-aware image editor. To understand the concept, it is easiest to imagine you operate on a growing stack of overhead slides. You can put a new transparent slide ("layer") on top of the stack and paint on this without modifying the lower layers.

A few important commands:

**Zooming** Ctrl + Mouse Wheel

**Layer visibility and transparency** Make sure to have layer dialog shown ( Windows ≫ Dockable Dialogs ).
A gray bar indicates opacity for the currently active layer. Note the mouse cursor in this opacity bar (often also called transparency bar): near the top of the bar the upward pointer immediately sets percentage. A bit lower the pointer looks different and can be used for fine-tuning.

The most obvious post-processing need for our panorama is making the sky transparent. The optimal tool usually is the "Fuzzy Select", which is equivalent to the "Magic Wand" tool in **Photoshop**. Simply mark the sky, and then delete it. The checkerboard background indicates transparent pixels.

It sometimes helps to put an intensive bright red or blue background layer under the panorama photo to see the last remaining clouds and other specks. In the layer dialog, create a new layer, bucket-fill with blue or red, and drag it in the layer dialog below the pano layer. Write-protect this layer, work on the image layer, and before exporting the image layer with transparent sky to PNG, don't forget to switch off the background.

We need this layer functionality especially to align the panorama on a calibration grid, see section 7.3.3.

### 7.3.2 ImageMagick

**ImageMagick** (**IM**)[15] can be described as "Swiss Army Knife of image manipulation". It can do most operations usually applied to images in a GUI program, but is called from the command line. This allows also to include **IM** in your own command scripts[16]. We will use it to do our final cut and resize operations. I cannot give an exhaustive tutorial about more than a few of **IM**'s functions, but the commands given here should be enough for our purpose.

---

[15]`https://www.imagemagick.org/`

[16]These may typically be `.BAT` files on Windows, or various shell scripts on Linux or Mac.

To open a command window (console, a.k.a. DOS window), press the Windows key and enter `cmd`, then press ⏎. (On Linux and Mac, you surely know how to open a console window.)

There are some things you might need to know:

- The command line is not your enemy, but a way to call expert tools.
- The Windows command line processor **cmd.exe** is far from user friendly.
- There are remedies and alternatives. See notes on **clink** (7.5.3) for a considerable improvement, and **WSL** (7.5.4) for experts.

### 7.3.2.1 Command-line magick for spherical landscapes

Let's start with the commands for final dressing of an equirectangular panorama to be used as spherical landscape which has been created in size $4096 \times 2048$, but where you have seen that nothing interesting is in the image above $11.25°$. This means we can cut away the sky area and compress the image to $4096 \times 1024$ to save graphics memory.[17]

To understand the numbers in the example, consider that in a panorama image of $4096 \times 2048$ pixels, 1024 pixels represent $90°$, $512\,\text{px} = 45°$, $256\,\text{px} = 22.5°$, $128\,\text{px} = 11.25°$. To keep a top line of $11.25°$, we keep an image height of $1024 + 128 = 1152\,\text{px}$, but the crop starts at pixel $Y = 1024 - 128 = 896$.

```
convert landscape.png -crop 4096x1152+0+896
        -resize 4096x1024! landscape_cropped.png
```

Note the exclamation mark in the -resize argument, which is required to stretch the image in a non-proportional way.

Alternatively, you can operate with **IM**'s "gravity", which indicates the corner or edge geometric offsets are referred to. Given that we want the lower part of the image to exist completely, you only need to compute the size of the cropped image:

```
convert landscape.png -gravity SouthWest -crop 4096x1152+0+0
        -resize 4096x1024! landscape_cropped.png
```

You still need the addition +0+0 in the -crop option, else the image will be cut into several pieces. In the file `landscape.ini`, you then have to set `maptex_top=11.25`.

### 7.3.2.2 Command-line magick for old_style landscapes

Let us assume we want to create a high-resolution landscape from a pano image of width 16384 which we have carefully aligned and calibrated on an oversized grid template that also shows a measured horizon line (see 7.3.3). Usually it is not necessary to create the full-size image, but only the horizon range, in this high resolution. Assume this image has been aligned and justified on our grid image and is `HEIGHT` pixels high, the left border is at pixel `X_LEFT`, and top border (i.e., the point where relevant content like the highest tree is visible) is on pixel `Y_TOP`. Assume our graphics card is a bit oldish or you aim for maximum compatibility, so we can load only textures of at most 2048 pixels in size. Given that the horizon area usually only covers a few degrees, a vertical extent of $2048\,\text{px}$ seem a pretty good range for that most interesting zone. The ground can then be filled with some low-resolution image of grass, soil, or a properly oriented site map, or you can use **Hugin** to create a ground image (and using the maximum of $2048 \times 2048$ also here usually is far more than enough).

In **GIMP** (or **Photoshop**, . . . ), we must find the values for `X_LEFT`, `Y_TOP` and `HEIGHT`. `HEIGHT` is being resized to 2048, strictly, by the exclamation mark in the resize command. We can create our image tiles now with this singular beast of a command line (write all in 1 line!), which puts our files directly into `STELLARIUM_LANDSCAPEPATH/LANDSCAPE_NAME`:

```
convert PANO.png  -crop 16384xHEIGHT+X_LEFT+Y_TOP +repage
     -resize 16384x2048!
     -type TrueColorMatte -depth 8
     -crop 2048x2048 +repage
      png:STELLARIUM_LANDSCAPEPATH/LANDSCAPE_NAME/Horiz-%d.png
```

This creates 8 images. See section 7.1.4 for the `landscape.ini` where these images can be referenced. Don't forget to read off top and bottom lines (altitudes in degrees) from your grid, the vertical extent will form the `decor_alt_angle`, and the bottom line the `decor_angle_shift` entries in this file.

---

[17]Most modern graphics cards no longer require the "powers of two" image sizes, but we keep this practice to increase compatibility.

**Creating a ground image for old_style landscapes**

When you want a good ground image for an `old_style` landscape from your panorama and not just fill the `groundtex` with a monochrome texture or a map, you have to create a ground view in **Hugin**. But you may have already created a huge pano! This can also be used as source image, and a ground shot can be extracted with a reversed operation. In principle, all you need to know is the field of view around the nadir. Figure 7.5 shows a simple configuration file.

```
# hugin project file
#hugin_ptoversion 2
p f0 w2048 h2048 v92 E0 R0 n"TIFF_m c:LZW r:CROP"
m g1 i0 f0 m2 p0.00784314

# image lines
#-hugin  cropFactor=1
i w16384 h8192 f4 v360 Ra0 Rb0 Rc0 Rd0 Re0 Eev0 Er1 Eb1 r0
  p90 y0 TrX0 TrY0 TrZ0 Tpy0 Tpp0 j0 a0 b0 c0 d0 e0 g0 t0
  Va1 Vb0 Vc0 Vd0 Vx0 Vy0  Vm5 n"Eqirect_Pano360.png"
```

Figure 7.5: Project file `ground.pto` usable to create the ground image with **Hugin** or, on the command line, its **nona** stitcher. The last line, starting with `i`, has been wrapped, but must be 1 line.

Say, the side panels extend down to `decor_angle_shift=-44` degrees, which means you must close the ground with a Nadir $FoV = 2 \times (90 - 44) = 92$. For maximum compatibility, we will again make an image of width and height both 2048 px. These values can be found in the p line in Figure 7.5. The i line describes the input image, which is our full equirectangular pano of width `w`= 16384 and height `h`= 8192. The last argument of that line is the image file name.

For processing, we do not use the **Hugin** GUI, but simply the command line. The actual program to call is **nona**. If your stitched panorama is a 16-bit TIFF, **nona** will also make a 16-bit image, but our textures are limited to 8-bit PNGs. We apply our most useful tool, **convert** from the **ImageMagick** suite.

```
nona -v -m PNG  ground.pto -o ground.png
convert ground.png -depth 8 ground_8bit.png
```

The file `ground_8bit.png` is then used in the `groundtex` field on `landscape.ini`.

### 7.3.3 Final Calibration

The creation of a *calibrated panorama* (which can be regarded as dependable proxy for further measurements taken inside Stellarium) requires reference measurements to match the photos against. We must take azimuth/altitude measurements with a theodolite or total station, in the optimal case along the full horizon, and in addition I recommend to take azimuth and altitudes of some distinct features along the horizon which must also be visible in the photographs: mountain summits, electrical towers, church towers, …

I recommend you create grid templates of the sizes you are going to create, e.g. 4096, 8192, 16386 and 20480 pixels wide with some diagram tool. On these, you can then also draw the measured horizon line.

Now, load a panorama on top of this in the **GIMP**, i.e., copy it into a separate layer over the grid image, and set it semi-transparent.

Try to align the center of the image (where the geometric anchor has been defined; remember: this should be the image pointing south!) with the measured horizon line or the distinct features.

The optimal solution consists of a photo panorama which aligns perfectly with the measured line and features. We now have to iteratively bring deviations to a minimum. The process depends on processor speed, image size, your training and – most of all – your requirements in accuracy!

In the **GIMP**, load your grid image with horizon line. Now select File ≫ Open as Layers…, load your photo panorama, and then set layer transparency in the Layers dialog to about 50%.

Select the double-arrow tool to move the panorama via mouse drag and cursor keys over the grid, and align the outline of the photo horizon's southern point with the measured line. Now it's time to estimate the quality of the panorama.

In **Hugin**'s Photos tab, select the Positions view on the right side. Now you see "Yaw", "Pitch" and "Roll" values of camera-to-world orientation listed in the photos list. It should now be possible, by changing
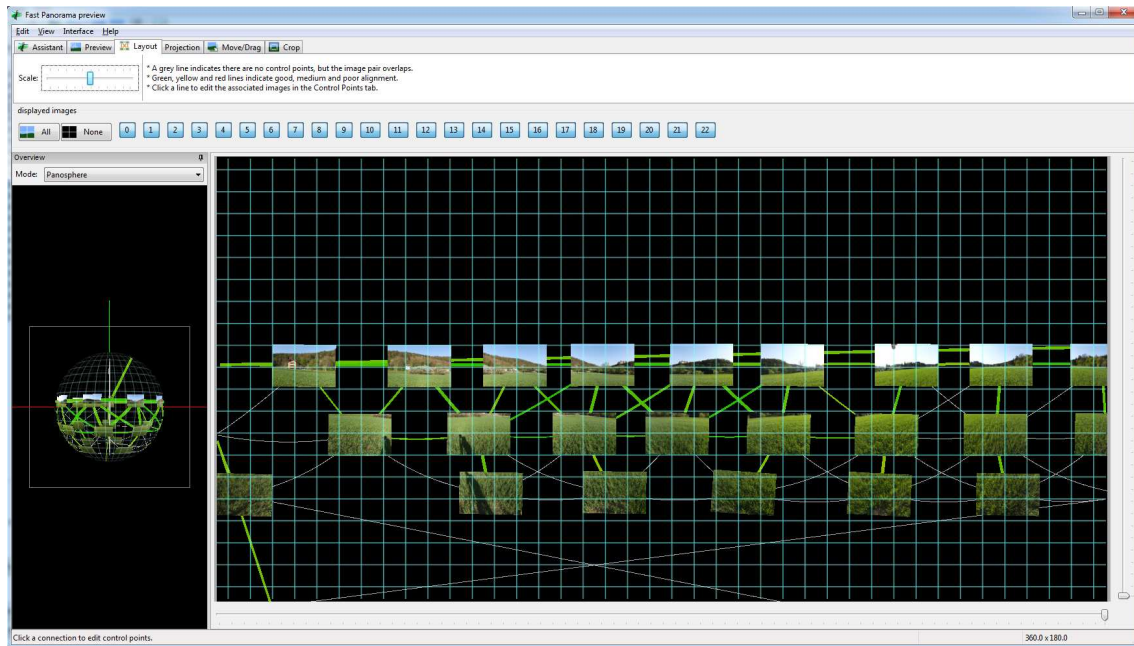
Figure 7.6: **Hugin**'s Fast Panorama Preview can be used to check which images are connected to its neighbors. Most important are good matches along the horizon, the images in the lower rows are clearly less important. If captured on a tripod, they should still match.

the values *only for the anchor image* and re-optimizing, to come to a panorama with only minimal error. In the process, start with Optimizing Positions ⟩ incremental from anchor , then go for view and barrel optimization, and so on. Always try to remove foreground match points which have large error and are irrelevant for the task to match the horizon. Those are especially cross-matches of horizon and sub-horizon rows of images. Only vertically and horizontally adjacent images should be required to match. For handheld panoramas, also links between adjacent images in the non-horizontal rows are usually too erroneous to be useful, just remove these match points. Use the Layout tab in the Fast Panorama Preview to see the relations between images (Fig. 7.6): Red lines have big errors, green lines are good, thin gray lines indicate possible overlap without specified match points. After each optimization step, export a new pano image, load as layer in **GIMP**, and check again.

> Basic rules to observe (use obvious inverses).
> - If image aligns well in azimuth but overshoots the grid to the right: Increase yaw accordingly (0.022°/pixel if image is 16384 pixels wide).
> - If the north end (left and right borders) is higher than the southern contact point: Increase pitch angle.
> - If north and south points are OK, but the western (right) half is higher than the eastern (left) half: Increase Roll angle.
> The corrections required for pitch and roll may be surprisingly small!

Within a few rounds of adjustments, panorama creation, adding as layer in the image editor, and comparing to the reference data, you should achieve a match to fit your needs.

In case you have taken photographs in several rings but without a panorama tripod, you may have to first align only the horizontal images (deselect the lower images to exclude from optimization), and when the horizon ring is aligned perfectly, deactivate further optimization in **Hugin** for those photos while "attaching" (optimizing) the lower photos. In **Hugin**'s Photos tab, select Optimize ⟩ Geometric ⟩ Custom Parameters . This opens an extra tab Optimizer , where you can fine-tune your needs: Switch off all variables for the photos in the horizon ring, and make sure the lower photos fit in the preview after optimization.

It may even help to define that the lower rows have been taken with a different Lens, so the field of view and distortion settings of the horizon row will be used as it had been found during the horizon-only match.

By now you should have enough experience what level of error may be acceptable for you.

### 7.3.4 Artificial Panoramas

I have created a website[18] where you can enter geographical coordinates and download a file `pano.kml` which helps with image creation from **Google Earth** imagery. Store this file for a site, let us call it *MYPLACE*, into a new directory GE_MYPLACE inside your `landscapes` directory.

Store all scenes visible from the respective viewpoint *MYPLACE* as picture into one common folder in your `landscapes/GE_MYPLACE` under the viewpoint name, e.g., `75-30.jpg`, which means 75 degrees from Nadir, azimuth 30 degrees. Also, double-click the pano entry or the marker in **Google Earth** to open a window with the basic content of your `landscape.ini`. Copy and paste from there into a new file `landscape.ini` and adjust the obvious entries. Complete as required with the entries described in section 7.1.3.

On loading of the images, Hugin will not be able to detect any EXIF lens data and ask you for the horizontal field of view. Enter 60 degrees, which is the standard value for **Google Earth** screenshots[19].

The viewpoint names translate almost directly to the yaw and pitch angles which you can enter in the image list in **Hugin**'s Photos tab. For example, switch to the Positions display on the right window edge in the Photo tab, mark all images that start with 25- and assign a pitch angle of $-90 + 25 = -65$. The second part of the names is directly the azimuth. In this case, don't run the optimizer, but you can immediately set an output resolution and stitch (see 7.2.3.4). To get rid of the image decorations (compass etc), apply masks[20]. Post-processing steps are the same as for photo-panoramas: make sky invisible, crop, etc.

It is also interesting to switch on the 3D buildings layer before creating the images. If temples or other buildings are accurate, this will give an even closer approximation to what would be visible on-site. Note however that not every building will be modelled in usable quality, and that usually vegetation is not included in the 3D buildings layer. Also, if you are too close to buildings, they may be cut away by the *near clipping plane* of the rendering.

These images, based on **Google Earth** imagery and the SRTM topographic model, seem usable as *first rough approximation* to a photo-based or surveyed panorama. Note that it is definitely not accurate enough for representing nearby horizon features or critically important mountain peaks, and please note that Google has image copyright which at least requires you to acknowledge when displaying these pictures.

### 7.3.5 Nightscape Layer

Since version 0.13, Stellarium can simulate artificial illumination, like streetlamps, bright windows, or the skyglow over cities (Zotti and Wuchterl, 2016). One way to create this layer is to make 2 panorama series during the day and night and process these in the same **Hugin** project to align those photos, and then stitch two separate images by selecting either the daylight or the nighttime shots. The night panorama has to be processed to remove stars, airplanes, etc.

The other way is a simple layer overpainted in the image processing program. As rough recommendation, use several layers to prepare this feature:

- Put a semitransparent black layer over your daylight image, this helps you to place your painted pixels.
- Paint windows, street lamps, signs, . . . . You may apply a layer style to produce some glow.
- To draw an impression of more light in the atmosphere (city skyglow), use a gradient with some brownish color. Generally the color depends on the appropriate mix of city lights (sodium, mercury vapour, etc.). Note that on the city outskirts a simple vertical gradient will not work, towards the city the horizon is much brighter. Use a huge but weak brush to make a more spotty sky.
- Use the existing landscape as template for the layer mask for this gradient sky layer. (You want to hide skyglow by leaves in the foreground!)
- If you want to add only a few lights to an `old_style` landscape, you need to provide only the panels showing those lights. Just load a side panel for reference, place a new layer on top, and paint the lights on windows, lamps etc. There is no light option for the ground texture. This makes `old_style` landscapes best suited for localized light pollution, not city skyglow.

The resulting image is then declared in the `maptex_illum` line of `landscape.ini`. Try also to balance the global strength of light pollution with the `light_pollution` key, and a probable minimal brightness with the `minimal_brightness` key.

---

[18] `https://homepage.univie.ac.at/Georg.Zotti/php/panoCam.php`

[19] Note that if you work with **Google Earth Pro**, you can create different FoV!

[20] There is a wide overlap in the images to allow generous trimming.

Try to match the visual appearance, not necessarily what photographs may have recorded. E.g., the *Grossmugl* sky shows horizon glow mostly towards the city of Vienna, where long-time exposures may already be saturated.

The possibilities seem limited only by your time and skills!

## 7.4 Troubleshooting

If something does not work as described and Stellarium does not show your landscape as expected but maybe just a bright magenta-colored box, don't panic. Double and triple-check the entries in `landscape.ini`. Make sure the texture is in PNG format and the file name is correct. Check the logfile for error messages. If the image is too large, it will be re-scaled on loading, but it is more efficient to keep images as small as required. Only few systems can use textures larger than $16384 \times 16384$ Pixels. If you need high resolution, use the `old_style` type (see section 7.1.4).

## 7.5 Other recommended software

Here is a short collection of other useful programs for (panorama) image manipulation and other tasks on Windows.

### 7.5.1 IrfanView

**IrfanView** is a free image viewer for Windows with many options. It can show almost any image format, including several camera RAW formats, in windowed and full-screen mode. It is definitely preferable over any image viewer built into Windows. Unfortunately however, it has no panorama viewer function!

### 7.5.2 FSPViewer

**FSPViewer**[21] by Fulvio Senore is an excellent panorama viewer for equirectanglar images. Images centered along the horizon can be viewed directly, while settings for images with different minimum and maximum angles, as well as "hotspots" (similar to hyperlinks) which move to neighboring panoramas, can be configured in an `.FSV` text file like figure 7.7.

```
ImageName=Horizon_Rosenburg.jpg
WindowTitle=Horizon_Rosenburg
hFov=70
#Formula: HP=100*(h/2-upper)/(lower-upper) in Hugin crop, or
#          HP=100*zeroRow/imgHeight
HorizonPosition=33.8
```

Figure 7.7: FSP configuration file (example)

### 7.5.3 Clink and GNUWin32

**Clink**[22] is a command line enhancement for Windows developed by Martin Ridgers. If you have ever worked under a Linux **bash**-like command line, you will easily feel that Windows' **cmd.exe** is extremely limited. **Clink** provides several useful features, most notably a really usable command-line completion. It is not essential for our tasks, but a general improvement of usability of the Windows command line which else has not caused me any trouble.

Compared to Linux, the command line of Windows can still be a humbling experience. None of the wonderful helpers taken for granted on Linux are available. Many of the nice tools known and taken for granted by Linux users (**make**, **sed**, **awk** etc.) have also been made available as standalone commands for Windows. If you don't need the inline scripting capabilities in `Makefiles` which you would get from a more complete Linux installation but just want to call **awk** or **sed** inside your **.BAT** scripts, maybe this is enough.

---

[21]Further details are available on its home page `http://www.fsoft.it/FSPViewer/`.

[22]`http://mridgers.github.io/clink/`

### 7.5.4 WSL – Windows Subsystem for Linux

Finally, the 64-bit editions of Windows 10 come with an optional feature that allows you to install a complete Linux distribution like Ubuntu inside your Windows system. Combined with an X11 server like XMing[23], you can even run graphic applications like Stellarium, and all the command-line tools are available.

---

[23]`https://sourceforge.net/projects/xming/`

# 8. Deep-Sky Objects

Since version 0.10.0 Stellarium uses the "json" cataloguing system of configuring textures. At the same time the Simbad online catalogue was added to the search feature, making the catalog somewhat redundant and used now only as a first search point or if there is no Internet connection.

If the object has a name (not just a catalogue number), you should add one or more records to the file `.../nebulae/default/names.dat` (where `...` is either the installation directory or (preferably) the user directory). See section 8.1.2 Modifying `names.dat` for details of the file format.

If you wish to associate a texture (image) with the object, you must add a record to the file `.../nebulae/default/textures` See section 8.1.3 for details.

If you wish to associate an outline with the object, you must add the series of lines to the file `.../nebulae/default/outlines.dat`. See section 8.1.4 for details.

## 8.1 Stellarium DSO Catalog

Stellarium's DSO Catalog contains over 94000 objects[1] (up to $15.5^m$ for galaxies) and is available for end users as collection of files:

| | |
|---|---|
| `catalog.txt` | Stellarium DSO Catalog in ASCII format for editing data |
| `catalog.dat` | Stellarium DSO Catalog in zipped binary format for usage within Stellarium[2] |
| `names.dat` | List of proper names of the objects from file `catalog.dat` |

An edited ASCII file can be converted into binary format through enabling an option in the file `config.ini` (See 5.4):

```
[devel]
convert_dso_catalog = true
```

The file `catalog.txt` should be put into the directory `.../nebulae/default/` and you should create an empty file `catalog.pack` to storing the binary catalog. After converting the data into binary format you should gzip them by the command

```
gzip -nc catalog.pack > catalog.dat
```

Stellarium DSO Catalog contains data and supports the designations for follow catalogs[3]:

**NGC** New General Catalogue
**IC** Index Catalogue
**M** Messier Catalog

---

[1] An extended edition of this catalog with over one million objects may be downloaded and installed manually (see section 5.5.2).

[2] The file name `catalog-VERSION.dat` is used for extended edition of DSO Catalog, where *VERSION* is version of catalog.

[3] Abell Catalog of Planetary Nebulae was added in v0.18.2 and removed in v0.20.1

**C**  Caldwell Catalogue

**B**  Barnard Catalogue (Barnard, 1927)

**SH2**  Sharpless Catalogue (Sharpless, 1959)

**vdB**  van den Bergh Catalogue of reflection nebulae (van den Bergh, 1966)

**RCW**  A catalogue of H$\alpha$-emission regions in the southern Milky Way (Rodgers, Campbell, and Whiteoak, 1960)

**LDN**  Lynds' Catalogue of Dark Nebulae (Lynds, 1962)

**LBN**  Lynds' Catalogue of Bright Nebulae (Lynds, 1965)

**Cr**  Collinder Catalogue (Collinder, 1931)

**Mel**  Melotte Catalogue of Deep Sky Objects (Melotte, 1915)

**PGC**  HYPERLEDA. I. Catalog of galaxies[4]

**UGC**  The Uppsala General Catalogue of Galaxies

**Ced**  Cederblad Catalog of bright diffuse Galactic nebulae (Cederblad, 1946)

**Arp**  Atlas of peculiar galaxies[5] (Arp, 1966)

**VV**  The catalogue of interacting galaxies by Vorontsov-Velyaminov (Vorontsov-Velyaminov, Noskova, and Arkhipova, 2001)

**PK**  Version 2000 of the Catalogue of Galactic Planetary Nebulae (Kohoutek, 2001)

**PN G**  The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae[6] (Acker et al., 1992)

**SNR G**  A catalogue of Galactic supernova remnants (Green, 2025)

**Abell**  A Catalog of Rich Clusters of Galaxies (Abell, Corwin, and Olowin, 1989)

**HCG**  Atlas of compact groups of galaxies (Hickson, 1993)

**ESO**  ESO/Uppsala Survey of the ESO(B) Atlas (Lauberts, 1982)

**vdBH**  Catalogue of southern stars embedded in nebulosity[7] (van den Bergh and Herbst, 1975)

**DWB**  Catalogue and distances of optically visible H II regions (Dickel, Wendker, and Bieritz, 1969)

**Tr**  Trumpler Catalog[8]

**St**  Stock Catalog

**Ru**  Ruprecht Catalog

**vdB-Ha**  van den Bergh-Hagen Catalog (van den Bergh and Hagen, 1975)

**Other**  deep-sky objects without designations and sky regions — by formal rules objects from this list are not included in any catalog known to Stellarium

Cross-index data for Stellarium's DSO Catalog is partially obtained from "Merged catalogue of reflection nebulae" (Magakian, 2003) and astronomical databases SIMBAD[9] (Wenger et al., 2000) and NED[10].

Distances for some deep-sky objects obtained from "The Magellanic Cloud Calibration of the Galactic Planetary Nebula Distance Scale" (Stanghellini, Shaw, and Villaver, 2008), "A 1.4 GHz Arecibo Survey for Pulsars in Globular Clusters" (Hessels et al., 2007), "Distance measurements of LYNDS galactic dark nebulae." (J. Hilton and Lahulla, 1995) and "A Catalog of Parameters for Globular Clusters in the Milky Way" (Harris, 1996).

Morphological class for many open clusters obtained from "Classification of open star clusters" (Ruprecht, 1966).

Visual magnitudes for Messier objects obtained from "Revised New General Catalogue and Index Catalogue" by Dr. Wolfgang Steinicke (Version: 2 February 2021 — NI2021)[11].

---

[4]The PGC and UGC catalogs are partially supported

[5]Arp, VV and PK was added in version 0.16.0

[6]PN G, SNR G and Abell was added in version 0.16.1

[7]vdBH and DWB was added in version 0.19.2

[8]Tr, St, Ru and vdB-Ha was added in version 0.20.2

[9]SIMBAD Astronomical Database — `https://simbad.u-strasbg.fr/simbad/`

[10]NASA/IPAC Extragalactic Database (NED) — `https://ned.ipac.caltech.edu/`

[11]Discovery and Cataloguing of Nebulae and Star Clusters — `http://www.klima-luft.de/steinicke/index_e.htm`

### 8.1.1 Modifying catalog.dat

This section describes the inner structure of the files `catalog.dat` (binary format) and `catalog.txt` (ASCII format). Stellarium can convert ASCII file into the binary format file for faster usage within the program.

Each line contains one record, each record consisting of the following fields with *tab* char as delimiter:

| Column | Type | Description |
|---:|---|---|
| 1 | integer | Deep-Sky Object Identificator |
| 2 | float | RA (decimal degrees) |
| 3 | float | Dec (decimal degrees) |
| 4 | float | B magnitude |
| 5 | float | V magnitude |
| 6 | string | Object type (See section 8.1.1.1 for details). |
| 7 | string | Morphological type of object |
| 8 | float | Major axis size or radius (arcmin) |
| 9 | float | Minor axis size (arcmin) |
| 10 | integer | Orientation angle (degrees) |
| 11 | float | Redshift |
| 12 | float | Error of redshift |
| 13 | float | Parallax (mas) |
| 14 | float | Error of parallax (mas) |
| 15 | float | Non-redshift distance (Mpc for galaxies, kpc for other objects) |
| 16 | float | Error of non-redsift distance (Mpc for galaxies, kpc for other objects) |
| 17 | integer | NGC number (New General Catalogue) |
| 18 | integer | IC number (Index Catalogue) |
| 19 | integer | M number (Messier Catalog) |
| 20 | integer | C number (Caldwell Catalogue) |
| 21 | integer | B number (Barnard Catalogue) |
| 22 | integer | SH2 number (Sharpless Catalogue) |
| 23 | integer | vdB number (van den Bergh Catalogue of reflection nebulae) |
| 24 | integer | RCW number (A catalogue of H$\alpha$-emission regions in the southern Milky Way) |
| 25 | integer | LDN number (Lynds' Catalogue of Dark Nebulae) |
| 26 | integer | LBN number (Lynds' Catalogue of Bright Nebulae) |
| 27 | integer | Cr number (Collinder Catalogue) |
| 28 | integer | Mel number (Melotte Catalogue of Deep Sky Objects) |
| 29 | integer | PGC number (HYPERLEDA. I. Catalog of galaxies); partial |
| 30 | integer | UGC number (The Uppsala General Catalogue of Galaxies); partial |
| 31 | string | Ced identificator (Cederblad Catalog of bright diffuse Galactic nebulae) |
| 32 | integer | Arp number (Atlas of Peculiar Galaxies) |
| 33 | integer | VV number (The catalogue of interacting galaxies) |
| 34 | string | PK identificator (Catalogue of Galactic Planetary Nebulae) |
| 35 | string | PN G identificator (The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae) |
| 36 | string | SNR G identificator (A catalogue of Galactic supernova remnants) |
| 37 | string | Abell identificator (A Catalog of Rich Clusters of Galaxies) |
| 38 | string | HCG identificator (Atlas of compact groups of galaxies) |
| 39 | string | ESO identificator (ESO/Uppsala Survey of the ESO(B) Atlas) |
| 40 | string | vdBH identificator (Catalogue of southern stars embedded in nebulosity) |
| 41 | integer | DWB identificator (Catalogue and distances of optically visible H II regions) |
| 42 | integer | Tr identificator (Trumpler Catalogue) |
| 43 | integer | St identificator (Stock Catalogue) |
| 44 | integer | Ru identificator (Ruprecht Catalogue) |
| 45 | integer | vdB-Ha identificator (Uniform survey of clusters in the Southern Milky Way — van den Bergh-Hagen Catalogue) |

#### 8.1.1.1  Types of Objects

Possible values for type of objects in the file `catalog.dat`.

| Type | Description |
|------|-------------|
| G | Galaxy |
| GX | Galaxy |
| AGX | Active Galaxy |
| RG | Radio Galaxy |
| IG | Interacting Galaxy |
| GC | Globular Cluster |
| OC | Open Cluster |
| NB | Nebula |
| PN | Planetary Nebula |
| DN | Dark Nebula |
| RN | Reflection Nebula |
| C+N | Cluster associated with nebulosity |
| HII | HII Region |
| SNR | Supernova Remnant |
| SNC | Supernova Candidate |
| SNRC | Supernova Remnant Candidate |
| BN | Bipolar Nebula |
| EN | Emission Nebula |
| SA | Stellar Association |
| SC | Star Cloud |
| CL | Cluster |
| IR | Infra-Red Object |
| QSO | Quasar |
| Q? | Possible Quasar |
| ISM | Interstellar Matter |
| EMO | Emission Object |
| LIN | LINEAR-type Active Galaxies |
| BLL | BL Lac Object |
| BLA | Blazar |
| MOC | Molecular Cloud |
| YSO | Young Stellar Object |
| PN? | Possible Planetary Nebula |
| PPN | Protoplanetary Nebula |
| * | Star |
| ** | Double Star |
| MUL | Multiple Star |
| SY* | Symbiotic Star |
| EM* | Emission-line Star |
| CLG | Cluster of galaxies |
| *empty* | Unknown type, catalog errors, *Unidentified Southern Objects* etc. |

### 8.1.2  Modifying names.dat

Each line in the file `names.dat` contains one record. A record relates an extended object catalog number (from `catalog.dat`) with a name. A single catalogue number may have more than one record in this file.

The record structure is as follows:

| Offset | Length | Type | Description |
|--------|--------|------|-------------|
| 0 | 5 | %5s | Designator for catalog (prefix) |
| 5 | 15 | %d | Identificator for object in the catalog |
| 20 | end | %s | Proper name of the object (translatable) [# references] |

If an object has more than one record in the file `names.dat`, the last record in the file will be used for the nebula label.

#### 8.1.2.1 Too many names?

Over the years, a large collection of names from many references has been added. DSO names are not                          v 25.1
standardized and are generally not used by professional astronomers, but are often used for popularisation
of objects. Some of the collected names may be too fanciful for your taste. If you can identify that those
names that annoy you all come from a single or just a few entries of the reference list, you can exclude those
sources, and thus the names they bring. Note that if a fancy name comes from more than one book, you
would have to exclude all books to ban that name from your display.

    To exclude entries, add the following key to `config.ini`:

```
[astro]
nebula_exclude_references = default:ADI,DSC-HT
```

Here, `default` names the nebula set, and the comma-separated entries are references you want excluded
from `nebulae/default/names.dat`.

### 8.1.3  Modifying textures.json

This file is used to describe each nebula image. The file structure follows the JSON format, a detailed
description of which may be found at `www.json.org`. The `textures.json` file which ships with Stellarium
has the following structure:

**serverCredits (optional)**  a structure containing the following key/value pairs:

> **short**  a short identifier of a server where the json file is found, e.g. "ESO"
> **full**  a longer description of a server, e.g. "ESO Online Digitized Sky Survey Server"
> **infoURL**  a URL pointing at a page with information about the server

**imageCredits**  a structure containing the same parts as a serverCredits structure but referring to the image
data itself

**shortName**  an identifier for the set of images, to be used inside Stellarium

**minResolution**  minimum resolution, applies to all images in the set, unless otherwise specified at the image
level

**maxBrightness**  the maximum brightness of an image, applies to all images in the set, unless otherwise
specified at the image level

**subTiles**  a list of structures describing individual image tiles, or referring to another json file. Each subTile
may contain:

> **minResolution**
> **maxBrightness**
> **worldCoords**
> **subTiles**
> **imageCredits**
> **imageUrl**
> **textureCoords**

**shortName**  (name for the whole set of images, e.g. "Nebulae")

**miniResolution**  (applies to all images in set)

**alphaBlend**  (applies to all images in set)

**subTiles**  list of images. Each image record has the following properties:

> **imageCredits**  (itself a list of key/pairs)
> **imageUrl**  (e.g. file name)
> **worldCoords**  (a list of four pairs of coordinates representing the corners of the image)
> **textureCoords**  (a list of four pairs of corner descriptions. i.e. which is top left of image etc)
> **minResolution**  (over-rides file-level setting)
> **maxBrightness**

    Items enclosed in Quotation marks are strings for use in the program. Syntax is extremely important.
Look at the file with a text editor to see the format. Items in <> are user provided strings and values to suit
the texture and source.

```
{
  "imageCredits"  : { "short" : "<author name>" ,
                      "infoUrl" : "http://<mysite.org>"
                    },
  "imageUrl"      : "<myPhoto.png>",
  "worldCoords"   : [[[ X0, Y0], [ X1, Y1], [ X2, Y2], [ X3, Y3] ]],
```

```
   "textureCoords" : [[[ 0,0],[1,0],[1,1],[0,1]]],
   "minResolution" : 0.2148810463,
   "maxBrightness" : <mag>
},
```

where

**worldCoords** Decimal numerical values of the J2000 coordinates (RA and dec both in degrees) of the corners of the texture. These values are usually given to 4 decimal places.

**textureCoords** Where 0,0 is South Left, 1,0 the South Right, 1,1 North Right, 0,1 North Left corners of the texture.

**minResolution** UNDOCUMENTED VALUE! Sorry!

**maxBrightness** total object brightness, magnitude

Calculating of the coordinates of the corners of the images (plate solving) is a time consuming project and needs to be fine tuned from the screen display. As most images will be two dimensional, display on a spherical display will limit the size to about 1 degree before distortion becomes evident. Larger images should be sectioned into a mosaic of smaller textures for a more accurate display.

### 8.1.4   Modifying outlines.dat

Each line in the file `outlines.dat` contains three "columns" of data for outline elements. The structure for each line is as follows:

| Offset | Length | Type | Description |
|---|---|---|---|
| 0 | 8 | %d | Right ascension (decimal hours) |
| 10 | 18 | %d | Declination (decimal degrees) |
| 20 | 60 | %s | Command |

Coordinates for each point of outline is represented in the equatorial coordinate system for epoch J2000.0. The possible values of the third "column" (*Command*) are:

**start** This command marks a start point of the outline. This command should also contain the designation of the deep-sky object.

**vertex** This command marks an intermediate point of the outline.

**end** This command marks an end point of the outline.

Example for outline of M42:

```
05.56401  -05.49880  start   M 42
05.56759  -05.39201  vertex
05.56635  -05.31749  vertex
05.57158  -05.21922  vertex
05.57601  -05.21716  vertex
05.58830  -05.30164  vertex
05.59140  -05.34341  vertex
05.59028  -05.37076  vertex
05.59008  -05.38175  vertex
05.59581  -05.37159  vertex
05.59943  -05.47123  vertex
05.59912  -05.65838  vertex
05.59520  -05.73212  vertex
05.58490  -05.68102  vertex
05.56948  -05.57675  end
```

The format of the file `outlines.dat` is compatible with the similar file of the **SkyChart (Cartes du Ciel)** planetarium.

## 8.2 Adding Extra Nebula Images

GLENN NEWELL



Figure 8.1: Screen shot of nebula images displayed in Stellarium

In previous versions of this guide, the technique for preparing Deep Space Object (DSO) images for inclusion in Stellarium involved *plate solving* the image to find its center on the sky, and then calculating the corners of the image in the World Coordinate System (WCS[12]) using the scale of the image, arc-seconds/pixel.

The problem with that approach is that it did not account for any spatial distortion in the image, due to telescope optics or sensor tilt, etc. This resulted in a labor intensive manual process of trial and error to adjust the WCS corners of the image until the stars in the image aligned with those displayed in Stellarium.

Fortunately, this problem has been solved for us by astronomers with similar needs, extending *FITS*[13] file headers to include information on how to map every pixel in an image correctly onto WCS coordinates. This information can be added to your image when you plate solve it on **nova.astrometry.net**, or similar services (local copies of **astrometry.net**, such as **ansvr**, or in **Pixinsight**, etc.). This system of correcting for distortions in astronomical images was refined for the Spitzer Space Telescope[14].

It is now possible to utilize this pixel to WCS transformation data included in plate solved images to prepare images for Stellarium that map perfectly to the Stellarium sky without manual WCS corner adjustments.

There are **Python** libraries, namely **astropy** and a related "channel" **astroquery**, that can automate some or all of the needed steps, and there are both manual and fully automated scripts for that purpose available on Stellarium's GitHub site. These scripts can be run on Windows, Mac, or Linux platforms, using the **Anaconda Python** distribution.

Nowadays, you can quickly plate solve deep space images and add them to the custom texture module using the Nebula Textures plugin (see section 13.9).

### 8.2.1 Image requirements for inclusion in Stellarium

The final image must be aligned with the equatorial (J2000.0) coordinate system so that north is directly up and not inverted side to side or up and down as can happen with photos taken with a diagonal mirror in the path (In the WCS system, "Parity" must be 1.)

Next you will need to crop and/or re-scale the picture, setting the main feature at the center and making the cropped size a power of 2, e.g. 64, 128, 256, 512, 1024 or 2048 pixels square (or elongated like $512 \times 1024$). If this requirement is not met, your textures may not be visible, or graphics performance may be seriously impacted on some systems. Textures larger than 2048 may only be supported on high-end hardware. Images must be in PNG format. When cropping, make sure you leave at least six prominent background stars for *plate solving*). The next step is to process your photo to make the background black, really black.

---

[12]https://fits.gsfc.nasa.gov/fits_wcs.html

[13]The *Flexible Image Transport System* is the dominating image format used in astronomy.

[14]https://www.cs.helsinki.fi/group/goa/viewing/viewtransf/viewTrans.html

This will ensure that your background will meld with the Stellarium background and not be noticed as ugly gray square. Do not use "transparent" pixels available in the PNG format as they will show as white, not black, in Stellarium.

Images covering more than 10 degrees of sky should be divided into separate images, and images with pixel scales less than 1 arc-sec per pixel should be re-scaled so as to have a pixel scale of 1 arc-sec per pixel or larger.

## 8.2.2 Processing requirements

- **Python 3.7** (Anaconda 64 bit installer[15]) During installation, follow directions, taking defaults to install for just your user (vs. everyone on your computer)
- **Astropy** (included in Anaconda)
- **Astroquery** (latest version) To install on Windows, open an "Anaconda Prompt". On Mac and Linux, just open a terminal. At the prompt, enter:

```
pip install --pre --upgrade astroquery
```

- For the fully automated process:
  - An API Key from your account at `https://nova.astrometry.net`:
    - Create an account (or log in with google, etc.) at `https://nova.astrometry.net`
    - On the API tab, copy your API key (shown in green)
    - Using a text editor (e.g., **Notepad++** on Windows, **Text Wrangler** on Mac OS), paste that key over the X's in `Stellarium_Nebulae_Images_Prep.py`'s `ast.api_key = 'XXXXXXXXXXXXXXXX'`
- For the more manual process:
  - Images plate solved at `https://nova.astrometry.net` (or **Pixinsight** – not yet tested) so that WCS data is created
  - Graphics software to flip, rotate, scale, etc. and save as `.png`, e.g., **Photoshop**, **GIMP**, **Pixinsight**, etc.

### 8.2.2.1 Script and Shortcut placement

Download the Python scripts from Stellarium's site at Github[16]:
- `WCS_corners.py` script
- `Stellarium_Nebulae_Image_Prep.py` script

**Windows**
- Place the two `.py` and `.bat` scripts into `%USERPROFILE%\Anaconda3\`
- Place the two Shortcuts on your desktop or an `astro tools` folder (optional)
- You can now drag and drop one or more images or `wcs.fits` files onto the shortcuts (or `.bat` scripts) for processing

**Mac**
- Place the two `.py` script files in the `anaconda3` directory, which should be inside your home directory (the directory with your username).
- Place the two `.app` files on your desktop or an `astro tools` folder (optional)
- You can now drag and drop one or more images or `wcs.fits` files onto the **Automator** app icons for processing

**Linux**
- Place the two `.py` script files in the `anaconda3` directory, which should be inside your home directory (the directory with your username).
- Place the two `.desktop` files on your desktop or an `astro tools` folder (optional)
- You can now drag and drop one or more images or `wcs.fits` files onto the desktop icons for processing
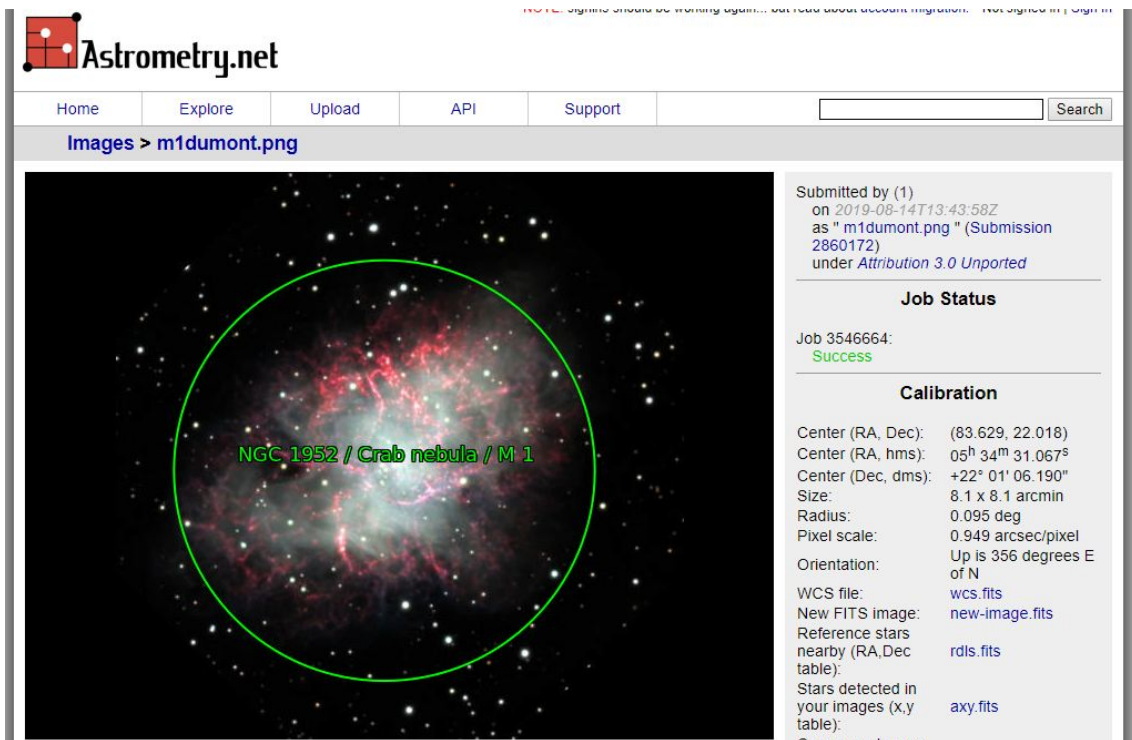
## 8.2.3 Manual processing

We present the more manual of the two workflows and script first, **WCS_Corners.py**, so you understand the process, before introducing the completely automated image processing pipeline. It is also possible that if plate solving fails in the fully automated script, you could continue, using this manual process:
**Plate Solve**

---

[15]`https://www.anaconda.com/distribution/`
[16]`https://github.com/Stellarium/stellarium-data/tree/master/adding-nebula-images`

Figure 8.2: Online plate solving



Figure 8.3: Python processing. If you just leave a space after `python WCS_corners.py`, you can drag and drop your `wcs.fits` file into Windows' Anaconda Prompt window.

- Plate solve your image @ `nova.astrometry.net` (Fig. 8.2)
- Note *pixel scale* and *orientation*

**Adjust Parity**

- Download the `wcs.fits` file from the "Results" page and run **WCS_Corners.py** on it (Fig. 8.3).
- If *Parity* is -1, flip your image horizontally (do this before rotate step below)

**Rotate** Rotate your image so "up" is exactly "North". i.e., if the orientation of your image was "261 degrees East of North" then rotate your image 261 degrees CW.

**"Blacken" Sky** Fill in the blank areas of your rotated image with black pixels, and set your "sky" background to be black.

**Crop** Crop your image so that both *x* and *y* dimensions are powers of two pixels, e.g. $512 \times 512$, $1024 \times 1024$, $2048 \times 2048$, $1024 \times 2048$, etc.

**Save PNG**

- Save your image as `.png` file
- Place a copy into the `%USERDIR%/nebulae/default` directory

**Plate Solve final image**

- Plate Solve your flipped, rotated, and cropped image again @ `nova.astrometry.net`
- Download the new `wcs.fits` file.

**Calculate WCS corners**

- Run **WCS_Corners.py** on the final `wcs.fits` file
- Edit Stellarium's `textures.json` with the image file name and the generated world coordinates

**Finalize image** Try to minimize the number of stars visible around your nebula in your image. Stellarium draws its own stars, and a rectangle of excessive stars may look bad. Just blacken them out.

**Restart Stellarium** View your image in Stellarium (and adjust `maxBrightness` in `textures.json` if needed)

Some additional information you should be aware of:

- Images in Stellarium are NOT tied to an object, just placed on the sky by `worldCoords`
  - So multiple image can overlap. E.g., the bubble nebula has overlapping textures
  - Black is rendered transparent
  - "Transparent" areas of `.png` show as white
- See section 5.1 on Directories for where to put your own copy of the default images + yours, so yours won't get overwritten by Stellarium Updates
- If plate solve fails: adjust gamma/blackpoint so "only" stars are showing (Fig. 8.4)
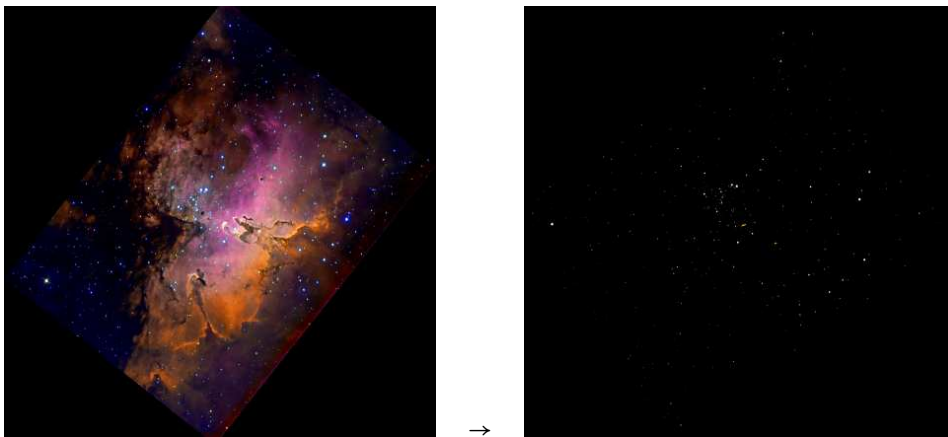


Figure 8.4: Reduce gamma to temporarily help the plate solving algorithm finding stars.

Stellarium keyboard shortcuts you may find useful when adding images:

Figure 8.5: Automated Python processing with **Stellarium_Nebulae_Image_Prep.py**

| F3 | brings up object search – Tab through search results |
| G | to remove ground (in case your object is currently behind the landscape) |
| A | to remove atmosphere (in case it is daytime) |
| I | to toggle nebulae images on and off – use to test star alignment |
| M | to toggle Milky Way on and off |
| / | to zoom into selected object |
| \ | to zoom back out |

### 8.2.4 Automated processing

With the recent addition of **astrometry.net** queries to the Python **astroquery** library it is now possible to automate the entire image processing pipeline as well as automatically create full .json entries for each image for inclusion in the textures.json file. The python script for this is **Stellarium_Nebulae_Image_Prep.py**. Wrapper scripts **Stellarium_Nebulae_Image_Prep.bat** and **Stellarium_Nebulae_Image_Prep.sh** are also included so you can process multiple images at once. With the desktop links you can even process one or more .jpg or .tiff files by drag and drop, on Windows, Mac, and Linux systems.

Figure 8.5 is an example run of **Stellarium_Nebulae_Image_Prep.py**. This converts (rotates, scales, etc.) the JPEG image as seen in Fig. 8.6, and a .json file for inclusion in textures.json (Fig. 8.7), along with two "unstretched" _stars.jpg images used for plate solving, which can be deleted.
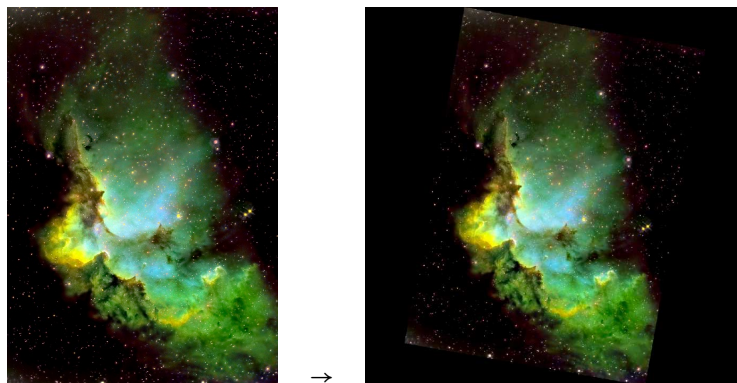


Figure 8.6: Automatic processing of a DSO image.

### 8.2.5 Troubleshooting

If no images show up in Stellarium, chances are you have introduced one or more errors in the textures.json file. You can use **Json Lint** [17] to check for problems.

Just paste the entire contents of the file in and press "Validate JSON".

However, the original textures.json file as shipped in v0.19.1 also fails:

- Missing leading zeros in front of decimal points

---

[17] An online service available at https://jsonlint.com/

Figure 8.7: `.json` result from processing with **Stellarium_Nebulae_Image_Prep.py**

- White space (a tab in this case) before `http` in `infoUrl` entries

These minor issues seem however not to irritate Stellarium.

# 9. Adding Sky Cultures

GEORG ZOTTI, WITH ADDITIONS BY ALEXANDER WOLF AND SUSANNE M. HOFF-MANN

Stellarium comes with a nice set of sky cultures from all over the world (see section 4.4.6). For ethnographers or historians of science it may be a worthwhile consideration to illustrate the sky culture of the people they are studying. It is not very hard to do so, but depending on your data, may require some skills in image processing.

Version 25.1 introduces a completely new format for skyculture data. If you are interested in the old $\qquad$ v 25.1 format, please refer to the 24.4 edition of the User Guide. In case you have created your own skycultures in the old format, we have created a format converter described in section 9.3.

If you add a new sky culture, please adhere to this description for an optimal result! Some features regarding translation and multilinguality have evolved over the years, and not all sky cultures currently included in Stellarium adhere to the standards described in the following sections. Incomplete skycultures may be improved, or removed when found too deficient.

A *sky culture* in Stellarium is the entity that consists of

- a description of the role these constellations and other celestial features (clouds, polar lights (aurorae), meteors, comets, . . . ) had or still have for the human culture that used or use these constellations, including some relevant background on the culture.
- a set of names for constellations
- stick figure definitions connecting stars into those constellations
- (optional) a list of names for individual stars
- (optional) artwork supporting the stick figures
- (optional) a description of boundaries or borders between the constellations
- (optional) names and stick figure definitions of additional figures of lesser importance, termed *asterisms*.
- A CC-licence that the author of the SC chooses; this is valid for the entire set of files, i.e. all texts and images provided.

## 9.1 Text description

A sky culture must contain the file `description.md`, this is a text in **Markdown** format. Markdown is a plaintext format which allows the simple declaration of text regions like sections, subsections, lists, images, or references. The file is automatically broken into pieces, translated and converted to HTML for display or else processed for speech output. Also some important skyculture components are extracted from here.

The first line of the file starts with the only Level 1 header, i.e., a line starting with a single hash (#), a space and then the *name* of the skyculture. This name is used in the selection list in the Sky Culture GUI

(see 4.4.6).

The other sections typically start with Level 2 or 3 headers (with two or three hash characters) which are displayed as smaller section and subsection titles (HTML: h2 or h3, respectively). All header lines (except the first) should be enclosed by empty lines.

The continuous text should be formatted like that, please do not add newlines where they do not signal the end of a paragraph with an empty line. Use an editor which just auto-wraps long lines to the window width. These long lines/paragraphs are automatically fed into the translation system. References (see 9.1.2) should be given like [#42].

You should provide a good description in the interest of future users: some cultural/ethnographical background of the users of this sky culture, the history or background of sky culture research that provided this work, tables of names/translations, links to external resources, whatever seems suitable. The length of the description texts is not limited, but of course if this is your PhD thesis work, there is no need to repeat all 500 pages, you can add a link to the references.

The skyculture description should include the following Level 2 sections. Any other section must be a subsection (i.e. Level 3 or deeper) of one of these sections. Each of these sections except Constellations will have its own entry in the translations files. The Constellations section will be split, so that each constellation's description will be translated separately.

Introduction – a summary that could ideally be shown on a small screen entirely.

Description – the actual text of the description.

Constellations – a sequence of Level 5 sections, where the header is the "english" name of a constellation (as given in the index.json file), and the body gives some information on this constellation. This text is used for display and speech output when the constellation is selected.

References – a list of references, see 9.1.2 for details.

Authors – all authors and acknowledgments go here.

License – either a license id (see 9.1.3), or a sequence of lines separated by empty lines (i.e. Markdown paragraphs) describing which part of the culture has which license, in the format "Sky culture item: License-ID".

Note that the Constellations section has the strict format described above. In particular, there's no place for an introduction for all the constellations, or closing remarks or a similar deviation from the format of this section. If this kind of text is desired, it can be placed in a subsection of the Description section.

To allow the correct display of special characters like ÄÖÜßáé you must provide the file in UTF-8 encoding. If you write only English/ASCII, this may not be relevant.

## 9.1.1 Images

You can also have embedded images in the file (your book cover? Views of sacred landscapes/buildings/artwork/. . . ?), just provide them in PNG or JPG format please. Use the following syntax, where the last line is fixed and is required for proper formatting.

```
![](illustrations/my_image.png)
My image caption
{: .img_and_caption }
```

Alternatively, you can format an image in HTML if you need specialized extras like right-alignment or size specifications:

```
<p>
<img src="illustrations/my_image.png" width="150" align="right"/>
My image caption
{: .img_and_caption }
</p>
```

or (note the manual <br/>)

```
<p class="img_and_caption">
<img src="illustrations/my_image.png" width="150" align="right"/><br/>
My image caption
{: .img_and_caption }
</p>
```

### 9.1.2 References

The optional Level 2 section "References" contains a list of information sources. Each line of the section contains one record of 2 discernible fields: a hyphen followed by a numerical key in brackets, a colon and then the actual description of the reference. The latter may include hyperlinks, e.g.:

```
 - [#1]: Kunitzsch, P.; Smart T. (2006). "A Dictionary of Modern star Names: ...
```

This list is most important for "traditional" sky cultures collected from various sources to provide traceable references.

**Caution!**

These reference numbers are not only used in the text, but also in the data description. If you re-arrange references, you must also fix all affected references in the JSON file (9.2).

### 9.1.3 License

The level 2 section "License" is mandatory if you want your sky culture to be distributed with Stellarium to prevent "unexpected" distribution of your content to other software or applications out of our hands.

We recommend to use one of the following possible licenses in this section:

**GNU GPL v2.0 (or later)** – this is the most famous "copyleft" license for code and it may be acceptable also for text and data.

**CC0** (No Rights Reserved) – this is a "don't care" license. Content may be freely distributed without attribution for all purposes.

**CC BY** (Creative Commons Attribution License) – this license lets others distribute, remix, adapt, and build upon your work, even commercially, as long as they credit you for the original creation. This is the most accommodating of licenses offered. Recommended for maximum dissemination and use of licensed materials.

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**FAL** For illustrations we also expect usage of the **Free Art License**[1] (in addition to any other licenses) – it is a "copyleft" license that grants the right to freely copy, distribute, and transform creative works. You can specify, e.g., "GPL2, FAL" to indicate that the images are additionally released under Free Art License.

Creative Commons provides a range of licenses[2], each of which grants different rights to use the materials licensed under them. All of these licenses offer more permissions than "all rights reserved". Some of Creative Commons are free and some are non-free. For example you can apply only the most permissive of its licenses (**CC0**, **CC BY** and **CC BY-SA**) to material you create, to meets the Freedom Defined definition of a "Free Cultural Work".[3]

---

[1] https://artlibre.org/licence/lal/en/

[2] Creative Commons License Chooser – https://creativecommons.org/choose/

[3] See Creative Commons website to details – https://creativecommons.org/share-your-work/public-domain/freeworks

If you have used one of the keys above in your `license` entry, a short (unofficial! Informative only) description of license conditions will be displayed. You can use other licenses as well, but then please describe the conditions sufficiently well in this section.

### Caution for users!

While Stellarium is provided under the free GPL v2.0 licence which allows for commercial use, some of our sky cultures have been contributed under CC NC/ND licenses, i.e., are for noncommercial use only. Please respect their heritage holders and check the CC licence version in the description before you use sky cultures in public events like TV documentaries, YouTube videos, lectures, planetarium shows or printed matter. If in doubt, contact the respective authors.

### 9.1.4 Technical Test

Using correct syntax is required for making display and translation work. If you have checked out Stellarium's sources, you can run

```
util/skycultures/generate-pot.py -s my_culture
```

This may emit some warnings about issues that should be fixed (if any remain). It will also generate a `.po` directory in the skycultures directory, but these files aren't supposed to be committed, you can remove it.

## 9.2 Technical data: index.json

The file `index.json` contains all "technical data" of the skyculture. JSON is a text-based format in which strings, numerical values and arrays can be stored in nested *dictionaries*, i.e. unordered collections of comma-separated `"tag": value` pairs in braces: `{ "Tag1": "Value1", "number": 123.456 }`. Values can be strings, numbers, arrays or other dictionaries. Arrays are ordered sequences in `[...]` delimiters. You must take care to close any open brackets and separate entries by commas.

```
{
  "id": "modern",
  "region": "World",
  "classification": ["traditional"],
  "fallback_to_international_names": false,
  "asterisms": [ ... ],
  "constellations": [ ... ],
  "edges_type": "iau",
  "edges_source": "https://pbarbier.com/constellations/edges_18.txt",
  "edges_epoch": "B1875",
  "edges": [ ... ],
  "common_names": { ... }
}
```

in which

`"id"` A unique identifier for program-internal use. It is never displayed to users.

`"region"` See 9.2.1

`"classification"` See 9.2.2

`"fallback_to_international_names"` if `true`, the IAU-approved star names are loaded after all names given here, so names will be mixed without a clear separation, and newly-approved star names will just appear automatically. Also all DSO names from `nebulae/default/names.dat` are loaded. This is most useful for skycultures which have no names of their own, or where such mix is intended, like `"personal"` contemporary skycultures (see 9.2.2) which are allowed to auto-adapt to newly given names.

`"common_names"` includes names for star, planet and deep-sky objects, see 9.2.7

`"constellations"` describes constellations, see 9.2.4

`"edges..."` describes boundaries between constellations, see 9.2.3

`"asterisms"` describes asterisms, see 9.2.5

Tags not described here may be used in other programs but are ignored by Stellarium.

### 9.2.1 Region

The "region" tag marks the origin region of the respective sky culture. It allows some form of additional grouping. The names of regions are following the United Nations geoscheme UN M49[4]:

**Northern Africa** – Algeria, Egypt, Libya, Morocco, Sudan, Tunisia, Western Sahara.

**Eastern Africa** – British Indian Ocean Territory, Burundi, Comoros, Djibouti, Eritrea, Ethiopia, French Southern Territories, Kenya, Madagascar, Malawi, Mauritius, Mayotte, Mozambique, Réunion, Rwanda, Seychelles, Somalia, South Sudan, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.

**Central Africa** – Angola, Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Sao Tome and Principe.

**Southern Africa** – Botswana, Eswatini, Lesotho, Namibia, South Africa.

**Western Africa** – Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Saint Helena, Senegal, Sierra Leone, Togo.

**Caribbean** – Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Bonaire, Sint Eustatius and Saba, British Virgin Islands, Cayman Islands, Cuba, Curaçao, Dominica, Dominican Republic, Grenada, Guadeloupe, Haiti, Jamaica, Martinique, Montserrat, Puerto Rico, Saint Barthélemy, Saint Kitts and Nevis, Saint Lucia, Saint Martin (French Part), Saint Vincent and the Grenadines, Sint Maarten (Dutch part), Trinidad and Tobago, Turks and Caicos Islands, United States Virgin Islands.

**Central America** – Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama.

**Southern America** – Argentina, Bolivia (Plurinational State of), Bouvet Island, Brazil, Chile, Colombia, Ecuador, Falkland Islands (Malvinas), French Guiana, Guyana, Paraguay, Peru, South Georgia and the South Sandwich Islands, Suriname, Uruguay, Venezuela (Bolivarian Republic of).

**Northern America** – Bermuda, Canada, Greenland, Saint Pierre and Miquelon, United States of America.

**Antarctica** – Antarctica.

**Northern Asia** – Russian Federation (Asian part).

**Central Asia** – Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.

**Eastern Asia** – China, Hong Kong Special Administrative Region of China, Macao Special Administrative Region of China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea, Taiwan.

**South-eastern Asia** – Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam.

**Southern Asia** – Afghanistan, Bangladesh, Bhutan, India, Iran (Islamic Republic of), Maldives, Nepal, Pakistan, Sri Lanka.

**Western Asia** – Armenia, Azerbaijan, Bahrain, Cyprus, Georgia, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, State of Palestine, Syrian Arab Republic, Türkiye, United Arab Emirates, Yemen.

**Eastern Europe** – Belarus, Bulgaria, Czechia, Hungary, Poland, Republic of Moldova, Romania, Russian Federation (European part), Slovakia, Ukraine.

**Northern Europe** – Åland Islands, Channel Islands, Denmark, Estonia, Faroe Islands, Finland, Iceland, Ireland, Isle of Man, Latvia, Lithuania, Norway, Svalbard and Jan Mayen Islands, Sweden, United Kingdom of Great Britain and Northern Ireland.

**Southern Europe** – Albania, Andorra, Bosnia and Herzegovina, Croatia, Gibraltar, Greece, Holy See, Italy, Malta, Montenegro, North Macedonia, Portugal, San Marino, Serbia, Slovenia, Spain.

**Western Europe** – Austria, Belgium, France, Germany, Liechtenstein, Luxembourg, Monaco, Netherlands, Switzerland.

**Australasia** – Australia, Christmas Island, Cocos (Keeling) Islands, Heard Island and McDonald Islands, New Zealand, Norfolk Island.

**Melanesia** – Fiji, New Caledonia, Papua New Guinea, Solomon Islands, Vanuatu.

**Micronesia** – Guam, Kiribati, Marshall Islands, Micronesia (Federated States of), Nauru, Northern Mariana Islands, Palau, United States Minor Outlying Islands.

**Polynesia** – American Samoa, Cook Islands, French Polynesia, Niue, Pitcairn, Samoa, Tokelau, Tonga, Tuvalu, Wallis and Futuna Islands.

For "modern" sky cultures we use the special region name **World** to define worldwide applicable data.

---

[4]Standard country or area codes for statistical use (M49) – `https://unstats.un.org/unsd/methodology/m49/`
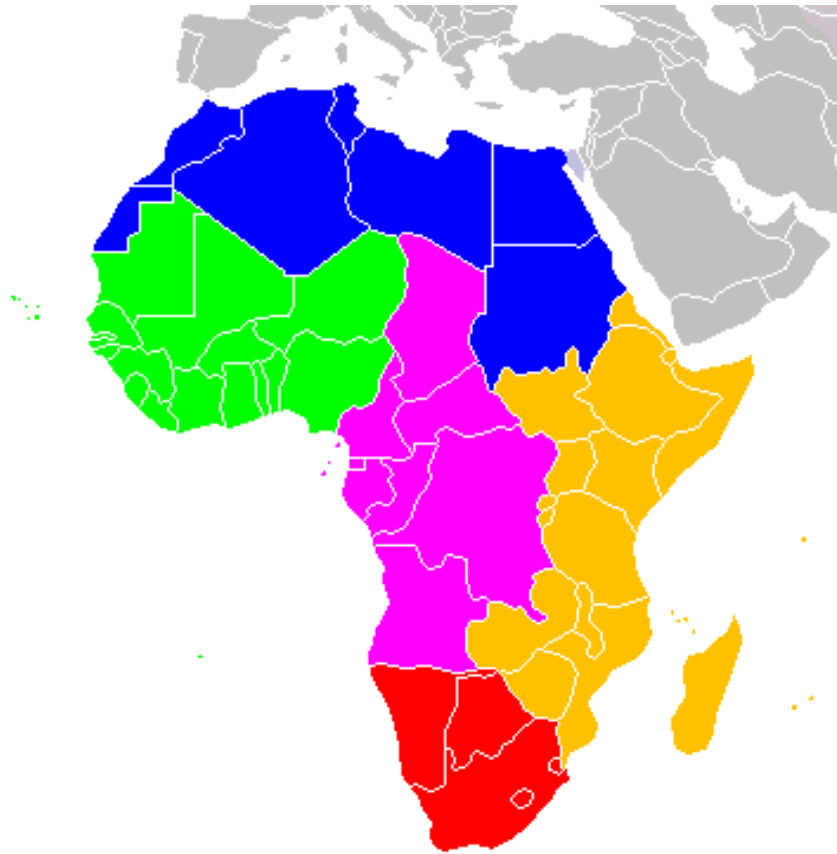
Figure 9.1: Africa: subregions as delineated by United Nations geographic classification scheme:
■ Eastern Africa, ■ Central Africa, ■ Northern Africa, ■ Southern Africa, ■ Western Africa.
*Wikipedia / CC BY-SA 3.0*
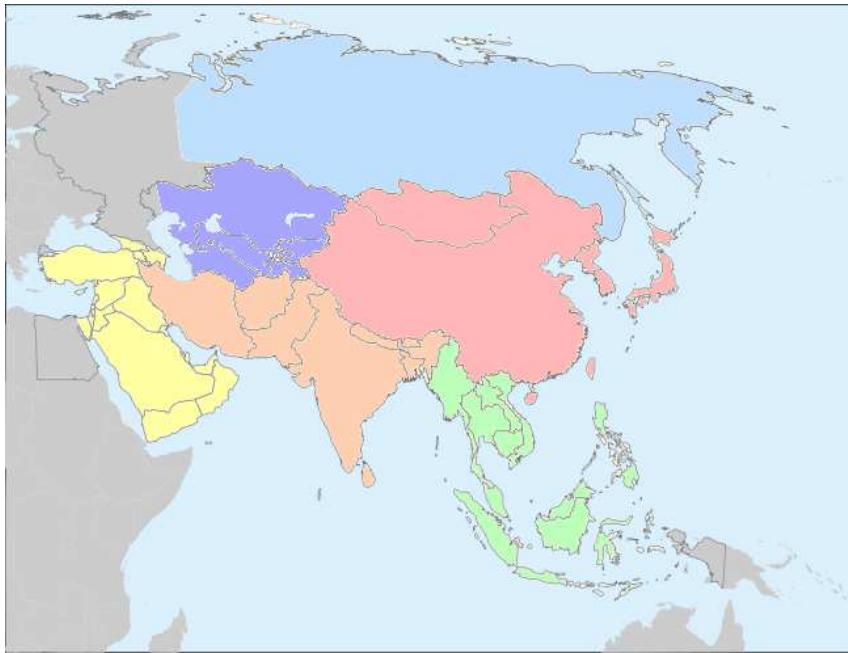
Figure 9.2: Asia: subregions as delineated by United Nations geographic classification scheme: ■ Central Asia, ■ Eastern Asia, ■ South-eastern Asia, ■ Southern Asia, ■ Western Asia, ■ Northern Asia. *Wikipedia / CC BY-SA 3.0*
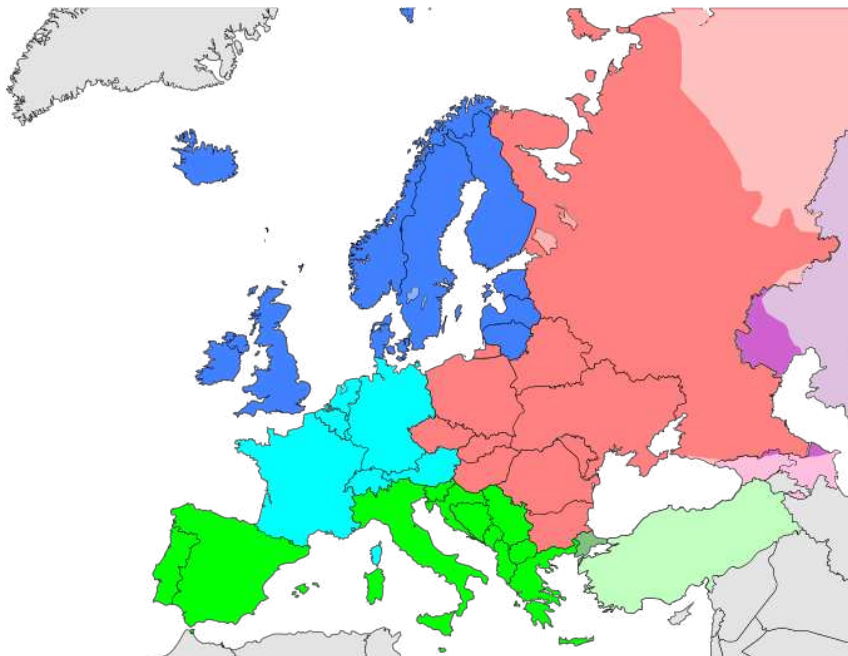


Figure 9.3: Europe: subregions as delineated by United Nations geographic classification scheme: ■ Eastern Europe, ■ Northern Europe, ■ Southern Europe, ■ Western Europe. *Wikipedia / CC BY-SA 3.0*

Figure 9.4: Americas: subregions as delineated by United Nations geographic classification scheme: ■ Caribbean, ■ Central America, ■ Northern America, ■ Southern America. *Wikipedia / CC BY-SA 3.0*
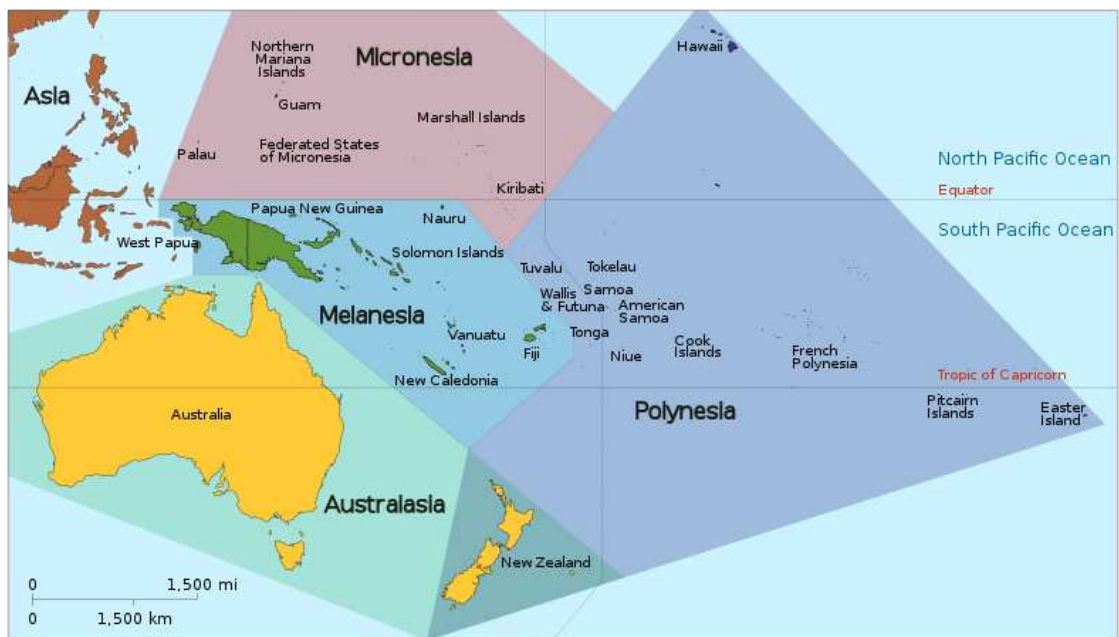


Figure 9.5: Oceania: subregions as delineated by United Nations geographic classification scheme: ■ Australasia, ■ Melanesia, ■ Micronesia, ■ Polynesia. *Wikipedia / CC BY-SA 3.0*

## 9.2.2 Classification

The tag "classification" allows describing the origin and intended use of this skyculture:

**personal** – this is a personally developed sky culture which is not founded in published historical or ethnological research. Stellarium may include it when it is "pretty enough" without really approving its contents.

**traditional** – (default value) content represents "common" knowledge by several members of an ethnic community, and the sky culture has been developed by members of such community. Our "Modern" sky culture is a key example: rooted in antiquity it has evolved for about 2500 years in what is now commonly known as "western" world, and modern astronomers use it.

**ethnographic** – provided by ethnographic researchers based on interviews of indigenous people.

**historical** – based on historical written sources from a (usually short) period of the past.

**single** – represents a single source like a historical atlas, or related publications of a single author.

**comparative** – special-purpose compositions of e.g. artwork from one and stick figures from another sky culture, and optionally asterisms as representations of a third. Or comparison of two stick figure sets in constellations and asterisms. These figures sometimes will appear not to fit together well. This may be intended, to explain and highlight just those differences! The description text must clearly explain and identify all sources and how these differences should be interpreted.

## 9.2.3 Constellation boundaries

In the late 18th century, when variable stars started to be catalogued by a code that included the star's constellation, a necessity arose to define which sky region belonged to which constellation. Atlases of this period showed curved boundaries between the constellations. Such boundaries are hard to describe by coordinates, though. The Uranographia Argentina (Gould, 1879) proposed a different approach. The boundaries were described by mostly straight segments along great circles of equal right ascension and small circles of equal declination. The atlas used coordinates for epoch B1875.0. Based on this work, in 1930 the International Astronomical Union (IAU) ratified a partition of the sky into the 88 constellations (now only using lines along constant right ascension/declination of B1875.0) used by scientists and amateurs ever since. When looking at these boundaries in J2000.0 coordinates, we can see they are no longer parallel to the J2000.0 coordinate grid, the deviation caused by precession.

Partitions of the full sky into contiguous regions defined by edges between coordinate vertices defined in equatorial coordinates at a certain epoch can be described in the following elements of the `index.json`:

```
"edges_type": "iau",
"edges_source": "https://pbarbier.com/constellations/edges_18.txt",
"edges_epoch": "B1875",
"edges": [
  "001:002 M+ 22:52:00 +34:30:00 22:52:00 +52:30:00 AND LAC",
  "002:003 P+ 22:52:00 +52:30:00 23:20:00 +52:30:00 AND CAS",
  "004:005 P+ 23:20:00 +50:00:00 23:35:00 +50:00:00 AND CAS",
  ...
  ]
```

where

`"edges_type"` is optional and may contain the following values:

    `"none"` — (default) designates that this culture doesn't have constellation boundaries, and any `edges` entry is ignored.

    `"iau"` — use this value for variants of "modern" sky cultures to declare use of IAU boundaries.

    `"own"` — used for cultures which have their own set of constellation boundaries.

`"edges_source"` is optional and only given for reference. It is not evaluated.

`"edges_epoch"` describes the coordinate epoch. Allowed values:

    `"J2000"` (default)

    `"B1875"` used for the edge list defining the IAU borders.

    `"Byyyy.y"` (a number with B prepended) Arbitrary epoch as Besselian year.

    `"Jyyyy.y"` (a number with J prepended) Arbitrary epoch as Julian year.

    `"JDdddddddd.ddd"` (a number with JD prepended) Arbitrary epoch as Julian Day number.

    `"ddddddd.ddd"` (a pure number) Arbitrary epoch as Julian Day number.

The lines in the array "edges" were taken from the given reference. The first component is ignored. The next element provides information whether the segment runs along a meridian (M, right ascension) or parallel (P, declination) circle in ascending + or descending - sense. Then it provides $\alpha_1$, $\delta_1$, $\alpha_2$, $\delta_2$ in sexagesimal

numbers ($\alpha$ in HH:MM:SS, $\delta$ in DD:MM:SS format) and the uppercased constellation abbreviations. As described in the original source file, Serpens has been split into SER1 and SER2, these tags are treated both as SER.

These edges are used to define isolated boundaries for each constellation (for proper working of the Select single constellation option).

### 9.2.4 Constellations

Constellations are coded as array of dictionaries:

```
"constellations": [
    {
        "id": "CON modern Aql",
        "lines": [[98036, 97649, 97278], [97649, 95501, 97804], [99473, 97804],
                  [95501, 93747, 93244], [95501, 93805]],
        "image": {
          "file": "illustrations/aquila.png",
          "size": [512, 512],
          "anchors": [
            {"pos": [163, 232], "hip": 97649},
            {"pos": [385, 131], "hip": 93244},
            {"pos": [397, 397], "hip": 93805}
          ]
        },
        "common_name": {"english": "Aquila", "native": "Aquila"}
    }, ...
], ...
```

where

"id"  A unique figure identifier, consisting of CON (for *constellations*), skyculture id, and a short Latin-character based label still unique within the skyculture. For IAU-based skycultures, these short labels must be the IAU standard labels. For others, you can invent your own. It is not necessary to have exactly 3-letter keys, but they should act as mnemonic support, so numerical keys are not recommended: the short label is displayed when enabling abbreviated screen labels (s. 4.4.6). If you want to prevent certain abbreviations from being displayed, let them start with a dot. See the effect in the Modern (H.A.Rey) sky culture: with abbreviated labels enabled, only the official abbreviations are displayed.

"lines"  an array of arrays, each describing a polyline with star numbers. The star numbers are usually the Hipparcos (HIP) numbers. For very dim stars, the longer numbers from the Gaia DR3 catalog are

v 25.2        acceptable, but they must be written as string. Even Deep-Sky objects (like a naked-eye open cluster) can be added to a constellation line when written as string starting with "DSO:", like "DSO:M7".

v 25.2        To describe *dark constellations* formed from dust clouds in the Milky Way or other non-stellar items, another variant can use coordinate lists and is technically an array of arrays of 2-part arrays of float numbers, each pair being right ascension $\alpha$ (decimal hours) and declination $\delta$ (decimal degrees) in equinox J2000.0. See below how Stellarium can help you write these arrays.

v 25.1        *Single-star constellations* or particular highlights can be described with just one star repeated in a two-element segment. The respective star will be encircled with a radius of

v 25.1  "single_star_radius" (float, default 0.5).
v 25.2  "hull_extension" (optional) A vector of star IDs (HIP number as integer, Gaia DR3 long integer number as string, or a Deep-Sky object (like a naked-eye cluster) as string starting with "DSO:", like "DSO:M44" that are seen as part of the constellation. See below about *convex hull*.
v 25.2  "hull_radius" (float, defaults to "single_star_radius" or (if that is not defined)0.5).
        "image" Optional, see 9.2.4.1
        "common_name" Dictionary of names.
            "native"  name in the original language of the skyculture.
            "english"  translation of the name's meaning. This is translated to users' language.
v 25.3        "byname"  an optional explanatory addition to the name. May be helpful to explain mythological figures. This is translated to users' language, but is not included in search functions.
            "pronounce"  (optional, but recommended) a Latin-character based transliteration/pronunciation aid, e.g. Pinyin for Chinese. This may also be translated to user language.
            "transliteration"  (optional) a scientific Latin-character based transliteration where applicable. This is not translatable or adaptable to user language conventions, but may include extended

diacritics. An example is Wylie for Tibetan, which is not meant to help in pronunciation.

`"IPA"` (optional) International Phonetic Alphabet, a standardized phonetic spelling.

These names are used in the sky culture name style settings (s. 4.4.6). If your sky culture is a variant of the `Modern` sky culture, please use the canonical Latin as `"native"` name and the `"english"` names from the default Modern skyculture, they have all been translated already. Also star names should provide both `"native"` and `"english"` entries, even if both are identical, to allow translation/transliteration to languages with other script systems or spelling variants.

If your sky culture is not a variant of the generally known `Modern` (western) sky culture, please make sure to provide an `"english"` translation (where possible) in addition to the name given in the `"native"` language, or a `"byname"` which may help better understanding a figure. Else translators will not be able to translate the name, and users will be less interested to learn about the culture. Also make very sure to use the same spelling consistently in `index.json` and `description.md`, and explain the context of stars (how these stars are used, or what they mean to the respective members of the culture), especially where only an untranslatable proper name is given.

`"label_offset"` optional. An array of [`deltaRA`, `deltaDE`] (decimal degrees) used as offset that shifts the auto-computed label positions.

`"label_positions"` optional. An array of sub-arrays of [`RA`, `DE`] tuples (decimal hours, decimal degrees) used as label positions. By default, the label position is computed from the star positions used in the `"lines"`. With this entry you can set specialized positions, or also use more than one label per constellation.

`"visibility"` (optional) special cases for rule-based visibility, e.g. seasonally changing aspects of figures. Currently only a `"months"` rule has been defined. Its "payload" is an array of two integers, start and end of visibility in months, e.g:

```
"visibility": {"months": [6, 3]},
```

This specifies that the afflicted constellation is visible only from June to March, wrapping over the 12-month cycle. A second entry of the same constellation (with possibly different lines, artwork, or even name) that would be visible from April to May, would be specified as:

```
"visibility": {"months": [4, 5]},
```

### Drawing dark constellations

The outlines of figures like the "Emu in the Sky" cannot be described with connect-the-dot star patterns, as they are formed from the absence of luminous patterns. We need to describe them using coordinate lists. To make the process less tedious, we can extend setting Markers (see 3.6). For this to work, add the following key to `config.ini`:

v 25.2

```
[devel]
markers_to_logfile = true
```

After program restart, setting a marker also writes a numbered line into the logfile, containing marker number and the array of coordinates ([`RA`, `dec`]). In the text editor you are using to edit `index.json`, the arrays can be collated into the format required to code coordinate lists for dark constellations.

### Constellation area (convex hull)

The *constellation area*, or *convex hull* of a constellation, is an area of the sky described by a convex polygon which surrounds all stars that are part of the lines that form the constellation "stick figure", plus those objects which are listed in `"hull_extension"`. While the IAU has defined 88 constellation areas in 1930, constellations of other cultures are not as clearly defined. These areas can help analyzing historical records. Note that a point may lie in zero, one or more than one constellation area(s) when it overlaps two or even more adjacent figures.

v 25.2

Technically, the stars are projected perspectively onto a tangential plane to the celestial sphere at the balance point of all involved stars. Then a simple *package wrapping* algorithm (Sedgewick, 1990, ch.25) can be applied to find the convex hull. Straight lines in the projection are great circle arcs. Note that this limits constellation size to less than 180 degrees in the sky, outlying stars will currently be discarded. (Please report an error if this affects you, so we might find a better solution.)

This functionality is an advanced topic mostly used by sky culture researchers (e.g. S. M. Hoffmann, 2017, pages 94–98) who are also not afraid of calling scripting functions (see ch. 17), and is therefore hidden

from beginning users. To make use of it, edit your `config.ini` and add a key:

```
[gui]
skyculture_enable_hulls = true
```

The constellation areas of a skyculture can be queried by a scripting function:

```
ConstellationMgr.outputHullAreas(<filename_start>);
```

The argument `<filename_start>` is optional and defaults to `"hullAreas"`. The created CSV file `<filename_start>_skycultureName.csv` in your Stellarium user data directory lists hull areas for all constellations of the current skyculture.

You can list stars which belong to a thusly defined constellation with a scripting function:

```
ConstellationMgr.starsInHullOf("Taurus", false, 12.0, <start>);
```

This creates a file `hullStars_Modern_Taurus-12.00.csv` in your Stellarium user data directory which contains all stars within the convex hull of Taurus in the current (here: "Modern") sky culture. The arguments to the function are:

**constellation** string; name or abbreviation.

**hipOnly** Boolean, optional, defaults to `true`; if you are only interested in brighter stars contained in the Hipparcos catalog, set it `true`.

**maxMag** float, optional, default: 25.0. Dimmest stellar magnitude to use. The default value just makes sure all stars that are contained in the catalogs are listed, the result will only have few entries dimmer than mag 18.

`<start>` string, optional, default `hullStars`; the start of the filename can be changed here.

#### 9.2.4.1 Constellation Artwork

Constellation artwork is optional, but may give your sky culture the final touch, if it requires artwork at all. E.g., H. A. Rey's variant of the `Modern` sky culture deliberately does not contain artwork other than his new set of stick figures.

Each constellation artwork is linked to 3 stars in its constellation. This is programmed in the `"image"` dictionary. It contains entries

`"file"` is the file name of your texture. All constellation artwork files should reside in a subdirectory `illustrations`. For best efficiency it should be sized in a power of two, like $512 \times 512$, $1024 \times 2048$ etc. Avoid dimensions larger than 2048, they are not supported on all systems. Use as little border in your textures as possible instead. You can distort images to better exploit the pixels, the texture will be stretched back. The background of the artwork image must be absolutely black.

`"size"` Image size (width, height) in pixels. This size specified here, and not the real image size, is relevant for the `"anchors"` entry. This may be important on very memory limited systems where you decide to downscale all textures.

`"anchors"` An array of three similar dicts with

    `"pos"` pixel addresses [x, y] given from upper left corner (find those in any image editor)

    `"hip"` The star index as Hipparcos (HIP) number, given as integer. This may technically also be a Gaia DR3 number when given as string.

In case the artwork is only available in a certain projection (e.g., an all-sky map), or is otherwise heavily distorted so that the match is not satisfactory, you may have to re-project the image somehow. For aligning, you should switch Stellarium to Stereographic projection for optimal results.

You don't have to shutdown and restart Stellarium during creation/matching, you can just press Ctrl + Alt + I to reload.

### 9.2.5 Asterisms and help rays

Sometimes auxiliary figures were created for easier orientation. Some part of a constellation may have been redefined into a figure in its own right, or parts from different constellations were merged into one big figure — e.g. "Big Dipper" as part of Ursa Major, or the "Summer Triangle" consisting of 3 stars from the constellations Cygnus, Lyra and Aquila. After the codification of the official 88 constellations by the IAU, those additional figures have generally been called *asterisms*. [5]

---

[5] In a more generalized context when describing the sky of other cultures, the distinction may be less strict, and the term "asterism" may even be used for the "primary figures" observed by those cultures.

Other simple figures might be used as navigation and orientation helpers: the *help rays*. As example to help in orientation in the sky the additional lines between constellations Ursa Major, Ursa Minor and Cassiopeia might be useful. The asterisms and help rays are listed in `"asterisms"` which is similar to the `"constellations"` dict, but has no `"figures"` entry:

```
"asterisms": [
    {
      "id": "AST modern HeG",
      "common_name": {"english": "Heavenly G", "references": [30,32]},
      "lines": [[21421, 24608, 36850, 37826, 37279, 32349, 24436, 25336, 27989]]
    }, ...
]
```

`"id"` A unique asterism identifier, consisting of AST (for asterism), skyculture id, and a short Latin-character based label still unique within the skyculture. It is not necessary to have exactly 3-letter keys, but they should act as mnemonic support, so numerical keys are not recommended: the short label is displayed when activating abbbreviated labels (s. 4.4.6). If you want to prevent certain abbreviations from being displayed at all, let them start with a dot.

`"common_name"` Another dict with entries `"native"` (as used in the source), `"english"` (the translatable english name), `"pronounce"`, `"transliteration"`, `"IPA"` and `"byname"` as defined for constellations, and an optional array `"references"` which lists from which sources (from 9.1.2) this asterism was taken.

Collecting sources and giving such references is always a good idea. If you feel ther are more in the collection than you like, read 9.2.9.1 about suppressing excessive entries.

`"label_offset"` optional. An array of [deltaRA, deltaDE] (decimal degrees) used as offset that shifts the auto-computed label positions.

`"label_positions"` optional. An array of sub-arrays of [RA, DE] tuples (decimal hours, decimal degrees) used as label positions. By default, the label position is computed from the star positions used in the `"lines"`. With this entry you can set specialized positions, or also use more than one label per asterism.

`"is_ray_helper"` (optional, default=false). Set to true to declare this asterism as "ray helper" which is shown in a different color and without label.

`"lines"` an array of arrays, each describing a polygon with integer star numbers. The star numbers are usually the Hipparcos (HIP) numbers. For the very dim stars of telescopic asterisms, the longer numbers from the Gaia DR3 catalog are acceptable, but they must be written as string. Another variant can use coordinate lists and is technically an array of arrays of 2-part arrays of float numbers, each pair being right ascension $\alpha$ (decimal hours) and declination $\delta$ (decimal degrees) in equinox J2000.0. *Single-star asterisms* can be described with a two-element array that repeats the first entry (star or coordinate pair) – the respective star/coordinate will be encircled with a radius of    v 25.1

`"single_star_radius"` (float, default 0.5) radius of a circle (degrees) marking single-star segments in    v 25.1
`"lines"`.

### 9.2.6 Culture Relevant Coordinate Systems: Zodiac and Lunar Systems

Ancient high cultures in and around Asia took special note of the zone where the planets move: along the    v 25.2
path of the Moon, a system of 27 or 28 lunar stations or lunar mansions were formed, and later the Sun's annual path was split into 12 equal-size parts of 30 degrees along the ecliptic.

The best-known system in modern times is that of the *tropical zodiac* of $12 \times 30$ degrees along the ecliptic, counted from the equinox point (First point of Aries ♈). The 12 sections, or *zodiacal signs*, were named after the constellations which resided there at the time the system was codified. Precessional movement since antiquity moved the stars eastwards along the ecliptic by about one full sign, so that meanwhile there is usually a mismatch between the *constellation* the sun is in and the *sign* which you find listed in bad newspapers' horoscope pages. Astronomically, the zodiacal sign is just an old-fashioned way to write ecliptical coordinates of date.

In India, the partitions were defined so that the star Spica rests at the 180° mark, so that the Indian or *sidereal zodiac* moves along the ecliptic with precession.

```
"zodiac": {
  "name": { "pronounce": "Rāśi", "english": "Indian Zodiac"},
  "context": "indian zodiac sign",
  "partitions": [ 12, 3, 2, 5],
  "extent": 9,
```

```
  "link": { "star": 65474, "offset": 180},
  "names": [ { "symbol": "\u2648", "native": "...", "english": "Ram"},
             { "symbol": "\u2649", "native": "...", "english": "Bull"},
               ...
             { "symbol": "\u2653", "native": "...", "english": "Fishes"}]},
```

where

`"name"` cultural name as described in 9.2.7.

`"context"` (optional, recommended) context data for all English names in zodiac (enhancement of localization support).

`"comment"` (optional) commentary for zodiac, it will be used as extra commentary for translators also.

`"partitions"` regular division of the centerline. The first element commonly is 12 (30-degree sign). The other elements (up to 3) are used to describe the tick marks in decreasing order. The example means, the 30 degrees are further divided in 3 sections (large 10-degree ticks), these are split in 2 5-degree sections with 5 sections (1-degrees) each.

`"extent"` The zone of interest is closed off by parallel lines this many degrees north and south of the centerline. A zodiac of 9 degrees encloses extreme positions of all major planets.

`"link"` (optional) The Indian *sidereal zodiac* is described to be defined with the longitude of a certain star. Usually and in this sample, Spica ($\alpha$ Vir, HIP 65474) is declared to lie at 180°. If missing, the zodiac starts from ♈.

`"names"` Sequence of names. In addition to the elements listed in 9.2.7, `"symbol"` provides a Unicode symbol (as shown here, these are the common zodiacal signs) or 1-2 letter string (for practical reasons, a number seems generally useful). The number of entries must be equal to (or larger than) the first element of `"partitions"`. Excessive entries are ignored.

More important for Indians however, and still relevant today, is the traditional system of *lunar stations*, the *nakshatras*. the ecliptic is split into 27 equal-sized partitions, which are then further split into 4 equal parts.

```
"lunar_system":  {
  "name": { "native": "...", ..., "english": "Nakshatras"},
  "context": "indian lunar mansion",
  "partitions": [ 27, 4],
  "extent": 5,
  "link": { "star": 65474, "offset": 180},
  "names": [ { "symbol": "1", "native": "...", ..., "english": "Physician to the
      ↪ Gods"},
             { "symbol": "2", "native": "...", ..., "english": "Bearer"},
             { "symbol": "3", "native": "...", ..., "english": "Pleiades"},
               ...
```

where

`"name"` cultural name as described in 9.2.7.

`"context"` (optional, recommended) context data for all English names in lunar mansions (enhancement of localization support).

`"comment"` (optional) commentary for lunar system, it will be used as extra commentary for translators also.

`"partitions"` regular division of the centerline. 27 stations which are further divided in 4 equal parts.

`"extent"` The zone of interest. With an obliquity of the Lunar orbit of about 5 degrees, a 5-degree zone seems appropriate.

`"link"` (optional) The Indian system is again described to be defined with the longitude of Spica ($\alpha$ Vir, HIP 65474) to lie at 180°. If missing, the count starts from ♈.

`"names"` Sequence of names. In addition to the elements listed in 9.2.7, `"symbol"` provides a Unicode symbol or 1-2 letter string (for practical reasons, a sequential number seems generally useful). The number of entries must be equal to (or larger than) the first element of `"partitions"`. Excessive entries are ignored.

In the Arabian peninsula, a similar system of 28 *lunar stations* is in use until today, but the actual asterism appears to be more important than the regularity of the ecliptic partition. The first station is centered around *al-Thurayya* (the Pleiades star cluster). In some skycultures the "band" of stations around the ecliptic is shown irregular, with boxes trying to frame the associated asterisms:

```
"lunar_system":  {
  "name": {"english": "Lunar Stations", "native": "...", "pronounce": "Manazil
      ↪ alQamar", "IPA": "manazilulqamar"},
```

```
  "partitions": [ 28, 3, 2],
 "extent": [10.0, -10.0, 10.0, -10.0, 10.0, -15.0, 10.0, -15.0, 15.0, ... ],
   "context": "arabian lunar stations",
   "link": { "star": 17702, "offset": 6.428571428571429, "comment": "center of
       ↪ first station is Lucida Pleiadum"},
   "names": [{ "symbol":  "1", "english": "Al-Thurayya", "native": "...", ... },
            { "symbol":  "2", "english": "Al-Dabaran",  "native": "...", ... },
              ...
```

where

"partitions"  regular division of the centerline. 28 stations which are further divided into 3 equal parts
        that are further halved.

"extent"  As array of latitude coordinates, they provide alternating north and south latitudes for all stations.    v 25.3
        The number of entries must be twice the number of partitions.

In China, the 28 *lunar mansions* are defined in a different way. 28 *defining stars* mark the begin (western
edge) of each mansion, and great circles are drawn from the celestial poles through these stars. In Stellarium,
the defining stars are marked with a little circle. The mansions are quite different in width.

```
"lunar_system": {
  "name": { "native": "...", "pronounce": "Xiù", "english": "Lunar Mansion"},
  "context": "chinese lunar mansion",
  "defining_stars": [65474, 69427, ...],
  "coordsys": "equatorial",
  "extent": 90,
  "names": [ { "symbol": "1", "native": "...", "pronounce": "Jiǎo", "english":
      ↪ "Horn"},
            { "symbol": "2", "native": "...", "pronounce": "Kàng", "english":
                ↪ "Neck"},
              ...
```

where

"name"  cultural name as described in 9.2.7.

"context"  (optional, recommended) context data for all English names in lunar mansions (enhancement
        of localization support).

"comment"  (optional) commentary for lunar system, it will be used as extra commentary for translators
        also.

"defining_stars"  List of HIP numbers of the 28 defining stars.

"coordsys"  may be "equatorial" or "ecliptical" (default).

"extent"  The zone of interest. The Chinese mansions extend from pole to pole.

"names"  Sequence of names. In addition to the elements listed in 9.2.7, "symbol" provides a Unicode
        symbol or 1-2 letter string (for practical reasons, a number seems generally useful). The number of
        entries must be equal to (or larger than) the number of elements of "defining_stars". Excessive
        entries are ignored.

## 9.2.7 Names of Stars, Planets and Nonstellar Objects

Many cultures have defined their own names for stars, planets and even a few deep-sky objects bright enough
to be seen with the unaided eye. The "common_names" dict in a skyculture file index.json contains entries
of arrays tagged with HIP catalog numbers or other names.

    Names for stars, constellations, asterisms, planets and DSOs can be specified with a plethora of options:    v 25.2

"native"  name in the original language of the skyculture.

"english"  translation of the name's meaning. This is translated to users' language.

"pronounce"  (optional, but recommended) a Latin-character based transliteration/pronunciation aid, re-
        quired when "native" is written in non-Latin-based glyphs (e.g., Chinese, Arab, Hindu, Tibetan,
        . . .), e.g. Pinyin for Chinese. This is usually written with simple characters found on typewriters and
        may also be translated to user language to adopt different customs.

"transliteration"  (optional) a scientific Latin-character based transliteration where applicable. Not
        translatable to user language, but may use extended diacritics. The scheme may not be helpful as
        pronunciation aid. For example, Wylie for Tibetan.

"IPA"  (optional) International Phonetic Alphabet, a standardardized phonetic spelling.

"byname"  an optional explanatory addition to the name. May be helpful to explain mythological figures.    v 25.3
        This is translated to users' language, but is not included in search functions.

`"translator_comments"` (optional): comments to be shown to translators on Transifex.

`"references"` (optional): array of integers, referring to the references list in `description.md`.

As example, we show a part of the Samoan skyculture:

```
"common_names": {
  "HIP 32349": [{"english": "Gliding Star", "native": "Fētūsolonuʻu"}],
  "HIP 68702": [{"english": "Mea", "native": "Mea"}],
  "HIP 71683": [{"english": "Filo", "native": "Filo"}],
  "M45": [{"english": "Face of Liʻi", "native": "Matāliʻi"}],
  "NGC2055": [{"english": "Pale Cloud", "native": "Aotea"}],
  "NGC292": [{"english": "Flying Cloud", "native": "Aolele"}],
  "NGC6093": [{"english": "Pae"}],
  "NGC6121": [{"english": "Suga"}],
  "NAME Earth": [{"english": "Earth", "native": "Lalolagi"}],
  "NAME Jupiter": [{"english": "Undying Mystery", "native": "Tupualēgase"}],
  "NAME Mars": [{"english": "Reddish Face/Surface", "native": "Matamemea"}],
  "NAME Mercury": [{"english": "Brownish", "native": "Ta'elo"}],
  "NAME Moon": [{"english": "Moon", "native": "Māsina"}],
  "NAME Saturn": [{"english": "Garland Star", "native": "Fētūʻāsoa"}],
  "NAME Sun": [{"english": "Sun", "native": "Lā"}],
  "NAME Venus": [{"english": "Morning Star / Forbidden Radiance", "native":
      ↪ "Tapu'itea"}]
}
```

### 9.2.7.1  No translation in Modern Skyculture?

The star names that have been collected over the years in our default *Modern* skyculture come from an extensive collection of sources. Some names from Latin and Arab sources have a well-known meaning. In contrast to what we recommend for non-modern skycultures, we still keep the original name as translation in the `"english"` string, as such names are used internationally, without thinking about the translated meaning. Translated names may show slight, language dependent, spelling variations, or transliterations to other glyph systems, though. At best, the `"byname"` can transport a translation of the meaning to user language.

### 9.2.7.2  Star names

The Keys for stars generally start with `"HIP "`. The associated array contains again dicts providing `"native"` (original) and `"english"` (translatable) spellings of the star names, and `"references"` (optional but highly recommended) which indicates in which sources (see 9.1.2) these star names or particular spellings occur. The `"english"` name will be translated. An additional `"native"` entry can be given, which is the culture-native version of the spelling (also in language-specific glyphs when available in UTF8 and the current font) and will never be translated but can be shown on screen if so configured.

```
"common_names": {
    "HIP 677": [{"native": "Alpheratz",          "english": "Alpheratz",          "references": [1
        ↪ ,2,5,6,11,12,37]},
               {"native": "Sirrah",              "english": "Sirrah",             "references": [23,37]}],
    "HIP 746": [{"native": "Caph",               "english": "Caph",               "references": [1
        ↪ ,2,6,11,12,23,37]},
               {"native": "Al Sanam al Nakah", "english": "Al Sanam al Nakah", "references": [37]}],
    ... }
```

When there is more than one name for a star, the first in the list is used as screen label.

### 9.2.7.3  Planet Names

The `"common_names"` array can also contain dicts of native names of the planets. For these, the JSON key is formed from `"NAME "`, a space and the English name of the planet. The value array provides the dict entries (`"native"`, `"english"`, . . . ) listed above.

Currently, if more than one `"english"` strings are given, the first is used as screen label. This may change as the features further evolve.

v 25.2      In some cultures, Venus and even Mercury may have different names, depending on evening or morning visibility. We can add a tag `"visible"` which may be either `"morning"` or `"evening"` to select the name. If the base name should be the screen label, you must repeat it as first entry of the object's `"NAME "` name array. If the elongation-dependent name should be screen label, place the names with `"visible"` first, then repeat the standard name to be shown in the Info text. See the examples for *Venus* as *Morning Star* and *Evening Star* in the modern skyculture.

In earlier versions it was recommended to combine the native name with an English translation. In the new format here we should keep them separate, and the actual screen label can be combined from available

v 25.2      components on the fly (see 4.4.6).

### 9.2.8 Deep-Sky Objects Names

"`common_names`" can also contain native names for deep-sky objects (DSO). The content of the dicts is similar to the format for planet names above. Known tags are

"`english`"  English meaning

"`native`"  (optional) Native name. May be in native glyphs when supported in UTF8.

"`pronounce`"  (optional) Native name in European glyphs, if needed. For Chinese, expect Pinyin here.

"`translators_comments`"  (optional) English explanations that help in translation. Not displayed in the program.

"`references`"  (optional) the sources for these names where applicable

### 9.2.9 User Settings for the Skycultures

The large number of label combinations requires storing them in a user accessible way. In essence, we are using a 6-bit scheme with name elements that either show up or are omitted.  *(v 25.2)*

Native to show the native name in native glyphs.

Pronounce to show a Latin-character based transliteration usable as pronunciation aid.

Translit to show a scienticic transliteration that is not necessarily aimed at pronunciation.

Translated to show the meaning of the name translated to user language.

IPA to show the name in International Phonetic Alphabet.

Modern to show the contemporary scientific object name.

The names for the active parts are joined with commas (the sequence of entries is irrelevant and does not influence displayed order), and the resulting strings stored in `config.ini` in two dedicated sections like:

```
[SCInfoLabelStyle]
arabic_arabian_peninsula   = Native,Pronounce,Modern
boorong                    = Native,Translated
chinese                    = Native,Pronounce,Translated,Modern
modern                     = Native,Modern
russian_siberian           = Native,Pronounce,Translit,Translated,IPA,Modern

[SCScreenLabelStyle]
arabic_arabian_peninsula   = Pronounce,Translated,Modern
aztec                      = Native,Translated
chinese                    = Pronounce,Translated,Modern
modern                     = Native,Modern
russian_siberian           = Pronounce,Translated,Modern
```

#### 9.2.9.1 Not enough, or too many names?

Over the years, we have collected a quite extensive list of star names from many references. Until recently, the scientific community was not interested in standardizing names. With the introduction of Exoplanet naming contests, the International Astronomical Union started to also be concerned with the names of the brighter stars, and a proper Working Group on Star Names has formed.

Stellarium comes with a list of standardized names in `skycultures/common_star_names.fab`. These are always used when a skyculture shows "`fallback_to_international_names`" (see 9.2). If you always want to see these names, regardless of whether they are used or not in the respective skyculture, add the following to your `config.ini`:

```
[viewing]
flag_skyculture_always_fallback_to_international_names = true
```

Activating this flag for non-modern skycultures may feel weird, though, as it mixes these names into the other-cultural namespace.

#### Excluding excessive names

In contrast, some of the collected names may be too fanciful for your taste. If you can identify that those names that irritate you all come from a single or just a few entries of the reference list, you can exclude those sources, and thus the names they bring into the program. Note that if a fancy name comes from more than one book, you would have to exclude all books to ban that name from your display.  *(v 25.2)*

In a similar way, some of the collected asterisms (secondary figures), especially in the default Modern sky culture, may be too much for you. There are overlapping entries like the "Winter Hexagon" vs. "Heavenly G", or parts of constellations like Orion's shield and cudgel are marked as asterism. Some users may find that this clutters their screens too much. If you cannot identify a reference which introduces the unwanted

asterism (for some entries we cannot specify a source, unfortunately), you can also exclude them by their unique abbreviation, which is the last part of their `"id"` entries.

    To exclude entries from being displayed for a particular skyculture, add an entry like this to `config.ini`:

```
[SCExcludeReferences]
modern  = 11,36,OrB,OrS,OSh,OrC,HeG,Sal,TPT
```

Here, `modern` names the skyculture, and the comma-separated entries are references listed in the file `description.md` or asterism abbreviations you want to be ignored.

## 9.3 The Skyculture Converter

Many sky cultures have been created and maintained outside of Stellarium. They follow the old format, which is no longer supported since Stellarium version 25.1. To ease the transition we have developed a converter tool. It is a console application that takes a path to the old-format sky culture directory, and a path where to put the converted sky culture.

    The converter is installed together with the program, but there is no menu entry for it. On Windows, press the Windows key and type `cmd` to startup the command console.

    Let us assume you have created a skyculture following the format used until version 24.4 and described in previous editions of this Guide, and that this skyculture `mine` resides in the default user data directory on Windows (see 5.1 for other platforms). First we rename the skyculture to indicate that it is old and outdated. Then we must call the converter in its absolute path name, with names of old (source) and new (target) directories as *program arguments*.

    Example command to run it:

```
cd c:\Users\<ME>\AppData\Roaming\skycultures
move mine mine.old
"c:\Program Files\stellarium\skyculture-converter" mine.old mine
```

    While the converter tries hard to convert the description text from HTML to Markdown adding some sections from other parts of the sky culture, the conversion result may not be perfect. Formerly the description was completely free in structure, while now there are some structural requirements on it, so the text may need some editing to conform.

    If you have **gettext** translation files (the ones whose names are in the form `locale-name.po`) for the names of stars, constellations etc., you can pass the path to the directory that contains them as an optional third positional argument to the converter.

    Additionally, there are some options that you can use to control the conversion:

`--footnotes-to-references` Convert footnotes in a particular form to references. Such footnotes are expected to be in the form of

```
<p id="footnote-9">This is a footnote</p>
```

while the references to them are expected to be in the form of

```
<sup><a href="#footnote-9">[9]</a></sup>
```

`--untrans-names-are-native` Put the names that in `star_names.fab` or in `dso_names.fab` are denoted without an underscore into the `"native"` section of the name, rather than `"english"`. For example, with this option `32349|("Fētūsolonuʻu")` would be used for the `"native"` name, while `32349|_("Gliding Star")` would be used for the `"english"` tag.

`--native-locale LOCALE` In addition to files `star_names.fab` or `dso_names.fab`, some sky cultures have localized versions of them, like e.g. `star_names.zh_CN.fab`, that were never actually used but do contain useful information. If you pass the locale (`zh_CN` in this example) as the `LOCALE` parameter, these names will be read and put into the `"native"` section of the corresponding JSON entry. Note that the order of stars/DSOs in the normal and localized files must be the same, otherwise there's no way to match the names.

`--translated-md` To check the look of the translated description texts you can use this option. The output directory will contain files named like `description.es_419.DO_NOT_COMMIT.md`, in addition to `description.md`, with the `DO_NOT_COMMIT` part reminding you that they are not a part of the sky culture.

After the run, read the notes and warnings, and adjust your text accordingly. Make especially sure to prepare and adjust your old `description.en.utf8` for successful conversion. For example, it must start with an HTML header of level `<h1>` (the only such header in this file!) which is expected to match the skyculture `name` given in the old `info.ini`. If in doubt, the latter will be used in the new files.

Generally, clean HTML should be converted successfully. Given the wide variety of writing styles, not every conversion may however work flawlessly, and you may have to adjust the result, also in light of the new features. To protect any changes you may have added after conversion, running the converter again needs a new target directory.

## 9.4 Publish Your Work

If you are willing to let other users enjoy the result of your hard work (and we certainly hope you do!), when you are done, please write a note in the Forum or at GitHub. We will decide about acceptability and classification, or may ask for better descriptions for the benefit of our users.
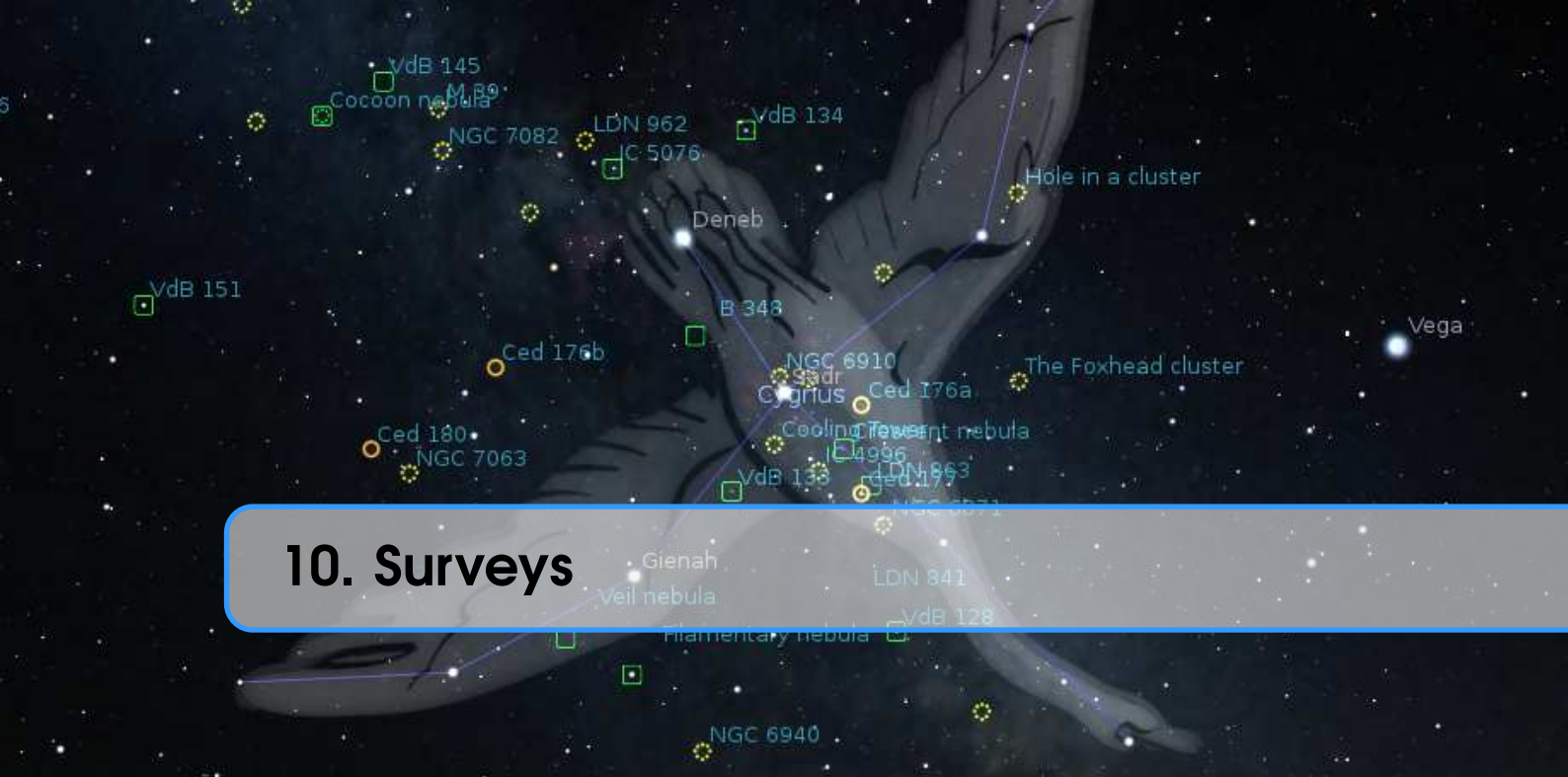
Please put the imagery and text under some compatible open-source license (see 9.1.3). Else the sky culture cannot be hosted by us. While we cannot be held responsible for legal problems, it seems that CC BY 4.0 International[6] or CC BY-SA 4.0 International[7] licenses are best suited. See notes in section 9.1.3 above.

---

[6] `https://creativecommons.org/licenses/by/4.0/`
[7] `https://creativecommons.org/licenses/by-sa/4.0/`

# 10. Surveys

GUILLAUME CHÉREAU

## 10.1 Introduction

A *sky survey* is a map of the sky stored as a hierarchical set of a potentially large number of smaller images (called tiles). The advantage compared to a regular texture is that we need to render only the visible tiles of a potentially gigantic image at the lowest resolution needed. This is particularly interesting for rendering online images that can be stored on a server, while the client only has to download the parts he currently uses.

Since version 0.18.0, Stellarium added some preliminary support for loading and rendering online surveys in the *Hierarchical Progressive Surveys* (HiPS) format, developed by the *International Virtual Observatory Alliance*. A full description of the format can be found on the IVOA website[1].

## 10.2 Hipslist file and default surveys

Hipslist files are text files used to describe catalogs of HiPS surveys. The full specification is part of the HiPS format, and looks like that:

```
# Example of a hipslist file.
# Date: 2018-03-19

obs_title         = callisto
hips_service_url  = https://data.stellarium.org/surveys/callisto
hips_release_date = 2018-03-18T14:01Z
hips_status       = public mirror clonableOnce
...
```

Stellarium by default tries to load HiPS from two sources:
- `http://alasky.u-strasbg.fr/MocServer/query?*/P/*&get=record` (deep sky)
- `https://data.stellarium.org/surveys/hipslist` (planets)

This can be changed with the `sources` entries in the `[hips]` section of the configuration file (see also section D.1.29). You can add your own private HiPS surveys by either running your own (even machine-local) webserver, or just placing your files into any directory and adding a `file://` URL:

```
[hips]
sources/1/url = http://alasky.u-strasbg.fr/MocServer/query?*/P/*&get=record
sources/2/url = https://data.stellarium.org/surveys/hipslist
sources/3/url = http://localhost/Stellarium/hips/hipslist
sources/4/url = file:///D:/Stellarium/hips/hipslist
sources/size  = 4
```

---

[1]`https://www.ivoa.net/documents/HiPS/20170519/REC-HIPS-1.0-20170519.pdf`

## 10.3 Solar system HiPS survey

Though not specified in the HiPS standard, Stellarium recognises HiPS surveys representing planet textures, as opposed to sky surveys. If the `obs_frame` property of a survey is set to the name of a planet or other solar system body, Stellarium will render it in place of the default texture used for the body.

## 10.4 Digitized Sky Survey 2 (TOAST Survey)

GEORG ZOTTI, ALEXANDER WOLF

The older way to provide a tessellated all-sky survey uses the TOAST encoding[2]. Stellarium provides access to the Digitized Sky Survey 2, a combination of high-resolution scans of red- and blue-sensitive photographic plates taken in 1983–2006 at Palomar Observatory and the Anglo-Australian Observatory.[3]

To enable access to the DSS layer, see section 4.3.3 and enable the DSS button. Then just press that DSS button in the lower button bar, wait a moment, zoom in and enjoy!

### 10.4.1 Local Installation

This display normally requires access to the Internet. However, in some situations like frequent and extensive use in fixed observatories, or use in the field when Internet connection is not possible, you can download all image tiles to your local harddisk for local use. Please be considerate, don't waste bandwidth, and do this only if you really need it.

The images are stored in subdirectories that increase in size and number of files (see Table 10.1). Zooming in loads the next level if available.

| Level | No of files | Filespace (kB) | Level | No of files | Filespace (kB) | Level | No of files | Filespace (kB) |
|-------|-------------|----------------|-------|-------------|----------------|-------|-------------|----------------|
| 0 | 1 | 32 | 4 | 256 | 7.172 | 8 | 65.536 | 1.661.808 |
| 1 | 4 | 124 | 5 | 1.024 | 27.920 | 9 | 262.144 | 6.119.092 |
| 2 | 16 | 472 | 6 | 4.096 | 109.628 | 10 | 1.048.576 | 20.250.216 |
| 3 | 64 | 1.820 | 7 | 16.384 | 429.800 | 11 | 4.194.305 | 83.583.724 |

Table 10.1: Number of files and storage requirements for local DSS TOAST installation

For partial downloads, you can limit the maximally used level (e.g. 9 or 10). The difference from level 10 to 11 is really hardly noticeable, yet level 11 contains almost 75% of all data. On a small system like Raspberry Pi 3, you may run into troubles with too little texture memory when level is more than 7.

Another issue: the level 11 subdirectory holds over 4 million files. Windows **Explorer** is not optimized to open and display this number of files and will take a long time to open. Just unpack this archive, but don't access the folder with **Explorer**.

If all that does not discourage you, you can download the archives at `https://dss.stellarium.org/offline/`.

Then add a few entries to the `[astro]` section in Stellarium's `config.ini`. On Windows, if you have a harddisk `T:` with path `T:\StelDSS` that contains the unpacked image subdirectories 0, 1, 2, ..., 10, the section may look like

```
[astro]
toast_survey_directory = StelDSS
toast_survey_host = T:/
toast_survey_levels = 10
```

On Linux, with the files stored in `/usr/local/share/Stellarium/StelDSS`, the same section could look like

```
[astro]
toast_survey_directory = usr/local/share/Stellarium/StelDSS
toast_survey_host = /
toast_survey_levels = 10
```

---

[2]Please see `http://montage.ipac.caltech.edu/docs/WWT/` for details

[3]The original data are available at `https://archive.stsci.edu/cgi-bin/dss_form`.

# 11. Stellarium's Skylight Models

Georg Zotti

## 11.1 Introduction

Stellarium's main aim is a realistic simulation of the night sky. This is more than just the creation of a star map. Especially a realistic simulation of twilight and the visibility of stars, deep-sky objects or the Zodiacal light is a challenge. Since early in its history Stellarium has used models from the computer graphics literature to achieve its goals. For most users, the models seem to work well, but more advanced users may want to tweak some of the values.

## 11.2 The Skylight Models

### 11.2.1 Legacy Mode: The Preetham Skylight Model

A well-known fast computer graphics model for daylight has been presented by Preetham, Shirley, and Smits (1999). Its brightness distribution is based on an all-weather model for sky luminance distribution by Perez, Seals, and Michalsky (1993) and models chromaticity distribution with similarly-shaped functions. It works reasonably well for average conditions, and a "turbidity" parameter $T$ allows a simple modelling of visibility conditions. In terms of the atmospheric extinction coefficient $k$ (see 19.13.1), we can define

$$T = 25(k - 0.16) + 1 \tag{11.1}$$

In Stellarium, a value of $T = 5$ has been used for many years, and the chromaticity parameters have been slightly changed for a more pleasing color distribution at this value for $T$. Recently, we have made the many parameters of the Preetham model accessible for users to fine-tune. Not many users will even want to do this, and therefore you must enable this manually by editing `config.ini`:

```
[Skylight]
enable_gui=true
```

Only with this setting, a button ✎ will be available in the View settings, Sky tab (section 4.4.1.2).

All settings described here will immediately be stored in `config.ini`.

One setting allows to compute $T$ from $k$ with the above relation 11.1.

Please note that the parameters are far from intuitive, therefore we added two sets of reset functions. One sets the values to those in the original paper, the other re-establishes Stellarium's sky colors from version 0.21.3 and earlier, which however seem only suitable for $T = 5$.

A sky brightness model better suited for astronomical simulation, including twilight and brightness contributions of the Moon and airglow, was presented by B. E. Schaefer (1989-93 and 1993). By default, Stellarium uses this model in combination with chromaticity from the Preetham model. For experiments, you can however revert from the Schaefer brightness model to the Preetham model. The parameters of the Schaefer model are currently not accessible for further experiments.

Some more parameters fine-tune some aspects of rendering of the Solar disk and the solar glare. It makes a slight difference whether the Sun's disk is plotted before or after the glare, and whether the solar sphere is rendered after the atmosphere.

### 11.2.2  Advanced Mode: The ShowMySky Skylight Model

A much more advanced skylight model has been presented by Bruneton and Neyret (2008). An implementation of this has been developed by Ruslan Kabatsayev just in time for inclusion in version 1.0. Switching between the models is described in section 4.4.1.2.

It requires graphics hardware which uses OpenGL 3.3 or better and consists of two components. Atmospheric data (a description of gas composition) is processed by an auxiliary program, **CalcMySky**, which creates a lot of textures and shaders. For final display, a software component (the **ShowMySky** library) is used that processes these data in real-time to compute the final sky colors. This model and its default atmosphere data especially can deliver stunning reality of twilight colors in a dry atmosphere, and also provides special modes for the "circular twilight" during a Total Solar Eclipse.

**To choose a dataset**  press ▣ near the *Path to data* entry field, and in the dialog that opens, choose the directory with the dataset. Stellarium comes with a default dataset that's automatically chosen after a fresh installation. Power users can use **CalcMySky**[1] to generate other atmospheres. Creating a new dataset requires some understanding of the physics of light scattering.

**Eclipse simulation quality**  option lets you configure the balance between realism of skylight simulation during a solar eclipse. The values of this option can be:

**0**  This is the fastest and crudest mode. The atmosphere is simply dimmed to account for the lower amount of direct sunlight.

**1**  This is the first mode that actually tries to simulate an eclipse. It uses precomputed textures, and may look blocky in some cases like e.g. very low Sun (and Moon).

**2**  This mode is much slower than the previous one (2.5 FPS on an NVIDIA GeForce GTX 750Ti). In this mode part of the calculation is done on the fly for the current eclipse phase to improve correctness of the simulation, unlike the previous mode where a texture was used that contains data only for totality, other phases being approximated from this.

**3**  This is the slowest mode (1.1 FPS on NVIDIA GeForce GTX 750Ti), but computation is done on the fly for the whole simulation, which yields best quality.

**To achieve higher frame rates**  on slow systems, the configuration parameter in `config.ini`:

```
[landscape]
atmosphere_resolution_reduction = 4
```

allows reducing the resolution of the skylight texture. Preferred values are:

**1**  full resolution (default)
**2**  half resolution
**4**  quarter resolution

**The configuration switch**  in `config.ini`:

```
[landscape]
flag_atmosphere_dynamic_resolution = true
```

allows to use the reduced resolution only while moving the view, when panning, zooming, dimming or in time-lapse mode. With the real-time display, on the other hand, the full resolution is retained. Possible values are:

**false**  static resolution (default)
**true**  dynamic resolution

---

[1] `https://github.com/10110111/CalcMySky`

**Note:** In dynamic resolution mode, a motion analyzer selects either full or reduced resolution. The change in resolution could be particularly visible in close proximity to the Sun. Especially at full resolution, frames will be skipped depending on the speed of movement.

A more detailed description of how to create a custom atmosphere will be given in a future version of this User Guide.

## 11.3 Light Pollution

In urban and suburban areas the night sky is lit by ground sources of light. This light is scattered by the atmosphere, and the sky appears brighter. This reduces visibility of astronomical objects.

Stellarium simulates this effect. The main physical quantity that describes light pollution is zenith luminance, measured in candelas per square meter ($cd/m^2$). It can be measured using a device called *sky quality meter* (SQM).

For astronomical observations often another unit of sky brightness is useful: magnitudes per square arcsecond ($mag/arcsec^2$). It is related to $cd/m^2$ as

$$L = 10.8 \times 10^{4-0.4M}, \tag{11.2}$$

where $L$ is the value in $cd/m^2$, and $M$ is the value in $mag/arcsec^2$. Some SQMs give readings in $mag/arcsec^2$. Stellarium supports input in both units.

Another way to characterize light pollution is by defining the *naked-eye limiting magnitude* (NELM). Unlike luminance, which, although based on human vision, is well-standardized (in particular, the candela is part of the SI), NELM is subjective and variable: it is based on human vision, depends on weather conditions, and is not standardized. In Stellarium the calculations follow B. E. Schaefer (1990). In particular, equation (18) is used, assuming observer's acuity $F_s = 1$ (as suggested in the text as "typical observer"), and absorption term $k_v = 0.3$ (as suggested for "typical weather").

A related subjective characterization of light pollution is the *Bortle Dark Sky Scale*, which assigns an integral number from 1 to 9 to the sky based on its brightness. This scale is described in detail in Appendix B.

Stellarium calculates both Bortle class and NELM for user convenience. They aren't used in the actual calculations for visualization.

## 11.4 Tone Mapping

Tone mapping is the process which attempts to compress the brightness values found in nature into the range of brightness values which can be achieved on a display device so that an image of a natural scene looks reasonably natural and realistic. The process has been described by Tumblin and Rushmeier (1993), Larson, Rushmeier, and Piatko (1997) and Devlin et al. (2002). For low-light conditions like night and the transitional phase, twilight, special considerations have to be taken, first described by Jensen et al. (2000). Stellarium's transformation from skylight model to display colors is based on these papers.

Parameters to tweak the tone mapping can be reached in the view settings dialog after pressing ▮➡ .

**Display max luminance** maximal brightness of the used screen. This used to be $100 cd/m^2$ applicable for CRT monitors, but more modern screens can achieve much higher luminances of $250 cd/m^2$ or more, to be found in the spec sheets. Adjust this value to influence the displayed brightness along the horizon.

**Display adaptation luminance** describes the view environment where the screen is set up. For an average office environment, $50 cd/m^2$ seems a usable default. In an outdoor setting, much higher values are possible.

**Display Gamma** describes the exponent of a nonlinear correlation between input values and output luminance of the screen. Higher values push the average image brightness.

**Use extra Gamma term** The original implementation of tone mapping included a gamma term which did not exactly follow the description from Larson, Rushmeier, and Piatko (1997), but looks better (more colorful) than the implementation without the gamma term. You can now play with it to find your preferred setting. This flag is only used with the Preetham skylight model.

**Use sRGB** The final step of color creation is a transformation from CIE Yxy to some display RGB color space. Nowadays most monitors can display the sRGB color space, therefore this flag is usually enabled. Disabling this flag will lead to using the Adobe RGB (1998) color space. The colors may look a bit better on monitors which are set to display Adobe RGB, but washed-out on sRGB monitors.

# III Extending Stellarium

# 12. Plugins: An Introduction

Starting with version 0.10.3, Stellarium's packages have included a steadily growing number of optional extensions called plug-ins which are presented in the following chapters. All these plug-ins are "built-in" in the standard Stellarium distribution and don't need to be downloaded separately.

## 12.1 Enabling plugins

To enable a plugin:

1. Open the **Configuration dialog** (press $\boxed{\text{F2}}$ or use the left tool bar button $\boxed{\mkern-2mu \text{🔧}^{\star} \mkern-2mu}$ )
2. Select the **Plugins** tab
3. Select the plugin you want to enable from the list
4. Check the **Load at startup** option
5. Restart Stellarium

If the plugin has configuration options, the **configuration** button will be enabled when the plugin has been loaded and clicking it will open the plugin's configuration dialog. When you only just activated loading of a plugin, you must restart Stellarium to access the plugin's configuration dialog. The plugin's configuration dialog  is also available by right-clicking on the respective plugin's main button in the bottom button bar.

## 12.2 Data for plugins

Some plugins contain files with different data, e.g., catalogs. JSON is a typical format for those files, and you can edit its contents manually. Of course, each plugin has a specific format of data for its own catalogs, and you should read the documentation for the plugin before editing its catalog.

You can read some common instructions for editing catalogs of plugins below. In this example we use file name `catalog.json` for identification of the catalog for a typical plugin.

You can modify the `catalog.json` files manually using a text editor. **If you are using Windows, it is strongly recommended to use an advanced text editor such as Notepad++[1] to avoid problems with end-of-line characters.** (It will also color the JSON code and make it easier to read.)

**Warning**: Before editing your `catalog.json` file, make a backup copy. Leaving out the smallest detail (such as a comma or forgetting to close a curly bracket) may prevent Stellarium from starting.

As stated in section 5, the path to the directory[2] which contains `catalog.json` file is something like:
**Windows**  C:\Users\**UserName**\AppData\Roaming\Stellarium\modules\*PluginName*
**Mac OS X**  **HomeDirectory**/Library/Application Support/Stellarium/modules/*PluginName*
**Linux and UNIX-like OS**  ~/.stellarium/modules/*PluginName*

---

[1] `https://notepad-plus-plus.org/`

[2] This is a hidden folder, so in order to find it you may need to change your computer's settings to display hidden files and folders.

# 13. Interface Extensions

Most users will soon be familiar with the usual user interface. A few plugins are available which extend the regular user interface with a few small additions which are presented first. However, some applications and installations of Stellarium require completely different user interfaces. Mostly, these serve to avoid showing the user interface panels to an audience, be that in your astronomy club presentations, a domed planetarium or in a museum installation.

## 13.1 Angle Measure Plugin

*goes misty eyed*
I recall measuring the size of the Cassini Division when I was a student. It was not the high academic glamor one might expect... It was cloudy... It was rainy... The observatory lab had some old scopes set up at one end, pointing at a *photograph* of Saturn at the other end of the lab. We measured. We calculated. We wished we were in Hawaii. A picture is worth a thousand words.



Figure 13.1: Interface of Angle Measure plugin

The Angle Measure plugin is a small tool which is used to measure the angular distance between two points

on the sky.

1. Enable the tool by clicking the tool-bar button $\angle$ , or by pressing $\boxed{\text{Ctrl}}$ + $\boxed{\text{A}}$ . A message will appear at the bottom of the screen to tell you that the tool is active.
2. Drag a line from the first point to the second point using the left mouse button.
3. To measure to a different endpoint, click the right mouse button.
4. To deactivate the angle measure tool, press the tool-bar button again, or press $\boxed{\text{Ctrl}}$ + $\boxed{\text{A}}$ on the keyboard.

In the configuration dialog, you can configure if you want to have distances given on the rotating sphere, or in horizontal (alt-azimuthal) coordinates. You can also link one point to the resting horizon, the other to the sky and observe how angles change. You can choose where to display the measurement.

When option "Allow snap to selected object" is activated the process of measurement is changed:

* The left mouse button is not used for angle measurement, so you can pan the screen and left-click to select an object as usual.
* To draw the angle dimension line, you can drag with the right mouse button.
* A right click moves the end of the angle line that is closest to the mouse pointer.
* If an object is selected, right-clicking will snap the end of the protractor line (closest to the mouse pointer) to the selected object.
* Double-click the right mouse button to capture the end of the line. Another double click with the right mouse button removes the angle measuring line.
* Which end of the protractor line is chosen depends on the position of the mouse pointer in relation to the two ends of the line. The end of the line that is closer to the mouse pointer is moved and defined as the new end point. The end of the line farther from the mouse pointer is not moved and is defined as the new starting point.

## 13.2 Equation of Time Plugin
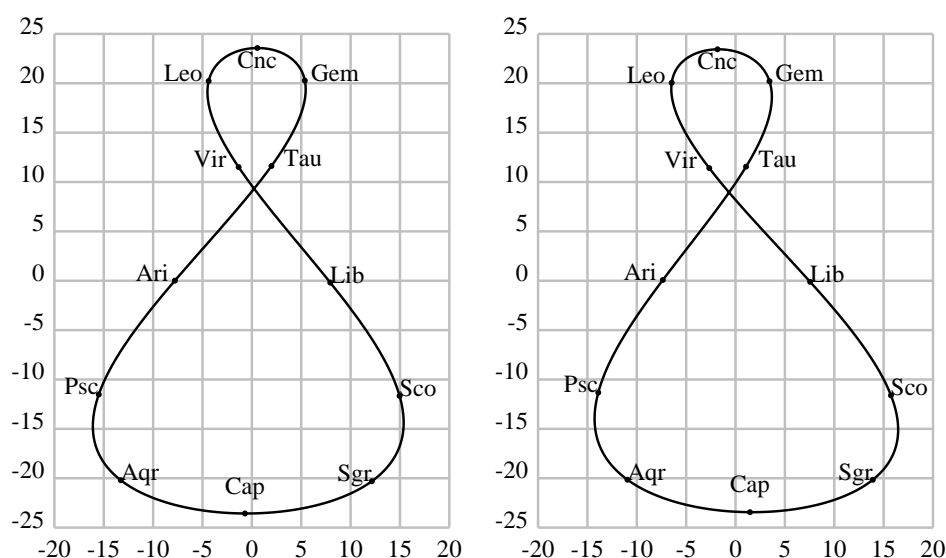


Figure 13.2: Figure-8 plots for Equation of Time, for years 1000 (left) and 2000 (right). These plots, often found on sundials, link solar declination (vertical axis) and its deviation at mean noon from the meridian, in minutes. Labeled dots indicate when the sun entered the respective Zodiacal sign (30°section of the ecliptic). Figures by Georg Zotti.

The Equation of Time plugin shows the solution of the equation of time. This describes the discrepancy between two kinds of solar time:

**Apparent solar time**  directly tracks the motion of the sun. Most sundials show this time.

**Mean solar time**  tracks a fictitious "mean" sun with noons 24 hours apart.

There is no universally accepted definition of the sign of the equation of time. Some publications show it as positive when a sundial is ahead of a clock; others when the clock is ahead of the sundial. In the English-speaking world, the former usage is the more common, but is not always followed. Anyone who makes use of a published table or graph should first check its sign usage.

If enabled (see section 12.1), click on the Equation of Time button ⌛ on the bottom toolbar to display the value for the equation of time on top of the screen.

### 13.2.1 Section [EquationOfTime] in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Equation of Time plugin – just make it carefully!

| ID | Type | Description |
|---|---|---|
| enable_at_startup | bool | Display solution of the equation of time at startup of Stellarium |
| flag_use_ms_format | bool | Set format for the displayed solution – minutes and seconds or decimal minutes |
| flag_use_inverted_value | bool | Change sign of the equation of time |
| flag_show_button | bool | Show the tool's button on the bottom toolbar |
| text_color | R,G,B | Font color for the displayed solution of the equation of time |
| font_size | int | Font size for the displayed solution of the equation of time |

## 13.3  Pointer Coordinates Plugin



Figure 13.3: Interface of Pointer Coordinates plugin

The Pointer Coordinates plugin shows the coordinates of the mouse pointer. If enabled, click on the plugin button ⟨✳⟩ on the bottom toolbar to display the coordinates of the mouse pointer.

### 13.3.1  Section ⌈PointerCoordinates⌋ in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Pointer Coordinates plugin – just make it carefully!

| ID | Type | Description |
|---|---|---|
| enable_at_startup | bool | Enable displaying mouse pointer coordinates at program startup |
| flag_show_button | bool | Show the plugin's tool button on the bottom toolbar |
| text_color | R,G,B | Color for coordinates text of the mouse pointer |
| font_size | int | Font size for the displayed mouse pointer coordinates |
| current_displaying_place | string | Specifies the place of displaying coordinates of the mouse pointer. *Possible values*: `TopRight`, `TopCenter`, `RightBottomCorner`, `Custom`. *Default value*: `TopRight`. |
| custom_coordinates | int,int | Specifies the screen coordinates of the custom place for displaying coordinates of the mouse pointer |
| current_coordinate_system | string | Specifies the coordinate system. *Possible values*: `RaDecJ2000`, `RaDec`, `HourAngle`, `Ecliptic`, `AltAzi`, `Galactic`. *Default value*: `RaDecJ2000`. |
| flag_show_constellation | bool | Add the 3-letter IAU abbreviation for the constellation of the mouse pointer location (Roman, 1987). |
| flag_show_crossed_lines | bool | Show crossed lines under mouse cursor. |

## 13.4   Text User Interface Plugin

This plugin re-implements the "TUI" of the pre-0.10 versions of Stellarium, an unobtrusive menu used primarily by planetarium system operators to change settings, run scripts and so on.

   A full list of the commands for the TUI plugin is given in section 13.4.2.

### 13.4.1   Using the Text User Interface

1. Activate the text menu using the Alt + T key.[1]
2. Navigate the menu using the cursors keys.
3. To edit a value, press the right cursor until the value you wish to change it highlighted with > and < marks, e.g. >3.142<. Then press the cursor keys ↑ and ↓ to change the value. You may also type in a new value with the other keys on the keyboard.

### 13.4.2   TUI Commands

| | | |
|---|---|---|
| 1 | Location | (menu group) |
| 1.1 | Latitude | Set the latitude of the observer in degrees |
| 1.2 | Longitude | Set the longitude of the observer in degrees |
| 1.3 | Altitude | Set the altitude of the observer in meters |
| 1.4 | Solar System Body | Select the solar system body on which the observer is |
| 2 | Set Time | (menu group) |
| 2.1 | Current date/time | Set the time and date for which Stellarium will generate the view |
| 2.2 | Set Time Zone | (disabled in 0.15) |
| 2.3 | Days keys | (disabled in 0.15) |
| 2.4 | Startup date/time preset | Select the time which Stellarium starts with (if the "Sky Time At Start-up" setting is "Preset Time" |
| 2.5 | Startup date and time | The setting "system" sets Stellarium's time to the computer clock when Stellarium runs. The setting "preset" selects a time set in menu item "2.4 - Startup date/time preset" |
| 2.6 | Date Display Format | Change how Stellarium formats date values. "system_default" takes the format from the computer settings, or it is possible to select "yyyymmdd", "ddmmyyyy" or "mmddyyyy" modes |
| 2.7 | Time Display Format | Change how Stellarium formats time values. "system_default" takes the format from the computer settings, or it is possible to select "24h" or "12h" clock modes |
| 3 | General | (menu group) |
| 3.1 | Sky Culture | Select the sky culture to use (changes constellation lines, names, artwork) |
| 3.2 | Sky Language | Change the language used to describe objects in the sky |
| 3.3 | App Language | Change the application language (used in GUIs) |
| 4 | Stars | (menu group) |
| 4.1 | Show stars | Turn on/off star rendering |
| 4.2 | Relative Scale | Change the relative brightness of the stars. Larger values make bright stars much larger. |
| 4.3 | Absolute Scale | Change the absolute brightness of the stars. Large values show more stars. Leave at 1 for realistic views. |
| 4.4 | Twinkle | Sets how strong the star twinkling effect is - zero is off, the higher the value the more the stars will twinkle. |
| 4.5 | Mag limit | Sets a custom magnitude cutoff for stars |
| 4.6 | Use mag limit | Activates this magnitude limit |
| 4.7 | Spiky stars | Use pointed star figures |

---

[1]This used to be hard-coded to M before version 0.15, but Alt + T is better to remember as it runs parallel with Ctrl + T for switching the GUI panels, and frees up M for the Milky Way. The Alt + T keybinding is hard-coded, i.e., cannot be reconfigured by the user, and should not be used for another function.

| | | |
|------|------------------------------|------------------------------------------------------------------------|
| 4.8  | Labels and Markers           | configures the amount of labels                                        |
| 4.9  | Show additional star names   |                                                                        |
| 4.10 | Use designations for screen labels |                                                                  |
| 5    | Colors                       | (menu group) change color/brightness of the...                        |
| 5.1  | Constellation lines          | constellation lines                                                   |
| 5.2  | Constellation labels         | labels used to name stars                                             |
| 5.3  | Art brightness               | constellation art                                                     |
| 5.4  | Constellation boundaries     | constellation boundary lines                                          |
| 5.5  | Cardinal points              | cardinal points markers                                               |
| 5.6  | Planet labels                | labels for planets                                                    |
| 5.7  | Planet orbits                | orbital guide lines for planets                                       |
| 5.8  | Planet trails                | planet trails lines                                                   |
| 5.9  | Meridian Line                | meridian line                                                         |
| 5.10 | Azimuthal Grid               | lines and labels for the azimuthal grid                              |
| 5.11 | Equatorial Grid              | lines and labels for the equatorial grid                             |
| 5.12 | Equatorial J2000 Grid        | lines and labels for the equatorial J2000.0 grid                     |
| 5.13 | Equator Line                 | equator line                                                         |
| 5.14 | Ecliptic Line                | ecliptic line                                                        |
| 5.15 | Ecliptic Line (J2000)        | J2000 ecliptic line                                                  |
| 5.16 | Nebula names                 | labels for nebulae                                                   |
| 5.17 | Nebula hints                 | circles used to mark positions of unspecified nebulae               |
| 5.18 | Galaxy hints                 | ellipses used to mark positions of galaxies                         |
| 5.19 | Bright nebula hints          | squares used to mark positions of bright nebulae                    |
| 5.20 | Dark nebula hints            | squares used to mark positions of dark nebulae                      |
| 5.21 | Clusters hints               | symbols used to mark positions of clusters                          |
| 5.22 | Horizon line                 | horizon line                                                         |
| 5.23 | Galactic grid                | galactic grid                                                        |
| 5.24 | Galactic equator line        | galactic equator line                                                |
| 5.25 | Opposition/conjunction longitude line | opposition/conjunction line                                 |
| 5.26 | Sky background               | sky background. Note that anything but black is only useful for artistic works. |
| 6    | Effects                      | (menu group)                                                         |
| 6.1  | Light Pollution              | Changes the intensity of the light pollution (see Appendix B Bortle Scale index) |
| 6.2  | Landscape                    | Select the landscape which Stellarium draws when ground drawing is enabled. Press ⏎ to activate. |
| 6.3  | Setting Landscape Sets Location | If "Yes" then changing the landscape will move the observer location to the location for that landscape (if one is known). Setting this to "No" means the observer location is not modified when the landscape is changed. |
| 6.4  | Auto zoom out returns to initial ...view | Changes the behavior when zooming out from a selected object. When set to "Off", selected object will stay in center. When set to "On", view will return to startup view. |
| 6.5  | Zoom Duration                | Sets the time for zoom operations to take (in seconds)              |
| 6.6  | Milky Way intensity          | Changes the brightness of the Milky Way                             |
| 6.6  | Milky Way saturation         | Changes the saturation of the Milky Way                            |
| 6.7  | Zodiacal light intensity     | Changes the brightness of the Zodiacal light                       |
| 7    | Scripts                      | (menu group)                                                         |
| 7.1  | Run local script             | Run a script from the scripts sub-directory of the User Directory or Installation Directory (see section 5 (Files and Directories)) |
| 7.1  | Stop running script          | Stop execution of a currently running script                        |
| 8    | Administration               | (menu group)                                                         |

| 8.1 | Load default configuration | Reset all settings according to the main configuration file |
| 8.2 | Save current configuration | Save the current settings to the main configuration file |
| 8.3 | Shutdown | Emits a command configured in |

### 13.4.3 Section [tui] in config.ini file

The section in `config.ini` for this plugin is named only `[tui]` for historical reasons. As always, be careful when editing!

| ID | Type | Description |
|---|---|---|
| tui_font_color | R,G,B | Font color for TUI text |
| tui_font_size | int | Font size for the TUI |
| flag_show_gravity_ui | bool | Bend menu text around the screen center. May be useful in planetarium setups, and should then be used together with "Disc viewport" in the configuration menu (see 4.3.5). |
| flag_show_tui_datetime | bool | Show date and time in lower center. |
| flag_show_tui_short_obj_info | bool | Show some object info in lower right, or (in planetarium setups with "Disc viewport" active,) wrapped along the outer circle border. |
| admin_shutdown_cmd | string | executable command to shutdown your system. Best used on Linux or Mac systems. E.g. `shutdown -h now` |

## 13.5    Remote Control Plugin

The Remote Control plugin enables the user to control Stellarium through an external web interface using a standard web browser like Firefox or Chrome, instead of using the main GUI. This works on the same computer Stellarium runs as well as over the network. Even more, multiple "remote controls" can access the same Stellarium instance at the same time, without getting in the way of each other. Apart from system configuration options, most of the functionality the main interface provides is available through it (Zotti, Schaukowitsch, and Wimmer, 2017).

The plugin may be most useful for presentation scenarios, hiding the GUI from the audience and allowing the presenter to change settings on a separate monitor without showing distracting dialog windows. It also allows to start and stop scripts remotely.

Because the web interface can be customized (or completely replaced) with some knowledge of HTML, CSS and JavaScript, another possibility is a kiosk mode, where untrusted users can execute a variety of predefined actions (like starting recorded tours) without having access to all Stellarium settings. The web API can also be accessed directly (without using a browser and the HTML interface), allowing control of Stellarium with external programs and scripts using HTTP calls like with the tools `wget` and `curl`.

This plugin allows also interfacing other programs with Stellarium.

### 13.5.1    Using the plugin
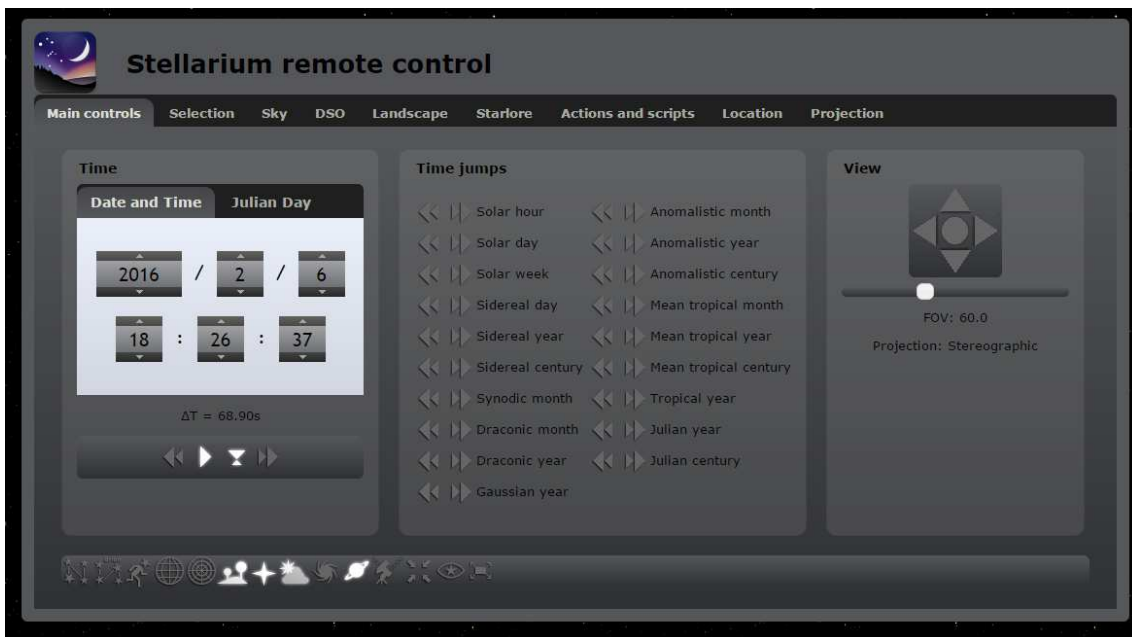


Figure 13.4: The default remote control web interface

After enabling the plugin, you can set it up through the configuration dialog. You can configure it to start the web server automatically whenever Stellarium starts or manually start/stop the server using the "Server enabled" checkbox or the button ⬚ in the toolbar.

The plugin starts an HTTP server on the specified port. The default port is 8090, so you should reach the remote control after enabling it by starting a web browser on the same computer and entering `http://localhost:8090` in the address bar. When trying to access the remote control from another computer, you need the IP address or the hostname of the server on which Stellarium runs. On a small tablet, you may want to use `http://myserver:8090/tablet7in.html` instead.

The plugin shows the locally detected address, but depending on your network or if you need external access you might need to use a different one — contact your network administrator if you need help with that.

#### 13.5.1.1    Password

The access to the remote control may optionally be restricted with a simple password.

**Warning:** *currently no network encryption is used, meaning that an attacker having access to your network can easily find out the password by waiting for a user entering it. Access from the Internet to the plugin should generally be restricted, except if countermeasures such as VPN usage are taken! If you are in a home network using NAT (network access translation), this should be enough for basic security except if port forwarding or a DMZ is configured.*

#### 13.5.1.2 CORS

The Web API also supports Cross-Origin Resource Sharing (CORS). By enabling CORS, compatible websites and web apps can be used to control your Stellarium server.

Enable CORS by checking the "Enable CORS for the following origin" option in the configuration dialog. Then, enter the URL of the website you'd like to use to control Stellarium – e.g. `https://telesc opius.com`. Specify "*" to let any website take control. Do this at your own risk.

### 13.5.2 Remote Control Web Interface

If you are familiar with the main Stellarium interface, you should easily find your way around the web interface. The remote control automatically uses the same language as set in the main program. Tabs at the top allow access to different settings and controls.

**Main** Contains the time controls and most of the buttons of the main bottom toolbar. An additional control allows moving the view like when dragging the mouse or using the arrow keys in Stellarium, and a slider enables the changing of the field of view. There are also buttons to quickly execute time jumps using the commonly used astronomical time intervals.

**Selection** Allows searching and selecting objects like in section 4.5. SIMBAD search is also supported. Quick select buttons are available for the primary solar system objects. It also displays the information text for current selection.

**Sky** Settings related to the sky display as shown in the "View" dialog as shown in subsection 4.4.1.

**DSO** The deep-sky object catalog, filter and display settings like in subsection 4.4.4.

**Landscape** Changing and configuring the background landscape, see subsection 4.4.5

**Actions and scripts** Lists all registered actions, and allows starting and stopping of scripts (chapter 17). If there is no button for the action you want in another tab, you can find all actions which can be configured as a keyboard shortcut (section 4.3) here.

**Location** Allows changing the location, like in section 4.2. Custom location saving is currently not supported.

**Projection** Switch the projection method used, like subsection 4.4.4.

### 13.5.3 Remote Control API

Apart from retrieving quick object info in your browser with e.g. `http://localhost:8090/api/obj ects/info?format=json&name=Sun`, you can access a running instance of Stellarium with various programming languages. A few examples:

#### 13.5.3.1 Commandline

It is possible to send commands via command line, e.g.:

```
curl -d "x=1&y=0.3" http://localhost:8090/api/main/move
wget --post-data "id=show.ssc" http://stella:8090/api/scripts/run -O /dev/null
curl -d "id=myScript.ssc" http://localhost:8090/api/scripts/run
curl -d "id=LandscapeMgr.fogDisplayed&value=false" \
     http://localhost:8090/api/stelproperty/set
```

This allows triggering automatic show setups for museums etc. via some centralized schedulers like `cron`.

To get a complete pretty-printed list of properties and actions, use:

```
curl -G -d "propId=-2&actionId=-2" http://localhost:8090/api/main/status | \
     python -m json.tool
```

#### 13.5.3.2 Node.js

If you want to use **node.js** to build your own interface app, you may find the following example helpful.[2] It sets the view direction in one of 3 coordinate systems, depending on the argument:

```
    "j2000" : "[x,y,z]",
    "jNow"  : "[x,y,z]",
    "altAz" : "[x,y,z]"
```

---

[2]Thanks to user FogoVoar

The vector $[x, y, z]$ should be a normalized vector (unit length), derived from either J2000.0 or current equatorial coordinates $(\alpha, \delta)$, or from alt-azimuthal coordinates $(Az, alt)$ which are however always counted from south ($[1,0,0]$) towards east ($[0,1,0]$), with the azimuth $Az'$ counted from South towards East, $Az' = 180 - Az$.

$$
\begin{aligned}
x &= \cos(\delta) * \cos(\alpha) \\
y &= \cos(\delta) * \sin(\alpha) \\
z &= \sin(\delta)
\end{aligned}
\qquad\qquad
\begin{aligned}
x &= \cos(alt) * \cos(Az') \\
y &= \cos(alt) * \sin(Az') \\
z &= \sin(alt)
\end{aligned}
$$

```
const url = 'http://192.168.xxx.xxx:8090/api/main/view?j2000=[0.5,0.3,0.2]';
fetch(url, {
    method: 'POST',
    headers: {
      'Content-Type': 'application/json'
    }
  })
  .then(response => {
    response.text().then(text => console.log('Raw response:', text));
    return response.json();
  })
```

### 13.5.3.3 Python

An example for time control:

```
import requests
STELLARIUM_URL='http://192.168.1.100:8090/api/main'
def set_time(julian_day,timerate):
    url = f"{STELLARIUM_URL}/time"
    data = "time="+str(julian_day)+"&timerate="+str(timerate)
    print(f"Request URL: {url}")
    print(f"Request Data: {data}")
    try:
        response = requests.post(url, data=data)
        print(f"Response Status Code: {response.status_code}")
        print(f"Response Content: {response.text}")
        response.raise_for_status()
        if response.text.strip() == "ok":
            return {"status": "success", "message": "Time set successfully"}
        else:
            return {"status": "error", "message": response.text}
    except requests.exceptions.RequestException as e:
        print(f"Error setting time: {e}")
        return {"status": "error", "message": str(e)}
```

## 13.5.4 Developer information

If you are a developer and would like to add functionality to the Remote Control API, customize the web interface or access the API through another program, further information can be found in the plugin's developer documentation[3].

## 13.5.5 Acknowledgements

This plugin was created by Florian Schaukowitsch in the 2015 campaign of the *ESA Summer of Code in Space*[4] programme.

If you are using this plugin in your scientific publications, please cite Zotti, Schaukowitsch, and Wimmer (2017).

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## 13.6 Remote Sync Plugin

The Remote Sync plugin enables setups which connect several instances of Stellarium running on a network. This may be useful in installations where one presenter wants to allow a larger audience to follow the actions on several dim screens (e.g., when you need to avoid a projector's bright light in a public observatory). The actions performed on a "master" instance, which acts as a server, are automatically replicated on all connected clients. These clients may run on the same device the server runs, or may access the server over a network.

The plugin is still quite experimental, but is provided for testing and developing purposes. You can configure it through the standard plugin settings dialog (Figure 13.5). One Stellarium instance can either run in the server mode or connect to an existing server as a client. A custom TCP protocol is used for the connection. The port used by the server is configurable, and the clients must know the IP address or host name and the port of the server.
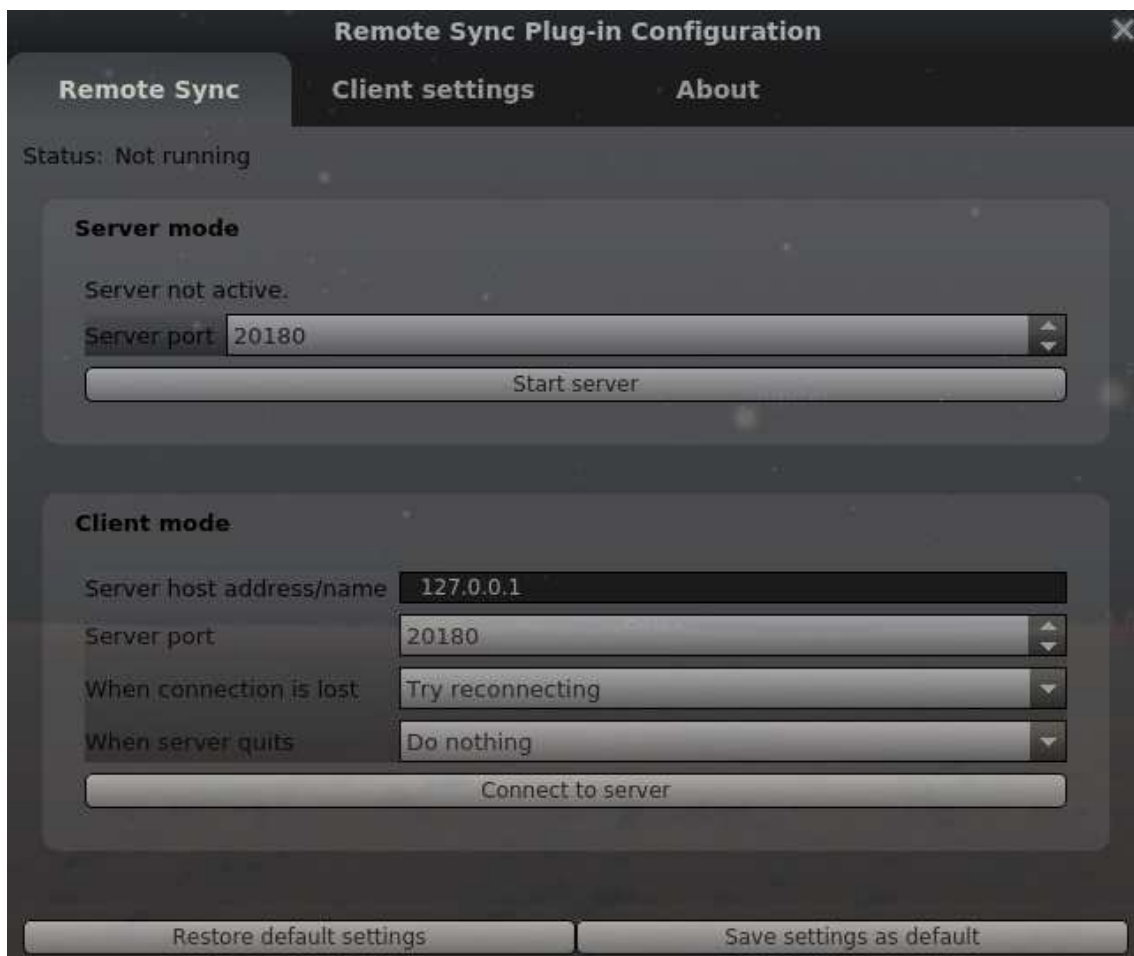


Figure 13.5: RemoteSync settings window

Alternatively, you may start the plugin through command line arguments. This is useful for automated setups or when multiple instances are running on the same computer. To start the instance as a server, use the `--syncMode=server` argument with the optional `--syncPort` parameter to specify the port to listen on. To start a client instance, use `--syncMode=client` and use `--syncHost` and `--syncPort` to specify the server to connect to.

In the settings window, you can also specify what should happen when the client loses the connection to its server, and what to do when the server quits normally. You can choose between

**Do nothing:** connection is lost and will not be re-established. Stellarium client keeps running in whatever state it was, waiting for keyboard/mouse interaction.

**Try reconnecting:** Assume Stellarium is switched off on the server but may come back online again, or assume some temporary network problem. Stellarium client just keeps running in whatever state it

was, but tries to reconnect.

**Quit:** Assume the server always runs until switched off at the end of operating hours. This is intended for pure client screens without keyboards. When the server is shut down, assume this is the end of the day, and exit Stellarium. An enclosing run script can then shutdown the client computer before power is switched off with some main switch.

By default, the following things are synchronized:

- simulation time
- viewer location
- the selected object
- view direction
- current field of view
- all StelProperty-based settings except for GUI-related properties. This includes almost all settings visible in the configuration dialogs such as projection type, sky and view options, landscape settings, line colors, etc.

Because there is currently no full time synchronization implemented, for the best results all client computers should make sure their system clocks are set as close as possible to the server computer's clock (preferably a few milliseconds difference at most). This can be done for example by using an NTP server.[5] If all your Stellarium instances run on the same device, this is of course not necessary.
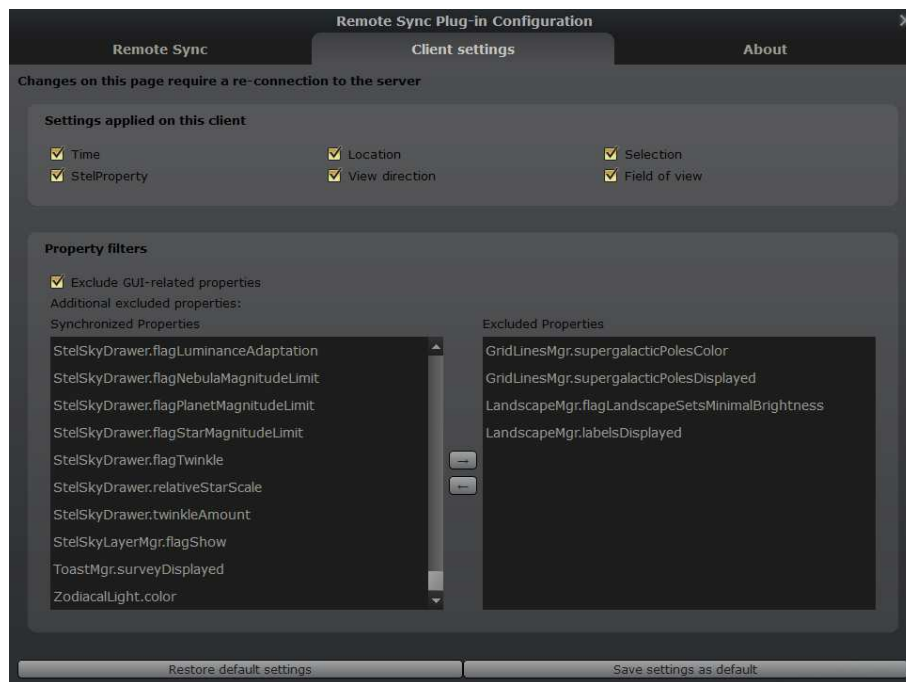


Figure 13.6: RemoteSync client settings window

It is also possible to exclude some state from being synchronized. On each client, the client configuration GUI (Figure 13.6) allows to disable specific settings from being synchronized on this client.

The lower part of this dialog allows you to fine-tune which named StelProperties (which hold parts of the internal program state) should be excluded from synchronization. The configuration dialog lists all available properties which usually have easy to understand names on the left side. Highlight one or more properties which you don't want synchronized and press the arrow button to move them to the list of excluded properties.

For historic reasons there are two kinds of Properties: Actions (Boolean switches, for which also hotkeys can be assigned) and (genuine) StelProperties. The latter have names indicating which module they belong to and may have other data types (numbers, colors, . . . ). Note that the actions frequently are just alias names of Boolean StelProperties, so in order to inhibit a certain property from being synchronized, you must find

---

[5]Instructions on how to use the public NTP server pool for the most common operating systems can be found at `https://www.pool.ntp.org/en/use.html`.

both entries.

Properties of plugins will only be visible when the respective plugin has been enabled. When a plugin has been disabled, its properties may vanish from the stored list of non-synchronized properties.

Each client can have different settings. This could allow installations with several screens where on one screen you show the constellation figures, another screen shows the distribution of deep-sky objects in the same frame, and a third screen may show a close-up view of the currently centered object. Or just show several sky cultures, or show the sky at different locations, . . . .

The names of all available StelProperties from which you might want to select a few to exclude from synchronisation can also be found with a little scripting (see chapter 17). Open the script console F12 and enter the following call:

```
core.output(core.getPropertyList());
```

Run the script and inspect the output tab. It may take a little guesswork to select the right names, but the general structure of property names like <Module>.<Property> should help you to find your way around.

### 13.6.1 Developer notes

Usually the synchronisation fails if you attempt to use different versions of Stellarium. You can override this behaviour with an entry in the respective section of config.ini:

```
[RemoteSync]
allowVersionMismatch = true
```

### 13.6.2 Finetuning

This plugin makes use of the QLoggingCategory infrastructure. By default it is very verbose and prints each transmitted property to the logfile. To reduce verbosity when it works, configure an environment variable with these entries (Note the closing semicolon!):

```
QT_LOGGING_RULES="stel.plugin.remoteSync.debug=true;
                  stel.plugin.remoteSync.client.debug=false;
                  stel.plugin.remoteSync.protocol.debug=false;"
```

The final parts may be debug|info|warning|critical = true|false. Default: true.

### Author and Acknowledgements

This plugin was created mostly by Florian Schaukowitsch in the 2015-16 campaigns of the *ESA Summer of Code in Space*[6] programme.

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[6]https://socis.esa.int/

## 13.7 OnlineQueries Plugin

Stellarium includes and provides lots of information about many kinds of objects. However, there are scientific websites which provide even more specialized information about particular objects. This plugin (Zotti, S. M. Hoffmann, et al., 2023) allows online access to several websites on a variety of special topics. To retrieve information, select the first tab and press the respective button labeled with the information source. The result is displayed in a browser view[7].

**Wikipedia** The free online encyclopedia provides information about many bright stars, the planets, moons and many asteroids, as well as many deep-sky objects. The lookup is based on the English proper name.

**AAVSO** The *International Variable Star Index*[8] of the *American Association of Variable Star Observers* (AAVSO) provides data about variable stars.

**GCVS** The *General Catalogue of Variable Stars*[9] of the Sternberg Astronomical Institute and the Institute of Astronomy of the Russian Academy of Sciences in Moscow.

In addition, you can configure up to three further websites. These must provide some public website which takes a query for a Hipparcos star number or object name.

Regardless of the current program language, the result is always presented in English or the language of the respective website.

### 13.7.1 Section [OnlineQueries] in config.ini file

You can edit the config.ini file to change settings of the OnlineQueries plugin. The only strings you should need to touch are the customN_... entries ($N \in \{1,2,3\}$). The placeholder %1 will be filled by either the Hipparcos number (if the respective customN_use_hip is true) or by the first English name used in Stellarium. The customN_use_hip should be true to use a star's Hipparcos number, or false to use the English name as key.

| ID | Type | Default |
|---|---|---|
| aavso_hip_url | string | (don't override) |
| aavso_oid_url | string | (don't override) |
| gcvs_url | string | (don't override) |
| wikipedia_url | string | (don't override) |
| custom1_url | string | |
| custom2_url | string | |
| custom3_url | string | |
| custom1_use_hip | boolean | true |
| custom2_use_hip | boolean | true |
| custom3_use_hip | boolean | true |
| disable_webview | boolean | false |

---

[7]For technical reasons, on some platforms the result is displayed in the system's default web browser. On some other platforms, e.g. Windows/WSL with Ubuntu or some ARM computers, the web view fails to work properly. On these platforms you should manually edit config.ini and set the disable_webview entry in the config file.

[8]https://www.aavso.org/vsx/

[9]http://www.sai.msu.su/gcvs/

## 13.8 Solar System Editor Plugin

Stellarium stores its data (orbital elements and other details) about solar system objects (planets, their moons, minor bodies) in two files. File `data/ssystem_major.ini` in the installation directory contains data for the planets and their moons, and should never be touched by users. File `data/ssystem_minor.ini` contains data for minor bodies, i.e., planetoids and comets. The file will be taken from the user data directory if it also exists there, which means that users can add minor planets or comets as they become observable by editing this file.

The orbits of minor bodies (minor planets and comets) are specified with *orbital elements* for *Kepler orbits* (after JOHANNES KEPLER (1572–1630) who found the true shape of the orbit of a small body around a large one being a conic section, i.e., circle, ellipse, parabola or hyperbola). These elements describe the instantaneous shape and orientation of the object's orbit around the Sun at a particular time called the *epoch*. We compute positions from these *osculating elements* of minor body orbits, but the result is only valid for a moderately short timespan around the epoch, because the major planets can exert noticeable gravitational perturbations on the objects when they come close, and so these orbital elements, which are mere snapshots in time, need to be updated on a regular basis. Stellarium does not perform numerical integration that could work out the orbital changes automatically, and so the element file needs to be modified to compute positions further away from the orbit's epoch. See Appendix D.2 for more details, and see e.g. Meeus (2007) for a discussion of a few interesting examples of orbital development. When you go out hunting for asteroids and comets, this plugin is for you.

This plugin provides access to the Minor Planet Center (MPC[10]) server where the latest Solar System information can be found. When this plugin is loaded (see section 12.1) and you open the configuration dialog, the first tab allows to import, export or reset your `ssystem_minor.ini`, and also to load extra data for minor bodies in Stellarium's `.ini` format. For example, the installation directory contains a file `ssystem_1000comets.ini` which contains data for over 1000 historical comets. Currently it is not possible to select only a few from that, so try loading this only on a reasonably fast computer, and think about deleting comets again (or resetting the file) when you don't require them.
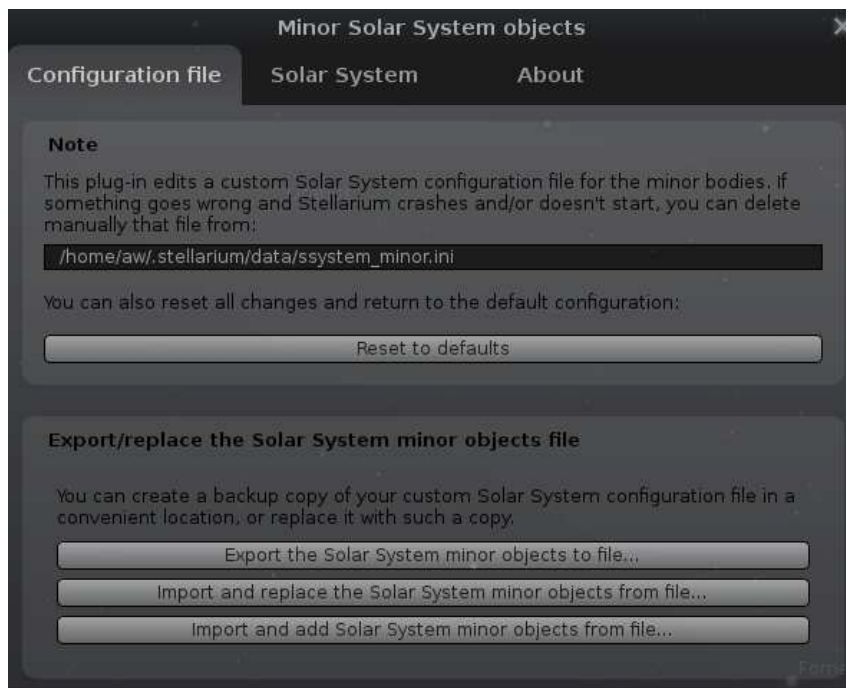


Figure 13.7: Interface of Solar System Editor plugin: Configuration file tab

The second tab lists all currently loaded minor bodies (see figure 13.8). It is recommended to remove old entries of yesteryear's comets if you don't need them any longer. Just select one or more objects and press Remove . If you have a very weak computer, you may want to reduce the number of minor bodies to

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[10]`https://www.minorplanetcenter.net`

just a handful to improve performance.
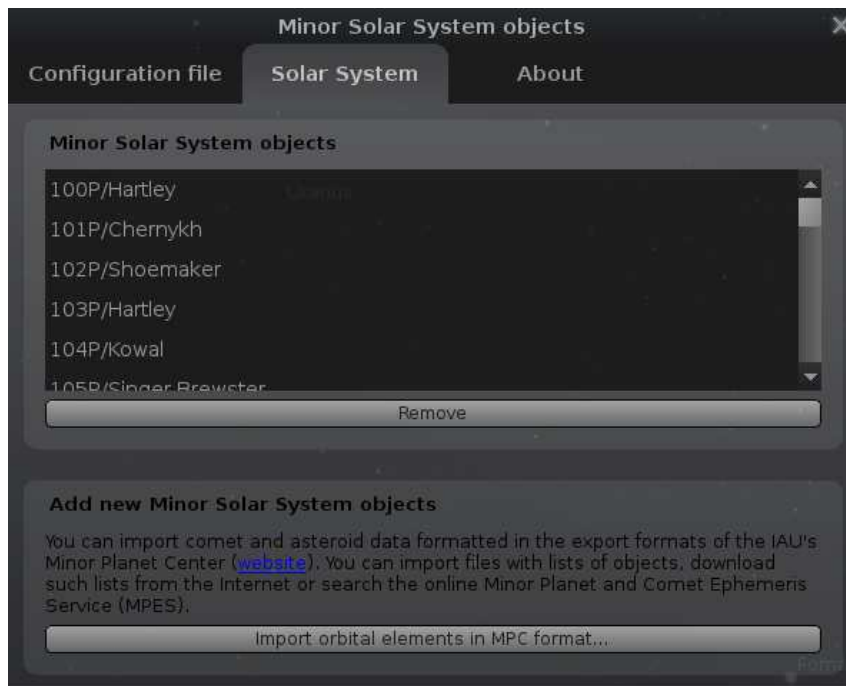


Figure 13.8: Interface of Solar System Editor plugin: Solar System tab

On this tab, you also find the option to connect to the MPC and download current orbital elements, or load a text file in the format provided by MPC (see figures 13.9 and 13.10).

Once MPC data has been downloaded, the user can select objects for updating the user's `ssystem_minor.ini`.
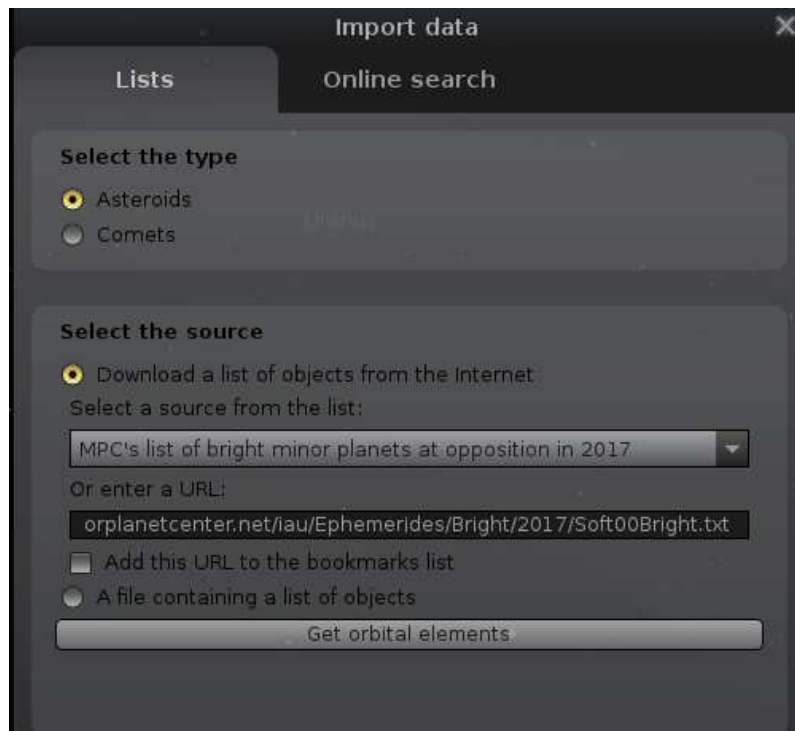
Figure 13.9: Interface of Solar System Editor plugin: Import data dialog



Figure 13.10: Interface of Solar System Editor plugin: Import data dialog — view after downloading and parsing the MPC data.

## 13.9    Nebula Textures Plugin

The Nebula Textures plugin allows users to customize deep-sky object (DSO) textures, precisely rendering them in Stellarium like default textures. Astronomy amateurs can use it to create a collection of their own astrophotography, visual-like sketches, paintings, and even more in Stellarium. It also serves as a simple client for Astrometry.net, enabling blind-solving and precise positioning of astronomical images. The plugin's full functionality includes online plate-solving and positioning of astronomical images, as well as the management and rendering of custom textures.

### 13.9.1    Online Solving and Texture Management

Instructions for integrating astrophotography images via online plate solving.

1. **Prepare an Image**: Prepare a processed rectangular bitmap file of a deep-sky object, in a format that supports both Astrometry analysis and rendering, such as PNG, JPG, TIF, or GIF. You should adjust the image background brightness to suit Stellarium by referencing the nebulae images in the Stellarium `nebulae/default` directory. Typical astrophotography images with TAN projections are fine, but avoid images with high field distortion. If the image's FOV is too large, it is recommended to manually split it into multiple sub-images beforehand. **Ensure that the image is not flipped horizontally or vertically!!!** It's recommended to use a descriptive ID or nickname as the filename. While Nova Astrometry does not strictly limit image size, keeping it below 20 MP ensures efficient plate solving.

2. **Open Image**: By default, the plugin opens the "Solve and Add" page. Click the $\boxed{\text{Open File}}$ button to select an image file or paste the file path into the "Image Filepath" text box.

3. **Enter API Key**: Paste your Astrometry API key into the corresponding text box (password mode by default). If you don't have one, click Astrometry API key to obtain it after registering or logging in. Check $\boxed{\text{☑ Remember me}}$ to store the key for future use.

4. **Upload and Solve**: Click $\boxed{\text{Online Solve}}$ to begin uploading and solving the image. Ensure system proxies are disabled to avoid errors. The solving process may take seconds to minutes, depending on the Astrometry.net server. If you need to stop the solving process, click the $\boxed{\text{Cancel}}$ button.

5. **View Solving Results**: After successful solving, the image's center and corners' J2000 equatorial coordinates (in decimal degrees) will be displayed.

6. **Optional Testing**:
   - Click $\boxed{\text{Goto Center}}$ to locate the texture's center.
   - Use $\boxed{\text{Test this texture}}$ to preview the texture. If it overlaps with default textures, you should check $\boxed{\text{Disable default textures}}$ to avoid visual conflicts. The $\boxed{\text{Test this texture}}$ button will toggle between "Test this texture" and "Stop test" to start and stop the rendering process. Remember to click $\boxed{\text{Stop Test}}$ afterward to restore the rendering of the default nebula textures!
   - When testing is active, modifying the coordinate spinboxes (including using the mouse wheel) will immediately update and redraw the texture in real-time, enabling an interactive experience for fine-tuning alignment.
   - For images solved via Astrometry.net, if manual coordinate adjustments deviate too much, $\boxed{\text{Reset}}$ will appear. Click it to reset the coordinates back to the original astrometric solution.
   - The dropdown menu is used to adjust texture brightness, with three options: **Bright**, **Normal**, and **Dark**. The default **Normal** setting is suitable for most cases.
   - You can repeatedly press the `s` key in the main view to toggle star visibility and verify whether the image is aligned accurately.

7. **Add Texture to Storage**: Click $\boxed{\text{Add the Texture to Custom Storage}}$ to permanently save the texture. The original image will be copied to Stellarium's plugin folder in the user directory. After adding a texture, you should restart Stellarium to fully integrate the texture into the module.

8. **Display Settings**: After restarting Stellarium, switch to the $\boxed{\text{Custom Textures}}$ page of the plugin to manage your custom textures. Options include $\boxed{\text{Show Custom Textures}}$ (showing/hiding textures), $\boxed{\text{Avoid Area Conflict}}$ (avoiding overlaps with default textures), and $\boxed{\text{Reload}}$ (reloading custom textures).

9. **Locate a Texture**: Double-clicking a texture item in the list will center the view on that texture.

10. **Remove a Texture**: To remove a texture, switch to the $\boxed{\text{Custom Textures}}$ page, select it in the list view and click $\boxed{\text{Remove selected item in Custom Textures}}$. The configuration file will update, and the corresponding image file in the plugin folder will be deleted. However, Stellarium may continue rendering the texture until it is restarted.

### 13.9.2 Manual Texture Addition)

Instructions for adding manual textures (e.g., sketches, paintings). The process is similar to the one above, but performing online solving is not required:

- Open the image file. Stars in non-astrophotographic images may not align precisely with the software's stars, so it is recommended to use the texture without stars (de-star it).
- Input the J2000 equatorial coordinates (in decimal degrees) for the image corners, aligning with the bitmap display.
- If needed, use an astrophotography image with a similar field of view (FOV) to obtain approximate corner coordinates via online solving first. Alternatively, enable Digitized Sky Survey layers in Stellarium (Disable constellation lines, illustrations, grids, and other unrelated elements to approximate a realistic effect), adjust the field of view and rotation to match the texture, and capture a screenshot for solving. After obtaining the solved coordinates, replace the image path with the texture path.
- Then, debug and render the texture, adjusting coordinates until the texture stars align accurately with Stellarium stars. Finally, add the texture to the custom storage.

### 13.9.3 Notes

1. All uploaded images are automatically assigned a **CC BY-NC-ND 3.0** license by Astrometry.net and are not publicly visible by default. Avoid excessive uploads to prevent server congestion or issues with your API key.
2. After adding a texture, you must restart Stellarium to fully integrate the texture into the module. The same applies when deleting a texture.
3. To back up your texture library or share it with others, copy the plugin folder from your user config directory. You can find the exact plugin storage path in the "About" section of the plugin GUI. For Windows systems, this path is usually something like:

   `%APPDATA%\Stellarium\modules\NebulaTextures`

   You can then share this folder with others, and they can place it in the same directory on their system to use the custom textures.

## 13.10  Calendars Plugin

GEORG ZOTTI

### 13.10.1  Introduction

The calendar dates in the main program behave like most other astronomical software titles:

- Dates are given in the Gregorian calendar for all dates beginning with October 15, 1582.
- All earlier dates are given in the Julian Calendar in its finalized form by AUGUSTUS. Historically, only dates beginning with March 1st, 4 A.D. coincide with historically recorded dates: the Roman priesthood messed up the 4-year count introduced by JULIUS CAESAR and counted leap years every third year. AUGUSTUS decreed to omit leap days from 12 B.C. to 4 A.D. to move the seasons to where JULIUS CAESAR had placed them.
- Given the errors in the Julian calendar, simulation in early prehistory will provide non-intuitive calendar dates for the seasons' beginnings.
- Astronomical counting of years includes a year zero and negative years. Historical calendars don't have a year zero. 1 A.D. is preceded by 1 B.C. Therefore a negative year in Stellarium may look uncommon to historians who may think Stellarium is one year off.

Since earliest times people all over the world have observed the sky and used its phenomena to structure their lives, agree on future events ("we shall meet here again and exchange goods at the third Full Moon from now"), record and measure time. Over millennia, various systematic calendars evolved. A classic and often-cited presentation of calendars from the pre-computer era is still the monumental work by Ginzel (1906; 1908; 1911). The next challenge was then to describe the systematic of these algorithmically and make them available for computer programs. Reingold and Dershowitz (2018) have presented a modern masterpiece of this kind and are our preferred source of algorithms. This plugin will evolve over the next time to bring a good sample of calendars into Stellarium.

In the configuration panel you can select which calendars you want to display in the lower right corner of the screen, and you can also directly interact with some of them.

The calendars displayed in this plugin come with their own logic. Historically, when a calendar was introduced, dates which precede its starting point (era) were of little interest to its users, therefore if a date bears negative years (or negative units of its largest component) those dates may not be useful.

Note that in some calendars the day did not begin at midnight, but for example at sunrise, sunset, or dawn. This cannot be reflected in this plugin. Dates should be correct at noon, and may be one day off dependent on these aspects.[11]

### 13.10.2  The Calendars

#### 13.10.2.1  Lunisolar European calendars

**Julian**  JULIUS CAESAR introduced this calendar, advised by the Egyptian astronomer SOSIGENES. Every 4th year is a leap year of 366 instead of 365 days, yielding a mean length of the year of 365.25 days. In contrast to the default calendar display of Stellarium, this implementation utilizes historical year counting, i.e., has no year zero. Years are marked A.D. or B.C., respectively. The omission of year zero makes negative leap years break the simple 4-year count. Now they are 1 B.C., 5 B.C., 9 B.C. etc. However, note that before 8 A.D. leap years are just counted proleptic, but the Romans did not keep the leap years commanded by JULIUS CAESAR until AUGUSTUS put things back in order. This means, displayed dates before 8 A.D. may be off by up to 3 days from historical accounts written by contemporaries.

**Gregorian**  This implementation acts like Stellarium with respect to year counting and counts signed negative and positive years, with a year zero between them. It shows dates in a *Proleptic Gregorian* calendar for dates before October 15, 1582. Given its improved rules for leap years which provide a mean length of the year of 365.2425 days, it keeps the seasons' beginnings closer to the commonly known dates, at least for many more centuries in the past than the Julian calendar commonly used by historians.

**Revised Julian Calendar**  (also named **Milanković Calendar**) In 1923, the Serbian scientist MILUTIN MILANKOVIĆ (1879–1958) proposed a calendar which should overcome the then 13-day calendar

---

[11]At the current point of implementation I cannot exclude further errors! The plugin reproduces the given sample dates, but we cannot give any guarantee about the accuracy of historical dates. If you are more familiar with any of the non-European calendars, you are invited to identify errors or at least additions to this documentation, e.g. variants to the schemes used.

gap between the Eastern European Orthodox churches who still adhered to the Julian calendar and the rest of the world which followed the Gregorian calendar. It amends the 4-year Julian leap year cycle by omitting century years except for those where division by 900 leaves a remainder of 200 or 600. Therefore the mean length of the year is 365.2422̄ days, 24 seconds less than the Gregorian and within 2 seconds of the correct length of the mean tropical year. For a synchronisation with the Gregorian, October 1-13 1923 were omitted. Between March 1600 and February 2800 the calendar dates are identical to those in the Gregorian calendar. The calendar was adopted by several but not all Eastern Orthodox churches, although date of Easter is still computed according to the Julian calendar[12].

In historical context giving dates in the Revised Julian calendar for years before the dates of religious festivals were defined in the calendar makes no sense. Its idea was to have a continuous calendar as it was in use at the concile of Nicaea in A.D.325. Therefore dates before A.D.325 are displayed like in the traditional Julian calendar.

**ISO Week**  The International Standards Organization describes weeks in the Gregorian calendar from Monday (Day 1) to Sunday (Day 7). Week 1 of each year contains the first Thursday of the year. Years may have a week 53, where the last days already belong to the next Gregorian year.

**Icelandic calendar**  Since 1700, this counts weeks in summer and winter seasons, 12 months of 30 days with a few extra days and the occasional leap week after the third month of summer. Year numbers concur with the Gregorian, but start with summer in late April.

**Roman calendar**  This presents the Roman way of writing calendar dates in the Julian calendar and provides dates *ab urbe condita* (A.U.C.).

**Olympic calendar**  Another way to write the years in the Julian calendar uses the Greek Olympiads, a 4-year cycle starting in 776 B.C.E. The Olympic games of antiquity were held in year 1 of each cycle.

#### 13.10.2.2  Near Eastern Solar calendars

Several calendars with 12 months of 30 days plus 5 (6 for leap years in some calendars) *epagomenae* days, with different *calendar eras*.

**Egyptian**  A 365 day year without leap days. Following the tradition of PTOLEMY, we use the *era of Nabonassar*.

**Armenian**  also has no leap days.

**Zoroastrian**  also has no leap days. This uses different names for each day of the month and for each *epagomenae* day. Month names are from Ginzel (1906, §69) with transliteration adapted to Reingold and Dershowitz (2018).

**Coptic**  uses Month names derived from the Egyptian calendar, but observes leap years every 4th year. Its *era martyrum* is also called *Diocletian era*.

**Ethiopic**  like the Coptic calendar, just with different year numbers, counted from the *ethiopic era of mercy*.

**Persian**  a Solar calendar adopted in 1925, but based on the earlier Jalālī calendar of the 11th century A.D. Years begin at the Vernal equinox (*nowruz*) and follow a complicated leap year cycle of 2820 years. Days begin at midnight (zone time). An identical calendar with different month names was adopted in Afghanistan in 1957.

Stellarium provides both versions: the algorithmic version and the astronomically specified one. They occasionally deviate from each other by 1 day.

**Bahá'í**  is a Solar calendar with years beginning on the day of Vernal equinox. In the algorithmic version used in the West, March 21 in the Gregorian calendar was used, but the astronomical version used since 2015 uses Tehran as reference location. Days begin at sunset. The calendar uses a 7-day week but is else based on cycles of the number 19: 19 named months of 19 named days plus 4-5 additional days after month 18. In addition, years are structured in named 19-years (*Vāḥid*, "unity") and numbered $19^2$ = 361-years (*Kull-i-shay*) cycles.

#### 13.10.2.3  Near Eastern calendars

Several more calendars have been worked out in algorithmic forms:

**Islamic**  is a strict Lunar calendar without observance of seasons. Days begin at sunset, but we cannot currently show this. The date should be correct at Noon. The week begins on Sunday. Note that this algorithmic solution may deviate from the dates given by religious authorities on basis of observation.

**Hebrew**  is a Lunisolar calendar with strict Lunar months, but adherence to the seasons. It has 12 or 13 months, and 353-355 or 383-385 days per year. The algorithmic form was introduced in the mid-4th century A.D.

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[12]More details can be found on `https://en.wikipedia.org/wiki/Revised_Julian_calendar`

### 13.10.2.4 Asian calendars

**Old Hindu Solar**  used before about 1100 A.D. The implementation follows the (First) *Ārya Siddhānta* of
Āryabhaṭa (499 C.E.), as amended by Lalla (circa 720–790 C.E.). The year is split into 12 months
(*saura*) of equal length. Days begin with sunrise, simplified as 6 am. Years are counted as *elapsed
years* (starting at 0) from the *Kali Yuga* (Iron Age) epoch (Feb. 18., 3102 B.C. jul.).

**Old Hindu Lunisolar**  used before about 1100 A.D. This implementation shows the south-Indian method
with months starting at New Moon (*amānta* scheme). (In the north, the *pūrṇimānta* scheme describes
months starting with Full Moon. There are also some local differences.) It also shows the K.Y. day
count (*ahargaṇa*), i.e., days elapsed since the K.Y. epoch.

**New Hindu Solar and Lunisolar**  This is the Hindu calendar from the *Sūrya-Siddhānta* (ca. 1000 A.D.). It
is based on epicyclical motions of the Sun and Moon around the Earth. While still an approximation,
this provides more accurate models of the motions at cost of much more complicated computation.
The Solar month begins when the Sun enters a sign on the *Sidereal Zodiac*. Months are therefore 29
to 32 days long. Solar days begin at sunrise, and the zodiacal position of the sun at sunrise in Ujjain,
India, decides on the date. Years given for the Solar calendar are counted from the *Saka* era (A.D. 78).
The lunar month name is determined by the (first) zodiacal sign entered by the sun during the month.
When no sign is entered, the month is "leap" (*adhika*) and named after the following month. When a
Solar month passes without a New Moon, a lunar month can also be skipped (*kshaya*). The Lunisolar
year has 12 or 13 months, of which up to 2 can be leap and one skipped!

A lunar day varies in length from 21.5 to 26.2 hours, and therefore may occasionally have to be
repeated (here the second day is the leap day or *adhika*), or skipped.

Years are given in the *Vikrama era* which began in 58 B.C. Both months schemes share the same 12
names.

Also this calendar is shown in the *amānta* scheme, i.e., months start at New Moon. There are again
several local variants, and of course a longitude difference to the reference location may also lead to
deviations.

In addition to the New Hindu Lunisolar date, the Hindu *panchang* is shown, a 5-part description of
the day consisting of

**Tithi**  (lunar day)

**Weekday**

**Nakṣatra**  the part of the ecliptic the Moon is in at time of sunrise (in Ujjain).

**Yoga**  a cycle of 27 names resulting from the "addition" of Solar and Lunar longitudes.[13]

**Karaṇa**  a count of 60 lunar half-days resulting in 11 names. The *karaṇa* at time of sunrise (in Ujjain)
governs the *karaṇa* for the day [14].

**Hindu Astronomical Solar and Lunisolar**  These are similar to the New Hindu calendars, but with even
more accurate positional computations from the *Sūrya-Siddhānta* for Solar and Lunar positions.

**Tibetan calendar**  is actually only one of several calendars used in Tibet. We show the date in the official
*Phuglugs* (or *Phug-pa*, *Phukluk*) version of the *Kālacakra* calendar, derived from the *Kālacakra
Tantra* which was translated from Sanskrit to Tibetan in the 11th century, and has been sanctioned by
the Dalai Lama. It is similar to the Hindu Lunisolar calendar, but has also regional variants where
astronomical events are computed in local time. In Tibet, the actual calendar is issued only annually
(after empirical corrections) by the Tibetan School for Astro and Medicine and may diverge from the
calendar shown here.

Months are 29 or 30 days long and numbered 1 to 12. Leap months precede their "regular" counterparts
but else have the same name.

Years are counted from the date of ascension of the first Yarlung king, NYATRI TSENPO, in 128 B.C.
(We write "A.T." for Anno Tibetorum.) However, it is more common to designate years in a cycle of
60 years, with 5 elements which label two consecutive years which are further named "male" and
"female", and a parallel cycle of 12 animal totems. This cycle has been synchronized with the similar
Chinese 60-years cycle.

**Balinese Pawukon**  is a 10-part sequence of day names with cycle lengths of 2 to 10, which can also be
written as numbers or symbols. Some numbers repeat in simple cycles, while others follow more
complicated rules. A full cycle takes 210 days. Due to space reasons this needs two lines on the

---

[13]For technical reasons this is currently shown for midnight UTC. It is currently unclear if *yoga* should be given for
the time of sunrise or for the current moment.

[14]Again, this is unconfirmed. If you know better, please tell us!

display. Formatting may improve in later versions.

#### 13.10.2.5 Chinese calendars

The Chinese calendar (and related Japanese, Korean and Vietnamese) is a Lunisolar calendar based on astronomical events. Days begin at midnight. Lunar months begin on the day of New Moon. The position of the Sun along the Zodiac is given by Major (*zhōngqì*) and Minor (*jiéqì*) Solar Terms.

**Chinese**  The version here is the 1645 version. Earlier dates may be wrong. The calendar's location for astronomical computations is Beijing.

**Japanese**  The same principles of the Chinese calendar have been followed since 1844, but with Tokyo as reference location. The years given are in the *kigen* count (years from 660 BCE).

**Korean**  Korea adopted the Gregorian calendar in 1896, but the older Chinese-based calendar is still used for traditional purposes. The reference location for computing Solar longitudes and lunar phases is Seoul City Hall. Years are counted in the Danki system starting in 2333 BCE.

**Vietnamese**  From 1813-1967 the Chinese calendar was used directly. The currently used traditional calendar parallels the Chinese, but with Saigon as reference location. Years are not counted, only named. It also seems that Solar terms are not used.

#### 13.10.2.6 Mesoamerican calendars

**Maya Long Count**  is a 5-part sequence of numbers, conventionally written with dot separators. Just like most modern people write numbers in the decimal system (base 10), and the Mesopotamians developed a scheme with base 60 still used today for angular and temporal minutes and seconds, the Maya used base 20 as their unit. However, this count uses a mixed-base system. The lowest (rightmost) number (*kin*) runs from 0 to 19, the second-lowest (*uinal*) from 0 to 17, the others from 0 to 19 again. It is assumed these lowest places of $18 \times 20 = 360$ days have been used to approximate the solar year, so that the third number from the right (*tun*) increases about once per year. The higher places are called *katun* and *baktun*. Most scientists agree that the zero point of the long count corresponds to Monday, September 6, 3114 B.C. (Julian), but in many sources dates in the proleptic Gregorian calendar are listed, where this date is given as August 11, -3113. This plugin finally allows the use of both systems, and of Long Count dates directly.

In December of 2012 some people were afraid that the switchover from *baktun* 12 to 13 (something which occurs about every 400 years) would cause Armageddon, just as other people prefer to be afraid of turns of centuries or millennia of the Christian year count.

**Maya Haab**  is a calendar of 18 "months" of 20 days each (counted 1 to 20), plus 5 days (*Uayeb*) at the end, providing "years" of 365 days. Years are not counted, but you can use buttons in the calendar interface to move forth and back to the previous or next, respectively, day with the same Haab name.

**Maya Tzolkin**  is described as ritual calendar consisting of two cycles with 13 day numbers (1 to 13) and 20 names. Each day both counters are advanced. Date names repeat after 260 days. Usually Haab and Tzolkin calendars were both used to define a unique date which repeats only after a *calendar round* of 52 Haab years, corresponding to 73 Tzolkin cycles.

**Aztec Xihuitl**  is similar to the Maya Haab, consisting of 18 "months" of 20 days, plus 5 *nemontemi* (worthless days). Days are counted from 1 to 20. The Aztecs may have used intercalation, but details have been lost. The correlation in use here is based on the recorded Aztec date of the fall of their empire to Hernán Cortés in 1521 and should provide correct dates in the early 16th century.

**Aztec Tonalpohualli**  is similar in structure to the Mayan Tzolkin. Also an Aztec date is usually given by both systems.

#### 13.10.2.7 French Revolution calendar

The French Revolution of 1789 brought also a calendar reform. After a few years with different year count only, a new calendar was introduced effective on November 24, 1793 (4. Frimaire, II). This was based on an astronomical determination of the autumnal equinox at Paris, which marked the start of the years.

The calendar has 12 months of $3 \times 10$ days (*décades*), plus 5 (in leap years: 6) extra days at the end of the year. These 10-day "weeks" made it pretty unpopular. The months were given names that alluded to the climate or vegetation.

In 1795, an arithmetic version was proposed which got rid of the difficult astronomical computation with a leap year scheme similar to the Gregorian. However, this version of the calendar never came into use. Stellarium also shows this calendar, which may be off from the original by 1 day.

With the end of Gregorian year 1805, the calendar was abolished, but re-introduced for a few days in May 1871.

### 13.10.3   Scripting

Advanced users who have the book at hand may find it useful that almost all functions from Reingold and Dershowitz (2018) are available as scripting functions (as far as the implementation of the described calendars has come). Whenever a location is needed, the current location is used, or you can use a location from the location database by giving its name like "Vienna, Austria" or "Madrid, Western Europe". This should also work for user-specified locations. Take care to use a "real" name for the timezone, or specify an UTC based zone exactly like "UTC+03:15", else timezone will be read as zero. Full documentation for this can be found at `https://stellarium.org/doc/head/group__calendars.html`.

### 13.10.4   Configuration Options

The configuration dialog allows the selection of the calendars which are of interest to you, and also provides direct interaction with the calendars. The Mayan and Aztec calendars allow moving to the previous or next date of that respective name.

#### Section ⌈Calendars⌉ in config.ini file

Apart from changing settings using the plugin configuration dialog, you can also edit the `config.ini` file to change settings for the Calendars plugin – just make it carefully!

| ID | Type | Default | | ID | Type | Default |
|----|------|---------|---|----|------|---------|
| show | bool | true | | | | |
| flag_text_color_override | bool | false | | text_color | R,G,B | 0.5,0.5,0.7 |
| show_julian | bool | true | | show_gregorian | bool | true |
| show_revised_julian | bool | false | | show_iso | bool | true |
| show_icelandic | bool | false | | | | |
| show_roman | bool | false | | show_olympic | bool | false |
| show_egyptian | bool | false | | | | |
| show_armenian | bool | false | | show_zoroastrian | bool | false |
| show_coptic | bool | false | | show_ethiopic | bool | false |
| show_persian_astronomical | bool | false | | show_persian_arithmetic | bool | false |
| show_bahai_astronomical | bool | false | | show_bahai_arithmetic | bool | false |
| show_islamic | bool | true | | show_hebrew | bool | true |
| show_old_hindu_solar | bool | false | | show_old_hindu_lunar | bool | false |
| show_new_hindu_solar | bool | true | | show_new_hindu_lunar | bool | true |
| show_astro_hindu_solar | bool | false | | show_astro_hindu_lunar | bool | false |
| show_tibetan | bool | false | | show_balinese_pawukon | bool | false |
| show_chinese | bool | false | | show_japanese | bool | false |
| show_korean | bool | false | | show_vietnamese | bool | false |
| show_maya_long_count | bool | true | | | | |
| show_maya_haab | bool | false | | show_maya_tzolkin | bool | false |
| show_aztec_tonalpohualli | bool | false | | show_aztec_xihuitl | bool | false |
| show_french_astronomical | bool | false | | show_french_arithmetic | bool | false |

### 13.10.5   Further development

The plugin is still in development. More calendars will be added in later versions, and formatting and setting options may be improved. Members of non-European cultures who are actually using the output and can judge its correctness are invited to report errors or suggest better formatting for their respective calendars.

For example, our source book (Reingold and Dershowitz, 2018) describes one solution for the "New Hindu" calendars, but notes several variants, which are in fact also location dependent. We cannot show every variant here, but hope to have the version described in the book correct. If you know what you are doing: we are accepting improvements and extensions in form of working code plus documentation where this variant is used. Not just a few example dates, but an algorithmic solution.

### 13.10.6   Acknowledgments

If you are using this plugin in scientific publications, please cite Zotti, S. Hoffmann, et al. (2021).

# 14. Object Catalog Plugins

Several plugins provide users with some more object classes.

## 14.1 Bright Novae Plugin
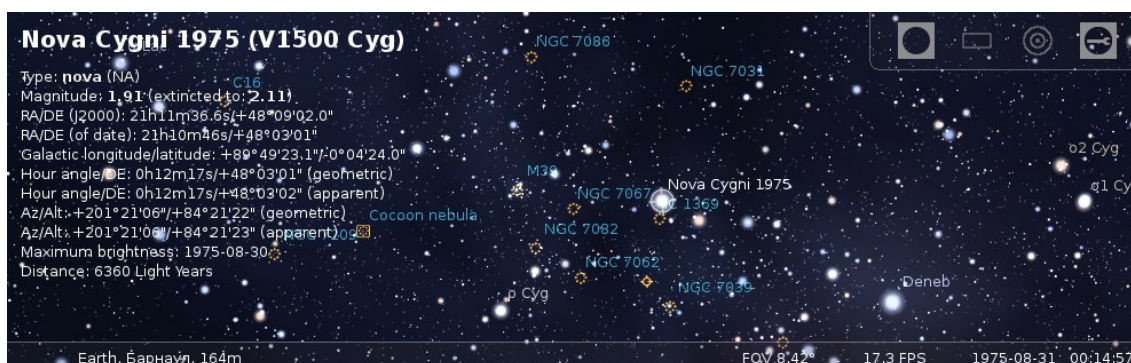


Figure 14.1: Nova Cygni 1975 (also known as **V1500 Cyg**)

The Bright Novae plugin provides visualization of some bright novae in the Milky Way galaxy. If enabled (see section 12.1), bright novae from the past will be presented in the sky at the correct times. For example, set date and time to 30 August 1975, look at the constellation *Cygnus* to see *Nova Cygni 1975*[1] (Fig. 14.1).

### 14.1.1 Section $\lceil$Novae$\rceil$ in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Bright Novae plugin – just make it carefully!

| ID | Type | Description |
|----|------|-------------|
| last_update | string | Date and time of last update |
| update_frequency_days | int | Frequency of updates, in days |
| updates_enable | bool | Enable updates of bright novae catalog from Internet |
| url | string | URL of bright novae catalog |

### 14.1.2 Format of bright novae catalog

To add a new nova, open a new line after line 5 and paste the following, note commas and brackets, they are important:

---

[1] https://en.wikipedia.org/wiki/V1500_Cygni

```
"Nova designation":
{
    "name": "name of nova",
    "type": "type of nova",
    "maxMagnitude": value of maximal visual magnitude,
    "minMagnitude": value of minimal visual magnitude,
    "peakJD": JD for maximal visual magnitude,
    "m2": Time to decline by 2mag from maximum (in days),
    "m3": Time to decline by 3mag from maximum (in days),
    "m6": Time to decline by 6mag from maximum (in days),
    "m9": Time to decline by 9mag from maximum (in days),
    "distance": value of distance between nova and
                Earth (in thousands of Light Years),
    "RA": "Right ascension (J2000)",
    "Dec": "Declination (J2000)"
},
```

For example, the record for **Nova Cygni 1975** (**V1500 Cyg**) looks like:

```
"V1500 Cyg":
{
    "name": "Nova Cygni 1975",
    "type": "NA",
    "maxMagnitude": 1.69,
    "minMagnitude": 21,
    "peakJD": 2442655,
    "m2": 2,
    "m3": 4,
    "m6": 32,
    "m9": 263
    "distance": 6.36,
    "RA": "21h11m36.6s",
    "Dec": "48d09m02s"
},
```

### 14.1.3  Light curves

This plugin uses a very simple model for calculation of light curves for novae stars. This model is based on time for decay by *N* magnitudes from the maximum value, where *N* is 2, 3, 6 and 9. If a nova has no values for decay of magnitude then this plugin will use generalized values for it.

## 14.2   Historical Supernovae Plugin



Figure 14.2: Supernova 1604 (also known as **Kepler's Supernova**, **Kepler's Nova** or **Kepler's Star**)

Similar to the Historical Novae plugin (section 14.1), the Historical Supernovae plugin provides visualization of bright historical supernovae (Fig. 14.2) from the table below. If enabled (see section 12.1), bright supernovae from the past will be presented in the sky at the correct times. For example, set date and time to 29 April 1006, and look at the constellation *Lupus* to see *SN 1006A*.

### 14.2.1   List of supernovae in default catalog

| Supernova | Date of max. brightness | Max. apparent mag. | Type | Name |
|-----------|-------------------------|--------------------|------|------|
| SN 185A[2] | 7 December | -6.0 | Ia | |
| SN 386A | 24 April | 1.5 | II | |
| SN 1006A[3] | 29 April | -7.5 | I | |
| SN 1054A[4] | 3 July | -6.0 | II | |
| SN 1181A[5] | 4 August | -2.0 | II | |
| SN 1572A[6] | 5 November | -4.0 | I | Tycho's Supernova |
| SN 1604A[7] | 8 October | -2.0 | I | Kepler's Supernova |
| SN 1680A[8] | 15 August | 6.0 | IIb | Cassiopeia A |

---

[2] https://en.wikipedia.org/wiki/SN_185
[3] https://en.wikipedia.org/wiki/SN_1006
[4] https://en.wikipedia.org/wiki/SN_1054
[5] https://en.wikipedia.org/wiki/SN_1181
[6] https://en.wikipedia.org/wiki/SN_1572
[7] https://en.wikipedia.org/wiki/SN_1604
[8] https://en.wikipedia.org/wiki/Cassiopeia_A

| SN 1885A[9] | 17 August | 5.8 | IPec | S Andromedae |
|---|---|---|---|---|
| SN 1895B | 5 July | 8.0 | I | |
| SN 1919A | 14 March | 11.0 | I | |
| SN 1920A | 17 December | 11.7 | II | |
| SN 1921C | 11 December | 11.0 | I | |
| SN 1937C | 21 August | 8.5 | Ia | |
| SN 1937D | 15 September | 11.87 | Ia | |
| SN 1960F | 21 April | 11.6 | Ia | |
| SN 1960R | 19 December | 12.0 | I | |
| SN 1961H | 8 May | 11.8 | Ia | |
| SN 1962M | 26 November | 11.5 | II | |
| SN 1965I | 19 Juni | 11.8 | Ia | |
| SN 1966J | 2 December | 11.3 | I | |
| SN 1968L | 12 July | 11.9 | IIP | |
| SN 1970G | 30 July | 11.4 | IIL | |
| SN 1971I | 29 May | 11.9 | Ia | |
| SN 1972E[10] | 8 May | 8.4 | Ia | |
| SN 1974G | 27 April | 11.8 | Ia | |
| SN 1979C | 15 April | 11.6 | IIL | |
| SN 1980K | 31 October | 11.6 | IIL | |
| SN 1981B | 9 March | 12.0 | Ia | |
| SN 1983N | 17 July | 11.4 | Ib | |
| SN 1986G | 12 May | 11.44 | Ia Pec | |
| SN 1987A[11] | 24 February | 2.9 | IIPec | |
| SN 1989B | 6 February | 11.9 | Ia | |
| SN 1991T | 26 April | 11.6 | IaPec | |
| SN 1993J[12] | 30 March | 10.8 | IIb | |
| SN 1994ae | 12 January | 12.0 | Ia | |
| SN 1994D | 31 March | 11.8 | Ia | |
| SN 1998bu | 21 May | 11.9 | Ia | |
| SN 2004dj | 31 July | 11.3 | IIP | |
| SN 2004et | 2 October | 11.57 | II | |
| SN 2011fe[13] | 13 September | 10.06 | Ia | |
| SN 2012cg | 6 Juni | 11.954 | Ia | |
| SN 2012fr | 16 November | 11.95 | Ia | |
| SN 2013aa | 13 February | 11.9 | Ia | |
| SN 2014j | 30 January | 10.5 | Ia | |
| SN 2017cbv | 22 March | 11.5 | Ia | |

### 14.2.2 Light curves

In this plugin a simple model of light curves for different supernovae has been implemented (Figure 14.3). While Type I supernovae show a peak and slow but steady decay, Type II supernovae show a longer "plateau" in the decay curve.

In both images for light curves the maximum brightness is marked as day 0.

---

[9] https://en.wikipedia.org/wiki/S_Andromedae

[10] https://en.wikipedia.org/wiki/SN1972e

[11] https://en.wikipedia.org/wiki/SN_1987A

[12] https://en.wikipedia.org/wiki/SN_1993J

[13] https://en.wikipedia.org/wiki/SN_2011fe
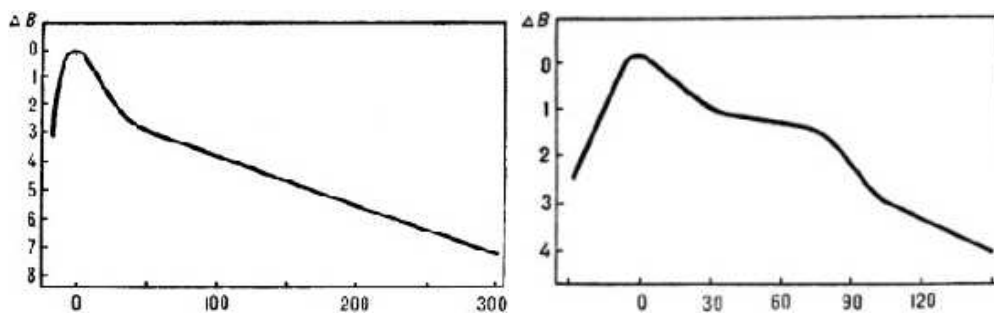
Figure 14.3: Light Curves of Supernovae Types I (left) and II (right)

### 14.2.3 Section [Supernovae] in config.ini file

You can edit config.ini file by yourself for changes of the settings for the Historical Supernovae plugin – just make it carefully!

| ID | Type | Description |
|---|---|---|
| last_update | string | Date and time of last update |
| update_frequency_days | int | Frequency of updates, in days |
| updates_enable | bool | Enable updates of bright novae catalog from Internet |
| url | string | URL of bright novae catalog |

### 14.2.4 Format of historical supernovae catalog

To add a new nova, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"Supernova designation":
{
    "type": "type of supernova",
    "maxMagnitude": value of maximal visual magnitude,
    "peakJD": JD for maximal visual magnitude,
    "alpha": "Right ascension (J2000)",
    "delta": "Declination (J2000)",
    "distance": value of distance between supernova and
                Earth (in thousands of Light Years),
    "note": "notes for supernova"
},
```

For example, the record for **SN 1604A** (**Kepler's Supernova**) looks like:

```
"1604A":
{
    "type": "I",
    "maxMagnitude": -2,
    "peakJD": 2307190,
    "alpha": "17h30m36.00s",
    "delta": "-21d29m00.0s",
    "distance": 14,
    "note": "Kepler's Supernova"
},
```

## 14.3    Exoplanets Plugin



Figure 14.4: Planetary system $\tau$ Ceti

This plugin plots the position of stars with *exoplanets*. Exoplanets data is derived from "The Extrasolar Planets Encyclopaedia"[14]. List of potential habitable exoplanets and data about them were taken from "The Habitable Exoplanets Catalog"[15] by the Planetary Habitability Laboratory[16]. If enabled (see section 12.1), just click on the Exoplanet button [🪐] on the bottom toolbar to display markers for the stars with known exoplanets. You can then either click on such a marked star or find the stars with exoplanets by their designation (e.g., *24 Sex*) in the [F3] dialog (see 4.5).

A large number of exoplanets was discovered by the *Kepler* space observatory mission (2009–18) which in its primary mission observed a small field in the Cyg/Lib/Dra area. Accordingly you will find a huge concentration of exoplanets there. This should give us a hint about how many more must be out there. Its extended mission added many more exoplanet systems along the ecliptic.

The second tab in the plugin's dialog shows a scatter plot relating two selectable properties. In some cases a logarithmic axis is more useful, but if the original values can be negative only the positive data are shown in log plots. Additional entry fields allow filtering the data range.

### 14.3.1    Potential habitable exoplanets

This plugin can display potential habitable exoplanets (orange marker) and some information about those planets.

**Planetary Class**  Planet classification from host star spectral type (F, G, K, M; see section 19.2.4), habitable zone (hot, warm, cold) and size (miniterran, subterran, terran, superterran, jovian, neptunian) (Earth = G-Warm Terran).

**Equilibrium Temperature**  The planetary equilibrium temperature[17] is a theoretical temperature (in °C) that the planet would be at when considered simply as if it were a black body being heated only by its parent star (assuming a 0.3 bond albedo). As example the planetary equilibrium temperature of Earth is -18.15°C (255 K).

**Earth Similarity Index (ESI)**  Similarity to Earth[18] on a scale from 0 to 1, with 1 being the most Earth-like. ESI depends on the planet's radius, density, escape velocity, and surface temperature.

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[14]http://exoplanet.eu/

[15]https://phl.upr.edu/projects/habitable-exoplanets-catalog

[16]https://phl.upr.edu/home

[17]https://en.wikipedia.org/wiki/Planetary_equilibrium_temperature

[18]https://phl.upr.edu/projects/earth-similarity-index-esi

## 14.3.2 Proper names

In December 2015[19] and in December 2019[20], the International Astronomical Union (IAU) has officially approved names for several exoplanets after a public vote.

**Veritate** * (14 And) – From the latin Veritas, truth. The ablative form means *where there is truth*[21].

**Spe** * (14 And b) – From the latin Spes, hope. The ablative form means *where there is hope*.

**Musica** (18 Del) – Musica is Latin for *music*.

**Arion** (18 Del b) – Arion was a genius of poetry and music in ancient Greece. According to legend, his life was saved at sea by dolphins after attracting their attention by the playing of his kithara.

**Fafnir** (42 Dra) – Fafnir was a Norse mythological dwarf who turned into a dragon.

**Orbitar** (42 Dra b) – Orbitar is a contrived word paying homage to the space launch and orbital operations of NASA.

**Chalawan** (47 UMa) – Chalawan is a mythological crocodile king from a Thai folktale.

**Taphao Thong** (47 UMa b) – Taphao Thong is one of two sisters associated with the Thai folk tale of Chalawan.

**Taphao Kaew** (47 UMa c) – Taphao Kae is one of two sisters associated with the Thai folk tale of Chalawan.

**Helvetios** (51 Peg) – Helvetios is Celtic for the *Helvetian* and refers to the Celtic tribe that lived in Switzerland during antiquity.

**Dimidium** (51 Peg b) – Dimidium is Latin for *half*, referring to the planet's mass of at least half the mass of Jupiter.

**Copernicus** (55 Cnc) – Nicolaus Copernicus or Mikolaj Kopernik (1473-1543) was a Polish astronomer who proposed the heliocentric model of the solar system in his book "De revolutionibus orbium coelestium".

**Galileo** (55 Cnc b) – Galileo Galilei (1564-1642) was an Italian astronomer and physicist often called the *father of observational astronomy* and the *father of modern physics*. Using a telescope, he discovered the four largest satellites of Jupiter, and the reported the first telescopic observations of the phases of Venus, among other discoveries.

**Brahe** (55 Cnc c) – Tycho Brahe (1546-1601) was a Danish astronomer and nobleman who recorded accurate astronomical observations of the stars and planets. These observations were critical to Kepler's formulation of his three laws of planetary motion.

**Lipperhey** * (55 Cnc d) – Hans Lipperhey (1570-1619) was a German-Dutch lens grinder and spectacle maker who is often attributed with the invention of the refracting telescope in 1608[22].

**Janssen** (55 Cnc e) – Zacharias Janssen (1580s-1630s) was a Dutch spectacle maker who is often attributed with invention of the microscope, and more controversially with the invention of the telescope.

**Harriot** (55 Cnc f) – Thomas Harriot (ca. 1560-1621) was an English astronomer, mathematician, ethnographer, and translator, who is attributed with the first drawing of the Moon through telescopic observations.

**Amateru** * ($\varepsilon$ Tau b) – *Amateru* is a common Japanese appellation for shrines when they enshrine Amaterasu, the Shinto goddess of the Sun, born from the left eye of the god Izanagi[23].

**Hypatia** ($\iota$ Dra b) – Hypatia was a famous Greek astronomer, mathematician, and philosopher. She was head of the Neo-Platonic school at Alexandria in the early $5^{th}$ century, until murdered by a Christian mob in 415.

**Ran** * ($\varepsilon$ Eri) – Ran is the Norse goddess of the sea, who stirs up the waves and captures sailors with her net.

**AEgir** * ($\varepsilon$ Eri b) – Ægir is Ran's husband, the personified god of the ocean. *Ægir* and *Ran* both represent the *Jotuns* who reign in the outer Universe; together they had nine daughters[24].

**Tadmor** * ($\gamma$ Cep b) – Ancient Semitic name and modern Arabic name for the city of Palmyra, a UNESCO World Heritage Site.

**Dagon** ($\alpha$ PsA b) – Dagon was a Semitic deity, often represented as half-man, half-fish.

**Tonatiuh** (HD 104985) – Tonatiuh was the Aztec god of the Sun.

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[19] https://www.iau.org/news/pressreleases/detail/iau1514/

[20] https://www.iau.org/news/pressreleases/detail/iau1912/

[21] The original name proposed, Veritas, is that of an asteroid important for the study of the solar system.

[22] The original spelling of Lippershey was corrected to Lipperhey on 15.01.2016. The commonly seen spelling Lippershey (with an s) results in fact from a typographical error dating back from 1831, thus should be avoided.

[23] The name originally proposed, Amaterasu, is already used for an asteroid.

[24] Note the typographical difference between Ægir and Aegir, the Norwegian transliteration. The same name, with the spelling Aegir, has been attributed to one of Saturn's satellites, discovered in 2004.

**Meztli**  (HD 104985 b) – Meztli was the Aztec goddess of the Moon.

**Ogma**  * (HD 149026) – Ogma was a deity of eloquence, writing, and great physical strength in the Celtic mythologies of Ireland and Scotland, and may be related to the Gallo-Roman deity *Ogmios*[25].

**Smertrios**  (HD 149026 b) – Smertrios was a Gallic deity of war.

**Intercrus**  (HD 81688) – Intercrus means *between the legs* in Latin style, referring to the star's position in the constellation Ursa Major.

**Arkas**  (HD 81688 b) – Arkas was the son of Callisto (Ursa Major) in Greek mythology.

**Cervantes**  ($\mu$ Ara) – Miguel de Cervantes Saavedra (1547-1616) was a famous Spanish writer and author of "El Ingenioso Hidalgo Don Quixote de la Mancha".

**Quijote**  ($\mu$ Ara b) – Lead fictional character from Cervantes's "El Ingenioso Hidalgo Don Quixote de la Mancha".

**Dulcinea**  ($\mu$ Ara c) — Fictional character and love interest of Don Quijote (or Quixote) in Cervantes's "El Ingenioso Hidalgo Don Quixote de la Mancha".

**Rocinante**  ($\mu$ Ara d) – Fictional horse of Don Quijote in Cervantes's "El Ingenioso Hidalgo Don Quixote de la Mancha".

**Sancho**  ($\mu$ Ara e) – Fictional squire of Don Quijote in Cervantes's "El Ingenioso Hidalgo Don Quixote de la Mancha".

**Thestias**  * ($\beta$ Gem b) – Thestias is the patronym of Leda and her sister Althaea, the daughters of Thestius. Leda was a Greek queen, mother of Pollux and of his twin Castor, and of Helen and Clytemnestra[26].

**Lich**  (PSR B1257+12) – Lich is a fictional undead creature known for controlling other undead creatures with magic.

**Draugr**  (PSR B1257+12 b) – Draugr refers to undead creatures in Norse mythology.

**Poltergeist**  (PSR B1257+12 c) – Poltergeist is a name for supernatural beings that create physical disturbances, from German for noisy ghost.

**Phobetor**  (PSR B1257+12 d) – Phobetor is a Greek mythological deity of nightmares, the son of Nyx, the primordial deity of night.

**Titawin**  ($\upsilon$ And) – Titawin (also known as Medina of Tetouan) is a settlement in northern Morocco and UNESCO World Heritage Site. Historically it was an important point of contact between two civilizations (Spanish and Arab) and two continents (Europe and Africa) after the $8^{th}$ century.

**Saffar**  ($\upsilon$ And b) – Saffar is named for Abu al-Qasim Ahmed Ibn-Abd Allah Ibn-Omar al Ghafiqi Ibn-al-Saffar, who taught arithmetic, geometry, and astronomy in $11^{th}$ century Cordova in Andalusia (modern Spain), and wrote an influential treatise on the uses of the astrolabe.

**Samh**  ($\upsilon$ And c) – Samh is named for Abu al-Qasim 'Asbagh ibn Muhammad ibn al-Samh al-Mahri (or Ibn al-Samh), a noted $11^{th}$ century astronomer and mathematician in the school of al Majriti in Cordova (Andalusia, now modern Spain).

**Majriti**  ($\upsilon$ And d) – Majriti is named for Abu al-Qasim al-Qurtubi al-Majriti, a notable mathematician, astronomer, scholar, and teacher in $10^{th}$ century and early $11^{th}$ century Andalusia (modern Spain).

**Libertas**  * ($\xi$ Aql) – Libertas is Latin for liberty. Liberty refers to social and political freedoms, and a reminder that there are people deprived of liberty in the world even today. The constellation Aquila represents an eagle – a popular symbol of liberty.

**Fortitudo**  * ($\xi$ Aql b) – Fortitudo is Latin for fortitude. Fortitude means emotional and mental strength in the face of adversity, as embodied by the eagle (represented by the constellation Aquila).

**Illyrian**  (HD 82886) – Historians largely believe that the Albanians are descendants of the Illyrians, a term Albanians proudly call themselves.

**Arber**  (HD 82886 b) – Arber is the term for the inhabitants of Albania during the middle ages.

**Hoggar**  (HD 28678) – Hoggar is the name of the main mountain range in the Sahara Desert in southern Algeria.

**Tassili**  (HD 28678 b) – Tassili is a UNESCO World Heritage Site situated in the Sahara Desert and is renowned for its prehistoric cave art and scenic geological formations.

**Arcalís**  (HD 131496) – Arcalis is a famous peak in the north of Andorra, where the Sun passes through a hole in the mountain twice a year at fixed dates. It was used as a primitive solar calendar and reference point for shepherds and early inhabitants of Andorra.

**Madriu**  (HD 131496 b) – Madriu (*Mare del riu* in Catalan, *Mother of the River* in English) is the name of a

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[25]Ogmios is a name already attributed to an asteroid.

[26]The original proposed name Leda is already attributed to an asteroid and to one of Jupiter's satellites. The name Althaea is also attributed to an asteroid.

glacial valley and of the river that runs through it in the southeast of Andorra. It is the main part of the Madriu-Perafita-Claror UNESCO World Heritage Site.

**Nosaxa** (HD 48265) – Nosaxa means *spring* in the Moqoit language. The word comes from a combination of nosahuec, which means renew, and ñaaxa, which means *year*.

**Naqaya** (HD 48265 b) – Naqaya means *brother-family-relative* in the Moqoit language and leads us to call all humans, indigenous or non-indigenous, brother.

**Malmok** (WASP-39) – Malmok is an indigenous name given to a beach in Aruba with a narrow sandy stretch that interrupts the limestone and rocky terrace along the coast. Its shallow clear Caribbean waters make it a popular snorkelling spot.

**Bocaprins** (WASP-39 b) – Boca Prins is a secluded beach with white dunes and iconic scenery situated in Arikok National Park along the northeast coast of Aruba. It is named after Plantation Prins where coconuts are cultivated.

**Bubup** (HD 38283) – Bubup is the Boonwurrung word for child.

**Yanyan** (HD 38283 b) – YanYan is the Boonwurrung word for boy.

**Franz** (HAT-P-14) – Franz is a character in the movie "Sissi" embodying an emperor of Austria in the 19$^{th}$ century. The role is played by the actor Karlheinz Böhm.

**Sissi** (HAT-P-14 b) – Sissi is a character in the movie "Sissi", who is married with Franz. The role is played by the actress Romy Schneider.

**Mahsati** (HD 152581) – Mahsati Ganjavi (1089–1159) is one of the brightest shining stars of Azerbaijani poetry. She was said to have associated with both Omar Khayyam and Nizami and was well educated and talented and played numerous musical instruments.

**Ganja** (HD 152581 b) – Ganja is an ancient city of Azerbaijan, and is the birth place of many prominent people such as the poets Mahsati and Nizami. It is the ancient capital of Azerbaijan, the first capital of the Azerbaijan Democratic Republic and the city with the spirit of wisdom and freedom.

**Timir** (HD 148427) – Timir means darkness in Bengali language, alluding to the star being far away in the darkness of space.

**Tondra** (HD 148427 b) – Tondra means *nap* in Bengali language, alluding to the symbolic notion that the planet was asleep until discovered.

**Nervia** (HD 49674) – Nervia, adapted from Nervii, was a prominent Belgian Celtic tribe.

**Eburonia** (HD 49674 b) – Eburonia, adapted from Eburones, was a prominent Belgian Celtic tribe.

**Gakyid** (HD 73534) – Gakyid means *happiness*. Gross National Happiness is the development philosophy conceived and followed in Bhutan and is one of Bhutan's contributions to the world.

**Drukyul** (HD 73534 b) – Drukyul (land of the thunder dragon) is the native name for Bhutan, the country that came up with the philosophy of Gross National Happiness.

**Tapecue** (HD 63765) – Tapecue means *eternal path* in Guarani and represents the Milky Way through which the first inhabitants of the Earth arrived and could return.

**Yvaga** (HD 63765 b) – Yvaga means *paradise* for the Guarani and the Milky Way was known as the road to Yvaga or paradise.

**Bosona** (HD 206610) – Bosona is the name given to the territory of Bosnia in the 10$^{th}$ century. Later, the name was transformed to Bosnia originating from the name of the Bosna river.

**Naron** (HD 206610 b) – Naron is one of the names given to the Neretva river in Herzegovina (and partly in Croatia) in antiquity originating with the Celts who called it Nera Etwa which means the Flowing Divinity.

**Tupi** (HD 23079) – Tupi is the name of the most populous Indigenous People living on the eastern coast of South America, before the Portuguese arrived in the 16$^{th}$ century.

**Guarani** (HD 23079 b) – Guarani is the name of the most populous Indigenous people living in South Brazil and parts of Argentina, Paraguay and Uruguay.

**Gumala** (HD 179949) – Gumala is a Malay word, which means a magic bezoar stone found in snakes, dragons, etc.

**Mastika** (HD 179949 b) – Mastika is a Malay word, which means *a gem, precious stone, jewel* or *the prettiest, the most beautiful*.

**Tangra** (WASP-21) – Tangra is the supreme celestial god that early Bulgars worshiped.

**Bendida** (WASP-21 b) – Bendida is the Great Mother Goddess of the Thracians. She was especially revered as a goddess of marriage and living nature.

**Mouhoun** (HD 30856) – Mouhoun, also called Volta Noire, is the largest river in Burkina Faso and plays an important role in the lives of the people in the areas it passes through.

**Nakanbé** (HD 30856 b) – The Nakanbé, also called Volta Blanche, is the second largest river in Burkina

Faso. Its source is in the heart of the Sahara Burkinabe and ends in Ghana.

**Nikawiy** (HD 136418) – Nikawiy is the word for mother in the Indigenous Cree language of Canada.

**Awasis** (HD 136418 b) – Awasis is the word for child in the Indigenous Cree language of Canada.

**Pincoya** (HD 164604) – Pincoya is a female water spirit from southern Chilean mythology who is said to bring drowned sailors to the Caleuche so that they can live in the afterlife.

**Caleuche** (HD 164604 b) – Caleuche is a large ghost ship from southern Chilean mythology which sails the seas around the island of Chiloé at night.

**Lionrock** (HD 212771) – Lion Rock is a lion-shaped peak overlooking Hong Kong and is a cultural symbol with deep respect from the local community.

**Victoriapeak** (HD 212771 b) – Victoria Peak overlooks the bustling Victoria Harbour and is regarded as an ambassadorial gateway for foreign visitors wishing to experience Hong Kong first hand.

**Xihe** (HD 173416) – Xiheis the goddess of the sun in the Chinese mythology and also represents the earliest astronomers and developers of calendars in ancient China.

**Wangshu** (HD 173416 b) – Wangshu is the goddess who drives for the Moon and also represents the Moon in Chinese mythology.

**Formosa** (HD 100655) – Formosa is the historical name of Taiwan used in the $17^{th}$ century, meaning beautiful in Latin.

**Sazum** (HD 100655 b) – Sazum is the traditional name of Yuchi, a Township in Nantou county, in which the famous Sun-Moon Lake lies. Sazum means water in the language of the Thao people who are a tribe of Taiwanese aborigines who lived in the region for hundreds of years.

**Macondo** (HD 93083) – Macondo is the mythical village of the novel "One Hundred Years of Solitude" ("Cien años de soledad") the classic novel by Gabriel García Marquez. Macondo is a fictional place where magic and reality are mixed.

**Melquíades** (HD 93083 b) – Melquíades is a fictional character that walks around Macondo, like a planet orbiting a star, connecting it with the external world by introducing new knowledge using his inventions as well as his stories.

**Poerava** (HD 221287) – Poerava is the word in the Cook Islands Maori language for a large mystical black pearl of utter beauty and perfection.

**Pipitea** (HD 221287 b) – Pipitea is a small, white and gold pearl found in Penrhyn lagoon in the northern group of the Cook Islands.

**Dìwö** (WASP-17) – Dìwö in Bribri language means *the sun (bigger than the sun we know)* and that never turns off.

**Ditsö** (WASP-17 b) – Ditsö is the name that the god Sibö gave to the first Bribri people.

**Stribor** (HD 75898) – Stribor is God of winds in Slavic mythology, as well as a literature character in the book Priče iz davnine (Croatian Tales of Long Ago) by the Croatian author Ivana Brlić-Mažuranić.

**Veles** (HD 75898 b) – Veles is a major Slavic god of earth, waters and the underworld.

**Felixvarela** (BD-17 63) – Felix Varela (1788–1853) was the first to teach science in Cuba at the San Carlos and San Ambrosio Seminary. He opened the way to education for all, and began the experimental teaching of physics in Cuba.

**Finlay** (BD-17 63 b) – Carlos Juan Finlay (1833–1915) was an epidemiologist recognized as a pioneer in the research of yellow fever, determining that it was transmitted through mosquitoes.

**Alasia** (HD 168746) – Alasia is the first historically recorded name of Cyprus, dating back to mid-fifteenth century BC.

**Onasilos** (HD 168746 b) – Onasilos is the oldest historically recorded doctor in Cyprus, inscribed on the fifth century BC Idalion Tablet. Also known as the Onasilou Plate, it is considered as the oldest legal contract found in the world.

**Absolutno** (XO-5) – Absolutno is a fictional miraculous substance in the sci-fi novel "Továrna na absolutno" ("The Factory for the Absolute") by influential Czech writer Karel Čapek.

**Makropulos** (XO-5 b) – Makropulos is the name from Karel Čapek's play Věc Makropulos (The Makropulos Affair), dealing with problems of immortality and consequences of an artificial prolongation of life.

**Muspelheim** (HAT-P-29) – Muspelheim is the Norse mythological realm of fire. The first gods used the sparks of Muspelheim to form the sun, moon, planets, and stars.

**Surt** (HAT-P-29 b) – Surt is the ruler of Muspelheim and the fire giants there in Norse mythology. At Ragnarok, the end of the world, he will lead the attack on our world and destroy it in flames.

**Márohu** (WASP-6) – Márohu the god of drought is the protector of the Sun and is engraved at a higher position on the stalagmite than Boinayel in the El Puente cave, where the Sun makes its way down

every 21 December.

**Boinayel**  (WASP-6 b) – Boinayel the god of rain that fertilizes the soil is engraved on the stalagmite at a lower position than Márohu in the El Puente cave.

**Nenque**  (HD 6434) – Nenque means *the Sun* in the language spoken by the Indigenous Waorani tribes of the Amazon regions of Ecuador

**Eyeke**  (HD 6434 b) – Eyeke means *near* in the language spoken by the Indigenous Waorani tribes of the Amazon regions of Ecuador. This word is suggested for the exoplanet owing to the proximity of the planet to the host star.

**Citalá**  (HD 52265) – Citalá means *River of stars* in the native Nahuat language.

**Cayahuanca**  (HD 52265 b) – Cayahuanca means *The rock looking at the stars* in the native Nahuat language.

**Koit**  (XO-4) – Koit is Estonian for the time when the Sun rises in the morning (dawn).

**Hämarik**  (XO-4 b) – Hämarik is Estonian for the time when the Sun goes down in the evening (twilight).

**Buna**  (HD 16175) – Buna is the commonly used word for coffee in Ethiopia.

**Abol**  (HD 16175 b) – Abol is the first of three rounds of coffee in the Ethiopian traditional coffee ceremony.

**Horna**  (HAT-P-38) – Horna is hell or the underworld from Finnic mythology.

**Hiisi**  (HAT-P-38 b) – Hiisi represents sacred localities and later evil spirits from Finnic mythology.

**Bélénos**  (HD 8574) – Bélénos was the god of light, of the Sun, and of health in Gaulish mythology.

**Bélisama**  (HD 8574 b) – Bélisama was the goddess of fire, notably of the hearth and of metallurgy and glasswork, in Gaulish mythology.

**Itonda**  (HD 208487) – Itonda, in the Myene tongue, corresponds to all that is beautiful.

**Mintome**  (HD 208487 b) – Mintome, in the Fang tongue, is a mythical land where a brotherhood of brave men live.

**Mago**  (HD 32518) – Mago is a National Park in Ethiopia noted for its giraffes. The star also happens to be in the constellation of Camelopardis (the giraffe).

**Neri**  (HD 32518 b) – The Neri river in Ethiopia runs through parts of the Mago National park.

**Sika**  (HD 181720) – Sika means *gold* in the Ewe language and gold is one of Ghana's principal exports.

**Toge**  (HD 181720 b) – Toge means *earring* in the Ewe language.

**Lerna**  (HAT-P-42) – Lerna was the name of a lake in the eastern Peloponnese, where the Lernaean Hydra, an immortal mythical nine-headed beast lived. The star lies in the constellation of Hydra.

**Iolaus**  (HAT-P-42 b) – Iolaus was the nephew of Heracles from Greek mythology, moving around lake Lerna in helping Heracles to exterminate the Lernaean Hydra. Similarly this exoplanet in the constellation of Hydra moves around its parent star.

**Tojil**  (WASP-22) – Tojil is the name of one of the Mayan deities related to rain, storms, and fire.

**Koyopa'**  (WASP-22 b) – Koyopa' is the word associated with lightning in K'iche' (Quiché) Mayan language.

**Citadelle**  (HD 1502) – The Citadelle is a large mountaintop fortress in Nord, Haiti built after Haiti's independence, and was designated a UNESCO World Heritage site along with the nearby Sans-Souci Palace.

**Indépendance**  (HD 1502 b) – Indépendance is named after the Haitian Declaration of Independence on 1 January 1804, when Haiti became the first independent black republic.

**Hunahpú**  (HD 98219) – Hunahpú was one of the twin gods who became the Sun in K'iche' (Quiché) Mayan mythology as recounted in the Popol Vuh.

**Ixbalanqué**  (HD 98219 b) – Ixbalanqué was one of the twin gods who became the Moon in K'iche' (Quiché) Mayan mythology as recounted in the Popol Vuh.

**Hunor**  (HAT-P-2) – Hunor was a legendary ancestor of the Huns and the Hungarian nation, and brother of Magor.

**Magor**  (HAT-P-2 b) – Magor was a legendary ancestor of the Magyar people and the Hungarian nation, and brother of Hunor.

**Funi**  (HD 109246) – Funi is an old Icelandic word meaning *fire* or *blaze*.

**Fold**  (HD 109246 b) – Fold is an old Icelandic word meaning *earth* or *soil*.

**Bibhā**  (HD 86081) – Bibhā is the Bengali pronunciation of the Sanskrit word Vibha, which means *a bright beam of light*.

**Santamasa**  (HD 86081 b) – Santamasa in Sanskrit means *clouded*, which alludes to the exoplanet's atmosphere.

**Dofida**  (HD 117618) – Dofida means *our star* in Nias language.

**Noifasui**  (HD 117618 b) – Noifasui means *revolve around* in Nias language, derived from the word ifasui, meaning *to revolve around*, and no, indicating that the action occurred in the past and continued to the present time.

**Kaveh**  (HD 175541) – Kaveh is one of the heroes of Shahnameh, the epic poem composed by Persian poet Ferdowsi between 977 and 1010 CE. Kaveh is a blacksmith who symbolises justice.

**Kavian**  (HD 175541 b) – Kaveh carries a banner called Derafsh Kaviani (Derafsh: banner, Kaviani: relating to Kaveh).

**Uruk**  (HD 231701) – Uruk was an ancient city of the Sumer and Babylonian civilizations in Mesopotamia situated along an ancient channel of the Euphrates river in modern-day Iraq.

**Babylonia**  (HD 231701 b) – Babylonia was a key kingdom in ancient Mesopotamia from the $18^{th}$ to $6^{th}$ centuries BC whose name-giving capital city was built on the Euphrates river.

**Tuiren**  (HAT-P-36) – Tuiren was the aunt of the hunterwarrior Fionn mac Cumhaill of Irish legend, who was turned into a hound by the jealous fairy Uchtdealbh.

**Bran**  (HAT-P-36 b) – Tuiren's son Bran was a hound and cousin of the hunterwarrior Fionn mac Cumhaill of Irish legend.

**Tevel**  (HAT-P-9) – Tevel means *Universe* or *everything* and begins with the letter Taf, the last letter in the Hebrew alphabet.

**Alef**  (HAT-P-9 b) – Alef is the first letter in the Hebrew alphabet and also means bull.

**Flegetonte**  (HD 102195) – Flegetonte is the underworld river of fire from Greek Mythology in the Italian narrative poem on the afterlife "Divina Commedia" ("Divine Commedy") by Dante Alighieri, chosen as an allusion to the star's fiery nature.

**Lete**  (HD 102195 b) – Lete is the oblivion river made of fog from Greek Mythology in the Italian narrative poem on the afterlife "Divina Commedia" ("Divine Commedy") by Dante Alighieri, chosen as an allusion to the planet's gaseous nature.

**Nyamien**  (WASP-15) – Nyamien refers to the supreme creator deity of Akan mythology.

**Asye**  (WASP-15 b) – Asye refers to the Earth goddess of Akan mythology.

**Kamui**  (HD 145457) – Kamui is a word in the Ainu language denoting a supernatural entity possessing spiritual energy.

**Chura**  (HD 145457 b) – Chura is a word in the Ryukyuan/Okinawan language meaning *natural beauty*.

**Petra**  (WASP-80) – Petra is a historical and archaeological city in southern Jordan and a UNESCO World Heritage site.

**Wadirum**  (WASP-80 b) – Wadi Rum (Valley of the Moon) is located at the far south of Jordan, it is the largest valley in Jordan, set on the high plateau at the western edge of the Arabian Desert.

**Kalausi**  (HD 83443) – The word Kalausi means *a very strong whirling column of wind* in the Dholuo language of Kenya.

**Buru**  (HD 83443 b) – Buru means *dust* in the Dholuo language of Kenya and is typically associated with wind storms.

**Liesma**  (HD 118203) – Liesma means *flame*, and it is the name of a character from the Latvian poem Staburags un Liesma.

**Staburags**  (HD 118203 b) – Staburags is the name of a character from the Latvian poem Staburags un Liesma, and denotes a rock with symbolic meaning in literature and history.

**Phoenicia**  (HD 192263) – Phoenicia was an ancient thalassocratic civilisation of the Mediterranean that originated from the area of modern-day Lebanon.

**Beirut**  (HD 192263 b) – Beirut is one of the oldest continuously inhabited cities in the world and was a Phoenician port. Beirut is now the capital and largest city of Lebanon.

**Pipoltr**  (TrES-3) – In the local dialect of Triesenberg, Pipoltr is a bright and visible butterfly, alluding to the properties of a star.

**Umbäässa**  (TrES-3 b) – In the local dialect of southern Liechtenstein, Umbäässa is a small and barely visible ant, alluding to the properties of a planet with respect to its star.

**Taika**  (HAT-P-40) – Taika means *peace* in the Lithuanian language.

**Vytis**  (HAT-P-40 b) – Vytis is the symbol of the Lithuanian coat of arms.

**Lucilinburhuc**  (HD 45350) – The Lucilinburhuc fortress was built in 963 by the founder of Luxembourg, Count Siegfried.

**Peitruss**  (HD 45350 b) – Peitruss is derived from the name of the Luxembourg river Pétrusse, with the river's bend around Lucilinburhuc fortress alluding to the orbit of the planet around its star.

**Rapeto**  (HD 153950) – Rapeto is a giant creature from Malagasy tales.

**Trimobe**  (HD 153950 b) – Trimobe is a rich ogre from Malagasy tales.

**Intan**  (HD 20868) – Intan means *diamond* in the Malay language (Bahasa Melayu), alluding to the shining of a star.

**Baiduri**  (HD 20868 b) – Baiduri means *opal* in Malay language (Bahasa Melayu), alluding to the mysterious

beauty of the planet.

**Sansuna** (HAT-P-34) – Sansuna is the name of the mythological giant from traditional Maltese folk tales that carried the stones of the Gozo megalithic temples on her head.

**Ġgantija** (HAT-P-34 b) – Ġgantija means *giantess*: the megalithic temple complex on the island of Gozo, which alludes to the grandeur of this gas giant exoplanet.

**Diya** (WASP-72) – Diya is an oil lamp that is brought by Indian ancestors to Mauritius in the 1820's, and is used for lighting during special occasions, including the light festival of Diwali.

**Cuptor** (WASP-72 b) – Cuptor is a thermally insulated chamber used for baking or drying substances, that has long disappeared in Mauritius and has been replaced by more sophisticated ovens.

**Axólotl** (HD 224693) – Axólotl means *water animal* in the native Nahuatl language, which is a unique and culturally significant endemic amphibious species from the basin of Mexico.

**Xólotl** (HD 224693 b) – Xólotl means *animal* in the native Nahuatl language and was an Aztec deity associated with the evening star (Venus).

**Tislit** (WASP-161) – Tislit is the name of a lake in the Atlas mountains of Morocco. It means *the bride* in the Amazigh language and it is associated with a heartbroken beautiful girl in an ancient local legend.

**Isli** (WASP-161 b) – Isli is the name of a lake in the Atlas mountains of Morocco. It means *the groom* in the Amazigh language and it is associated with a heartbroken handsome boy in an ancient local legend.

**Emiw** (HD 7199) – Emiw represents love in the local Makhuwa language of the northern region of Mozambique.

**Hairu** (HD 7199 b) – Hairu represents unity in the local Makhuwa language of the northern region of Mozambique.

**Ayeyarwady** (HD 18742) – Ayeyarwady is the largest and most important river in Myanmar.

**Bagan** (HD 18742 b) – Bagan is one of Myanmar's ancient cities that lies beside the Ayeyarwardy river.

**Sagarmatha** (HD 100777) – Sagarmatha is the Nepali name for the highest peak in the world (also known as Mount Everest) and symbol of national pride of Nepal.

**Laligurans** (HD 100777 b) – Laligurans are the Nepali variation of the rhododendron flower and is the national flower of Nepal.

**Sterrennacht** (HAT-P-6) – The Sterrennacht (Starry Night) is a world-famous painting by Dutch grand master Van Gogh that was painted in France in 1889 and now belongs to the permanent collection of New York's Museum of Modern Art.

**Nachtwacht** (HAT-P-6 b) – The Nachtwacht (Night Watch) is a world-famous painting by Dutch grand master Rembrandt that was completed in 1642 and now belongs to the collection of the Rijksmuseum in Amsterdam.

**Karaka** (HD 137388) – Karaka is the word in the Māori language for a plant endemic to New Zealand that produces a bright orange, fleshy fruit.

**Kererū** (HD 137388 b) – Kererū is the word in the Māori language for a large bush pigeon native to New Zealand.

**Cocibolca** (HD 4208) – Cocibolca is the Nahualt name for the largest lake in Central America in Nicaragua.

**Xolotlan** (HD 4208 b) – Xolotlan is the name of the second largest lake of Nicaragua and its name is from the Nahualt language of the indigenous tribe that settled in Nicaragua, which symbolises a native god and a refuge for animals.

**Amadioha** (HD 43197) – Amadioha is the god of thunder in Igbo mythology. As well as representing justice, Amadioha is also a god of love, peace and unity.

**Equiano** (HD 43197 b) – Equiano was a writer and abolitionist from Ihiala, Nigeria who fought injustice and the elimination of the slave trade.

**Násti** (HD 68988) – Násti means *star* in the Northern Sami language of Norway.

**Albmi** (HD 68988 b) – Albmi means *sky* in the Northern Sami language of Norway.

**Shama** (HAT-P-23) – Shama is an Urdu literary term meaning *a small lamp* or *flame*, symbolic of the light of the star.

**Perwana** (HAT-P-23 b) – Perwana means *moth* in Urdu, alluding to the eternal love of an object circling the source of light (the lamp).

**Moriah** (HD 99109) – Moriah is an ancient name for the mountain within the Old City of Jerusalem.

**Jebus** (HD 99109 b) – Jebus was the ancient name of Jerusalem in $2^{nd}$ millennium BC when populated by the Canaanite tribe of Jebusites.

**Montuno** (WASP-79) – Montuno is the traditional costume the man wears in the "El Punto", a Panamanian dance in which a man and woman dance to the sound of drums.

**Pollera** (WASP-79 b) – Pollera is the traditional costume the woman wears in the El Punto, a Panamanian

dance in which a man and woman dance to the sound of drums.

**Tupã**  (HD 108147) – Tupã is one of four principle gods of the Guarani Cosmogony in popular Paraguayan folklore that helped the supreme god Ñamandu to create the Universe.

**Tumearandu**  (HD 108147 b) – Tume Arandu is a son of Rupavê and Sypavê, the original man and woman of the Universe, who is known as the Father of Wisdom in popular Paraguayan folklore.

**Inquill**  (HD 156411) – Inquil was one half of the couple involved in the tragic love story Way to the Sun by famous Peruvian writer Abraham Valdelomar.

**Sumajmajta**  (HD 156411 b) – Sumaj Majta was one half of the couple involved in a tragic love story Way to the Sun by famous Peruvian writer Abraham Valdelomar.

**Amansinaya**  (WASP-34) – Aman Sinaya is one of the two trinity deities of the Philippine's Tagalog mythology, and is the primordial deity of the ocean and protector of fisherman.

**Haik**  (WASP-34 b) – Haik is the successor of the primordial Aman Sinaya as the God of the Sea of the Philippine's Tagalog mythology.

**Uklun**  (HD 102117) – Uklun means *us* or *we* in the Pitkern language of the people of Pitcairn Islands.

**Leklsullun**  (HD 102117 b) – Lekl Sullun means *child* or children in the Pitkern language of the people of Pitcairn Islands.

**Solaris**  (BD+14 4559) – Solaris is the title of a 1961 science fiction novel about an ocean-covered exoplanet by Polish writer Stanislaw Lem.

**Pirx**  (BD+14 4559 b) – Pirx is a fictional character from books by Polish science-fiction writer Stanislaw Lem.

**Lusitânia**  (HD 45652) – Lusitânia is the ancient name of the western region of the Iberic Peninsula where the Lusitanian people lived and where most of modern-day Portugal is situated.

**Viriato**  (HD 45652 b) – Viriato was a legendary leader of the Lusitanian people, a herdsman and hunter who led the resistance against Roman invaders during $2^{nd}$ century B.C.

**Koeia**  (HIP 12961) – Koeia was the word for star in the language of the Taíno Indigenous People of the Caribbean.

**Aumatex**  (HIP 12961 b) – Aumatex was the God of Wind in the mythology of the Taíno Indigenous People of the Caribbean.

**Moldoveanu**  (XO-1) – Moldoveanu is the highest peak in Romania of the Făgăraș mountain range with an altitude of 2544 metres.

**Negoiu**  (XO-1 b) – Negoiu is the second highest peak in Romania of the Făgăraș mountain range with an altitude of 2535 metres.

**Dombay**  (HAT-P-3) – Dombay is a resort region in the North Caucasus mountains that is enclosed by mountain forests and rich wildlife, including bears (as this star lies in the constellation Ursa Major, the great bear).

**Teberda**  (HAT-P-3 b) – Teberda is a mountain river in Dombay region with a rapid water flow, symbolising the planet's rapid motion around its host star.

**Belel**  (HD 181342) – Belel is a rare source of water in the north of Senegal.

**Dopere**  (HD 181342 b) – Dopere is an expansive historical area in the north of Senegal where Belel was located.

**Morava**  (WASP-60) – Morava is the longest river system in Serbia.

**Vlasina**  (WASP-60 b) – Vlasina is one of the most significant tributaries of the South Morava river.

**Parumleo**  (WASP-32) – Parumleo is a Latin term for little lion, symbolising Singapore's struggle for independence.

**Viculus**  (WASP-32 b) – Viculus is a Latin term for little village, embodying the spirit of the Singaporean people.

**Chasoň**  (HAT-P-5) – Chasoň is an ancient Slovak term for Sun.

**Kráľomoc**  (HAT-P-5 b) – Kráľomoc is an ancient Slovak term for the planet Jupiter.

**Irena**  (WASP-38) – Irena is a leading character in the novel "Under the Free Sun: a Story of the Ancient Grandfathers" by Slovene writer Fran Saleški Finžgar. Irena is a woman of the court.

**Iztok**  (WASP-38 b) – Iztok is a leading character in the novel "Under the Free Sun: a Story of the Ancient Grandfathers" by Slovene writer Fran Saleški Finžgar. Iztok is a freedom fighter for the Slavic people.

**Naledi**  (WASP-62) – Naledi means *star* in the Sesotho, SeTswana and SePedi languages and is typically given as a name to girls in the hope that they will bring light, joy and peace to their communities.

**Krotoa**  (WASP-62 b) – Krotoa is considered the Mother of Africa and member of the indigenous Khoi people, who was a community builder and educator during colonial times.

**Baekdu**  (8 Umi) – Baekdu is the highest mountain on the Korean peninsula, situated in North Korea, and

symbolises the national spirit of Korea.

**Halla** (8 Umi b) – Halla is the highest mountain in South Korea and is regarded as a sacred place in the region.

**Rosalíadecastro** (HD 149143) – Rosalía de Castro was a significant figure of Galician culture and prominent Spanish writer, whose pioneeting work often referenced the night and celestial objects.

**Riosar** (HD 149143 b) – Rio Sar is the name of a river that was present in much of the literary work of the pioneering Spanish author Rosalía de Castro.

**Sāmaya** (HD 205739) – Sāmaya means *peace* in the Sinhalese language.

**Samagiya** (HD 205739 b) – Samagiya means *togetherness and unity* in the Sinhalese language.

**Aniara** (HD 102956) – Aniara is the name of a spaceship in the epic poem Aniara by Swedish author Harry Martinson.

**Isagel** (HD 102956 b) – Isagel is the name of the spaceship pilot in the epic science fiction poem Aniara written by Swedish author Harry Martinson.

**Mönch** (HD 130322) – Mönch is one of the prominent peaks of the Bernese Alps in Switzerland.

**Eiger** (HD 130322 b) – Eiger is one of the prominent peaks of the Bernese Alps, in the Jungfrau-Aletsch protected area.

**Ebla** (HD 218566) – Ebla was one of the earliest kingdoms in Syria, and served as a prominent region in the $2^{nd}$ and $3^{rd}$ millennia B.C.

**Ugarit** (HD 218566 b) – Ugarit was a city where its scribes devised the Ugaritic alphabet around 1400 B.C. The alphabet was made up of thirty letters and was inscribed on clay tablets.

**Mpingo** (WASP-71) – Mpingo is a famous tree that grows in southern Tanzania and produces ebony wood used for musical instruments and curios.

**Tanzanite** (WASP-71 b) – Tanzanite is the name of a precious stone mined in Tanzania and is treasured worldwide.

**Chaophraya** (WASP-50) – Chao Phraya is the great river of Thailand.

**Maeping** (WASP-50 b) – Mae Ping is one of the tributaries of Thailand's great river Chao Phraya.

**Atakoraka** (WASP-64) – Atakoraka means *the chain* of the Atacora: the largest mountain range in Togo.

**Agouto** (WASP-64 b) – Agouto (Mount Agou) is the highest mountain in Togo and a treasured region of the Atakoraka.

**Dingolay** (HD 96063) – Dingolay means *to dance, twist and turn in elaborate movements*, symbolising the culture and language of the ancestors of the people of Trinidad and Tobago.

**Ramajay** (HD 96063 b) – Ramajay means *to sing and make music in a steelpan style*, representing the love of culture and languages of the ancestors of the people of Trinidad and Tobago.

**Chechia** (HD 192699) – Chechia is a flat-surfaced, traditional red wool hat worn by men and women, symbolising the country's rich traditions and is considered as the national headdress for in Tunisia.

**Khomsa** (HD 192699 b) – Khomsa is a palm-shaped amulet that is popular in Tunisia, used in jewelry and decorations. It depicts an open right hand and is often found in modern designs.

**Anadolu** (WASP-52) – Anadolu is the primary homeland of Turkey and refers to the motherland in Turkish culture.

**Göktürk** (WASP-52 b) – Göktürk refers to the historical origin of the Turkish people, as it was the first established state in Turkey in $5^{th}$ century AD. It is also the name of a Turkish satellite and is the combination of two words, of which "Gök" means *sky*.

**Berehinya** (HAT-P-15) – Berehinya was a Slavic deity of waters and riverbanks but in more recent times her status has been promoted to that of a national goddess — "hearth mother, protectress of the earth".

**Tryzub** (HAT-P-15 b) – Tryzub is the most recognised ancient symbol of Ukraine, that was minted on the coins of Prince Volodymyr the Great and today remains one of the country's state symbols (a small coat).

**Sharjah** (HIP 79431) – Sharjah is the cultural capital of United Arab Emirates, and considered the city of knowledge due to its many educational centers, institutes, museums, libraries and heritage centers.

**Barajeel** (HIP 79431 b) – A barajeel is a wind tower used to direct the flow of the wind so that air can be recirculated as a form of air conditioning.

**Gloas** (WASP-13) – In Manx Gaelic, Gloas means *to shine* (like a star).

**Cruinlagh** (WASP-13 b) – In Manx Gaelic, Cruinlagh means *to orbit* (like a planet around its star).

**Nushagak** (HD 17156) – Nushagak is a regional river near Dilingham, Alaska, which is famous for its wild salmon that sustain local Indigenous communities.

**Mulchatna** (HD 17156 b) – The Mulchatna River is a tributary of the Nushagak River in southwestern Alaska, USA.

**Ceibo** (HD 63454) – Ceibo is the name of the native tree of Uruguay that gives rise to the national flower.

**Ibirapitá** (HD 63454 b) – Ibirapitá is the name of a native tree that is characteristic of the country of Uruguay, and is also known as Artigas' tree, after the national hero.

**Natasha** (HD 85390) – Natasha means *thank you* in many languages of Zambia.

**Madalitso** (HD 85390 b) – Madalitso means *blessings* in the native language of Nyanja in Zambia.

All names with asterix mark (*) are modified based on the original proposals, to be consistent with the IAU rules.

### 14.3.3 Section ⌈Exoplanets⌉ in config.ini file

You can edit `config.ini` file to change the settings for the Exoplanets plugin – just make it carefully!

| ID | Type | Description |
|---|---|---|
| last_update | string | Date and time of last update |
| update_frequency_hours | int | Frequency of updates, in hours |
| updates_enable | bool | Enable updates of exoplanets catalog from Internet |
| url | string | URL of exoplanets catalog |
| flag_show_exoplanets_button | bool | Enable showing button of exoplanets on bottom bar |
| distribution_enabled | bool | Enable distribution mode of display |
| timeline_enabled | bool | Enable timeline mode of display |
| habitable_enabled | bool | Enable habitable mode of display |
| enable_at_startup | bool | Enable displaying exoplanets at startup of the plugin |
| exoplanet_marker_color | R,G,B | Color for marker of star with planetary system |
| habitable_exoplanet_marker_color | R,G,B | Color for marker of star with planetary system with potential habitable exoplanets |
| temperature_scale | string | Temperature scale for equilibrium temperature of exoplanets. Possible values: *Kelvin*, *Celsius*, *Fahrenheit*. Default value: *Celsius*. |

### 14.3.4 Format of exoplanets catalog

To add a new exoplanet system, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"Star designation":
{
   "exoplanets":
   [
   {
      "mass": mass of exoplanet (M jup),
      "radius": radius of exoplanet (R jup),
      "period": period of exoplanet (days),
      "semiAxis": semi-major axis (AU),
      "eccentricity": orbit's eccentricity,
      "inclination": orbit's inclination (degree),
      "angleDistance": angle distance from star (arcseconds),
      "discovered": exoplanet discovered year,
      "detectionMethod": "exoplanet detection method",
      "pclass": "planetary class",
      "EqTemp": equilibrium temperature (K),
      "conservative": conservative or optimistic
                habitability of the exoplanet,
      "ESI": Earth Similarity Index (*100),
      "planetProperName": "proper name of planet",
      "planetName": "designation of planet"
   },
   {
      "mass": mass of exoplanet (M jup),
      "radius": radius of exoplanet (R jup),
      "period": period of exoplanet (days),
      "semiAxis": semi-major axis (AU),
```

```
        "eccentricity": orbit's eccentricity,
        "inclination": orbit's inclination (degree),
        "angleDistance": angle distance from star (arcseconds),
        "discovered": exoplanet discovered year,
        "detectionMethod": "exoplanet detection method",
        "pclass": "planetary class",
        "EqTemp": equilibrium temperature (K),
        "conservative": conservative or optimistic habitability of the
                        exoplanet,
        "ESI": Earth Similarity Index (*100),
        "planetProperName": "proper name of planet",
        "planetName": "designation of planet"
    }
    ],
    "distance": value of distance to star (pc),
    "stype": "spectral type of star",
    "smass": value of mass of star (M sun),
    "smetal": value of metallicity of star,
    "Vmag": value of visual magnitude of star,
    "sradius": value of radius of star (R sun),
    "effectiveTemp": value of effective temperature of star (K),
    "starProperName": "proper name of the star",
    "hasHP": boolean (has potential habitable planets),
    "RA": "Right ascension (J2000)",
    "DE": "Declination (J2000)"
},
```

For example, the record for *24 Sex* looks like:

```
"24 Sex":
{
    "exoplanets":
    [
    {
        "mass": 1.99,
        "period": 452.8,
        "semiAxis": 1.333,
        "eccentricity": 0.09,
        "angleDistance": 0.017821,
        "discovered": 2010,
        "planetName": "b"
    },
    {
        "mass": 0.86,
        "period": 883.0,
        "semiAxis": 2.08,
        "eccentricity": 0.29,
        "angleDistance": 0.027807,
        "discovered": 2010,
        "planetName": "c"
    }
    ],
    "distance": 74.8,
    "stype": "G5",
    "smass": 1.54,
    "smetal": -0.03,
    "Vmag": 7.38,
    "sradius": 4.9,
    "effectiveTemp": 5098,
    "RA": "10h23m28s",
    "DE": "-00d54m08s"
},
```

## 14.4    Pulsars Plugin
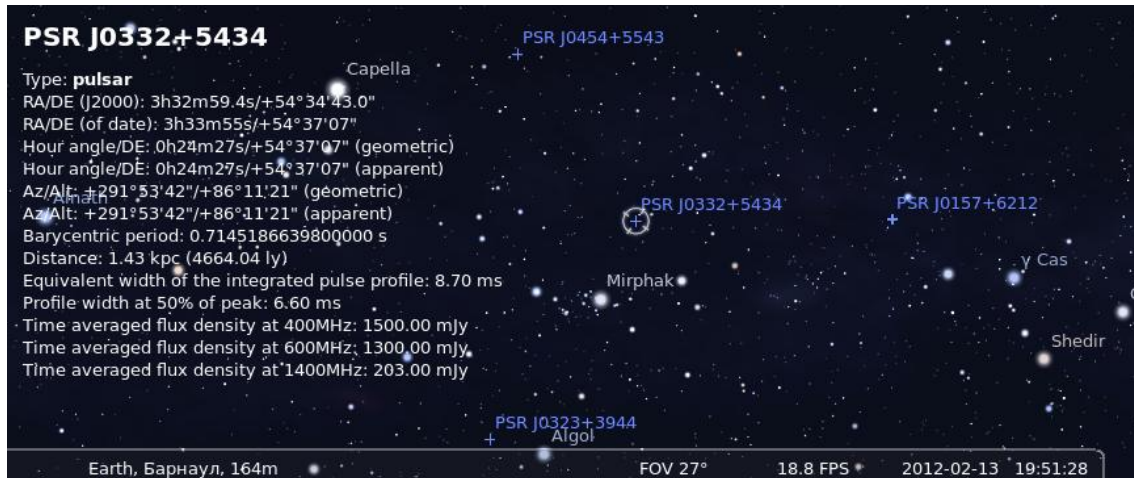


Figure 14.5: PSR J0332+5434

This plugin plots the position of various pulsars, with object information about each one. Pulsar data is derived from "The Australia Telescope National Facility Pulsar Catalogue" (Manchester et al., 2005).

If enabled (see section 12.1), use the ⟦ ⟧ button to activate display of pulsars. The GUI allows a few configuration options. You can also find a pulsar (⟦ F3 ⟧) by its designation (e.g., *PSR J0437-4715*).

### 14.4.1   Section ⌈Pulsars⌉ in config.ini file

| ID | Type | Description |
|---|---|---|
| last_update | string | Date and time of last update |
| update_frequency_days | int | Frequency of updates [days] |
| updates_enable | bool | Enable updates of pulsars catalog from Internet |
| url | string | URL of pulsars catalog |
| enable_at_startup | bool | Enable displaying of pulsars at startup of Stellarium |
| distribution_enabled | bool | Enable distribution mode for the pulsars |
| flag_show_pulsars_button | bool | Enable displaying pulsars button on toolbar |
| marker_color | R,G,B | Color for marker of the pulsars |
| glitch_color | R,G,B | Color for marker of the pulsars with glitches |
| use_separate_colors | bool | Use separate colors for different types of the pulsars |

### 14.4.2 Format of pulsars catalog

To add a new pulsar, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"Pulsar designation":
{
    "RA": "Right ascension (J2000)",
    "DE": "Declination (J2000)",
    "notes": "type of pulsar",
    "distance": value of distance based on electron density
                model (kpc),
    "period": value of barycentric period of the pulsar (s),
    "parallax": value of annual parallax (mas),
    "bperiod": value of binary period of pulsar (days),
    "pderivative": value of time derivative of barcycentric
                   period,
    "dmeasure": value of dispersion measure (pc/(cm*cm*cm)),
    "frequency": value of barycentric rotation frequency (Hz),
    "pfrequency": value of time derivative of barycentric
                  rotation frequency (1/(s*s))
    "eccentricity": value of eccentricity,
    "w50": value of profile width at 50% of peak (ms),
    "s400": value of time averaged flux density at
            400 MHz (mJy),
    "s600": value of time averaged flux density at
            600 MHz (mJy),
    "s1400": value of time averaged flux density at
             1400 MHz (mJy)
},
```

For example, the record for **PSR J0014+4746** looks like:

```
"PSR J0014+4746":
{
    "distance": 1.82,
    "dmeasure": 30.85,
    "frequency": 0.805997239145,
    "pfrequency": -3.6669E-16,
    "w50": 88.7,
    "s400": 14,
    "s600": 9,
    "s1400": 3,
    "RA": "00h14m17.75s",
    "DE": "47d46m33.4s"
},
```

## 14.5  Quasars Plugin

The Quasars plugin provides visualization of some quasars brighter than 16 visual magnitude. The catalogue of quasars has been compiled from "A catalogue of quasars and active nuclei: 13th edition" (Véron-Cetty and Véron, 2010).
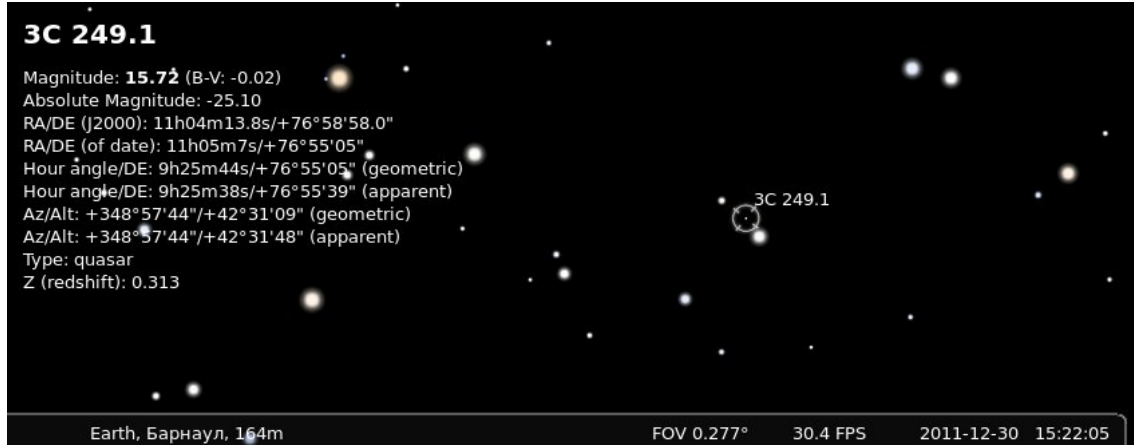


Figure 14.6: 3C 249.1, also known as LEDA 2821945 or 4C 77.09

If enabled (see section 12.1), use the [✗] button to activate display of quasars. The GUI allows a few configuration options. You can also find a quasar ( F3 ) by its designation (e.g., *3C 273*).

### 14.5.1  Section ⌈Quasars⌉ in config.ini file

| ID | Type | Description |
|---|---|---|
| last_update | string | Date and time of last update |
| update_frequency_days | int | Frequency of updates, in days |
| updates_enable | bool | Enable updates of quasars catalog from Internet |
| url | string | URL of quasars catalog |
| enable_at_startup | bool | Enable displaying of quasars at startup of Stellarium |
| distribution_enabled | bool | Enable distribution mode for the quasars |
| flag_show_quasars_button | bool | Enable displaying quasars button on toolbar |
| marker_color | R,G,B | Color for marker of the quasars |

### 14.5.2  Format of quasars catalog

To add a new quasar, open a new line after line 5 and create a new section. For example, the record for **3C 249.1** looks like (note commas and brackets – they are important!):

```
"3C 249.1":                     // Quasar designation
{
    "RA": "11h04m13.8s",        // Right ascension (J2000)
    "DE": "+76d58m58s",         // Declination (J2000)
    "Amag": -25.1,              // value of absolute magnitude
    "Vmag": 15.72,              // value of visual magnitude
    "z": 0.313,                 // value of Z (redshift)
    "bV": -0.02                 // value of B-V colour
},
```

## 14.6 Meteor Showers Plugin



Figure 14.7: The 1833 Leonids replayed with the Meteor Showers plugin.

In contrast and extension of the random *shooting stars* feature of Stellarium (see section 19.6), this plugin provides data for real meteor showers and a marker for each active and inactive radiant, showing real information about its activity. If enabled (see section 12.1), just click on the Meteor Showers button on the bottom toolbar to display markers for the radiants.

### 14.6.1 Terms

#### Meteor shower

A *meteor shower* is a celestial event in which a number of meteors are observed to radiate, or originate, from one point in the night sky. These meteors are caused by streams of cosmic debris called *meteoroids* entering Earth's atmosphere at extremely high speeds on parallel trajectories. Most meteors are smaller than a grain of sand, so almost all of them disintegrate and never hit the Earth's surface. Intense or unusual meteor showers are known as meteor outbursts and meteor storms, which may produce greater than 1,000 meteors an hour.

#### Radiant

The *radiant* or *apparent radiant* of a meteor shower is the point in the sky from which (to a planetary observer) meteors appear to originate. The Perseids, for example, are meteors which appear to come from a point within the constellation of Perseus.

An observer might see such a meteor anywhere in the sky but the direction of motion, when traced back, will point to the radiant. A meteor that does not point back to the known radiant for a given shower is known as a sporadic and is not considered part of that shower.

Many showers have a radiant point that changes position during the interval when it appears. For example, the radiant point for the Delta Aurigids drifts by more than a degree per night.

#### Zenithal Hourly Rate (ZHR)

The *Zenithal Hourly Rate* (ZHR) of a meteor shower is the number of meteors a single observer would see in one hour under a clear, dark sky (limiting apparent magnitude of 6.5) if the radiant of the shower were at the zenith. The rate that can effectively be seen is nearly always lower and decreases the closer the radiant is to the horizon.

#### Population index

The *population index* indicates the magnitude distribution of the meteor showers. Values below 2.5 correspond to distributions where bright meteors are more frequent than average, while values above 3.0 mean that the share of faint meteors is larger than usual.

**Solar longitude**

The *solar longitude* (equinox J2000) gives the position of the Earth on its orbit. It is a more appropriate information on a meteor shower than the date.

### 14.6.2 Section ⌈MeteorShowers⌉ in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Meteor Showers plugin – just make it carefully!

| ID | Type | Description |
|---|---|---|
| last_update | string | Date and time of last update |
| update_frequency_hours | int | Frequency of updates, in hours |
| updates_enable | bool | Enable updates of the meteor showers catalog from Internet |
| url | string | URL of the meteor showers catalog |
| flag_show_ms_button | bool | Enable showing button of the meteor showers on bottom bar |
| flag_show_radiants | bool | Enable displaying markers for the radiants of the meteor showers |
| flag_active_radiants | bool | Flag for displaying markers for the radiants of the active meteor showers only |
| enable_at_startup | bool | Enable displaying meteor showers at startup plugin |
| show_radiants_labels | bool | Flag for displaying labels near markers of the radiants of the meteor showers |
| font_size | int | Font size for label of markers of the radiants of the meteor showers |
| colorARG | R,G,B | Color for marker of active meteor showers with generic data |
| colorARR | R,G,B | Color for marker of active meteor showers with real data |
| colorIR | R,G,B | Color for marker of inactive meteor showers |

### 14.6.3 Format of Meteor Showers catalog

To add a new meteor shower, you just need to:
1. Copy the code of some valid meteor shower;
2. Paste it in the line 6 (right after the "showers": {) of the MeteorShowers.json document;
3. Replace the information according with your needs.

Note commas and brackets, they are very important!

```
"Three-letter code":
    {
        "designation": "Name",
        "IAUNo": "IAU shower number",
        "activity":
        [{
            "year": "generic",
            "zhr": Maximum ZHR (-1 if variable),
            "variable": "Minimum-maximum (if variable)",
            "start": Solar longitude at start,
            "finish": Solar longitude at finish,
            "peak": Solar longitude at peak,
            "disttype": Type of distribution function
                        (0=Gauss, 1=Lorentz),
            "b1": Slope of distribution function
                  before peak,
            "b2": Slope of distribution function
                  after peak
        }],
        "speed": Geocentric speed (km/s),
        "radiantAlpha": Right Ascension (J2000) (degree),
        "radiantDelta": Declination (J2000) (degree),
        "driftAlpha": Radiant drift in Right Ascension,
        "driftDelta": Radiant drift in Declination,
        "colors":
        [{
            "color": "white",
            "intensity": 70
```

```
        },
        {
            "color": "blueGreen",
            "intensity": 30
        }],
        "parentObj": "Parent object",
        "pidx": population index
    },
```

For example, below is a record for the *Northern Taurids*:

```
"NTA":
    {
        "designation": "Northern Taurids",
        "IAUNo": "17",
        "activity":
        [{
            "year": "generic",
            "zhr": 5,
            "start": 206,
            "finish": 258,
            "peak": 230
         }],
        "speed": 29,
        "radiantAlpha": 58,
        "radiantDelta": 22,
        "driftAlpha": 1.03,
        "driftDelta": 0.26,
        "colors":
        [{
            "color": "yellow",
            "intensity": 80
         },
         {
            "color": "white",
            "intensity": 20
        }],
        "parentObj": "Comet 2P/Encke",
        "pidx": 2.3
    },
```

### 14.6.4 Notes

- This plugin uses two models (P. Jenniskens, 1994) and (Peter Jenniskens et al., 1998) to calculate ZHR, assuming that the activity profile of meteor shower follows a double exponential shape.
- To predict the local hourly rate, altitude of radiant and limiting magnitude of the sky are taken into account. Moonlight can also reduce the hourly rate, but is not taken into account.
- Most of the numerical data for past meteor outbursts (Leonids, etc.) come from (P. Jenniskens, 2006). There is a wide range of reported values for the maximum ZHR for the 1833 and 1966 Leonids (P. Brown, 1999). We decided to use a maximum number of 150,000 to demonstrate meteor outbursts with very high rate.

### 14.6.5 Further Information

You can get more info about meteor showers here:

- Wikipedia about Meteor showers: `https://en.wikipedia.org/wiki/Meteor_Showers`
- International Meteor Organization: `https://www.imo.net/`
- IAU Meteor Data Center: `https://www.ta3.sk/IAUC22DB/MDC2007/`

### Acknowledgements

This plugin was initially created as project of ESA Summer of Code in Space 2013[27].

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[27]`http://sophia.estec.esa.int/socis2013/?q=about`

## 14.7   Navigational Stars Plugin
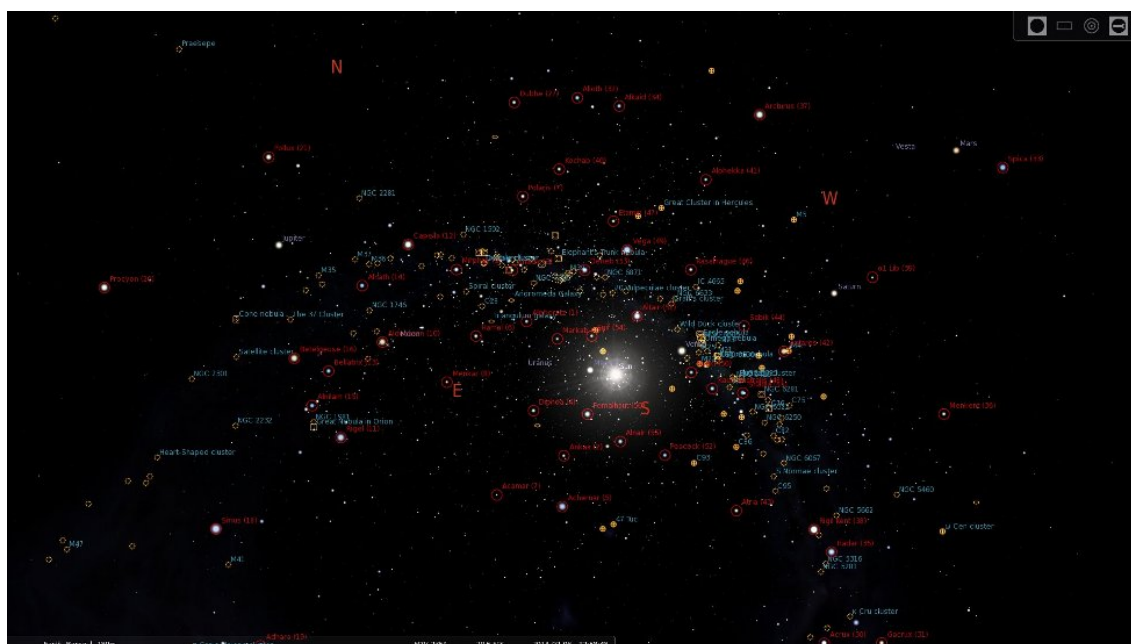


Figure 14.8: Navigational stars on the screen

This plugin marks navigational stars from a selected set (Figure 14.9):

**Anglo-American** — the 57 "selected stars" that are listed in *The Nautical Almanac*[28] jointly published by Her Majesty's Nautical Almanac Office and the US Naval Observatory since 1958; consequently, these stars are also used in navigational aids such as the *2102-D Star Finder*[29] and *Identifier*.

**French** — the 81 stars that are listed in the *Ephémérides Nautiques* published by the French Bureau des Longitudes.

**Russian** — the 160 stars that are listed in the Russian Nautical Almanac.

**German** — the 80 stars that are listed in the German Nautical Almanac (The original German title is *Nautisches Jahrbuch*) published by the Federal Maritime and Hydrographic Agency of Germany.

If enabled (see section 12.1), just click on the Sextant button ⚓ on the bottom toolbar to display markers for the navigational stars. This can help you in training your skills in astronomical navigation before you cruise the ocean in the traditional way, with your sextant and chronometer.

In the second tab ("Today", see Figure 14.10) in the plugin's dialog (right-click the button) you can see times of sunrise and sunset, twilights, moonrise and moonset.

**Civil Twilight** occurs when the zenith angle of the center of the Sun is less than 96° (6° below the horizon) and the available skylight is still typically sufficient for most civilian outdoor activities. The apparent horizon is still clearly visible against the glowing sky and only the brightest stars are beginning to show.

**Nautical Twilight** occurs when the zenith angle of the center of the Sun is less than 102° (12° below the horizon) and the available skylight is no longer sufficient for detailed outdoor activities. However, the outline of the apparent horizon, as well as most large topographical features, are still distinguishable and the key stars used for navigational purposes have all typically become visible.

**Astronomical Twilight** occurs when the zenith angle of the center of the Sun is less than 108° (18° below the horizon) and the available skylight is effectively imperceptible compared to moonlight and starlight. Beyond this angle there is no longer any discernible atmospheric scattering of sunlight, so the time after astronomical twilight is basically night.

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[28]The Nautical Almanac website – `https://aa.usno.navy.mil/publications/docs/na.php`

[29]Rude Starfinder 2102-D description and usage instruction – `https://oceannavigation.blogspot.com/2008/12/rude-starfinder-2102-d.html`
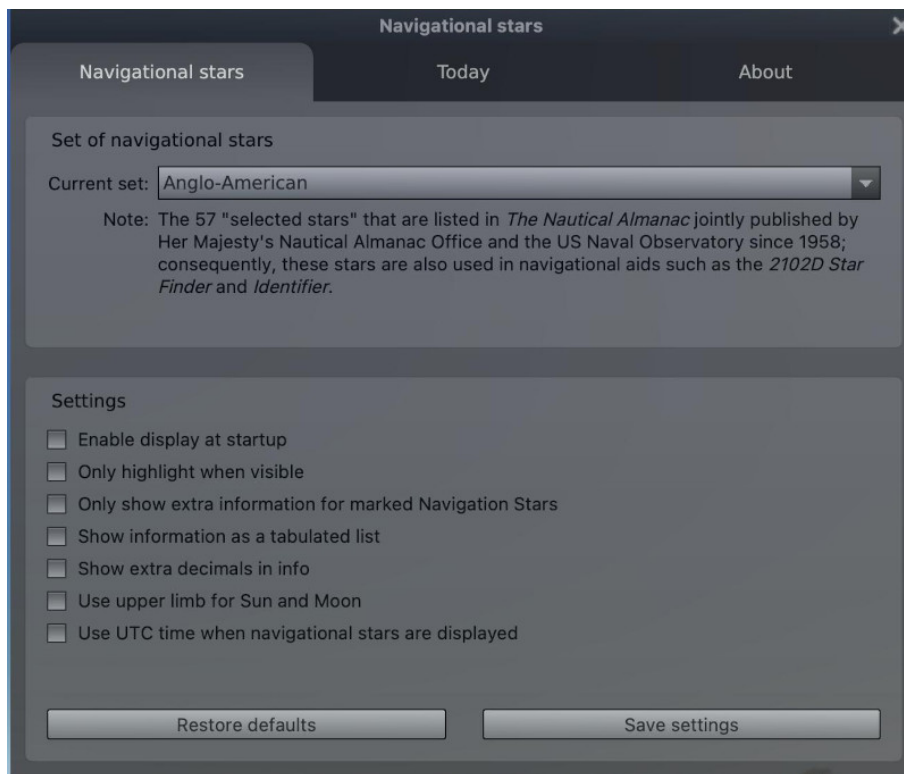
Figure 14.9: Settings of the Navigational stars plugin



Figure 14.10: Today tab in the Navigational stars plugin

## 14.7.1   Section [NavigationalStars] in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Navigational Stars plugin – just make it carefully!

| ID | Type | Description |
|---|---|---|
| navstars_color | R,G,B | Color of markers of navigational stars |
| enable_at_startup | bool | Set to *true* to display navigational stars at startup of planetarium |
| use_utc_time | bool | Set to *true* to use UTC time when navigational stars are displayed |
| extra_decimals | bool | Set to *true* to show extra decimals in info |
| upper_limb | bool | Set to *true* to use upper limb for Sun and Moon |
| tabulated_display | bool | Set to *true* to show information as a tabulated list |
| limit_info_to_nav_stars | bool | Set to *true* to show extra information only for marked Navigation Stars |
| highlight_when_visible | bool | Set to *true* to highlight only visible stars |
| current_ns_set | string | Current set of navigational stars. Possible values: *AngloAmerican*, *French*, *Russian* and *German*. |

## 14.8 Satellites Plugin

The Satellites plugin displays the positions of artificial satellites in Earth's orbit based on a catalog of orbital data. It allows automatic updates from online sources and manages a list of update file URLs.

To calculate satellite positions, the plugin uses an implementation of the SGP4/SDP4 algorithms (J.L. Canales' **gsat** library), using as its input data in NORAD's two-line element set (*TLE*[30]) format. Lists with TLEs for hundreds of satellites are available online and are regularly updated. The plugin downloads the lists prepared by `https://celestrak.org` to keep itself up-to-date, but the users can specify other sources online or load updates from local files.
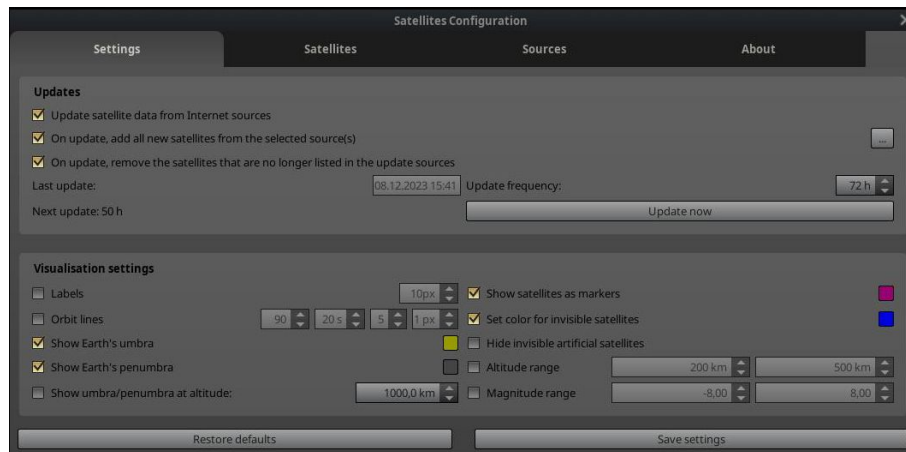


Figure 14.11: Configuration of the Satellites plugin

If the plugin has been enabled (see section 12.1), just click on the Satellite button ⌗ on the bottom toolbar to display markers for the satellites, or use right click to call the GUI.

You can search for artificial satellites using the regular search dialog ( F3 ). Note that at any given time, most Satellites will be below the horizon.

Satellites can be either shown as white dots of appropriate brightness similar to moving stars (just like they appear to the naked eye), or as satellite-shaped markers (icons). Especially this latter view shows the huge number of satellites in orbit, most of which are invisible to the unaided eye. Satellites which are reported to transit the penumbra (twilight) zone are rendered with a subdued color.

You can display circles representing the Earth's shadow (penumbra and umbra, defined just like for Lunar eclipses, see section 19.11.2), at the altitude of the currently selected satellite, or at a fixed (configurable) altitude from Earth's surface.[31]

v 25.4

### 14.8.1 Satellite Properties

**Name** Each satellite has a name. It's displayed as a label of the satellite hint and in the list of satellites. Names are not unique though, so they are used only for presentation purposes.

**Catalog number** In the *Satellite Catalog* satellites are uniquely identified by their NORAD number, which is encoded in *TLE*s.

**I.D. (The International Designator)** In the *Satellite Catalog* satellites are also uniquely identified by their International Designator also known as *COSPAR ID*, which is encoded in TLEs.

**Standard magnitude** The *standard magnitude* may be an estimate based on the mean cross-sectional area derived from its dimensions, or it may be a mean value derived from visual observations (see section 14.8.4).

**RCS** The *Radar Cross Section* is a median value derived from the last several years of values in the Satellite Situation Report. The units of the RCS are square meters (see section 14.8.4).

**Perigee** The *perigee* is the nearest point respectively of a satellite's direct orbit around the Earth. The unit of perigee is kilometers.

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[30]TLE: `https://en.wikipedia.org/wiki/Two-line_element_set`

[31]The height of the selected satellite is computed above the WGS84 ellipsoid, while the fixed (configurable) altitude from Earth's surface is computed over the sphere. You may note these circles will deviate slightly from each other when displayed altitudes are equal.
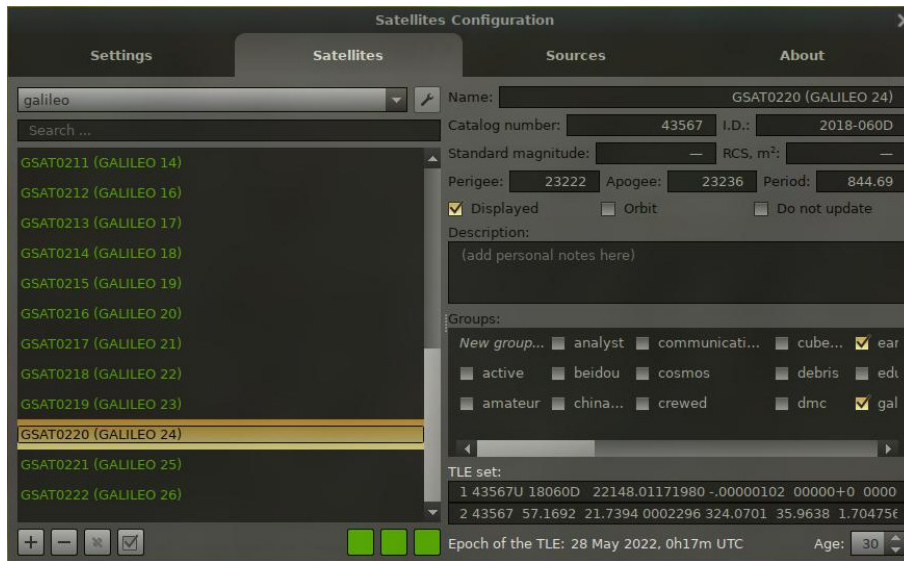
Figure 14.12: Configuration of the Satellites plugin: satellite properties

**Apogee**  The *apogee* is the farthest point respectively of a satellite's direct orbit around the Earth. The unit of apogee is kilometers.

**Period**  The orbital period is simply how long an orbiting satellite takes to complete one orbit. The unit of period is minutes.

**Displayed**  In the *Satellite Catalog* tab this property controls whether the selected satellite should be displayed on the sky.

**Orbit**  In the *Satellite Catalog* tab this property controls whether the orbit of the selected satellite should be displayed in the sky.

**Do not update**  In the *Satellite Catalog* tab this property marks satellites for which TLE should not be updated.

**Description**  The user-defined notes for the selected satellite.

**Groups**  A satellite can belong to one or more groups such as "amateur", "geostationary" or "navigation". They have no other function but to help the user organize the satellite collection. Group names are arbitrary strings defined in the Satellite Catalog for each satellite and are more similar to the concept of tags than a hierarchical grouping. A satellite may also not belong to any group at all.

By convention, group names are in lowercase. The GUI translates some of the groups used in the default catalog.

The group names also can be used as an additional filters for the satellites (see UI elements on the left side).

**TLE set**  The raw TLE data of selected satellite. A two-line element set (TLE) is a data format encoding a list of orbital elements of an Earth-orbiting object for a given point in time, the epoch. Using a suitable prediction model, the state (position and velocity) at any point in the past or future can be estimated to some accuracy.

**Epoch of the TLE**  Human-readable epoch of current TLE set.

On the left side of this tab you may see tools for filtering the satellites. The upper part shows a drop-down list with many predefined filters. Some filters are connected to user defined groups to quickly get a list of satellites in some group, such as all satellites from group "navigation". Some filters are connected to orbital properties of satellites, e.g., selecting the filter "[LEO]" will show all low-orbital satellites.

You can display a list of satellites by specific selection of their properties, when the filter "[custom filter]" has been selected (Fig. 14.13). The settings of this filter are available through the button ⌀, which is located at the right of the drop-down list.

You can edit communication data for individual satellites by pressing ⌀ (Fig. 14.14), where "Description" and "Frequency" are required fields and field "Modulation" is optional. Some individual satellites and their groups already have the communication data filled in the default catalog.

Abbreviations of some types of modulation:
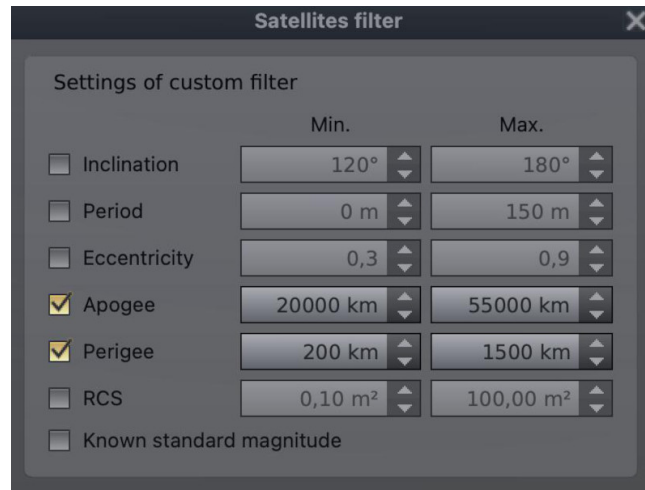
Figure 14.13: Configuration of the Satellites plugin: satellites custom filter
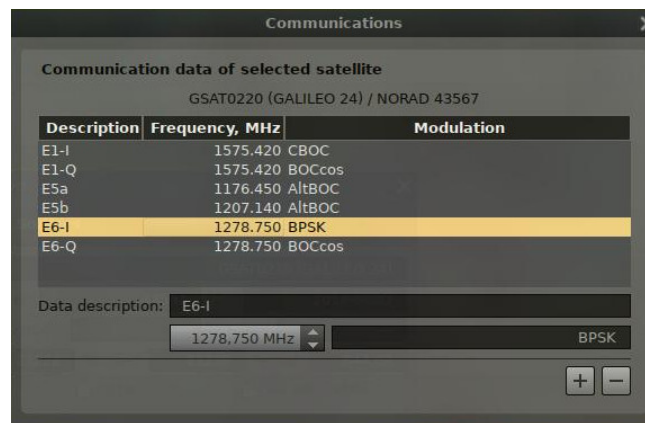


Figure 14.14: Configuration of the Satellites plugin: satellite communication data

**APT** Automatic Picture Transmission
**LRPT** Low Resolution Picture Transmission
**HRPT** High Resolution Picture Transmission
**AHRPT** Advanced High Resolution Picture Transmission
**AX.25** Amateur Radio adaptation of X.25 packet protocol
**CW** Continuous Wave, Morse Code
**AM** Amplitude Modulation
**FM** Frequency Modulation
**DUV** Data Under Voice
**FSK** Frequency Shift Keying
**GFSK** Gaussian Frequency Shift Keying
**GMSK** Gaussian Minimum Shift Keying
**AFSK** Audio Frequency Shift Keying
**ASK** Amplitude-shift Keying
**PSK** Phase-shift Keying
**BPSK** Binary Phase-shift Keying
**QPSK** Quadrature Phase-shift Keying
**OQPSK** Offset Quadrature Phase-shift Keying
**DPSK** Differential Phase-shift Keying
**BOC** Binary Offset Carrier
**MBOC** Multiplexed Binary Offset Carrier

## 14.8.2  Satellite Catalog

The satellite catalog is stored on disk in JSON[32] format, in a file named `satellites.json`. A default copy is embedded in the plug-in at compile time. A working copy is kept in the user data directory.

To add a new satellite, open a new line after line 5 and paste the following. Note the structure of commas and brackets, they are important:

```
"NORAD number":
{
  "name": "name of the satellite"
  "description": "description goes here",
  "comms": [
      {
         "description": "downlink 1",
         "frequency": 437.49,
         "modulation": "AFSK 1200 bps"
      },
      {
         "description": "downlink 2",
         "frequency": 145.825
      }
  ],
  "groups": ["group1", "group2"],
  "stdMag": 2.0,
  "tle1": "1 12345U 90005D   09080.85236265  .00000014  00000-0  20602-4 0  5632",
  "tle2": "2 12345 98.2700  53.2702 0011918  71.1776 289.0705 14.31818920   653",
  "visible": true
},
```

Explanation of the fields:

**NORAD number**  required parameter, surrounded by double quotes (`"`), followed by a colon (`:`). It is used internally to identify the satellite. You should replace the text `"NORAD number"` with the first number on both lines of the TLE set (in this case, `"12345"`). It must match the number of the satellite in the source you are adding from if you want the TLE to be automatically updated.

The remaining parameters should be listed between two curly brackets, and the closing curly bracket must be followed by a comma to separate it from the next satellite in the list:

**name**  required parameter. It will be displayed on the screen and used when searching for the satellite with the Find window. Use the description field for a more readable name if you like.

**description**  optional parameter, double quoted. Appears when you click on the satellite. The description field can accept HTML tags such as `<br/>` (new line), `<b>`**bold**`</b>`, etc.

**comms**  optional parameter, square bracketed list of curly bracketed communications information.

**groups**  optional parameter, comma separated list of double quoted group names contained in square brackets. Used for grouping satellites in the drop down box on the config (see above)

**tle1**  required, line 1 of the TLE, must be contained in double quotes and begin with `"1 "`

**tle2**  required, line 2 of the TLE, must be contained in double quotes and begin with `"2 "`

**visible**  required parameter, set to true if you want to see it, this can be toggled from the configuration window once the satellite is loaded.

**stdMag**  optional parameter, containing standard magnitude of satellite.

**rcs**  optional parameter, containing the satellite's *Radar Cross Section*. The units of the RCS are square meters.

You can edit the tags for a satellite, modify the description and comms data, and even add new satellites.

## 14.8.3  Configuration

The plug-in's configuration data is stored in Stellarium's main configuration file.

## 14.8.4  The approximated visual magnitude

To calculate an approximated visual magnitude of satellites we use the radar cross section (RCS) data and standard magnitudes from Mike McCants' database (with permissions)[33]; the radar cross section (RCS) data from CelesTrack database[34]; the standard magnitudes from database of the MMT-9 observatory (belongs to

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[32]`https://www.json.org/`

[33]Mike McCants' Satellite Tracking Web Pages — `https://mmccants.org`

[34]Satellite Catalog (SATCAT) — `https://celestrak.org/satcat/search.php`
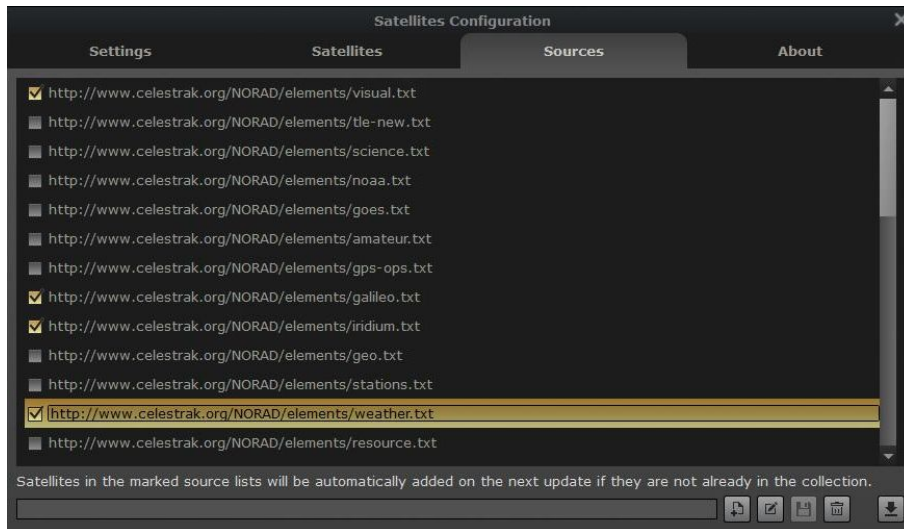
Figure 14.15: Configuration of the Satellites plugin: sources for TLE data

Kazan Federal University) (Beskin et al., 2017; Karpov et al., 2016).

We use a spherical shape of satellite to calculate an approximated visual magnitude from RCS values. For modelling Starlink visual magnitudes we use Anthony Mallama's formula[35] (Mallama, 2020) and Mike McCants' formula[36] for other satellites.

### 14.8.5 Sources for TLE data

TLE sets have to be accessed online. Occasionally the source path changes, and configurations set up with previous versions may no longer be available. Use the bottom right button in the Sources tab (Figure 14.15) to restore the installation defaults.

**Celestrak** [37] used as default update source, it also has TLE lists beyond those included by default in Satellite plug-in

**TLE.info** [38]

**Space Track** [39] the definitive source, requires sign-up, operated by United States Department of Defense

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[35]http://www.satobs.org/seesat/Aug-2020/0079.html

[36]https://mmccants.org/tles/mccdesc.html

[37]https://celestrak.org/NORAD/elements/

[38]https://www.tle.info/joomla/index.php

[39]https://www.space-track.org/

## 14.9    ArchaeoLines Plugin

GEORG ZOTTI



Figure 14.16: Declination Lines provided by the ArchaeoLines plugin

### 14.9.1    Introduction

In the archaeoastronomical literature, several astronomically derived orientation schemes are prevalent. Often prehistorical and historical buildings are described as having been built with a main axis pointing to a sunrise on summer or winter solstice. There can hardly be a better tool than Scenery3D (see chapter 15) to investigate a 3D model of such a building, and this plugin has been introduced in version 0.13.3 as a further tool in the archaeoastronomer's toolbox (Zotti, 2016b).

When activated (see section 12.1), you can find a a tool bar button ⊓ (in the shape of a *trilithon* with the sun shining through it). Press this, or Ctrl + U , to display the currently selected set of characteristical diurnal arcs.

### 14.9.2    Characteristic Declinations

The ArchaeoLines plugin displays any combination of declination arcs $\delta$ most relevant to archaeo- or ethnoastronomical studies. Of course, principles used in this context are derived from natural observations, and many of these declinations are still important in everyday astronomy.

- Declinations of equinoxes (i.e., the equator, $\delta = 0$) and the solstices ($\delta = \pm\varepsilon$)
- Declinations of the crossquarter days (days between solstices and equinoxes, $\delta(\lambda = \pm45°)$)
- Declinations of the Major Lunar Standstills ($\delta = \pm(\varepsilon + i)$)
- Declinations of the Minor Lunar Standstills ($\delta = \pm(\varepsilon - i)$)
- Declination of the Zenith passage ($\delta = \varphi$)
- Declination of the Nadir passage ($\delta = -\varphi$)
- Declination $\delta$ of the currently selected object
- Current declination $\delta_{\odot}$ of the sun
- Current declination $\delta_{\leftmoon}$ of the moon
- Current declination $\delta_P$ of a naked-eye planet

The principal relation between declinations $\delta$, geographic latitude $\varphi$, and the rising azimuth $A$ is computed from

$$\cos A = -\frac{\sin \delta}{\cos \varphi}. \tag{14.1}$$

This formula does not take into account local horizon elevation nor atmospheric refraction nor lunar parallax correction. The effect applied to characteristic declinations is shown graphically for the present time
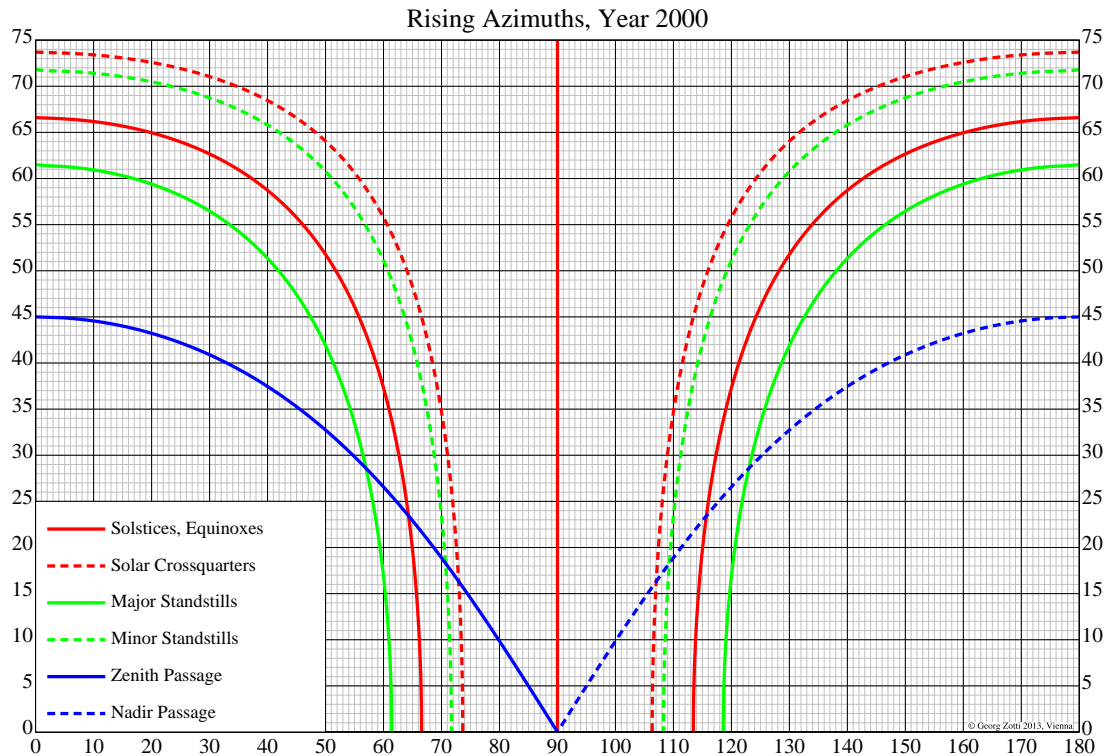
Figure 14.17: Rising azimuths of a few important events for sun and moon, and zenith and nadir passages depending on geographic latitudes (vertical axis).

(J2000.0) in figure 14.17. For example, in a latitude of 30°, an object which goes through the zenith rises at azimuth 55°. Lunar major standstill risings occur at azimuths 56.7° and 123.5°, lunar minor standstill risings at azimuths 69° and 111°. The summer solstice sun rises at 62.6°, the winter solstice sun at 117.3°. An object which goes through the nadir rises at 125°.

The blue lines seem to vanish at $\varphi = 45°$: while there are still objects going through the zenith in higher latitudes, they are *circumpolar* and do not cross the horizon.

For the lunar events, there are two lines each drawn by the plugin, for maximum and minimum distance of the moon. The lunar extreme declinations are computed taking horizon parallax effects into account. For technical reasons however, the derived declinations are then used to draw *small circles* of constant declinations on the sphere, without taking the change of lunar horizontal parallax into account. Note that therefore the observed declination of the moon at the major standstill can exceed the indicated limits if it is high in the sky. The main purpose of this plugin is however to show an indication of the intersection of the standstill lines with the horizon.

It may be very instructive to let the time run quite fast and observe the declination line of "current moon" swinging between its north and south limits each month. These limits grow and shrink between the Major and Minor Standstills in the course of 18.6 years.

The sun likewise swings between the *solstices*. Over centuries, the solstice declinations very slightly move as well due to the slightly changing *obliquity of the ecliptic*.

## 14.9.3 Geographical Targets

Some religions, e.g., Islam or Bahai, adhere to a practice of observing a prayer direction towards a particular location. Azimuth lines for two locations can be shown, these lines indicate the great circle direction towards the locations which can be edited in the configuration window. Default locations are Mecca (Kaaba) and Jerusalem. The azimuth $q$ towards a location $T = (\lambda_T, \varphi_T)$ can be computed for an observer at $O = (\lambda_O, \varphi_O)$ based on spherical trigonometry on a spherical Earth (Abdali, 1997) as

$$q = \arctan \frac{\sin(\lambda_T - \lambda_O)}{\cos \varphi_O \tan \varphi_T - \sin \varphi_O \cos(\lambda_T - \lambda_O)} \tag{14.2}$$

You can set geographical coordinates and a name label directly, or select locations from Stellarium's location list by pressing the Pick... button. You can search for locations in the list. When you click on a location, its data are taken as target.

### 14.9.4 Custom Lines

In addition, lines can be shown which indicate arbitrary azimuths (great circles through the zenith), altitudes, and declinations. Note that these azimuths are always counted from north, regardless of the azimuth setting described in section 4.3.5. These lines can be marked with a custom label.

When some celestial object is selected, you can take over its current respective data and name by pressing the ⊕ button, however the lines are *not* linked to the selected objects, and changing angle values or time will make labels invalid.

### 14.9.5 Configuration Options

The configuration dialog allows the selection of the lines which are of interest to you. In addition, you can select the color of the lines by clicking on the color swatches.

### Section [ArchaeoLines] in config.ini file

| ID | Type | Default | |
|---|---|---|---|
| enable_at_startup | bool | false | |
| line_thickness | int | 1 | |
| color_equinox | float R,G,B | 1.00,1.00,0.50 | |
| color_solstices | float R,G,B | 1.00,1.00,0.25 | |
| color_crossquarters | float R,G,B | 1.00,0.75,0.25 | |
| color_major_standstill | float R,G,B | 0.25,1.00,0.25 | |
| color_minor_standstill | float R,G,B | 0.20,0.75,0.20 | |
| color_zenith_passage | float R,G,B | 1.00,0.75,0.75 | |
| color_nadir_passage | float R,G,B | 1.00,0.75,0.75 | |
| color_selected_object | float R,G,B | 1.00,1.00,1.00 | |
| color_current_sun | float R,G,B | 1.00,1.00,0.75 | |
| color_current_moon | float R,G,B | 0.50,1.00,0.50 | |
| color_current_planet | float R,G,B | 0.25,0.80,1.00 | |
| color_geographic_location_1 | float R,G,B | 0.25,1.00,0.25 | |
| color_geographic_location_2 | float R,G,B | 0.25,0.25,1.00 | |
| color_custom_azimuth_1 | float R,G,B | 0.25,1.00,0.25 | |
| color_custom_azimuth_2 | float R,G,B | 0.25,0.50,0.75 | |
| color_custom_altitude_1 | float R,G,B | 0.25,1.00,0.25 | |
| color_custom_altitude_2 | float R,G,B | 0.25,0.50,0.75 | |
| color_custom_declination_1 | float R,G,B | 0.45,1.00,0.15 | |
| color_custom_declination_2 | float R,G,B | 0.45,0.50,0.65 | |
| show_equinox | bool | true | |
| show_solstices | bool | true | |
| show_crossquarters | bool | true | |
| show_major_standstills | bool | true | |
| show_minor_standstills | bool | true | |
| show_zenith_passage | bool | true | |
| show_nadir_passage | bool | true | |
| show_selected_object | bool | true | |
| show_current_sun | bool | true | |
| show_current_moon | bool | true | |
| show_current_planet | string | none | |
| show_geographic_location_1 | bool | false | |

| | | |
|---|---|---|
| show_geographic_location_2 | bool | false |
| geographic_location_1_longitude | double | 39.826175 |
| geographic_location_1_latitude | double | 21.4276 |
| geographic_location_1_label | string | Mecca (Qibla) |
| geographic_location_2_longitude | double | 35.235774 |
| geographic_location_2_latitude | double | 31.778087 |
| geographic_location_2_label | string | Jerusalem |
| show_custom_azimuth_1 | bool | false |
| show_custom_azimuth_2 | bool | false |
| custom_azimuth_1_angle | double | 0.0 |
| custom_azimuth_2_angle | double | 0.0 |
| custom_azimuth_1_label | string | custAzi1 |
| custom_azimuth_2_label | string | custAzi2 |
| show_custom_altitude_1 | bool | false |
| show_custom_altitude_2 | bool | false |
| custom_altitude_1_angle | double | 0.0 |
| custom_altitude_2_angle | double | 0.0 |
| custom_altitude_1_label | string | custAlt1 |
| custom_altitude_2_label | string | custAlt2 |
| show_custom_declination_1 | bool | false |
| show_custom_declination_2 | bool | false |
| custom_declination_1_angle | double | 0.0 |
| custom_declination_1_label | string | custDec1 |
| custom_declination_2_angle | double | 0.0 |
| custom_declination_2_label | string | custDec2 |
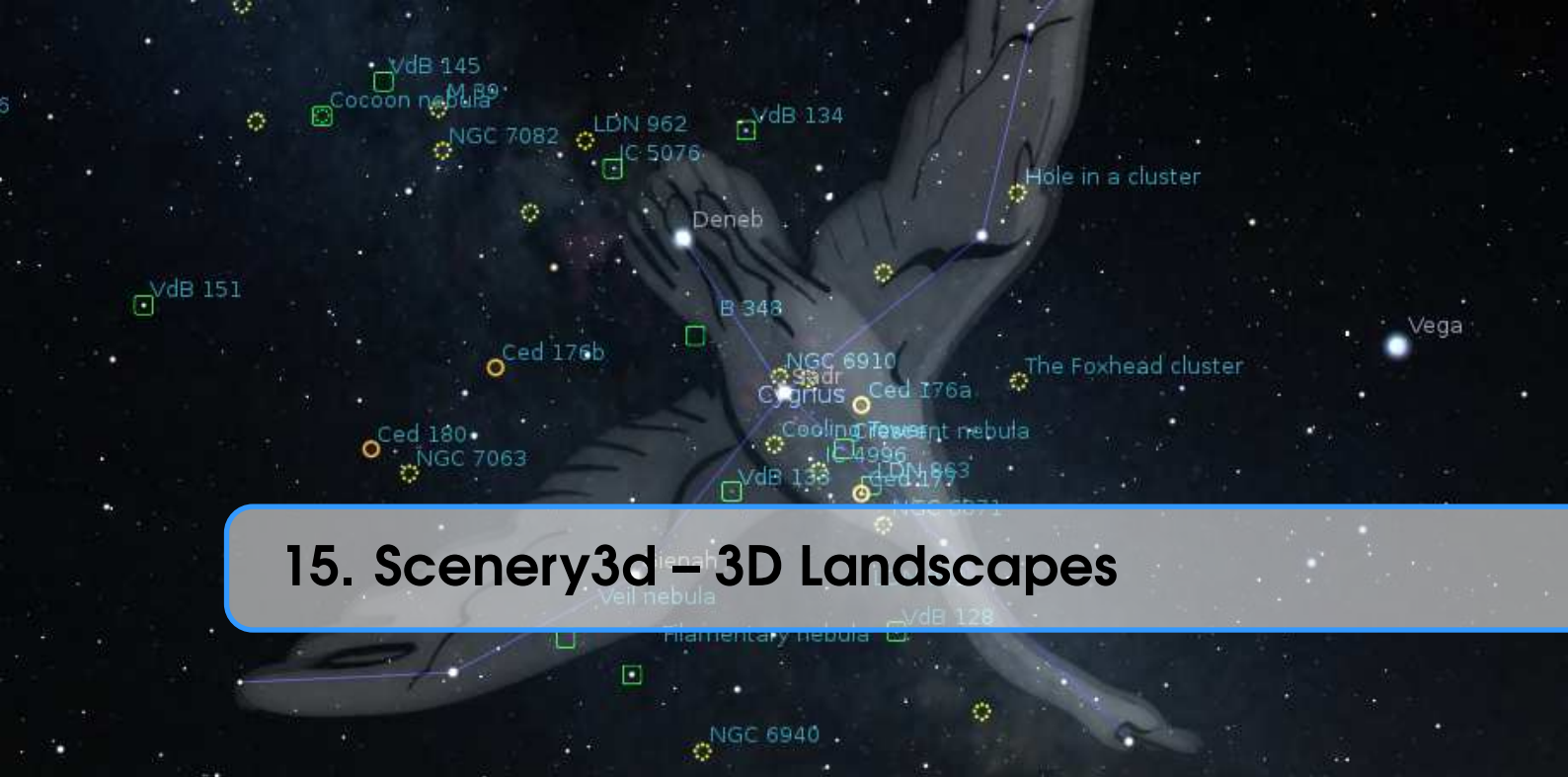
### 14.9.6 Acknowledgements

If you are using this plugin in scientific publications, please cite Zotti (2016b).

# 15. Scenery3d – 3D Landscapes

GEORG ZOTTI AND FLORIAN SCHAUKOWITSCH

## 15.1 Introduction

Have you ever wished to be able to walk through Stonehenge or other ancient building structures described as being constructed with astronomical orientation in mind, and experience such orientation in a 3D virtual environment that also provides a good sky simulation?

The Stellarium Scenery3d plugin allows you to see architectural 3D models embedded in a landscape combined with the excellent representation of the sky provided by Stellarium. You can walk around, check for (or demonstrate) possible astronomical alignments of ancient architecture, see sundials and other shadow casters in action, etc.

## 15.2 Usage

You activate the plugin with the *circular enclosure* button ⟨⊛⟩ at screen bottom or by pressing `Ctrl`+`W`. A right-click on that button (or `Ctrl`+`⇧`+`W`) opens the settings dialog. Once loaded and displaying, you can walk around pressing `Ctrl` plus cursor keys. Change eye height with `Ctrl`+`Page↑`/`Ctrl`+`Page↓` keys. Adding `⇧` key increases speed by 10, adding `Alt` multiplies by 5 (pressing both keys multiplies by 50!). If you release `Ctrl` before the cursor key, animation will continue. (Press `Ctrl`+any cursor key to stop moving.)

Further key bindings exist which can be configured using the Stellarium default key-binding interface. Some options are also available in the Scenery3d dialog. For example, coordinate display can be enabled with `Ctrl`+`R`+`T`. If your models are georeferenced in a true geographical coordinate grid, e.g. UTM or Gauss-Krueger, you will especially like this, and this makes the plugin usable for scientific purposes. Display shows grid name, Easting, Northing, Altitude of ground, and eye height above ground.

Other features include a virtual "torchlight", which can be enabled with `Ctrl`+`R`+`L` to give additional local illumination around the viewer to help to see in the dark. Interesting points of view can be saved and restored later by the user, including a description of the view. Scene authors can also distribute predefined viewpoints in their scene.

The plugin also simulates the shadows of the scene's objects cast by the Sun, Moon and even Venus (only 1 shadow caster used at a time, you will never see shadows cast by Venus in moonlight), so you could use it for examining sundials, or analyze and simulate light-and-shadow interactions in archaeological structures.

Sometimes, light patches cast through small holes are important, e.g., in churches with *meridiana* "sundial/calendar" lines. If these patches appear too dim, you can increase the power of the directional light using the `Directional light enhancement` switch. (Use value 1.0 to revert to normal.)

## 15.3   Hardware Requirements & Performance

In order to work with the non-linear projection models in Stellarium, this plugin uses a trick to create the foreground renderings: it renders the scene into the six planes of a so-called cubemap, which is then correctly reprojected onto the sides of a cube, depending on the current projection settings. Your graphics card must be able to do this, i.e. it must support the OpenGL extension called `EXT_framebuffer_object`. Typical modern 3D cards (by Nvidia or ATI/AMD) support this extension. In case your graphics hardware does not support it, the plugin will still work, but you are limited to perspective projection.

You can influence rendering quality, but also speed, using the plugin's GUI, which provides some options such as enabling the use of shadows, bumpmapping (provides more realistic surface lighting) or configuring the sizes of the textures used for the cubemap or shadowmaps. Larger values there improve the quality, but require faster hardware and more video memory for smooth results.

Because the "cubemap trick" requires quite a large amount of performance (in essence, the scene has to be rendered 6 times), there are some options available that try to reduce this burden. The first option is to change the type of the "cubemap". The most compatible setting is *6 textures*, which seems to work best on older integrated Intel GPUs. The recommended default is the second setting, *Cubemap*, which uses a more modern OpenGL feature and generally works a bit faster than *6 textures* on more modern graphics cards. Finally, the *Geometry shader* option tries to render all 6 cube faces at once. This requires a more recent GPU + drivers (at least OpenGL 3.2 must be supported), the setting is disabled otherwise. Depending on your hardware and the scene's complexity, this method may give a speedup or may be slower, you must find this out yourself.

Another option prevents re-rendering of the cubemap if nothing relevant has changed. You can define the interval (in Stellarium's simulation time) in which nothing is updated in the GUI. You can still rotate the camera without causing a re-draw, giving a subjective performance that is close to Stellarium's performance without Scenery3d. When moving, the cubemap will be updated. You can enable another option that only causes 1 or 2 sides of the cubemap to be updated while you move, giving a speedup but causing some parts of the image to be outdated and discontinuous. The cubemap will be completed again when you stop moving.

Shadow rendering may also cause quite a performance impact. The *Simple shadows* option can speed this up a lot, at the cost of shadow quality especially in larger scenes. Another performance/quality factor is shadow filtering. The sharpest (and fastest) possible shadows are achieved with filtering *Off*, but depending on shadowmap resolution and scene size the shadows may look quite "blocky". *Hardware* shadow filtering is usually very fast, but may not improve appearance a lot. Therefore, there are additional filter options available, the *High* filter option is relatively expensive. Finally, the *PCSS* option allows to approximate the increase of solar and lunar shadow penumbras relative to the distance from their shadow casters, i.e. shadows are sharp near contact points, and more blurred further away. This again requires quite a bit of performance, and only works if the shadow filter option is set to *Low* or *High* (without *Hardware*).

The configuration GUI shows tooltips for most of its settings, which can explain what a setting does. All settings are saved automatically, and restored when you reopen Stellarium.

### 15.3.1   Performance notes

This plugin clearly runs better with proper 3D graphics cards. On reasonably good hardware (tested on a notebook PC with Nvidia M960), models with over 10.000.000 triangles are working nicely with shadows and bumpmaps, although your mileage may vary. On very small hardware like single-board computers with native OpenGL ES2, models may be limited to 64k vertices (points). If display is too slow, switch to perspective projection: all other projections require almost sixfold effort! Or try the "lazy" cubemap mode and lazy updates of tiles, where the scene is only rendered in specific timesteps or when movement happens.

## 15.4   Model Configuration

The model format supported in Scenery3d is Wavefront .OBJ, which is pretty common for 3D models. You can use several modeling programs to build your models. Software such as **Blender**, **Maya**, **3D Studio Max** etc. can export OBJ.

### 15.4.1   Exporting OBJ from Sketchup

A simple to use and cost-free modeling program is **Sketchup**, commonly used to create the 3D buildings seen in **Google Earth**. It can be used to create georeferenced models. OBJ is not a native export format for the standard version of **Sketchup**. If you are not willing to afford **Sketchup Pro**, you have to find another way to export a textured OBJ model.

| Geometry | Yes |
|---|---|
| Lights | Yes |
| Clay | No |
| Photomatched | Yes |
| DefaultUVs | No |
| Instanced | No |

Table 15.1: Kerkythea Export Settings

One good exporter is available in the **Kerkythea** renderer project[1]. You need **SU2KT 3.17** or better, and **KT2OBJ 1.1.0** or better. Deselect any selection, then export your model to the **Kerkythea** XML format with settings shown in 15.1. (Or, with selection enabled, make sure settings are No-Yes-Yes-No-Yes-No-No.) You do not have to launch **Kerkythea** unless you want to create nice renderings of your model. Then, use the **KT2OBJ** converter to create an OBJ. You can delete the XML after the conversion. Note that some texture coordinates may not be exported correctly. The setting `Photomatched:Yes` seems now to have corrected this issue, esp. with distorted/manually shifted textures.

Another free OBJ exporter has been made available by TIG: `OBJexporter.rb`[2]. This is the only OBJ exporter tested so far capable of handling large TIN landscapes (> 450.000 triangles). As of version 2.6 it seems to be the best OBJ exporter available for **Sketchup**.

This exporter swaps Y/Z coordinates, but you can add a key to the config file to correct swapped axes, see below. Other exporters may also provide coordinates in any order of X, Y, Z – all those can be properly configured.

Another quirk has to be fixed manually though: in the material description file (MTL), TIG's exporter writes both d and Tr lines with the same value. Actually, $Tr = 1.0 - d$ according to OBJ/MTL documentation, so you should edit away one line, or else the later line overwrites the value given earlier. Moreover, given that `Tr=1` should actually specify fully transparent objects, such a line will make your object entirely invisible!

Another (almost) working alternative: `ObjExporter.rb` by author Honing. Here, export with settings `0xxx00`. This will not create a `TX...` folder but dump all textures in the same directory as the OBJ and MTL files. Unfortunately, currently some material assignments seem to be bad.

### 15.4.2 Notes on OBJ file format limitations

The OBJ format supported is only a subset of the full OBJ format: Only (optionally textured) triangle meshes are supported, i.e., only lines containing statements: `mtllib`, `usemtl`, `v`, `vn`, `vt`, `f` (with three elements only!), `g`. Negative vertex numbers (i.e., a specification of relative positions) are not supported.

A further recommendation for correct illumination is that all vertices should have vertex normals. **Sketchup** models exported with the **Kerkythea** or TIG plugins should have correct normals. If your model does not provide them, default normals can be reconstructed from the triangle edges, resulting in a faceted look.

If possible, the model should also be triangulated, but the current loader may also work with non-triangle geometry. The correct use of objects (o) and groups (g) will improve performance: it is best if you pre-combine all objects that use the same material into a single one. The loader will try to optimize it anyways if this is not the case, but can do this only partly (to combine 2 objects with the same material into 1, it requires them to follow directly after each other in the OBJ). A simple guide to use **Blender**[3] for this task follows:

1. File ⟩ Import ⟩ Wavefront .obj - you may need to change the forward/up axes for correct orientation, try "-Y forward" and "Z up"
2. Select an object which has a shared material
3. Press ⇧ + L and select 'By Material'
4. Select 'Join' in the left (main) tool window
5. Repeat for other objects that have shared materials
6. Export the .obj, making sure to select the same forward/up axes as in the import, also make sure "Write Normals", "Write Materials" and "Include UVs" are checked

---

[1] Available at `http://www.kerkythea.net/cms/`

[2] Available from `http://forums.sketchucation.com/viewtopic.php?f=323&t=33448`

[3] `https://www.blender.org`

| Parameter | Default | Range | Meaning |
|---|---|---|---|
| Ka | set to Kd values | 0…1 each | R/G/B Ambient color |
| Kd | 0.8 0.8 0.8 | 0…1 each | R/G/B Diffuse color |
| Ke | 0.0 0.0 0.0 | 0…1 each | R/G/B Emissive color |
| Ks | 0.0 0.0 0.0 | 0…1 each | R/G/B Specular color |
| Ns | 8.0 | 0…∞ | shinyness |
| d or Tr | 1.0 | 0…1 | opacity |
| bAlphatest | 0 | 0 or 1 | perform alpha test |
| bBackface | 0 | 0 or 1 | render backface |
| map_Kd | (none) | filename | texture map to be mixed with Ka, Kd |
| map_Ke | (none) | filename | texture map to be mixed with Ke |
| map_bump | (none) | filename | normal map for surface roughness |
| illum | 2 | integer | illumination mode in the standard MTL format. |
| vis_fadeIn | (none) | double | see 15.4.5 |
| vis_fadeOut | (none) | double | see 15.4.5 |

Table 15.2: MTL parameters evaluated

For transparent objects (with a `d` or `Tr` value, alpha testing does NOT need this), this recommendation does NOT hold: for optimal results, each separate transparent object should be exported as a separate "OBJ object". This is because they need to be sorted during rendering to achieve correct transparency. If the objects are combined already, you can separate them using **Blender**:

1. Import .obj (see above)
2. Select the combined transparent object
3. Enter "Edit" mode with ⇥ and make sure everything is selected (press A if not)
4. Press P and select "By loose parts", this should separate the object into its unconnected regions
5. Export .obj (see above), also check "Objects as OBJ Objects"

The MTL file specified by `mtllib` contains the material parameters. The minimum that should be specified is either `map_Kd` or a `Kd` line specifying color values used for the respective faces. But there are other options in MTL files, and the supported parameters and defaults are listed in Table 15.2.

If no ambient color is specified, the diffuse color values are taken for the ambient color. An optional emissive term `Ke` can be added, which is modulated to only be visible during nighttime. This also requires the landscape's self-illumination layer to be enabled. It allows to model self-illuminating objects such as street lights, windows etc. It can optionally also be modulated by the emissive texture `map_Ke`.

If a value for `Ks` is specified, specularity is evaluated using the Phong reflection model[4] with `Ns` as the exponential shininess constant. Larger shininess means smaller specular highlights (more metal-like appearance). Specularity is not modulated by the texture maps. Unfortunately, some 3D editors export unusable default value combinations for `Ks` and `Ns`. **Blender** may create lines with `Ks=1/1/1` and `Ns=0`. This creates a look of "partial overexposed snow fields". While the values are allowed in the specification, in most cases the result looks ugly. *Make sure to set `Ns` to 1 or higher, or disable those two lines.*

If a value for `d` or `Tr` exists, alpha blending is enabled for this material. This simulates transparency effects. Transparency can be further controlled using the alpha channel of the `map_Kd` texture.

A simpler and usually more performant way to achieve simple "cutout" transparency effects is alpha-testing, by setting `bAlphatest` to 1. This simply discards all pixels of the model where the alpha value of the `map_Kd` is below the `transparency_threshold` value from `scenery3d.ini`, making "holes" in the model. This also produces better shadows for such objects. If required, alpha testing can be combined with "real" blending-based transparency.

Sometimes, exported objects only have a single side ("paper wall"), and are only visible from one side when looked at in Scenery3d. This is caused by an optimization called *back-face culling*[5], which skips drawing the back sides of objects because they are usually not visible anyway. If possible, avoid such "thin" geometry, this will also produce better shadows on the object. As a workaround, you can also set `bBackface` to 1 to disable back-face culling for this material.

The optional `map_bump` enables the use of a tangent-space normal maps[6], which provides a dramatic

---

[4]`https://en.wikipedia.org/wiki/Phong_reflection_model`
[5]`https://en.wikipedia.org/wiki/Back-face_culling`
[6]`https://en.wikipedia.org/wiki/Normal_mapping`

improvement in surface detail under illumination.

## 15.4.3 Configuring OBJ for Scenery3d

The walkaround in your scene can use a ground level (piece of terrain) on which the observer can walk. The observer eye will always stay "eye height" above ground. Currently, there is no collision detection with walls implemented, so you can easily walk through walls, or jump on high towers, if their platform or roof is exported in the ground layer. If your model has no explicit ground layer, walk will be on the highest surface of the scenery layer. If you use the special name `NULL` as ground layer, walk will be above `zero_ground_height` level.

Technically, if your model has cavities or doors, you should export your model twice. Once, just the ground plane, i.e. where you will walk. Of course, for a temple or other building, this includes its socket above soil, and any steps, but pillars should not be included. This plane is required to compute eye position above ground. Note that it is not possible to walk in several floors of a building, or in a multi-plane staircase. You may have to export several "ground" planes and configure several scenery directories for those rare cases. For optimal performance, the ground model should consist of as few triangles as you can tolerate.

The second export includes all visible model parts, and will be used for rendering. Of course, this requires the ground plane again, but also all building elements, walls, roofs, etc.

If you have not done so by yourself, it is recommended to separate ground and buildings into Sketchup layers (or similar concepts in whichever editor you are using) in order to easily switch the model to the right state prior to exporting.

Filename recommendations:

| | |
|---|---|
| `<Temple>.skp` | Name of a Sketchup Model file. (The `<>` brackets signal "use your own name here!") The SKP file is not used by Scenery3d, but you may want to leave it in the folder for later improvements. |
| `<Temple>.obj` | Model in OBJ format. |
| `<Temple>_ground.obj` | Ground layer, if different from Model file. |

OBJ export may also create folders `TX_<Temple>` and `TX_<Temple>_ground`. You can delete the folder `TX_<Temple>_ground`, `<Temple>_ground.obj` is just used to compute vertical height.

Put the OBJ, MTL and TX directories into a subdirectory of your user directory (see section 5.1), e.g. `<USERDATA>/Stellarium/scenery3d/<Temple>`, and add a text file into it called `scenery3d.ini` (This name is mandatory!) with content described as follows.

```
[model]
```

| | |
|---|---|
| `name=<Temple>` | Unique ID within all models in scenery3d directory. Recommendation: use directory name. |
| `landscape=<landscapename>` | Name of an available Stellarium landscape. |

This is required if the landscape file includes geographical coordinates and your model does not: First, the location coordinates of the `landscape.ini` file are used, then location coordinates given here. The landscape also provides the background image of your scenery. If you want a zero-height (mathematical) horizon, use the provided landscape called `Zero Horizon`.

| | |
|---|---|
| `scenery=<Temple>.obj` | The complete model, including visible ground. |
| `ground=<Temple>_ground.obj` | Optional: separate ground plane. (NULL for zero altitude.) |
| `description=<Description>` | A basic scene description (including HTML tags) |

The `scenery3d.ini` may contain a simple scene description, but it is recommended to use the *localizable* description format: in the scene's directory (which contains `scenery3d.ini`) create files in the format `description.<lang>.utf8` which can contain arbitrary UTF-8–encoded HTML content. `<lang>` stands for the ISO 639 language code.

| | |
|---|---|
| `author=<Your Name yourname@yourplace.com>` | |
| `copyright=<Copyright Info>` | |
| `obj_order=XYZ` | Use this if you have used an exporter which swaps Y/Z coordinates. Defaults to XYZ, other options: XZY, YZX, YXZ, ZXY, ZYX |
| `camNearZ=0.3` | This defines the distance of the camera near plane, default 0.3. Everything closer than this value to the camera can not be displayed. Must be larger than zero. It may seem tempting to set this very small, but this will lead to accuracy issues. Recommendation is not to go under 0.1 |
| `camFarZ=10000` | Defines the maximal viewing distance, default 10000. |

| | |
|---|---|
| `shadowDistance=<val>` | The maximal distance shadows are displayed. If left out, the value from `camFarZ` is used here. If this is set to a smaller value, this may increase the quality of the shadows that are still visible. |
| `shadowSplitWeight=0..1` | Decimal value for further shadow tweaking. If you require better shadows up close, try setting this to higher values. The default is calculated using a heuristic that incorporates scene size. |

`[general]`

The general section defines some further import/rendering options.

| | |
|---|---|
| `transparency_threshold=0.5` | Defines the alpha threshold for alpha-testing, as described in section 15.4.2. Default `0.5` |
| `scenery_generate_normals=0` | Boolean, if true normals are recalculated by the plugin, instead of imported. Default `false` |
| `ground_generate_normals=0` | Boolean, same as above, for ground model. Default `false`. |

`[location]`

Optional section to specify geographic longitude $\lambda$, latitude $\varphi$, and altitude. The section is required if `coord/convergence_angle={from_grid|from_utm}`, else location is inherited from landscape.

```
planet = Earth
latitude = +48d31'30.4"
longitude = +16d12'25.5"
altitude =from_model|<int>
```

| | |
|---|---|
| `latitude = +48d31'30.4"` | Required if `coord/convergence_angle=from_{grid|utm}` |
| `longitude = +16d12'25.5"` | `"–"` |
| `altitude =from_model|<int>` | altitude (for astronomical computations) can be computed from the model: if `from_model`, it is computed as $(z_{min} + z_{max})/2 + \texttt{orig\_H}$, i.e. from the model bounding box centre height. |

```
display_fog = 0
atmospheric_extinction_coefficient = 0.2
atmospheric_temperature = 10.0
atmospheric_pressure = -1
light_pollution = 1
[coord]
```

Entries in the `[coord]` section are again optional, default to zero when not specified, but are required if you want to display meaningful eye coordinates in your survey (world) coordinate system, like UTM or Gauss-Krüger.

| | |
|---|---|
| `grid_name=<string>` | Name of grid coordinates, e.g. `"UTM 33 U (WGS 84)"`, `"Gauss-Krüger M34"` or `"Relative to <Center>"` This name is only displayed, there is no evaluation of its contents. |
| `orig_E=<double>  \| (Easting)` | East-West-distance to zone central meridian |
| `orig_N=<double>  \| (Northing)` | North distance from Equator |
| `orig_H=<double>  \| (Height)` | Altitude above Mean Sea Level of model origin |

These entries describe the offset, in metres, of the model coordinates relative to coordinates in a geographic grid, like Gauss-Krüger or UTM. If you have your model vertices specified in grid coordinates, do not specify `orig_...` data, but please definitely add `start_...` data, below.

Note that using grid coordinates without offset for the vertices is usually a bad idea for real-world applications like surveyed sites in UTM coordinates. Coordinate values are often very large numbers (ranging into millions of meters from equator and many thousands from the zone meridian). If you want to assign millimetre values to model vertices, you will hit numerical problems with the usual single-precision floating point arithmetic. Therefore we can specify this offset which is only necessary for coordinate display.

Typically, digital elevation models and building structures built on those are survey-grid aligned, so true geographical north for a place with geographical longitude $\lambda$ and latitude $\varphi$ will in general not coincide with grid north, the difference is known as *meridian convergence*[7] and, on a spherical globe, amounts to:

$$\gamma(\lambda, \varphi) = \arctan(\tan(\lambda - \lambda_0)\sin\varphi) \tag{15.1}$$

---

[7]`https://en.wikipedia.org/wiki/Transverse_Mercator_projection`

This amount can be given in `convergence_angle` (degrees), so that your model will be rotated clockwise by this amount around the vertical axis to be aligned with True North[8].

```
convergence_angle=from_grid|from_utm|<double>
grid_meridian=<double>|+<int>d<int>'<float>"
```

`grid_meridian` is the central meridian $\lambda_0$ of the grid zone, e.g. for Gauss-Krüger, and is only required to compute convergence angle if `convergence_angle=from_grid`. If your model coordinates is based on UTM, you can use `coord/convergence_angle=from_utm` for a more accurate computation.

```
zero_ground_height=<double>
```

height of terrain outside `<Temple>_ground.OBJ`, or if `ground=NULL`. Allows smooth approach from outside. This value is relative to the model origin, or typically close to zero, i.e., use a Z value in model coordinates, not world coordinates! (If you want the terrain height surrounding your model to be `orig_H`, use 0, not the correct mean height above sea level!) Defaults to minimum of height of ground level (or model, resp.) bounding box.

```
        start_E=<double>
        start_N=<double>
        start_H=<double>        only meaningful if ground==NULL, else H is derived from ground
        start_Eye=<double>    default: 1.65m
        start_az_alt_fov=<az_deg>,<alt_deg>,<fov_deg>
                              initial view direction and field of view.
```

`start_...` defines the view position to be set after loading the scenery. Defaults to center of model boundingbox.

It is advisable to use the grid coordinates of the location of the panoramic photo (landscape) as `start_...` coordinates, or the correct coordinates and some carefully selected `start_az_alt_fov` in case you want to highlight a certain view corridor (temple axis, . . . ).

In some setups like digital full-dome planetaria it is advisable to disable the use of the `start_az_alt_fov`. You can do that in the Scenery3D configuration dialog or by the entry `ignore_start_az_alt_fov` in `config.ini`.                                                                                     v 23.2

### 15.4.4 Concatenating OBJ files

Some automated workflows may involve tiled landscape areas, e.g. to overcome texture limitations or triangle count limits in simpler tools like **Sketchup**. In this case you can create separate meshes in the same coordinate system, but you need to concatenate them. One powerful program to assemble your parts is again **Blender**.

In **Blender**, import the OBJ files File ≫ Import ≫ Wavefront .obj . If your OBJ coordinates have Z as vertical axis (common for terrestrial models), use "Z up", "-Y Forward" as import settings for the coordinate axes. The model will appear south-up.

Blender may not show anything except the default cube because of aggressive camera far plane clipping. Press N and in the View set at least the far clipping plane as required to see the full extent of your terrain model. Then press View ≫ View All (or Home ).

The landscape may look white now. Switch on textured view if required ( Alt + Z ). If the scene looks almost black now, reconfigure the light to be sunlight: Select the lamp in the outliner graph, press the lamp icon and in the Lamp select "Sun". Now the scene should be in full color, and the Y axis should point towards grid-south.

After importing the first model, you may consider locking it in place to avoid errors. Select the model in the outliner, select the cube button below, then open Transform Locks and lock all. The other model parts may have to be transformed, and numerical transformation can be added in the Transform settings in this menu.

If you have created a VRML (WRL) of some structures in **ArcScene**, export that without shifting to center, and import the WRL file in **Blender** with default orientation "Y up", "Z forward". Models from other sources may still be different.

In the end, all parts should fit neatly together. **Blender** is a very powerful program, you can enhance your model as you wish.

---

[8]Note that Sketchup's *georeferencing dictionary* provides a NorthAngle entry, which is $360 -$ `convergence_angle`.

When the model configuration is complete, select all relevant parts which you want to have visible in Stellarium (click on the lines in the outline view containing the object names to light them up gray, then Rightclick-Select, so that the triangle (mesh) icon has a colored background circle) and press [Ctrl]+[ J ] to optionally join them, then export to a single OBJ [File] >> [Export] >> [Wavefront .obj]. In the export options, apply "Selection Only", and "-Y Forward" and "Z Up"[9].

Verify the new model loads correctly, e.g. in **Meshlab**[10]!

### 15.4.5 Beyond 3D: Temporally evolving Models

Stellarium working as "time machine" can display the sky for any calendar date in its range of valid dates. Also landscapes and human-built structures evolve. Temples are being rebuilt, changed, re-dedicated or repurposed, new windows are cut, old windows closed. To show landscape and buildings in the right shape for the time in question, we can make material transparent, so that parts of the model are not displayed. To allow for archaeological uncertainties in dating construction and destruction, we can gradually fade in and fade out the model parts in question (Zotti, Schaukowitsch, and Wimmer, 2018).

To enable this magic, you must combine all your models into one (see section 15.4.4), export as one OBJ/MTL as usual, and manually edit the MTL file. It is wise to give the material for the parts in question a reasonable name that you can later identify in the MTL file. Then you simply add one or both of the new keywords `vis_fadeIn` or `vis_fadeOut` to the material description, with 2 arguments which are the Julian days of begin and end of a phase transition. For sharp transitions, just use the same JD dates.

```
# Some structure has been put up around -3100/-3000
vis_fadeIn  588783.5 625308.5
# Fade away between 500AD/700AD
vis_fadeOut 1903682.5 1976732.5
```

### 15.4.6 Working with non-georeferenced OBJ files

There exists modeling software which produces nice models, but without concept of georeference. One spectacular example is **AutoDesk PhotoFly**, a cloud application which delivers 3D models from a bunch of photos uploaded via its program interface. This "technological preview" is in version 2 and free of cost as of mid-2011.

The problem with these models is that you cannot assign surveyed coordinates to points in the model, so either you can georeference the models in other applications, or you must find the correct transformation matrix. Importing the OBJ in **Sketchup** may take a long time for detailed photo-generated models, and the texturing may suffer, so you can cut the model down to the minimum necessary e.g. in **Meshlab**, and import just a stub required to georeference the model in **Sketchup**.

Now, how would you find the proper orientation? The easiest chance would be with a structure visible in the photo layer of **Google Earth**. So, start a new model and immediately [add location] from the **Google Earth** interface. Then you can import the OBJ with TIG's importer plugin. If the imported model looks perfect, you may just place the model into the **Sketchup** landscape and export a complete landscape just like above. If not, or if you had to cut/simplify the OBJ to be able to import it, you can rotate/scale the OBJ (it must be grouped!). If you see a shadow in the photos, you may want to set the date/time of the original photos in the scene and verify that the shadows created by **Sketchup** illuminating the model match those in the model's photo texture. When you are satisfied with placement/orientation, you create a `scenery3d.ini` like above with the command [Plugins] >> [ASTROSIM/Stellarium scenery3d helpers] >> [Create scenery3d.ini].

Then, you select the OBJ group, open the [Windows] >> [Ruby Console] and readout data by calling [Plugins] >> [ASTROSIM/Stellarium scenery3d helpers] >> [Export transformation of selected group].

On the Ruby console, you will find a line of numbers (the $4 \times 4$ transformation matrix) which you copy/paste (all in one line!) into the [model] section in `scenery3d.ini`.

```
obj2grid_trafo=<a11>,<a12>,<a13>,<a14>,<a21>,<a22>,<a23>,<a24>,
               <a31>,<a32>,<a33>,<a34>,<a41>,<a42>,<a43>,<a44>
```

You edit the `scenery3d.ini` to use your full (unmodified) **PhotoFly** model and, if you don't have a panorama, take `Zero Horizon` landscape as (no-)background. It depends on the model if you want to be

---

[9] https://blender.stackexchange.com/questions/3352/merging-multiple-obj-files

[10] https://www.meshlab.net/

able to step on it, or to declare `ground=NULL` for a constant-height ground. Run Stellarum once and adjust the `start_N`, `start_E` and `zero_ground_height`.

### 15.4.7 Rotating OBJs with recognized survey points

If you have survey points measured in a survey grid plus an image-based model with those points visible, you can use Meshlab to find the model vertex coordinates in the photo model, and some other program like **CoordTrans** in the **JavaGraticule3D** suite to find either the matrix values to enter in `scenery3d.ini` or even rotate the OBJ points. However, this involves more math than can be described here; if you came that far, you likely know the required steps. Here it really helps if you know how to operate automatic text processors like **AWK**.

## 15.5 Predefined views

You can also configure and distribute some predefined views with optional date of interest with your model in a `viewpoints.ini` file. The viewpoints can be loaded and stored with the viewpoint dialog which you can call with the ⊚ button. See the provided "Sterngarten" scene for an example. These entries are not editable by the user through the interface. The user can always save his own views, they will be saved into the file `userviews.ini` in the user's Stellarium user directory, and are editable.
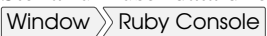
```
[StoredViews]
size=<int>              Defines how many entries are in this file.
                        Prefix each entry with its index!
1/label=<string>        The name of this entry
1/description=<string>  A description of this entry (can include HTML)
1/position=<x,y,z,h>    The x,y,z grid coordinates
                        (like orig_* or start_* in scenery3d.ini)
                        + the current eye height h
1/view_fov=<az_deg,alt_deg,fov_deg>  The view direction + FOV
                                     (like start_az_alt_fov in scenery3d.ini)
; an example for a second entry (note the 2 at the beginning of each line!)
2/label       = Signs
2/description = Two signs that describe the Sterngarten
2/position    = 593155.2421,5333348.6304,325.7295809038,0.8805
2/view_fov    = 84.315399,-8.187078,83.000000
2/JD          = 2451545.5 [optional]
```

## 15.6 Example

Let us add a quick example here. A recent paper (Pollard, 2017) claims that the Uffington White Horse, a geoglyph carved into a hillsite in England during the Bronze Age, may depict the mythical "Sun Horse", a common conception of that period.

Unfortunately, as of 2017, the official UK Lidar repository does not include the Uffington area, so a detailed GIS-based model is not available. We could use EUdem25 data with aerial imagery, or for a quick look, we just use **Sketchup**. Yet another unfortunate development: Trimble declared that after the 5-year transition period from Google to Trimble is over in May 2017, terrain modelling will be limited to **Sketchup Pro**. But note that a fresh installation comes with a 30-day Pro trial time, this should be enough for this example.

First, locate the site in **Google Earth** at $\lambda = -1.56718, \varphi = 51.582843$. (Or just search for "Uffington".) Try to identify which parts of the landscape may be visible from your site, so you can estimate which parts of terrain should be included in the model. Open **Sketchup**, select the meter-based "Landscape Architecture" template, add View ⟩ Toolbars…: Locations. Click on the "Add Location" button of that toolbar. Enter "Uffington" into the location search dialog. This brings you close to our site of interest. Clip a part of terrain to import it to Sketchup. Optionally, add more terrain.

If installed, TIG's OBJ exporter is available from the File menu, or you can use **Sketchup Pro**'s built-in OBJ export. Export `UffingtonHorse.obj` to a subdirectory `scenery3d/Uffington` in your Stellarium user data directory. The geolocation is stored in an "AttributeDictionary". To read this, press Window ⟩ Ruby Console to open the Ruby Console. Then write a few lines of Ruby to get access to the `Georeference` dictionary and other data:

```
model=Sketchup.active_model
attrdicts=model.attribute_dictionaries
```

```
attrdicts.each {|d|
  puts "AttributeDictionary: %s" % d.name
  d.each_pair { |k, v| puts "  %s=%s" % [k, v] }
}
model.shadow_info.each{|k,v| puts " #{k} #{v}"}
utm=model.point_to_utm Geom::Point3d.new(0,0,0)
puts("grid_name=UTM %i %s (%s)" %
    [ utm.zone_number, utm.zone_letter, model.get_datum])
```

Note the `ModelTranslation` values. Those are inches (of all units!) in the UTM reference frame and define the model coordinate origin in world coordinates. (Actually, it uses the negative values.) Multiplication by 2.54 gives cm, and by 0.0254, meters in the UTM coordinate system. We will use the negatives of these values as `orig_E`, `orig_N`, `orig_H`. Additionally, we have found information about meridian convergence correction (**Sketchup**'s `NorthAngle`), UTM zone number etc. All this goes into our configuration file. Create this file `scenery3d.ini` with the content seen in fig. 15.1

## 15.7 Limitations

Models with up to 14 million triangles have been used successfully on a mid-range notebook PC from 2016. However, take some restrictions into account:

- The model is rendered in Cartesian coordinates. Earth's surface is curved. If your model extends by tens of kilometres, the visible horizon formed by faraway mountains may appear too high. You can display a landscape polygon defined in the currently displayed Landscape on top of your 3D scene by activating Draw horizon polyline in foreground in the plugin's settings dialog.
- The OBJ format is static. Simulation of interaction with 3D objects is not possible with this plugin.

## Authors and Acknowledgements

Scenery3d was conceived by Georg Zotti for the ASTROSIM[11] project. A first prototype was implemented in 2010/2011 by Simon Parzer and Peter Neubauer as student work supervised by Michael Wimmer (TU Wien). Models for accuracy tests (Sterngarten, Testscene), and later improvements in integration, user interaction, `.ini` option handling, OBJ/MTL loader bugfixes and georeference testing by Georg Zotti.

Andrei Borza in 2011/12 further improved rendering quality (shadow mapping, normal mapping) and speed (Zotti, 2015; Zotti and Neubauer, 2012a; Zotti and Neubauer, 2012b).

In 2014–17, Florian Schaukowitsch adapted the code to work with Qt 5 and the Stellarium 0.13 codebase, replaced the renderer with a more efficient, fully shader-based system, implemented various performance, quality and usability enhancements, and did some code cleanup. Both Andrei and Florian were again supervised by Michael Wimmer (Zotti, 2016a; Zotti, 2016b; Zotti, Schaukowitsch, and Wimmer, 2018).

This work has been originally created during the ASTROSIM project supported 2008-2012 by the Austrian Science Fund (FWF) under grant number P 21208-G19. Further development has partially been supported by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology in Vienna, Austria[12].

If you are using this plugin in scientific work, please cite: (Zotti, 2016a; Zotti, 2016b; Zotti, 2019; Zotti, Frischer, et al., 2019; Zotti, S. Hoffmann, et al., 2021; Zotti, Schaukowitsch, and Wimmer, 2018).

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[11]`https://astrosim.univie.ac.at`
[12]`https://archpro.lbg.ac.at`

```
[model]
name=UffingtonHorse
;Either a fitting landscape or just 'Zero Horizon':
landscape=Zero Horizon
scenery=UffingtonHorse.obj
;activate the next line if you have a separate ground layer
;ground=UffingtonHorse_ground.obj
;If model Y-axis points up, activate the next line
;obj_order=XZY
author=Georg Zotti
copyright=(c) 2017 Georg Zotti
description=Uffington Horse may represent the Sun Horse. \
        See Joshua Pollard in Antiquity 91 356(2017): 406-20.
[location]
name=UffingtonHorse
country=UK
planetName=Earth
;Set the following to a fitting landscape
landscapeKey=Zero Horizon
longitude=-1.56718254089355
latitude=51.5828432749823
altitude=137
[coord]
grid_name=UTM 30 U (WGS 84)
gridType=UTM
orig_E=599273.02119578
orig_N=5715615.15079106
orig_H=136.295297626736
convergence_angle=1.12284363771988
;Height used outside the terrain, to not "fall off" the rim.
zero_ground_height=137
;You may want to reset these coordinates.
;Observer is set to those on loading the scenery.
start_E=599273.02119578
start_N=5715615.15079106
start_az_alt_fov=50,10,83
```

Figure 15.1: scenery3d.ini for the Uffington example.

# 16. Stellarium at the Telescope

Stellarium is great for indoor use on the desktop, but it is also very useful outdoors under the real sky, and several plugins enhance its usability particularly for observers.

Right at the telescope, Oculars (section 16.1) provides field of view hints for telescopes, oculars and sensors, and TelescopeControl (section 16.2), which allows you to send GOTO commands to most motorized telescope mounts. Other GOTO telescopes are supported by external programs which you must install separately: **RTS2** (16.2.6), **INDI** (16.2.7) or **ASCOM** (16.2.8). This can also help DIY hardware tinkerers who like to build their own control systems (section 16.2.10).

In addition, the Observability plugin (16.3) can be used for planning the best times to observe your favorite objects, and the Mosaic Camera plugin (16.4) can be used to show the orientations of more complicated camera mosaics.

## 16.1 Oculars Plugin

TIMOTHY REAVES, WITH ADDITIONS BY ALEXANDER WOLF

This plugin serves several purposes:

- to see what the sky looks like through a particular combination of eyepiece, lens (Barlow or Shapley types) and telescope. This plugin helps to get an idea of what you should see when looking through a physical telescope, and understand why one eyepiece may be better suited to observe a particular target than another. This can also be very useful for deciding what telescope is best suited to a style of viewing. And with the support for binoculars, you also have the ability to understand just about any type of optics-enhanced visual observing.
- to show what a particular combination of camera and telescope (or photographic lens) would be able to photograph of the sky.
- lastly, with the help of the Telrad sight, understand where object in the sky are in relation to each other. This can be helpful for star-hopping with a non-GOTO telescope.

None of these activities can take the place of hands-on experience, but they are a good way to supplement your visual astronomy interests.

### 16.1.1 Using the Ocular plugin

The plugin is controlled through a popup menu or through an on-screen control panel (see top right corner on screens in fig. 16.17). By default, the hot key to display the popup is Alt + O (Option + O for Mac users). This can be changed in the Editing Keyboard Shortcuts window (see section 4.8). The menu will popup where your cursor is located.

The options available in the popup menu depend on what you are currently doing. In the default menu, you can choose to configure the plugin, activate a CCD, or activate the Telrad finder (see fig. 16.1). The menu is navigated by either the arrow keys on your keyboard or by your mouse. The ↑ and ↓ arrow
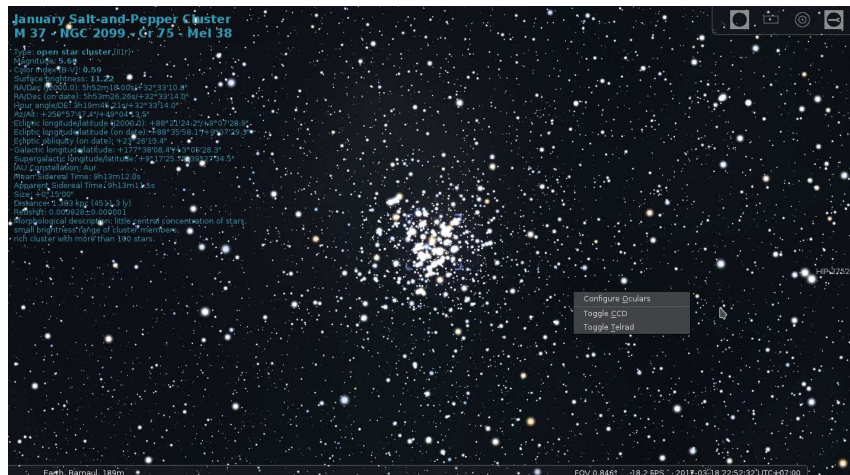
Figure 16.1: The on-screen menu (top right) and popup menu (lower right) of the Oculars plugin.

keys move the selection up or down the menu, and the ← and → arrow keys display or hide sub-menus. ↵ activates an option.

### Telrad Finder

The Telrad view can be used without defining any of the items below. As a reflex sight is non-magnifying, this feature can only be enabled when no eyepiece is selected. You still may want to zoom in a bit to better see which stars are in the circles (fig. 16.2). The three circles that appear in the center of the screen are 0.5°, 2.0°, and 4.0° in diameter. They stay centered in the screen, so move the "telescope" (click-drag the background) to center the circles on the object of interest.

While the Telrad finder is active, you can not activate a CCD with the popup menu, but only with the on-screen menu.

### CCD Sensors

This is a great way to get an idea of what a particular camera will be able to capture when attached to a particular telescope or lens. For using camera lenses, describe them as telescope with the appropriate values for the lens. When active, this feature will display a red bounding box of the area that will be captured, as well as zoom in to give a better view of the surroundings. You can manually zoom in or out from there.

The default CCD view will appear similar to fig. 16.3 or, when you are working without the on-screen control panel, the information area in the upper right hand corner also shows angular size captured by the CCD (see fig. 16.4).

When a CCD view is displayed, the popup menu changes as seen in fig. 16.5. You can select what telescope to use, as well as progress to the previous or next CCD, or go to a specific CCD. You can also rotate the CCD to better frame your subject, or to see if the CCD can be rotated in such a way as to catch your area of interest (see fig. 16.6). Once rotated, the CCD frame on screen displays the new orientation (see fig. 16.7).
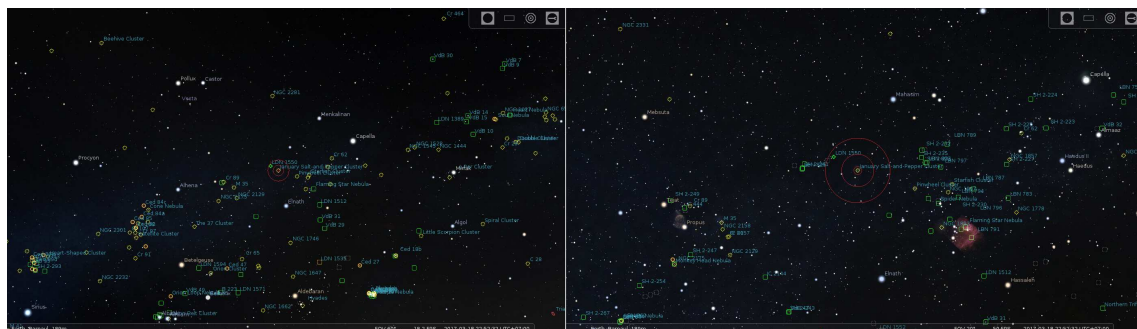


Figure 16.2: The left image is the default 60°, and the right one is 40°.
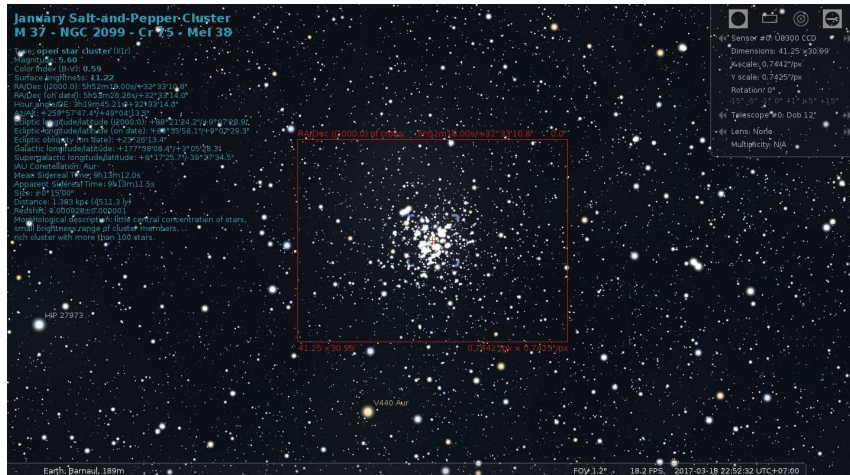
Figure 16.3: View of M37 through a CCD sensor of the Oculars plugin.
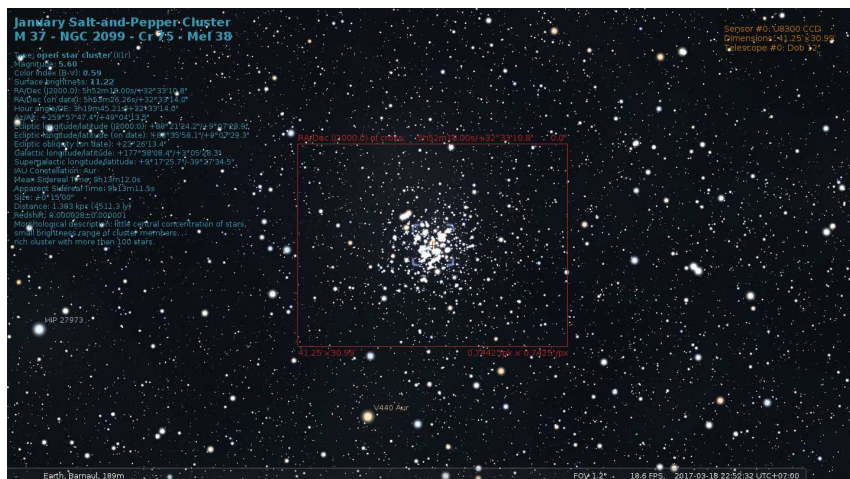


Figure 16.4: View of M37 through a CCD sensor of the Oculars plugin (without on-screen control panel).

### Oculars

- Define some eyepieces and telescope (see section 16.1.2).
- Select an object to view (i.e. a star, planet, etc.)
- Click the toolbar button 👁 for toggling the Ocular view, or press [Ctrl]+[O] ([⌘]+[O] for Mac users).
- Swap between eye pieces and telescopes to see how the view changes.

This is really the area of interest to most telescopic observers. It is a great way to compare different eyepiece/telescope combinations, to see how they change the view of the sky. And it is easy to do so with binoculars too. To show this, let us use the M37 cluster as target. Through a pair of Celestron 15x70 binoculars, it would look like in fig. 16.8.

A very pretty sight. Now, what would it look like through a Celestron 80 mm EDF finder 'scope, with an Explore Scientific 14 mm 100° eyepiece? See fig. 16.9!

Not bad at all. But we like to see more! So we move the eyepiece to a C1400. See fig. 16.10 for the resulting view.

Very nice indeed! So for this target, the C1400 is going to be the best bet. However, if my target was the Pleiades, the C1400 with that eyepiece would not be good — the 80EDF would do much better!

When an eyepiece is active, the popup menu again changes. With a non-binocular eyepiece selected, you also have the ability to select a particular eyepiece or telescope. When a binocular is active, you can not select a telescope, as it is not relevant. Changing the eyepiece to a non-binocular will again allow the
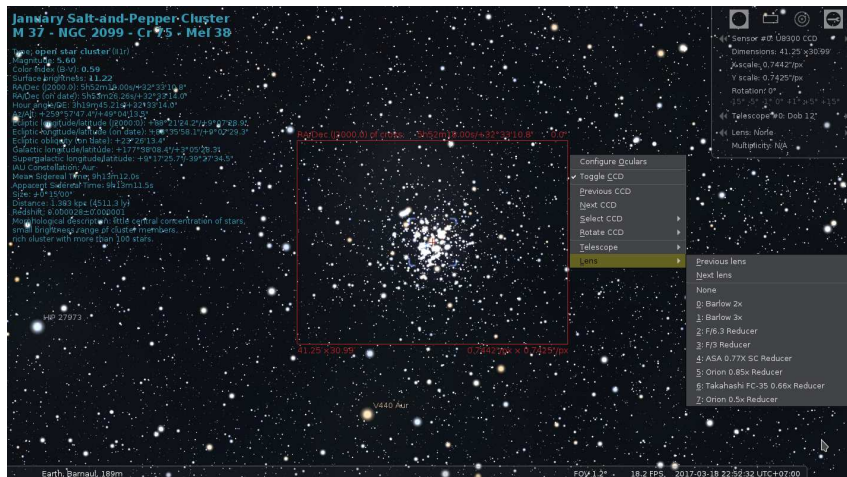
Figure 16.5: The CCD sensor popup menu of the Oculars plugin.
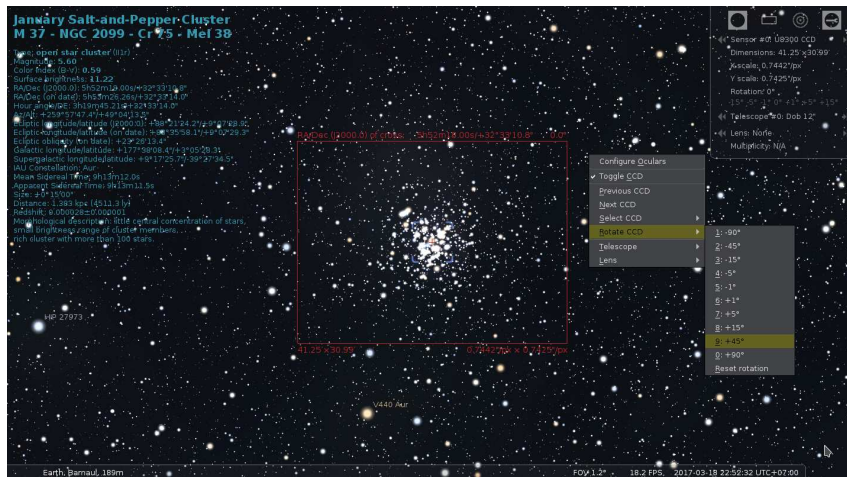


Figure 16.6: Setting rotation of CCD sensor in the popup menu.
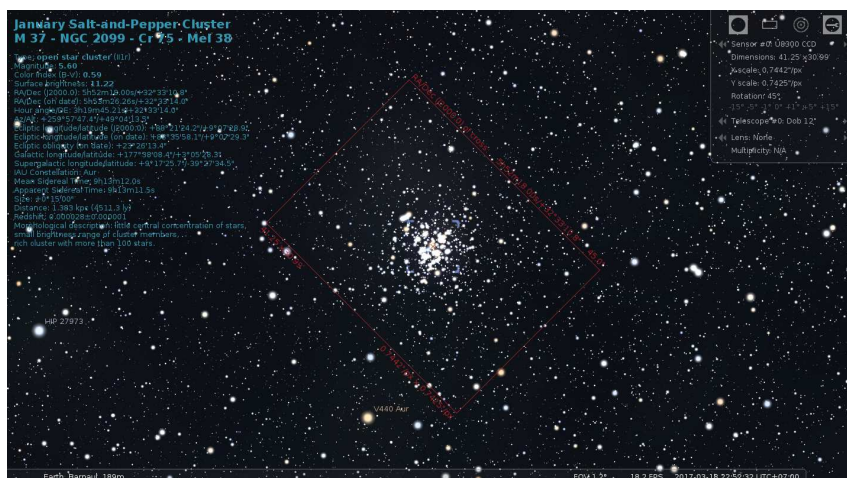


Figure 16.7: A rotated CCD sensor frame of the Oculars plugin.
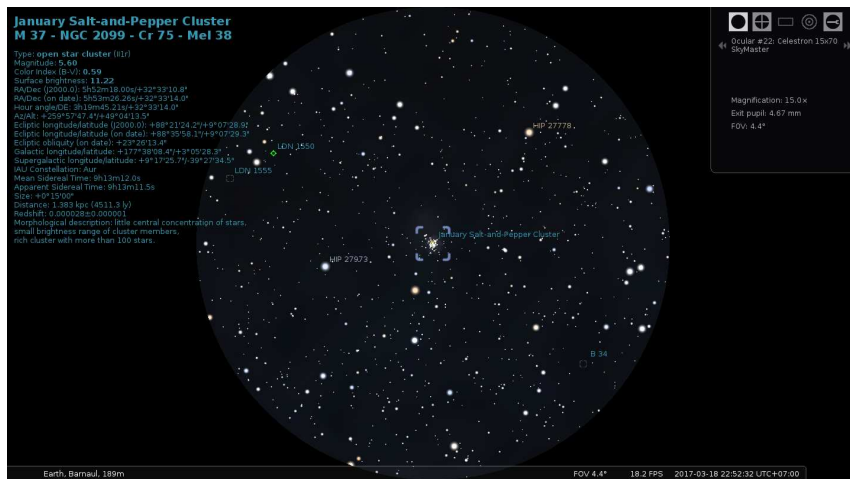
Figure 16.8: The M37 cluster through a Celestron 15x70 binocular.
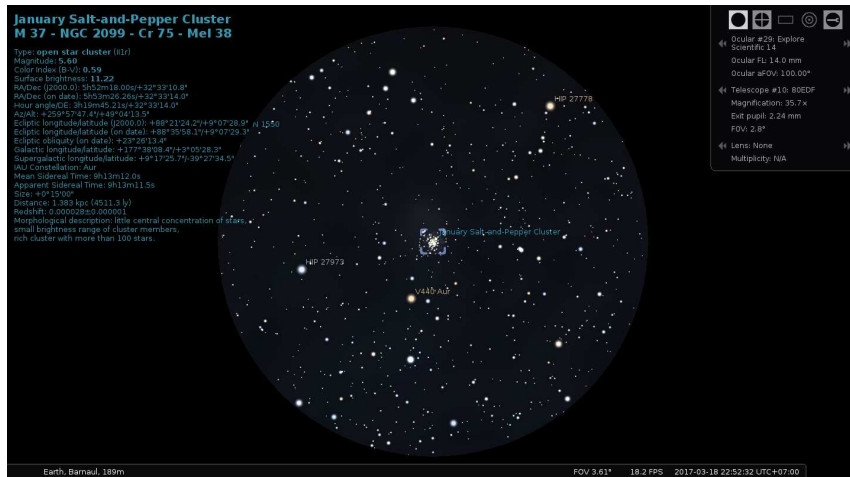


Figure 16.9: The M37 cluster through a Celestron 80 mm EDF with Explore Scientific 14 mm eyepiece.
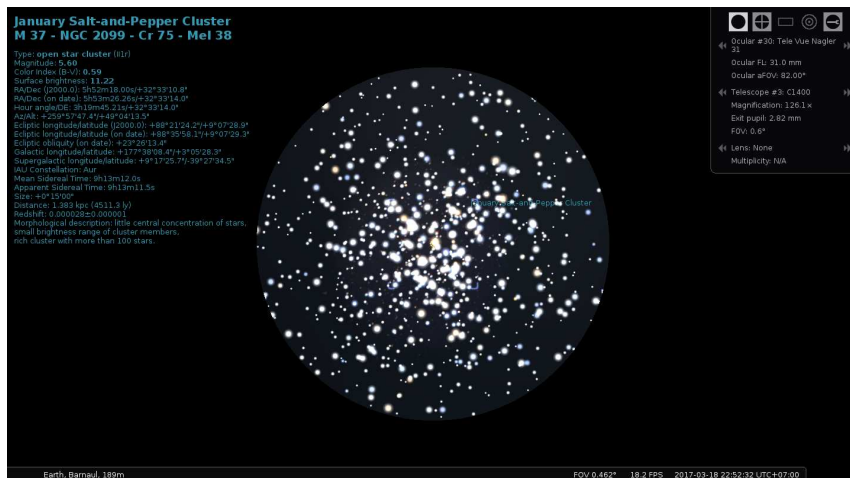


Figure 16.10: The M37 cluster through a Celestron C1400 with Tele Vue Nagler 31 mm eyepiece.

telescope to be selected. Also notice that when your mouse cursor is very near the right hand border of the screen, the popup menu's sub-menus display to the left, not the right.

#### 16.1.1.1 Star Scales

As you know from section 4.4.1, the number and relative size of stars of various magnitudes can be adjusted to your personal preferences in the view settings window to approximate the appearance of the stars as seen by the naked eye. Some observers prefer to have a simulated ocular view with very small, or more, stars, quite different from what Stellarium usually shows. The Oculars plugin therefore keeps two additional sets of scaling values for ocular views and CCD views, which are activated automatically when you switch to ocular or CCD view, and which are stored immediately and permanently in the plugin's `ocular.ini` file.[1]

### 16.1.2 Configuration

All configuration is done through the user interface in the application. To open the configuration dialog hit the Alt + O key, or click the configure button on the plugin setup dialog (available in the Plugins tab of Stellarium's Configuration window (opened by pressing F2 or the 🔧 button in the left toolbar)), or the rightmost button of the on-screen panel (if displayed in the top right corner of screen). There are six tabs in the configuration dialog: *General*, *Eyepieces*, *Lenses*, *Sensors*, *Telescopes*, and *About*. The first five are the ones we are interested in here.

#### General

The first option allows you to define the general behavior of the plugin. The options are grouped by areas of usage: *Interface*, *Ocular view*, *Sensor view* and *Telrad view* (see figure 16.11).
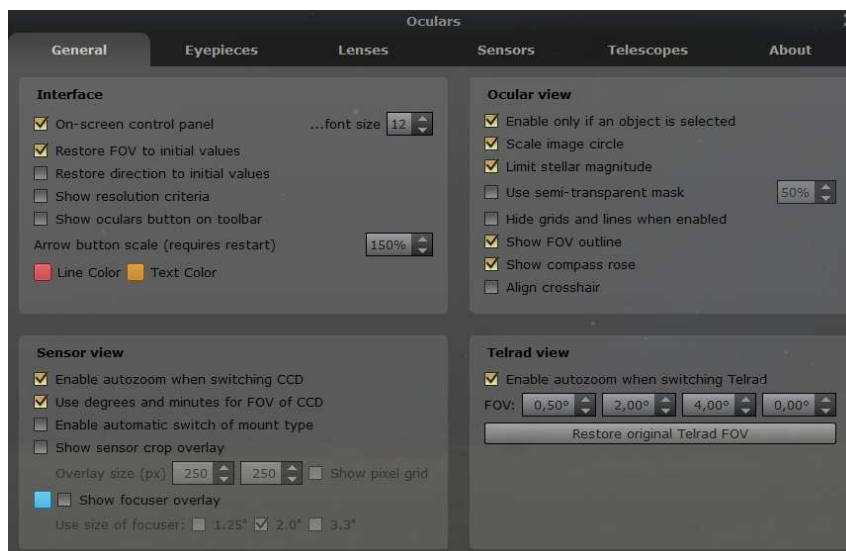


Figure 16.11: General tab of the Oculars plugin configuration dialog.

**Interface:** this group of options allows to change behavior of the plugin in general.

    **On-screen control panel:** show an additional GUI panel in the top-right corner of the screen to allow switching features of the plugin (in addition to the popup window).

    **Restore FOV to initial values** and

    **Restore direction to initial values** options allow restoration field of view and direction of view, resp., to the initial values at program start at the end of the plugin usage (e.g., when disabling the view through CCD frame).

    **Show resolution criteria** compute and show Rayleigh criterion, Dawes', Abbe's and Sparrow's limits for combination of telescope, lens and eyepiece. In addition, this option will show visual resolution for selected "setup". This option may be very helpful for double star observers.

    **Show oculars button on toolbar** option allows to toggle visibility the plugin button on main toolbar.

    **Arrow button scale** allows to change the size of the arrow buttons in the ocular GUI panel.

---

[1]The appearance of stars may depend on various other factors: telescope type, ocular type, quality of optics, seeing, …Such details with all combinations cannot meaningfully be stored, though. These values should allow a rapid toggle on any single night.

**Line Color** Select color for ocular and sensor outlines and their labels.

**Text Color** Select color for screen messages which are shown only when the on-screen control panel is not shown.

**Ocular view** is a group of options that allows to change the plugin's behavior in visual observation mode.

**Enable only if an object is selected** – uncheck this option if you want to use the visual observation mode when no object is selected.

**Auto-limit stellar magnitude** sets the magnitude limitation for stars based on telescope diameter. When disabled, the main program's setting applies (see section 4.4.1). Note that two manual limits for ocular view and main program are handled, and switching between ocular and main view also switches those values.

**Hide grids and lines when enabled** allows to hide grids and lines when you observe the sky through the eyepiece and re-enables their visibility when leaving visual observation mode.

**Scale image circle** option allows you to define whether or not to scale the images based on apparent FOV. When deactivated, the image circle will fill your screen. In general, we recommend you not select this, unless you have a need to, because it can really reduce the image size on the screen. It can however be very useful in comparing two eyepieces. If you set this option, the on-screen image will be scaled based on the eyepieces and telescopes you define. See section 16.1.3 for information on what scaling means, and why you might want to use it.

**Use semi-transparent mask** uncheck this option if you want to see visible field of view as in real telescope. You may define level of transparency for mask.

**Hide grids and lines when enabled** allows to hide grids and lines when you observe the sky through the eyepiece and re-enables their visibility when leaving visual observation mode.

**Show FOV outline** option enables drawing the border of the eyepiece's FOV and it may be helpful in combination with a semi-transparent mask.

**Show compass rose** option enables drawing cardinal directions in the equatorial coordinate system.

**Align crosshair** option enables alignment of the cross-hair according to the equatorial coordinate system.

**Sensor view** is group of options allows to change behavior of the plugin for photographic observations mode.

**Enable autozoom when switching CCD**

**Use degrees and minutes for FOV of CCD** – for many cases the use of decimal degrees for the value of the field of view is not comfortable, and this option allows to use the more human readable format for FOV.

**Use horizontal coordinates instead of equatorial (J2000.0) coordinates** in the top left frame corner.

**Show max exposure time for moving objects** For solar system objects, the top right edge can indicate the maximum exposure time so that the object moves less than a pixel against the stars.

**Enable automatic switch of mount type** allows to store the CCD frame orientation when the type of telescope mount is changed.

**Show sensor crop overlay** toggles drawing a crop box within the CCD frame. In addition, a pixel grid can be drawn within the crop overlay especially for astrophotographers.

**Show focuser overlay** allows drawing a circle which represents the telescope's focuser. We added sizes of 3 common modern focusers to allow users to check the visible aberrations in the FOV of the telescope.

**Telrad view** is a group of options which allows to change behavior of the plugin for Telrad mode.

**Enable autozoom when switching Telrad** option allows you to define whether or not to zoom the field of view to twice the size of the Telrad circles.

**FOV:** If you don't use the original Telrad but a similar device, you may define up to 4 circles to show its specific FOV in the sky.

## Eyepieces

This is the tab used to enter your own eyepieces (see figures 16.12 and 16.13). By default, a few sample ones have been added; feel free to delete those once you've entered your own.

The fields on this tab are:

**Name** – a free-text description of the eye piece. You could modify this to match your personal descriptions of eyepieces.

**aFOV** – apparent field of view in degrees.
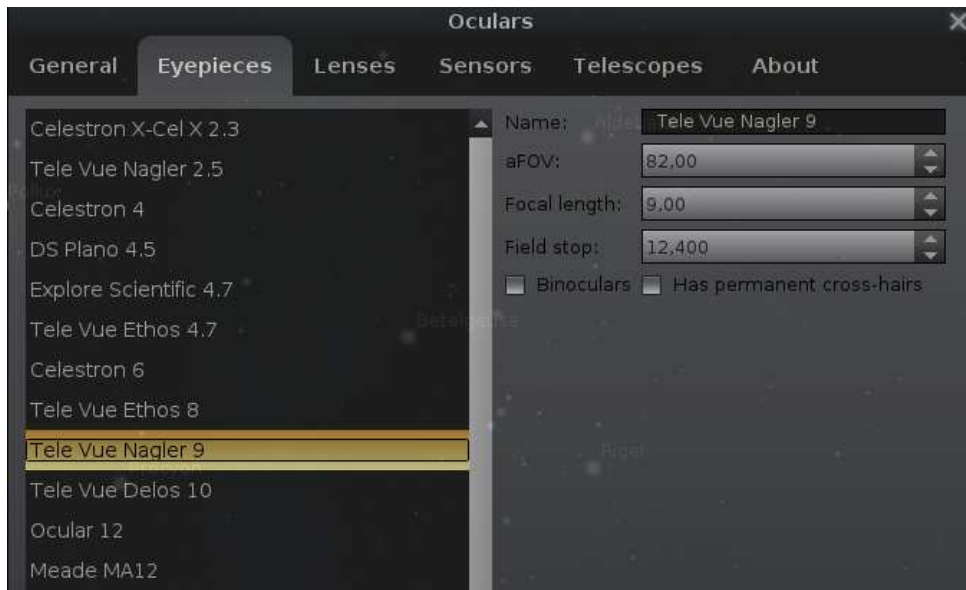
Figure 16.12: Eyepieces tab of Oculars plugin configuration dialog.
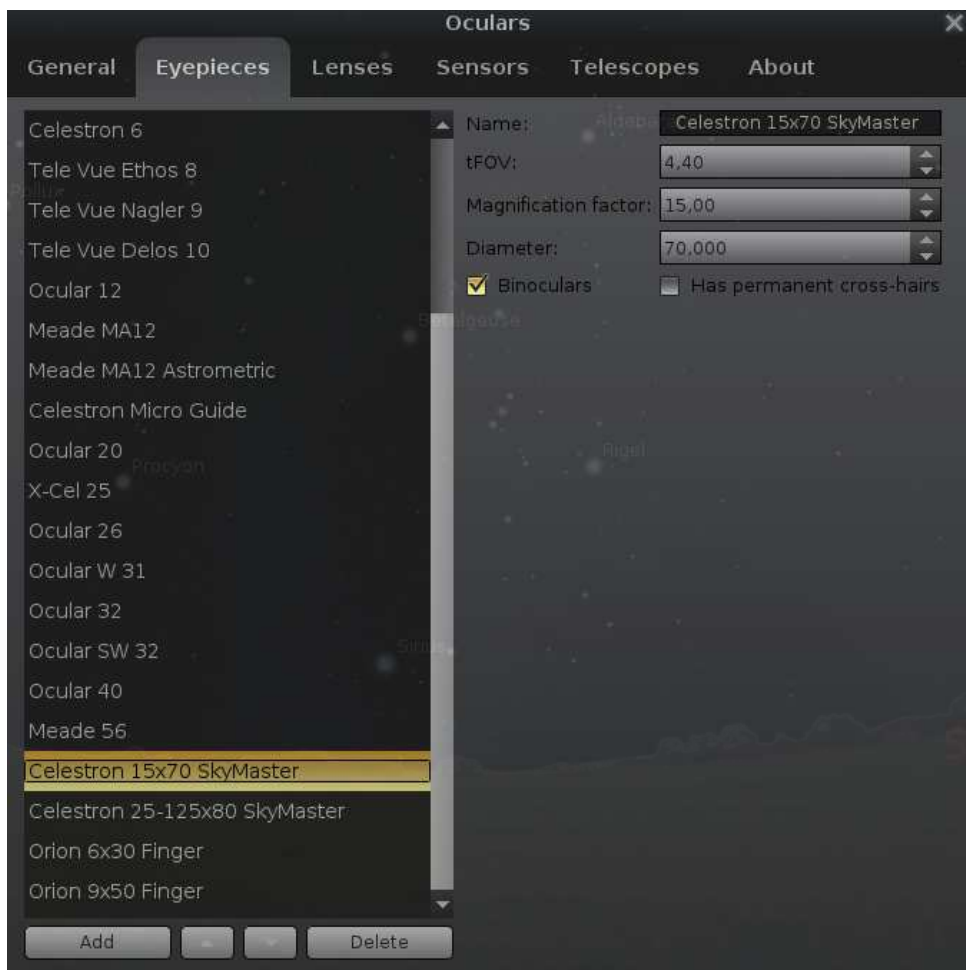


Figure 16.13: Eyepieces tab of Oculars plugin configuration dialog (settings for binocular).

**Focal Length** – eyepiece focal length in mm.

**Field Stop** – the field stop of the eyepiece in mm. This is used to calculate the true field of view of an eyepiece. If you do not know what it is just leave it the default zero. Not all manufacturers provide this value; Tele Vue is one that does.

**Binoculars** – selecting this checkbox tells the system that this eyepiece is binoculars or finders; this means that this eyepiece can be used without defining a telescope.

**Has permanent cross-hairs** – selecting this checkbox tells the system that this eyepiece or binocular (finder) has also simple cross-hairs[2].

When Binoculars are described, the relevant fields change to

**tFOV** – true field of view in degrees. The true field of view can be given as **meters at 1000 m**. The approximate conversion of this to degrees is to divide by 17.5. Thus, 87 m at 1000 m = $(87/17.5)° \approx 5°$.

**Magnification factor** – the magnification of the binocular.

**Diameter** – the diameter of the binocular objective in mm.

For binoculars, we're computed a few important factors in additional to the exit pupil[3] (these factors are visible in an on-screen control panel):

**Relative Brightness.** This is the square of the diameter of the exit pupil. For example, for a 10x50 binocular, the exit pupil is 5 mm and relative brightness is $(50/10)^2 = 5^2 = 25$. However, the calculation for a 20x100 binocular, through which a great deal more can be seen, gives exactly the same relative brightness: $(100/20)^2 = 5^2 = 25$, so this is an inadequate rating to use for astronomical binoculars. Relative brightness is a number used to compare the brightness of binoculars of similar magnification. The larger the relative brightness number, the brighter the image.

**Twilight Factor** (**Twilight Index** or **Twilight Performance Factor**). This was used by *Carl Zeiss International* as an indication of the *distance* at which comparable detail would be seen in different binoculars. It's calculated by finding the square root of the product of the magnification and aperture. For the two binoculars above, the calculations are:

$$\sqrt{(10*50)} = \sqrt{(500)} = 22.36$$
$$\sqrt{(20*100)} = \sqrt{(2000)} = 44.72$$

In this instance, the larger binocular has an index that is double that of the smaller binocular. Twilight factor is a number used to compare the effectiveness of binoculars used in low light. The larger the twilight factor, the more detail you can see in low light.

**Bishop Index** (or **Visibility Factor**). This is due to Roy Bishop (Bishop, 2002) and is evaluated simply by multiplying the magnification by the aperture in mm. For our two binocular above, we obtain:

$$10 * 50 = 500$$
$$20 * 100 = 2000$$

The larger binocular has a visibility factor four times greater than the smaller one.

**Adler Index** (or **Astro Index**). This is due to Alan Adler (Adler, 2002) and is evaluated as the product of the magnification and the square root of the aperture in mm. For our two binocular above, we obtain:

$$10 * \sqrt{50} = 10 * 7.1 = 71$$
$$20 * \sqrt{100} = 20 * 10 = 200$$

This gives the larger binocular an Astro Index of 2.8x the smaller one. At the moment this is the best index to comparison of astronomical binoculars (of course for the simplest indexes, because others have tried to expand on these by including the effect of coatings, baffles, and other aspects of individual quality).

### Lenses

This is the tab used to enter your own focal extender or reducer lenses (see figure 16.14). By default, a few sample ones have been added; feel free to delete them once you've entered your own.

The fields on this tab are:

**Name** – a free-text description of the lens. You could modify this to match your personal descriptions of lenses.

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[2]The Oculars plugin supports eyepieces with reticle patterns – both special eyepieces are available in the default list of eyepieces, and the option *Has permanent cross-hairs* is not related to those eyepieces.

[3]The exit pupil diameter is calculated by dividing the aperture by the magnification.
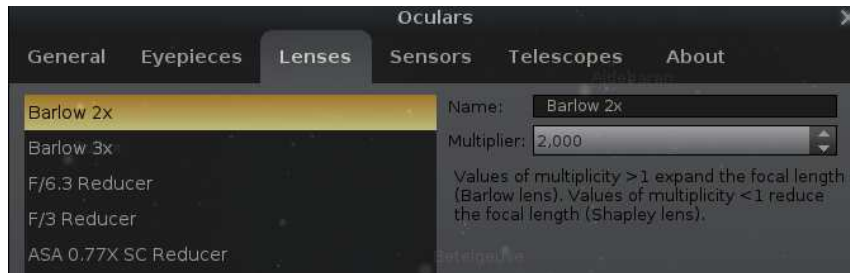
Figure 16.14: Lenses tab of Oculars plugin configuration dialog.

**Multiplier** – a factor larger than 1 expands the focal length, and lenses with this type are named Barlow
lens; a factor less than 1 reduces the focal length, and lenses with this type are named Shapley lens or
focus reducer.

### Sensors

This tab allows you to define sensors for any camera you may have (see figure 16.15). When defined and
selected, this will draw a red bounding rectangle in the center of the eye piece view, showing what the CCD
will capture. Because of the way floating point numbers are stored, sometimes you may see one of your
defined values change (for example from 2.2 to 2.19999) but this should not affect what you see.
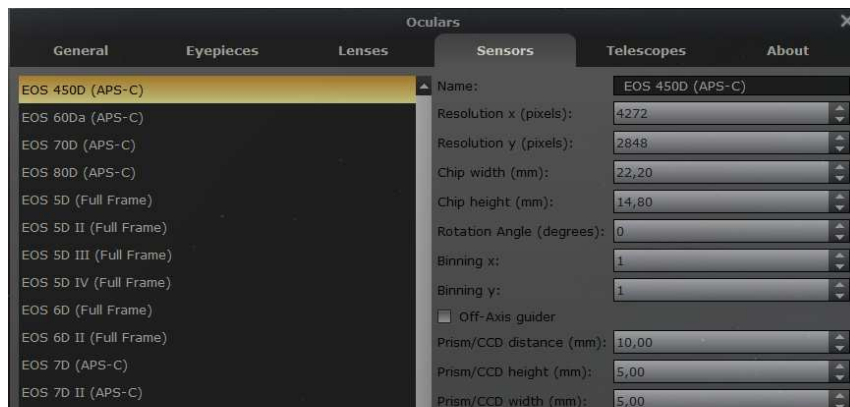


Figure 16.15: Sensors tab of Oculars plugin configuration dialog.

The fields on this tab are:

**Name** – A free-text description of the sensor.

**Resolution x** – the width of the sensor in pixels.

**Resolution y** – the height of the sensor in pixels.

**Chip width** – the width of the sensor in mm.

**Chip height** – the height of the sensor in mm.

**Rotation Angle** – the rotation angle of the sensor, in degrees.

**Binning x** – the binning factor for the width of the sensor.

**Binning y** – the binning factor for the height of the sensor.

**Off-Axis guider** – selecting this checkbox tells the system that this sensor has support an off-axis guider
also.

**Prism/CCD distance** – distance between center of prism/CCD of Off-Axis Guider and optical axis of
telescope in mm.

**Prism/CCD width** – the width of the prism/CCD of Off-Axis Guider in mm.

**Prism/CCD height** – the height of the prism/CCD of Off-Axis Guider in mm.

**Position Angle** – the position angle of the prism/CCD of Off-Axis Guider, in degrees.

The resolution is easy to find: these are simply the image dimensions of a (non-binned) frame. The chip size
and pixel size may be more difficult, but the manual, or searching the Internet, should turn up these values.
For a "full-frame" DSLR, this should be close to 36x24mm, while APS-C should be around 22.5x15mm.
Some cameras may have unsquare pixels.

**Telescopes**

This is the tab used to enter your own telescopes and photographic objectives (see fig. 16.16). The fields on this tab are:
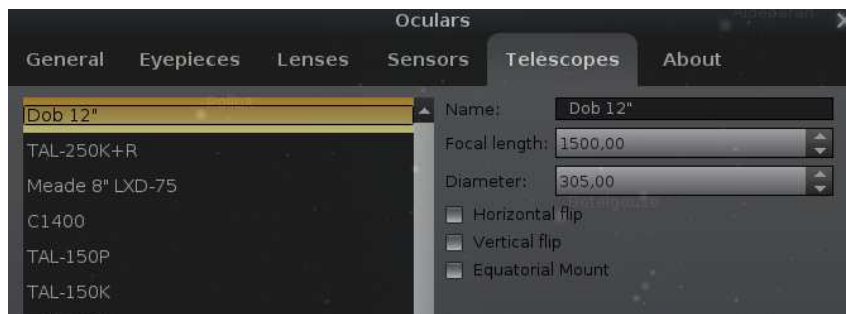


Figure 16.16: Telescopes tab of Oculars plugin configuration dialog.

**Name** – A free-text description of the telescope.

**Focal Length** – telescope focal length $f$ in mm.

**Diameter** – telescope diameter (aperture $\varnothing$) in mm. If you add a photographic objective that does not provide this information but provides a largest f stop like "100 mm f/2.8", you can estimate from $\varnothing = f/s$, where $s = 2.8$ and thus $\varnothing = 100/2.8 = 35.7$ mm in this example.

**Horizontal flip** – if the view through this telescope should flip horizontally.

**Vertical flip** – if the view through this telescope should flip vertically.

**Equatorial Mount** – select it if this telescope has an equatorial mount.

### 16.1.3  Scaling the eyepiece view

I (TR) would like to thank Al Nagler over at Tele Vue[4] for helping to set me straight on the topic of eyepieces. They are a lot more complicated than you might think!

By default, the view drawn on your computer screen when the plugin is active fills the screen. That is, there is a circle drawn to represent the view through the eyepiece, and this circle will fill the screen. For general use, this is what most people would want. There will be times that it's not.

If you are going to be observing any deep space object, it can be very important to choose the best eyepiece for that object. You will typically want an eyepiece that will magnify the object as much as possible, while showing all of the object in the eyepiece view. Getting this can be tricky, especially if you do not like changing eyepieces at the telescope. Or maybe you want to understand why one type of telescope may be better than another type for observing what you are interested in. This is where you will want to scale the image on screen based on your eyepiece.

Different eyepieces generally have a different apparent field of view (aFOV). An easy way to think about this is: the larger the aFOV, the bigger the picture you see in the eyepiece. Older types of eyepiece (some types still built and in wide use today have been constructed in the 19th century) generally have their aFOV in the 50° range. Today, there are massive eyepieces available with 82°, and recently even 100° aFOV! These eyepieces are huge, as they require a lot of very special glass to achieve their incredible fields of view. An eyepiece of the same focal length with a 100° aFOV will produce an image through the eyepiece that is twice as wide as one produced by a 50° eyepiece.

Different telescopes, with an eyepiece of a given aFOV, will also produce a different true field of view. This is the actual size of the piece of sky that you see through the eyepiece. Getting these two "just right" can be very important. It's easy to assume that you want the biggest telescope you can get, with the eyepiece that gives you the highest magnification. This is never true in reality. Depending on where you live, and especially what you like to look at, a 100-120 mm quality refractor with a wide aFOV eyepiece may very well be better than a large SCT with the same eyepiece. This is something I learned the hard way.

So how does scaling the eyepiece view help? The plugin will find the eyepiece you have with the largest aFOV. This aFOV becomes 100% of the computer screen diameter. Then, any other eyepiece will have its aFOV compared, and the view on screen will be scaled down accordingly. These 100° aFOV eyepieces makes the math here easy. If you have one, then when that eyepiece is used, the circle that represents the view through the eyepiece will take up 100% of the screen diameter. Next, if you select an eyepiece with an

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[4] https://www.televue.com/

82° aFOV, its view will be scaled to 82% of the screen, and a 62° aFOV eyepiece will be scaled to 62% of the screen.

### Example in action

This is easier to understand in action, so let us look at an example that uses three eyepieces all with the same 17 mm focal length, so they all produce the same level of magnification (well, one has an 17.3 mm focal length, but its magnification is nearly identical) and see how the view changes. These example all use a Celestron C8 8" SCT telescope, and the target is the Great Orion Nebula.

We can see from the images in fig. 16.17 that the target is all three images is the same size. The 100° image fills the screen, the 82° is smaller, and the 62° is smallest yet, filling 62% of the computer screen. Note that in each image, the field of view that you see changes. The larger the aFOV, the more you can see of the sky. So in this example, if you had an 8" telescope, you would want to use the 17 mm 100° Ethos eyepiece to see as much of the nebula as possible.
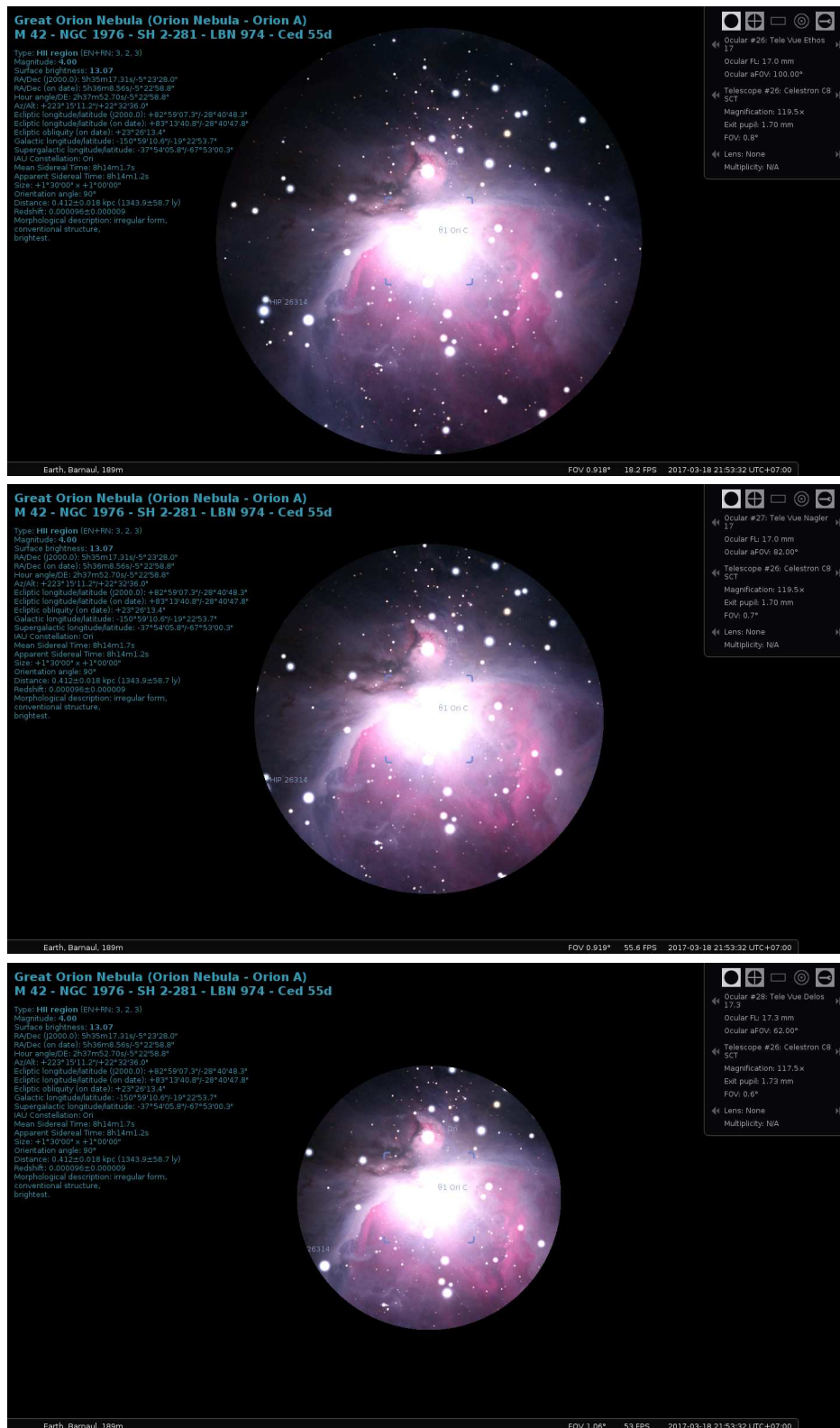
Figure 16.17: Comparing apparent fields of view of (top) a 17 mm Tele Vue Ethos eyepiece with an aFOV of 100°. Magnification is 119.5×. (center) a 17 mm Tele Vue Nagler eyepiece with an aFOV of 82°. Magnification is 119.5×. (bottom) a 17.3 mm Tele Vue Delos eyepiece with an aFOV of 62°. Magnification is 117.5×.

## 16.2    TelescopeControl Plugin

This plugin provides a simple control mechanism for motorized telescope mounts. The user selects an object (i.e. by clicking on something – a planet, a star etc.) and presses the telescope go-to key, and the telescope will be guided to the object.

Multiple telescopes may be controlled simultaneously.

**WARNING**

*Stellarium cannot prevent your telescope from being pointed at the Sun. It is up to you to ensure proper filtering and safety measures are applied!*

Never point your telescope at the Sun without a proper solar filter installed. The powerful light amplified by the telescope WILL cause *irreversible damage* to your eyes and/or your equipment.

Even if you don't do it deliberately, a slew during daylight hours may cause your telescope to point at the sun on its way to the given destination, so it is strongly recommended to avoid using the telescope control feature before sunset without appropriate protection.

### 16.2.1    Abilities and limitations

This plug-in allows Stellarium to send 'slew' ('go to') commands to the device and to receive its current position. There are some scopes which additionally support 'sync' commands to be received in order to update the internal pointing model of the mount. Some scopes also have the ability to abort a previous slew command. However, users should always be aware of the possibility for mount collisions and similar situations. You should always make sure that a slew does not cause parts of the telescope to collide with the environment or mount itself.

Currently this plug-in does not allow satellite tracking unless the controlled telescope is an RTS2 system (see section 16.2.6), and is not very suitable for lunar or planetary observations. Many mounts can be set to a 'lunar' tracking speed, you may prefer this.

Some users are running Stellarium on little, low-power "Telescope computers" connected to their powerful indoor PCs via RemoteDesktop or similar setups. Keep in mind that Stellarium is a graphics-heavy program that may challenge the outdoor computer's graphics subsystem or network. See framerate intent settings on page 26 for optimizing your screen refresh rates. Better, run Stellarium on your indoor system and use INDI or ASCOM network protocols.

### 16.2.2    Using this plug-in

Here are two general ways to control a device with this plug-in, depending on the situation:

**DIRECT CONNECTION**  A device supported by the plug-in is connected with a cable to the computer running Stellarium

**INDIRECT CONNECTION**

    **local**  A device is connected to the same computer but it is driven by a stand-alone telescope server program or a third-party application that can 'talk' to Stellarium;

    **remote**  A device is connected to a remote computer and the software that drives it can 'talk' to Stellarium over the network; this software can be either one of Stellarium's stand-alone telescope servers, or a third party application.

Most older telescopes use cables that connect to a serial port (RS-232), the newer ones use USB (Universal Serial Bus). On Linux and Max OS X, both cases are handled identically by the plug-in. On Windows, a USB connection may require a 'virtual serial port' software, if it is not supplied with the cable or the telescope. Such a software creates a virtual ('fake') COM port that corresponds to the real USB port so it can be used by the plug-in. On all three platforms, if the computer has no 'classic' serial ports and the telescope can connect only to a serial port, a serial-to-USB (RS-232-to-USB) adapter may be necessary.

Telescope set-up (setting geographical coordinates, performing alignment, etc.) should be done before connecting the telescope to Stellarium.

### 16.2.3    Main window ('Telescopes')

The plug-in's main window can be opened:

- By pressing the `configure` button for the plug-in in the `Plugins` tab of Stellarium's Configuration window (opened by pressing `F2` or the [wrench] button in the left toolbar).

- By pressing the `Configure telescopes...` button in the `Slew to` window (opened by pressing `Ctrl`+`0` or the respective button on the bottom toolbar).

The `Telescopes` tab displays a list of the telescope connections that have been set up:

- The *number (#)* column shows the number used to control this telescope. For example, for slewing telescope #2, the shortcut is Ctrl + 2 .
- The *Status* column indicates if this connection is currently active or not. Unfortunately, there are some cases in which 'Connected' is displayed when no working connection exists.
- The *Type* field indicates what kind of connection this is:
  **virtual**  means a virtual telescope (test mode).
  **local, Stellarium**  means a DIRECT connection to the telescope (see above).
  **local, external**  means an INDIRECT connection to a program running on the same computer.
  **local, ASCOM**  means an INDIRECT connection to a ASCOM driver running on the same computer.
  **remote, unknown**  means an INDIRECT connection over a network to a remote machine.
  **remote, RTS2**  means an INDIRECT connection over a network to an RTS2 server.
  **remote, INDI**  means an INDIRECT connection over a network to an INDI server.

To set up a new telescope connection, press the Add button. To modify the configuration of an existing connection, select it in the list and press the Configure button. In both cases, a telescope connection configuration window will open.

### 16.2.4  Telescope configuration window

#### Connection type

The topmost field represents the choice between the types of connections (see section 16.2.2): Telescope controlled by:

**Stellarium, directly through a serial port**  is the DIRECT case

**External software or a remote computer**  is an INDIRECT case

**RTS2 Telescope**  is another INDIRECT case

**INDI**  is another INDIRECT case

**ASCOM**  is another INDIRECT case

**Nothing, just simulate one (a moving reticle)**  is a *virtual telescope* (no connection)

#### Telescope properties

**Name**  is the label that will be displayed on the screen next to the telescope reticle.

**Connection delay**  If the movement of the telescope reticle on the screen is uneven, you can try increasing or decreasing this value.

**Coordinate system**  Some Celestron telescopes have had their firmware updated and now interpret the coordinates they receive as coordinates that use the equinox of the date (EOD, also known as JNow), making necessary this setting. With ASCOM telescopes it's also possible to use this setting to override the default device preference.

**Start/connect at startup**  Check this option if you want Stellarium to attempt to connect to the telescope immediately after it starts. Otherwise, to start the telescope, you need to open the main window, select that telescope and press the Start/Connect button.

#### Device settings

This section is active only for DIRECT connections (see above).

**Serial port**  sets the serial port used by the telescope. A pop-up box suggests some default values:

- On Windows, serial ports `COM1` to `COM10`
- On Linux, serial ports are labelled `/dev/ttyS0` to `/dev/ttyS3` and USB ports `/dev/ttyUSB0` to `/dev/ttyUSB3`. Make sure you have read/write access to the `tty` device. Depending on your flavour of Linux, this may e.g. require some group membership.
- On Mac OS X, the list is empty as it names its ports in a peculiar way. If you are using a USB cable, the default serial port of your telescope most probably is not in the list of suggestions. To list all valid serial port names in Mac OS X, open a terminal and type:

```
ls /dev/*
```

This will list all devices, the full name of your serial port should be somewhere in the list (for example, `/dev/cu.usbserial-FTDFZVMK`).

**Device model**  : see 16.2.5 Supported devices.

#### Connection settings

Both fields here refer to INDIRECT connections, which implies communication over a network (TCP/IP).

**Host**  can be either a host name or an IPv4 address such as '127.0.0.1'. The default value of 'localhost' means 'this computer'.

Modifying the default host name value makes sense only if you are attempting a remote connection over a network. In this case, it should be the name or IP address of the computer that runs a program that runs the telescope.

**Port** refers to the TCP port used for communication. The default value depends on the telescope number and ranges between 10001 and 10009.

### RTS2 settings

(see also 16.2.6) You will need access to an RTS2 HTTPD server through HTTP/JSON calls. Please see RTS2 documentation (man rts2-httpd) for details. You will as well need username and password for HTTPD. Please be aware that in order to move the telescope, your user must have the telescope in the list of allowed devices in the database. Please see `man rts2-user` for details on how to manipulate RTS2 users.

**URL** points to RTS2 HTTPD. Can include anything a URL can have - port (:8889) and prefix path for RTS2 access.

**Username** username used for login to RTS2 HTTPD.

**Password** password for login to RTS2 HTTPD.

### INDI settings

(see also 16.2.7) You will need access to an INDI server through a TCP/IP connection. Please see INDI documentation for details. You will need to select the correct INDI device to manage it.

### ASCOM settings

You can choose an ASCOM telescope driver installed in your system using the ASCOM chooser. Additionally you can choose how Stellarium is determining the coordinate system used to communicate with the ASCOM mount. For more information, please see 16.2.8.

### User Interface Settings: Field of view indicators

A series of circles representing different fields of view can be added around the telescope marker. This is a relic from the times before the Oculars plug-in (see 16.1) existed.

Activate the 'Use field of view indicators' option, then enter a list of values separated with commas in the field below. The values are interpreted as degrees of arc.

These marks can be used in combination with a virtual telescope to display a moving reticle with the Telrad circles.

#### 16.2.4.1 'Slew telescope to' window

The `Slew telescope to` window can be opened by pressing `Ctrl`+`0` or the respective button in the bottom toolbar.

It contains two fields for entering celestial coordinates, selectors for the preferred format (Hours-Minutes-Seconds, Degrees-Minutes-Seconds, or Decimal degrees), a drop-down list and two buttons.

The drop-down list contains the names of the currently connected devices. If no devices are connected, it will remain empty, and the `Slew` button will be disabled.

Pressing the `Slew` button slews the selected device to the selected set of coordinates. See the section about keyboard commands below for other ways of controlling the device.

Pressing the `Configure telescopes...` button opens the main window of the plug-in.

TIP: Inside the 'Slew' window, underlined letters indicate that pressing `Alt`+`underlined letter` can be used instead of clicking. For example, pressing `Alt`+`S` is equivalent to clicking the `Slew` button, pressing `Alt`+`E` switches to decimal degree format, etc.

#### 16.2.4.2 Sending commands

Once a telescope is successfully started/connected, Stellarium displays a telescope reticle labelled with the telescope's name on its current position in the sky. The reticle is an object like every other in Stellarium - it can be selected with the mouse, it can be tracked and it appears as an object in the 'Search' window.

To point a device to an object: Select an object (e.g. a star) and press the number of the device while holding down the `Ctrl` key. (For example, `Ctrl`+`1` for telescope #1.) This will move the telescope to the selected object. Note that most telescopes can only execute a single command to move to that object's position, but if the telescope is an RTS2 telescope, you can even track a satellite (if the mount then is fast enough to support it).[5]

To point a device to the center of the view: Press the number of the device while holding down the Alt key. (For example, `Alt`+`1` for telescope #1.) This will slew the device to the point in the center of the

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[5]Actually, the TLE orbital elements of the selected satellite are transmitted to RTS2, which does then compute the satellite position itself.

current view. (If you move the view after issuing the command, the target won't change unless you issue another command.)

To point a device to a given set of coordinates: Use the `Slew to` window (press `Ctrl`+`0`).

## 16.2.5 Supported devices

### 16.2.5.1 Directly connected telescopes

All devices listed in the 'Device model' list are convenience definitions using one of the two built-in interfaces: the Meade LX200 (the Meade Autostar controller) interface and the Celestron NexStar interface.

The device list contains the following:

**Celestron NexStar (compatible)** Any device using the NexStar interface.

**Losmandy G-11** A computerized telescope mount made by Losmandy (Meade LX-200/Autostar interface).

**Meade Autostar compatible** Any device using the LX-200/Autostar interface.

**Meade ETX-70 (#494 Autostar, #506 CCS)** The Meade ETX-70 telescope with the #494 Autostar controller and the #506 Connector Cable Set. According to the tester, it is a bit slow, so its default setting of 'Connection delay' is 1.5 seconds instead of 0.5 seconds.

**Meade LX200 (compatible)** Any device using the LX-200/Autostar interface.

**Sky-Watcher SynScan AZ mount** The Sky-Watcher SynScan AZ GoTo mount is used in a number of telescopes.

**Sky-Watcher SynScan (version 3 or later)** SynScan is also the name of the hand controller used in other Sky-Watcher GoTo mounts, and it seems that any mount that uses a SynScan controller version 3.0 or greater is supported by the plug-in, as it uses the NexStar protocol.

**Wildcard Innovations Argo Navis (Meade mode)** Argo Navis is a 'Digital Telescope Computer' by Wildcard Innovations. It is an advanced digital setting circle that turns an ordinary telescope (for example, a dobsonian) into a 'Push To" telescope (a telescope that uses a computer to find targets and human power to move the telescope itself). Just don't forget to set it to Meade compatibility mode and set the baud rate to 9600B1.

### 16.2.5.2 RTS2 telescopes

Setting up a robotic telescope and dome control system with RTS2 is beyond the scope of this handbook, but see section 16.2.6 for a few notes to be able to connect and command the telescope with Stellarium. Please refer to the RTS2 Web pages[6] for further details.

Please be aware that some RTS2 usernames might have only read-only access. If this is case for your username, the telescope marker will be painted red (or `color_telescope_readonly` from Stellarium's settings file).

### 16.2.5.3 INDI telescopes

Setting up a robotic telescope and dome control system with INDI is beyond the scope of this handbook, but see section 16.2.7 for a few notes to be able to connect and command the telescope with Stellarium. Please refer to the INDI web pages[7] for further details.

### 16.2.5.4 ASCOM telescopes

ASCOM specific settings can be configured when a ASCOM telescope was selected. Please see section 16.2.8 for further information about configuration possibilities.

### 16.2.5.5 Virtual telescope

If you want to test this plug-in without an actual device connected to the computer, choose "Nothing, just simulate one (a moving reticle)" in the `Telescope controlled by:` field. It will show a telescope reticle that will react in the same way as the reticle of a real telescope controlled by the plug-in. See the section above about field of view indicators for a possible practical application (emulating 'Telrad' circles).

## 16.2.6 RTS2

*RTS2*, the Remote Telescope System 2, is a complete robotic observatory control system for Linux by Petr Kubánek, who kindly provided the plugin code to make RTS2 interoperate with Stellarium. We cannot give a full manual or any further support for RTS2 here, please refer to its website[8] for complete instructions about dome control, cameras, filter wheels, weather sensors, etc. A few notes may be useful for beginners, though.

RTS2's central piece is a daemon. Start the system:

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[6] `https://rts2.org/`
[7] `https://indilib.org`
[8] `https://rts2.org`

```
sudo service rts2 start
```

RTS2's main control screen is text-based, **rts2-mon**. For a quick check, switch on the system using F9. Telescope T0 is a dummy telescope which you can select and operate with commands like `move 120 35` (this moves to RA=120°=8h, DEC=35°, but only when this position is above your horizon).

Stellarium's Telescope plugin can communicate with RTS2 using the RTS2 web interface. You must run **rts2-httpd** for this, which may require the right permissions to write the lock files in `/var/run`. This program requires that a database has been created as described in the file RUN in RTS2's source directory and on the RTS2 website[9]. Also, you must create a 'user' for RTS2. This is not a regular Linux account, but an entry in the RTS2 database. Create a user with **rts2-user -a <user>**. You should use a password different from your regular Linux password, as this will be transmitted in plain text between the computer running Stellarium and the RTS2 control computer, and may also be written into Stellarium's logfile. Then you can enable device control for the respective user. If you want to send slew commands from Stellarium, make sure to allow access to telescope T0. If not, Stellarium will be able to show the telescope marker, but you will not be able to control the telescope. To enable control for existing users in the default stars database,

```
psql stars
update users set allowed_devices = '*';
```

In case you cannot properly connect to the RTS2 telescope or cannot send slew commands, check Stellarium's logfile `log.txt` for some diagnostic messages.

RTS2 is the only type of telescope supported by Stellarium which can autonomously track satellites. Tracking accuracy fully depends on Stellarium's TLE satellite elements being up-to-date (see section 14.8) and the accuracy of your RTS2 installation.

## 16.2.7 INDI

*INDI*, the Instrument Neutral Distributed Interface, is a distributed control system (DCS) protocol to enable control, data acquisition and exchange among hardware devices and software front ends, emphasizing astronomical instrumentation[10].

INDI client (v1.6.0) has been incorporated into Stellarium's Telescope Control plugin by Alessandro Siniscalchi to allow Stellarium to communicate with INDI hardware drivers via INDI server. INDI server is a hub that sits between drivers and clients. It reroutes traffic for control and data across distributed networks. Each device or client in the network is a node and may communicate with other nodes whenever desired. The server supports broadcasting, chaining, and marshalling of data.

Stellarium only supports INDI mounts (no other INDI devices), and you will need to select the correct INDI device to manage it at the stage of configuration of telescope. For this purpose the plug-in has a tool to getting the list of connected devices from the INDI server (when the server is working!). Please define hostname and port[11] in the "INDI Settings" block, press Refresh devices and select the required device in the list "Devices".

List of telescope types supported by INDI[12]:
- Meade Autostar
- Meade LX200 (Classic/GPS/16)
- Celestron NexStar
- Celestron NexStar Evolution
- Orion Synscan Telescope
- EQ-6 MCU Update
- HEQ-5 MCU Update
- LittleFoot Vpower
- LittleFoot Elegance Photo
- Astro-Electronic FS-2
- EQMod
- Pulsar2
- SkySensor2000PC

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[9] `https://rts2.org/faq.html`

[10] `https://en.wikipedia.org/wiki/Instrument_Neutral_Distributed_Interface`

[11] The Internet Assigned Numbers Authority (IANA) has assigned to INDI the Transmission Control Protocol and User Datagram Protocol (TCP/UDP) port 7624.

[12] `https://indilib.org/devices/telescopes/all.html`

- Takahashi Temma
- 10 Micron
- Losmandy Gemini
- Astrophysics
- Skywatcher Virtuoso (Alt/Az)
- IOptron IEQPro/CEM60
- IOptron ZEQ25/SmartEQ
- IOptron GotoNova Upgrade Kit 8400

### 16.2.8  ASCOM 7 (Windows only)

*ASCOM* is probably the most widely used way how to communicate with telescopes, mounts and other astronomy equipment on Microsoft Windows operating systems. The ASCOM platform aims to decouple device dependent specifics by introducing a common standard for communication between device drivers and applications. Almost every telescope mount comes with an ASCOM driver and most of the astronomy software and tools can communicate with ASCOM compatible devices.

The ASCOM telescope support has been added to Stellarium's Telescope Control plugin by Gion Kunz in version 0.19.3.[13]

Note that in order for Stellarium to communicate with your ASCOM compatible mount, you will need to have the ASCOM platform installed on your Windows machine (version 7 or higher[14]). Also, the ASCOM driver of your telescope mount needs to be installed before you can start using the telescope in Stellarium.

**Important:** Most modern ASCOM drivers are written to run in 32bit and 64bit mode (any) and therefore are compatible with the 64bit and 32bit version of Stellarium. However, if you happen to have a 32bit or 64bit only driver for your telescope mount, you will also need to install the respective Stellarium version.

In order to use your ASCOM telescope you need to select the correct device in the ASCOM chooser by clicking the button Choose ASCOM telescope. The selected device is shown below that button.

By default, Stellarium is trying to ask the ASCOM driver in order to determine if JNow or J2000 coordinates should be used for communicating with the mount. If you'd like to override this behavior and tell the ASCOM telescope to communicate in the coordinate system configured in the section Telescope properties, you can switch the radio button Let ASCOM device decide to Use Stellarium settings in the ASCOM settings of the Configure Telescope dialog.

### 16.2.9  StellariumScope

**StellariumScope** is a free add-on that enables you to control your ASCOM enabled telescope with Stellarium.

Note that Stellarium supports ASCOM telescopes natively since version 0.19.3. There's no need to use StellariumScope in order to use your ASCOM telescopes with Stellarium anymore. We are encouraging our users to use the native ASCOM option unless they need particular features of StellariumScope.

The original **StellariumScope** program was designed and implemented by Scott of ByteArts but is no longer available. It is now maintained by and available for download from Welsh Dragon Computing [15].

**Features**

- Provides an interface between Stellarium and ASCOM telescope drivers.
- Provides the ability to both "Sync" and "Slew" the telescope. It's also possible to issue a stop/cancel command from Stellarium.
- You can easily host Stellarium on one computer linked to another control computer that hosts the telescope driver.
- The installation program will automatically install the documentation, but the link to the documentation is provided by the developer[16] so you can read it before installation.

Use this application (like all software that controls your mount) with supervision of your mount's movements.

---

[13]Unfortunately ASCOM version 6 seems to be incompatible with Qt6. After numerous error reports we had to disable ASCOM support on Qt6-based builds of version 24.3-24.4. However, preliminary tests showed that ASCOM 7 *may* work again, so this way of connection is back. Without proper instruments, the maintainers depend on your feedback, though. If you depend on ASCOM support, please update to ASCOM version 7, or use a Qt5-based build of the same version.

[14]`https://ascom-standards.org/Downloads/Index.htm`

[15]`https://welshdragoncomputing.ca/x/index.php/home/stellariumscope/about-stellariumscope`

[16]**StellariumScope** User's Guide — `https://welshdragoncomputing.ca/x/st/misc/stellariumscope_user_guide.2016.03.05.pdf`

## 16.2.10   Other telescope servers and Stellarium

Other developers have also been busy creating hard- and software often involving Arduino or Raspberry Pi boards which can control GOTO or PUSHTO (manually driven but position-aware, usually Dobsonian) telescopes and are ultimately controlled from Stellarium. Those are not related nor authored by the Stellarium team, so while we welcome such development (esp. open-sourced) in general, we cannot provide documentation nor any support.

A few examples:

**iTelescope** `http://simonbox.info/index.php/astronomy/93-raspberry-pi-itelescope`
**node-telescope-server** `https://www.npmjs.com/package/node-telescope-server`
**OnStep** `https://groups.io/g/onstep`

One anonymous user sent a troubleshooting solution when connecting Stellarium to the Celestron **NexRemote** software:

> One tricky Window XP issue I fixed was that my older laptop would transiently lose connection with Stellarium although the status would still be "Connected" and all looked normal. [...]
>
> I boosted the *NexRemote.exe* process in Windows XP to *High* under *Set Priority* under the **Windows Task Manager** via Ctrl + Alt + Del.
>
> All slews now proceed normally. Problem went away.[17]

### 16.2.10.1   Stellarium Telescope Protocol

In the early days of Stellarium, telescope control required standalone server programs. These were later integrated in the plugin. However, there are situations where external control servers are still useful, e.g. when they are running on some tiny telescope computer while the user sits in the warm control room in front of the powerful PC running Stellarium. For you DIYers out there, figure 16.18 shows the original protocol.

---

[17]`https://sourceforge.net/p/stellarium/discussion/278769/thread/16e4c054/?limit=25#8ffa`

```
/*
Author and Copyright of this file and of the stellarium telescope library:
Johannes Gajdosik, 2006
*/

Stellarium Telescope Protocol version 1.0

The Stellarium Telescope Protocol works on top of TCP/IP.
The client is the stellarium program (or any similar program),
the server is called "telescope server" and controls the telescope.
Depending on the implementation the server may handle one or many
simultaneous clients. The reference server implementation accepts
an unlimited number of simultaneous clients.

The protocol is message based: both server and client may
spontaneousely send messages as often as they want.
When the server looses control of the telescope he should
actively close the connection to all clients.

The first two bytes of any message describes the total
length of that message in bytes (including the first 2 bytes).

The next 2 bytes of any message describe the type of this message.

The byte order for all kind of integers is always
"least significant byte first".

----------------------
server->client:
MessageCurrentPosition (type = 0):

LENGTH (2 bytes,integer): length of the message
TYPE   (2 bytes,integer): 0
TIME   (8 bytes,integer): current time on the server computer in microseconds
           since 1970.01.01 UT. Currently unused.
RA     (4 bytes,unsigned integer): right ascension of the telescope (J2000)
           a value of 0x100000000 = 0x0 means 24h=0h,
           a value of 0x80000000 means 12h
DEC    (4 bytes,signed integer): declination of the telescope (J2000)
           a value of -0x40000000 means -90degrees,
           a value of 0x0 means 0degrees,
           a value of 0x40000000 means 90degrees
STATUS (4 bytes,signed integer): status of the telescope, currently unused.
           status=0 means ok, status<0 means some error


--------------------

client->server:
MessageGoto (type =0)
LENGTH (2 bytes,integer): length of the message
TYPE   (2 bytes,integer): 0
TIME   (8 bytes,integer): current time on the client computer in microseconds
                 since 1970.01.01 UT. Currently unused.
RA     (4 bytes,unsigned integer): right ascension of the telescope (J2000)
           a value of 0x100000000 = 0x0 means 24h=0h,
           a value of 0x80000000 means 12h
DEC    (4 bytes,signed integer): declination of the telescope (J2000)
           a value of -0x40000000 means -90degrees,
           a value of 0x0 means 0degrees,
           a value of 0x40000000 means 90degrees
```

Figure 16.18: The Stellarium Telescope Protocol, version 1.0

## 16.3  Observability Plugin

This Plugin is activated with the button ⚑ . It analyzes the observability of the selected object (or the screen center, if no object is selected). The plugin can show the best epoch of the year (i.e., largest angular separation from the Sun), the date range when the source is above the horizon at dark night, and the dates of Acronychal and Cosmical rise/set. Ephemerides of the Solar-System objects and parallax effects are taken into account.

### Explanation of some parameters

**Sun altitude at twilight**  Any celestial object will be considered visible when the Sun is below this altitude. The altitude at astronomical twilight ranges usually between -12 and -18 degrees. This parameter is only used for the estimate of the range of observable epochs (see below).

**Horizon altitude**  Minimum observable altitude (due to obstructions or just a limited telescope mount).

**Acronychal/Cosmical/Heliacal rise/set**  The days of Cosmical rise/set of an object are estimated as the days when the object rises (or sets) together with the rise/set of the Sun. The exact dates of these events depend on the Observer's location. In contrast, the Acronychal rise (or set) happens when the star rises/sets with the setting/rising of the Sun (i.e., opposite to the Sun). It is obvious that the source is hardly observable (or not observable at all) in the dates between Cosmical set and Cosmical rise. On the other hand, the dates around the Acronychal set and rise are those when the altitude of the celestial object uses to be high when the Sun is well below the horizon (hence the object can be well observed). The date of Heliacal rise is the first day of the year when a star becomes visible. It happens when the star is close to the eastern horizon roughly before the end of the astronomical night (i.e., at the astronomical twilight). In the following nights, the star will be visible during longer periods of time, until it reaches its Heliacal set (i.e., the last night of the year when the star is still visible). At the Heliacal set, the star sets roughly after the beginning of the astronomical night.

**Largest Sun separation**  Happens when the angular separation between the Sun and the celestial object are maximum. In most cases, this is equivalent to say that the Equatorial longitudes of the Sun and the object differ by 180 degrees, so the Sun is in opposition to the object. When an object is at its maximum possible angular separation from the Sun (no matter if it is a planet or a star), it culminates roughly at midnight, and on the darkest possible area of the Sky at that declination. Hence, that is the 'best' night to observe a particular object.

**Nights with source above horizon**  The program computes the range of dates when the celestial object is above the horizon at least during one moment of the night. By 'night', the program considers the time span when the Sun altitude is below that of the twilight (which can be set by the user; see above). When the objects are fixed on the sky (or are exterior planets), the range of observable epochs for the current year can have two possible forms: either a range from one date to another (e.g., 20 Jan to 15 Sep) or in two steps (from 1 Jan to a given date and from another date to 31 Dec). In the first case, the first date (20 Jan in our example) shall be close to the so-called 'Heliacal rise of a star' and the second date (15 Sep in our example) shall be close to the 'Heliacal set'. In the second case (e.g., a range in the form 1 Jan to 20 May and 21 Sep to 31 Dec), the first date (20 May in our example) would be close to the Heliacal set and the second one (21 Sep in our example) to the Heliacal rise. More exact equations to estimate the Heliacal rise/set of stars and planets (which will not depend on the mere input of a twilight Sun elevation by the user) will be implemented in future versions of this plugin.

**Full Moon**  When the Moon is selected, the program can compute the exact closest dates of the Moon's opposition to the Sun.

### Note on Terminology

The (sparse) literature on terminology about computing these Heliacal, Acronychal or Cosmic events seems to disagree on which end of the night is to be computed. While all agree about Heliacal rises taking place in the morning, Acronychal and Cosmic are sometimes applied in reverse order from those described here. In case you use these data, make sure you keep this definition as well.

### Author

This plugin has been contributed by Ivan Marti-Vidal (Onsala Space Observatory)[18] with some advice by Alexander Wolf and Georg Zotti.

---

[18]`mailto:i.martividal@gmail.com`
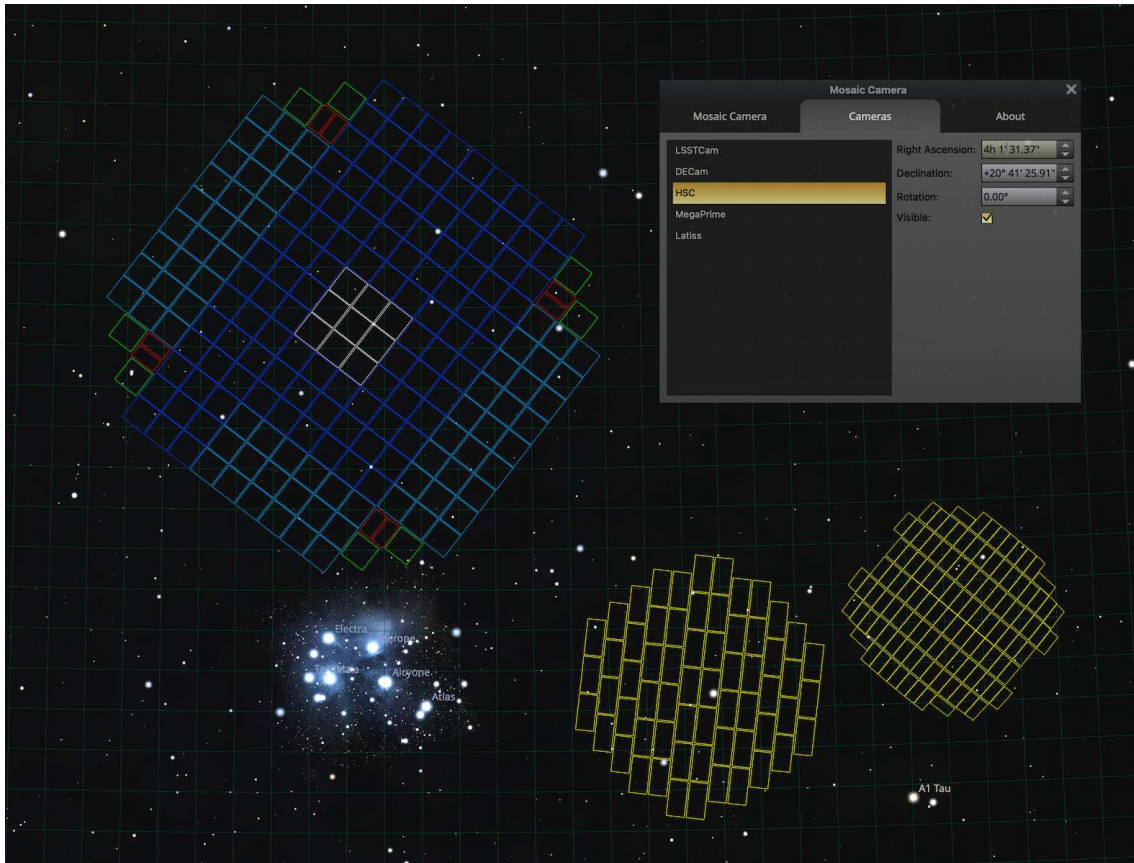
Figure 16.19: The Mosaic Camera plugin in action. Overlays of LSSTCam(left), DECam (center), and HyperSuprimeCam (right) are shown, as well as the configuration dialog for the plugin (top right).

## 16.4 Mosaic Camera Plugin

JOSH MEYERS[19]

### 16.4.1 Introduction

This plugin overlays an outline of one or more mosaic cameras, i.e., cameras with multiple sensors, onto the Stellarium celestial sphere. With this functionality, one may compare the fields of view of different cameras, including potentially one's own astrophotography setup. Combined with the scripting and remote control features of Stellarium, various visualizations are possible, including real-time tracking of the observations of telescopes, playback of past observations, or public outreach demonstrations of the capabilities of various instruments.

### 16.4.2 Usage

From the "Cameras" tab of the Mosaic Camera configuration window, you can select from the available cameras, setting their RA, Dec, rotation, and visibility as desired.

### 16.4.3 Cameras

Multiple cameras can be individually configured and displayed.

#### 16.4.3.1 Default Cameras

A few cameras come pre-packaged with Stellarium. These are:

---

[19]mailto:jmeyers314@gmail.com

### LSSTCam

The largest (as of 2025) digital camera ever assembled at 3.2 gigapixels. Now mounted on the Simonyi Survey Telescope at the Vera C. Rubin Observatory, this camera will be used to execute the Legacy Survey of Space and Time, creating a 10-year multicolor 'movie' of the southern sky.

Note that the individual CCDs within this camera's overlay are color-coded by their functionality: Two shades of blue indicate the main science sensors. (LSSTCam features a hybrid focal plane. Light blue corresponds to sensors made by Imaging Technology Laboratory, while dark blue corresponds to sensors made by Imaging Teledyne e2v.) The white sensors in the middle show the field-of-view of the Rubin Commissioning Camera, a smaller camera used to commission the telescope mount and mirrors before the main LSSTCam camera was ready. The red sensors in the corners are wavefront sensors, used to monitor and correct the telescope's optical alignment in real time. The green sensors are the guider sensors, used to inform the telescope's tracking system. See more at `https://rubinobservatory.org/explore/how-r ubin-works/technology/camera`.

### HyperSuprimeCam (HSC)

A 900 megapixel camera mounted on the Subaru telescope at the Mauna Kea Observatory. See more at `https://www.naoj.org/Projects/HSC/`.

### Dark Energy Camera (DECam)

A 570 megapixel camera mounted on the Blanco telescope at the Cerro Tololo Inter-American Observatory. See more at `https://www.darkenergysurvey.org/the-des-project/instrument/`.

### MegaPrime

A 378 megapixel camera mounted on the Canada-France-Hawaii Telescope at Mauna Kea Observatory. See more at `https://www.cfht.hawaii.edu/Instruments/Imaging/MegaPrime/`.

### LATISS

The LSST Atmospheric Transmission Imager and Slitless Spectrograph. A 16 megapixel camera mounted on the Rubin Observatory Auxiliary telescope. See more at `https://rubinobservatory.org/explore /how-rubin-works/technology/auxtel`.

### JWST

The James Webb Space Telescope's focal plane. See more at `https://jwst-docs.stsci.edu/jwst-o bservatory-hardware/jwst-telescope/jwst-focal-plane#gsc.tab=0`.

### HST

The Hubble Space Telescope's focal plane. See more at `https://hst-docs.stsci.edu/acsihb/chapt er-3-acs-capabilities-design-and-operations/3-1-acs-location-in-the-hst-focal-p lane`.

### Roman

The Nancy Grace Roman Space Telescope's focal plane. See more at `https://roman.gsfc.nasa.gov/ science/WFI_technical.html`.

### Euclid

The Euclid Space Telescope's focal plane. See more at `https://www.euclid-ec.org/public/missi on/vis/`.

#### 16.4.3.2  Adding a Camera

When the Mosaic Camera plugin is first enabled, it checks the user data directory for the existence of a directory <USERDATA>/modules/MosaicCamera/. If this directory does not exist, it will be created and populated with JSON files for each of the default cameras, and one JSON file `camera_order.json` which specifies the order in which the cameras are displayed.

To add a new camera, create a new JSON file inside this directory, and add a reference to it in the `camera_order.json` file.

Camera sensors are specified via their corners, which are assumed to form spherical polygons. The corners should be specified as gnomonic projections from the sphere to a tangent plane in radians. Multiple groups of sensors can compose the same camera. For example, LSSTCam has separate sensor groups for wavefront sensors, guider sensors, and each of two types of science sensors.

Each camera is defined via a JSON file with the structure:

```
[
    {
        "camera_name": "telescope/camera full name",
        "camera_description": "telescope/camera description in HTML"
    },
```

```
{
    "name": "name-of-group-1",
    "corners": [
        [
            [corner1_x, corner1_y],
            [corner2_x, corner2_y],
            ...
        ], # sensor 1
        [
            ...
        ], # sensor 2
        ...
    ]
    "color": {
        "value": [R, G, B, alpha]
    }
},
{
    "name": "name-of-group-2",
    ...
},
...
]
```

See the default camera JSON files for examples.

To reset the plugin to its default state, simply delete the `<USERDATA>/modules/MosaicCamera/` directory.

### 16.4.4  Control

There are several ways to control the Mosaic Camera plugin.

#### 16.4.4.1  Mosaic Camera Settings Dialog

The Mosaic Camera settings dialog can be opened by right-clicking the MosaicCamera icon, or by selecting "configure" from the Plugins tab of the main Stellarium Configuration window. This dialog allows you to configure the cameras, as well as the visibility of the overlays.

#### 16.4.4.2  Keyboard Shortcuts

Keyboard shortcuts (see section 4.8) can be configured to perform the following actions:
- Cycle the active camera forward or backward
- Increase or decrease the rotation angle of the current camera by 5 degrees.
- Set the pointing of the current camera to the current Stellarium view.
- Toggle the visibility of Mosaic Camera overlays.
- Toggle the Mosaic Camera settings dialog.

#### 16.4.4.3  Stellarium Scripting

The Mosaic Camera plugin can be controlled via Stellarium's scripting interface. In the following example, we set the LSSTCam overlay to be centered at RA=3.0, Dec=4.0 (in J2000 degrees), with a rotation of 1.0 degrees.

```
MosaicCamera.setCurrentCamera("LSSTCam")
MosaicCamera.setCurrentRA(3.0)
MosaicCamera.setCurrentDec(4.0)
MosaicCamera.setCurrentRotation(1.0)
```

an equivalent script is:

```
MosaicCamera.setRA("LSSTCam", 3.0)
MosaicCamera.setDec("LSSTCam", 4.0)
MosaicCamera.setRotation("LSSTCam", 1.0)
```

or even:

```
MosaicCamera.setPosition("LSSTCam", 3.0, 4.0, 1.0)
```

#### 16.4.4.4  Stellarium Remote Control

The Mosaic Camera plugin is also accessible via Stellarium's remote control interface (see 13.5). Here's a short python script equivalent to the above example:

```python
import requests
port = 8090  # Default Stellarium port
url = f"http://localhost:{port}/api/stelproperty/set"

for name, val in [
  ["MosaicCamera.currentCamera", "LSSTCam"],
  ["MosaicCamera.ra", 3.0],
  ["MosaicCamera.dec", 4.0],
  ["MosaicCamera.rotation", 1.0]
]:
  requests.post(url, data={"id": name, "value": val})
```
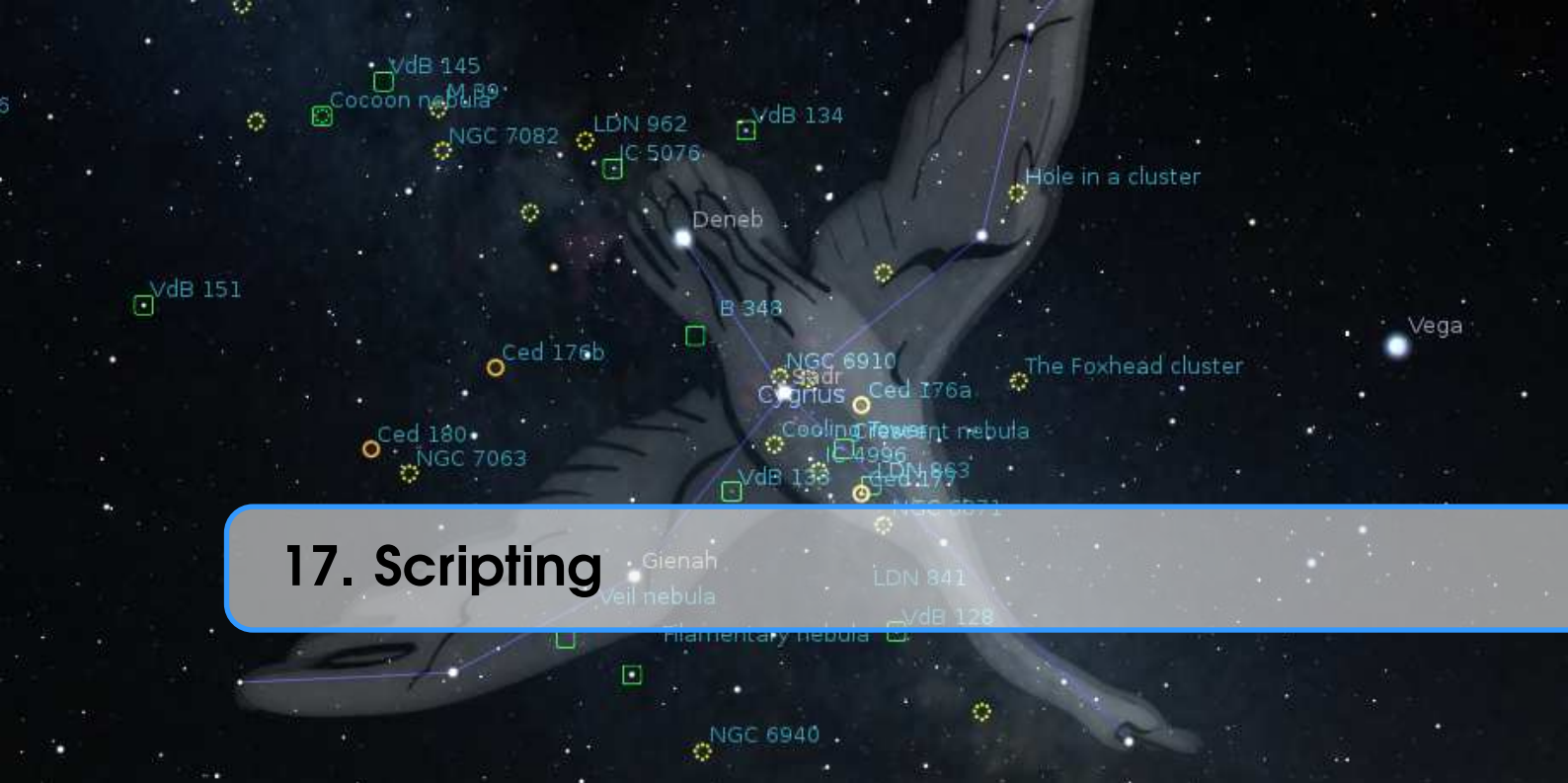
# 17. Scripting

A. WOLF, G. ZOTTI, WITH ADDITIONS BY WOLFGANG LAUN

## 17.1 Introduction

The scripting facility is Stellarium's version of a *Presentation*, a feature that may be used to run an astronomical or other show for instruction or entertainment from within the Stellarium program. The use of scripts was recognized as a perfect way of arranging a presentation of a sequence of astronomical events from the earliest versions of Stellarium.

The original *Stratoscript* was quite limited in what it could do, and so a new Stellarium Scripting System has been developed.

Since version 0.10.1, Stellarium has included a scripting feature based on the Qt5 Scripting Engine[1]. This made it possible to write small programs within Stellarium to produce automatic presentations, set up custom configurations, and to automate repetitive tasks. By version 0.14.0 the new scripting engine had reached a level where it had all required features for usage, and support of scripts for the old *Stratoscript* engine has been discontinued.

The programming language *ECMAScript*[2] (also known as *JavaScript*) gives users access to all basic ECMAScript language features such as flow control, variables, string manipulation and so on. Its integration with Qt's QtScript module and the way Stellarium's main components ("StelModule"s) have been designed to work means that all module functions which are labeled as "slots" can be called from JavaScript.

Interaction with Stellarium-specific features is done via a collection of objects which represent components of Stellarium itself. The various modules of Stellarium, and also activated plugins, can be called in scripts to calculate, move the scene, switch on and off display of objects, etc. You can write text output into text files with the `output()` command. You can call all public slots which are documented in the scripting API documentation[3].

With the adaptation to Qt6 in versions 1.0 and later we had to switch to yet another scripting engine in 2022. Qt6 comes with QJSEngine[4], another JavaScript engine which behaves mostly similar to the older QtScript. However, small differences exist, so that care must be taken if scripts should be developed for both series of Stellarium. Some older scripts will not work on versions 1.0 and later or at least require some adaptations described in section 17.5.

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[1] `https://doc.qt.io/qt-5/qtscript-index.html`
[2] `https://en.wikipedia.org/wiki/ECMAScript`
[3] `https://www.stellarium.org/doc/25.0/scripting.html`
[4] `https://doc.qt.io/qt-6/qtjavascript.html`

## 17.2    The Script Console

It is possible to load, edit, run and save scripts using the script console window. To toggle the script console, press F12.

### 17.2.1    The Tabs in the Console

The three tabs "Script", "Log" and "Output" each provide a text field. In the "Script" text field you can edit a script, which can be loaded from and saved to a file, and executed. The "Log" text field receives all errors and other messages resulting from the script's execution; the "Output" text field will show the results of `core.output()` function calls.

The fourth tab, "Settings", provides some configuration options.

### 17.2.2    The Menu Bar

The menu bar contains buttons for loading and saving a script. A file dialog is shown for selecting the file. The "clear" button lets you clear the contents of the text field in the currently selected tab. The drop-down menu "Execute:" offers a selection of menu entries, mainly intended to let you restore the sky to a clean state. The entry "selected text as script" executes selected text in the "Script" text field, allowing to test scripts during development. Entries "remove screen text", "remove screen images" and "remove screen markers" remove labels, images and markers, respectively, that may have been left over on the screen from previous script actions. Each of the "clear map" entries results in a call to `core.clear()`, using one of the arguments "natural", "starchart", "deepspace", "galactic" or "supergalactic". These calls reset Stellarium's state, resulting in a basic state of the display and providing a clean starting point for another run of your script.

The button SSC runs the Stellarium Script Preprocessor with the script in the text field as input and produces an output by recursively inserting all included scripts into the text. *This output replaces the contents of the Script text field. Store the original script if you need it!*

### 17.2.3    German Keyboards

There is a glitch in the keyboard module of the underlying system that is responsible for keyboard handling. It affects users of Windows and Linux systems with a German, and probably also other international keyboards: The key combinations AltGr + 8 and AltGr + 9 cannot be used for typing [ and ]. You need to work around by copy-pasting these two characters. You can also try to use a command line argument like `-platform windows:altgr`.

## 17.3    Includes

Stellarium provides a mechanism for splitting scripts into different files. Typical functions or lists of variables or celestial objects can be stored in separate `.inc` files and used within other scripts through the **include()** command:

```
include("common_objects.inc");
```

## 17.4    Minimal Scripts

This script prints "Hello Universe" in the Script Console log window and into `log.txt`:

```
core.debug("Hello Universe");
```

This script prints "Hello Universe" in the Script Console output window and into the file `output.txt` which you will also find in the user data directory. The absolute path to the file will also be given in `log.txt`.

```
core.output("Hello Universe");
```

The file `output.txt` will be rewritten on each run of Stellarium. In case you need to save a copy of the current output file to another file, call

```
core.saveOutputAs("myImportantData.txt");
core.resetOutput();
```

This script uses the LabelMgr module to display "Hello Universe" in red, fontsize 20, on the screen for 3 seconds.

```
var label=LabelMgr.labelScreen("Hello Universe", 200, 200,
                               true, 20, "#ff0000");
core.wait(3);
LabelMgr.deleteLabel(label);
```

## 17.5 Critical Scripting Differences introduced with version 1.0

Qt5's QtScript module which has been used in versions 0.10 to 0.22 was more flexible and easier to fine-tune than Qt6's QJSEngine, which is used in the Qt6-based 1.* series of the program, i.e., versions 1.0 (22.3) and later. Still, most scripts that have been developed for Stellarium versions 0.10 to 0.22 still run without or with just minor modifications as described in this section.

### 17.5.1 Pause/Resume

The Qt6-based builds (version 1.0 and later) do not offer a way to pause and resume a script as was available in the Qt5-based builds (0.10 to 0.22).

### 17.5.2 The Vec3f problem

One of the most important little helper classes in the main program are three-dimensional vectors. `Vec3f` describe those with single-precision floating point data, and `Vec3d` are those with double-precision floating point data.

As late as in version 0.19 we added `Vec3f` and later `Vec3d` data types to the Javascript environment. These allowed addressing variables of C++ classes `Vec3f` or `Vec3d` with named sub-fields `r`, `g`, `b` (if used to describe colors), or `x`, `y`, `z` (same data but contextually understood as 3D data). These functions may have pleased the JavaScript connoisseur when running scripts with Qt5-based builds of Stellarium (series 0.*, and now usually found on 32-bit and older systems), but we recommend to abstain from their use in new scripts.

Qt6's scripting module cannot be extended that easily. The `Vec3d` and `Vec3f` data types are not directly scriptable, but we can deal with method arguments of these types when they are mentioned in the API documentation (see 17.1). To access internals of these classes, we must use wrapper classes which bear different names:

`V3d` can be used where `Vec3d` must be accessed.

`V3f` can be used where `Vec3f` must be accessed.

`Color` can be used where a `Vec3f` must be accessed which represents a color value.

They behave slightly different when run using Qt5 or Qt6, as shown in Table 17.1. If you aim for maximum compatibility between versions, only use the calls which provide equal results in both series. This current state is far from optimal or even pretty, but a pragmatic solution that works. We invite advanced developers to find a better solution that works with both Qt5 and Qt6.

## 17.6 Example: Retrograde motion of Mars

A good way begin writing of scripts: set yourself a specific goal and try to achieve it with the help of few simple steps. Any complex script can be split into simple parts or tasks, which may solve any newbie problems in scripting.

Let me explain it with examples.

Imagine that you have set a goal to make a demonstration of a very beautiful, but longish phenomenon — the retrograde motion of the planet Mars (Fig. 17.1).

### 17.6.1 Script header

Any "complex" script should contain a few lines in the first part of the file, which contains important data for humans — the name of the script and its description — and some rules for Stellarium. You can even assign default shortcuts in the script header, but make sure you assign a key not used elsewhere! The shortcuts are read during startup from all scripts in the `scripts` sub-directories of both program and user data directories (see section 5.2). The description may cover several lines (until the end of the commented header) and should therefore be the last entry of the header.

```
//
// Name: Retrograde motion of Mars
// Author: John Doe
// License: Public Domain
```

| | Input | Result with Qt5 | Result with Qt6 |
|---|---|---|---|
| x | var f1=new V3d(.1,.2,.3); | | |
| x | core.output(f1); | [0.1, 0.2, 0.3] | V3d(0x2493a1cf37c0) [some address] |
| x | core.output(+f1.toString()); | [0.1, 0.2, 0.3] | V3d(0x2493a1cf37c0) [some address] |
| x | core.output(f1.toHex()); | #19334c | #19334c |
| x | core.output(f1.toVec3d()); | [0.1, 0.2, 0.3] | [0.1, 0.2, 0.3] |
| x | var f2=new V3d(f1.x(), 2*f1.y(), 3*f1.z()); | | |
| x | core.output(f2); | [0.1, 0.4, 0.9] | V3d(0x2493a1cf3a60) [some address] |
| x | core.output(f2.toVec3d()); | [0.1, 0.4, 0.899999999999999] | [0.1, 0.4, 0.9] |
| x | var crimson=new Color("Crimson"); | | |
| x | core.output(crimson.toHex()); | #dc143c | #dc143c |
| x | core.output(crimson.toVec3f()); | [r:0.862745106220245, g:0.0784313753247261, b:0.235294118523597772] | [0.862745, 0.0784314, 0.235294] |
| x | core.output(crimson.r()); | error | error |
| x | core.output(crimson.getR()); | 0.862745106220245 | 0.862745106220245 |
| x | core.output(crimson.getG()); | 0.0784313753247261 | 0.0784313753247261 |
| x | core.output(crimson.getB()); | 0.235294118523597772 | 0.235294118523597772 |
| | crimson..g=0.444; | (works) | (error) |
| | crimson.g=0.444; | (error) | (error) |
| | crimson.setG(0.444); | (works) | (works) |
| x | crimson=new Color(crimson.getR(), 0.444, crimson.getB()); | (reassign crimson; recommended for qt5 and qt6) | |
| x | core.output(crimson.toRGBString()); | [r:0.862745, g:0.444, b:0.235294] | [r:0.862745, g:0.444, b:0.235294] |
| x | var eq=new Color(GridLinesMgr.getColorEquatorJ2000Grid()); | | |
| x | core.output(eq.toHex()); | #00aaff | #00aaff |
| x | core.output(eq.toVec3f()); | [r:0, g:0.666666984581055, b:1] | [0, 0.666667, 1] |
| x | core.output(eq.toVec3d()); | (n.a.) | [0, 0.666667, 1] |
| x | core.output(eq.toString()); | [0, 0.666667, 1] | Color(0x24a11712910) [some address] |
| x | core.output(eq.toRGBString()); | [r:0, g:0.666667, b:1] | [r:0, g:0.666667, b:1] |
| x | var c=new Color(core.vec3f(.3, .4, .5)); | | |
| x | core.output(c.toString()); | [0.3, 0.4, 0.5] | Color(0x249a1e078b0) [some address] |
| x | core.output(c.toVec3f()); | [r:0.300000011920928896, g:0.400000005960464645, b:0.5] | [0.3, 0.4, 0.5] |
| x | var d=c; // assign to other | | |
| x | core.output(d.toVec3f()); | [r:0.300000011920928896, g:0.400000005960464645, b:0.5] | [0.3, 0.4, 0.5] |
| x | var c2=new Color(.3, .4, .5); | | |
| x | core.output(c2.toString()); | [0.3, 0.4, 0.5] | Color(0x24a11712a60) [some address] |
| x | core.output(c2.toVec3f()); | [r:0.300000011920928896, g:0.400000005960464645, b:0.5] | [0.3, 0.4, 0.5] |
| x | var d2=c2; // assign to other | | |
| x | core.output(d2.toVec3f()); | [r:0.300000011920928896, g:0.400000005960464645, b:0.5] | [0.3, 0.4, 0.5] |

Table 17.1: Use of V3d, V3f and Color wrapper classes. Only use the calls marked with x in scripts targeted at all versions of Stellarium.

Figure 17.1: Retrograde motion of Mars in 2005. (Credit & Copyright: Tunc Tezel — APOD: 2006 April 22 – Z is for Mars.)

```
// Version: 1.0
// Shortcut: Ctrl+M
// Description: A demo of retrograde motion of Mars.
//
```

### 17.6.2  A body of script

At the first stage of writing of the script for a demo of retrograde motion of Mars we should set some limits for our demo. For example we want to see motion of Mars every day during 250 days since October 1$^{st}$, 2009. Choosing a value of field of view and of the coordinates of the center of the screen should be done at the this stage also.

Let's add few lines of code into the script after the header and run it:

```
core.setDate("2009-10-01T10:00:00");
core.moveToRaDec("08h44m41s", "+18d09m13s",1);
StelMovementMgr.zoomTo(40, 1);
for (i=0; i<250; i++)
{
      core.setDate("+ 1 days");
      core.wait(0.2);
}
```

**Note:** The `wait(delay_seconds)` instruction inside the loop is important: when you are just setting the time in rapid succession, there is no guarantee that the view is updated, or a textual result has been updated when writing ephemerides, before executing the next time update! The `wait()` ensures the program can update the main simulation loop and put the planets where they should be at that set time. The minimum delay required may depend on your computer's speed.

OK, Stellarium is doing something, but what exactly is it doing? The ground and atmosphere is enabled and any motion of Mars is invisible. Let's add an another few lines into the script (hiding the landscape and atmosphere) after setting date and time:

```
LandscapeMgr.setFlagLandscape(false);
```

```
LandscapeMgr.setFlagAtmosphere(false);
```

The whole sky is moving now — let's lock it! Add this line after previous lines:

```
StelMovementMgr.setFlagLockEquPos(true);
```

It looks better now, but what about cardinal points, elements of GUI and some "glitch of movement"?
Let's change the script:

```
core.setDate("2009-10-01T10:00:00");
LandscapeMgr.setFlagCardinalsPoints(false);
LandscapeMgr.setFlagLandscape(false);
LandscapeMgr.setFlagAtmosphere(false);
core.setGuiVisible(false);
core.moveToRaDec("08h44m41s", "+18d09m13s",1);
StelMovementMgr.setFlagLockEquPos(true);
StelMovementMgr.zoomTo(40, 1);
core.wait(2);
for (i=0; i<250; i++)
{
     core.setDate("+ 1 days");
     core.wait(0.2);
}
core.setGuiVisible(true);
```

It's better, but let's draw the "path" of Mars! Add those line before the loop:

```
core.selectObjectByName("Mars", false);
SolarSystem.setFlagIsolatedTrails(true);
SolarSystem.setFlagTrails(true);
```

Hmm... let's add a few strings with info for users (insert those lines after the header):

```
var color = "#ff9900";
var info = LabelMgr.labelScreen("A motion of Mars", 20, 20,
           false, 24, color);
var apx = LabelMgr.labelScreen("Setup best viewing angle, FOV
           and date/time.", 20, 50, false, 18, color);
LabelMgr.setLabelShow(info, true);
LabelMgr.setLabelShow(apx, true);
core.wait(2);
LabelMgr.setLabelShow(apx, false);
```

Let's add some improvements to display info for users — change in the loop:

```
var label = LabelMgr.labelObject("  Normal motion, West to
           East", "Mars", true, 16, color, "SE");
for (i=0; i<250; i++)
{
     core.setDate("+ 1 days");
     if ((i % 10) == 0)
     {
          var strDate = "Day " + i;
          LabelMgr.setLabelShow(apx, false);
          var apx = LabelMgr.labelScreen(strDate, 20,
                             50, false, 16, color);
          LabelMgr.setLabelShow(apx, true);
     }
     if (i == 75)
     {
          LabelMgr.deleteLabel(label);
          label = LabelMgr.labelObject("  Retrograde or
```

```
                         opposite motion begins", "Mars",
                         true, 16, color, "SE");
             core.wait(2);
             LabelMgr.deleteLabel(label);
             label = LabelMgr.labelObject("  Retrograde
                         motion", "Mars", true, 16, color,
                         "SE");
       }
       if (i == 160)
       {
             LabelMgr.deleteLabel(label);
             label = LabelMgr.labelObject("  Normal motion
                         returns", "Mars", true, 16, color,
                         "SE");
             core.wait(2);
             LabelMgr.deleteLabel(label);
             label = LabelMgr.labelObject("  Normal motion",
                         "Mars", true, 16, color, "SE");
       }
       core.wait(0.2);
}
```

## 17.7 More Examples

The best source of examples is the `scripts` sub-directory of the main Stellarium source tree. This directory contains a sub-directory called `tests` which are not installed with Stellarium, but are nonetheless useful sources of example code for various scripting features.

# IV

# Practical Astronomy

# 18. Astronomical Concepts

BARRY GERDES, WITH ADDITIONS BY GEORG ZOTTI

This section includes some general notes on astronomy in an effort to outline some concepts that are helpful to understand features of Stellarium. Material here is only an overview, and the reader is encouraged to get hold of a couple of good books on the subject. A good place to start is a compact guide and ephemeris such as the *National Audubon Society Field Guide to the Night Sky*[1]. Also recommended is a more complete textbook such as *Universe*[2]. There are also some nice resources on the net, such as the *Wikibooks Astronomy book*[3].

## 18.1 The Celestial Sphere

The *Celestial Sphere* is a concept which helps us think about the positions of objects in the sky. Looking up at the sky, you might imagine that it is a huge dome or top half of a sphere (a hemisphere), and the stars are points of light on that sphere. Visualizing the sky in such a manner, it appears that the sphere moves, taking all the stars with it — it seems to rotate. Watching the movement of the stars we can see that they seem to rotate around a static point about once a day (the diurnal motion). Stellarium is the perfect tool to demonstrate this!

1. Open the location dialog ( F6 ). Set the location to be somewhere in mid-northern latitudes. (Just click on the map to select a location, or fine-tune with the settings.) The United Kingdom is an ideal location for this demonstration.
2. Turn off atmospheric rendering A and ensure cardinal points are turned on ( Q ). This will keep the sky dark so the Sun doesn't prevent us from seeing the motion of the stars when it is above the horizon.
3. Pan round to point north, and make sure the field of view is about 90°.
4. Pan up so the 'N' cardinal point on the horizon is at the bottom of the screen.
5. Now increase the time rate. Press K , L , L , L , L – this should set the time rate so the stars can be seen to rotate around a point in the sky about once every ten seconds. If you watch Stellarium's clock you'll see this is the time it takes for one day to pass at this accelerated rate.

The point which the stars appear to move around is one of the *Celestial Poles*.

The apparent movement of the stars is due to the rotation of the Earth. Our location as the observer on the surface of the Earth affects how we perceive the motion of the stars. To an observer standing at Earth's North Pole, the stars all seem to rotate around the *zenith* (the point directly upward). As the observer moves

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[1] https://www.amazon.com/National-Audubon-Society-Field-Series/dp/0679408525
[2] https://www.amazon.com/Universe-Definitive-Visual-Martin-Rees/dp/0756636701
[3] https://en.wikibooks.org/wiki/Subject:Astronomy

south towards the *equator*, the location of the celestial pole moves down towards the horizon. At the Earth's equator, the North Celestial Pole appears to be on the northern horizon.

Similarly, observers in the southern hemisphere see the Southern Celestial Pole at the zenith when they are at the South Pole, and it moves to the horizon as the observer travels towards the equator.

1. Leave time moving on nice and fast, and open the configuration window. Go to the location tab and click on the map right at the top – i.e., set your location to the North Pole. See how the stars rotate parallel to the horizon, around a point right at the top of the screen. With the field of view set to 90° and the horizon at the bottom of the screen, the top of the screen is the zenith.
2. Now click on the map again, this time a little further south. You should see the positions of the stars jump, and the center of rotation has moved a little further down the screen.
3. Click on the map even further towards and equator. You should see the centre of rotation having moved down again.

To help with the visualization of the celestial sphere, turn on the equatorial grid by clicking the button on the main toolbar or pressing the $\boxed{\text{E}}$ key. Now you can see grid lines drawn on the sky. These lines are like lines of longitude and latitude on the Earth, but drawn for the celestial sphere.

The *Celestial Equator* is the line around the celestial sphere that is half way between the celestial poles – just as the Earth's equator is the line half way between the Earth's poles.

## 18.2  Coordinate Systems

### 18.2.1  Altitude/Azimuth Coordinates

The *Horizontal Coordinate System* (also called Altitude/Azimuth coordinate system) can be used to describe a direction of view (the *azimuth* angle) and an angular height in the sky (the *altitude* angle). The azimuth angle is measured clockwise round from due north[4]. Hence North itself is 0°, East 90°, Southwest is 225° and so on. The altitude angle is measured up from the *mathematical horizon*, which is just halfway between "straight up" and "straight down", without regard to the landscape. Looking directly up (at the *zenith*) would be 90°, half way between the zenith and the horizon is 45° and so on. The point opposite the zenith is called the *nadir*.

The Altitude/Azimuth coordinate system is attractive in that it is intuitive – most people are familiar with azimuth angles from bearings in the context of navigation, and the altitude angle is something most people can visualise pretty easily.

However, the altitude/azimuth coordinate system is not suitable for describing the general position of stars and other objects in the sky – the altitude and azimuth values for a celestial object change with time and the location of the observer.

Stellarium can draw grid lines for altitude/azimuth coordinates. Use the $\boxed{\circledast}$ button on the main toolbar to activate this grid, or press the $\boxed{\text{Z}}$ key.

In addition, the *cardinal points* can be highlighted using the $\boxed{+}$ button or $\boxed{\text{Q}}$ key.

There are a few great circles with special names which Stellarium can draw (see section 4.4.4).

**Meridian**  This is a great circle which runs through the North Pole towards the zenith and further to the South Pole and nadir.

**(Mathematical) Horizon**  This is the line exactly 90° away from the zenith.

**First Vertical**  This is the vertical circle perpendicular to the horizon and which runs from the East point through the zenith, down the West point and to the nadir.

### 18.2.2  Right Ascension/Declination Coordinates

Like the Altitude/Azimuth system, the *Right Ascension/Declination* (RA/Dec) Coordinate System (or *Equatorial Coordinate System*) uses two angles to describe positions in the sky. These angles are measured from standard points on the celestial sphere. *Right ascension* $\alpha$ and *declination* $\delta$ are to the celestial sphere what longitude and latitude are to terrestrial map makers.

The Northern Celestial Pole has a declination of $\delta = 90°$, the celestial equator has a declination of $\delta = 0°$, and the Southern Celestial Pole has a declination of $\delta = -90°$.

Occasionally, instrument makers of the past may have engraved polar distance $p$ instead: $p = 90° - \delta$. Stellarium can be configured to use this convention, see section 4.3.3.

---

[4]In some textbooks azimuth is counted from south. There is no global authority to decide upon this issue, just be aware of this when you compare numbers with other sources.
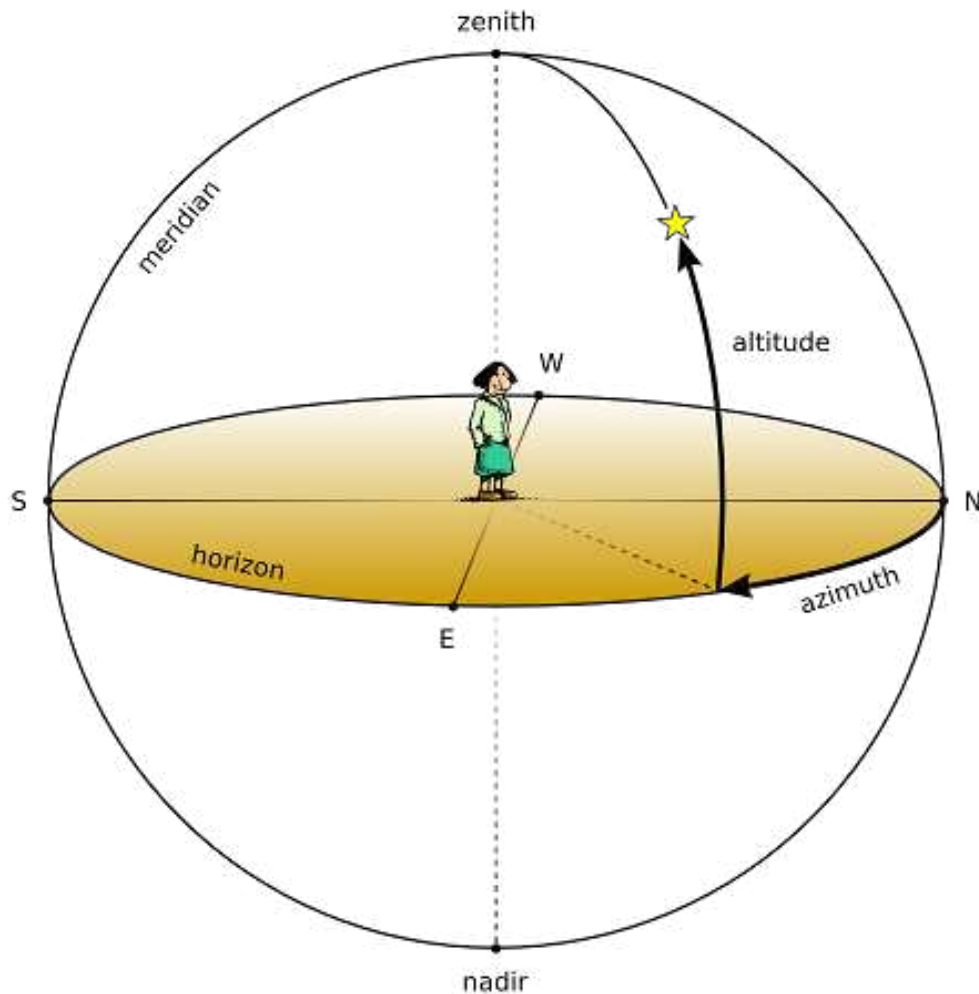
Figure 18.1: Altitude/Azimuth (Horizontal) Coordinate System

Right ascension is measured as an angle round from the *vernal equinox*, a point in the sky also known as the *First Point of Aries* ♈, in the same way that longitude is measured around the Earth from Greenwich. Figure 18.2 illustrates RA/Dec coordinates. The angle $\alpha$ is usually expressed as time with minute and seconds, with 15° equaling one hour.

Unlike Altitude/Azimuth coordinates, RA/Dec coordinates of a star do not change when the observer changes latitude, and do not change noticeably over the course of the day due to the rotation of the Earth. RA/Dec coordinates are generally used nowadays in star catalogs such as the Hipparcos catalog.

However, the story is complicated a little by *precession* (section 18.8) and *parallax* (section 18.9). Precession causes a slow drift of the coordinates almost parallel to the *ecliptic*, and therefore star catalogs always have to specify their *equinox* of validity.

Current catalogs and atlases use coordinates for the *standard epoch* J2000.0. The currently best defined coordinate system, the International Celestial Reference Frame (*ICRF*), is one particular version described in detail in the astronomical literature (Urban and Seidelmann, 2013). Other catalogs with data referring to "J2000.0" may have to be slightly adjusted (usually in sub-arcsecond rotations) to match the ICRF coordinate system (short ICRS).

Stars close to the *celestial poles* are permanently visible above the horizon and thus called *circumpolar*. Those stars have observable *upper* and *lower culminations* when they pass the meridian arc spanning from the celestial pole over the zenith to the opposite point on the horizon, or from the celestial pole to the horizon
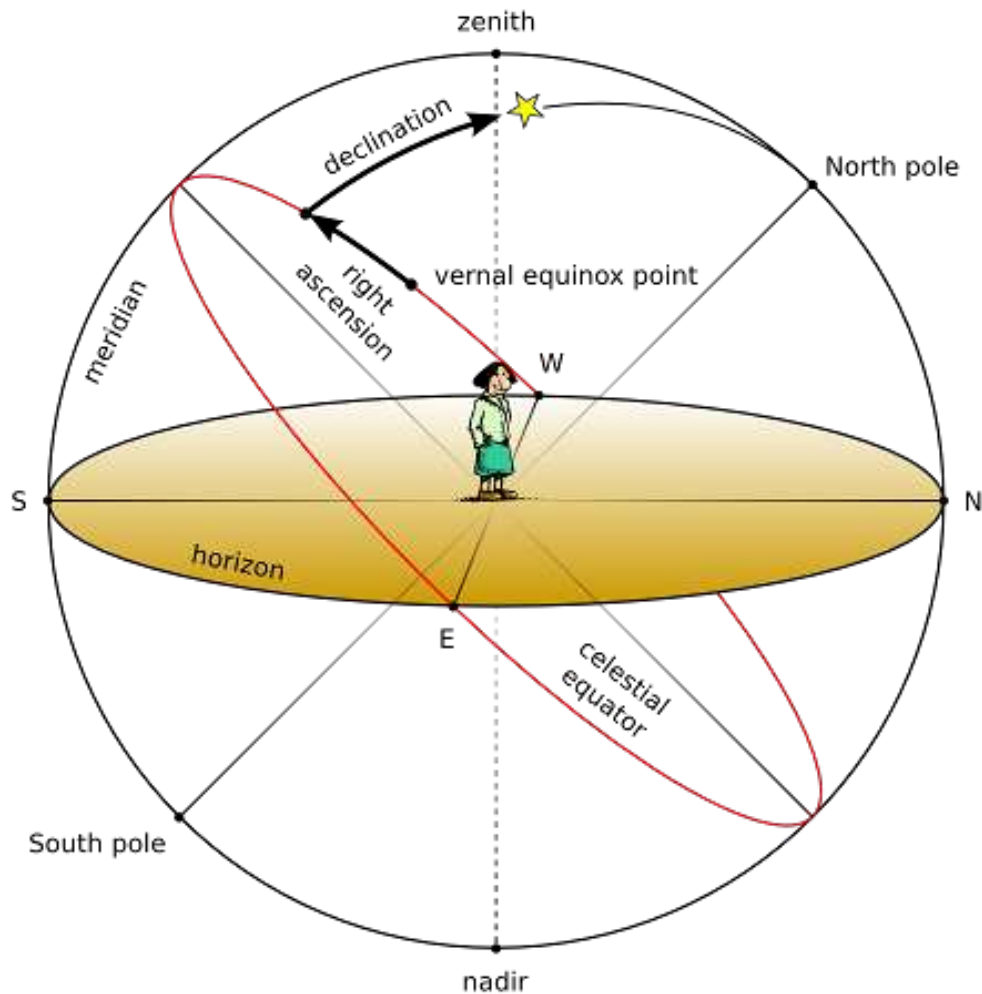
Figure 18.2: Equatorial Coordinates

below, respectively.

Those circumpolar stars which show their upper culmination between *pole* and *zenith* also have limits in *azimuth* which they can reach in their daily course, the points of *greatest digression*. At these points they move vertically upwards (in the east) or downwards (in the west), respectively.

Stellarium can draw grid lines for equatorial coordinates. Use the button 🌐 on the main toolbar to activate this grid, or press the E key to draw the equatorial grid for the simulation time. The Markings dialog (4.4.4) allows you to set also the grid for J2000.0 standard coordinates.

There are again a few great circles with special names which Stellarium can draw in addition, both for simulation time and for J2000.0 (see section 4.4.4).

**Celestial Equator** the line directly above the Earth's (or more generally, the observer's planet's) equator.
**Colures** These are lines similar to meridian and first vertical in the azimuthal system. The *Equinoctial Colure* runs from the North Celestial Pole NCP through the First Point of Aries ♈, South Celestial Pole SCP and First Point of Libra ♎, while the *Solstitial Colure* runs from the NCP through *First Point of Cancer* ♋, SCP and *First Point of Capricorn* ♑.

In case you are observing from another celestial object, the equatorial coordinates use a system similar to the one referring to the Earth-based coordinates, but parallel to the planet's rotational axis.

### 18.2.3 Fixed Equatorial Coordinates

The celestial sphere with its stars and other objects located in equatorial coordinates seems to rotate around the celestial polar axis. When observing with a telescope, it proved useful to mount the instrument on an axis which is aimed to be parallel to the earth's axis, i.e., points to the celestial pole. In this case, after setting the objects's declination, it is enough to move the telescope around this polar axis to track its course over time and keep the object in the field of view. We can describe the *Fixed Equatorial Coordinate System* as an intermediate coordinate system which uses the same equator and declination as the equatorial system, but does not rotate as time goes by. The longitudinal coordinate is conventionally counted in 0. . . 24 hours from the meridian (0h) along the celestial equator towards the west (6h) and is aptly named *Hour Angle*. A star which has passed the meridian will reach hour angle of 1 hour one sidereal hour later. In some traditions, decimal degrees may be preferred, and negative hour angles are used instead on the eastern half of the sky. (See section 4.3.3 for settings.)

Stellarium can display the fixed equatorial coordinates in the Markings dialog (4.4.4).

### 18.2.4 Ecliptical Coordinates

The Earth's orbit around the Sun, i.e., the *ecliptic*, defines the "equatorial line" of this coordinate system, which is traditionally used when computing the coordinates for planets because of their close proximity to this line. Mirroring Earth's motion, the Sun is seen to move along the ecliptic.

The zero point of *ecliptical longitude* $\lambda$ is the same as for equatorial coordinates ($\Upsilon$), and the *ecliptical latitude* $\beta$ is counted positive towards the *Northern Ecliptical Pole* NEP in the constellation of Draco.

Moon and Sun (and to a much lesser extent, the other planets) pull on the equatorial bulge and try to put Earth's axis normal to its orbital plane. Earth acts like a spinning top and evades this pull in a sideways motion, so that Earth's axis seems to describe a small circle over a period of almost 26.000 years (see section 18.8).

In addition, *ecliptic obliquity* against the equatorial coordinates, which mirrors the Earth's axial tilt, slowly changes.

Therefore, also for ecliptical coordinates it is required to specify which date (epoch) the coordinates refer to. Stellarium can draw grids for two epochs. Use the ⌑ key to draw the *ecliptic* for the simulation time. The Markings dialog (4.4.4) allows you to add date marks to the ecliptic line and also show a line for epoch J2000.0 and grids for the ecliptical coordinates for current epoch and epoch J2000.0. You can assign your own shortcut keys (section 4.8) if you frequently operate with these coordinates.

Since version 0.14.0 Stellarium can very accurately show the motions between the coordinate systems (Vondrák, Capitaine, and Wallace, 2011; Vondrák, Capitaine, and Wallace, 2012), and it is quite interesting to follow these motions for several millennia. To support such demonstrations, Stellarium can also draw the *precession circles* between celestial and ecliptical poles (activate them in the Markings dialog (4.4.4). However, these circles are simply plotted centered on the instantaneous ecliptic pole by the instantaneous value of obliquity. If you observe long enough, you will see that these circles vary in size, reflecting the changes in ecliptic *obliquity*. The real track of where Earth's axis is pointing forms an open helical loop.

The inner planets are best observed when their apparent distance from the Sun, or *elongation*, reaches a maximum. Unfortunately there are two definitions for elongation, though:

$\psi$ angular distance on the sphere. This is today the most widely used definition.

$\Delta\lambda_{\odot}$ difference between solar and the object's ecliptical longitude. The advantage of using this definition is that we can easily read *opposition* ($\Delta\lambda_{\odot} = 180°$) and *conjunction* ($\Delta\lambda_{\odot} = 0°$). We can also see whether we have *eastern elongation* ($\Delta\lambda_{\odot} > 0$) where the planet is visible in the evening sky, or *western elongation* ($\Delta\lambda_{\odot} < 0$) where the planet is visible in the morning sky. For the inner planets Mercury and Venus we further discern *superior conjunction*, when the planet is "above", or behind, the Sun, and *inferior conjunction*, when the planet is "below", or closer than, the Sun.

Many of the minor bodies are best observed around the times of their opposition. Stellarium can display a great circle in the ecliptical coordinates which runs through the ecliptic poles and through the Sun, thereby allowing to estimate opposition and conjunction. Activate display of this *Opposition/Conjunction Line* in the Markings dialog (Labeled "O./C. longitude"; 4.4.4). The Markings dialog also provides the possibility to visualize the *antisolar point*, which lies opposite of the Sun, on the intersection of the ecliptic and the O/C line.

Another interesting aspect of planets is their *quadrature* from the Sun. Here their angular distance is 90°. You can activate display of the quadrature circle in the Markings dialog (4.4.4).

It is interesting to note that star catalogs before TYCHO BRAHE's (1546–1601), most notably the one in PTOLEMY's *Almagest*, used ecliptical coordinates. The reason is simple: it was known since HIPPARCHUS

that stellar coordinates slowly move along the ecliptic through *precession*, and the correction to coordinates of a date of interest was a simple addition of a linear correction to the ecliptical longitude in the catalog. Changes of ecliptic obliquity were discovered much later.

### 18.2.5 Galactic Coordinates

The Milky Way appears to run along a great circle over the sky, mirroring the fact that the Sun is a star in it. Coordinates for non-stellar objects which belong to the Milky Way like *pulsars* or *planetary nebulae* are often mapped in *Galactic Coordinates*, where *galactic longitude l* and *galactic latitude b* are usually given in decimal degrees. Here, the zero point of galactic longitudes lies in the Galactic Center.

Stellarium can also draw a galactic grid and the galactic equator by activating the respective options in the Markings dialog (see section 4.4.4). You can assign a keyboard shortcut if you frequently use these coordinates (see 4.8).

### 18.2.6 Planet Coordinates

The larger objects in the Solar system are described as spheroids, sometimes flattened into slightly ellipsoid shape.

Just like the Prime Meridian on Earth has been defined to run through Greenwich Observatory, each such object in the Solar system for which any kind of rotation has been detected has a prime meridian defined by the IAU Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE). On a rocky planet this is usually defined by some surface feature like a crater. For the Moon, it has traditionally been the center of the Lunar disk. For the gas giant planets with ever-changing atmospheric features, there are even several systems of rotation. Most notably on Jupiter, System I describes the rotation of its equatorial area, while System II describes the mean atmospheric rotation north of the south component of the north equatorial belt, and south of the north component of the south equatorial belt. Official sources prefer to list the rotation of the magnetic fields (System III) for these planets. The most interesting feature on Jupiter for most observers is the *Great Red Spot* (GRS), a huge storm that has been observed since the 19th, if not even since the 17th century.

Astronomical almanacs and observing guides often list *transit times* when the GRS crosses the center of Jupiter's visible disk. Stellarium aims to show it at the right place. The storm moves in longitude, and to adjust for this you can configure its System II longitude in the settings, see 4.4.2.

Like many planet moons, also Earth's Moon shows one side towards its planet. However, given its elliptical orbit and disturbations by Earth, Sun and other planets, the Moon seems to nod slightly in east-west and north-south directions. This motion is called *Libration*. Stellarium gives geocentric libration in longitude $L$ and latitude $B$, which are the coordinates of the apparent center of the Lunar disk. Another way to express this shift is the total angle of libration and the direction into which the Moon's mean center has been shifted. This angle is given counterclockwise from the direction of the North pole on the Lunar disk. The larger this shift is, the better you can observe the opposite side, which is therefore marked in brackets. If libration is larger than 3/5/7 degrees, Stellarium shows 1, 2 or 3 exclamation marks to draw your attention further to this lunar rim. However, you also need light on this edge.

Another interesting point for which Stellarium gives coordinates is the sub-solar point $(L_s, B_s)$.

The Selenographic colongitude of the Sun $c_0 = 450° - L_s$ is given for the Moon. This helps estimating the terminator (Meeus, 1998):

- The morning terminator is at $360° - c_0$.
- The evening terminator is at $180° - c_0$.
- When $c_0 = 0°$, the Sun rises at selenographic longitude $L = 0°$, near First Quarter.
- When $c_0 = 90°$, the Sun rises at selenographic longitude $L = 270°$, near Full Moon.
- When $c_0 = 180°$, the Sun rises at selenographic longitude $L = 180°$, near Last Quarter.
- When $c_0 = 270°$, the Sun rises at selenographic longitude $L = 90°$, near New Moon.

$c_0$ is used to compute the Sun's altitude $h$ over a surface point, e.g. a crater on the Moon at position $(\eta, \theta)$, which is displayed when you select a surface feature.

$$\sin h = \sin B_s \sin \theta + \cos B_s \cos \theta \sin(c_0 + \eta) \tag{18.1}$$

## 18.3 Distance

As DOUGLAS ADAMS (1952–2001) pointed out in *The Hitchhiker's Guide to the Galaxy* (Adams, 1981),

> Space [...] is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts to space.[p.76]

Astronomers use a variety of units for distance that make sense in the context of the mind-boggling vastness of space.

**Astronomical Unit (AU)** This is the mean Earth-Sun distance. Roughly 150 million kilometers ($1.49598 \times 10^8$ km). The AU is used mainly when discussing the solar system – for example the distance of various planets from the Sun.

**Light year (LY)** A light year is not, as some people believe, a measure of time. It is the distance that light travels in a year. The speed of light being approximately 300,000 kilometers per second means a light year is a very large distance indeed, working out at about 9.5 trillion kilometers ($9.46073 \times 10^{12}$ km). Light years are most frequently used when describing the distance of stars and galaxies or the sizes of large-scale objects like galaxies, nebulae etc.

**Parsec (pc)** A parsec is defined as the distance of an object that has an annual parallax of 1 second of arc. This equates to 3.26156 light years ($3.08568 \times 10^{13}$ km). Parsecs (and derivatives: kiloparsec kpc, megaparsec Mpc) are most frequently used when describing the distance of stars or the sizes of large-scale objects like galaxies, nebulae etc.

## 18.4 Time
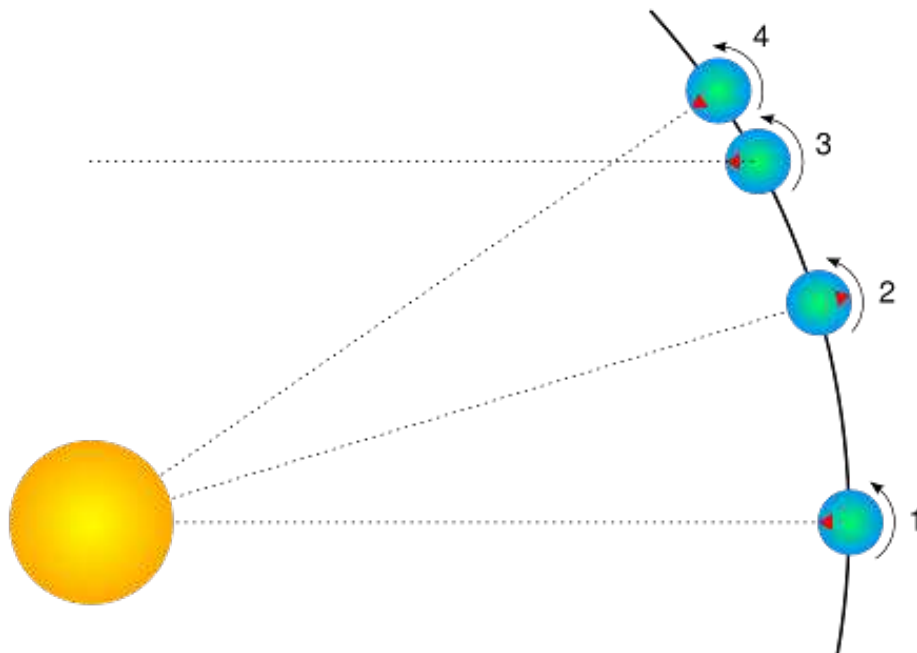


Figure 18.3: Sidereal day

The length of a day is defined as the amount of time that it takes for the Sun to travel from the highest point in the sky at mid-day to the next high-point on the next day. In astronomy this is called a *solar day*. The apparent motion of the Sun is caused by the rotation of the Earth. However, in this time, the Earth not only spins, it also moves slightly round its orbit. Thus in one solar day the Earth does not spin exactly 360° on its axis. Another way to measure day length is to consider how long it takes for the Earth to rotate exactly 360°. This is known as one *sidereal day*.

Figure 18.3 illustrates the motion of the Earth as seen looking down on the Earth orbiting the Sun. The red triangle on the Earth represents the location of an observer. The figure shows the Earth at four times:

1. The Sun is directly overhead - it is mid-day.

2. Twelve hours have passed since 1. The Earth has rotated round and the observer is on the opposite side of the Earth from the Sun. It is mid-night. The Earth has also moved round in its orbit a little.
3. The Earth has rotated exactly 360°. Exactly one sidereal day has passed since 1.
4. It is mid-day again – exactly one solar day since 1. Note that the Earth has rotated more than 360° since 1.

It should be noted that in figure 18.3 the sizes of the Sun and Earth and not to scale. More importantly, the distance the Earth moves around its orbit is much exaggerated. The Earth takes a year to travel round the Sun – $365\frac{1}{4}$ solar days. The length of a sidereal day is about 23 hours, 56 minutes and 4 seconds.

### 18.4.1 Sidereal Time

It takes exactly one sidereal day for the celestial sphere to make one revolution in the sky. Astronomers find *sidereal time* useful when observing. This is the Right Ascension which is currently passing the meridian line, or, equivalent, the *Hour Angle* of the First Point of Aries ♈. When visiting observatories, look out for doctored alarm clocks that have been set to run faster and show sidereal time!

### 18.4.2 Julian Day Number

In the 19th century, astronomer JOHN HERSCHEL (1792–1871) introduced the use of *Julian Day* numbers (invented around the time of the Gregorian calendar reform). This is a simple continuous day count starting on January 1, -4712 (4713 BC). There are no years, months etc., and the integral day number switches at noon, so during a single night of observation (in Europe) the date never changes.

The fractional part of the number is just the fraction of day that has elapsed since last noon. Given that a day has 86400 seconds, we should give a JD with 5 decimal places to capture the nearest second.

This causes a problem for modern computers: even a "double precision float" can keep only about 13 decimal places. More than 2.4 million days have passed, so that e.g. January 1, 2000, 12:00UT is 2451545.0, which is an accurately storable number with 7 decimal places, but 12:34:56UT is computed as 2451545.02426. A more accurate result would yield 2451545.024259259259... So, for a field where sub-second accuracy became crucial like spacecraft operations, the *Modified Julian Day* (MJD) has been introduced. It is simply

$$MJD = JD - 2400000.5. \tag{18.2}$$

This means, days start at midnight, and the (constant, in our era) decimal places of the "big numbers" at the begin of the number have been traded in for more decimal places at the end.

Don't put your expectations too high when you see MJD displayed (section 4.1): Stellarium uses a double-precision floating point number for JD for internal timekeeping, and Stellarium's display of MJD is simply computed from it. So you cannot set temporal increments smaller than a second, and it hardly would make sense to expect more accuracy from the simulation algorithms.

### 18.4.3 Delta T

Until around 1900, the Earth's rotation was regarded as perfect standard of time. There were 86400 seconds per mean solar day, and the accuracy of reproducing time with mechanical clocks only in this time started to become as good as the Earth's rotation itself.

Astronomers who computed solar eclipses reported in texts from antiquity wondered about a required time shift which they originally attributed to a yet-unknown "secular acceleration of the lunar motion". However, it turned out that indeed the gravitational effect of the Moon which causes the tides also has effects on Earth's rotation: the tides slowly break Earth's rotational speed. The energy is also transferred to the Moon, and the acceleration leads to the Moon slowly moving away from the Earth[5].

This led to the introduction of a time named Ephemeris Time (ET) with progresses in the speed of the second in the year 1900, to be used for positional computation in our solar system, in addition to Greenwich Mean Time (GMT), from which all zone times and "civil" clock times were derived.

The introduction of atomic clocks in the middle of the 20th century led to a redefinition of the (temporal) second, which has been de-coupled from Earth's rotation. This time, the International Atomic Time TAI[6], is

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[5] No need to worry, the Moon recedes from the Earth only a few centimeters per year as measured with the laser reflectors left by the Apollo astronauts in the 1970s. In a very far future, however, there will only be annular solar eclipses as a consequence!

[6] From the French name *temps atomique international*

the basis for Terrestrial Time TT which can be considered as constantly progressing at constant speed[7], and is used for computation of the planetary positions.

Still, people living on Earth prefer to have the mean solar noon governing the run of day and night. Therefore all forms of civil time are linked to Coordinated Universal Time UTC. Seconds in UTC and TAI are of equal length. The slow and irregular divergence between TAI and UTC is observed by a few standardization institutes. When necessary, a leap second can be introduced to the UTC to bring the Earth's rotation back in sync so that the Mean Sun again culminates at noon.

The difference $\Delta T = TT - UT$ (or "Delta T") describes the temporal offset which amounts already to more than a minute in the 21st century. There have been many attempts to properly model $\Delta T$, and Stellarium offers several models you can choose from in the configuration dialog (see section 4.3.4). "Espenak and Meeus (2006, 2014)", is a widely accepted standard. The default, "Modified Espenak and Meeus (2006, 2014, 2023)", is created to make $\Delta T$ closely in line with observed and predicted values between the years 2015-2050. But if you are a researcher and want to experiment with alternative models, you will hopefully like this feature. you can even specify your own data for $a$, $b$, $c$, $y$ and the secular term for lunar acceleration $n$ (actually $\dot{n} = dn/dt$ in units of arcseconds/century$^2$) if you can model $\Delta T$ according to the formula

$$\Delta T \quad = \quad a + b \cdot u + c \cdot u^2 \quad \text{where} \tag{18.3}$$
$$u \quad = \quad \frac{\text{year} - y}{100} \tag{18.4}$$

### 18.4.3.1 List of $\Delta T$ models in Stellarium

The following list describes sources and a few details about the models for $\Delta T$ implemented in Stellarium.

**Without correction.** Correction is disabled. Use only if you know what you are doing!

**Schoch (1931).** This historical formula was obtained by Schoch (1931) and was also used in "A New Test of Einstein's Theory of Relativity by Ancient Solar Eclipses" (Henriksson, 2009). See for more in Peters (2010). $\dot{n} = -29.68''/\text{cy}^2$.

**Clemence (1948).** This empirical equation was published in "On the system of astronomical constants" (Clemence, 1948). Valid range of usage: between years 1681 and 1900. $\dot{n} = -22.44''/\text{cy}^2$.

**IAU (1952).** This formula is based on a study of post-1650 observations of the Sun, the Moon and the planets (Spencer Jones, 1939) and reproduced in *Astronomical Formulae for Calculators* (Meeus, 1988). It was also adopted in the PC program **SunTracker Pro**. Valid range of usage: between years 1681 and 1936. $\dot{n} = -22.44''/\text{cy}^2$.

**Astronomical Ephemeris (1960).** This is a slightly modified version of the IAU 1952 (Spencer Jones, 1939) formula which was adopted in the "Astronomical Ephemeris" (Wilkins, 1961) and in the *Canon of Solar Eclipses -2003 to +2526* (Mucke and Meeus, 1983). Valid range of usage: between years -500 and 2000. $\dot{n} = -22.44''/\text{cy}^2$.

**Tuckerman (1962, 1964) & Goldstine (1973).** The famous tables (Tuckerman, 1962; Tuckerman, 1964) list the positions of the Sun, the Moon and the planets at 5- and 10-day intervals from 601 BCE to 1649 CE. The same relation was also implicitly adopted in the syzygy tables of Goldstine (1973). Valid range of usage: between years -600 and 1649.

**Muller & Stephenson (1975).** This equation was published in "The accelerations of the earth and moon from early astronomical observations" (Muller and F. R. Stephenson, 1975). Valid range of usage: between years -1375 and 1975. $\dot{n} = -37.5''/\text{cy}^2$.

**Stephenson (1978).** This equation was published in "Pre-Telescopic Astronomical Observations" (F. R. Stephenson, 1978). $\dot{n} = -30.0''/\text{cy}^2$.

**Schmadel & Zech (1979).** This 12th-order polynomial equation (outdated and superseded by Schmadel and Zech (1988)) was published in "Polynomial approximations for the correction delta T E.T.-U.T. in the period 1800-1975" (Schmadel and Zech, 1979) as fit through data published by Brouwer (1952). Valid range of usage: between years 1800 and 1975, with meaningless values outside this range. $\dot{n} = -23.8946''/\text{cy}^2$.

**Morrison & Stephenson (1982).** This algorithm Morrison and F. R. Stephenson, 1982 was adopted in *Planetary Programs and Tables from –4000 to +2800* (Pierre Bretagnon and Simon, 1986) and in the PC planetarium program **RedShift**. Valid range of usage: between years -4000 and 2800. $\dot{n} = -26.0''/\text{cy}^2$.

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[7]We don't discuss relativity here. The advanced reader is referred to the presentation in the Wikipedia, `https://en.wikipedia.org/wiki/Delta_T`.

**Stephenson & Morrison (1984).** This formula was published in "Long-term changes in the rotation of the earth - 700 B.C. to A.D. 1980" (F. R. Stephenson and Morrison, 1984). Valid range of usage: between years -391 and 1600. $\dot{n} = -26.0''/\text{cy}^2$.

**Stephenson & Houlden (1986).** This algorithm (Houlden and F. Stephenson, 1986) is used in the PC planetarium program **Guide 7**. Valid range of usage: between years -600 and 1600. $\dot{n} = -26.0''/\text{cy}^2$.

**Espenak (1987, 1989).** This algorithm was given in *Fifty Year Canon of Solar Eclipses: 1986 – 2035* (Espenak, 1987) and in *Fifty Year Canon of Lunar Eclipses: 1986 – 2035* (Espenak, 1989). Valid range of usage: between years 1950 and 2100.

**Borkowski (1988).** This formula was obtained by Borkowski (1988) from an analysis of 31 solar eclipse records dating between 2137 BCE and 1715 CE. Valid range of usage: between years -2136 and 1715. $\dot{n} = -23.895''/\text{cy}^2$.

**Schmadel & Zech (1988).** This 12th-order polynomial equation was published in "Empirical Transformations from U.T. to E.T. for the Period 1800-1988" (Schmadel and Zech, 1988) as data fit through values given by F. R. Stephenson and Morrison (1984). Valid range of usage: between years 1800 and 1988, with a mean error of less than one second, max. error 1.9s, and meaningless values outside this range. $\dot{n} = -26.0''/\text{cy}^2$.

**Chapront-Touze & Chapront (1991).** This formula was adopted by M. Chapront-Touze & J. Chapront in the shortened version of the ELP 2000-85 lunar theory in their *Lunar Tables and Programs from 4000 B.C. to A.D. 8000* (Chapront-Touzé and Chapront, 1991). The relations are based on those of F. R. Stephenson and Morrison (1984), but slightly modified to make them compatible with the tidal acceleration parameter of $\dot{n} = -23.8946''/\text{cy}^2$ adopted in the ELP 2000-85 lunar theory (Chapront-Touzé and Chapront, 1988a).

**Stephenson & Morrison (1995).** This equation was published in "Long-Term Fluctuations in the Earth's Rotation: 700 BC to AD 1990" (F. R. Stephenson and Morrison, 1995). Valid range of usage: between years -700 and 1600. $\dot{n} = -26.0''/\text{cy}^2$.

**Stephenson (1997).** F. R. Stephenson published this formula in his book *Historical Eclipses and Earth's Rotation* (F. Richard Stephenson, 1997). Valid range of usage: between years -500 and 1600. $\dot{n} = -26.0''/\text{cy}^2$.

**Meeus (1998) (with Chapront, Chapront-Touze & Francou (1997)).** Used in *Astronomical Algorithms* (Meeus, 1998), and elsewhere. Table for 1620..2000, and includes a variant of Chapront, Chapront-Touze & Francou (1997) for dates outside 1620..2000. Valid range of usage: between years -400 and 2150. $\dot{n} = -25.7376''/\text{cy}^2$.

**JPL HORIZONS.** The JPL Solar System Dynamics Group of the NASA Jet Propulsion Laboratory use this formula in their interactive website JPL HORIZONS[8]. Valid range of usage: between years -2999 and 1620, with zero values outside this range. $\dot{n} = -25.7376''/\text{cy}^2$.

**Meeus & Simons (2000).** This polynome was published in "Polynomial approximations to Delta T, 1620-2000 AD" (Meeus and Simons, 2000). Valid range of usage: between years 1620 and 2000, with zero values outside this range. $\dot{n} = -25.7376''/\text{cy}^2$.

**Montenbruck & Pfleger (2000).** The fourth edition of *Astronomy on the Personal Computer* (Montenbruck and Pfleger, 2000) provides simple 3rd-order polynomial data fits for the recent past. Valid range of usage: between years 1825 and 2005, with a typical 1-second accuracy and zero values outside this range.

**Reingold & Dershowitz (2002, 2007, 2018).** E. M. Reingold & N. Dershowitz present this polynomial data fit in *Calendrical Calculations: The Ultimate Edition* (Reingold and Dershowitz, 2018) and in their *Calendrical Calculations* (Reingold and Dershowitz, 2007), *Calendrical Tabulations 1900-2200* (Reingold and Dershowitz, 2002). It is based on *Astronomical Algorithms* (Meeus, 1991).

**Morrison & Stephenson (2004, 2005).** This important solution was published in "Historical values of the Earth's clock error ΔT and the calculation of eclipses" (Morrison and F. R. Stephenson, 2004) with addendum (Morrison and F. R. Stephenson, 2005). Valid range of usage: between years -1000 and 2000. $\dot{n} = -26.0''/\text{cy}^2$.

**Stephenson, Morrison & Hohenkerk (2016, 2021).** This important new solution was published in "Measurement of the Earth's rotation: 720 BC to AD 2015" (F. R. Stephenson, Morrison, and Hohenkerk, 2016). The solution combines a spline fit to observations (used between the given limits) with a parabolic fit (used as fallback outside the range, but without smooth transitions at the limits, i.e., values for 2016 and later deviate notably from current estimates, and should not be used for dates after

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[8]https://ssd.jpl.nasa.gov/?horizons

2015). The solution was updated in "Addendum 2020 to 'Measurement of the Earth's rotation: 720 BC to AD 2015'" (Morrison, F. R. Stephenson, et al., 2021). Recommended range of usage: between years -720.0 and 2019.0 $\dot{n} = -25.82''/\text{cy}^2$.

**Espenak & Meeus (2006, 2014).** This solution by F. Espenak and J. Meeus, based on Morrison and F. R. Stephenson (2004) and a polynomial fit through tabulated values for 1600-2000, is used for the NASA Eclipse Web Site[9] , in their *Five Millennium Canon of Solar Eclipses: -1900 to +3000* (Espenak and Meeus, 2006) and *Thousand Year Canon of Solar Eclipses 1501 to 2500* (Espenak, 2014). This formula is also used in the solar, lunar and planetary ephemeris program **SOLEX**. Valid range of usage: between years -1999 and 3000. $\dot{n} = -25.858''/\text{cy}^2$.

**Modified Espenak & Meeus (2006, 2014, 2023).** This solution[10] is a modification from Espenak & Meeus (2006, 2014). Values for 2015-2033 are interpolated from observations and predictions by IERS Rapid Service/Prediction Center. A simple formula is used to connect with F. Espenak's predicted value at year 2050. Valid range of usage: between years -1999 and 3000. $\dot{n} = -25.858''/\text{cy}^2$.

**Reijs (2006).** From the Length of Day (LOD; as determined by Morrison and F. R. Stephenson (2004)), Victor Reijs derived a $\Delta T$ formula by using a Simplex optimization with a cosine and square function. This is based on a possible periodicity described by Morrison and F. R. Stephenson (2004). Valid range of usage: between years -1500 and 1100. $\dot{n} = -26.0''/\text{cy}^2$.

**Banjevic (2006).** This solution is based on F. R. Stephenson and Morrison (1984) and was published in "Ancient eclipses and dating the fall of Babylon" (Banjevic, 2006). Valid range of usage: between years -2020 and 1620, with zero values outside this range. $\dot{n} = -26.0''/\text{cy}^2$.

**Islam, Sadiq & Qureshi (2008, 2013).** This solution by S. Islam, M. Sadiq and M. S. Qureshi, based on Meeus and Simons (2000), was published in "Error Minimization of Polynomial Approximation of Delta T" (Islam, Sadiq, and Qureshi, 2008) and revisited by Sana Islam in 2013. Valid range of usage: between years 1620 and 2007, with zero values outside this range.

**Khalid, Sultana & Zaidi (2014).** This polynomial approximation with 0.6 seconds of accuracy was published in "Delta T: Polynomial Approximation of Time Period 1620–2013" (Khalid, Sultana, and Zaidi, 2014). Valid range of usage: between years 1620 and 2013, with zero values outside this range.

**Henriksson (2017).** A solution which combines Schoch's 1931 solution (parabolic fit) with a discussion of and correction for relativistic effects. The author claims an accurate fit for solar eclipses probably depicted in artifacts going back to the mid-fourth millennium BC. Also with this setting, the exact times from his paper (Henriksson, 2017) cannot be reproduced probably because the author used a different ephemeris, but the phenomena are plausibly reproduced. Recommended range of usage: between years -4000.0 and 2000.0 $\dot{n} = -30.128''/\text{cy}^2$.

**Custom equation of $\Delta T$.** This is the quadratic formula 18.3 for calculation of $\Delta T$ with coefficients defined by the user.

## 18.5  Angles

Astronomers typically use degrees to measure angles. Since many observations require very precise measurement, the degree is subdivided into sixty *minutes of arc* also known as *arc-minutes*. Each minute of arc is further subdivided into sixty *seconds of arc*, or *arc-seconds*. Thus one degree is equal to 3600 seconds of arc. Finer grades of precision are usually expressed using the SI prefixes with arc-seconds, e.g. *milli arc-seconds* (one milli arc-second is one thousandth of an arc-second).

### 18.5.1  Notation

Degrees are denoted using the ° symbol after a number. Minutes of arc are denoted with a ′, and seconds of arc are denoted using ″. Angles are frequently given in two formats:
1. DMS format — degrees, minutes and seconds. For example 90°15′12″. When more precision is required, the seconds component may include a decimal part, for example 90°15′12.432″.
2. Decimal degrees, for example 90.2533°

### 18.5.2  Handy Angles

Being able to estimate angular distance can be very useful when trying to find objects from star maps in the sky. One way to do this with a device called a *crossbow*.

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[9]https://eclipse.gsfc.nasa.gov/eclipse.html
[10]This solution is used by default.

Crossbows are a nice way get an idea of angular distances, but carrying one about is a little cumbersome. A more convenient alternative is to hold up an object such as a pencil at arm's length. If you know the length of the pencil, $d$, and the distance of it from your eye, $D$, you can calculate its angular size, $\theta$ using this formula:

$$\theta = 2 \cdot \arctan\left(\frac{d}{2 \cdot D}\right) \tag{18.5}$$

Another, more handy (ahem!) method is to use the size of your hand at arm's length:

**Tip of little finger**  About 1°
**Middle three fingers**  About 4°
**Across the knuckles of the fist**  About 10°
**Open hand**  About 18°

Using your hand in this way is not very precise, but it's close enough to give you some way to translate an idea like "Mars will be 45° above the southeastern horizon at 21:30". Of course, there are variations from person to person, but the variation is compensated for somewhat by the fact that people with long arms tend to have larger hands. In exercise 21.2 you will work out your own "handy angles".

## 18.6  The Magnitude Scale

When astronomers talk about magnitude, they are referring to the brightness of an object. How bright an object appears to be depends on how much light it is giving out and how far it is from the observer. Astronomers separate these factors by using two measures: *absolute magnitude* (Mag or *M*) which is a measure of how much light is being given out by an object, and *apparent magnitude* (mag or *m*) which is how bright something appears to be in the sky.

For example, consider two 100 watt lamps, one which is a few meters away, and one which is a kilometer away. Both give out the same amount of light – they have the same absolute magnitude. However the nearby lamp seems much brighter – it has a much greater apparent magnitude. When astronomers talk about magnitude without specifying whether they mean apparent or absolute magnitude, they are usually referring to apparent magnitude.

The magnitude scale has its roots in antiquity. The Greek astronomer HIPPARCHUS defined the brightest stars in the sky to be *first magnitude*, and the dimmest visible to the naked eye to be *sixth magnitude*. In the 19th century British astronomer NORMAN POGSON (1829–1891) quantified the scale more precisely, defining it as a logarithmic scale where a magnitude 1 object is 100 times as bright as a magnitude 6 object (a difference of five magnitudes). The zero-point of the modern scale was originally defined as the brightness of the star Vega, however this was re-defined more formally in 1982 (Aller et al., 1989). Objects brighter than Vega are given negative magnitudes.

The absolute magnitude of a star is defined as the magnitude a star would appear if it were 10 parsecs from the observer.

Table 18.1 lists several objects that may be seen in the sky, their apparent magnitude and their absolute magnitude where applicable (only stars have an absolute magnitude value. Planets nor Moon emit light like a star does – they reflect the light from the Sun).

| *Object* | *m* | *M* |
|---|---|---|
| The Sun | -27 | 4.8 |
| Vega | 0.05 | 0.6 |
| Betelgeuse | 0.47 | -7.2 |
| Sirius (the brightest star) | -1.5 | 1.4 |
| Venus (at brightest) | -4.4 | — |
| Full Moon (at brightest) | -12.6 | — |

Table 18.1: Magnitudes of a few objects

## 18.7  Luminosity

*Luminosity* is an expression of the total energy radiated by a star. It may be measured in watts, however, astronomers tend to use another expression — *solar luminosities* where an object with twice the Sun's luminosity is considered to have two solar luminosities and so on. Luminosity is related to absolute magnitude.

## 18.8  Precession
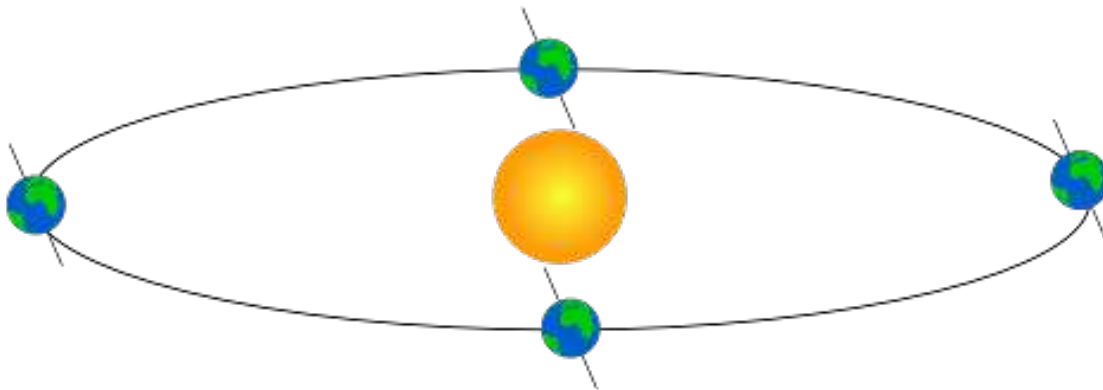


Figure 18.4: Ecliptic obliquity

As the Earth orbits the Sun throughout the year, the axis of rotation (the line running through the rotational poles of the Earth) seems to point towards the same position on the celestial sphere, as can be seen in figure 18.4. The angle between the axis of rotation and the perpendicular of the orbital plane is called the *obliquity of the ecliptic*. It is currently about 23°27′ and is the angle between equatorial plane (18.2.2) and ecliptical plane (18.2.4).

   Observed over very long periods of time the direction the axis of rotation points to does actually change. The angle between the axis of rotation and the orbital plane stays fairly constant, but the direction the axis points — the position of the celestial pole — transcribes a figure similar to a circle on the celestial sphere. The motion is similar to the way in which a gyroscope slowly twists, as figure 18.5 illustrates. This process is called *precession*. The circles can be shown in Stellarium: from the View menu ( F4 ), tab "Markings", switch on "Precession Circles" (4.4.4).

   Precession is a slow process. The axis of rotation twists through a full 360° about once every 26,000 years. However, over these long times other gravitational perturbations ("planetary precession") play a role, and what may be thought of as rigid "precession circle" can actually only show the instantaneous (current) state. Over millennia the circle slightly varies.

   Precession has some important implications:

1. RA/Dec coordinates change over time, albeit slowly. Measurements of the positions of stars recorded using RA/Dec coordinates must also include a date ("equinox") for those coordinates. Therefore the current star catalogues list their objects for the epoch and equinox J2000.0.
2. Polaris, the Pole Star, won't stay a good indicator of the location of the Northern Celestial Pole. In 14,000 years time Polaris will be nearly 47° away from the celestial pole!
3. The change in declination causes a shift in the rising and setting positions of the stars along the horizon. Figure 18.6 shows part of the horizon for latitude $\varphi = 30°$ north. For a given year (left vertical labels), make a horizontal line to find rising azimuth of the bright stars indicated by the twisting lines. Depending on where on the celestial sphere a star is located, it may appear to move north or south, or be almost stationary for several centuries.

## 18.9  Parallax

Parallax is the change of angular position of two stationary points relative to each other as seen by an observer, due to the motion of said observer. Or more simply put, it is the apparent shift of an object against a background due to a change in observer position.
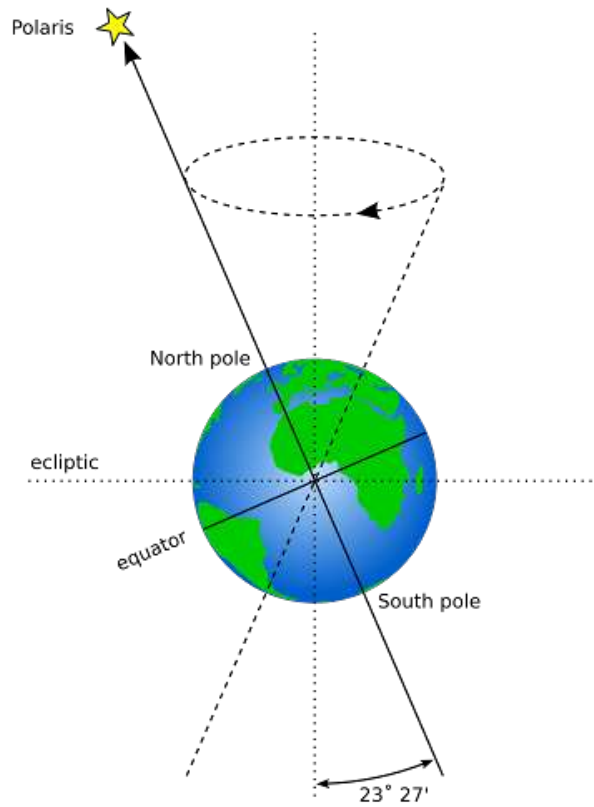
Figure 18.5: Precession
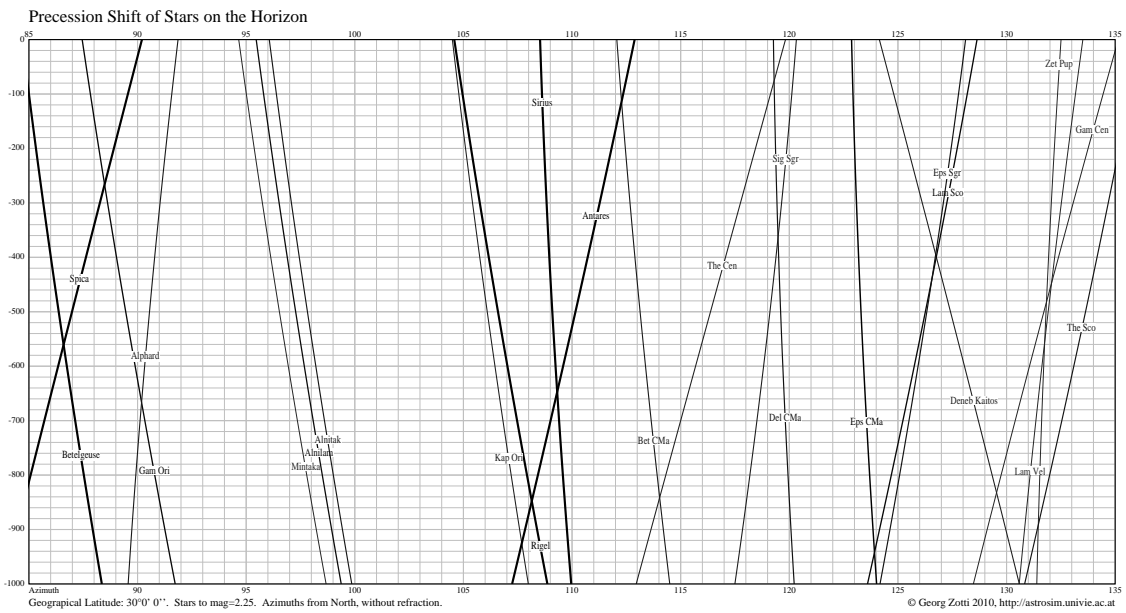


Figure 18.6: Precession: Change of rising positions of the stars along the eastern horizon from azimuths 85 to 135 degrees, between years 1000 BC and 0, for latitude $\varphi = 30°$.
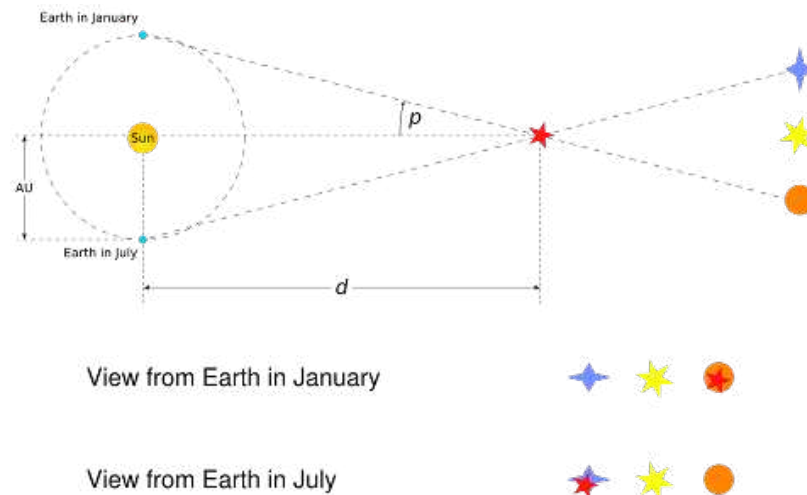
Figure 18.7: Stellar Parallax

This can be demonstrated by holding one's thumb up at arm's length. Closing one eye, note the position of the thumb against the background. After swapping which eye is open (without moving), the thumb appears to be in a different position against the background.

### 18.9.1 Geocentric and Topocentric Observations

When computing planetary positions was done manually by adding numbers tabulated in yearly almanacs, computing the Earth's position and, say, the position of a minor planet was usually good enough to find the object in the sky. In both cases, the exact numbers refer to the gravitational centers of the respective bodies. However, we are sitting on Earth's surface, so the observed planet will be seen in a slightly shifted location. The amount for objects in the inner solar system is usually just a few arc-seconds and is mostly negligible when we just want to find an object. But it makes a difference when it comes to observations of stellar occultations by planets or asteroids. Such a body may measure only a few tens of kilometers, and the shadow track which it leaves on Earth's surface is of approximately the same size.[11]

A much closer and bigger object is the Moon, which can also occult stars. It can even occult the one big star we call the Sun: this is a solar eclipse. And here it makes a huge difference where on the planet you are located.

If you are interested in astronomical computing, you may still be interested in geocentric numerical results. From the Settings panel ( F2 ), tab "Tools", there is a checkbox for "Topocentric Coordinates". Switch it off to put yourself into the center of the planet you are located.

### 18.9.2 Stellar Parallax

A similar thing happens due to the Earth's motion around the Sun. Nearby stars appear to move against more distant background stars, as illustrated in figure 18.7. The movement of nearby stars against the background is called *stellar parallax*, or *annual parallax*.

Since we know the radius of the Earth's orbit around the Sun from other methods, we can use simple geometry to calculate the distance of the nearby star if we measure annual parallax.

As can be seen from figure 18.7, the annual parallax $p$ is half the angular distance between the apparent positions of the nearby star. The distance of the nearby object is $d$. Astronomers use a unit of distance called the parsec (pc) which is defined as the distance at which a nearby star has $p = 1''$.

Even the nearest stars exhibit very small movement due to parallax. The closest star to the Earth other than the Sun is Proxima Centauri. It has an annual parallax of $0.77199''$, corresponding to a distance of $1.295\,\text{pc}$ (4.22 light years). Currently, Gaia satellite is the most accurate instrument for measuring stellar parallax. It can measure parallax at the precision level of sub milli-arcseconds for bright stars ($G < 15$), measuring distance with $\approx 10\%$ to stars up to 10,000 parsecs.

In Stellarium, the annual parallax can be listed in the object information for stars when available and is

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[11]Unfortunately Stellarium (as of v0.15.0) is not accurate enough to reliably compute such occultations. Even a deviation of 0.5 arc-seconds is too much here.

accounted for by default in the positional calculations on any Solar System objects including the Earth. You can also exaggerate the parallax effect up to $10,000\times$ to make it more apparent.

## 18.10 Aberration of Light

When you are standing under a rainy but windless sky with an umbrella placed vertically over your head, your feet will not be hit by raindrops. But when you are walking, raindrops which just missed the umbrella may hit your feet. Relative to your umbrella and feet, it seems that the raindrops are coming not quite vertically from above, but inclined from the direction you are heading into, and therefore you tilt the umbrella slightly forward to fend off the raindrops from your feet.

Light propagates very fast compared to the motion of the planets, but still with a finite velocity. Therefore, just like the raindrops mentioned above, light from all celestial objects seem to come in from a position slightly distorted towards the point in space the observer is heading to.

In search for stellar parallax (see section 18.9.2), this effect of the *aberration of light* was fortuitously discovered and then explained by JAMES BRADLEY (1693–1762) in 1725. This was also the final proof for Earth's movement around the Sun. For an observer on the moving Earth, the apparent deviation of a star from the mean coordinates can reach 20.4". As the months pass, Earth is changing its direction along its orbit, and so the light distortion also changes, i.e., the direction towards the object moves against the fixed coordinate axes. The effect is significant when we want to compute, for example, stellar occultations by the Moon.

In Stellarium, you can observe a slight annual wobble in all objects' positions against the fixed celestial grids. Just enable the equatorial grid, zoom in and run through the months. You can also exaggerate the aberration effect up to $5\times$ to make it more apparent. [12]

## 18.11 Proper Motion

*Proper motion* is the change in the position of a star over time as a result of its motion through space relative to the Sun. Stellarium also includes the apparent shift in position of star due to annual parallax. The star exhibiting the greatest proper motion is *Barnard's Star* which moves more than ten seconds of arc per year.

v 25.1

If you want to simulate the effect of proper motion with Stellarium, put the map into equatorial view mode, switch off ground and cardinal marks, and set some high time lapse speed. You will see a few stars change their locations quite soon, those are usually stars in our galactic neighbourhood (see section 21.12).

Note however some limitations:

1. Stellarium will stop at $\pm100,000$ years. This limit may be still suitable for most stellar locations. The planetary locations are not trustworthy outside of a much narrower temporal window (see section F). You cannot simulate the sky over the dinosaurs or such things.
2. For most bright stars ($V < 10.5$), their full 6D astrometry (2D sky positions, 2D proper motion, parallax, radial velocity) computed by assuming straight-line motion at constant speed. Otherwise proper motion are only modelled by linear components.

### 18.11.1 Binary Stars

Binary stars are listed in catalogs as two individual stars with their current proper motion which consists of a common spatial motion and the orbital motion around their common center of gravity. Their orbital motion around each other, where known, is now properly modelled in Stellarium.

v 25.1

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[12]Exaggerating even more causes graphics defects and has been disabled for now.

# 19. Astronomical Phenomena

BARRY GERDES, WITH ADDITIONS BY GEORG ZOTTI

This chapter focuses on the observational side of astronomy — what we see when we look at the sky.

## 19.1 The Sun

Without a doubt, the most prominent object in the sky is the Sun. The Sun is so bright that when it is in the sky, its light is scattered by the atmosphere to such an extent that almost all other objects in the sky are rendered invisible.

The Sun is a star like many others but it is much closer to the Earth at approximately 150 million kilometres (a distance also called 1 Astronomical Unit). The next nearest star, Proxima Centauri is approximately 260,000 times further away from us than the Sun! The Sun is also known by its Latin name, *Sol*.

Over the course of a year, the Sun appears to move round the celestial sphere in a great circle known as the *ecliptic*. Stellarium can draw the ecliptic on the sky. To toggle drawing of the ecliptic, press the ⎡ , ⎤ key.

*WARNING: Looking at the Sun with even the smallest telescope or binoculars can permanently damage the eye. Never look at the Sun without using the proper filters attached to the front end (objective lens) of your instrument! Never use screw-in ocular filters, they may break in the heat and expose your eye to damaging amounts of energy. By far the safest way to observe the Sun is to look at it on a computer screen, courtesy of Stellarium!*

### 19.1.1 Twilight

The sunlight is scattered in Earth's atmosphere even if the Sun is below the horizon. The period after sunset when the Sun is higher than −6° is called *civil twilight*. The sky is generally bright enough for outdoor activity or reading the newspaper.

As time progresses, the first stars will appear. The phase where the Sun is between −6° and −12° below the (mathematical) horizon is called *nautical twilight*: before the invention of satellite navigation, celestial navigation was used to find a ship's position on the oceans. This required that it was still bright enough so that the horizon line was visible, but already dark enough to see enough stars to clearly identify them and measure the altitude of a few of them. (See also section 14.7.)

The twilight phase when the Sun is between −12° and −18° is called *astronomical twilight*. Only the western horizon shows some brightening, but else the natural sky is "almost" as dark as it can get.

In the morning the game is reversed. Dawn starts with astronomical twilight, progresses to nautical and civil twilight, and sunrise ends the night.

In Stellarium, you can set the time when the Sun reaches a configured altitude. See section 4.8.1 about how to configure the program.

Figure 19.1: Ursa Major

## 19.2 Stars

The Sun is just one of billions of stars. Even though many stars have a much greater absolute magnitude than the Sun (they give out more light), they have an enormously smaller apparent magnitude due to their large distance. Stars have a variety of forms — different sizes, brightnesses, temperatures, and colours. Measuring the position, distance and attributes of the stars is known as *astrometry*, and is a major part of observational astronomy.

### 19.2.1 Multiple Star Systems

Many stars have stellar companions. As many as six stars can be found orbiting one-another in close associations known as *multiple star systems — binary systems* being the most common with two stars. Multiple star systems are more common than solitary stars, putting our Sun in the minority group.

Sometimes multiple stars orbit each other in a way that means one will periodically eclipse the other. These are *eclipsing binaries* or *Algol variables*.

#### 19.2.1.1 Optical Doubles & Optical Multiples

Sometimes two or more stars appear to be very close to one another in the sky, but in fact have great separation, being aligned from the point of view of the observer but of different distances. Such pairings are known as *optical doubles* and *optical multiples*.

### 19.2.2 Constellations

The constellations are groupings of stars that are visually close to one another in the sky. The actual groupings are fairly arbitrary — different cultures have grouped stars together into different constellations. In many cultures, the various constellations have been associated with mythological entities. As such people have often projected pictures into the skies as can be seen in figure 19.1 which shows the constellation of Ursa Major. On the left is a picture with the image of the mythical Great Bear, on the right only a line-art version (or *stick figure*) is shown. The seven bright stars of Ursa Major are widely recognised, known variously as "the plough", the "pan-handle", and the "big dipper". This sub-grouping is known as an *asterism* — a distinct grouping of stars. On the right, the picture of the bear has been removed and only a constellation diagram remains.

Stellarium can draw both constellation diagrams and artistic representations of the constellations. Multiple sky cultures are supported: Western, Polynesian, Egyptian, Chinese, and several other sky cultures are available, although at time of writing the non-Western constellations are not complete, and as yet there are no artistic representations of these sky-cultures.

Aside from historical and mythological value, to the modern astronomer the constellations provide a way to segment the sky for the purposes of describing locations of objects, indeed one of the first tasks for an amateur observer is *learning the constellations* — the process of becoming familiar with the relative positions of the constellations, at what time of year a constellation is visible, and in which constellations observationally interesting objects reside. The International Astronomical Union has adopted 88 "Western" constellations as a common system for segmenting the sky (Table 19.1). They are based on Greek/Roman

| Abbr. | Name | Genitive | | Abbr. | Name | Genitive |
|---|---|---|---|---|---|---|
| And | Andromeda | Andromedae | | Lac | Lacerta | Lacertae |
| Ant | Antlia | Antliae | | Leo | Leo | Leonis |
| Aps | Apus | Apodis | | LMi | Leo Minor | Leonis Minoris |
| Aqr | Aquarius | Aquarii | | Lep | Lepus | Leporis |
| Aql | Aquila | Aquilae | | Lib | Libra | Librae |
| Ara | Ara | Arae | | Lup | Lupus | Lupi |
| Ari | Aries | Arietis | | Lyn | Lynx | Lyncis |
| Aur | Auriga | Aurigae | | Lyr | Lyra | Lyrae |
| Boo | Bootes | Bootis | | Men | Mensa | Mensae |
| Cae | Caelum | Caeli | | Mic | Microscopium | Microscopii |
| Cam | Camelopardalis | Camelopardalis | | Mon | Monoceros | Monocerotis |
| Cnc | Cancer | Cancri | | Mus | Musca | Muscae |
| Cvn | Canes Venatici | Canum Venaticorum | | Nor | Norma | Normae |
| CMa | Canis Maior | Canis Maioris | | Oct | Octans | Octantis |
| CMi | Canis Minor | Canis Minoris | | Oph | Ophiuchus | Ophiuchi |
| Cap | Capricornus | Capricorni | | Ori | Orion | Orionis |
| Car | Carina | Carinae | | Pav | Pavo | Pavonis |
| Cas | Cassiopeia | Cassiopeiae | | Peg | Pegasus | Pegasi |
| Cen | Centaurus | Centauri | | Per | Perseus | Persei |
| Cep | Cepheus | Cephei | | Phe | Phoenix | Phoenicis |
| Cet | Cetus | Ceti | | Pic | Pictor | Pictoris |
| Cha | Chamaeleon | Chamaeleonis | | Psc | Pisces | Piscium |
| Cir | Circinus | Circini | | PsA | Piscis Austrinus | Piscis Austrini |
| Col | Columba | Columbae | | Pup | Puppis | Puppis |
| Com | Coma Berenices | Comae Berenicis | | Pyx | Pyxis | Pyxidis |
| CrA | Corona Australis | Coronae Australis | | Ret | Reticulum | Reticuli |
| CrB | Corona Borealis | Coronae Borealis | | Sge | Sagitta | Sagittae |
| Crt | Crater | Crateris | | Sgr | Sagittarius | Sagittarii |
| Crv | Corvus | Corvi | | Sco | Scorpius | Scorpii |
| Cru | Crux | Crucis | | Scl | Sculptor | Sculptoris |
| Cyg | Cygnus | Cygni | | Sct | Scutum | Scuti |
| Del | Delphinus | Delphini | | Ser | Serpens | Serpentis |
| Dor | Dorado | Doradus | | Sex | Sextans | Sextantis |
| Dra | Draco | Draconis | | Tau | Taurus | Tauri |
| Equ | Equuleus | Equulei | | Tel | Telescopium | Telescopii |
| Eri | Eridanus | Eridani | | Tri | Triangulum | Trianguli |
| For | Fornax | Fornacis | | TrA | Triangulum Australe | Trianguli Australis |
| Gem | Gemini | Geminorum | | Tuc | Tucana | Tucanae |
| Gru | Grus | Gruis | | UMa | Ursa Maior | Ursae Maioris |
| Her | Hercules | Herculis | | UMi | Ursa Minor | Ursae Minoris |
| Hor | Horologium | Horologii | | Vel | Vela | Velae |
| Hya | Hydra | Hydrae | | Vir | Virgo | Virginis |
| Hyi | Hydrus | Hydri | | Vol | Volans | Volantis |
| Ind | Indus | Indi | | Vul | Vulpecula | Vulpeculae |

Table 19.1: The official 88 IAU constellation names and abbreviations

| $\alpha$ | alpha | $\varepsilon$ | epsilon | $\iota$ | iota | $\nu$ | nu | $\rho$ | rho | $\varphi$ | phi |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\beta$ | beta | $\zeta$ | zeta | $\kappa$ | kappa | $\xi$ | xi | $\sigma$ | sigma | $\chi$ | chi |
| $\gamma$ | gamma | $\eta$ | eta | $\lambda$ | lambda | o | omicron | $\tau$ | tau | $\psi$ | psi |
| $\delta$ | delta | $\theta$ | theta | $\mu$ | mu | $\pi$ | pi | $\upsilon$ | upsilon | $\omega$ | omega |

Table 19.2: The Greek alphabet used by Bayer

mythology, but with several additions from Renaissance and later centuries. As such some formalisation has been adopted, each constellation having a *proper name*, which is in Latin, and a three letter abbreviation of that name. For example, Ursa Major has the abbreviation UMa. Also, the "Western" constellation have clearly defined boundaries (Delporte, 1930), which you can draw in Stellarium when you press the ⌷B⌷ key[1]. The IAU constellation a selected object is placed in is also available in the object information data (Roman, 1987), regardless of the currently active sky culture. On the other hand, the shapes of mythological figures, and also stick figures, have not been canonized, so you will find deviations between Stellarium and printed atlases.

### 19.2.3 Star Names

The brighter stars often have one or more *common names* relating to mythical characters from the various traditions. For example the brightest star in the sky, Sirius is also known as The Dog Star (the name Canis Major — the constellation Sirius is found in — is Latin for "The Great Dog").

Most bright names have been given names in antiquity. PTOLEMY's most influential book, the *Syntaxis*, was translated to the Arab language in the age of early Muslim scientists. When, centuries later, the translation, called *Almagest*, was re-introduced to the re-awakening European science, those names, which often only designated the position of the star within the figure, were taken from the books, often misspelled, and used henceforth as proper names.

A few more proper names have been added later, sometimes dedicatory names added by court astronomers into their maps. There are also 3 stars named after the victims of the Apollo 1 disaster in 1967. Today, the International Astronomical Union (IAU) is the only scientifically accepted authority which can give proper names to stars. Some companies offer a paid name service for commemoration or dedication of a star for deceased relatives or such, but all you get here is a piece of paper with coordinates of (usually) an unremarkably dim star only visible in a telescope, and a name to remember, stored (at best) in the company's database.

There are several more formal naming conventions that are in common use.

#### 19.2.3.1 Bayer Designation

The German astronomer JOHANN BAYER (1572–1625) devised one such system for his atlas, the *Uranographia*, first published in 1603. His scheme names the stars according to the constellation in which they lie prefixed by a lower case Greek letter (see Tab. 19.2), starting at $\alpha$ for (usually) the brightest star in the constellation and proceeding with $\beta, \gamma, \ldots$ in descending order of apparent magnitude. For example, such a *Bayer Designation* for Sirius is "$\alpha$ Canis Majoris" (note that the genitive form of the constellation name is used, refer to Table 19.1; today also the short form $\alpha$ CMa is in use). There are some exceptions to the descending magnitude ordering, and some multiple stars (both real and optical) are named with a numerical superscript after the Greek letter, e.g. $\pi^1 \ldots \pi^6$ Orionis.

#### 19.2.3.2 Flamsteed Designation

English astronomer JOHN FLAMSTEED (1646–1719) numbered stars in each constellation in order of increasing right ascension followed by the genitive form of the constellation name, for example "61 Cygni" (or short: "61 Cyg").

#### 19.2.3.3 Hipparcos

Hipparcos (for High Precision Parallax Collecting Satellite) was an astrometry mission of the European Space Agency (ESA) dedicated to the measurement of stellar parallax and the proper motions of stars. The project was named in honour of the Greek astronomer HIPPARCHUS.

Ideas for such a mission dated from 1967, with the mission accepted by ESA in 1980. The satellite was launched by an Ariane 4 on 8 August 1989. The original goal was to place the satellite in a geostationary orbit above the earth, however a booster rocket failure resulted in a highly elliptical orbit from 500 to 35,800 km (310 to 22,240 miles) altitude. Despite this difficulty, all of the scientific goals were accomplished. Communications were terminated on 15 August 1993.

The program was divided in two parts: the *Hipparcos experiment* whose goal was to measure the five astrometric parameters of some 120,000 stars to a precision of some 2 to 4 milli arc-seconds and the *Tycho experiment*, whose goal was the measurement of the astrometric and two-colour photometric properties of some 400,000 additional stars to a somewhat lower precision.

The final Hipparcos Catalogue (120,000 stars with 1 milli arc-second level astrometry) and the final Tycho Catalogue (more than one million stars with 20-30 milli arc-second astrometry and two-colour

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[1]These boundaries or borders have been drawn using star maps from 1875. Due to the effect of *precession*, these borders are no longer parallel to today's coordinates.

photometry) were completed in August 1996. The catalogues were published by ESA in June 1997. The Hipparcos and Tycho data have been used to create the Millennium Star Atlas: an all-sky atlas of one million stars to visual magnitude 11, from the Hipparcos and Tycho Catalogues and 10,000 non-stellar objects included to complement the catalogue data.



Figure 19.2: Star Names and Data

There were questions over whether Hipparcos has a systematic error of about 1 milli arc-second in at least some parts of the sky. The value determined by Hipparcos for the distance to the Pleiades is about 10% less than the value obtained by some other methods. By early 2004, the controversy remained unresolved.

Stellarium uses the Hipparcos Catalogue for star data, as well as having traditional names for many of the brighter stars. The stars tab of the search window allows for searching based on a Hipparcos Catalogue number (as well as traditional names), e.g. the star Sadalmelik in the constellation of Aquarius can be found by searching for the name, or its Hipparcos number, 109074.

Figure 19.2 shows the information Stellarium displays when a star is selected. At the top, the common name, Bayer/Flamsteed designations and Hipparcos number are shown, followed by the RA/Dec coordinates, apparent magnitude, distance and other data.

### 19.2.4 Spectral Type & Luminosity Class

Stars have many different colours. Seen with the naked eye most appear to be white, but this is due to the response of the eye — at low light levels the eye is not sensitive to colour. Typically the unaided eye can start to see differences in colour only for stars that have apparent magnitude brighter than 1. Betelgeuse, for example has a distinctly red tinge to it, and Sirius appears to be blue, while Vega is the prototype "white" star.

By splitting the light from a star using a prism attached to a telescope and measuring the relative intensities of the colours of light the star emits — the *spectrum* — a great deal of interesting information can be discovered about a star including its surface temperature, and the presence of various elements in its atmosphere.

Astronomers groups stars with similar spectra into *spectral types*, denoted by one of the following letters: O, B, A, F, G, K and M.[2] Type O stars have a high surface temperature (up to around 50,000 K) while the at other end of the scale, the M stars are red and have a much cooler surface temperature, typically 3000 K. The Sun is a type G star with a surface temperature of around 5,500 K. Spectral types may be further sub-divided using a numerical suffix ranging from 0-9 where 0 is the hottest and 9 is the coolest. Table 19.3 shows the details of the various spectral types.

For about 90% of stars, the absolute magnitude increases as the spectral type tends to the O (hot) end of the scale. Thus the whiter, hotter stars tend to have a greater luminosity. These stars are called *main sequence* stars. There are however a number of stars that have spectral type at the M end of the scale, and yet they

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[2]The classic mnemonic for students of astrophysics says: "Oh, Be A Fine Girl, Kiss Me".

| Spectral Type | Surface Temperature (K) | Star Colour |
|---|---|---|
| O | 28,000—50,000 | Blue |
| B | 10,000—28,000 | Blue-white |
| A | 7,500—10,000 | White-blue |
| F | 6,000—7,500 | Yellow-white |
| G | 4,900—6,000 | Yellow |
| K | 3,500—4,900 | Orange |
| M | 2,000—3,500 | Red |

Table 19.3: Spectral Types

| Luminosity class | Description |
|---|---|
| Ia, Ib | Super-giants |
| II | Bright giants |
| III | Normal giants |
| IV | Sub-giants |
| V | Main sequence |
| VI | Sub-dwarfs |
| VII | White-dwarfs |

Table 19.4: Luminosity Classification

have a high absolute magnitude. These stars are close to the ends of their lives and have a very large size, and consequently are known as *giants*, the largest of these known as *super-giants*.

There are also stars whose absolute magnitude is very low regardless of the spectral class. These are known as *dwarf stars*, among them *white dwarfs* (dying stars) and *brown dwarfs* ("failed stars").

The *luminosity class* is an indication of the type of star — whether it is main sequence, a giant or a dwarf. Luminosity classes are denoted by a number in roman numerals, as described in table 19.4.

Plotting the luminosity of stars against their spectral type/surface temperature gives a diagram called a Hertzsprung-Russell diagram (after the two astronomers EJNAR HERTZSPRUNG (1873–1967) and HENRY NORRIS RUSSELL (1877–1957) who devised it). A slight variation of this is shown in figure 19.3 (which is technically a colour/magnitude plot).

### 19.2.5 Variable Stars

Most stars are of nearly constant luminosity. The Sun is a good example of one which goes through relatively little variation in brightness (usually about 0.1% over an 11 year solar cycle). Many stars, however, undergo significant variations in luminosity, and these are known as *variable stars*. There are many types of variable stars falling into two categories, *intrinsic* and *extrinsic*.

Intrinsic variables are stars which have intrinsic variations in brightness, that is, the star itself gets brighter and dimmer. There are several types of intrinsic variables, probably the best-known and most important of which is the Cepheid variable whose luminosity is related to the period with which its brightness varies. Since the luminosity (and therefore absolute magnitude) can be calculated, Cepheid variables may be used to determine the distance of the star when the annual parallax is too small to be a reliable guide. This is especially welcome because they are giant stars, and so they are even visible in neighboring galaxies.

Extrinsic variables are stars of constant brightness that show changes in brightness as seen from the Earth. These include rotating variables, stars whose apparent brightness change due to rotation, and eclipsing binaries.

Stellarium's catalogs include many kinds variable stars. See section C.3 for more details.

## 19.3  Our Moon

The Moon is the large satellite which orbits the Earth approximately every 28 days. It is seen as a large bright disc in the early night sky that rises later each day and changes shape into a crescent until it disappears near the Sun. After this it rises during the day then gets larger until it again becomes a large bright disc again.
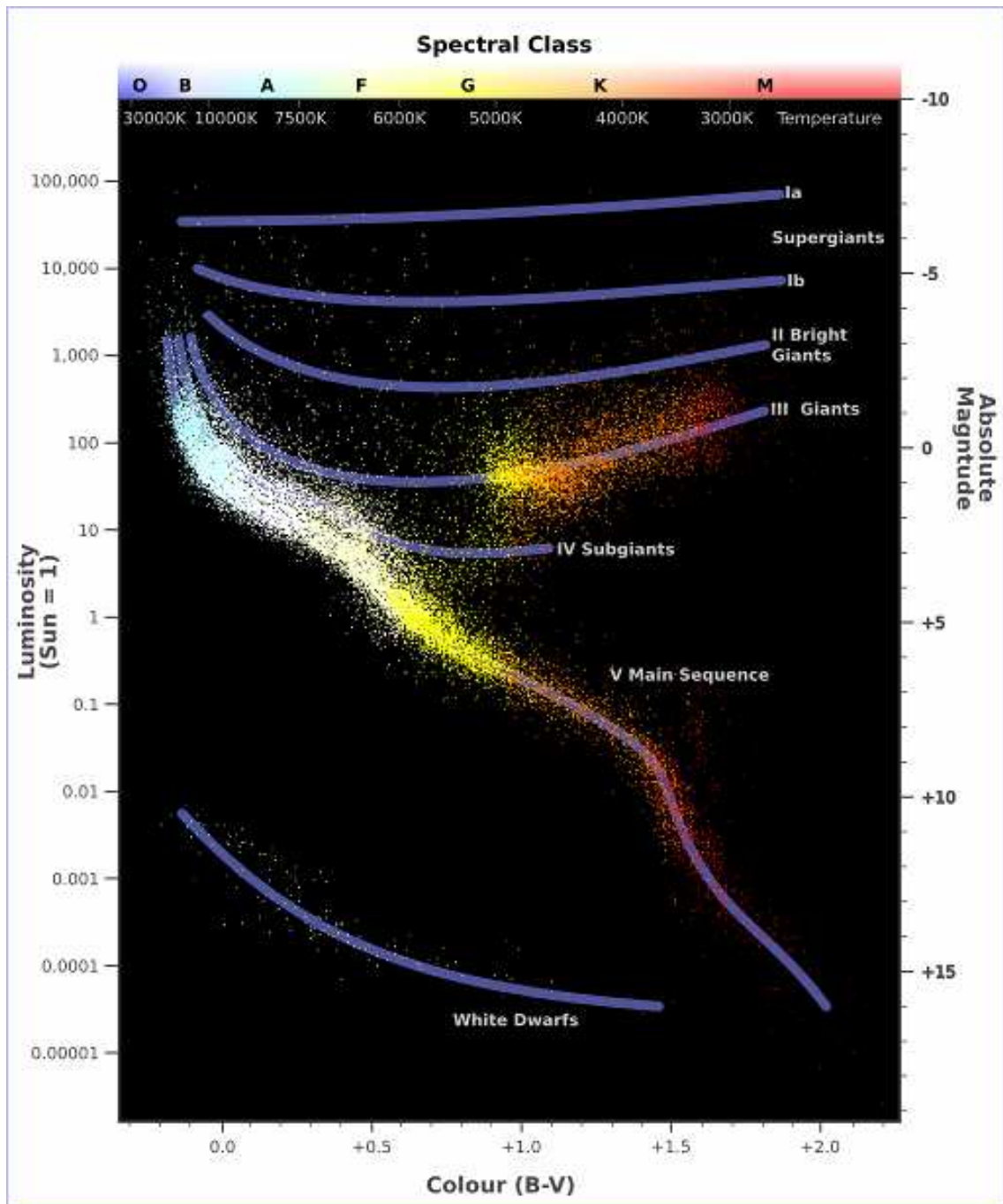
Figure 19.3: Hertzsprung-Russell Diagram

| New Moon | The moon's disc is fully in shadow, or there is just a slither of illuminated surface on the edge. |
| Waxing Crescent | Less than half the disc is illuminated, but more is illuminated each night. |
| First Quarter | Approximately half the disc is illuminated, and increasing each night. |
| Waxing Gibbous | More than half of the disc is illuminated, and still increasing each night. |
| Full Moon | The whole disc of the moon is illuminated. |
| Waning Gibbous | More than half of the disc is illuminated, but the amount gets smaller each night. |
| Last Quarter | Approximately half the disc is illuminated, but this gets less each night. |
| Waning Crescent | Less than half the disc of the moon is illuminated, and this gets less each night. |

Table 19.5: Lunar Phases

### 19.3.1 Phases of the Moon

As the moon moves round its orbit, the amount that is illuminated by the sun as seen from a vantage point on Earth changes. The result of this is that approximately once per orbit, the moon's face gradually changes from being totally in shadow to being fully illuminated and back to being in shadow again. This process is divided up into various phases as described in table 19.5.

### 19.3.2 The Lunar Magnitude

The eastern half of the Moon has more dark *maria*, therefore careful studies (Russell, 1916) have shown that in the waxing phases the Moon is slightly brighter than in the waning phase of the same degree of illumination.

Around Full Moon, the Moon shows an *opposition surge*, a strong increase in brightness which Krisciunas and B. Schaefer (1991) describe as a 35% increase in luminous flux over the curve extrapolated from measurements when the phase angle $|\alpha| < 7°$.

Of course, just at Full Moon when the opposition is near-perfect, the Moon will also move through Earth's shadow during a Lunar eclipse.

The Moon reflects not only sunlight which directly hits it, but also sunlight reflected from Earth to the Moon (Agrawal, 2016). This *earthshine*, also known as *ashen glow*, is brightest when the Moon is most strongly illuminated by the Earth, i.e., when the Moon as seen from Earth shows only a thin crescent. In these days around the New Moon, the thin crescent can often be seen complemented into a softly glowing full disk. Stellarium's estimate for visual magnitude is based on the mentioned references and a new standard value for the solar illumination constant of 133.1 klx (Ashdown, 2019).

## 19.4 The Major Planets

Unlike the stars whose relative positions remain more or less constant, the planets seem to move across the sky over time (the word "planet" comes from the Greek for "wanderer"). The planets are siblings of the Earth, massive bodies that are in orbit around the Sun. Until 2006 there was no formal definition of a planet, leading to some confusion about the classification for some bodies traditionally regarded as being planets, but which didn't seem to fit with the others.

In 2006 the International Astronomical Union (IAU) defined a planet as a celestial body that, within the Solar System:

1. is in orbit around the Sun
2. has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape; and
3. has cleared the neighbourhood around its orbit

or within another system:

1. is in orbit around a star or stellar remnants
2. has a mass below the limiting mass for thermonuclear fusion of deuterium; and
3. is above the minimum mass/size requirement for planetary status in the Solar System.

Moving from the Sun outwards, the 8 major planets are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Since the formal definition of a planet in 2006 Pluto has been relegated to having the status of *dwarf planet*, along with bodies such as Ceres and Eris. See figure 19.4.
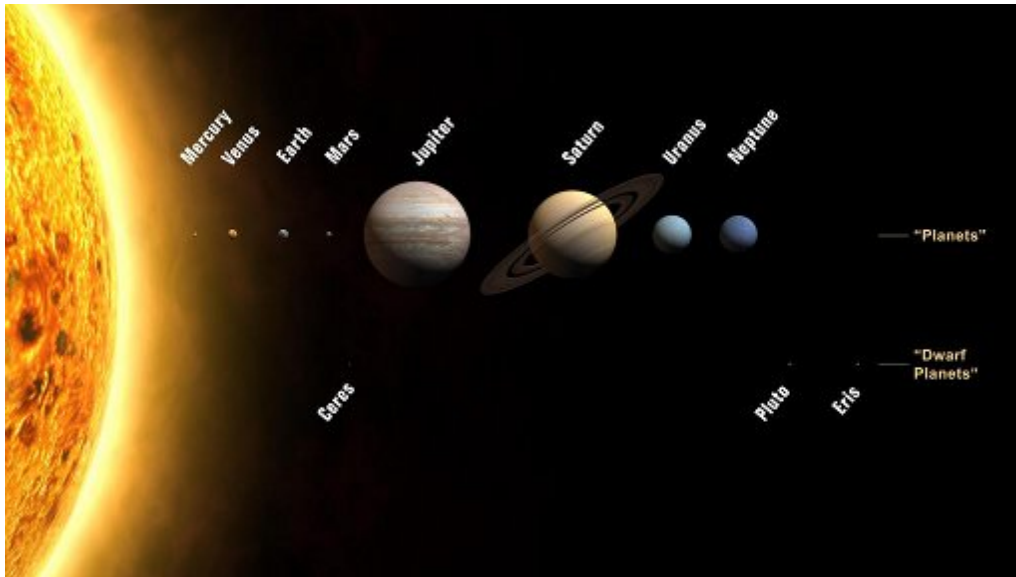
Figure 19.4: The Planets

### 19.4.1 Terrestrial Planets

The planets closest to the sun are called collectively the *terrestrial planets*. The terrestrial planets are: Mercury, Venus, Earth and Mars.

The terrestrial planets are relatively small, comparatively dense, and have solid rocky surface. Most of their mass is made from solid matter, which is mostly rocky and/or metallic in nature.

### 19.4.2 Jovian Planets

Jupiter, Saturn, Uranus and Neptune make up the *Jovian planets*, also called *gas giants*. They are much more massive than the terrestrial planets, and do not have a solid surface. Jupiter is the largest of all the planets with a diameter of about 12, and mass over 300 times that of the Earth!

The Jovian planets do not have a solid surface – the vast majority of their mass being in gaseous form (although they may have rocky or metallic cores). Because of this, they have an average density which is much less than the terrestrial planets. Saturn's mean density is only about $0.7\,\mathrm{g/cm^3}$ – it would float in water!

### 19.4.3 Apparent Magnitudes of the Planets

The apparent magnitude of the planets can be found in astronomical almanachs. Over time, several scientific studies have refined these models. A few of them have been implemented in Stellarium:

**Müller 1893**  G. Müller formulated *visual magnitudes* for the planets from visual observations of 1877–1891. They can be found in Meeus (1998) and Wilkins (1961). They give notably lower brightness estimates than the later models, which however provide *instrumental magnitudes* in the Johnson V photometric system. Several important historical studies from the early 20th century are based on these estimates.

**Astronomical Almanac 1984**  This model was used in the Astronomical Almanac starting in 1984. The expressions are allegedly "due to D. L. Harris", but J. Meeus (1998, p.286) denies this origin.

**Explanatory Supplement 1992**  Expressions from Seidelmann (1992).

**Explanatory Supplement 2013**  Expressions from Urban and Seidelmann (2013).

**Mallama & Hilton 2018**  The currently most modern expressions include e.g. a model for Mars which takes the brightening and dimming of albedo features into account (Mallama and J. L. Hilton, 2018).

**Generic**  A simple model based on albedo, size and distance.

## 19.5 The Minor Bodies

As well as the Major Planets, the solar system also contains innumerable smaller bodies in orbit around the Sun. These are generally the *dwarf planets* (Ceres, Pluto, Eris), the other *minor planets*, also known as *planetoids* or *asteroids*, and comets.

While the positions of the major planets can meanwhile be computed for many millennia in the past and

future, the minor bodies have only been systematically observed since the beginning of the 19th century.[3] The small masses occasionally pass by the larger planets which exert gravitational forces, so that the orbits of the minor bodies are not stable and cannot be computed for long periods. The positions are computed by using *osculating orbital elements*, which describe the motions on instantaneous *Kepler orbits*[4]. If you want to compute positions of these objects with Stellarium, you need to have valid (current) *orbital elements*. See Solar System Editor plugin (section 13.8) and Appendix D.2.2 for more details.

### 19.5.1   Asteroids

Asteroids are celestial bodies orbiting the Sun in more or less regular orbits mostly between Mars and Jupiter. They are generally rocky bodies like the inner (terrestrial) planets, but of much smaller size. They are countless in number ranging in size from about ten meters to hundreds of kilometres.

### 19.5.2   Comets

A comet is a small body in the solar system that orbits the Sun and (at least occasionally) exhibits a coma (or atmosphere) and/or a tail.

Most comets have a very eccentric orbit (featuring a highly flattened ellipse, or even a parabolic track), and as such spend most of their time a very long way from the Sun. Comets are composed of rock, dust and ices. When they come close to the Sun, the heat evaporates the ices, causing a gaseous release. This gas and loose material which comes away from the body of the comet is swept away from the Sun by the Solar wind, forming the tail. The outgassing may also change the orbit of the comet, so that its orbital elements should be used only for a few months around their *epoch*.

Most larger comets exhibit two kinds of tail: a straight gas tail (often blue-green in photographs), and a wider, occasionally curved dust tail (reflecting whitish sunlight).

Comets whose orbit brings them close to the Sun more frequently than every 200 years are considered to be *short period* comets, the most famous of which is probably Comet Halley, named after the British astronomer EDMUND HALLEY (1656–1741/42[5]), which has an orbital period of roughly 76 years.

## 19.6   Meteoroids

These objects are small pieces of space debris left over from the early days of the solar system or which crumbled off a comet when it came close to the sun. These particles orbit the Sun and come in a variety of shapes, sizes an compositions, ranging from microscopic dust particles up to about ten meters across.

Sometimes these objects collide with the Earth. The closing speed of these collisions is generally extremely high (tens of kilometres per second). When such an object ploughs through the Earth's atmosphere, a large amount of kinetic energy is converted into heat and light, and a visible flash or streak can often be seen with the naked eye. Even the smallest particles can cause these events which are commonly known as *shooting stars*.

While smaller objects tend to burn up in the atmosphere, larger, denser objects can penetrate the atmosphere and strike the surface of the planet, sometimes leaving meteor craters.

Sometimes the angle of the collision means that larger objects pass through the atmosphere but do not strike the Earth. When this happens, spectacular fireballs are sometimes seen.

To clarify some terminology:

**Meteoroids**  are the objects when they are floating in space.

**Meteor**  is the name given to the visible atmospheric phenomenon.

    **Shooting Star**  colloquial term for a small meteor

    **Fireball, Bolide**  term for a very bright meteor. These illuminate the landscape, sometimes for several seconds, and occasionally even cause sounds. These are also candidates for

**Meteorites**  , the objects that penetrate the atmosphere and land (or *impact*) on the surface.

In some nights over the year you can observe increased meteorite activity. Those meteors seem to come from a certain point in the sky, the *Radiant*. But what we see is similar to driving through a mosquito swarm

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[3]The first discovered asteroid, (1) Ceres, was in fact discovered on January 1, 1801.

[4]The mathematician and astronomer JOHANNES KEPLER (1571–1630) discovered that planets do not move on circles (which had been postulated since antiquity), but on "conical sections", i.e., ellipses, parabolae or even hyperbolae. The latter two can be observed for far-out comets and recently even interstellar objects passing the Sun.

[5]EDMUND HALLEY lived in a time when Great Britain still used the Julian calendar and started the years in March. He died on January 14th, 1741 (British Julian), which was called January 25th 1742 (Gregorian) in most other European countries.

which all seem to come head-on. Earth itself moves through space, and sweeps up a dense cloud of particles which originates from a comet's tail. Stellarium's Meteor Shower plugin (see section 14.6) can help you planning your next meteor observing night.

## 19.7 Zodiacal Light and *Gegenschein*

In very clear nights on the best observing sites, far away from the light pollution of our cities, you can observe a feeble glow also known as "false twilight" after evening twilight in the west, or before dawn in the east. The glow looks like a wedge of light along the ecliptic. Exactly opposite the sun, there is another dim glow that can be observed with dark-adapted eyes in perfect skies: the *Gegenschein* (counterglow).

This is sunlight reflected off the same dust and meteoroids in the plane of our solar system which is the source of meteors. Stellarium's sky can show the Zodiacal light (Kwon, Hong, and Weinberg, 2004), but observe how quickly light pollution kills its visibility!

## 19.8 The Milky Way

There is a band of very dense stars running right round the sky in huge irregular stripe. Most of these stars are very dim, but the overall effect is that on very dark clear nights we can see a large, beautiful area of diffuse light in the sky. It is this for which we name our galaxy the *Milky Way*.

The reason for this effect is that our galaxy is somewhat like a disc, and we are off to one side. Thus when we look towards the centre of the disc, we see more a great concentration of stars (there are more star in that direction). As we look out away from the centre of the disc we see fewer stars - we are staring out into the void between galaxies!

It's a little hard to work out what our galaxy would look like from far away, because when we look up at the night sky, we are seeing it from the inside. All the stars we can see are part of the Milky Way, and we can see them in every direction. However, there is some structure. There is a higher density of stars in particular places.

## 19.9 Nebulae

Seen with the naked eye, binoculars or a small telescope, a *nebula* (plural *nebulae*) is a fuzzy patch on the sky. Historically, the term referred to any extended object, but the modern definition excludes some types of object such as galaxies.

Observationally, nebulae are popular objects for amateur astronomers – they exhibit complex structure, spectacular colours (in most cases only visible in color photography) and a wide variety of forms. Many nebulae are bright enough to be seen using good binoculars or small to medium sized telescopes, and are a very photogenic subject for astro-photographers.

Nebulae are associated with a variety of phenomena, some being clouds of interstellar dust and gas in the process of collapsing under gravity, some being envelopes of gas thrown off during a supernova event (so called *supernova remnants*), yet others being the remnants of dumped outer layers around dying stars (*planetary nebulae*).

Examples of nebulae for which Stellarium has images include the Crab Nebula (M1), which is a supernova remnant, and the Dumbbell Nebula (M27) and the Ring Nebula (M57) which are planetary nebulae.

### 19.9.1 The Messier Objects

The *Messier* objects are a set of astronomical objects catalogued by Charles Messier (1730–1817) in his catalogue of *Nebulae and Star Clusters* first published in 1774. The original motivation behind the catalogue was that Messier was a comet hunter, and he was frustrated by objects which resembled but were not comets. He therefore compiled a list of these annoying objects.

The first edition covered 45 objects numbered M1 to M45. The total list consists of 110 objects, ranging from M1 to M110. The final catalogue was published in 1781 and printed in the *Connaissance des Temps* in 1784. Many of these objects are still known by their Messier number.

Because the Messier list was compiled by astronomers in the Northern Hemisphere, it contains only objects from the north celestial pole to a celestial latitude of about −35°. Many impressive Southern objects, such as the Large and Small Magellanic Clouds are excluded from the list. Because all of the Messier objects are visible with binoculars or small telescopes (under favourable conditions), they are popular viewing

objects for amateur astronomers. In early spring, astronomers sometimes gather for "Messier Marathons", when all of the objects can be viewed over a single night.

Stellarium includes images of many Messier objects.

### 19.9.2  The Caldwell catalogue

The *Caldwell* catalogue is an astronomical catalogue of 109 star clusters, nebulae, and galaxies for observation by amateur astronomers. The list was compiled by PATRICK MOORE (1923–2012) as a complement to the Messier catalogue (O'Meara, 2003).

While the Messier catalogue is used by amateur astronomers as a list of deep-sky objects for observation, Moore noted that Messier's list was not compiled for that purpose and excluded many of the sky's brightest deep-sky objects (O'Meara, 2003), such as the Hyades, the Double Cluster (NGC 869 and NGC 884), and the Sculptor Galaxy (NGC 253). The Messier catalogue was actually compiled as a list of known objects that might be confused with comets. Moore also observed that since Messier compiled his list from observations in Paris, it did not include bright deep-sky objects visible in the Southern Hemisphere, such as Omega Centauri, Centaurus A, the Jewel Box, and 47 Tucanae (O'Meara, 2003). Moore compiled a list of 109 objects to match the commonly accepted number of Messier objects (he excluded M110 (Moore, 1995)), and the list was published in *Sky & Telescope* in December 1995 (Moore, 1995).

Moore used his other surname – Caldwell – to name the list, since the initial of "Moore" is already used for the Messier catalogue (O'Meara, 2003). Entries in the catalogue are designated with a "C" and the catalogue number (1 to 109).

Unlike objects in the Messier catalogue, which are listed roughly in the order of discovery by Messier and his peers, the Caldwell catalogue is ordered by declination, with C1 being the most northerly and C109 being the most southerly (O'Meara, 2003), although two objects (C 26=NGC 4244 and C 41, the Hyades) are listed out of sequence (O'Meara, 2003). Other errors in the original list have since been corrected: it incorrectly identified the S Norma Cluster (C 89=NGC 6087) as NGC 6067 and incorrectly labelled the Lambda Centauri Cluster (C 100=IC 2944) as the Gamma Centauri Cluster (O'Meara, 2003).

## 19.10  Galaxies

Stars, it seems, are gregarious – they like to live together in groups. These groups are called galaxies. The number of stars in a typical galaxy is literally astronomical – many *billions* – sometimes over *hundreds of billions* of stars!

Our own star, the sun, is part of a galaxy. When we look up at the night sky, all the stars we can see are in the same galaxy. We call our own galaxy the Milky Way (or sometimes simply "the Galaxy"[6]).

Other galaxies appear in the sky as dim fuzzy blobs. Only four are normally visible to the naked eye. The Andromeda galaxy (M31) visible in the Northern hemisphere, the two Magellanic clouds, visible in the Southern hemisphere, and the home galaxy Milky Way, visible in parts from north and south under dark skies.

There are thought to be billions of galaxies in the universe comprised of an unimaginably large number of stars.

The vast majority of galaxies are so far away that they are very dim, and cannot be seen without large telescopes, but there are dozens of galaxies which may be observed in medium to large sized amateur instruments. Stellarium includes images of many galaxies, including the Andromeda galaxy (M31), the Pinwheel Galaxy (M101), the Sombrero Galaxy (M104) and many others.

Astronomers classify galaxies according to their appearance. Some classifications include *spiral galaxies*, *elliptical galaxies*, *lenticular galaxies* and *irregular galaxies*.

## 19.11  Eclipses and Transits

Eclipses occur when an apparently large celestial body (planet, moon etc.) moves between the observer and a more distant object – the more distant object being eclipsed by the nearer one.

### 19.11.1  Solar Eclipses

Solar eclipses occur when our Moon moves between the Earth and the Sun. This happens when the inclined orbit of the Moon causes its path to cross the ecliptic and our line of sight to the Sun. In essence it is the observer falling under the shadow of the Moon.

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[6]Which means closely the same thing, the word deriving from Greek *gala*=milk.

By a wonderful coincidence, Sun and Moon appear of almost identical size in Earth's sky, but the Moon's elliptical orbit sometimes causes it to appear just a bit smaller than the Sun.

There are therefore three types of solar eclipses:

**Partial**  The Moon only covers part of the Sun's surface which, for higher eclipse magnitudes, appears as crescent.

**Total**  The Moon completely obscures the Sun's surface.

**Annular**  The Moon is at or close to apogee (furthest from Earth in its elliptic orbit) and its disc is too small to completely cover the Sun. In this case most of the Sun's disc is obscured – all except a thin ring around the edge.

Sometimes the eclipse starts annular, but when the shadow reaches the part of the globe closest to the Moon, it becomes just large enough to cover the sun totally, and when receding, it may go back to the annular characteristic. This is called *annular-total* in the classical literature, or *hybrid* in more recent works.

### 19.11.2 Lunar Eclipses

Lunar eclipses occur when the Earth moves between the Sun and the Moon, and the Moon is in the Earth's shadow. They occur under the same basic conditions as the solar eclipse but appear to occur more often because the Earth's shadow is so much larger than the Moon's, and a Lunar eclipse is observable from more than half the Earth's surface, while a Solar eclipse is limited to a smaller region.

The geometrical begin of a Lunar eclipse is totally unobservable: Seen from a point near the observable edge of the Lunar surface, the large black disk of Earth just touches the Solar disk. While the time of this event can be determined, the effect on the apparent brightness of the Moon's surface as observed from Earth is close to zero. Only as more of the Solar disk is occulted by Earth, this spot on the Lunar surface will receive less sunlight and will appear darker when observed from Earth. A rule of thumb says that 70% of the Moon must enter the Earth's *penumbra* (partial shadow) before a light defect can be noted by attentive human observers.

The Earth's *umbra* (deep shadow) is then much darker. As soon as an observer on the Lunar edge experiences a Total Solar eclipse, observers on Earth see the begin of the partial eclipse.

Total lunar eclipses are more noticeable than partial eclipses because the Moon moves fully into the Earth's shadow and there is very noticeable darkening. However, the Earth's atmosphere refracts light (bends it) in such a way that some sunlight can still fall on the Moon's surface even during total eclipses. The blue parts of sunlight are scattered and filtered away, so that there is a marked reddening of the light as it passes through the atmosphere, and this makes the Moon appear in a deep red colour. The darkness and colors are notably influenced by atmospheric clarity and clouds. After big volcanic eruptions eclipses are often reported to appear darker. ANDRÉ DANJON (1890–1967) has introduced a scale for the apparent brightness of the fully eclipsed Moon, where 0 is given for extremely dark eclipses and 4 for very bright ones. These unpredictable brightness differences make accurate simulation of the exact appearance impossible, but Stellarium's display gives a pretty good impression for eclipses given as 2-3 on this *Danjon scale*.

Earth's atmosphere also makes the shadow slightly larger than what can be derived by the geometrical sizes and distances of the involved objects. The Astronomical Almanac uses a traditional enlargement by 2% after WILLIAM CHAUVENET (1820–1870) while recent eclipse experts prefer another formulation which leads to a slightly smaller enlargement after ANDRÉ DANJON (Espenak and Meeus, 2009). You can select which formulation you prefer (see section 4.4.2).

### 19.11.3 Transits

The term "transit" generally describes the passage of one object in front of another[7]. The most prominent examples are the passages of the *inferior planets* Mercury or Venus between the Sun and Earth, where they appear as tiny black disks on the glaringly bright Solar disk. The disk of Venus can be seen with the unaided eye[8], while Mercury is too small to be discernible.

Observing the transits of Venus from various locations on Earth was an important scientific endeavour in previous centuries. It allows a direct determination of the distance scale in the Solar System. Unfortunately, these transits are rare events: After two such transits 8 years apart, there is a gap lasting more than a century. The last such transits occurred in 2004 and 2012. Mercury's transits are much more frequent.

In the telescope age, this also can be a passage of a Jovian Moon in front of Jupiter, or even the passage of a shadow of such a moon over Jupiter's disk, or, more recently, the passage of an artificial satellite in front of the Sun or Moon.

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[7]Another "transit" means the crossing of the meridian by the object.

[8]Never look into the Sun without proper filters!

### 19.11.4 Contact Times

Eclipse and transit observers like to prepare tables of precomputed *contact times* for which they use terminology shown in Tables 19.6-19.8.

## 19.12 Observing Hints

When stargazing, there's a few little things which make a lot of difference, and are worth taking into account.

**Dark skies**  For many people getting away from light pollution isn't an easy thing. At best it means a drive away from the towns, and for many the only chance to see a sky without significant glow from street lighting is on vacation. If you can't get away from the cities easily, make the most of it when you are away.

**Wrap up warm**  The best observing conditions are the same conditions that make for cold nights, even in the summer time. Observing is not a strenuous physical activity, so you will feel the cold more than if you were walking around. Wear a lot of warm clothing, don't sit/lie on the floor (at least use a camping mat, better take a deck-chair), and take a flask of hot drink.

**Dark adaptation**  The true majesty of the night sky only becomes apparent when the eye has had time to become accustomed to the dark. This process, known as dark adaptation, can take up to half an hour, and as soon as the observer sees a bright light they must start the process over. Red light doesn't compromise dark adaptation as much as white light, so use a red torch if possible (and one that is as dim as you can manage with). A dim single red LED light is ideal, also to have enough light to take notes.

**The Moon**  Unless you're particularly interested in observing the Moon on a given night, it can be a nuisance—it can be so bright as to make observation of dimmer objects such as nebulae impossible. When planning what you want to observe, take the phase and position of the Moon into account. Of course Stellarium is the ideal tool for finding this out!

**Averted vision**  A curious fact about the eye is that it is more sensitive to dim light towards the edge of the field of view. If an object is slightly too dim to see directly, looking slightly off to the side but concentrating on the object's location can often reveal it.

**Angular distance**  Learn how to estimate angular distances. Learn the angular distances described in section 18.5.2. If you have a pair of binoculars, find out the angular distance across the field of view and use this as a standard measure.

## 19.13 Atmospheric effects

### 19.13.1 Atmospheric Extinction

*Atmospheric Extinction* is the attenuation of light of a celestial body by Earth's atmosphere. In the last split-second of its travel into our eyes or detectors, light from outer space has to pass our atmosphere, through layers of mixed gas, water vapour and dust. If a star is in the zenith, its light must pass one *air mass* and is reduced by whatever amount of water and dust is above you. When the star is on the horizon, it has to pass about 40 times longer through the atmosphere: 40 air masses (Fig. 19.5). The number of air masses increases fast in low altitudes, this is why we see so few stars along the horizon. Usually blue light is extinguished more, this is why the sun and moon (and brighter stars) appear reddish on the horizon.

Stellarium can simulate extinction, and you can set the opacity of your atmosphere with a global factor $k$, the *magnitude loss per airmass* (see section 4.4.1.2). The best mountaintop sites may have $k = 0.15$, while $k = 0.25$ seems a value usable for good locations in lower altitudes.

### 19.13.2 Atmospheric Refraction

*Atmospheric Refraction* is a lifting effect of our atmosphere which can be observed by the fact that objects close to the horizon appear higher than they should be if computed only with spherical trigonometry. Stellarium simulates refraction for terrestrial locations when the atmosphere is switched on. Refraction depends on air pressure and temperature. Figure 19.6 has been created from the same formulae that are employed in Stellarium. You can see how fast refraction grows very close to the mathematical horizon.

Note that these models can only give approximate conditions. There are many weird effects in the real atmosphere, when temperature inversion layers can create light ducts, double sunsets etc.

Also note that the models give meaningful results only for altitudes above approximately −2°. Below that, in nature, there is always ground which blocks our view. In Stellarium you can switch off the ground, and you can observe a sunset with a strange egg-shaped sun below the horizon. This is of course nonsense.

| Contact | Name | Description |
|---------|------|-------------|
| First | Begin of partial eclipse | Moon first touches Sun from the outside |
| Second | Begin of totality | Moon completely covers the Sun |
|  | Mid-eclipse | central time |
| Third | End of totality | Bright Solar edge re-appears from complete occultation |
| Fourth | End of partial eclipse | Moon leaves Sun completely |

Table 19.6: Contact terminology for Total Solar eclipses.

| Contact | Name, Description |
|---------|-------------------|
| First Penumbral | Begin of (penumbral) eclipse. Unobservable. |
|  | Moon first touches Earth's geometrical shadow cone from the outside. |
| Second Penumbral | Begin of total immersion in penumbra |
|  | Moon shows a notable darkening |
| First Umbral | Begin of partial eclipse |
|  | Moon first touches the central dark shadow |
| Second Umbral | Begin of totality |
|  | Moon completely immersed in Earth's umbra (dark shadow) |
| Maximum | Mid-eclipse, central time |
| Third Umbral | End of totality |
|  | A bright Lunar edge re-appears from complete occultation |
| Fourth Umbral | End of partial eclipse |
|  | Moon leaves umbra completely |
| Third Penumbral | End of total penumbral phase |
|  | Lunar edge leaves penumbra. The opposide side is still darkened |
| Fourth Penumbral | End of (penumbral) eclipse. Unobservable. |
|  | Moon leaves penumbra completely. |

Table 19.7: Contact terminology for Lunar eclipses. Depending on shadow geometry, the second penumbral contact may occur only after the first umbral, and third penumbral contact before fourth umbral.

| Contact | Name | Description |
|---------|------|-------------|
| First | Exterior Ingress | Planet/Moon first touches Sun from the outside |
| Second | Interior Ingress | Planet/Moon starts to be visible completely inside Sun |
|  | Mid-transit | central time |
| Third | Interior Egress | Planet/Moon first touches Sun from the inside |
| Fourth | Exterior Egress | Planet/Moon leaves Sun completely |

Table 19.8: Contact terminology for Transits and Annular Solar eclipses.
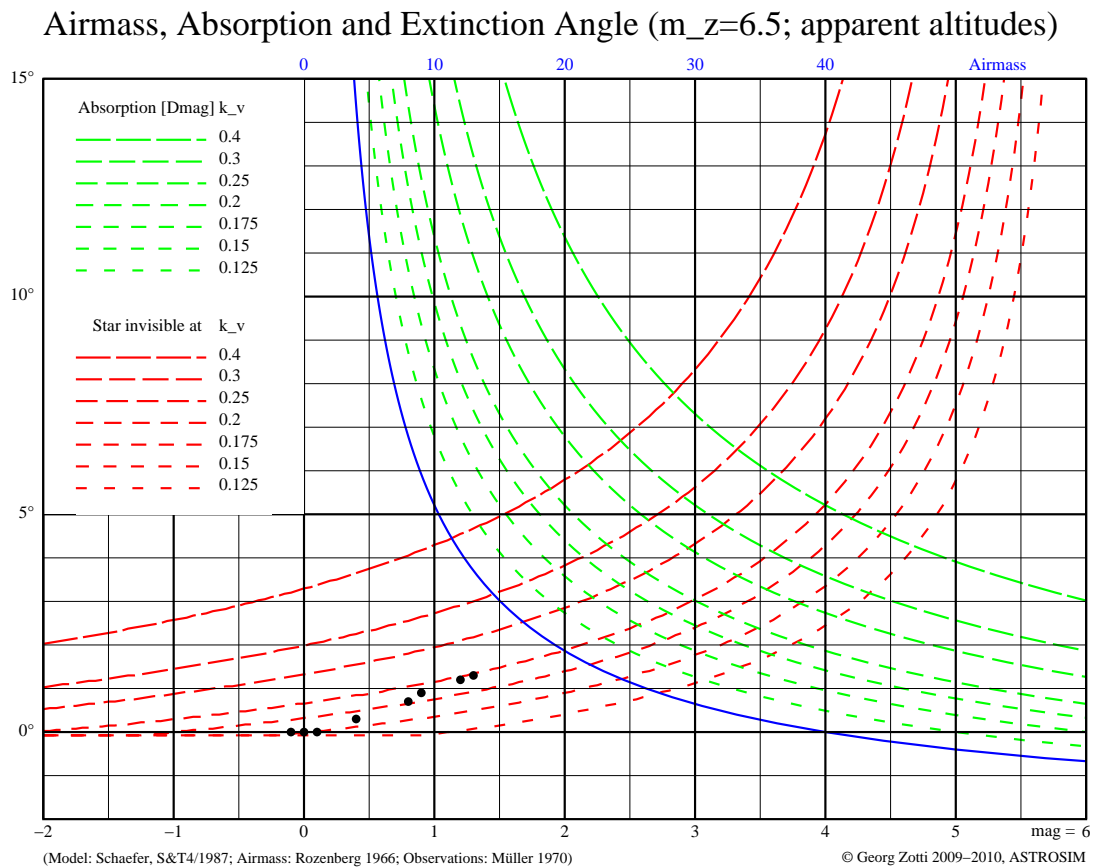
Figure 19.5: Airmass and Extinction. The figure shows Airmass (blue) along the line of sight in the altitude labeled on the left side. The green curves show how many magnitudes an object is dimmed down, depending on extinction factor $k$ (called $k_v$ in the figure). The red curves indicate at which altitude a star of given magnitude can be seen with good eyesight, again depending on $k$. The black dots are observed values found in the literature.
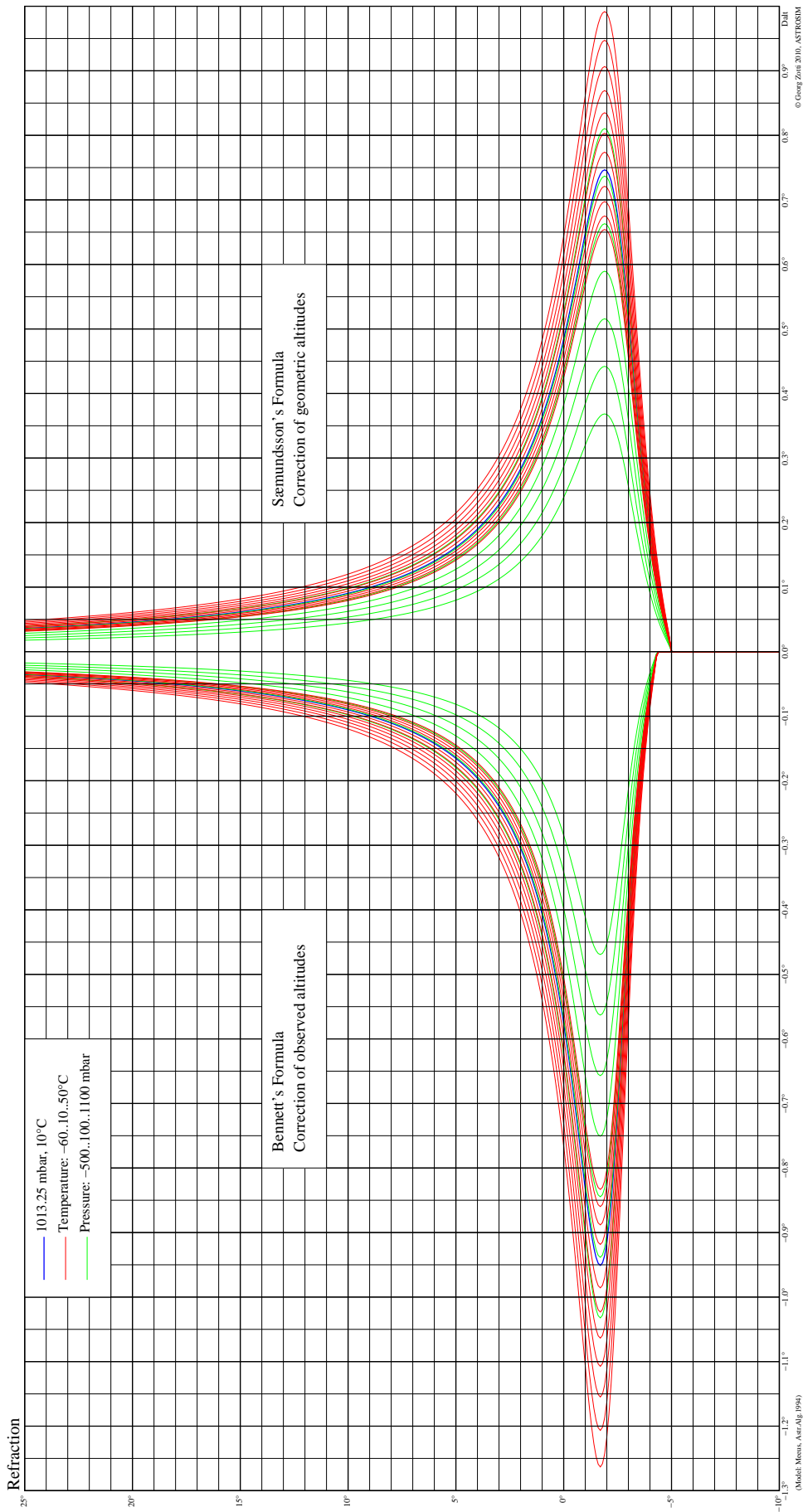
Figure 19.6: Refraction. The figure shows corrective values (degrees) which are subtracted from observed altitudes (left side) to reach geometric altitudes, or values to be added to computed values (right side). The models used are not directly inverse operations.

Stellarium is also not able to properly recreate the atmospheric distortions as seen from a stratosphere balloon, where the height of earth's surface is several degrees below the mathematical horizon.

#### 19.13.2.1 Scintillation

*Scintillation* is the scientific name of the twinkling which stars show in turbulent atmosphere. The twinkling is caused by moving pockets of air with different temperature. Observe a star low on the horizon with a telescope, and you will note it does not stand still but dances around a bit, often also changing color to show red or blue hues. While the twinkling of stars may look fine and comforting to the naked eye on a nice warm summer evening, telescopic observers and astrophotographers don't like it at all. They rather complain about "bad seeing", because it deteriorates the optical resolution of their instruments and photographs.

Just like extinction and refraction are stronger along the horizon, stars in low altitude in general show more twinkling than stars higher up in the sky.

Note that planets seem to be affected less by scintillation: they are not point sources, but little disks, and so the effect of the turbulent pockets of air distorting different parts of the disks cancels out a bit when observing with the naked eye: planets appear to be more stable. Of course, the view in a telescope will still be deteriorated by the turbulent atmosphere.

While bad seeing was one key motivation of sending telescopes into earth orbit since the 1970s, the latest generation of ground-based giant telescopes is able to compensate for the turbulent motion by rapidly deforming their secondary mirror.

### 19.13.3 Light Pollution

An ugly side effect of civilisation is a steady increase in outdoor illumination. Many people think it increases safety, but while this statement can be questioned, one definite result, aside from environmental issues like dangers for the nocturnal fauna, are ever worsening conditions for astronomical observations or just enjoyment of the night sky.

Stellarium can simulate the effect of light pollution on the visibility of celestial objects. This is controlled from the light pollution section of the *Sky* tab of the *View* window (see section 4.11). Light pollution levels are set using a numerical value between 1 and 9 which corresponds to the *Bortle Dark Sky Scale* (see Appendix B). Given that public lighting became bright enough to cause adverse effects on observability only during the 19th century, Stellarium presents an unpolluted sky for dates before 1825. Note that of course light pollution was not switched on over night, but became gradually noticeable over decades, but you have to estimate the appropriate level.

In addition, local variations of the amount of light pollution can be included in a light pollution layer in the landscapes, see section 7 for details. This foreground layer may include all kinds of light, e.g. campfires, so this is also available for earlier dates.

PAUL ROBINSON, WITH ADDITIONS BY ALEXANDER WOLF

This chapter lists some astronomical objects that can be located using Stellarium. All of them can be seen with the naked eye or binoculars. Since many astronomical objects have more than one name (often having a "proper name", a "common name" and various catalogue numbers), the chapter lists the name as it appears in Stellarium — use this name when using Stellarium's search function — and any other commonly used names.

The Location Guide entry gives brief instructions for finding each object using nearby bright stars or groups of stars when looking at the real sky — a little time spent learning the major constellations visible from your latitude will pay dividends when it comes to locating fainter (and more interesting!) objects. When trying to locate these objects in the night sky, keep in mind that Stellarium displays many stars that are too faint to be visible without optical aid, and even bright stars can be dimmed by poor atmospheric conditions and light pollution.

## 20.1 Dubhe and Merak, The Pointers

**Type:** Stars
**Magnitude:** 1.83, 2.36
**Location Guide:** *The two "rightmost" of the seven stars that form the main shape of "The Plough" (or "Big Dipper", part of Ursa Major).*

Northern hemisphere observers are very fortunate to have two stars that point towards Polaris, which lies very close to the Northern Celestial Pole. Whatever the time of night or season of the year, they are always an immediate clue to the location of Polaris, the Pole Star.

## 20.2 M31, Messier 31, The Andromeda Galaxy

**Type:** Spiral Galaxy
**Magnitude:** 3.4
**Location Guide:** *Find the three bright stars that constitute the main part of the constellation of Andromeda. From the middle of these look toward the constellation of Cassiopeia.*

M31 is the most distant object visible to the naked eye, and among the few nebulae that can be seen without a telescope or powerful binoculars. Under good conditions it appears as a large fuzzy patch of light. It is a galaxy containing billions of stars whose distance is roughly 2.5 million light years from Earth.

## 20.3  The Garnet Star, $\mu$ Cephei

**Type:** Variable Star
**Magnitude:** 4.25 (Avg.)
**Location Guide:** *Cephius lies "above" the W-shape of Cassiopeia. The Garnet Star lies slightly to one side of a point halfway between 5 Cephei and 21 Cephei.*

   A "supergiant" (1035 solar radii) of spectral class M with a strong red colour. Given its name by Sir William Herschel in the 18th century, the colour is striking in comparison to its blue-white neighbours.

## 20.4  4 and 5 Lyrae, $\varepsilon$ Lyrae

**Type:** Double Star
**Magnitude:** 4.7
**Location Guide:** *Close to Vega ($\alpha$ Lyrae), one of the brightest stars in the sky.*

   In binoculars $\varepsilon$ Lyrae is resolved into two separate stars. Remarkably, each of these is also a double star (although this will only be seen with a telescope) and all four stars form a physical system.

## 20.5  M13, Hercules Cluster

**Type:** Globular Cluster
**Magnitude:** 5.8
**Location Guide:** *Located approximately 1/3 of the way along a line from 44 ($\eta$) to 40 ($\zeta$) Herculis.*

   This cluster of hundreds of thousands of mature stars appears as a circular "cloud" using the naked eye or binoculars (a large telescope is required to resolve individual stars). Oddly the cluster appears to contain one young star and several areas that are almost devoid of stars.

## 20.6  M45, The Pleiades, The Seven Sisters

**Type:** Open Cluster
**Magnitude:** 1.2 (Avg.)
**Location Guide:** *Lies on the Bull's back, about 1/3 between Aldebaran in Taurus and Almaak in Andromeda.*

   Depending upon conditions, 6 to 9 of the blueish stars in this famous cluster will be visible to someone with average eyesight, and in binoculars it is a glorious sight. The cluster has more than 500 members in total, many of which are shown to be surrounded by nebulous material in long exposure photographs.

## 20.7  C41, The Hyades

**Type:** Open Cluster
**Magnitude:** 0.5 (Avg.)
**Location Guide:** *Lies near Aldebaran in Taurus.*

   The Hyades span about 6° of sky because they are one of the nearest open clusters, being about 153 light years away. The age of the Hyades is estimated to be about 625 million years. The five brightest member stars of the Hyades have consumed their hydrogen fuel in their cores and are now evolving into giant stars. Four of these stars, with Bayer designations $\gamma$, $\delta^1$, $\varepsilon$, and $\theta$ Tauri, form an asterism that is traditionally identified as the head of Taurus, the Bull.

## 20.8  Algol, The Demon Star, $\beta$ Persei

**Type:** Variable Star
**Magnitude:** 3.0 (Avg.)
**Location Guide:** *Halfway between Aldebaran in Taurus and the middle star of the "W" of Cassiopeia.*

   Once every three days or so, Algol's brightness changes from 2.1 to 3.4 and back within a matter of hours. The reason for this change is that Algol has a dimmer giant companion star, with an orbital period of about 2.8 days, that causes a regular partial eclipse. Although Algol's fluctuations in magnitude have been known since at least the 17th century, it was the first to be proved to be due to an eclipsing companion — it is therefore the prototype Eclipsing Variable.

## 20.9 Sirius, $\alpha$ Canis Majoris

**Type:** Star
**Magnitude:** -1.47
**Location Guide:** *Sirius is easily found by following the line of three stars in Orion's belt southwards.*

Sirius is a white dwarf star at a comparatively close 8.6 light years. This proximity and its high innate luminance makes it the brightest star in our sky. Sirius is a double star; its companion is a white dwarf, much dimmer but very hot, and is believed to be smaller than Earth.

## 20.10 M44, The Beehive, Praesepe

**Type:** Open Cluster
**Magnitude:** 3.7
**Location Guide:** *Cancer lies about halfway between the twins (Castor & Pollux) in Gemini and Regulus, the brightest star in Leo. The Beehive can be found between Asellus Borealis and Asellus Australis.*

There are probably 350 or so stars in this cluster, although it appears to the naked eye simply as a misty patch. It contains a mixture of stars from red giants to white dwarf and is estimated to be some 700 million years old.

## 20.11 27 Cephei, $\delta$ Cephei

**Type:** Variable Star
**Magnitude:** 4.0 (Avg.)
**Location Guide:** *Locate the four stars that form the square of Cepheus. One corner of the square has two other bright stars nearby forming a distinctive triangle — $\delta$ is at the head of this triangle in the direction of Cassiopeia.*

$\delta$ Cephei gives its name to a whole class of variables, all of which are pulsating high-mass stars in the later stages of their evolution. $\delta$ Cephei is also a double star with a companion of magnitude 6.3 visible in binoculars.

## 20.12 Betelgeuse, $\alpha$ Orionis, 58 Orionis

**Type:** Star
**Magnitude:** 0.45
**Location Guide:** *The distinctly reddish star in the constellation of Orion – one of the shoulders of Orion.*

Betelgeuse is a distinctly reddish, semiregular variable star whose apparent magnitude varies between 0.0 and 1.3. It is classified as a red supergiant of spectral type M1-2, and is one of the largest stars visible to the naked eye. If Betelgeuse were at the center of the Solar System, its surface would extend past the asteroid belt, completely engulfing the orbits of Mercury, Venus, Earth, Mars, and possibly Jupiter.

In 1920, Betelgeuse became the first extrasolar star to have the angular size of its photosphere measured. Subsequent studies have reported an angular diameter (apparent size) ranging from 0.042 to 0.056 arcseconds, with the differences ascribed to the non-sphericity, limb darkening, pulsations, and varying appearance at different wavelengths. It is also surrounded by a complex, asymmetric envelope roughly 250 times the size of the star, caused by mass loss from the star itself.

## 20.13 M42, The Great Orion Nebula

**Type:** Nebula
**Magnitude:** 4.0
**Location Guide:** *Almost in the middle of the area bounded by Orion's belt and lower stars, Saiph and Rigel.*

The Great Orion Nebula is the brightest nebula visible in the night sky and lies at about 1.500 light years from Earth. It is a truly gigantic gas and dust cloud that extends for several hundred light years, reaching almost halfway across the constellation of Orion. The nebula contains a cluster of hot young stars known as the Trapezium, and more stars are believed to be forming within the cloud.

## 20.14 La Superba, Y Canum Venaticorum, HIP 62223

**Type:** Star
**Magnitude:** 5.4 (Avg.)

**Location Guide:** *Almost the center of the arch of stars of Ursa Major's tail. Forms a neat triangle with Phekda (γ) and Alkaid (η, tail tip) in Ursa Major towards Canes Venatici.*

La Superba (215 solar radii) is a "Carbon Star" — a group of relatively cool gigantic (usually variable) stars that have an outer shell containing high levels of carbon. This shell is very efficient at absorbing the short wavelengths of blue light, giving carbon stars a distinctive red or orange tint. It is one of the coolest and reddest known stars.

## 20.15 52 and 53 Bootis, $\nu^1$ and $\nu^2$ Bootis

**Type:** Double Star
**Magnitude:** 5.0, 5.0
**Location Guide:** *Follow a line from Seginus (γ Boo, left shoulder) to Nekkar (β Boo, the head) and then continue for the same distance again to arrive at this double star.*

This optical double star consists of a pair of different spectral types. 52 Bootis, at approximately 800 light years, is twice as far away as 53 Boo.

## 20.16 Almach, $\gamma$ Andromedae

**Type:** Multiple Star
**Magnitude:** 2.15 (Avg.)
**Location Guide:** *The bright star located in the "legs" of Andromeda.*

In 1778, JOHANN TOBIAS MAYER discovered that γ Andromedae was a double star. When examined in a small telescope, it appears to be a bright, golden-yellow star ($\gamma^1$ Andromedae) next to a dimmer, indigo-blue star ($\gamma^2$ Andromedae), separated by approximately $10''$. It is often considered by stargazers to be a beautiful double star with a striking contrast of color. It was later discovered that $\gamma^2$ Andromedae is itself a triple star system. What appears as a single star to the naked eye is thus a quadruple star system.

## 20.17 Algieba, $\gamma$ Leonis, 41 Leonis

**Type:** Double Star
**Magnitude:** 2.20 (Avg.)
**Location Guide:** *The third brightest star in the constellation Leo – located on the "neck" of Leo.*

The bright binary system in Leo with orange-red and yellow or greenish-yellow components is visible through a modest telescope under good atmospheric conditions. To the naked eye, the Algieba system shines at mid-second magnitude, but a telescope easily splits the pair. On November 6, 2009, the discovery of a planetary companion around primary star $\gamma^1$ Leonis (γ Leonis A) was announced.

## 20.18 Castor, $\alpha$ Geminorum

**Type:** Multiple Star
**Magnitude:** 1.9 (Avg.)
**Location Guide:** *Castor is the second-brightest object in the constellation of Gemini.*

Castor is a multiple star system made up of six individual stars; there are three visual components, all of which are spectroscopic binaries. Appearing to the naked eye as a single star, Castor was first recorded as a double star in 1718 by JAMES POUND, but it may have been resolved into at least two sources of light by Cassini as early as 1678. The separation between Castor A and Castor B has increased from about $2''$ (2 arcseconds) in 1970 to about $6''$ in 2017. These two binary pairs have magnitudes of 1.9 and 3.0.

Both components have much fainter companions, Castor Aa and Ba, and both have orbits of a few days.

Castor C, or YY Geminorum, was discovered to vary in brightness with a regular period. It is an eclipsing binary with additional variations due to areas of different brightness on the surface of one or both stars, as well as irregular flares. The Castor C components orbit each other in less than a day. Castor C is believed to be in orbit around Castor AB, but with an extremely long period of several thousand years. It is $73''$ distant from the bright components.

## 20.19 PZ Cas, HIP 117078

**Type:** Variable Star
**Magnitude:** 8.2 (Avg.)

**Location Guide:** *Lies about 1/3 between Caph (β Cas, the top right star of "W") in Cassiopeia and ι Cephei (32 Cep, top left star in "rectangle" of Cepheus).*

This faint red star is one of the biggest known stars — its average size parameter is 1565 solar radii (the true value is from 1340 to 1940 solar radii). PZ Cas is a pulsating variable star located in a region with heavy dust extinction.

## 20.20   VV Cephei, HIP 108317

**Type:** Variable Star, Double Star
**Magnitude:** 5.1 (Avg.)
**Location Guide:** *Lies near the center of the "rectangle" of Cepheus).*

This is an interesting eclipsing binary system — VV Cep A (1457 solar radii) is a highly distorted star in a binary system, losing mass to its B-type companion VV Cephei B (10 solar radii) for at least part of its orbit.

## 20.21   AH Scorpii, HIP 84071

**Type:** Variable Star
**Magnitude:** 7.1 (Avg.)
**Location Guide:** *Lies in Scorpius, about $1\frac{1}{4}$ of a continuation of the Scorpion's "tail".*

AH Sco (1411 solar radii) is variable by nearly 3 magnitudes in the visual range, and an estimated 20% in total luminosity. The variation in diameter is not clear because the temperature also varies.

## 20.22   Albireo, β Cygni

**Type:** Double Star
**Magnitude:** 3.4, 5.1
**Location Guide:** *The "head" of Cygni.*

When viewed with the naked eye, it appears to be a single star. However, in a telescope it readily resolves into a double star, consisting of Albireo A (amber), and Albireo B (blue-green). Separated by 35″, the two components provide one of the best contrasting double stars in the sky due to their different colors.



Figure 20.1: Albireo: A Bright and Beautiful Double. *Credit & Copyright: Richard Yandrick.*

## 20.23   31 and 32 Cygni, o¹ and o² Cygni

**Type:** Multiple Star
**Magnitude:** 3.8, 4.0
**Location Guide:** *The two bright stars about 1/2 between Deneb (α Cygni, "tail" of Cygnus) and Rukh (δ Cygni, middle of the left "wing" of Cygnus).*

The wide binary o$^1$ Cygni and o$^2$ Cygni is separated 61′ (NNE), and this star is an easy naked-eye double. o$^1$ Cygni with 30 Cyg and HD 192579 (HIP 99676) is a moderately difficult triple system. And surprise — each of o$^1$ Cyg and o$^2$ Cyg are also Algol-type eclipsing binaries!

## 20.24 The Coathanger, Brocchi's Cluster, Cr 399

**Type:** Asterism
**Location Guide:** *It is best found by slowly sweeping across the Milky Way along an imaginary line from the bright star Altair toward the even brighter star Vega (around 1/3 between Altair and Vega).*

The asterism is made up of 10 stars ranging from 5th to 7th magnitude which form the conspicuous "coathanger", a straight line of 6 stars with a "hook" of 4 stars on the south side. Under a dark sky, Collinder 399 can be seen with the naked eye as an unresolved patch of light; binoculars or a telescope at very low power are usually needed in order to view the "coathanger" asterism.

## 20.25 Kemble's Cascade

**Type:** Asterism
**Location Guide:** *The asterism lies in the constellation Camelopardalis, about 1/3 between CS Cam and α Cam — HIP 18505 has magnitude 5 and can be found in the center of the chain.*

Kemble's Cascade is a chain of stars which are visible in binoculars, even in light-polluted skies.

## 20.26 The Double Cluster, χ and *h* Persei, NGC 884 and NGC 869

**Type:** Open Clusters
**Location Guide:** *The two open clusters near stars χ and h in the constellation Perseus.*

The Double Cluster (also known as Caldwell 14 or C14) is the common name for the naked-eye open clusters NGC 869 and NGC 884 (often designated *h* Persei and χ Persei, respectively). The Double Cluster is approximately the radiant of the Perseid meteor shower, which peaks annually around August 12 or 13. Although easy to locate in the northern sky, observing the Double Cluster in its two parts requires optical aid. They are described as being an "awe-inspiring" and "breathtaking" sight, and are often cited as targets in astronomical observers' guides.

## 20.27 Large Magellanic Cloud, PGC 17223

**Type:** Dwarf Spiral Galaxy
**Magnitude:** 0.9
**Location Guide:** *It is visible as a faint "cloud" in the night sky of the southern hemisphere straddling the border between the constellations of Dorado and Mensa, and it appears from Earth more than 20 times the width of the full moon.*

The *Large Magellanic Cloud* (LMC) is a satellite galaxy of the Milky Way. The Large Magellanic Cloud is usually considered an irregular galaxy. However, it shows signs of a bar structure, and has more recently been reclassified as a Magellanic-type dwarf spiral galaxy. At a distance of 50 kiloparsecs, the LMC is the third closest galaxy to the Milky Way, after the Sagittarius Dwarf Spheroidal (~16 kiloparsecs) and the putative Canis Major Dwarf Galaxy (~12.9 kiloparsecs, though its status as a galaxy is under dispute) lying closer to the center of the Milky Way. The LMC has a diameter of about 14,000 light-years (~4.3 kpc) and a mass of approximately 10 billion ($10^{10}$) solar masses, making it roughly 1/100 as massive as the Milky Way. The LMC has a wide range of galactic objects and phenomena — surveys of the galaxy have found roughly 60 globular clusters, 400 planetary nebulae, and 700 open clusters, along with hundreds of thousands of giant and supergiant stars.

## 20.28 Tarantula Nebula, C 103, NGC 2070

**Type:** Nebula
**Magnitude:** 7.3
**Location Guide:** *Part of Large Magellanic Cloud.*

The Tarantula Nebula (also known as 30 Doradus) is an H II region in the Large Magellanic Cloud (LMC). 30 Doradus has at its centre the star cluster NGC 2070 which includes the compact concentration of stars known as R136 that produces most of the energy that makes the nebula visible. The estimated mass of

Figure 20.2: Small and Large Magellanic Clouds over Paranal Observatory. *Credit: ESO/J. Colosimo.*

the cluster is 450,000 solar masses, suggesting it will likely become a globular cluster in the future (Bosch, E. Terlevich, and R. Terlevich, 2009). The closest supernova observed since the invention of the telescope, Supernova 1987A, occurred in the outskirts of the Tarantula Nebula.

## 20.29 Small Magellanic Cloud, NGC 292, PGC 3085

**Type:** Dwarf Irregular Galaxy
**Magnitude:** 2.2
**Location Guide:** *It is located mostly in the constellation of Tucana and appears as a hazy, light patch in the night sky about 3° across, looking like a detached piece of the Milky Way. Since it has a very low surface brightness, it is best viewed from a dark site away from city lights.*

The *Small Magellanic Cloud* (SMC) is a dwarf galaxy near the Milky Way. It is classified as a dwarf irregular galaxy. It has a diameter of about 7,000 light-years and has a total mass of approximately 7 billion times the mass of the Sun. The SMC contains a central bar structure and it is speculated that it was once a barred spiral galaxy that was disrupted by the Milky Way to become somewhat irregular. At a distance of about 200,000 light-years, it is one of the Milky Way's nearest neighbors. It is also one of the most distant objects that can be seen with the naked eye.

## 20.30 ω Centauri cluster, C 80, NGC 5139

**Type:** Globular Cluster
**Magnitude:** 5.3
**Location Guide:** *It is located around 1/3 between ζ and γ Centauri.*

Omega Centauri (ω Cen), or NGC 5139, is a globular cluster in the constellation of Centaurus that was first identified as a non-stellar object by Edmond Halley in 1677. Located at a distance of 15,800 light-years (4,850 pc), it is the largest globular cluster in the Milky Way at a diameter of roughly 150 light-years. It is estimated to contain approximately 10 million stars and a total mass equivalent to 4 million solar masses. Omega Centauri is so distinctive from the other galactic globular clusters that it is thought to have an alternate origin as the core remnant of a disrupted dwarf galaxy (Noyola, Gebhardt, and Bergmann, 2008).

## 20.31 47 Tucanae, C 106, NGC 104

**Type:** Globular Cluster
**Magnitude:** 4.1
**Location Guide:** *It can be seen with the naked eye near Small Magellanic Cloud.*

It is the one of brightest globular cluster in the sky, and is noted for having a very bright and dense core. It is also one of the most massive globular clusters in the Milky Way Galaxy, containing millions of stars. The cluster appears roughly the size of the full moon in the sky under ideal conditions.

## 20.32 The Coalsack Nebula, C 99

**Type:** Dark Nebula
**Location Guide:** *Dark region between α and β Crux.*

The Coalsack Nebula is the most prominent dark nebula in the skies, easily visible to the naked eye as a dark patch silhouetted against the southern Milky Way. It is located at a distance of approximately 600 light years away from Earth. The Coalsack is important in Australian Aboriginal astronomy, and forms the head of the Emu in the sky in several Aboriginal cultures.



Figure 20.3: The Coalsack Nebula taken by the Wide Field Imager on the MPG/ESO 2.2-metre telescope. *Credit: ESO*.

## 20.33 Mira, o Ceti, 68 Cet

**Type:** Variable Star
**Magnitude:** 2.0–10.1
**Location Guide:** *It is located around 1/3 between δ and θ Ceti.*

Mira (o Ceti) is a star estimated 200–400 light years away in the constellation Cetus. Mira is a binary star system that consists of a red giant (Mira A) undergoing mass loss and a high temperature white dwarf companion (Mira B) that is accreting mass from the primary. Such an arrangement of stars is known as a symbiotic system, and this is the closest such symbiotic pair to the Sun. Mira is the brightest periodic

variable in the sky that is not visible to the naked eye for part of its cycle. Its distance is uncertain. Mira A is a well-known example of a category of long-period variable stars known as Mira variables, which are named after it.

## 20.34 α Persei Cluster, Cr 39, Mel 20

**Type:** Open Cluster
**Magnitude:** 1.2
**Location Guide:** *Around the white-yellow supergiant Mirfak, also known as α Persei in direction to δ Persei.*

The Alpha Persei Cluster, also known as Melotte 20 or Collinder 39, is an open cluster in the constellation of Perseus. To the naked eye, the cluster consists of several blue (spectral class B) stars.

## 20.35 M7, The Ptolemy Cluster

**Type:** Open Cluster
**Magnitude:** 3.3
**Location Guide:** *The cluster is easily detectable with the naked eye, close to the "sting" of Scorpius — near the center of the line between Shaula (λ Scorpii) and Kaus Media (δ Sagittarii).*

M7 has been known since antiquity — it was first recorded by the 2nd-century Greek-Roman astronomer Ptolemy, who described it as a nebula in 130 AD. Telescopic observations of the cluster reveal about 80 stars within a field of view of 1.3° across. At the cluster's estimated distance of 980 light years this corresponds to an actual diameter of 25 light years.

## 20.36 M22, NGC 6656, The Great Sagittarius Cluster

**Type:** Globular Cluster
**Magnitude:** 5.1
**Location Guide:** *Located just south of the Ecliptic, and northwest of λ Sagittarii (Kaus Borealis), the northernmost star of the "Teapot" asterism.*

M22 is an elliptical globular cluster of stars in the constellation Sagittarius, near the Galactic bulge region. It is one of the brightest and nearest globular clusters that is visible in the night sky. M22 is very unusual in that it is one of only four globulars that are known to contain a planetary nebula. In 2012 two black holes of between 10 and 20 solar masses each have been discovered in this globular cluster, initially with the Very Large Array radio telescope in New Mexico, and corroborated by the Chandra X-ray telescope. The angular size of M22 is over 0.5°.

## 20.37 M24, The Sagittarius Star Cloud

**Type:** Star Cloud
**Magnitude:** 4.6
**Location Guide:** *In the Milky Way region near Polis (μ Sagittarii).*

The Sagittarius Star Cloud is a star cloud in the constellation of Sagittarius, approximately 600 light years wide. The stars, clusters and other objects comprising M24 are part of the Sagittarius or Sagittarius-Carina arms of the Milky Way galaxy. Messier described M24 as a "large nebulosity containing many stars" and gave its dimensions as being some 1.5° across.

## 20.38 IC 4665, The Summer Beehive Cluster

**Type:** Open Cluster
**Magnitude:** 4.2
**Location Guide:** *Visible to the naked eye near Cebalrai (β Ophiuchi).*

IC 4665 is an open cluster in the constellation Ophiuchus which is easily visible in the smallest of telescopes and also with binoculars. From a sufficiently dark place it is also visible to the naked eye.

## 20.39   The E Nebula, Barnard 142 and 143

**Type:** Dark Nebula

**Location Guide:** *A well-defined dark area on a background of Milky Way near Tarazed (γ Aquilae).*

The "E" or "Barnard's E" Nebula (officially designated as B142 and B143) is a pair of dark nebulae in the constellation Aquila. It is a well-defined dark area on a background of the Milky Way. The size of the nebula is roughly 0.5°, and its distance from Earth is estimated at about 2000 light years.

# 21. Exercises

PAUL ROBINSON, WITH ADDITIONS BY ALEXANDER WOLF

## 21.1 Find M31 in Binoculars

M31 – the *Andromeda Galaxy* – is the most distant object visible to the naked eye. Finding it in binoculars is a rewarding experience for new-comers to observing.

### 21.1.1 Simulation

1. Set the location to a mid-Northern latitude if necessary (M31 isn't always visible for Southern hemisphere observers). The UK is ideal.
2. Find M31 and set the time so that the sky is dark enough to see it. The best time of year for this at Northern latitudes is Autumn/Winter, although there should be a chance to see it at some time of night throughout the year.
3. Set the field of view to 6° (or the field of view of your binoculars if they're different. 6° is typical for 7x50 binoculars).
4. Practice finding M31 from the bright stars in Cassiopeia and the constellation of Andromeda. Learn the chain of stars that extends from Andromeda's central star perpendicular to her body.

### 21.1.2 For Real

This part is not going to be possible for many people. First, you need a good night and a dark sky. In urban areas with a lot of light pollution it's going to be very hard to see Andromeda.

## 21.2 Handy Angles

As described in section 18.5.2, your hand at arm's length provides a few useful estimates for angular size. It's useful to know whether your handy angles are typical, and if not, what they are. The method here below is just one way to do it – feel free to use another method of your own construction!

Hold your hand at arm's length with your hand open – the tips of your thumb and little finger as far apart as you can comfortably hold them. Get a friend to measure the distance between your thumb and your eye, we'll call this $D$. There is a tendency to over-stretch the arm when someone is measuring it – try to keep the thumb-eye distance as it would be if you were looking at some distant object.

Without changing the shape of your hand, measure the distance between the tips of your thumb and little finger. It's probably easiest to mark their positions on a piece of paper and measure the distance between the marks, we'll call this $d$. Using some simple trigonometry, we can estimate the angular distance $\theta$ using equation (18.5).

Repeat the process for the distance across a closed fist, three fingers and the tip of the little finger.

For example, for one author $D = 72$ cm, $d = 21$ cm, so:

$$\theta = 2 \cdot \arctan\left(\frac{21}{144}\right) \approx 16\frac{1}{2}°$$

(21.1)

Remember that handy angles are not very precise – depending on your posture at a given time the values may vary by a fair bit.

## 21.3    Find a Lunar Eclipse

Stellarium comes with two scripts for finding lunar eclipses, but can you find one on a different date?

## 21.4    Find a Solar Eclipse

Find a Solar Eclipse using Stellarium and take a screenshot of it. Use the location panel and see how the eclipse look on different locations at the same time. Don't forget to have "Topocentric coordinates" enabled in the settings (see section 18.9.1).

## 21.5    Find a retrograde motion of Mars

Find Mars using Stellarium and take a series of screenshots of its position at different times. Use the date and time panel and see how the motion of Mars changes over the time. Find periods of direct and retrograde motion of Mars (see also section 17.6).

## 21.6    Analemma

Set a time around noon and set time rate to pause, turn on the azimuthal grid. Find the Sun and check its horizontal coordinates. Use the date and time panel and see how the horizontal coordinates of the Sun change over time (please use one time step for simulation — look at the position of the Sun every 7 days for example). Use the location panel and see how the positions of the Sun look from different location at the same times. Check the change of positions of the Sun on Mars at the same times.

## 21.7    Transit of Venus

Set date to 6$^{th}$ of June, 2012, find Venus near the Sun and change scale of the view (zoom in). Find time of all four contacts and maximum of transit for your location. Because the Sun appears to rotate as it crosses the sky, Venus will appear to move on some curve — for example it will be an inverted "U" shape for eastern states of Australia. Check difference of path shape of Venus for equatorial and azimuthal mounts. Find a few dates and times for transit of Venus in past and in future. Notice how they usually come in pairs 8 years apart, with gaps of over 100 years between pairs.

## 21.8    Transit of Mercury

Set date to 9$^{th}$ of May, 2016, find Mercury near the Sun and change scale of the view (zoom in). Find time of all four contacts and maximum of transit for your location. Because the Sun appears to rotate as it crosses the sky, Mercury will appear to move on some curve — for example it will be an inverted "U" shape for observers from Europe. Check difference of path shape of Mercury for equatorial and azimuthal mounts. Find few dates and times for transit of Mercury in past and in future.

## 21.9    Triple shadows on Jupiter

Set date to 24$^{th}$ of January, 2015, find Jupiter and change scale of the view (zoom in). Find the time when three shadows will be visible on the disk of Jupiter. Which moons cast those shadows? Check which moons cause triple shadows on Jupiter at 3 June 2014. Details for this phenomenon you can find in the book *Mathematical Astronomy Morsels* (Meeus, 1997).

## 21.10    Jupiter without satellites

Set date to $9^{th}$ November, 2019, find Jupiter and change scale of the view (zoom in). Find time limits for the disappearance of the moons. Which moons are on the back of the planet, and which — in front of it? Please give answer on the same questions for 3 September 2009. Details for this phenomenon you can find in the book *Mathematical Astronomy Morsels* (Meeus, 1997)

## 21.11    Mutual occultations of planets

Set date to $13^{th}$ October, 1590, find Venus and change scale of the view (zoom in). Find time of minimal separation of Venus and Mars on this date. Set typical scale of view for visual observation and check Venus and Mars again. What would the typical observer of that time had said? Find the minimal separation between Venus and Saturn near end of August 1771. What would the typical observer on Earth had said? Find the minimal separation between Mars and Mercury in first half of August 2079.

Find mutual occultation of Earth and Mercury as seen from Mars near the end of November 2022. Find mutual occultation of Saturn and Mercury as seen from Venus near the middle of May 1967.

Details for this phenomenon you can find in the books *More Mathematical Astronomy Morsels* (Meeus, 2002) and *Mathematical Astronomy Morsels III* (Meeus, 2004).

## 21.12    The proper motion of stars

Turn off ground and atmosphere, set time rate on pause, find the star HIP 87937 and change the scale of the view to better see *Barnard's Star*. Use the date and time panel and see how the location of the star is changing in time (please try use one time step for simulation — look at the position of the star every year for example). When will Barnard's star cross the border of constellation? When has Barnard's star crossed the border of constellation in the past?

Please check the proper motions of Sirius (HIP 32349), Procyon (HIP 37279), 61 Cyg (HIP 104214) and $\tau$ Cet (HIP 8102). Which star has the fastest proper motion? Which star has the slowest rate of proper motion?

When will observers see Arcturus and HIP 68706 as close optical binary? Find the minimal angular separation between $\theta$ and $\varepsilon$ Ind in the past.

How will the appearance of following constellations change over a wide range of time ($-100000..100000$ years for example): Ursa Major, Orion, Bootes?

# V

# Appendices

# A. Default Hotkeys

The currently configured hotkeys are visible in the Help dialog (`F1`). Here is the default list for reference.

*WARNING: The list of hotkeys in this Guide uses notation for standard PC-compatible keyboards. Not all keyboards are PC-compatible – for example Apple's computers use keyboards with their own specific keys – `Option` and `Command`. The `Option` key is equivalent to the `Alt` key on the PC-compatible keyboards. The Haiku operating system is the successor of BeOS, and it swaps behaviour for `Ctrl` and `Alt` keys – e.g. PC's `Ctrl` + `A` will be `Alt` + `A` in Haiku.*

## A.1  Mouse actions with combination of the keyboard keys

| Actions | Description |
|---:|:---|
| Arrow keys & left mouse drag | Pan view around the sky |
| `Page Up/Down` & `Ctrl` + `Page Up/Down` | Zoom in/out |
| `Ctrl` & left mouse drag | Time dragging |
| `Ctrl` & mouse wheel | Time scrolling: minutes |
| `Ctrl` + `⇧` & mouse wheel | Time scrolling: hours |
| `Ctrl` + `Alt` & mouse wheel | Time scrolling: days |
| `Ctrl` + `Alt` + `⇧` & mouse wheel | Time scrolling: years |
| Left click | Select object |
| Right click | Clear selection |
| `⇧` & left click | Add custom marker |
| `⇧` & right click | Delete the one closest marker to mouse cursor |
| `Alt` + `⇧` & right click | Delete all custom markers |

## A.2 Display Options

| Shortcut key | Description |
|---:|:---|
| P | Planets |
| Alt + P | Planet labels |
| Ctrl + P | Planet markers |
| O | Planet orbits |
| ⇧ + T | Planet trails |
| Ctrl + ⇧ + P | Planet selection marker |
| Alt + N | Nomenclature labels |
| S | Stars |
| Alt + S | Star labels |
| D | Deep-sky objects (symbols) |
| I | Deep-sky objects background images |
| Ctrl + I | Reload the deep-sky objects background images |
| Ctrl + Alt + D | Toggle Hierarchical Progressive Surveys (experimental) |
| M | Milky Way |
| Ctrl + ⇧ + Z | Zodiacal Light |
| G | Ground |
| F | Fog |
| ⇧ + G | Landscape Illumination |
| Ctrl + ⇧ + G | Landscape Labels |
| A | Atmosphere |
| Q | Cardinal points |
| , | Ecliptic line |
| . | Equator line |
| E | Equatorial grid |
| Z | Azimuthal grid |
| H | Horizon line |
| ; | Meridian line |
| C | Constellation lines |
| V | Constellation labels |
| R | Constellation art |
| B | Constellation boundaries |
| Ctrl + Alt + ⇧ + V | Select single constellation |
| Tab | Remove selection of constellations |
| Ctrl + ⇧ + N | Native planet names (from sky culture) |
| Alt + V | Asterism labels |
| Alt + A | Asterism lines |
| Alt + R | Ray helpers |
| Ctrl + Alt + I | Reload the sky culture |
| W | Remove selection of constellations |
| Alt + W | Select all constellations |
| F11 | Full-screen mode |
| Ctrl + N | Night mode |
| Ctrl + ⇧ + H | Flip scene horizontally |
| Ctrl + ⇧ + V | Flip scene vertically |

## A.3 Miscellaneous

| Shortcut key | Description |
|---|---|
| Ctrl + ⇧ + C | Copy selected object information to clipboard |
| Ctrl + Q | Quit |
| Ctrl + S | Save screenshot |
| Ctrl + M | Switch between equatorial and azimuthal mount |
| Ctrl + T | Toggle visibility of GUI |
| Ctrl + R , P | Reload shaders (for development) |

## A.4 Movement and Selection

| Shortcut key | Description |
|---|---|
| | Center on selected object |
| Ctrl + H | Go to home |
| Ctrl + G | Set home planet to selected planet ("go there") |
| ⇧ + E | Look towards East |
| ⇧ + N | Look towards North |
| ⇧ + S | Look towards South |
| ⇧ + W | Look towards West |
| ⇧ + Z | Look towards Zenith |
| Alt + ⇧ + N | Look towards North Celestial pole |
| Alt + ⇧ + S | Look towards South Celestial pole |
| T | Track object |
| / | Zoom in on selected object |
| \ | Zoom out |
| Ctrl + Alt + 1 | Set FOV to 180° |
| Ctrl + Alt + 2 | Set FOV to 90° |
| Ctrl + Alt + 3 | Set FOV to 60° |
| Ctrl + Alt + 4 | Set FOV to 45° |
| Ctrl + Alt + 5 | Set FOV to 20° |
| Ctrl + Alt + 6 | Set FOV to 10° |
| Ctrl + Alt + 7 | Set FOV to 5° |
| Ctrl + Alt + 8 | Set FOV to 2° |
| Ctrl + Alt + 9 | Set FOV to 1° |
| Ctrl + Alt + 0 | Set FOV to 0.5° |

## A.5 Date and Time

| Shortcut key | Description |
|---|---|
| = | Add 1 solar day |
| - | Subtract 1 solar day |
| Ctrl + = | Add 1 solar hour |
| Ctrl + - | Subtract 1 solar hour |
| Alt + = | Add 1 sidereal day |
| Alt + - | Subtract 1 sidereal day |
| ) | Add 7 solar days |
| ( | Subtract 7 solar days |
| Ctrl + Alt + ⇧ + ) | Add 1 sidereal year |
| Ctrl + Alt + ⇧ + ( | Subtract 1 sidereal year |
| J | Decrease time speed |
| ⇧ + J | Decrease time speed (a little) |
| K | Set normal time rate |
| L | Increase time speed |
| ⇧ + L | Increase time speed (a little) |
| 7 | Set time rate to zero |
| 8 | Set time to now |
| 0 | Set reverse time direction |
| Ctrl + D , P | Pause script execution |
| Ctrl + D , R | Resume script execution |
| Ctrl + D , S | Stop script execution |

## A.6 Scripts

| Shortcut key | Description |
|---|---|
| Ctrl + D , 0 | Run script "Solar System Screensaver" |
| Ctrl + D , 1 | Run script "Western Constellations Tour" |
| Ctrl + D , 2 | Run script "Sky Culture Tour" |
| Ctrl + D , 3 | Run script "Screensaver" |
| Ctrl + D , B | Run script "Skybox Tiles" |
| Ctrl + D , M , 1 | Run script "Jupiter and triple shadow phenomena" |
| Ctrl + D , M , 2 | Run script "Jupiter without Galilean satellites" |
| Ctrl + D , M , 3 | Run script "Occultations of bright stars by planets" |
| Ctrl + D , M , 4 | Run script "Mutual occultations of planets" |

## A.7 Windows

| Shortcut key | Description |
|---|---|
| F1 | Toggle Help window |
| F2 | Toggle Configuration window |
| F3 | Toggle Search window |
| F4 | Toggle Sky and viewing options window |
| F5 | Toggle Date/time window |
| F6 | Toggle Location window |
| F7 | Toggle Shortcuts window |
| F10 | Toggle Astronomical calculations window |
| F12 | Toggle Script Console window |
| Alt + B | Toggle Bookmarks window |

## A.8 Plugins

### A.8.1 Angle Measure

| Shortcut key | Description |
| --- | --- |
| Ctrl + A | Toggle angle measurement |

### A.8.2 ArchaeoLines

| Shortcut key | Description |
| --- | --- |
| Ctrl + U | Toggle archaeolines |
| Ctrl + ⇧ + U | Toggle archaeolines dialog |

### A.8.3 Calendars

| Shortcut key | Description |
| --- | --- |
| Alt + K | Toggle Calendars display |
| Alt + ⇧ + K | Toggle Calendars dialog |

### A.8.4 Equation of Time

| Shortcut key | Description |
| --- | --- |
| Ctrl + Alt + T | Show solution for Equation of Time |

### A.8.5 Exoplanets

| Shortcut key | Description |
| --- | --- |
| Ctrl + Alt + E | Show exoplanets |
| Alt + E | Toggle Exoplanets configuration window |

### A.8.6 Meteor Showers

| Shortcut key | Description |
| --- | --- |
| Ctrl + ⇧ + M | Toggle meteor showers |
| ⇧ + M | Toggle radiant labels |
| Ctrl + Alt + M | Show search dialog |
| Ctrl + Alt + ⇧ + M | Show settings dialog |

### A.8.7 Oculars

| Shortcut key | Description |
| --- | --- |
| Ctrl + O | Ocular view |
| Alt + O | Oculars popup menu |
| Alt + C | Show crosshairs |
| Ctrl + B | Telrad sight |

### A.8.8 Pulsars

| Shortcut key | Description |
| --- | --- |
| Ctrl + Alt + P | Show pulsars |

### A.8.9 Quasars

| Shortcut key | Description |
|---|---|
| Ctrl + Alt + Q | Show quasars |

### A.8.10 Satellites

| Shortcut key | Description |
|---|---|
| Ctrl + Z | Toggle satellite hints |
| Alt + ⇧ + Z | Toggle satellite labels |
| Alt + Z | Toggle Satellites configuration window |

### A.8.11 Scenery3d: 3D landscapes

| Shortcut key | Description |
|---|---|
| Ctrl + W | Toggle 3D landscape |
| Ctrl + ⇧ + W | Show settings dialog |
| Ctrl + Alt + W | Show viewpoint dialog |
| Ctrl + R , T | Toggle location text |
| Ctrl + R , S | Toggle shadows |
| Ctrl + R , L | Toggle torchlight |
| Ctrl + R , D | Toggle debug information |
| Ctrl + R , P | Reload shaders |

### A.8.12 Solar System Editor

| Shortcut key | Description |
|---|---|
| Ctrl + Alt + S | Import orbital elements in MPC format... |

### A.8.13 Telescope Control

| Shortcut key | Description |
|---|---|
| Ctrl + 0 | Move a telescope to a given set of coordinates (shows dialog) |
| Ctrl + 1 | Move telescope #1 to selected object |
| Ctrl + 2 | Move telescope #2 to selected object |
| Ctrl + 3 | Move telescope #3 to selected object |
| Ctrl + 4 | Move telescope #4 to selected object |
| Ctrl + 5 | Move telescope #5 to selected object |
| Ctrl + 6 | Move telescope #6 to selected object |
| Ctrl + 7 | Move telescope #7 to selected object |
| Ctrl + 8 | Move telescope #8 to selected object |
| Ctrl + 9 | Move telescope #9 to selected object |
| Alt + 1 | Move telescope #1 to the point currently in the center of the screen |
| Alt + 2 | Move telescope #2 to the point currently in the center of the screen |
| Alt + 3 | Move telescope #3 to the point currently in the center of the screen |
| Alt + 4 | Move telescope #4 to the point currently in the center of the screen |
| Alt + 5 | Move telescope #5 to the point currently in the center of the screen |
| Alt + 6 | Move telescope #6 to the point currently in the center of the screen |
| Alt + 7 | Move telescope #7 to the point currently in the center of the screen |
| Alt + 8 | Move telescope #8 to the point currently in the center of the screen |
| Alt + 9 | Move telescope #9 to the point currently in the center of the screen |

| | |
|---|---|
| `Ctrl`+`⇧`+`0` | Move a telescope to a given set of coordinates (shows dialog) |
| `Ctrl`+`⇧`+`1` | Sync telescope #1 to selected object |
| `Ctrl`+`⇧`+`2` | Sync telescope #2 to selected object |
| `Ctrl`+`⇧`+`3` | Sync telescope #3 to selected object |
| `Ctrl`+`⇧`+`4` | Sync telescope #4 to selected object |
| `Ctrl`+`⇧`+`5` | Sync telescope #5 to selected object |
| `Ctrl`+`⇧`+`6` | Sync telescope #6 to selected object |
| `Ctrl`+`⇧`+`7` | Sync telescope #7 to selected object |
| `Ctrl`+`⇧`+`8` | Sync telescope #8 to selected object |
| `Ctrl`+`⇧`+`9` | Sync telescope #9 to selected object |
| `Ctrl`+`⇧`+`Alt`+`1` | Abort last slew command of telescope #1 |
| `Ctrl`+`⇧`+`Alt`+`2` | Abort last slew command of telescope #2 |
| `Ctrl`+`⇧`+`Alt`+`3` | Abort last slew command of telescope #3 |
| `Ctrl`+`⇧`+`Alt`+`4` | Abort last slew command of telescope #4 |
| `Ctrl`+`⇧`+`Alt`+`5` | Abort last slew command of telescope #5 |
| `Ctrl`+`⇧`+`Alt`+`6` | Abort last slew command of telescope #6 |
| `Ctrl`+`⇧`+`Alt`+`7` | Abort last slew command of telescope #7 |
| `Ctrl`+`⇧`+`Alt`+`8` | Abort last slew command of telescope #8 |
| `Ctrl`+`⇧`+`Alt`+`9` | Abort last slew command of telescope #9 |

### A.8.14 Text User Interface (TUI)

| Shortcut key | Description |
|---|---|
| `Alt`+`T` | Activate TUI |

## A.9 Special local keys

All these hotkeys are locally available to run when a specific window or tab is opened.

| Shortcut key | Description |
|---|---|
| | **Script console** |
| `Ctrl`+`⇧`+`O` | Load script from file |
| `Ctrl`+`⇧`+`S` | Save script to file |
| `Ctrl`+`Return` | Run script |
| | **Astronomical calculations** |
| `⇧`+`F10` | Update positions |
| `⇧`+`F10` | Calculate ephemeris |
| `⇧`+`F10` | Calculate transits |
| `⇧`+`F10` | Calculate phenomena |

# B. The Bortle Scale of Light Pollution

The Bortle scale is a nine-level numeric scale that measures the night sky's brightness of a particular location. It quantifies the astronomical observability of celestial objects and the interference caused by light pollution. JOHN E. BORTLE created the scale and published it in *Sky & Telescope* magazine (Bortle, 2001) to help amateur astronomers evaluate the darkness of an observing site, and secondarily, to compare the darkness of observing sites. The scale ranges from Class 1, the darkest skies available on Earth, through Class 9, inner-city skies. It gives several criteria for each level beyond *naked-eye limiting magnitude* (NELM). The accuracy and utility of the scale have been questioned in recent research (Crumey, 2014).
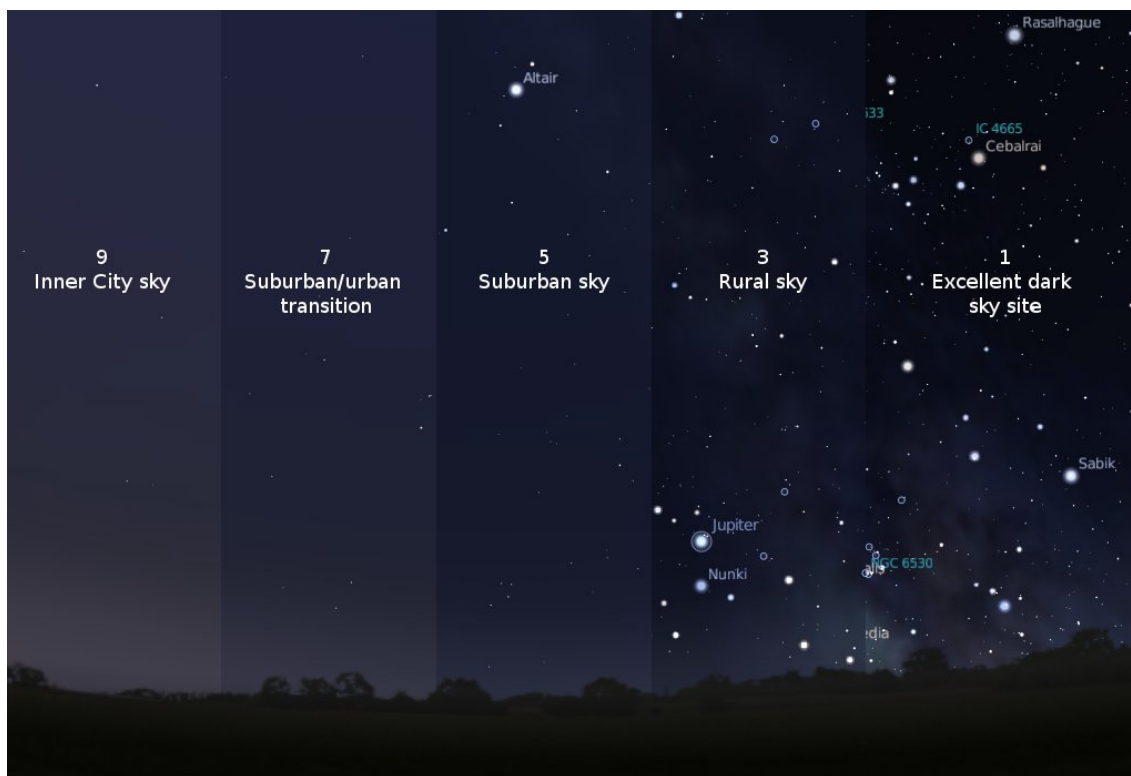


Figure B.1: Light Pollution Simulation / Bortle Scale

## B.1  Excellent dark sky site

**Level:** 1
**Naked-eye limiting magnitude:** 7.6 – 8.0
**Approx. SQM mag/arcsec$^2$:** 21.7 – 22.0[1]

Zodiacal light, gegenschein, zodiacal band visible; M33 direct vision naked-eye object; Scorpius and Sagittarius regions of the Milky Way cast obvious shadows on the ground; Airglow is readily visible; Jupiter and Venus affect dark adaptation; surroundings basically invisible.

## B.2  Typical truly dark site

**Level:** 2
**Naked-eye limiting magnitude:** 7.1 – 7.5
**Approx. SQM mag/arcsec$^2$:** 21.5 – 21.7

Airglow weakly visible near horizon; M33 easily seen with naked eye; highly structured Summer Milky Way; distinctly yellowish zodiacal light bright enough to cast shadows at dusk and dawn; clouds only visible as dark holes; surroundings still only barely visible silhouetted against the sky; many Messier globular clusters still distinct naked-eye objects.

## B.3  Rural sky

**Level:** 3
**Naked-eye limiting magnitude:** 6.6 – 7.0
**Approx. SQM mag/arcsec$^2$:** 21.3 – 21.5

Some light pollution evident at the horizon; clouds illuminated near horizon, dark overhead; Milky Way still appears complex; M15, M4, M5, M22 distinct naked-eye objects; M33 easily visible with averted vision; zodiacal light striking in spring and autumn, color still visible; nearer surroundings vaguely visible.

## B.4  Rural/suburban transition

**Level:** 4
**Naked-eye limiting magnitude:** 6.1 – 6.5
**Approx. SQM mag/arcsec$^2$:** 20.4 – 21.3

Light pollution domes visible in various directions over the horizon; zodiacal light is still visible, but not even halfway extending to the zenith at dusk or dawn; Milky Way above the horizon still impressive, but lacks most of the finer details; M33 a difficult averted vision object, only visible when higher than 55°; clouds illuminated in the directions of the light sources, but still dark overhead; surroundings clearly visible, even at a distance.

---

[1]Dark Skies Awareness – `http://www.darkskiesawareness.org/nomogram.php`

## B.5 Suburban sky

**Level:** 5
**Naked-eye limiting magnitude:** 5.6 – 6.0
**Approx. SQM mag/arcsec$^2$:** 19.1 – 20.4

Only hints of zodiacal light are seen on the best nights in autumn and spring; Milky Way is very weak or invisible near the horizon and looks washed out overhead; light sources visible in most, if not all, directions; clouds are noticeably brighter than the sky.

## B.6 Bright suburban sky

**Level:** 6
**Naked-eye limiting magnitude:** 5.1 – 5.5
**Approx. SQM mag/arcsec$^2$:** 18.0 – 19.1

Zodiacal light is invisible; Milky Way only visible near the zenith; sky within 35° from the horizon glows grayish white; clouds anywhere in the sky appear fairly bright; surroundings easily visible; M33 is impossible to see without at least binoculars, M31 is modestly apparent to the unaided eye.

## B.7 Suburban/urban transition

**Level:** 7
**Naked-eye limiting magnitude:** 4.6 – 5.0
**Approx. SQM mag/arcsec$^2$:** 18.0 – 19.1

Entire sky has a grayish-white hue; strong light sources evident in all directions; Milky Way invisible; M31 and M44 may be glimpsed with the naked eye, but are very indistinct; clouds are brightly lit; even in moderate-sized telescopes the brightest Messier objects are only ghosts of their true selves.

## B.8 City sky

**Level:** 8
**Naked-eye limiting magnitude:** 4.1 – 4.5
**Approx. SQM mag/arcsec$^2$:** <18.0

Sky glows white or orange — you can easily read; M31 and M44 are barely glimpsed by an experienced observer on good nights; even with telescope, only bright Messier objects can be detected; stars forming familiar constellation patterns may be weak or completely invisible.

## B.9 Inner-city sky

**Level:** 9
**Naked-eye limiting magnitude:** 4.0 at best
**Approx. SQM mag/arcsec$^2$:** <18.0

Sky is brilliantly lit with many stars forming constellations invisible and many weaker constellations invisible; aside from Pleiades, no Messier object is visible to the naked eye; only objects to provide fairly pleasant views are the Moon, the Planets and a few of the brightest star clusters.

# C. Star Catalogues

This chapter provides technical descriptions on how Stellarium records its star catalogues, and the related file formats.

## C.1 Stellarium's Sky Model

### C.1.1 Zones

The celestial sphere is split into zones, which correspond to the triangular faces of a geodesic sphere. The number of zones (faces) depends on the level of sub-division of this sphere plus one global zone for high proper motion stars that can cross zones in the past/future or stars. The lowest level, 0, is an icosahedron (20 faces + 1 global zone), subsequent levels $L$ of sub-division give the number of zones $n$ as:

$$n = 20 \cdot 4^L + 1 \tag{C.1}$$

Stellarium uses levels 0 to 8 in the existing star catalogues. So the number of zones are 21 for level 0 to 1,310,721 for level 8. Stars within the global zone are always checked if they are visible or not without any zone restriction, since stars can move out of their original zones due to proper motion and not drawn in the sky. Only level 0 to level 2 star catalogs have their global zone populated (i.e. level 3-8 global zones are empty).

For level 0, any stars who will move out of their original zones in $\pm 200,000$ years are moved to the global zone. For level 1 and 2, stars are moved to the global zone only if they move out of their original zones and the bordering zones **or** brighter than 0.3 mag from their present apparent magnitude in $\pm 200,000$ years.

## C.2 Star Catalogue File Format

With version 25.1, Stellarium is adopting the currently most modern class of astrometrical data: Gaia DR3. This astrometry satellite, operated by ESA, delivers unprecedented accuracy for millions of stars. However, just those stars most important to human casual observers, naked-eye stars, are too bright for the sensitive instruments. Therefore, for the brightest stars, data from the preceding Hipparcos mission are still used. Most indexing is still based on Hipparcos numbers. In previous versions, dimmer stars were stored without number. Now, you can use the long index from Gaia DR3 in descriptions of constellations, or search for the number directly.    v 25.1

Information about the previous format is easiest found in the v24.4 User Guide.

### C.2.1 General Description

Stellarium's star catalogue data is kept in the `stars/hip_gaia3` sub-directory of the Installation Directory    v 25.1

and/or User Directory (see section 5.1).[1]

The main catalogue data is split into several files:

```
stars_0_0v0_18.cat
stars_1_0v0_15.cat
stars_2_0v0_16.cat
stars_3_0v0_10.cat
stars_4_1v0_6.cat
stars_5_1v0_6.cat
stars_6_1v0_4.cat
stars_7_1v0_4.cat
stars_8_2v0_3.cat
```

There also exist some control and reference files:

```
object_types_v0_1.cat
stars_hip_sp_0v0_6.cat
gcvs.cat
wds_hip_part.dat
cross-id.cat
starsConfig.json
name.fab
binary_orbitparam.dat
```

When Stellarium starts, it reads the file `stars/hip_gaia3/starsConfig.json`[2], from which it de-termines the names of the other files which it then loads. The file `stars_hip_sp_0v0_6.cat` contain spectral type of HIP stars. The file `object_types_v0_1.cat` contain object type classification name for the main star catalogs. The file `gcvs.cat` contains data about variables stars (see section C.3) and file `wds_hip_part.dat` contains data about double stars (see section C.4) which again contains references into the main catalogue files. The file `cross-id.cat` (see section C.5) contains cross-identification data between HIP, Gaia DR3, SAO, HD and HR designations. The file `binary_orbitparam.cat` (see section C.6) contains binary star system orbital parameters.

A given catalogue file models stars for one and only one level (i.e. for a fixed number of zones), which is recorded in the header of the file. Individual star records do not contain full positional coordinates, instead they contain coordinates relative to the central position of the zone they occupy. Thus, when parsing star catalogues, it is necessary to know about the zone model to be able to extract positional data.

| File | Data Type | Data Record Size | Geodesic Level | #Records | Notes |
|------|-----------|------------------|----------------|----------|-------|
| `stars_0_0v0_18.cat` | 0 | 48 bytes | 0 | 5,045 | Hipparcos + Gaia |
| `stars_1_0v0_15.cat` | 0 | 48 bytes | 1 | 21,611 | Hipparcos + Gaia |
| `stars_2_0v0_16.cat` | 0 | 48 bytes | 2 | 141,761 | Hipparcos + Gaia |
| `stars_3_0v0_10.cat` | 0 | 48 bytes | 3 | 418,129 | Gaia |
| `stars_4_1v0_6.cat` | 1 | 32 bytes | 4 | 1,741,849 | Gaia |
| `stars_5_1v0_6.cat` | 1 | 32 bytes | 5 | 8,051,933 | Gaia |
| `stars_6_1v0_4.cat` | 1 | 32 bytes | 6 | 29,879,734 | Gaia |
| `stars_7_1v0_4.cat` | 1 | 32 bytes | 7 | 57,534,724 | Gaia |
| `stars_8_2v0_3.cat` | 2 | 16 bytes | 8 | 122,908,184 | Gaia |

For a given catalogue file, there may be one of three formats for the actual star data. The variation comes from the source of the data – the larger catalogues of fainter stars providing less data per star than the brighter star catalogues. See tables *Stellarium's star catalogue* and for details.

Stellarium's star catalogues are based on Hipparcos (Anderson and Francis, 2012; ESA, 1997) and Gaia (Gaia Collaboration and al., 2016) catalogues.

## C.2.2 File Sections

The catalogue files are split into three main sections as described in table C.1.

---

[1]The data has significantly changed in version 25.1. The previous structure can be found in older guides.

[2]Or `stars/hip_gaia3/defaultStarsConfig.json` file in Installation Directory

| Section | Offset | Description |
|---------|--------|-------------|
| File Header Record | 0 | Contains magic number, geodesic subdivision level, magnitude and epoch information |
| Zone Records | 28 | A list of how many records there are for each zone. The length of the zones section depends on the level value from the header |
| Star Data Records | $28 + 4n$ | This section of the file contains fixed-size star records, as described below. Records do not contain zone information, which must be inferred by counting how many records have been read so far and switching zones when enough have been read to fill the number of stars for the zone, as specified in the zones section above. The value of $n$ used in the offset description is the number of zones, as described above. |

Table C.1: File sections

## C.2.3 Record Types

### C.2.3.1 File Header Record

The File Header Record describes file-wide settings. It also contains a magic number which servers as a file type identifier. See table C.2.

| Name | Offset | Type | Size | Description |
|------|--------|------|------|-------------|
| Magic | 0 | int | 4 | magic number which identifies the file as a star catalogue. `0x835f040a` |
| Data Type | 4 | int | 4 | type of the file, which defines the size and structure of the Star Data record for the file. |
| Major Version | 8 | int | 4 | file format major version number |
| Minor Version | 12 | int | 4 | file format minor version number |
| Level | 16 | int | 4 | sets the level of sub-division of the geodesic sphere used to create the zones. 0 means an icosahedron (20 triangular faces + 1 global zone), subsequent levels of sub-division lead to numbers of zones as described in section C.2.3.2 |
| Magnitude Minimum | 20 | int | 4 | low bound of the magnitude of the catalog in milli-mag unit. |
| Catalog Epoch | 24 | float | 4 | Epoch of the catalog in Julian days. |

Table C.2: Header Record

### C.2.3.2 Zone Records

The *Zone Records* section of the file lists the number of star records there are per zone. The number of zones is determined from the level value in the File Header Record, as described in section C.1.1. The Zones section is simply a list of integer values which describe the number of stars for each zone. The total length of the Zones section depends on the number of zones. See table C.3.

### C.2.3.3 Star Data Records

After the Zones section, the actual star data starts. The star data records themselves do not contain the zone in which the star belongs. Instead, the zone is inferred from the position of the record in the file. For example, if the Zone Records section of the file says that the first 100 records are for zone 0, the next 80 for zone 1 and so on, it is possible to infer the zone for a given record by counting how many records have been read so far.

The actual record structure depends on the value of the Data Type, as found in the File Header Record. See tables C.4, C.5 and C.6 for record structure details.

Details about vector algebra related to astrometric calculations can be found in (van Altena, 2013).

| Name | Offset | Type | Size | Description |
|---|---|---|---|---|
| num stars in zone 0 | 0 | int | 4 | number of records in this file which are in zone 0 |
| num stars in zone 1 | 4 | int | 4 | number of records is this file which are in zone 1 |
| ... | | | | |
| num stars in zone $n-1$ | $4n-4$ | int | 4 | number of records is this file which are in zone $n$ |
| num stars in zone $n$ | $4n$ | int | 4 | number of records is this file which are in the global zone |

Table C.3: Zones section

| Name | Offset | Type | Size | Description |
|---|---|---|---|---|
| gaia_id | 0 | int64_t | 8 | Gaia source id |
| x0 | 8 | int | 4 | Cartesian x position of the star on an unit sphere at the catalog epoch scaled by $2 \times 10^9$ |
| x1 | 12 | int | 4 | Cartesian y position of the star on an unit sphere at the catalog epoch scaled by $2 \times 10^9$ |
| x2 | 16 | int | 4 | Cartesian z position of the star on an unit sphere at the catalog epoch scaled by $2 \times 10^9$ |
| dx0 | 20 | int | 4 | First component of the star's proper motion vector at the catalog epoch scaled by $1 \times 10^3$ |
| dx1 | 24 | int | 4 | Second component of the star's proper motion vector at the catalog epoch scaled by $1 \times 10^3$ |
| dx2 | 28 | int | 4 | Third component of the star's proper motion vector at the catalog epoch scaled by $1 \times 10^3$ |
| b_v | 32 | short | 2 | $B-V$ colour in milli-mag unit. |
| mag | 34 | short | 2 | $V$-band magnitude in milli-mag unit. |
| plx | 36 | unsigned short | 2 | parallax of the star in 0.02 mas unit. |
| plx_err | 38 | unsigned short | 2 | parallax error of the star in 0.01 mas unit. |
| rv | 40 | short | 2 | radial velocity of the star in 0.1 km/s unit. |
| sp_int | 42 | unsigned short | 2 | index into an array of spectral type descriptions which is taken from the file `stars_hip_sp.cat`, the index corresponds to the line number in the file - 1 |
| obtype | 44 | unsigned char | 1 | object type classification index. The index corresponds to the line number in the file `object_types_v*.cat` - 1. |
| hip | 45 | int | 3 | Hipparcos catalogue number with component ID (e.g. A, B, C...) |

Table C.4: Star Data Record Type 0

For the catalog with Star Data Record Type 0, in practice to convert $\texttt{x0},\texttt{x1},\texttt{x2}$ to right ascension $\alpha$ and declination $\delta$, one can use the following formulas:

$$\alpha = \arctan 2(\texttt{x1},\texttt{x0})$$
$$\delta = \arcsin(\texttt{x2}) \tag{C.2}$$

and to convert proper motion vector $(\texttt{dx0},\texttt{dx1},\texttt{dx2})$ to proper motion in right ascension $\mu_{\alpha*}$ and declination $\mu_\delta$, one can use the following formulas:

$$xy = \sqrt{\texttt{x0}^2 + \texttt{x1}^2};$$
$$\vec{p} = \left(-\frac{\texttt{x1}}{xy}, \frac{\texttt{x0}}{xy}, 0.\right);$$
$$\vec{q} = \left(-\frac{\texttt{x0}\cdot\texttt{x2}}{xy}, -\frac{\texttt{x1}\cdot\texttt{x2}}{xy}, xy\right); \tag{C.3}$$
$$\mu_{\alpha*} = \vec{p}\cdot(\texttt{dx0},\texttt{dx1},\texttt{dx2});$$
$$\mu_\delta = \vec{q}\cdot(\texttt{dx0},\texttt{dx1},\texttt{dx2});$$

where $\mu_{\alpha*} \equiv \mu_\alpha \cos(\delta)$.

| Name | Offset | Type | Size | Description |
| --- | --- | --- | --- | --- |
| gaia_id | 0 | int64_t | 8 | Gaia source id |
| x0 | 8 | int | 4 | Right ascension $\alpha$ of the star in mas unit. |
| x1 | 12 | int | 4 | Declination $\delta$ of the star in mas unit. |
| dx0 | 16 | int | 4 | Proper motion $\mu_\alpha$ of the star in $\mu$as/year |
| dx1 | 20 | int | 4 | Proper motion $\mu_\delta$ of the star in $\mu$as/year |
| b_v | 24 | short | 2 | $B-V$ colour in milli-mag unit. |
| mag | 26 | short | 2 | $V$-band magnitude in milli-mag unit. |
| plx | 28 | unsigned short | 2 | parallax of the star in 0.01 mas unit. |
| plx_err | 30 | unsigned short | 2 | parallax error of the star in 0.01 mas unit. |

Table C.5: Star Data Record Type 1

| Name | Offset | Type | Size | Description |
| --- | --- | --- | --- | --- |
| gaia_id | 0 | int64_t | 8 | Gaia source id |
| x0 | 8 | int | 3 | Right ascension $\alpha$ of the star in 0.1 arcsecond unit. |
| x1 | 11 | int | 3 | Declination $\delta$ of the star in 0.1 arcsecond unit. |
| b_v | 14 | unsigned short | 1 | $B-V$ colour in 25 milli-mag unit offset by +1 mag. |
| mag | 15 | unsigned short | 1 | $V$-band magnitude in 20 milli-mag unit offset by $-16$ mag. |

Table C.6: Star Data Record Type 2

| Name | Type | Description |
|------|------|-------------|
| HIP/Gaia | int | This is the HIP or Gaia DR3 identifier for the star. Used for reference to the main star catalogue. |
| GCVS | string | This is the GCVS designation for the variable star. |
| Type | string | Type of variability. |
| Max | float | Magnitude at maximum brightness. |
| MFlag | int | Magnitude flag code (0=No flag; 1="(" if max. magnitude is an amplitude; 2="<" if max. magnitude is a bright limit; 3=">" is max. magnitude is a faint limit). |
| Min I | float | First minimum magnitude or amplitude. |
| Min II | float | Second minimum magnitude. |
| V | char | The photometric system for magnitudes. |
| Epoch | float | Epoch for maximum or minimum light (in Julian days). |
| Period | float | Period for the variable star (in days). |
| M-m | float | Rising time or duration of the eclipse (in percent). |
| Spectrum | string | Spectral class of the variable star. |

Table C.7: Variable Star Catalog File Format

## C.3 Variable Stars

Since version 0.12.2 Stellarium supports the subset of variable stars from GCVS[3] which have HIP identifiers (i.e., stars from the Hipparcos catalog). Stellarium's Catalog of Variable Stars is based on the "General catalogue of variable stars: Version GCVS 5.1" (Samus' et al., 2017).

### C.3.1 Variable Star Catalog File Format

#### C.3.1.1 General Description
Stellarium's Variable Stars catalog data is kept in the `stars/hip_gaia3` sub-directory of the Installation Directory and/or User Directory (see section 5.1).

#### C.3.1.2 File Format
The `gcvs.cat` file contains data about 49800+ Variable Stars (see section 19.2.5) which have HIP or Gaia DR3 identifiers and are stored in a plain text format with tab delimiter (Table C.7).

### C.3.2 GCVS Variability Types

An improved system of variability classification is used in the fourth edition of the GCVS, based on recent developments in classification principles and taking into account the suggestions of a number of specialists. Variability types are grouped according to the major astrophysical reasons for variability.

All of these classes include objects of a dissimilar nature that belong to different types of light variability. On the other hand, an object may be variable because of almost all of the possible reasons or because of any combination of them. If a variable belongs to several types of variability, the types are joined in the data field by a "+" sign, e.g., E+UG, UV+BY.

Despite considerable success in understanding stellar variability processes, the classification adopted in the Catalogue is far from perfect. This is especially the case for explosive, symbiotic and novalike variables; X-ray sources; and peculiar objects.

The new variability types (ZZO, AM, R, BE, BLBOO, EP, SRS, LPB) have been added in the Name-Lists 67-77 and in the GCVS vol.V.

You can read about latest different types of variability at SAI GCVS page[4].

#### C.3.2.1 Eruptive Variable Stars
Eruptive variables are stars varying in brightness because of violent processes and flares occurring in their chromospheres and coronae. The light changes are usually accompanied by shell events or mass outflow in

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[3]`http://www.sai.msu.su/gcvs/gcvs/`
[4]`http://www.sai.msu.su/gcvs/gcvs/vartype.htm`

the form of stellar winds of variable intensity and/or by interaction with the surrounding interstellar medium. This class includes the following types:

**BE** It becomes more and more clear that, although the majority of Be stars are photometrically variable, not all of them could be properly called GCAS variables. Quite a number of them show small-scale variations not necessarily related to shell events; in some cases the variations are quasi-periodic. By now we are not able to present an elaborated system of classification for Be variables, but we adopt a decision that in the cases when a Be variable cannot be readily described as a GCAS star we give simply BE for the type of variability.

**FU** Orion variables of the FU Orionis type. Characterized by gradual increases in brightness by about 6 mag in several months, followed by either almost complete constancy at maximum that is sustained for long periods of time or slow decline by 1-2 mag. Spectral types at maximum are in the range Ae(alpha) - Gpe(alpha). After an outburst, a gradual development of an emission spectrum is observed and the spectral type becomes later. These variables probably mark one of the evolutionary stages of T Tauri-type Orion variables (INT), as evidenced by an outburst of one member, V1057 Cyg, but its decline (2.5 mag in 11 years) commenced immediately after maximum brightness was attained. All presently known FU Ori variables are coupled with reflecting cometary nebulae.

**GCAS** Eruptive irregular variables of the Gamma Cas type. These are rapidly rotating B III-IVe stars with mass outflow from their equatorial zones. The formation of equatorial rings or disks is often accompanied by temporary fading. Light amplitudes may reach 1.5 mag in V.

**I** Poorly studied irregular variables with unknown features of light variations and spectral types. This is a very inhomogeneous group of objects.

    **IA** Poorly studied irregular variables of early (O-A) spectral type.

    **IB** Poorly studied irregular variables of intermediate (F-G) to late (K-M) spectral type.

    **IN** Orion variables. Irregular, eruptive variables connected with bright or dark diffuse nebulae or observed in the regions of these nebulae. Some of them may show cyclic light variations caused by axial rotation. In the Spectrum-Luminosity diagram, they are found in the area of the main sequence and subgiants. They are probably young objects that, during the course of further evolution, will become light-constant stars on the zero-age main sequence (ZAMS). The range of brightness variations may reach several magnitudes. In the case of rapid light variations having been observed (up to 1 mag in 1-10 days), the letter "S" is added to the symbol for the type (INS). This type may be divided into the following subtypes:

        **INA** Orion variables of early spectral types (B-A or Ae). They are often characterized by occasional abrupt Algol-like fadings (T Ori);

        **INB** Orion variables of intermediate and late spectral types, F-M or Fe-Me (BH Cep, AH Ori). F-type stars may show Algol-like fadings similar to those of many INA stars; K-M stars may produce flares along with irregular light variations;

        **INT,IT** Orion variables of the T Tauri type. Stars are assigned to this type on the basis of the following (purely spectroscopic) criteria: spectral types are in the range Fe-Me. The spectra of most typical stars resemble the spectrum of the solar chromosphere. The feature specific to the type is the presence of the fluorescent emission lines Fe II 4046, 4132 A (anomalously intense in the spectra of these stars), emission lines [Si II] and [O I], as well as the absorption line Li I 6707 A. These variables are usually observed only in diffuse nebulae. If it is not apparent that the star is associated with a nebula, the letter "N" in the symbol for the type may be omitted, e.g., IT (RW AUR);

        **IN(YY)** Some Orion variables (YY Ori) show the presence of absorption components on the redward sides of emission lines, indicating the infall of matter toward the stars' surfaces. In such cases, the symbol for the type may be accompanied by the symbol "YY".

    **IS** Rapid irregular variables having no apparent connection with diffuse nebulae and showing light changes of about 0.5 - 1.0 mag within several hours or days. There is no strict boundary between rapid irregular and Orion variables. If a rapid irregular star is observed in the region of a diffuse nebula, it is considered an Orion variable and designated by the symbol INS. To attribute a variable to the IS type, it is necessary to take much care to be certain that its light changes are really not periodic. Quite a number of the stars assigned to this type in the third edition of the GCVS turned out to be eclipsing binary systems, RR Lyrae variables, and even extragalactic BL Lac objects.

        **ISA** Rapid irregular variables of the early spectral types, B-A or Ae;

        **ISB** Rapid irregular variables of the intermediate and late spectral types, F-M and Fe-Me.

**RCB**  Variables of the R Coronae Borealis type. These are hydrogen-poor, carbon- and helium-rich, high-luminosity stars belonging to the spectral types Bpe-R, which are simultaneously eruptive and pulsating variables. They show slow nonperiodic fadings by 1-9 mag in V lasting from a month or more to several hundred days. These changes are superposed on cyclic pulsations with amplitudes up to several tenths of a magnitude and periods in the range 30-100 days.

**RS**  Eruptive variables of the RS Canum Venaticorum type. This type is ascribed to close binary systems with spectra showing Ca II H and K in emission, their components having enhanced chromospheric activity that causes quasi-periodic light variability. The period of variation is close to the orbital one, and the variability amplitude is usually as great as 0.2 mag in V (UX Ari). They are X-ray sources and rotating variables. RS CVn itself is also an eclipsing system (see below).

**SDOR**  Variables of the S Doradus type. These are eruptive, high-luminosity Bpec-Fpec stars showing irregular (sometimes cyclic) light changes with amplitudes in the range 1-7 mag in V. They belong to the brightest blue stars of their parent galaxies. As a rule, these stars are connected with diffuse nebulae and surrounded by expanding envelopes (P Cyg, Eta Car).

**UV**  Eruptive variables of the UV Ceti type, these are K Ve-M Ve stars sometimes displaying flare activity with amplitudes from several tenths of a magnitude up to 6 mag in V. The amplitude is considerably greater in the ultraviolet spectral region. Maximum light is attained in several seconds or dozens of seconds after the beginning of a flare; the star returns to its normal brightness in several minutes or dozens of minutes.

**UVN**  Flaring Orion variables of spectral types Ke-Me. These are phenomenologically almost identical to UV Cet variables observed in the solar neighborhood. In addition to being related to nebulae, they are normally characterized by being of earlier spectral type and greater luminosity, with slower development of flares (V389 Ori). They are possibly a specific subgroup of INB variables with irregular variations superimposed by flares.

**WR**  Eruptive Wolf-Rayet variables. Stars with broad emission features of He I and He II as well as C II-C IV, O II-O IV, and N III-N V. They display irregular light changes with amplitudes up to 0.1 mag in V, which are probably caused by physical processes, in particular, by nonstable mass outflow from their atmospheres.

## C.3.2.2  Pulsating Variable Stars

Pulsating variables are stars showing periodic expansion and contraction of their surface layers. The pulsations may be radial or nonradial. A radially pulsating star remains spherical in shape, while in the case of nonradial pulsations the star's shape periodically deviates from a sphere, and even neighboring zones of its surface may have opposite pulsation phases.

Depending on the period value, on the mass and evolutionary status of the star, and on the scale of pulsational phenomena, the following types of pulsating variables may be distinguished:

**ACYG**  Variables of the Alpha Cygni type, which are nonradially pulsating supergiants of Bep-AepIa spectral types. The light changes with amplitudes of the order of 0.1 mag often seem irregular, being caused by the superposition of many oscillations with close periods. Cycles from several days to several weeks are observed.

**BCEP**  Variables of the Beta Cephei type (Beta Cep, Beta CMa), which are pulsating O8-B6 I-V stars with periods of light and radial-velocity variations in the range of 0.1 - 0.6 days and light amplitudes from 0.01 to 0.3 mag in V. The light curves are similar in shape to average radial-velocity curves but lag in phase by a quarter of the period, so that maximum brightness corresponds to maximum contraction, i.e., to minimum stellar radius. The majority of these stars probably show radial pulsations, but some (V469 Per) display nonradial pulsations; multiperiodicity is characteristic of many of these stars.

    **BCEPS**  A short-period group of Beta Cep variables. The spectral types are B2-B3 IV-V; periods and light amplitudes are in the ranges 0.02 - 0.04 days and 0.015 - 0.025 days, respectively, i.e., an order of magnitude smaller than the normally observed ones.

**BLBOO**  The so-called "anomalous Cepheids", i.e. stars with periods characteristic of comparatively long-period RRAB variables, but considerably brighter by luminosity (BL Boo = NGC 5466 V19).

**CEP**  Cepheids. Radially pulsating, high luminosity (classes Ib-II) variables with periods in the range of 1-135 days and amplitudes from several hundredths to 2 mag in V (in the B band, the amplitudes are greater). Spectral type at maximum light is F; at minimum, the types are G-K. The longer the period of light variation, the later is the spectral type. The maximum of the surface-layer expansion velocity almost coinciding with maximum light.

    **CEP(B)**  Cepheids (TU Cas, V 367 Sct) displaying the presence of two or more simultaneously operating pulsation modes (usually the fundamental tone with the period P0 and the first

overtone P1). The periods P0 are in the range from 2 to 7 days, with the ratio P1/P0 approx. 0.71.

**CW** Variables of the W Virginis type. These are pulsating variables of the galactic spherical component (old disk) population with periods of approximately 0.8 to 35 days and amplitudes from 0.3 to 1.2 mag in V. They obey a period-luminosity relation different from that for Delta Cep variables (see DCEP). For an equal period value, the W Vir variables are fainter than the Delta Cep stars by 0.7 - 2 mag. The light curves of W Vir variables for some period intervals differ from those of Delta Cep variables for corresponding periods either by amplitudes or by the presence of humps on their descending branches, sometimes turning into broad flat maxima. W Vir variables are present in globular clusters and at high galactic latitudes. They may be separated into the following subtypes:

    **CWA** W Vir variables with periods longer than 8 days (W Vir);

    **CWB** W Vir variables with periods shorter than 8 days (BL Her).

**DCEP** These are the classical cepheids, or Delta Cep-type variables. Comparatively young objects that have left the main sequence and evolved into the instability strip of the Hertzsprung-Russell (H-R) diagram, they obey the well-known Cepheid period-luminosity relation and belong to the young disk population. DCEP stars are present in open clusters. They display a certain relation between the shapes of their light curves and their periods.

    **DCEPS** These are Delta Cep variables having light amplitudes <0.5 mag in V (<0.7 mag in B) and almost symmetrical light curves (M-m approx. 0.4 - 0.5 periods); as a rule, their periods do not exceed 7 days. They are probably first-overtone pulsators and/or are in the first transition across the instability strip after leaving the main sequence (SU Cas).

    Traditionally, both Delta Cep and W Vir stars are quite often called Cepheids because it is often impossible to discriminate between them on the basis of the light curves for periods in the range 3 - 10 days. However, these are distinct groups of entirely different objects in different evolutionary stages. One of the significant spectral differences between W Vir stars and Cepheids is the presence, during a certain phase interval, of hydrogen-line emission in the former and of Ca II H and K emission in the latter.

**DSCT** Variables of the Delta Scuti type. These are pulsating variables of spectral types A0-F5 III-V displaying light amplitudes from 0.003 to 0.9 mag in V (usually several hundredths of a magnitude) and periods from 0.01 to 0.2 days. The shapes of the light curves, periods, and amplitudes usually vary greatly. Radial as well as nonradial pulsations are observed. The variability of some members of this type appears sporadically and sometimes completely ceases, this being a consequence of strong amplitude modulation with the lower value of the amplitude not exceeding 0.001 mag in some cases. The maximum of the surface layer expansion does not lag behind the maximum light for more than 0.1 periods. DSCT stars are representatives of the galactic disk (flat component) and are phenomenologically close to the SX Phe variables.

    **DSCTC** Low amplitude group of Delta Sct variables (light amplitude <0.1 mag in V). The majority of this type's representatives are stars of luminosity class V; objects of this subtype generally are representative of the Delta Sct variables in open clusters.

**GDOR** Gamma Doradus stars. Early type F dwarfs showing (multiple) periods from several tenths of a day to slightly in excess of one day. Amplitudes usually do not exceed 0.1 mag. Presumably low degree g-mode non-radial pulsators. Prototype: gamma Dor.

**L** Slow irregular variables. The light variations of these stars show no evidence of periodicity, or any periodicity present is very poorly defined and appears only occasionally. Like for the type I, stars are often attributed to this type because of being insufficiently studied. Many type L variables are really semiregulars or belong to other types.

    **LB** Slow irregular variables of late spectral types (K, M, C, S); as a rule, they are giants (CO Cyg). This type is also ascribed, in the GCVS, to slow red irregular variables in the case of unknown spectral types and luminosities.

    **LC** Irregular variable supergiants of late spectral types having amplitudes of about 1 mag in V (TZ Cas).

    **LPB** The comparatively long-period pulsating B stars (periods exceeding (LBV) one day).

**M** Mira (Omicron) Ceti-type variables. These are long-period variable giants with characteristic late-type emission spectra (Me, Ce, Se) and light amplitudes from 2.5 to 11 mag in V. Their periodicity is well pronounced, and the periods lie in the range between 80 and 1000 days. Infrared amplitudes are usually less than in the visible and may be <2.5 mag. For example, in the K band they usually do not exceed 0.9 mag. If the amplitudes exceed 1 - 1.5 mag , but it is not certain that the true light

amplitude exceeds 2.5 mag, the symbol "M" is followed by a colon, or the star is attributed to the semiregular class with a colon following the symbol for that type (SR).

**PVTEL** Variables of the PV Telescopii type. These are helium supergiant Bp stars with weak hydrogen lines and enhanced lines of He and C. They pulsate with periods of approximately 0.1 to 1 days, or vary in brightness with an amplitude of 0.1 mag in V during a time interval of about a year.

**RPHS** Very rapidly pulsating hot (subdwarf B) stars. Typical periods are hundreds of seconds, amplitudes are within several hundredths of a magnitude. Prototype: V361 Hya = EC 14026-2647.

**RR** Variables of the RR Lyrae type, which are radially-pulsating giant A-F stars having amplitudes from 0.2 to 2 mag in V. Cases of variable light-curve shapes as well as variable periods are known. If these changes are periodic, they are called the *Blazhko effect*.

Traditionally, RR Lyrae stars are sometimes called short-period Cepheids or cluster-type variables. The majority of these stars belong to the spherical component of the Galaxy; they are present, sometimes in large numbers, in some globular clusters, where they are known as pulsating horizontal-branch stars. Like Cepheids, maximum expansion velocities of surface layers for these stars practically coincide with maximum light.

**RR(B)** RR Lyrae variables showing two simultaneously operating pulsation modes, the fundamental tone with the period P0 and the first overtone, P1 (AQ Leo). The ratio P1/P0 is approximately 0.745;

**RRAB** RR Lyrae variables with asymmetric light curves (steep ascending branches), periods from 0.3 to 1.2 days, and amplitudes from 0.5 to 2 mag in V;

**RRC** RR Lyrae variables with nearly symmetric, sometimes sinusoidal, light curves, periods from 0.2 to 0.5 days, and amplitudes not greater than 0.8 mag in V (SX UMa).

**RV** Variables of the RV Tauri type. These are radially pulsating supergiants having spectral types F-G at maximum light and K-M at minimum. The light curves are characterized by the presence of double waves with alternating primary and secondary minima that can vary in depth so that primary minima may become secondary and vice versa. The complete light amplitude may reach 3-4 mag in V. Periods between two adjacent primary minima (usually called formal periods) lie in the range 30-150 days (these are the periods appearing in the Catalogue). Two subtypes, RVA and RVB, are recognized:

**RVA** RV Tauri variables that do not vary in mean magnitude (AC Her);

**RVB** RV Tauri variables that periodically (with periods from 600 to 1500 days and amplitudes up to 2 mag in V) vary in mean magnitude (DF Cyg, RV Tau).

**SR** Semiregular variables, which are giants or supergiants of intermediate and late spectral types showing noticeable periodicity in their light changes, accompanied or sometimes interrupted by various irregularities. Periods lie in the range from 20 to >2000 days, while the shapes of the light curves are rather different and variable, and the amplitudes may be from several hundredths to several magnitudes (usually 1-2 mag in V).

**SRA** Semiregular late-type (M, C, S or Me, Ce, Se) giants displaying persistent periodicity and usually small (<2.5 mag in V) light amplitudes (Z Aqr). Amplitudes and light-curve shapes generally vary and periods are in the range of 35-1200 days. Many of these stars differ from Miras only by showing smaller light amplitudes;

**SRB** Semiregular late-type (M, C, S or Me, Ce, Se) giants with poorly defined periodicity (mean cycles in the range of 20 to 2300 days) or with alternating intervals of periodic and slow irregular changes, and even with light constancy intervals (RR CrB, AF Cyg). Every star of this type may usually be assigned a certain mean period (cycle), which is the value given in the Catalogue. In a number of cases, the simultaneous presence of two or more periods of light variation is observed;

**SRC** Semiregular late-type (M, C, S or Me, Ce, Se) supergiants (Mu Cep) with amplitudes of about 1 mag and periods of light variation from 30 days to several thousand days;

**SRD** Semiregular variable giants and supergiants of F, G, or K spectral types, sometimes with emission lines in their spectra. Amplitudes of light variation are in the range from 0.1 to 4 mag, and the range of periods is from 30 to 1100 days (SX Her, SV UMa).

**SRS** Semiregular pulsating red giants with short period (several days to a month), probably high-overtone pulsators. Prototype: AU Ari.

**SXPHE** Phenomenologically, these resemble DSCT (Delta Sct) variables and are pulsating subdwarfs of the spherical component, or old disk galactic population, with spectral types in the range A2-F5. They may show several simultaneous periods of oscillation, generally in the range 0.04-0.08 days, with variable-amplitude light changes that may reach 0.7 mag in V. These stars are present in globular

clusters.

**ZZ**  ZZ Ceti variables. These are nonradially pulsating white dwarfs that change their brightnesses with periods from 30 s to 25 min and amplitudes from 0.001 to 0.2 mag in V. They usually show several close period values. Flares of 1 mag are sometimes observed; however, these may be explained by the presence of close UV Ceti companions.

These variables are divided into the following subtypes:

**ZZA**  ZZ Cet-type variables of DA spectral type (ZZ Cet) having only hydrogen absorption lines in their spectra;

**ZZB**  ZZ Cet-type variables of DB spectral type having only helium absorption lines in their spectra.

**ZZO**  ZZ Cet-type variables of the DO spectral type showing HeII and and CIV absorption lines in their spectra.

## C.3.2.3  Rotating Variable Stars

Variable stars with nonuniform surface brightness and/or ellipsoidal shapes, whose variability is caused by axial rotation with respect to the observer. The nonuniformity of surface brightness distributions may be caused by the presence of spots or by some thermal or chemical inhomogeneity of the atmosphere caused by a magnetic field whose axis is not coincident with the rotation axis. These stars are subdivided into the following types:

**ACV**  Alpha2 Canum Venaticorum variables. These are main-sequence stars with spectral types B8p-A7p and displaying strong magnetic fields. Spectra show abnormally strong lines of Si, Sr, Cr, and rare earths whose intensities vary with rotation. They exhibit magnetic field and brightness changes (periods of 0.5-160 days or more). The amplitudes of the brightness changes are usually within 0.01-0.1 mag in V.

**ACVO**  Rapidly oscillating Alpha2 CVn variables. These are nonradially pulsating, rotating magnetic variables of Ap spectral type (DO Eri). Pulsation periods are in the range of 6-12 mmag (0.004-0.01 days), while amplitudes of light variation caused by the pulsation are about 0.01 mag in V. The pulsational variations are superposed on those caused by rotation.

**BY**  BY Draconis-type variables, which are emission-line dwarfs of dKe-dMe spectral type showing quasiperiodic light changes with periods from a fraction of a day to 120 days and amplitudes from several hundredths to 0.5 mag in V. The light variability is caused by axial rotation of a star with a variable degree of nonuniformity of the surface brightness (spots) and chromospheric activity. Some of these stars also show flares similar to those of UV Cet stars, and in those cases they also belong to the latter type and are simultaneously considered eruptive variables.

**ELL**  Rotating ellipsoidal variables (b Per, Alpha Vir). These are close binary systems with ellipsoidal components, which change combined brightnesses with periods equal to those of orbital motion because of changes in emitting areas toward an observer, but showing no eclipses. Light amplitudes do not exceed 0.1 mag in V.

**FKCOM**  FK Comae Berenices-type variables. These are rapidly rotating giants with nonuniform surface brightnesses, which have G-K spectral types with broad H and K Ca II emission and sometimes Halpha. They may also be spectroscopic binary systems. Periods of light variation (up to several days) are equal to rotational periods, and amplitudes are several tenths of a magnitude. It is not excluded that these objects are the product of further evolution of EW (W UMa) close binary systems (see below).

**PSR**  Optically variable pulsars (CM Tau), which are rapidly rotating neutron stars with strong magnetic fields, radiating in the radio, optical, and X-ray regions. Pulsars emit narrow beams of radiation, and periods of their light changes coincide with rotational periods (from 0.004 to 4 s), while amplitudes of the light pulses reach 0.8 mag.

**R**  Close binary systems characterized by the presence of strong reflection (re-radiation) of the light of the hot star illuminating the surface of the cooler companion. Light curves are sinusoidal with the period equal to Porb, maximum brightness coinciding with the passage of the hot star in front of the companion. The eclipse may be absent. The range of light variation is about 0.5-1.0mag V (KV Vel).

**SXARI**  SX Arietis-type variables. These are main-sequence B0p-B9p stars with variable-intensity He I and Si III lines and magnetic fields. They are sometimes called helium variables. Periods of light and magnetic field changes (about 1 day) coincide with rotational periods, while amplitudes are approximately 0.1 mag in V. These stars are high-temperature analogs of the ACV variables.

## C.3.2.4  Cataclysmic (Explosive and Novalike) Variables

These are variable stars showing outbursts caused by thermonuclear burst processes in their surface layers (novae) or deep in their interiors (supernovae). We use the term "novalike" for variables that show novalike

outbursts caused by rapid energy release in the surrounding space (UG-type stars - see below) and also for objects not displaying outbursts but resembling explosive variables at minimum light by their spectral (or other) characteristics. The majority of explosive and novalike variables are close binary systems, their components having strong mutual influence on the evolution of each star. It is often observed that the hot dwarf component of the system is surrounded by an accretion disk formed by matter lost by the other, cooler, and more extended component. This category is subdivided into the following types:

**N**  Novae. Close binary systems with orbital periods from 0.05 to 230 days. One of the components of these systems is a hot dwarf star that suddenly, during a time interval from one to several dozen or several hundred days, increases its brightness by 7-19 mag in V, then returns gradually to its former brightness over several months, years, or decades. Small changes at minimum light may be present. Cool components may be giants, subgiants, or dwarfs of K-M type. The spectra of novae near maximum light resemble A-F absorption spectra of luminous stars at first. Then broad emission lines (bands) of hydrogen, helium, and other elements with absorption components indicating the presence of a rapidly expanding envelope appear in the spectrum. As the light decreases, the composite spectrum begins to show forbidden lines characteristic of the spectra of gas nebulae excited by hot stars. At minimum light, the spectra of novae are generally continuous or resemble the spectra of Wolf-Rayet stars. Only spectra of the most massive systems show traces of cool components.

Some novae reveal pulsations of hot components with periods of approximately 100 s and amplitudes of about 0.05 mag in V after an outburst. Some novae eventually turn out to be eclipsing systems. According to the features of their light variations, novae are subdivided into fast (NA), slow (NB), very slow (NC), and recurrent (NR) categories.

**NA**  Fast novae displaying rapid light increases and then, having achieved maximum light, fading by 3 mag in 100 or fewer days (GK Per);

**NB**  Slow novae that fade after maximum light by 3 mag in >= 150 days (RR Pic). Here the presence of the well-known "dip" in the light curves of novae similar to T Aur and DQ Her is not taken into account: The rate of fading is estimated on the basis of a smooth curve, its parts before and after the "dip" being a direct continuation of one another;

**NC**  Novae with a very slow development and remaining at maximum light for more than a decade, then fading very slowly. Before an outburst these objects may show long-period light changes with amplitudes of 1-2 mag in V (RR Tel); cool components of these systems are probably giants or supergiants, sometimes semiregular variables, and even Mira variables. Outburst amplitudes may reach 10 mag. High excitation emission spectra resemble those of planetary nebulae, Wolf-Rayet stars, and symbiotic variables. The possibility that these objects are planetary nebulae in the process of formation is not excluded;

**NL**  Novalike variables, which are insufficiently studied objects resembling novae by the characteristics of their light changes or by spectral features. This type includes, in addition to variables showing novalike outbursts, objects with no bursts ever observed; the spectra of novalike variables resemble those of old novae, and small light changes resemble those typical for old novae at minimum light. However, quite often a detailed investigation makes it possible to reclassify some representatives of this highly inhomogeneous group of objects into other types;

**NR**  Recurrent novae, which differ from typical novae by the fact that two or more outbursts (instead of a single one) separated by 10-80 years have been observed (T CrB).

**SN**  Supernovae (B Cas, CM Tau). Stars that increase, as a result of an outburst, their brightnesses by 20 mag and more, then fade slowly. The spectrum during an outburst is characterized by the presence of very broad emission bands, their widths being several times greater than those of the bright bands observed in the spectra of novae. The expansion velocities of SN envelopes are in the thousands of km/s. The structure of a star after outburst alters completely. An expanding emission nebula results and a (not always observable) pulsar remains at the position of the original star. According to the light curve shape and the spectral features, supernovae are subdivided into types I and II.

**SNI**  Type I supernovae. Absorption lines of Ca II, Si, etc., but no hydrogen lines are present in the spectra. The expanding envelope almost lacks hydrogen. During 20-30 days following maximum light, the brightness decreases by approximately 0.1 mag per day, then the rate of fading slows and reaches a constant value of 0.014/day;

**SNII**  Type II supernovae. Lines of hydrogen and other elements are apparent in their spectra. The expanding envelope consists mainly of H and He. Light curves show greater diversity than those of type I supernovae. Usually after 40-100 days since maximum light, the rate of fading is 0.1 mag per day.

**UG**  U Geminorum-type variables, quite often called dwarf novae. They are close binary systems consisting of a dwarf or subgiant K-M star that fills the volume of its inner Roche lobe and a white dwarf surrounded by an accretion disk. Orbital periods are in the range 0.05-0.5 days. Usually only small, in some cases rapid, light fluctuations are observed, but from time to time the brightness of a system increases rapidly by several magnitudes and, after an interval of from several days to a month or more, returns to the original state. Intervals between two consecutive outbursts for a given star may vary greatly, but every star is characterized by a certain mean value of these intervals, i.e., a mean cycle that corresponds to the mean light amplitude. The longer the cycle, the greater the amplitude. These systems are frequently sources of X-ray emission. The spectrum of a system at minimum is continuous, with broad H and He emission lines. At maximum these lines almost disappear or become shallow absorption lines. Some of these systems are eclipsing, possibly indicating that the primary minimum is caused by the eclipse of a hot spot that originates in the accretion disk from the infall of a gaseous stream from the K-M star. According to the characteristics of the light changes, U Gem variables may be subdivided into three types: SS Cyg, SU UMa, and Z Cam.

**UGSS**  SS Cygni-type variables (SS Cyg, U Gem). They increase in brightness by 2-6 mag in V in 1-2 days and in several subsequent days return to their original brightnesses. The values of the cycle are in the range 10 days to several thousand;

**UGSU**  SU Ursae Majoris-type variables. These are characterized by the presence of two types of outbursts called "normal" and "supermaxima". Normal, short outbursts are similar to those of UGSS stars, while supermaxima are brighter by 2 mag, are more than five times longer (wider), and occur several times less frequently. During supermaxima the light curves show superposed periodic oscillations (superhumps), their periods being close to the orbital ones and amplitudes being about 0.2-0.3 mag in V. Orbital periods are shorter than 0.1 days; companions are of dM spectral type;

**UGZ**  Z Camelopardalis-type stars. These also show cyclic outbursts, differing from UGSS variables by the fact that sometimes after an outburst they do not return to the original brightness, but during several cycles retain a magnitude between maximum and minimum. The values of cycles are from 10 to 40 days, while light amplitudes are from 2 to 5 mag in V.

**ZAND**  Symbiotic variables of the Z Andromedae type. They are close binaries consisting of a hot star, a star of late type, and an extended envelope excited by the hot star's radiation. The combined brightness displays irregular variations with amplitudes up to 4 mag in V. A very inhomogeneous group of objects.

## C.3.2.5  Close Binary Eclipsing Systems

We adopt a triple system of classifying eclipsing binary systems: according to the shape of the combined light curve, as well as to physical and evolutionary characteristics of their components. The classification based on light curves is simple, traditional, and suits the observers; the second and third classification methods take into account positions of the binary-system components in the (MV ,B-V) diagram and the degree of inner Roche lobe filling. Estimates are made by applying the simple criteria proposed by Svechnikov and Istomin (1979). The symbols for the types of eclipsing binary systems that we use are given below.

## C.3.2.6  Classification based on the shape of the light curve

**E**  Eclipsing binary systems. These are binary systems with orbital planes so close to the observer's line of sight (the inclination i of the orbital plane to the plane orthogonal to the line of sight is close to 90 deg) that the components periodically eclipse each other. Consequently, the observer finds changes of the apparent combined brightness of the system with the period coincident with that of the components' orbital motion.

**EA**  Algol (Beta Persei)-type eclipsing systems. Binaries with spherical or slightly ellipsoidal components. It is possible to specify, for their light curves, the moments of the beginning and end of the eclipses. Between eclipses the light remains almost constant or varies insignificantly because of reflection effects, slight ellipsoidality of components, or physical variations. Secondary minima may be absent. An extremely wide range of periods is observed, from 0.2 to >= 10000 days. Light amplitudes are also quite different and may reach several magnitudes.

**EB**  Beta Lyrae-type eclipsing systems. These are eclipsing systems having ellipsoidal components and light curves for which it is impossible to specify the exact times of onset and end of eclipses because of a continuous change of a system's apparent combined brightness between eclipses; secondary minimum is observed in all cases, its depth usually being considerably smaller than that of the primary minimum; periods are mainly longer than 1 day. The components generally belong to early spectral types (B-A). Light amplitudes are usually <2 mag in V.

**EP** Stars showing eclipses by their planets. Prototype: V0376 Peg.

**EW** W Ursae Majoris-type eclipsing variables. These are eclipsing binaries with periods shorter than 1 days, consisting of ellipsoidal components almost in contact and having light curves for which it is impossible to specify the exact times of onset and end of eclipses. The depths of the primary and secondary minima are almost equal or differ insignificantly. Light amplitudes are usually <0.8 mag in V. The components generally belong to spectral types F-G and later.

### C.3.2.7 Classification according to the components' physical characteristics

**GS** Systems with one or both giant and supergiant components; one of the components may be a main sequence star.

**PN** Systems having, among their components, nuclei of planetary nebulae (UU Sge).

**RS** RS Canum Venaticorum-type systems. A significant property of these systems is the presence in their spectra of strong Ca II H and K emission lines of variable intensity, indicating increased chromospheric activity of the solar type. These systems are also characterized by the presence of radio and X-ray emission. Some have light curves that exhibit quasi sine waves outside eclipses, with amplitudes and positions changing slowly with time. The presence of this wave (often called a distortion wave) is explained by differential rotation of the star, its surface being covered with groups of spots; the period of the rotation of a spot group is usually close to the period of orbital motion (period of eclipses) but still differs from it, which is the reason for the slow change (migration) of the phases of the distortion wave minimum and maximum in the mean light curve. The variability of the wave's amplitude (which may be up to 0.2 mag in V) is explained by the existence of a long-period stellar activity cycle similar to the 11-year solar activity cycle, during which the number and total area of spots on the star's surface vary.

**WD** Systems with white-dwarf components.

**WR** Systems having Wolf-Rayet stars among their components (V444 Cyg).

### C.3.2.8 Classification based on the degree of filling of inner Roche lobes

**AR** Detached systems of the AR Lacertae type. Both components are subgiants not filling their inner equipotential surfaces.

**D** Detached systems, with components not filling their inner Roche lobes.

    **DM** Detached main-sequence systems. Both components are main-sequence stars and do not fill their inner Roche lobes.

    **DS** Detached systems with a subgiant. The subgiant also does not fill its inner critical surface.

    **DW** Systems similar to W UMa systems in physical properties (KW, see below), but not in contact.

**K** Contact systems, both components filling their inner critical surfaces.

    **KE** Contact systems of early (O-A) spectral type, both components being close in size to their inner critical surfaces.

    **KW** Contact systems of the W UMa type, with ellipsoidal components of F0-K spectral type. Primary components are main-sequence stars and secondaries lie below and to the left of the main sequence in the (MV,B-V) diagram.

**SD** Semidetached systems in which the surface of the less massive component is close to its inner Roche lobe.

The combination of the above three classification systems for eclipsing binaries results in the assignment of multiple classifications for object types. These are separated by a solidus ("/") in the data field. Examples are: E/DM, EA/DS/RS, EB/WR, EW/KW, etc.

### C.3.2.9 Optically Variable Close Binary Sources of Strong, Variable X-ray Radiation (X-ray Sources)

**AM** AM Her type variables; close binary systems consisting of a dK-dM type dwarf and of a compact object with strong magnetic field, characterized by variable linear and circular polarization of light. The total range of light variations may reach 4-5 mag V.

**X** Close binary systems that are sources of strong, variable X-ray emission and which do not belong to or are not yet attributed to any of the above types of variable stars. One of the components of the system is a hot compact object (white dwarf, neutron star, or possibly a black hole). X-ray emission originates from the infall of matter onto the compact object or onto an accretion disk surrounding the compact object. In turn, the X-ray emission is incident upon the atmosphere of the cooler companion of the compact object and is reradiated in the form of optical high-temperature radiation (reflection effect), thus making that area of the cooler companion's surface an earlier spectral type. These effects lead to quite a peculiar complex character of optical variability in such systems. These objects may be subdivided into the following types:

    **XB** X-ray bursters. Close binary systems showing X-ray and optical bursts, their duration being from

several seconds to ten minutes, with amplitudes of about 0.1 mag in V (V 801 Ara, V 926 Sco);

**XF** Fluctuating X-ray systems showing rapid variations of X-ray (Cygnus X-1 = V1357 Cyg) and optical (V821 Ara) radiation on time scales of dozens of milliseconds;

**XI** X-ray irregulars. Close binary systems consisting of a hot compact object surrounded by an accretion disk and a dA - dM-type dwarf. These display irregular light changes on time scales of minutes and hours, and amplitudes of about 1 mag in V. Superposition of a periodic variation because of orbital motion is possible (V818 Sco);

**XJ** X-ray binaries characterized by the presence of relativistic jets evident at X-ray and radio wavelengths, as well as in the optical spectrum in the form of emission components showing periodic displacements with relativistic velocities (V1343 Aql);

**XND** X-ray, novalike (transient) systems containing, along with a hot compact object, a dwarf or subgiant of G-M spectral type. These systems occasionally rapidly increase in brightness by 4-9 mag in V, in the visible simultaneously with the X-ray range, with no envelope ejected. The duration of the outburst may be up to several months (V616 Mon);

**XNG** X-ray, novalike (transient) systems with an early-type supergiant or giant primary component and a hot compact object as a companion. Following the main component's outburst, the material ejected by it falls onto the compact object and causes, with a significant delay, the appearance of X rays. The amplitudes are about 1-2 mag in V (V725 Tau);

**XP** X-ray pulsar systems. The primary component is usually an ellipsoidal early-type supergiant. The reflection effect is very small and light variability is mainly caused by the ellipsoidal primary component's rotation. Periods of light changes are between 1 and 10 days; the period of the pulsar in the system is from 1 s to 100 min. Light amplitudes usually do not exceed several tenths of a magnitude (Vela X-1 = GP Vel);

**XPR** X-ray pulsar systems featuring the presence of the reflection effect. They consist of a dB-dF-type primary and an X-ray pulsar, which may also be an optical pulsar. The mean light of the system is brightest when the primary component is irradiated by X rays; it is faintest during a low state of the X-ray source. The total light amplitude may reach 2-3 mag in V (HZ Her);

**XPRM,XM** X-ray systems consisting of a late-type dwarf (dK-dM) and a pulsar with a strong magnetic field. Matter accretion on the compact object's magnetic poles is accompanied by the appearance of variable linear and circular polarization; hence, these systems are sometimes known as "polars". The amplitudes of the light changes are usually about 1 mag in V but, provided that the primary component is irradiated by X rays, the mean brightness of a system may increase by 3 mag in V. The total light amplitude may reach 4-5 mag in V (AM Her, AN UMa).

If the beam of X-ray emission originating at the magnetic poles of the rotating hot compact object does not pass through the observer's position and the system is not observed as a pulsar, the letter "P" in the above symbols for X-ray-system types is not used. If an X-ray system is also an eclipsing or an ellipsoidal variable, the X-ray symbol is preceded by "E" or "ELL" joined with the X-ray symbol by a "+" sign (e.g., E+X, ELL+X).

### C.3.2.10 Other Symbols

In addition to the variable-star types described above, certain other symbols that need to be explained will be found in the Type data field:

**BLLAC** Extragalactic BL Lacertae-type objects. These are compact quasistellar objects showing almost continuous spectra with weak emission and absorption lines and relatively rapid irregular light changes with amplitudes up to 3 mag in V or more. Sources of strong X-ray radiation and radio waves, their emission displays strong and variable linear polarization in the visible and infrared spectral regions. Some objects of this type, considered erroneously to be variable stars and designated in the GCVS system, will probably sometimes be included in the main table of the Catalogue in the future, too.

**CST** Nonvariable stars, formerly suspected to be variable and hastily designated. Further observations have not confirmed their variability.

**GAL** Optically variable quasistellar extragalactic objects (active galactic nuclei [AGNs]) considered to be variable stars by mistake.

**L:** Unstudied variable stars with slow light changes.

**QSO** Optically variable quasistellar extragalactic sources (quasars) that earlier were erroneously considered to be variable stars.

**S** Unstudied variable stars with rapid light changes.

**\*** Unique variable stars outside the range of the classifications described above. These probably represent ei-

ther short stages of transition from one variability type to another or the earliest and latest evolutionary stages of these types, or they are insufficiently studied members of future new types of variables.

**+** If a variable star belongs to several types of light variability simultaneously, the types are joined in the Type field by a "+" sign (e.g., E+UG, UV+BY).

**:** Uncertainty flag on Type of Variability

## C.4 Double Stars

Since version 0.15.0 Stellarium supports the subset of double stars from WDS[5] which have HIP identifiers (i.e., stars from the Hipparcos catalog). Stellarium's Catalog of Double Stars is based on the "The 2001 US Naval Observatory Double Star CD-ROM. I. The Washington Double Star Catalog" (Mason et al., 2001). Cross reference data for WDS and HIP designations is based on the XHIP catalog (Anderson and Francis, 2012) through the astronomical database SIMBAD (Wenger et al., 2000).

### C.4.1 Double Star Catalog File Format

Stellarium's Double Stars catalog data is kept in the `stars/hip_gaia3` sub-directory of the Installation Directory and/or User Directory (see section 5.1).

#### C.4.1.1 File Format

The `wds_hip_part.dat` file contains data about 16411 *double stars* which have HIP identifiers and stored in plain text format with tab delimiters.

| Name | Type | Description |
|---|---|---|
| HIP | int | HIP identifier for the star. Used for reference to the main star catalogue. |
| WDS | string | WDS designation for the double star. |
| Observation | int | Date of last satisfactory observation (in years). |
| Position Angle | float | Position Angle at date of last satisfactory observation (in decimal degrees). |
| Separation | float | Separation at date of last satisfactory observation (in arcsec). |

Table C.8: Format of `wds_hip_part.dat`

### C.4.2 Designations

In version 0.20.4 we incorporated support for additional designations for *double stars* which have also HIP identification. All these designations were added especially for double star observers and people who use Stellarium as reference software. The cross-identification data for double stars were obtained from *The Cambridge Double Star Atlas* (MacEvoy and Tirion, 2015; Mullaney and Tirion, 2009).

In version 0.21.1 we updated cross-identification data according to *The Washington Double Star Catalog* data (Mason et al., 2001).

| Traditional ID | Modern ID[6] | N.[7] | Observer | Active period |
|---|---|---|---|---|
| — | A | | R. G. Aitken | 1891—1937 |
| — | ABH | | H.A. Abt | 1961—2006 |
| — | ABT | | G. Abetti | 1911—1925 |
| AC | AC | | A. Clark | 1857—1864 |
| — | ACA | | A.C. Ashcraft | 2005—2007 |
| ACG | ACG | | *Astrographic Catalog (Greenwich)* | |
| — | ADA | | C. Adam | 2014 |
| — | ADM | | E.R. Adams | 2012—2013 |
| — | AG | | *Astronomische Gesellschaft Katalog* | 1903 |

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[5]`http://www.astro.gsu.edu/wds/` or `https://www.stelledoppie.it/index2.php?section=1`

[6]Latinized and capitalized version of traditional ID

[7]Note: * — Stellarium uses traditional designation of double star

| | | | |
|---|---|---|---|
| AGC | AGC | A.G. Clark | 1862 |
| — | AHD | A. Ahad | 2010—2020 |
| — | ALB | *Albany Observatory* | 1910–1936 |
| — | ALC | C. Allen | 2000—2014 |
| — | ALD | H.L. Alden | 1924—1957 |
| — | ALI | A. Ali | 1949—1955 |
| — | ALL | R.M. Aller | 1930—1960 |
| — | ALP | P.R. Allen | 2007—2012 |
| — | AMM | M. Ammler-von Eiff | 2016 |
| — | AMS | A. Amosse | 2012—2020 |
| — | ANJ | J.A. Anderson | 1920 |
| — | ANT | R. Anton | 2001— |
| AOT | AOT | *Astronomical Observatory Torino* | |
| — | ARA | S. Aravamudan | 1961—1963 |
| Arg | ARG | F.W.A. Argelander | 1857—1865 |
| — | ARI | E. Aristidi | 1997—1999 |
| — | ARN | D. Arnold | 2001—2013 |
| — | ARR | S. Arribas | 1998 |
| — | ARU | A.N. Argue | 1984—1992 |
| — | ARY | R.W. Argyle | 1977—2020 |
| — | AST | *HST FGS Astrometry Science Team* | 1991— |
| — | AZC | A.A. Azcona | 2012—2020 |
| — | B | W.H. van den Bos | 1921—1968 |
| — | BAG | Yu.Yu. Balega | 1977—2015 |
| — | BAK | G.A. Bakos | 2006 |
| — | BAL | R. Baillaud | 1924—1944 |
| — | BAR | E.E. Barnard | 1884—1922 |
| — | BAS | M.A. Barstow | 2001 |
| BAT | BAT | H. Batterman | |
| — | BAU | C. Bauer | 1994—2007 |
| — | BAZ | P. Baize | 1927—1994 |
| — | BDK | *Brown Dwarf Kinematic Project Catalog* | 2010 |
| — | BDT | T.D. Brandt | 2014— |
| — | BED | T.R. Bedding | 1993—1994 |
| — | BEU | J.-L. Beuzit | 2004 |
| — | BEW | U. Bastian, J. Eisloeffel, K. Wiese | 1988 |
| — | BGH | S. van den Bergh | 1958 |
| — | BGR | J.-P. Berger | 2011 |
| — | BHA | T.P. Bhaskaran | 1916—1938 |
| — | BHJ | A. Blaauw, W.A. Hiltner, H.L. Johnson | 1959 |
| — | BID | W.P. Bidelman | 1976—1980 |
| Big | BIG | G. Bigourdan | 1883—1903 |
| — | BIL | B.A. Biller | 2006—2014 |
| — | BKO | E. Berko | 2002—2012 |
| — | BLA | A. Blazit | 1877—1987 |
| — | BLK | D.R. Blackmore | 1990 |
| Bll | BLL | R.S. Ball | 1872—1884 |
| — | BLM | B.L. Morgan | 1978—1982 |
| — | BLO | M. Bloch | 1931 |
| — | BNK | A. Brandeker | 2001—2006 |
| — | BNS | D. Baines | 2006 |
| — | BNU | D. Bonneau | 1979—2011 |
| — | BNV | M. Bonavita | 2007—2020 |
| — | BNW | W.A. Baranov | 1909 |
| — | BOD | A.F. Boden | 1998—2012 |
| — | BOT | G. Boettger | 1958—1967 |
| Bow | BOW | W.M. Bowyer | 1896—1921 |

| | | | | |
|---|---|---|---|---|
| — | BPM | | *Bordeaux PM2000 catalogue* | 2010 |
| — | BRC | | C. Briceno | 1998—2017 |
| BRD | BRD | | F. Bird | |
| — | BRF | | F.L. Brown | 1916—1927 |
| — | BRG | | C. Bergfors | 2010—2016 |
| — | BRH | | W. Barth | 1994 |
| — | BRR | | W. Brandner | 1995—2004 |
| — | BRT | | S.G. Barton | 1926—1957 |
| BrsO | BSO | | *Brisbane Observatory* | 1834—1851 |
| — | BTG | | A. Bertoglio | 2007—2010 |
| — | BTM | | M. Bottom | 2015 |
| — | BTZ | | E. Bernewitz | 1920—1963 |
| β | BU | * | S. Burnham | 1873—1918 |
| β pm | BUP | * | *(Proper motion pairs)* | 1873—1918 |
| — | BVD | | R. Benavides | 2003—2018 |
| — | BWL | | B.P. Bowler | 2012—2018 |
| — | BYV | | V. Bailey | 2014 |
| — | CAB | | J.A. Caballero | 2005—2018 |
| — | CAN | | S.M. Caballero-Nieves | 2014—2020 |
| — | CAR | | M. Carbillet | 1996—1998 |
| — | CAT | | C. Catala | 2006 |
| — | CBL | | R. Caballero | 2008—2015 |
| — | CHE | | Stanislas Chevalier | 1908—1925 |
| — | CHM | | J. Chaname | 2004 |
| — | CHN | | M. Cohen | 1979—1983 |
| — | CHR | | *Center for High Ang. Res. Astronomy (speckle interferometry systems)* | |
| — | CHT | | A.C. Cheetham | 2015—2018 |
| — | CIA | | *Center for High Angular Resolution Astronomy (CHARA Interferometric Array)* | |
| — | CLL | | J.L. Comellas | 2003 |
| — | CLO | | L.P. Close | 1997—2014 |
| — | CLP | | P. Clark | 2011 |
| Cog | COG | | W.A. Cogshall | 1896—1905 |
| Com | COM | | G.C. Comstock | 1894—1911 |
| CorO | COO | | *Cordoba Observatory* | 1883—1920 |
| Cop | COP | | R. Copeland | 1875—1886 |
| — | COU | | P. Couteau | 1952—1999 |
| CpO, CapO | CPO | | *Cape Observatory* | 1822—1938 |
| — | CRB | | J.-L. Carballo | 2009—2016 |
| — | CRC | | M. Cortes-Contreras | 2014—2017 |
| — | CRE | | T. Currie | 2010—2020 |
| CRI | CRI | | F. Crifo | |
| — | CRJ | | J.P. Crepp | 2010—2015 |
| Cru | CRU | | L. Cruls | 1884 |
| — | CRZ | | K.L. Cruz | 2007 |
| — | CSE | | G. Csepany | 2015—2017 |
| — | CSI | | Sz. Csizmadia | 2009 |
| — | CSN | | J.C. Carson | 2005—2013 |
| — | CSR | | I. Coster | 2006—2016 |
| — | CSU | | O. Chesneau | 2014 |
| — | CTI | | P.S. Conti | 1971—1980 |
| — | CTT | | J.-F. Courtot | 1995— |
| — | CTU | | J.C. Christou | 2006—2009 |
| — | CUD | | K.M. Cudworth | 1973 |
| — | CUS | | F. Cusano | 2012 |
| — | CUY | | J. Cuypers | 1997—1999 |

| | | | | |
|---|---|---|---|---|
| — | CVE | | Z. Cvetkovic | 2005—2020 |
| — | CVN | | G. Chauvin | 2002—2015 |
| — | CVP | | R.J. Cava and R.A. Pascal, Jr. | 2004 |
| — | CVR | | J. Chivers | 2011—2015 |
| D | D | | H. Dembowski | 1856—1884 |
| Dawes | DA | | W.R. Dawes | 1831—1867 |
| — | DAE | | S. Daemgen | 2007—2015 |
| — | DAL | | J.A. Daley | 1998—2018 |
| — | DAM | | F. Damm | 2009— |
| — | DAN | | A. Danjon | 1937—1956 |
| $\delta$ | DAW | * | B.H. Dawson | 1918—1933 |
| — | DBK | | M. De Becker | 2004—2012 |
| — | DCH | | G. Duchene | 1999—2018 |
| — | DEA | | N.R. Deacon | 2005—2020 |
| — | DEL | | X. Delfosse | 1999—2000 |
| — | DIC | | J. Dick | 1921—1963 |
| — | DJU | | P. Djurkovic | 1953—1973 |
| Dob | DOB | | W.A. Doberck | 1875—1934 |
| — | DOM | | J. Dommanget | 1949—1979 |
| — | DON | | H.F. Donner | 1937—1964 |
| — | DOO | | E. Doolittle | 1901—1923 |
| — | DOR | | *Dorpat Observatory* | |
| — | DRD | | P. Durand | 1983—2011 |
| — | DRS | | R.J. De Rosa | 2011—2019 |
| — | DSG | | *DSSI-Gemini* | 2012 |
| $\Delta$ | DUN | * | J. Dunlop | 1825—1846 |
| — | DUQ | | A. Duquennoy | 1987—1996 |
| — | DVG | | M.J. del Valle Gonzalez | 2015— |
| DYR | DYR | | E.R. Dyer, Jr. | |
| — | EBE | | J. Ebersberger | 1979—1986 |
| EDG | EDG | | D.W. Edgecomb | |
| Egb | EGB | | H.V. Egbert | 1879—1906 |
| — | EGG | | O.J. Eggen | 1945—1982 |
| — | EGN | | P. Eggenberger | 2007—2008 |
| — | EHR | | D. Ehrenreich | 2010 |
| — | EIS | | T. Eisenbeiss | 2007 |
| — | ELP | | P. Elliott | 2015—2016 |
| Eng | ENG | | R. Engelmann | 1865—1887 |
| Enh | ENH | | B. von Engelhardt | 1887—1895 |
| — | ENO | | *European Network Observations* | |
| — | ES | | T.E. Espin | 1901—1933 |
| — | ESG | | S. Els | 2001 |
| — | EVS | | N.R. Evans | 1993—2020 |
| — | EVT | | T.M. Evans | 2012 |
| — | FAB | | C. Fabricius | 2000 |
| — | FAL | | J.L. Falin and F. Mignard | 1999 |
| — | FAR | | J. Farihi | 2004—2013 |
| — | FGL | | E.D. Feigelson | 1996—2006 |
| — | FGS | | *HST Fine Guide Sensor* | 2015 |
| $\phi$ | FIN | | W.S. Finsen | 1926—1978 |
| — | FLE | | J. Fleckenstein | 1956—1958 |
| — | FMR | | F.M. Rica Romero | 1996— |
| — | FOR | | L. Forgeron | 1911 |
| — | FOX | | P. Fox | 1909—1946 |
| — | FRH | | R. Furuhjelm | 1932 |
| — | FRK | | W.S. Franks | 1914—1919 |

| — | FRT | W.J. Forrest | 1988—1990 |
| — | FYM | M. Fay | 2013—2017 |
| — | GAA | A. Gallenne | 2014—2019 |
| — | GAL | J. Gallo | 1912—1914 |
| GAn | GAN | G. Anderson | 1888—1897 |
| — | GAT | G.D. Gatewood | 1973—2019 |
| — | GAU | P.L. Gauchet | 1923—1928 |
| — | GDM | B. Goldman | 2010 |
| — | GHE | A.M. Ghez | 1991—2016 |
| — | GIC | H. Giclas | 1961—1978 |
| — | GII | R. Gili | 1991—2020 |
| — | GIR | P.M. Girard | 1992—1994 |
| — | GIZ | J.E. Gizis | 2000—2006 |
| — | GJ | W. Gliese and H. Jahreiss | 1988 |
| — | GKI | D.A. Golimowski | 1993—2004 |
| Gale | GLE | W.F. Gale | 1897 |
| Gli | GLI | J.M. Gilliss | 1850—1868 |
| Glp | GLP | S. Glasenapp | 1888—1899 |
| — | GMC | G. Micello | 2011—2019 |
| — | GNS | C. Ginski | 2012—2016 |
| GNT | GNT | Grant | |
| — | GOE | K.-D. Goecking | 1994 |
| GOL | GOL | H. Goldschmidt | |
| — | GRB | S. Groombridge | 1913 |
| — | GRE | J. Gregorio-Hetem | 1992 |
| — | GRF | R.F. Griffin | 1975—2019 |
| — | GRV | J. Greaves | 2004— |
| — | GRY | C.A. Grady | 2004 |
| — | GSH | J. Glaisher | 1906—1908 |
| — | GTB | K. Gottlieb | 1948 |
| — | GUE | E.W. Guenther | 2001—2005 |
| — | GUI | J. Guillaume | 1912—1931 |
| — | GUL | K. Gullikson | 2016 |
| — | GVT | *GRAVITY collaboration* | 2018— |
| — | GWP | *Garraf Wide Pairs* | 2012—2016 |
| — | GYL | A.N. Goyal | 1958—1970 |
| — | GZA | B. Gauza | 2012—2015 |
| H I to VI, H N | H 1 to 6, H N | W. Herschel | 1777—1821 |
| — | HAT | P. Hartigan | 1994—2003 |
| — | HAU | H. Haupt | 1964—1966 |
| Hd, HdO | HDO | *Harvard Observatory* | 1866—1911 |
| — | HDS | *Hipparcos Double Star Catalog* | c. 1991 |
| — | HEG | E.K. Hege | 1983—1991 |
| — | HEI | W.D. Heintz | 1954—2001 |
| — | HEL | K. Helminiak | 2009—2016 |
| — | HER | G.H. Herbig | 1950—1998 |
| h | HJ | J.F.W. Herschel | 1826—1870 |
| — | HJL | J.L. Halbwachs | 1981—2020 |
| Hl | HL | A. Hall | 1866—1894 |
| — | HLA | L.A. Hirsch | 2019 |
| Hld | HLD | E.S. Holden | 1874—1884 |
| — | HLG | G. Hill | 1970—1988 |
| — | HLM | E. Holmes | 1906 |
| — | HLN | F. Holden | 1963—1979 |
| — | HMM | C.A. Hummel | 2001—2017 |
| — | HNK | S. Hinkley | 2010—2015 |

| | | | |
|---|---|---|---|
| Ho | HO | G.W. Hough | 1883—1907 |
| — | HOM | F. Hormuth | 2007 |
| Hrg | HRG | L. Hargrave | 1871—1892 |
| — | HRS | D.L. Harris | 1947 |
| — | HSL | J.N. Heasley | 2002 |
| — | HSW | R. Harshaw | 1990—1993 |
| HTG | HTG | C.S. Hastings | |
| Hu | HU | W.J. Hussey | 1896—1914 |
| — | HUB | S. Hubrig | 2001 |
| — | HUE | N. Huelamo | 2009—2015 |
| — | HWD | A.W. Howard | 2010 |
| Howe | HWE | H.A. Howe | 1876—1882 |
| — | HZE | A. Heinze | 2009—2010 |
| — | HZG | E. Hertzsprung | 1907—1958 |
| — | I | R.T.A. Innes | 1895—1948 |
| — | INN | P.A. Ianna | 1974—1988 |
| — | IOT | *IOTA Array* | 1995—2011 |
| — | ISO | S. Isobe | 1990—1992 |
| — | ITF | I.T. Falcon | 2011—2020 |
| — | ITO | Y. Itoh | 1999—2011 |
| — | ISM | R.M. Ismailov | 1998—2020 |
| — | J | R. Jonckheere | 1908—1958 |
| — | JAY | R. Jayawardhana | 2001—2006 |
| Jc | JC | W.S. Jacob | 1847—1860 |
| JCT | JCT | J.-C. Thorel | |
| — | JEF | H.M. Jeffers | 1945—1978 |
| — | JKA | K.A. Janes | 2017 |
| JKS | JKS | M.P. Jenniskens | |
| — | JNN | M. Janson | 2006—2020 |
| — | JOD | E. Jodar | 2013 |
| — | JOH | E.L. Johnson | 1916—1948 |
| — | JOY | A.H. Joy | 1941—1949 |
| — | JRN | A. Jorissen | 1988 |
| — | JSP | M.K. Jessup | 1937—1964 |
| — | KAL | P. Kalas | 2008 |
| — | KAM | P. van de Kamp | 1929—1969 |
| — | KAR | M. Karovska | 1986—1997 |
| — | KEL | A. Kellerer | 2007 |
| — | KIR | J.D. Kirkpatrick | 1995—2014 |
| — | KNG | B. Koenig | 2002—2005 |
| — | KNP | G.F.G. Knipe | 1959—1969 |
| Knott | KNT | G. Knott | 1865—1881 |
| Ko | KO | *Koenigstuhl (Max Planck Institute)* | |
| — | KOE | L. Koechlin | 1979—1983 |
| — | KOH | R. Koehler | 1998—2016 |
| — | KOI | *Kepler Object of Interest* | 2011—2018 |
| — | KON | Q.M. Konopacky | 2007—2010 |
| — | KOU | M.B.N. Kouwenhoven | 2005 |
| — | KPP | W. Knapp | 2015— |
| — | KPR | K.W. Kamper | 1976—1992 |
| — | KR | A. Kruger | |
| KRO | KRO | G. Kron | |
| — | KRS | C.D. Koresko | 1991—2002 |
| — | KRU | E.C. Kruger | 1936—1937 |
| — | KRV | P. Kervella | 2009—2019 |
| — | KRW | Carlos A. Krawczenko | 2009—2020 |

| | KSS | S. Kraus | 2007—2012 |
|---|---|---|---|
| — | KST | J.H. Kastner | 2012 |
| Ku | KU | F. Kustner | 1884—1902 |
| — | KUI | G.P. Kuiper | 1929—1961 |
| Kza | KZA | S.M. Kazeza | 1984 |
| L | L | T. Lewis | 1891—1921 |
| — | LAB | A. Labeyrie | 1974 |
| — | LAD | T. Ladanyi | 2003—2007 |
| — | LAF | D. Lafreniere | 2007—2014 |
| Lal | LAL | J.-J. de Lalande | 1825—1877 |
| Lam | LAM | J. Lamont | 1849 |
| — | LAU | H.E. Lau | 1905—1917 |
| — | LAW | N.M. Law | 2006—2010 |
| — | LBZ | P. Labitzke | 1925—1929 |
| Lcl | LCL | N.L. Lacaille | 1750 |
| — | LCS | P.W. Lucas | 2005 |
| — | LDS, LPM | *Luyten p.m. catalog* | |
| — | LEC | J. Lecacheux | 2000—2007 |
| LEE | LEE | O.J. Lee | |
| — | LEI | Ch. Leinert | 1986—2001 |
| — | LEO | F.C. Leonard | 1918—1943 |
| — | LEP | S. Lepine | 2001—2011 |
| — | LFR | L. Ferrero | 2009 |
| — | LGR | A.-M. Lagrange | 2006—2009 |
| — | LI | W. Li | 1994 |
| — | LIC | G. Li Causi | 2013 |
| — | LIM | M.C. Liu | 1996—2012 |
| — | LIN | J.F. Ling | 1983—2020 |
| — | LLO | J.P. Lloyd | 2002—2007 |
| — | LMP | P. Lampens | 2001—2016 |
| — | LNA | A. Luna | 2020 |
| — | LOC | G. Locatelli | 2013—2019 |
| — | LOS | F. Losse | 2005—2010 |
| — | LOU | N.P. Loutrel | 2011 |
| — | LPL | N. La Palombara | 2012 |
| LpO | LPO | *La Plata Observatory* | |
| — | LSC | *Lowell-Southern Connecticut Collaboration* | |
| — | LUH | K.L. Luhman | 2002—2013 |
| — | LUY | W.J. Luyten | 1933—1969 |
| Lv | LV | F.P. Leavenworth | 1887—1930 |
| — | LWR | P.J. Lowrance | 1999—2005 |
| — | LYS | L. Louys | 1987 |
| Mad | MAD | J.H. Maedler | 1835—1859 |
| — | MAJ | J. Manfroid | 1987 |
| — | MAM | E.E. Mamajek | 2010—2017 |
| — | MAR | C. Marois | 2008—2010 |
| — | MBA | B.A. Macintosh | 2001—2003 |
| — | MCA | H.A. McAlister | 1976—1996 |
| — | MCD | M. Michaud | 2012 |
| — | MCN | L. Maccarini | 2015—2019 |
| — | MCT | C. McCarthy | 2001 |
| — | MCY | D.W. McCarthy | 1982—1993 |
| — | MEL | E.L. Martin | 1998—2006 |
| — | MET | S.A. Metchev | 2003—2009 |
| — | MFL | F.L. Martinez | 2018—2019 |

| | | | |
|---|---|---|---|
| — | MGN | G.N. Mace | 2013 |
| — | MIL | J.A. Miller | 1903—1907 |
| — | MIU | N. Miura | 1992—1995 |
| — | MKR | V.V. Makarov | 2005—2010 |
| — | MKT | *Mark III Interferometer* | 1988—2006 |
| — | MLB | W. Milburn | 1918—1939 |
| — | MLD | A. Meilland | 2008—2011 |
| MlF | MLF | F. Muller | 1889 |
| MlbO | MLO | *Melbourne Observatory* | 1873—1898 |
| — | MLR | P. Muller | 1938—1997 |
| — | MOC | C. Moutou | 2017 |
| — | MRI | E.R. Masa Martin | 2005—2015 |
| — | MRN | L. Marion | 2014 |
| — | MRZ | W. Markowitz | 1956—1969 |
| — | MSH | T. Meshkat | 2015 |
| — | MUA | A. Muller | 2011 |
| — | MUG | M. Mugrauer | 2004—2020 |
| — | MWT | D. Mawet | 2011—2015 |
| — | MZA | J. Maiz-Apellaniz | 2007—2020 |
| — | NAJ | T. Nakajima | 1989—1995 |
| — | NHR | R. Neuhauser | 2000—2011 |
| — | NLS | E.L. Nielsen | 2010—2016 |
| — | NOI | *Navy Prototype/Precision Optical Interferometer* | 1997—2019 |
| — | NOR | J.R. North | 2007 |
| — | NOV | B. Novakovic | 2005—2008 |
| — | NSE | P. Nisenson | 1985 |
| — | NSN | J. Nanson | 2013—2018 |
| — | NVL | I. Novalbos | 2009—2016 |
| — | NYS | O. Nys | 1963—1983 |
| NZO | NZO | *New Zealand Observatory* | 1911 |
| — | OCC | *Occult. Doubles Cat.* | 1971— |
| — | ODE | M. Odenkirchen | 1995—1997 |
| — | OL | C.P. Olivier | 1907—1957 |
| — | OLE | D. Olevic | 1970—2006 |
| — | ONL | *Occult. News Letters* | |
| — | OPI | E. Opik | 1927—1932 |
| — | ORL | V.G. Orlov | 2007— |
| — | OSO | M.R. Zapatero Osorio | 2004—2010 |
| — | OSV | V. Osvalds | 1957—1964 |
| — | OSW | T.D. Oswalt | 1988—2012 |
| — | OUD | R.D. Oudmaijer | 2010 |
| — | PAR | J.A. Parkhurst | 1932 |
| — | PAT | J. Patience | 1998—2008 |
| — | PBL | T. Pribulla | 2006—2018 |
| — | PBS | T. Preibisch | 1999—2014 |
| Pck | PCK | E. Pickering | 1879—1912 |
| — | PEA | F.G. Pease | 1925—1927 |
| Per | PER | J. Perrotin | 1883—1887 |
| — | PES | S. Peretti | 2019 |
| — | PET | D. Peter | 2012 |
| — | PIC | W.H. Pickering | 1900—1937 |
| — | PIN | D.J. Pinfield | 2006—2012 |
| — | PKO | *Pulkova Observatory* | 1965— |
| — | PLQ | E. Paloque | 1923—1939 |
| — | PLT | L. Plaut | 1934—1940 |

| | | | | |
|---|---|---|---|---|
| — | PNT | | L.R. de Pont | 2012— |
| Pol | POL | | J.A. Pollock | 1887 |
| — | POP | | G.M. Popovic | 1967—2007 |
| — | POT | | D. Potter | 2002 |
| — | POU | | M.A. Pourteau | 1933 |
| — | PRB | | R.G. Probst | 2006 |
| Prn | PRN | | C.D. Perrine | 1899—1900 |
| PrO | PRO | | *Perth Observatory* | 1913 |
| — | PRU | | J.-L. Prieur | 2001—2017 |
| Pry | PRY | | J.J.M. Perry | 1880—1886 |
| — | PRZ | | E. Przbyllok | 1908—1926 |
| — | PSF | | *Project Sixteen Forty* | |
| — | PTI | | *Palomar Testbed Interferometer* | 2001—2004 |
| — | PTR | | M.G. Petr | 1998 |
| Pwl | PWL | | E.B. Powell | 1854—1892 |
| — | PWS | | T. Pauwels and P. Lampens | 1993 |
| Pz | PZ | | G. Piazzi | 1814 |
| R | R | | H.C. Russell | 1871—1892 |
| — | RAG | | D. Raghavan | 2004—2010 |
| — | RAO | | *Robo AO project* | 2014—2020 |
| — | RAS | | D.A. Rastegaev | 2007—2014 |
| — | RBR | | L.C. Roberts, Jr. | 2002—2018 |
| — | RBT | | J.G. Robertson | 1991—1999 |
| — | RCH | | A. Richichi | 1994—2020 |
| — | RDR | | D.R. Rodriguez | 2011—2015 |
| — | RED | | I.N. Reid | 1982—2008 |
| REI | REI | | K. Reinmuth | |
| — | REP | | B. Reipurth | 1986—2015 |
| — | REU | | D. Reuyl | 1931—1945 |
| — | RGS | | T.J. Rodigas | 2014—2016 |
| Rhd | RHD | | Father Richaud | 1729 |
| — | RIZ | | A.C. Rizzuto | 2013—2020 |
| — | RJJ | | J. Rajagopal | 2010 |
| Rmk | RMK | | C. Rumker | 1825—1837 |
| — | RMU | | J. Rameau | 2013 |
| — | ROE | | E.D. Roe | 1908—1919 |
| — | ROL | | T. Roell | 2012 |
| — | RSS | | J.M. Rousseau | 1996 |
| — | RST | | R.A. Rossiter | 1933—1964 |
| — | RUC | | S.M. Rucinski | 2007—2010 |
| S | S | | J. South | 1826—1825 |
| — | SAN | | R.F. Sanford | 1921—1940 |
| — | SAO | | *Special Astrophysical Observatory* | 2017 |
| — | SBK | | G.M. Seabroke | 1881—1910 |
| — | SBN | | E. Serabyn | 2006—2010 |
| — | SCA | | M. Scardia | 1979—2020 |
| — | SCE | | A. Schneider | 2011 |
| — | SCJ | | H. Schjellerup | 1906 |
| — | SCO | | M. Scholler | 1996—2020 |
| — | SCP | | C. Schnupp | 2010 |
| — | SCZ | | A.B. Schultz | 1998 |
| — | SDK | | N. Sanduleak | 1990 |
| — | SDR | | W.L. Sanders | 1966 |
| — | SDT | | T.O.B. Schmidt | 2008—2013 |
| Se | SE | | A. Secchi | 1855—1865 |
| λ | SEE | * | T.J.J. See | 1892—1900 |

| | | | | |
|---|---|---|---|---|
| — | SEI | | J. Scheiner | 1908 |
| Shb | SHB | | J.M. Schaeberle | 1893—1897 |
| Sh | SHJ | | J. South and J. Herschel | 1821—1840 |
| — | SHN | | G. Schneider | 1993—2004 |
| — | SHT | | N.I. Shatsky | 1998—2014 |
| — | SHY | | E.J. Shaya | 2011 |
| — | SIN | | D. Sinachopoulos | 1988—2007 |
| — | SKF | | B.A. Skiff | 2000— |
| Ski | SKI | | A.N. Skinner | 1872—1911 |
| — | SLE | | G. Soulie | 1966—2007 |
| Slr | SLR | | R.P. Sellors | 1892—1910 |
| — | SMA | | W.M. Smart | 1931—1932 |
| — | SMK | | P.C. Schmidtke | 1984—2011 |
| — | SML | | L.C. Smith | 2015 |
| — | SMR | | J. Schlimmer | 2007— |
| — | SMW | | G.V. Simonov | 1937—1951 |
| Smyth | SMY | | W.H. Smyth | 1833—1860 |
| — | SNA | | H. Sana | 2006—2014 |
| — | SOZ | | R.-D. Scholz | 2003—2017 |
| Sp | SP | | J.V. Schiaparelli | 1876—1909 |
| — | SPM | | *Springbook Middle School* | 2021 |
| — | SRT | | R. Shuart | 2005 |
| — | SRW | | R.W. Sinnott | 1999 |
| — | SS | | S. Sharpless | 1954 |
| — | ST | | C.L. Stearns | 1936—1939 |
| — | STA | | G.A. Starikova | 1962—1985 |
| — | STE | | C.B. Stephenson | 1965—1988 |
| Σ | STF | * | F. Wilhelm von Struve | 1814—1843 |
| Σ I, Σ II | STFA, STFB | * | *(Supplemental catalogs)* | 1814—1843 |
| — | STG | | G. Struve | 1932—1963 |
| — | STH | | H. Struve | 1901—1913 |
| — | STI | | J. Stein | 1926 |
| — | STJ | | J. Serot | 2009—2019 |
| Stone | STN | | O. Stone | 1867—1882 |
| ОΣ | STT | * | O. von Struve | 1832—1878 |
| ОΣΣ | STTA | * | *(Supplemental catalogs)* | 1832—1878 |
| — | STU | | K. Sturdy | 1984—1994 |
| — | STZ | | M.F. Sterzik | 1997—2005 |
| — | SUB | | J.P. Subasavage | 2005—2017 |
| — | SUN | | G. Sun | 2020 |
| SWI | SWI | | L. Swift | |
| — | SWR | | J. Stock | 1972—1997 |
| SyO | SYO | | *Sydney Observatory* | 1927—1986 |
| — | SZA | | T.B. Souza | 2020 |
| — | TAM | | V.S. Tamazian | 1999—2008 |
| Tar | TAR | | K.J. Tarrant | 1886—1893 |
| — | TDS, TDT | | *Tycho Double Star* | |
| — | THA | | C. Thalmann | 2009 |
| — | THB | | F. Thiebaut | 1995 |
| — | THP | | B. Thompson | 2006—2014 |
| — | TKA | | V.V. Tel'nyuk-Adamchuk | 1966 |
| — | TNG | | W.J. Tango | 1979—2009 |
| — | TNN | | A.M. Tanner | 2010 |
| — | TOB | | T. Tobal | 2000—2016 |
| — | TOI | | *TOI Numbers* from Stassun et al. | 2010 |
| — | TOK | | A.A. Tokovinin | 1979— |
| — | TOR | | *Torino Observatory* | 1978—1992 |

| | TRA | V. Trajkovska | 1999 |
|---|---|---|---|
| — | TRA | V. Trajkovska | 1999 |
| — | TRN | N.H. Turner | 1999—2010 |
| — | TRR | G. Torres | 1985—2020 |
| Tuc | TUC | R.H. Tucker | 1893 |
| — | TVB | T.V. Bryant | 2014—2019 |
| — | UC | *USNO CCD Astrographic Catalog (UCAC1, UCAC2, UCAC3, UCAC4)* | 2013—2015 |
| Upt | UPT | W. Upton | 1877—1878 |
| — | UR | *USNO Robotic Astrometric Telescope (URAT)* | 2015—2016 |
| — | USD | *US Numbers* from Esplin et al. | 2005—2018 |
| — | VAS | G. Vaskuti | 2011—2012 |
| — | VBS | G. Van Biesbroeck | 1904—1965 |
| — | VDK | J. Vanderdonck | 1909—1944 |
| — | VGT | N. Vogt | 2012—2015 |
| — | VIG | A. Vigan | 2012—2016 |
| — | VKI | E. Vilkki | 1984—1989 |
| — | VLM | W. Vollmann | 2006—2016 |
| — | VOU | J.G. Voute | 1908—1956 |
| — | VSP | *VLT + SPHERE* | 2019— |
| VVO | VVO | *Van Vleck Observatory* | 1962—1993 |
| — | VVV | *Vista Variables in Via Lactea* | |
| — | VYS | A.N. Vyssotsky | 1927—1956 |
| — | WAK | R.L. Walker | 1966—1985 |
| — | WAL | A. Wallenquist | 1934—1958 |
| — | WCK | W.C. Wickes | 1973—1975 |
| — | WDK | K. Patience Ward-Duong | 2015 |
| Webb | WEB | T.W. Webb | |
| — | WEI | M. Weisse | 1906 |
| — | WFC | *Washington Fundamental Cat. - astrographs* | 1939—1999 |
| — | WG | R.W. Wrigley | 1911 |
| — | WGA | G.A.H. Walker | 1994 |
| — | WGK | K. Wagner | 2016—2018 |
| — | WGT | G.P. Weigelt | 1978—2002 |
| WHC | WHC | H.C. Wilson | 1890 |
| — | WHI | G.L. White | 1991—2019 |
| — | WIL | J.C. Wilson | 2001 |
| — | WIR | C.A. Wirtanen | 1941—1981 |
| — | WIS | *Wide-field Infrared Survey Explorer* | 2010—2016 |
| — | WLF | Wolf | 1913 |
| Wnc | WNC | F.A. Winnecke | 1855—1909 |
| WNO | WNO | *Washington Naval Observatory* | 1866—1896 |
| — | WOR | C.E. Worley | 1956—2001 |
| Wrd | WRD | I.W. Ward | 1876—1878 |
| — | WRH | R.H. Wilson | 1933—1982 |
| — | WRS | K. Wierzchos | 2017—2019 |
| WS | WS | J.M. Wilson | 1875—1877 |
| — | WSI | *Washington Speckle Interferometer* | 1997— |
| — | WTT | J.M. Wittrock | 2016—2017 |
| — | WZ | C. Wirtz | 1912—1923 |
| — | XMI | X. Miret | 2007—2016 |
| Yng | YNG | C.A. Young | 1881—1887 |
| — | YR | *Yale-Rochester Collaboration* | |
| — | YSC | *Yale-Southern Connecticut Collaboration* | |

| — | YSJ | | *Yale-San Juan Collaboration* | |
|---|-----|---|------------------------------|---|
| — | ZHN | | Z.H. Zhang | 2010—2013 |
| — | ZUC | | B. Zuckerman | 1992—2001 |
| — | ZUL | | D.J. Zulevic | 1967—2000 |

Table C.9: Additional designations for double stars

## C.5 Cross-Identification Data

Stellarium supports cross-identification between stars from Hipparcos (HIP) (Anderson and Francis, 2012), Smithsonian Astrophysical Observatory (SAO) Star Catalog J2000.0 (SAO Staff, 1995), Henry Draper Catalogue and Extension (HD) (Cannon and Pickering, 1993) and *Catalogue of bright stars* (Hoffleit, 1964) (BSC5 or HR) catalogues.

### C.5.1 Cross-Identification Catalog File Format

Stellarium's Cross-Identification catalog data is kept in the `stars/hip_gaia3` sub-directory of the Installation Directory and/or User Directory (see section 5.1).

#### C.5.1.1 File Format

The file `cross-id.cat` contains cross reference data for catalogues HIP, SAO, HD and HR, which are stored in a binary format.

| *Name* | *Type* | *Description* |
|--------|--------|---------------|
| HIP | uint64_t | HIP or Gaia identifier for the star. Used for reference to the main star catalogue. |
| Component | unsigned char | Component of the star in the multiple star system. |
| SAO | int | SAO identifier for the star. |
| HD | int | HD identifier for the star. |
| HR | int | HR identifier for the star. |

Table C.10: Format of `cross-id.cat`

## C.6 Binary Star System Orbital Parameters

Since version 25.1 Stellarium supports modelling orbital motion of a handful of binary stars. These include      v 25.1

- $\alpha$ Centauri A & B
- Sirius A & B
- 61 Cygni A & B
- $\gamma$ Virginis A & B
- Alula Australis A & B
- Achird A & B
- $\varepsilon$1 Lyr A & B
- $\varepsilon$2 Lyr A & B
- $\beta$ Mus A & B
- Dalim A & B
- $\psi$ Vel A & B
- $\rho$ Oph A & B
- $\zeta$ Her A & B
- $\eta$ Oph A & B

### C.6.1 Binary Star System Orbital Parameters Catalog File Format

Stellarium's Binary Star System Orbital Parameters catalog data is kept in the `stars/hip_gaia3` sub-directory of the Installation Directory and/or User Directory (see section 5.1).

#### C.6.1.1 File Format

The file `binary_orbitparam.dat` contains binary system orbital parameter data, which are stored in plain text format (C.11).

| *Name* | *Type* | *Description* |
|---|---|---|
| binary period $p$ | double | Orbital period [days] |
| eccentricity $e$ | float | Eccentricity |
| inclination $i$ | float | Orbit inclination [rad] |
| big omega $\Omega$ | float | Position angle of ascending node [rad] |
| small omega $\omega$ | float | Argument of periastron [rad] |
| periastron epoch $JD$ | double | Julian Date at periastron passage |
| semi major $a$ | double | Angular semi-major axis [arcsec] |
| bary distance $\Delta$ | double | distance [parsec] |
| data epoch $E$ | double | Julian Date of the data |
| bary ra $\alpha$ | double | Right Ascension of the barycenter [rad] |
| bary dec $\delta$ | double | Declination of the barycenter [rad] |
| bary rv $RV$ | double | Barycenter radial velocity [km/s] |
| primary mass $m_0$ | float | Primary star mass [solar mass] |
| secondary mass $m_1$ | float | Secondary star mass [solar mass] |
| bary pmra $\dot{\alpha}$ | double | Barycenter RA proper motion [mas/yr] |
| bary pmdec $\dot{\delta}$ | double | Barycenter DEC proper motion [mas/yr] |

Table C.11: Format of `binary_orbitparam.dat`

# D. Configuration Files

## D.1 Program Configuration

First, see 5.4 (The Main Configuration File) for information about the file `config.ini`, including its default installed location, and command line options that can affect how it is processed.

The file `config.ini` (or a file which you can load instead with the `--config <file>` option) is structured into the following parts. In addition, plugins can add a section named like the plugin (Exception: The Text User Interface plugin's section is named `[tui]` for historical reasons).

### D.1.1 [astro]

This section includes settings for the commonly displayed objects.

| ID | Type | Default | Description |
|---|---|---|---|
| apparent_magnitude_algorithm | string | Mallama2018 | Set algorithm for computation of apparent magnitude of the planets. Possible values: *Mallama2018*, *ExpSup2013*, *ExpSup1992*, *AstrAlm1984*, *Mueller1893* and *Generic*. |
| nebula_magnitude_limit | float | 8.5 | Value of limiting magnitude for the deep-sky objects. |
| star_magnitude_limit | float | 6.5 | Value of limiting magnitude for the stars. Sometimes you don't want to display more stars when zooming in. |
| planet_magnitude_limit | float | 6.5 | Value of limiting magnitude for the planets. Sometimes you don't want to display more planets when zooming in. |
| planets_orbits_color_style | string | one_color | Set the style of orbits color. Possible values: *one_color*, *groups* and *max*. |
| flag_nebula_magnitude_limit | bool | false | Set to *true* to activate limit for showing deep-sky objects. |
| flag_star_magnitude_limit | bool | false | Set to *true* to activate limit for showing stars |
| flag_planet_magnitude_limit | bool | false | Set to *true* to activate limit for showing planets. |
| extinction_mode_below_horizon | string | zero | Set extinction mode for atmosphere below horizon. Possible values: *zero*, *mirror* and *max*. |

| | | | |
|---|---|---|---|
| twilight_altitude | float | -6.0 | Solar altitude for going to previous/next twilight. |
| flag_stars | bool | true | Set to *false* to hide the stars on start-up |
| flag_star_name | bool | true | Set to *false* to hide the star labels on start-up |
| flag_star_additional_names | bool | true | Set *true* to use all available proper names for stars. |
| flag_star_designation_usage | bool | false | If *true*, use designations of stars on the sky (on-screen labels) instead of their common names. |
| flag_star_designation_dbl | bool | false | If *true*, and star doesn't have common name and Bayer or Flamsteed designations then use first of traditional designations of double stars to the on-screen labels. |
| flag_star_designation_var | bool | false | If *true*, and star doesn't have common name or Bayer, Flamsteed or double star designation then use designation of variable stars as the on-screen label. |
| flag_star_designation_hip | bool | false | If *true*, use HIP designations of stars for the on-screen labels if common name or traditional designations do not exist for star. |
| flag_planets | bool | true | Set to *false* to hide the planet labels on start-up |
| flag_planets_hints | bool | true | Set to *false* to hide the planet hints on startup (names and circular highlights) |
| flag_planets_orbits | bool | false | Set to *true* to show the planet orbits on startup |
| flag_permanent_orbits | bool | false | Set to *true* to show the orbit of planet, when planet is out of the viewport also. |
| flag_planets_pointers | bool | false | Set to *true* to show the planet pointer markers on startup |
| flag_planets_nomenclature | bool | false | Set to *true* to show the planetary nomenclature markers and labels |
| flag_planets_nomenclature_... terminator_only | bool | false | Set to *true* to show only items along the terminator |
| planet_nomenclature_... solar_altitude_min | int | -5 | minimum solar altitude for the terminator setting above |
| solar_altitude_max | int | 40 | maximum solar altitude for the terminator setting above |
| flag_hide_local_nomenclature | bool | true | Set to *true* to hide the planetary nomenclature items on the observer's celestial body |
| flag_light_travel_time | bool | true | Should be *true* to improve accuracy in the movement of the planets by compensating for the time it takes for light to travel. This has a slight impact on performance, but is essential e.g. for Jupiter's moons. |
| flag_object_trails | bool | false | Turns on and off drawing of object trails (which show the movement of the planets over time). |

| | | | |
|---|---|---|---|
| flag_nebula | bool | true | Set to *false* to hide the nebulae on start-up. |
| flag_nebula_name | bool | false | Set to *true* to show the nebula labels on start-up. |
| flag_nebula_display_no_texture | bool | false | Set to *true* to suppress displaying of nebula textures. |
| nebula_texture_decimation | int | 1 | Reduce nebula texture size by this factor [1...8]. May help on very limited systems. |
| nebula_hints_amount | float | 3.0 | Sets the amount of hints [0...10]. |
| nebula_labels_amount | float | 3.0 | Sets the amount of labels [0...10]. |
| flag_milky_way | bool | true | Set to *false* to hide the Milky Way. |
| milky_way_color | Color | 1.0,1.0,1.0 ☐ | Base color of the Milky Way. |
| milky_way_intensity | float | 1.0 | Sets the relative brightness with which the milky way is drawn. Typical [1...3]. |
| milky_way_saturation | float | 1.0 | Sets the color saturation with which the milky way is drawn [0...1]. |
| flag_zodiacal_light | bool | true | Set to *false* to hide the zodiacal light |
| zodiacal_light_color | Color | 1.0,0.0,1.0 ■ | Base color of the Zodiacal Light. |
| zodiacal_light_intensity | float | 1.0 | Sets the relative brightness with which the zodiacal light is drawn. |
| max_mag_nebula_name | float | 8.0 | Sets the magnitude of the nebulae whose name is shown. |
| flag_nebula_hints_proportional | bool | false | Enables/disables proportional markers for deep-sky objects. |
| flag_surface_brightness_usage | bool | false | Enables/disables usage surface brightness for markers for deep-sky objects. |
| flag_size_limits_usage | bool | false | Enables/disables usage angular size filter for markers for deep-sky objects. |
| size_limit_min | int | 1 | Minimal angular size of visible deep-sky objects in arcminutes. |
| size_limit_max | int | 600 | Maximum angular size of visible deep-sky objects in arcminutes. |
| flag_use_type_filter | bool | false | Enables/disables usage of the type filters for deep-sky objects. |
| flag_nutation | bool | true | Enables/disables usage nutation. |
| flag_topocentric_coordinates | bool | true | Enables/disables usage topocentric co-ordinates. |
| shadow_enlargement_danjon | bool | false | Earth shadow enlargement (see 19.11.2). |
| flag_dso_designation_usage | bool | false | If *true*, use designations of deep-sky objects on the sky instead of their common names. |
| flag_dso_outlines_usage | bool | false | If *true*, use outlines for big deep-sky objects on the sky instead of their hints. |
| flag_dso_additional_names | bool | true | Set *true* to use additional names (also known as) for deep-sky objects. |
| flag_dso_show_only_named | bool | false | If *true*, only show deep-sky objects with names, hiding those with only designations. |
| grs_longitude | int | 216 | Longitude (System II) of Great Red Spot on Jupiter in degrees. |

| | | | |
|---|---|---|---|
| grs_drift | float | 15.0 | Annual drift of Great Red Spot on Jupiter in degrees. |
| grs_jd | float | 2456901.5 | Initial JD for calculation of position of Great Red Spot on Jupiter. |
| grs_measurements_url | string | | URL of recent measurements of GRS' position[1]. |
| meteor_zhr | int | 10 | ZHR for sporadic meteors. |
| de430_path | string | | Path to JPL DE430 ephemerides file. |
| flag_use_de430 | bool | false | Enables/disables usage JPL DE430 ephemerides (if available). |
| de431_path | string | | Path to JPL DE431 ephemerides file. |
| flag_use_de431 | bool | false | Enables/disables usage JPL DE431 ephemerides (if available). |
| flag_toast_survey | bool | false | Enables/disables Digitized Sky Survey in TOAST format. |
| toast_survey_host | string | | Host of Digitized Sky Survey storage data. |
| toast_survey_directory | string | results | Directory name of Digitized Sky Survey storage data. |
| toast_survey_levels | int | 11 | Count of levels for Digitized Sky Survey storage data. |

## D.1.2 ⌈astrocalc⌉

This section includes settings for the Astronomical Calculations feature.

| *ID* | *Type* | *Default* | *Description* |
|---|---|---|---|
| flag_ephemeris_markers | bool | true | Set to *true* to show the calculated ephemeris markers for Solar system bodies. |
| flag_ephemeris_line | bool | false | Set to *true* to show the connecting line between the ephemeris markers. |
| flag_ephemeris_dates | bool | false | Set to *true* to show the dates of calculated ephemeris for Solar system bodies. |
| flag_ephemeris_magnitudes | bool | false | Set to *true* to show the magnitude of Solar system body for the calculated ephemeride. |
| flag_ephemeris_horizontal | bool | false | Set to *true* to use horizontal coordinates for ephemerides. |
| flag_ephemeris_skip_data | bool | false | Set to *true* to skip the showing data near ephemeris markers. |
| flag_ephemeris_smart_dates | bool | true | Set to *true* to use smart format for dates, who showing near ephemeris markers. |
| flag_ephemeris_scale_markers | bool | false | Set to *true* to use small ephemeris markers, when line is enabled. |
| ephemeris_celestial_body | string | Moon | Default celestial body for computation of ephemerides. |
| ephemeris_time_step | int | 6 | Identificator for time step category. |
| ephemeris_data_step | int | 0 | Value of skipping step when skipping option is enabled (label each N steps, where N is step). |
| celestial_magnitude_limit | float | 6.0 | Value of limiting magnitude for the celestial objects in computation of their positions. |
| celestial_category | int | 200 | Identificator for default category of celestial bodies. |

---

[1]Default value is `http://jupos.privat.t-online.de/rGrs.htm`

| | | | |
|---|---|---|---|
| flag_horizontal_coordinates | bool | false | Set to *true* to use horizontal coordinates for compute of positions for the celestial objects. |
| flag_phenomena_opposition | bool | false | Set to *true* to compute of opposition phenomenon between the Solar system bodies. |
| flag_phenomena_perihelion | bool | false | Set to *true* to compute perihelion and aphelion for Solar system bodies (except moons). |
| phenomena_angular_separation | float | 1.0 | Allowed angular separation between celestial bodies for computation of phenomena. |
| phenomena_celestial_body | string | Venus | Default celestial body for computation of phenomena. |
| phenomena_celestial_group | int | 0 | Identificator for group of celestial bodies for computation of phenomena. |
| wut_magnitude_limit | float | 10.0 | Value of limiting magnitude for calculations within What's Up Tonight feature. |
| wut_time_interval | int | 0 | Identificator for time interval within What's Up Tonight feature computations. |
| wut_angular_limit_flag | bool | false | Set to *true* to use the angular size filter. |
| wut_angular_limit_min | float | 1.0 | Minimal allowed angular size, arcminutes. |
| wut_angular_limit_max | float | 600.0 | Maximal allowed angular size, arcminutes. |
| wut_altitude_min | float | 0.0 | Minimal allowed altitude for compute rise and set times, degrees. |
| graphs_celestial_body | string | Moon | Default celestial body for draw of graphs. |
| graphs_duration | int | 1 | How much years account into calculation of graphs. |
| graphs_first_id | int | 1 | Identificator for left graph (blue line). |
| graphs_second_id | int | 2 | Identificator for right graph (yellow line). |

## D.1.3 [audio]

This section includes settings for Audio features.

| ID | Type | Default | Description |
|---|---|---|---|
| enabled | bool | true | Enable sound output |

## D.1.4 [color]

This section defines the RGB colors for the various objects, lines, grids, labels etc. Values are given in float from 0 to 1. e.g. *1.0,1.0,1.0* for white, or *1,0,0* for red. Leave no whitespace between the numbers!

| ID | Default | | Colour of the. . . |
|---|---|---|---|
| default_color | 0.5,0.5,0.7 | | default colour. |
| daylight_text_color | 0.0,0.0,0.0 | | info text at daylight. |
| info_text_color | 1.0,1.0,1.0 | | info text color when overwrite mode for text color is enabled. |
| sky_background_color | 0.0,0.0,0.0 | | sky background (non-black is useful for artists only). |
| ecliptical_J2000_color | 0.4,0.1,0.1 | | ecliptical grid (J2000.0 frame). |
| ecliptic_J2000_color | 0.7,0.2,0.2 | | ecliptic line (J2000.0 frame). |
| equinox_J2000_points_color | 0.7,0.2,0.2 | | equinox points (J2000.0 frame). |
| solstice_J2000_points_color | 0.7,0.2,0.2 | | solstice points (J2000.0 frame). |
| ecliptic_J2000_poles_color | 0.7,0.2,0.2 | | ecliptic poles (J2000.0 frame). |
| ecliptical_color | 0.6,0.3,0.1 | | ecliptical grid (of date). |

| | | | |
|---|---|---|---|
| ecliptic_color | 0.9,0.6,0.2 | | ecliptic line (of date). |
| equinox_points_color | 0.9,0.6,0.2 | | equinox points (of date). |
| solstice_points_color | 0.9,0.6,0.2 | | solstice points (of date). |
| ecliptic_poles_color | 0.9,0.6,0.2 | | ecliptic poles (of date). |
| precession_circles_color | 0.9,0.6,0.2 | | precession circles. |
| equator_J2000_color | 0.2,0.2,0.6 | | equator line (J2000.0 frame). |
| equatorial_J2000_color | 0.1,0.1,0.5 | | equatorial grid (J2000.0 frame). |
| celestial_J2000_poles_color | 0.2,0.2,0.6 | | celestial poles (J2000.0 frame). |
| equator_color | 0.3,0.5,1.0 | | equator line (of date). |
| equatorial_color | 0.2,0.3,0.8 | | equatorial grid (of date). |
| celestial_poles_color | 0.3,0.5,1.0 | | celestial poles (of date). |
| circumpolar_circles_color | 0.3,0.5,1.0 | | circumpolar circles. |
| fixed_equator_color | 0.5,0.5,0.7 | | fixed equator (hour angle) line. |
| fixed_equatorial_color | 0.5,0.5,0.7 | | fixed equatorial grid. |
| galactic_color | 0.3,0.2,0.1 | | galactic grid. |
| galactic_equator_color | 0.5,0.3,0.1 | | galactic equator line. |
| galactic_poles_color | 0.5,0.3,0.1 | | galactic poles. |
| supergalactic_color | 0.2,0.2,0.2 | | supergalactic grid. |
| supergalactic_equator_color | 0.4,0.4,0.4 | | supergalactic equator line. |
| supergalactic_poles_color | 0.4,0.4,0.4 | | supergalactic poles. |
| azimuthal_color | 0.0,0.3,0.2 | | azimuthal grid. |
| horizon_color | 0.2,0.6,0.2 | | horizon line. |
| meridian_color | 0.2,0.6,0.2 | | meridian line. |
| prime_vertical_color | 0.2,0.5,0.2 | | prime vertical. |
| zenith_nadir_color | 0.2,0.6,0.2 | | zenith and nadir. |
| cardinal_color | 0.8,0.2,0.1 | | cardinal points. |
| colures_color | 0.5,0.0,0.5 | | colures. |
| antisolar_point_color | 0.9,0.3,0.5 | | antisolar point. |
| apex_points_color | 0.8,0.2,0.3 | | apex points. |
| oc_longitude_color | 0.6,0.2,0.4 | | opposition/conjunction longitude. |
| quadrature_color | 0.6,0.2,0.4 | | quadrature circle. |
| const_lines_color | 0.2,0.2,0.6 | | constellation lines. |
| const_names_color | 0.4,0.6,0.9 | | constellation names. |
| const_boundary_color | 0.8,0.3,0.3 | | constellation boundaries. |
| const_hulls_color | 0.6,0.2,0.2 | | constellation areas (convex hulls). |
| asterism_lines_color | 0.4,0.4,0.8 | | asterism lines. |
| asterism_names_color | 0.4,0.4,0.8 | | asterism names. |
| rayhelper_lines_color | 1.0,1.0,0.0 | | the ray helper lines. |
| skyculture_zodiac_color | 1.0,1.0,0.0 | | Zodiac band. |
| skyculture_lunarsystem_color | 0.0,1.0,0.5 | | Band/boundaries of Lunar stations / mansions. |
| dso_label_color | 0.2,0.6,0.7 | | deep-sky objects labels. |
| dso_circle_color | 1.0,0.7,0.2 | | deep-sky objects symbols, if not of the types below. |
| dso_region_color | 0.7,0.7,0.2 | | regions symbols. |
| dso_galaxy_color | 1.0,0.2,0.2 | | galaxies symbols. |
| dso_radio_galaxy_color | 0.3,0.3,0.3 | | radio galaxies symbols. |

| dso_active_galaxy_color | 1.0,0.5,0.2 | | active galaxies symbols. |
|---|---|---|---|
| dso_interacting_galaxy_color | 0.2,0.8,1.0 | | clusters of galaxies symbols. |
| dso_galaxy_cluster_color | 0.2,0.5,1.0 | | interacting galaxies symbols. |
| dso_quasar_color | 1.0,0.2,0.2 | | quasars symbols. |
| dso_possible_quasar_color | 1.0,0.2,0.2 | | possible quasars symbols. |
| dso_bl_lac_color | 1.0,0.2,0.2 | | BL Lac objects symbols. |
| dso_blazar_color | 1.0,0.2,0.2 | | blazars symbols. |
| dso_nebula_color | 0.1,1.0,0.1 | | nebulae symbols. |
| dso_planetary_nebula_color | 0.1,1.0,0.1 | | planetary nebulae symbols. |
| dso_reflection_nebula_color | 0.1,1.0,0.1 | | reflection nebulae symbols. |
| dso_bipolar_nebula_color | 0.1,1.0,0.1 | | bipolar nebulae symbols. |
| dso_emission_nebula_color | 0.1,1.0,0.1 | | emission nebulae symbols. |
| dso_dark_nebula_color | 0.3,0.3,0.3 | | dark nebulae symbols. |
| dso_hydrogen_region_color | 0.1,1.0,0.1 | | hydrogen regions symbols. |
| dso_supernova_remnant_color | 0.1,1.0,0.1 | | supernovae remnants symbols. |
| dso_supernova_candidate_color | 0.1,1.0,0.1 | | supernova candidates symbols. |
| dso_supernova_remnant_cand_color | 0.1,1.0,0.1 | | supernova remnant candidates symbols. |
| dso_interstellar_matter_color | 0.1,1.0,0.1 | | interstellar matter symbols. |
| dso_molecular_cloud_color | 0.1,1.0,0.1 | | molecular clouds symbols. |
| dso_possible_planetary_nebula_color | 0.1,1.0,0.1 | | possible planetary nebulae symbols. |
| dso_protoplanetary_nebula_color | 0.1,1.0,0.1 | | protoplanetary nebulae symbols. |
| dso_cluster_color | 1.0,1.0,0.1 | | star clusters symbols. |
| dso_open_cluster_color | 1.0,1.0,0.1 | | open star clusters symbols. |
| dso_globular_cluster_color | 1.0,1.0,0.1 | | globular star clusters symbols. |
| dso_stellar_association_color | 1.0,1.0,0.1 | | stellar associations symbols. |
| dso_star_cloud_color | 1.0,1.0,0.1 | | star clouds symbols. |
| dso_star_color | 1.0,0.7,0.2 | | star symbols. |
| dso_symbiotic_star_color | 1.0,0.7,0.2 | | symbiotic star symbols. |
| dso_emission_star_color | 1.0,0.7,0.2 | | emission-line star symbols. |
| dso_emission_object_color | 1.0,0.7,0.2 | | emission objects symbols. |
| dso_young_stellar_object_color | 1.0,0.7,0.2 | | young stellar objects symbols. |
| planet_names_color | 0.5,0.5,0.7 | | planet names. |
| planet_pointers_color | 1.0,0.3,0.3 | | planet pointers. |
| planet_nomenclature_color | 0.1,1.0,0.1 | | planetary nomenclature hints and labels. |
| sso_orbits_color | 0.7,0.2,0.2 | | default orbits. |
| major_planet_orbits_color | 0.7,0.2,0.2 | | major planet orbits. |
| minor_planet_orbits_color | 0.7,0.5,0.5 | | minor planet orbits. |
| dwarf_planet_orbits_color | 0.7,0.5,0.5 | | dwarf planet orbits. |
| moon_orbits_color | 0.7,0.2,0.2 | | moon of planet orbits. |
| cubewano_orbits_color | 0.7,0.5,0.5 | | cubewano orbits. |
| plutino_orbits_color | 0.7,0.5,0.5 | | plutino orbits. |
| sdo_orbits_color | 0.7,0.5,0.5 | | scattered disk object orbits. |
| oco_orbits_color | 0.7,0.5,0.5 | | Oort cloud object orbits. |
| sednoid_orbits_color | 0.7,0.5,0.5 | | Sednoid object orbits. |
| interstellar_orbits_color | 1.0,0.6,1.0 | | Interstellar object "orbits" (trajectories). |
| comet_orbits_color | 0.7,0.8,0.8 | | comet orbits. |
| mercury_orbit_color | 0.5,0.5,0.5 | | orbit of Mercury. |
| venus_orbit_color | 0.9,0.9,0.7 | | orbit of Venus. |
| earth_orbit_color | 0.0,0.0,1.0 | | orbit of Earth. |
| mars_orbit_color | 0.8,0.4,0.1 | | orbit of Mars. |

| jupiter_orbit_color | 1.0,0.6,0.0 | | orbit of Jupiter. |
|---|---|---|---|
| saturn_orbit_color | 1.0,0.8,0.0 | | orbit of Saturn. |
| uranus_orbit_color | 0.0,0.7,1.0 | | orbit of Uranus. |
| neptune_orbit_color | 0.0,0.3,1.0 | | orbit of Neptune. |

| object_trails_color | 1.0,0.7,0.0 | | planet trails. |
|---|---|---|---|

| custom_marker_color | 0.1,1.0,0.1 | | custom marker. |
|---|---|---|---|

| script_console_keyword_color | 1.0,0.0,1.0 | | syntax highlight for keywords in the script console. |
|---|---|---|---|
| script_console_module_color | 0.0,1.0,1.0 | | syntax highlight for modules in the script console. |
| script_console_comment_color | 1.0,1.0,0.0 | | syntax highlight for comments in the script console. |
| script_console_function_color | 0.0,1.0,0.0 | | syntax highlight for functions in the script console. |
| script_console_constant_color | 1.0,0.5,0.5 | | syntax highlight for constants in the script console. |

| fov_center_marker_color | 0.5,0.5,0.7 | | FOV Center marker. |
|---|---|---|---|
| fov_circular_marker_color | 0.5,0.5,0.7 | | circular marker of FOV. |
| fov_rectangular_marker_color | 0.5,0.5,0.7 | | rectangular marker of FOV. |
| compass_marks_color | 0.5,0.5,0.7 | | compass marks. |

## D.1.5 [custom_selected_info]

You can fine-tune the bits of information to display for the selected object in this section. Set the entry to *true* to display it.

| ID | Type | Description |
|---|---|---|
| flag_show_name | bool | common name for object. |
| flag_show_catalognumber | bool | catalog designations for objects. |
| flag_show_type | bool | type of object. |
| flag_show_magnitude | bool | magnitude for object. |
| flag_show_absolutemagnitude | bool | absolute magnitude for objects. |
| flag_show_radecj2000 | bool | equatorial coordinates (J2000.0 frame) of object. |
| flag_show_radecofdate | bool | equatorial coordinates (of date) of object. |
| flag_show_hourangle | bool | hour angle for object. |
| flag_show_altaz | bool | horizontal coordinates for objects. |
| flag_show_eclcoordj2000 | bool | ecliptic coordinates (J2000.0 frame) of object. |
| flag_show_eclcoordofdate | bool | ecliptic coordinates (of date) of object. |
| flag_show_galcoord | bool | galactic coordinates (System II) of object. |
| flag_show_supergalcoord | bool | supergalactic coordinates of object. |
| flag_show_othercoord | bool | other coordinates of object (from plugins). |
| flag_show_constellation | bool | show 3-letter IAU constellation label. |
| flag_show_sidereal_time | bool | sidereal time. |
| flag_show_elongation | bool | elongation from the Sun for solar system objects. |
| flag_show_distance | bool | distance to object. |
| flag_show_velocity | bool | velocity of object. |
| flag_show_propermotion | bool | proper motion of object. |
| flag_show_size | bool | size of object. |
| flag_show_rts_time | bool | rise, transit and set times. |
| flag_show_solar_lunar | bool | horizontal coordinates for Sun and Moon. |
| flag_show_extra | bool | extra info for object. |

### D.1.6 [**custom_time_correction**]

Stellarium allows experiments with $\Delta T$. See 18.4.3 for details.

| ID | Type | Description |
|----|------|-------------|
| coefficients | [float,float,float] | Coefficients $a, b, c$ for custom equation of $\Delta T$ |
| ndot | float | n-dot value for custom equation of $\Delta T$ |
| year | int | Year for custom equation of $\Delta T$ |

### D.1.7 [**devel**]

This section is for developers only.

| ID | Type | Description |
|----|------|-------------|
| check_loading_constellation_data | bool | Set to *true* to check loading constellation data. This option is needed to debug new sky cultures. Default value: *false*. |
| convert_locations_list | bool | Set to *true* to convert file `base_locations.txt` into file `base_locations.bin`[2]. Default value: *false*. |
| convert_dso_catalog | bool | Set to *true* to convert file `catalog.txt` into file `catalog.dat`. Default value: *false*. |
| convert_dso_decimal_coord | bool | Set to *true* to use decimal values for coordinates in source catalog. Default value: *true*. |
| markers_to_logfile | bool | Write marker coordinates to logfile. Useful when developing dark constellations. See p. 115 |

### D.1.8 [**dso_catalog_filters**]

In this section you can fine-tune which of the deep-sky catalogs should be selected on startup.

| ID | Type | Default | Description |
|----|------|---------|-------------|
| flag_show_ngc | bool | true | New General Catalogue (NGC). |
| flag_show_ic | bool | true | Index Catalogue (IC). |
| flag_show_m | bool | true | Messier Catalog (M). |
| flag_show_c | bool | false | Caldwell Catalogue (C). |
| flag_show_b | bool | false | Barnard Catalogue (B). |
| flag_show_sh2 | bool | false | Sharpless Catalogue (SH2). |
| flag_show_vdb | bool | false | Van den Bergh Catalogue of reflection nebulae (vdB). |
| flag_show_rcw | bool | false | The RCW catalogue of H$\alpha$-emission regions in the southern Milky Way (RCW). |
| flag_show_lbn | bool | false | Lynds' Catalogue of Bright Nebulae (LBN). |
| flag_show_ldn | bool | false | Lynds' Catalogue of Dark Nebulae (LDN). |
| flag_show_cr | bool | false | Collinder Catalogue (Cr or Collinder). |
| flag_show_mel | bool | false | Melotte Catalogue of Deep Sky Objects (Mel or Melotte). |
| flag_show_pgc | bool | false | HYPERLEDA. I. Catalog of galaxies (PGC). |
| flag_show_ced | bool | false | Cederblad Catalog of bright diffuse Galactic nebulae (Ced). |
| flag_show_ugc | bool | false | The Uppsala General Catalogue of Galaxies (UGC). |
| flag_show_arp | bool | false | Atlas of Peculiar Galaxies (Arp). |
| flag_show_vv | bool | false | The Catalogue of Interacting Galaxies (VV). |
| flag_show_pk | bool | false | The Catalogue of Galactic Planetary Nebulae (PK). |
| flag_show_png | bool | false | The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (PN G). |
| flag_show_snrg | bool | false | A catalogue of Galactic supernova remnants (SNR G). |
| flag_show_aco | bool | false | A Catalog of Rich Clusters of Galaxies (Abell or ACO). |
| flag_show_hcg | bool | false | A Hickson Compact Group (HCG). |
| flag_show_eso | bool | false | ESO/Uppsala Survey of the ESO(B) Atlas (ESO). |
| flag_show_vdbh | bool | false | Catalogue of southern stars embedded in nebulosity (vdBH). |

---

[2]To get the standard packed `base_locations.bin.gz` file please run the command `gzip -nc base_locations.bin > base_locations.bin.gz`.

| | | | |
|---|---|---|---|
| flag_show_dwb | bool | false | Catalogue and distances of optically visible H II regions (DWB). |
| flag_show_tr | bool | false | Trumpler Catalogue (Tr or Trumpler). |
| flag_show_st | bool | false | Stock Catalogue (St or Stock). |
| flag_show_ru | bool | false | Ruprecht Catalogue (Ru or Ruprecht). |
| flag_show_vdbha | bool | false | van den Bergh-Hagen Catalogue (vdB-Ha). |
| flag_show_other | bool | true | All objects without identifiers. |

## D.1.9  [dso_type_filters]

In this section you can fine-tune which types of the deep-sky objects should be selected on startup.

| ID | Type | Default | Description |
|---|---|---|---|
| flag_show_galaxies | bool | true | display galaxies. |
| flag_show_active_galaxies | bool | true | display active galaxies. |
| flag_show_interacting_galaxies | bool | true | display interacting galaxies. |
| flag_show_open_clusters | bool | true | display open star clusters. |
| flag_show_globular_clusters | bool | true | display globular star clusters. |
| flag_show_bright_nebulae | bool | true | display bright nebulae. |
| flag_show_dark_nebulae | bool | true | display dark nebulae. |
| flag_show_planetary_nebulae | bool | true | display planetary nebulae. |
| flag_show_hydrogen_regions | bool | true | display hydrogen regions. |
| flag_show_supernova_remnants | bool | true | display supernovae remnants. |
| flag_show_galaxy_clusters | bool | true | display clusters of galaxies. |
| flag_show_other | bool | true | display other deep-sky objects. |

## D.1.10  [fov]

In this section you can fine-tune 10 predefined values of field of view in degrees (all FOV may be set through keyboard hotkeys, see section 3.2).

| ID | Type | Default | Description |
|---|---|---|---|
| quick_fov_1 | float | 180 | predefined value for FOV *1*. |
| quick_fov_2 | float | 90 | predefined value for FOV *2*. |
| quick_fov_3 | float | 60 | predefined value for FOV *3*. |
| quick_fov_4 | float | 45 | predefined value for FOV *4*. |
| quick_fov_5 | float | 20 | predefined value for FOV *5*. |
| quick_fov_6 | float | 10 | predefined value for FOV *6*. |
| quick_fov_7 | float | 5 | predefined value for FOV *7*. |
| quick_fov_8 | float | 2 | predefined value for FOV *8*. |
| quick_fov_9 | float | 1 | predefined value for FOV *9*. |
| quick_fov_0 | float | 0.5 | predefined value for FOV *0*. |

## D.1.11  [gui]

This section includes settings for the graphical user interface. See sections 4.3.3–4.3.5 for most of these keys.

| ID | Type | Default | Description |
|---|---|---|---|
| flag_show_gui | bool | true | If *true*, display GUI. |
| screen_font_size | int | 13 | Sets the font size for screen texts. Typical value: *13..15* |
| gui_font_size | int | 13 | Sets the dialog font size. Typical value: *10..20* |
| base_font_name | string | Verdana (Windows) DejaVu Sans (others) | Selects the name for base font |
| base_font_file | string | | Selects the name for font file, e.g. *DejaVuSans.ttf* |

| flag_font_selection | bool | false | Show GUI elements for font selection. |
|---|---|---|---|
| immediate_save_details | bool | false | Set to *true* to store some detail settings in the configuration dialog immediately, instead of having to press "Save settings" explicitly. |
| flag_mouse_cursor_timeout | bool | true | Set to *false* if you want to have cursor visible at all times. |
| mouse_cursor_timeout | float | 10 | Set to *0* if you want to keep the mouse cursor visible at all times. non-0 values mean the cursor will be hidden after that many seconds of inactivity |
| flag_show_boundaries_button | bool | false | Show a button to toggle constellation boundaries |
| flag_show_asterism_lines_button | bool | false | Show a button to toggle asterism lines |
| flag_show_asterism_labels_button | bool | false | Show a button to toggle asterism labels |
| flag_show_ecliptic_grid_button | bool | false | Show a button to toggle ecliptic grid |
| flag_show_icrs_grid_button | bool | false | Show a button to toggle ICRS (equatorial J2000.0) grid |
| flag_show_galactic_grid_button | bool | false | Show a button to toggle galactic grid |
| flag_show_goto_selected_button | bool | true | Show a button to center to selected object |
| flag_show_nightmode_button | bool | true | Show a button to toggle night mode |
| flag_show_nebulae_background_button | bool | false | Show a button to toggle images for deep-sky objects |
| flag_show_flip_buttons | bool | false | Show the image flipping buttons in the main toolbar |
| flag_show_dss_button | bool | false | Show a button to toggle Digitized Sky Survey (DSS) |
| flag_show_hips_button | bool | false | Show a button to toggle HiPS survey display |
| flag_show_bookmark_button | bool | false | Show a button to show and edit bookmarks |
| flag_show_fullscreen_button | bool | true | Show a button to toggle fullscreen view |
| flag_show_quit_button | bool | true | Show a button to quit via button press |
| flag_show_cardinal_button | bool | true | Show a button to toggle cardinals via button press |
| flag_show_compass_button | bool | false | Show a button to toggle compass marks via button press |
| flag_show_buttons_background | bool | true | If *true*, use background under buttons on bottom bar. |
| flag_overwrite_info_color | bool | false | Set *true* to use one color for test in info panel for all objects. |
| flag_info_shadow | bool | false | Set *true* to apply a slight shadow behind the infotext for increased readability. |
| pixmaps_brightness | float | 1.0 | Brighten the gray of GUI buttons. Usable: [1...1.8] |
| selected_object_info | string | all | Values: *default*, *all*, *short*, *none*, and *custom* (see 4.3.2). |
| custom_marker_size | float | 5.0 | Size of custom marker. |
| custom_marker_radius_limit | int | 15 | Limit the click radius for mouse cursor position in any direction for removing of closest custom marker. |
| auto_hide_horizontal_toolbar | bool | true | Set to *true* if you want auto hide the horizontal toolbar. |

| | | | |
|---|---|---|---|
| auto_hide_vertical_toolbar | bool | true | Set to *true* if you want auto hide the vertical toolbar. |
| flag_use_window_transparency | bool | false | If *false*, show menu bars opaque |
| flag_show_datetime | bool | true | display date and time in the bottom bar |
| flag_time_jd | bool | false | use JD format for time in the bottom bar |
| flag_show_tz | bool | false | show time zone info in the bottom bar |
| flag_show_location | bool | true | display location in the bottom bar |
| flag_show_fps | bool | true | show at how many frames per second Stellarium is rendering |
| flag_show_fov | bool | true | show how many degrees your vertical field of view is |
| flag_fov_dms | bool | false | use DMS format for FOV in the bottom bar |
| flag_show_decimal_degrees | bool | false | If *true*, use decimal degrees for coordinates |
| flag_use_azimuth_from_south | bool | false | If *true*, calculate azimuth from south towards west (as in some astronomical literature) |
| flag_use_negative_hour_angles | bool | false | If *true*, use hour angles -12h…12h |
| flag_use_polar_distance | bool | false | Use distance from North Celestial Pole, not declination from equator |
| flag_surface_brightness_arcsec | bool | false | Toggle usage the measure unit $^{mag}/_{\square}{}'$ ($^{mag}/arcmin^2$) or $^{mag}/_{\square}{}''$ ($^{mag}/arcsec^2$) for the surface brightness of deep-sky objects. |
| flag_surface_brightness_short | bool | false | Toggle usage the short notation for the surface brightness of deep-sky objects. |
| flag_enable_kinetic_scrolling | bool | true | If *true*, use kinetic scrolling in the GUI[3]. |
| pointer_animation_speed | float | 1.0 | Animation speed of pointers. |
| gpsd_hostname | string | localhost | hostname of server running **gpsd** (non-Windows only) |
| gpsd_port | int | 2947 | port number of **gpsd** (non-Windows only) |
| gps_interface | string | COM3 | Port number of serial/USB GPS device. (May look like `ttyUSB0` on Linux, if you really don't run **gpsd**.) |
| gps_baudrate | int | 4800 | baudrate of serial/USB GPS device (for direct serial connection only) |

## D.1.12 [init_location]

| ID | Type | Description |
|---|---|---|
| landscape_name | string | Sets the landscape you see. Built-in options are *garching, geneva, grossmugl, guereins, hurricane, jupiter, mars, moon, neptune, ocean, saturn, trees, uranus, zero*. |
| location | string | Name of location on which to start stellarium. |
| last_location | string | Coordinates of last used location in stellarium. |

## D.1.13 [landscape]

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[3]Scroll by dragging in the window directly, not a slider handle. Scrolling stops after a short time.

| ID | Type | Description |
|---|---|---|
| atmosphere_fade_duration | float | Sets the time (seconds) it takes for the atmosphere to fade when de-selected |
| flag_landscape | bool | Set *false* if you don't want to see the landscape at start-up |
| flag_fog | bool | Set *false* if you don't want to see fog on start-up |
| flag_atmosphere | bool | Set *false* if you don't want to see atmosphere on start-up |
| flag_landscape_sets_location | bool | Set *true* if you want Stellarium to modify the observer location when a new landscape is selected (changes planet and longitude/latitude/altitude if location data is available in the landscape.ini file) |
| minimal_brightness | float | Set minimal brightness for landscapes. [0...1] Typical value: *0.01* |
| atmosphereybin | int | Atmosphere tessellation coefficient for Y axis. Default=44. |
| flag_minimal_brightness | bool | Set *true* to use minimal brightness for landscape. |
| flag_landscape_sets_minimal_brightness | bool | Set *true* to use value for minimal brightness for landscape from landscape settings. |
| flag_enable_illumination_layer | bool | Set *true* to use illumination layer for landscape. |
| flag_enable_labels | bool | Set *true* to use landscape labels from gazetteer layer. |
| label_font_size | int | Font size for landscape labels. |
| label_color | 0.0,1.0,0.0 ▮ | Color for the labels |
| label_angle | int | Angle to display landscape labels [0...90]. |
| polyline_thickness | int | Thickness to draw polygon line, if one is defined [0...5] |
| polyline_color | 1.0,0.0,0.0 ▮ | Color for the polygon line, if one is defined |
| flag_transparency | bool | Set *true* to show landscape semitransparent. |
| transparency | float | Use this transparency for landscapes. [0...1] Typical value: *0.5* |
| atmospheric_extinction_coefficient | float | Set atmospheric extinction coefficient $k$ [mag/airmass] |
| temperature_C | float | Set atmospheric temperature [Celsius] |
| pressure_mbar | float | Set atmospheric pressure [mbar] |
| cache_size_mb | int | Set the cache size for landscapes [megabytes]. Default: 100 |

## D.1.14 [localization]

| ID | Type | Description |
|---|---|---|
| sky_culture | string | Sets the sky culture to use. E.g. *western, polynesian, egyptian, chinese, lakota, navajo, inuit, korean, norse, tupi, maori, aztec, sami*. |
| sky_locale | string | Sets language used for names of objects in the sky (e.g. planets). The value is a short locale code, e.g. *en, de, en_GB* |
| app_locale | string | Sets language used for Stellarium's user interface. The value is a short locale code, e.g. *en, de, en_GB*. |
| time_zone | string | Sets the time zone. Valid values: *system_default*, or some region/location combination, e.g. *Pacific/Marquesas* |
| flag_dst | bool | Set *true* to apply daylight saving time as required by time zone. |
| time_display_format | string | time display format: can be *system_default*, *24h* or *12h*. |
| date_display_format | string | date display format: can be *system_default*, *mmddyyyy*, *ddmmyyyy*, *yyyymmdd* (ISO8601), *wwmmddyyyy*, *wwddmmyyyy*, *wwyyyymmdd*. |

## D.1.15 [main]

| ID | Type | Description |
|---|---|---|
| invert_screenshots_colors | bool | If *true*, Stellarium will save the screenshots with inverted colors. |
| screenshot_dir | string | Path for saving screenshots |
| screenshot_format | string | File format. One of `png`\|`jpg`\|`jpeg`\|`tif`\|`tiff`\|`webp`\|`pbm`\|`pgm`\|`ppm`\|`xbm`\|`xpm`\|`ico` |
| screenshot_custom_size | bool | *true* if you want to specify particular dimensions next: |
| screenshot_custom_width | int | custom width of screenshots. Max. available size is hardware dependent! |
| screenshot_custom_height | int | custom height of screenshots. Max. available size is hardware dependent! |
| screenshot_dpi | int | DPI setting for screenshots. |
| observinglists_dir | string | Default path for saving and loading observing lists. Defaults to the user's home dir. |
| version | string | Version of Stellarium. This parameter may be used to detect necessary changes in config.ini file, do not edit. |
| use_separate_output_file | bool | Set to *true* if you want to create a new file for script output for each start of Stellarium |
| restore_defaults | bool | If *true*, Stellarium will restore default settings at startup. This is equivalent to calling Stellarium with the `-restore-defaults` option. |
| ignore_opengl_warning | bool | Set to *true* if you don't want to see OpenGL warnings for each start of Stellarium. |
| check_requirements | bool | Set to *false* if you want to disable and permanently ignore checking hardware requirements at startup. Expect problems if hardware is below requirements! |
| geoip_api_url | string | URL for JSON interface of GeoIP service. |

## D.1.16 [navigation]

This section controls much of the look&feel of Stellarium. Be careful if you change something here.

| ID | Type | Description |
|---|---|---|
| preset_sky_time | float | Preset sky time used by the dome version. Unit is Julian Day. Typical value: *2451514.250011573* |
| startup_time_mode | string | Set the start-up time mode, can be *actual* (start with current real world time), or *Preset* (start at time defined by preset_sky_time) |
| flag_enable_zoom_keys | bool | Set to *false* if you want to disable the zoom |
| flag_manual_zoom | bool | Set to *false* for normal zoom behaviour as described in this guide. When set to *true*, the auto zoom feature only moves in a small amount and must be pressed many times |
| flag_enable_move_keys | bool | Set to *false* if you want to disable the arrow keys |
| flag_enable_mouse_navigation | bool | Set to *false* if you want to disable the mouse pan (drag). |
| flag_enable_mouse_zooming | bool | Set to *false* if you want to disable the mouse zooming (mousewheel). |
| init_fov | float | Initial field of view, in degrees. Typical value: "60". |
| min_fov | float | Minimal field of view, in degrees. Typical value: "0.001389" (5"). |
| max_fov | float | Maximal field of view, in degrees. Typical value: "360.0". |

| init_view_pos | floats | Initial viewing direction. This is a vector with x,y,z-coordinates. x being N-S (S +ve), y being E-W (E +ve), z being up-down (up +ve). Thus to look South at the horizon use *1,0,0*. To look Northwest and up at 45°, use *-1,-1,1* and so on. |
|---|---|---|
| auto_move_duration | float | Duration (seconds) for the program to move to point at an object when the space bar is pressed. Typical value: *1.4* |
| return_home_duration | float | Duration (seconds) of movement of returning to a home location (for a demo). Default value: *0.* |
| return_fov_duration | float | Duration (seconds) of zooming to an initial field of view value (for a demo). Default value: *1.* |
| mouse_zoom | float | Sets the mouse zoom amount (mouse-wheel) |
| move_speed | float | Sets the speed of movement |
| zoom_speed | float | Sets the zoom speed |
| viewing_mode | string | If set to *horizon*, the viewing mode simulate an alt/azi mount, if set to *equator*, the viewing mode simulates an equatorial mount |
| auto_zoom_out_resets_direction | bool | Set to *true* if you want to auto-zoom restoring direction. |
| time_correction_algorithm | string | Algorithm of DeltaT correction. |

## D.1.17 [**plugins_load_at_startup**]

This section lists which plugins are loaded at startup (those with *true* values). Each plugin can add another section into this file with its own content, which is described in the respective plugin documentation, see 12. You activate loading of plugins in the [F2] settings dialog, tab "Plugins". After selection of which plugins to load, you must restart Stellarium.

| ID | Type | Description |
|---|---|---|
| AngleMeasure | bool | 13.1 Angle Measure plugin |
| ArchaeoLines | bool | 14.9 ArchaeoLines plugin |
| Calendars | bool | 13.10 Calendars plugin |
| EquationOfTime | bool | 13.2 Equation of Time plugin |
| Exoplanets | bool | 14.3 Exoplanets plugin |
| MeteorShowers | bool | 14.6 Meteor Showers plugin |
| NebulaTextures | bool | 13.9 Nebula Textures plugin |
| Novae | bool | 14.1 Bright Novae plugin |
| Observability | bool | 16.3 Observability Analysis |
| Oculars | bool | 16.1 Oculars plugin |
| Pulsars | bool | 14.4 Pulsars plugin |
| Quasars | bool | 14.5 Quasars plugin |
| RemoteControl | bool | 13.5 Remote Control plugin |
| RemoteSync | bool | 13.6 Remote Sync plugin |
| Satellites | bool | 14.8 Satellites plugin |
| Scenery3d | bool | 15 Scenery 3D plugin |
| SolarSystemEditor | bool | 13.8 Solar System Editor plugin |
| Supernovae | bool | 14.2 Historical Supernovae plugin |
| TelescopeControl | bool | 16.2 Telescope Control plugin |
| TextUserInterface | bool | 13.4 Text User Interface plugin |

## D.1.18 [**projection**]

This section contains the projection of your choice and several advanced settings important if you run Stellarium on a single screen, multi-projection, dome projection, or other setups.

| ID | Type | Description |
|---|---|---|

| | | |
|---|---|---|
| type | string | Sets projection mode. Values: *ProjectionPerspective, ProjectionEqualArea, ProjectionStereographic, ProjectionFisheye, ProjectionHammer, ProjectionCylinder, ProjectionCylinderFill, ProjectionMercator, ProjectionOrthographic, ProjectionMiller*, or *ProjectionSinusoidal*. |
| flip_horz | bool | |
| flip_vert | bool | |
| viewport | string | How the view-port looks. Values: *none* (regular rectangular screen), *disk* (circular screen, useful for planetarium setup). |
| viewportMask | string | How the view-port looks. Values: *none*. |
| viewport_fov_diameter | float | |
| viewport_x | float | Usually 0. |
| viewport_y | float | Usually 0. |
| viewport_width | float | |
| viewport_height | float | |
| viewport_center_x | float | Usually half of viewport_width. |
| viewport_center_y | float | Usually half of viewport_height. |
| viewport_center_offset_x | float | [-0.5…+0.5] Usually 0. |
| viewport_center_offset_y | float | [-0.5…+0.5] Use negative values to move the horizon lower. |

## D.1.19 [proxy]

This section has setting for connection to network through proxy server (proxy will be using when host of proxy is filled).

| ID | Type | Description |
|---|---|---|
| host_name | string | Name of host for proxy. E.g. *proxy.org* |
| type | string | Type of proxy. E.g. *socks* |
| port | int | Port of proxy. E.g. *8080* |
| user | string | Username for proxy. E.g. *michael_knight* |
| password | string | Password for proxy. E.g. *xxxxx* |

## D.1.20 [scripts]

| ID | Type | Default | Description |
|---|---|---|---|
| startup_script | string | startup.ssc | name of script executed on program start |
| flag_allow_screenshots_dir | bool | false | Allow scripts to set a target directory. |
| flag_allow_write_absolute_path | bool | false | set true to let scripts store output files to absolute pathnames. This may pose a security risk if you run scripts from other authors without checking what they are doing. |

## D.1.21 [search]

| ID | Type | Description |
|---|---|---|
| flag_search_online | bool | If *true*, Stellarium will be use SIMBAD for search. |
| simbad_server_url | string | URL for SIMBAD mirror |
| flag_start_words | bool | If *false*, Stellarium will be search phrase only from start of words |
| coordinate_system | string | Specifies the coordinate system. *Possible values:* equatorialJ2000, equatorial, horizontal, galactic. *Default value:* equatorialJ2000. |

## D.1.22 [spheric_mirror]

Stellarium can be used in planetarium domes. You can use a projector with a hemispheric mirror with geometric properties given in this section. Note: These functions are only rarely used or tested, some may not work as expected.

| ID | Type | Default | Description |
|---|---|---|---|
| flip_horz | bool | true | Flip the projection horizontally |
| flip_vert | bool | false | Flip the projection vertically |
| projector_alpha | float | 0 | This parameter controls the properties of the spheric mirror projection mode. |
| projector_gamma | float | | This parameter controls the properties of the spheric mirror projection mode. |
| projector_delta | float | -1e100 | This parameter controls the properties of the spheric mirror projection mode. |
| projector_phi | float | 0 | This parameter controls the properties of the spheric mirror projection mode. |
| projector_position_x | float | 0 | |
| projector_position_y | float | 1 | |
| projector_position_z | float | -0.2 | |
| mirror_position_x | float | 0 | |
| mirror_position_y | float | 2 | |
| mirror_position_z | float | 0 | |
| image_distance_div_height | float | -1e100 | |
| mirror_radius | float | 0.25 | |
| dome_radius | float | 2.5 | |
| custom_distortion_file | string | | |
| texture_triangle_base_length | float | | |
| zenith_y | float | 0.125 | deprecated |
| scaling_factor | float | 0.8 | deprecated |
| distorter_max_fov | float | 175.0 | Set the maximum field of view for the spheric mirror distorter in degrees. Typical value: *180* |
| viewportCenterWidth | float | | projected image width, pixels |
| viewportCenterHeight | float | | projected image height, pixels |
| viewportCenterX | float | | projected image center X, pixels |
| viewportCenterY | float | | projected image center Y, pixels |

## D.1.23 [stars]

This section controls how stars are rendered.

| ID | Type | Description |
|---|---|---|
| relative_scale | float | relative size of bright and faint stars. Higher values mean that bright stars are comparatively larger when rendered. Typical value: *1.0* |
| absolute_scale | float | Changes how large stars are rendered. larger value lead to larger depiction. Typical value: *1.0* |
| star_twinkle_amount | float | amount of twinkling. Typical value: *0.3* |
| flag_star_twinkle | bool | *true* to allow twinkling (but only when atmosphere is active!). |
| flag_forced_twinkle | bool | *true* to allow twinkling stars even without atmosphere. This is obvious nonsense and contrary to nature, but some users seem to like it. |
| flag_star_halo | bool | *false* to not draw a halo around the brightest stars. This looks poor, but some users seem to prefer it. |
| mag_converter_max_fov | float | maximum field of view for which the magnitude conversion routine is used. Typical value: *90.0*. |
| mag_converter_min_fov | float | minimum field of view for which the magnitude conversion routine is used. Typical value: *0.001*. |
| labels_amount | float | amount of labels. Typical value: *3.0* |
| init_bortle_scale | int | initial value of light pollution on the Bortle scale. Typical value: *3*. |

## D.1.24 [tui]

The built-in text user interface (TUI) plugin (see chapter 13.4) is most useful for planetariums. You can even configure a system shutdown command. For historical reasons, the section is not called [TextUserInterface]

but simply [`tui`].

| ID | Type | Default | Description |
|---|---|---|---|
| tui_font_size | float | 15 | Font size for TUI. |
| tui_font_color | floatRGB | 0.3,1,0.3 | Font color for TUI. |
| flag_show_gravity_ui | bool | false | Set to *true* to enable gravity mode for UI (for dome projection) |
| flag_show_tui_datetime | bool | false | Set to *true* if you want to see a date and time label suited for dome projections |
| flag_show_tui_short_obj_info | bool | false | Set to *true* if you want to see object info suited for dome projections |
| tui_admin_shutdown_command | string | | e.g. for Linux: `shutdown -poweroff +2` |

## D.1.25 [video]

| ID | Type | Description |
|---|---|---|
| fullscreen | bool | If *true*, Stellarium will start up in full-screen mode, else windowed mode |
| screen_w | int | Display width when in windowed mode. Value in pixels, e.g. *1024* |
| screen_h | int | Display height when in windowed mode. Value in pixels, e.g. *768* |
| screen_x | int | Horizontal position of the top-left corner in windowed mode. Value in pixels, e.g. *0* |
| screen_y | int | Vertical position of the top-left corner in windowed mode. Value in pixels, e.g. *0* |
| viewport_effect | string | This is used when the spheric mirror display mode is activated. Values include *none* and *sphericMirrorDistorter*. |
| minimum_fps | int | Sets the minimum number of frames per second to display at (hardware performance permitting) |
| maximum_fps | int | Sets the maximum number of frames per second to display at. This is useful to reduce power consumption in laptops. |
| min_time_bewteen_frames | int | Sets the minimum time (in milliseconds) between the end of rendering and the start of the next frame. Only takes effect on Macs. Used to work around `https://github.com/Stellarium/stellarium/issues/2778`. |
| multisampling | int | Sets the number of samples to use for multisampling antialiasing. *0* disables antialiasing, *1* is no-op (single sample per pixel), higher values increase smoothness and degrade performance. Too high a value may result in excessive blurriness of the GUI. A good starting value to try is *4*. |
| planet_shadows_supersampling | bool | Improves quality of shadows on the Moon by evaluating the color for each multisampling sample, rather than once per pixel. Level of improvement (and performance cost) depends on *multisampling* setting. Default is *false*, i.e. disabled. |
| anisotropic_filtering | int | Improves quality of rendering of inclined textured surfaces like e.g. planetary surface near the limb. Modern (and even quite old, like from 2010) GPUs can handle high anisotropy with no noticeable performance drop, so it should be fine to set this value as high as 16. If this setting value is higher than the GPU is capable of, the maximum value supported is used. The default is 16. To disable anisotropic filtering, set this value to 0. |

## D.1.26 [**viewing**]

This section defines which objects, labels, lines, grids etc. you want to see on startup. Set those to *true*. Most items can be toggled with hotkeys or switched in the GUI. Entries ending with `_line` or `..._lines` usually also have entries `..._parts` and `..._labels` which govern partitions and labels, respectively.

| ID | Type | Description |
|---|---|---|
| flag_asterism_drawing | bool | Display asterism line drawing |
| flag_asterism_name | bool | Display asterism names |
| flag_rayhelper_drawing | bool | Display the ray helper line drawing |
| flag_constellation_drawing | bool | Display constellation line drawing |
| flag_constellation_name | bool | Display constellation names |
| flag_constellation_art | bool | Display constellation art |
| flag_constellation_boundaries | bool | Display constellation boundaries |
| flag_constellation_isolate_selected | bool | If *true*, constellation lines, boundaries and art will be limited to the constellation of the selected star, if that star is "on" one of the constellation lines, adding more constellations as you click more |
| flag_constellation_pick | bool | If flag_constellation_isolate_selected is also true, set to *true* if you only want to see the line drawing, art and name of the currently selected constellation |
| flag_isolated_trails | bool | Set to *true* if you only want to see the trail line drawn for the selected planet (asteroid, comet, moon) |
| number_isolated_trails | int | Number of isolated trails for latest selected Solar system bodies [1..5]. |
| max_trail_points | int | Limit maximum length of trails. Trails are drawn for 1 year or this number of computing steps. Default 5000, reduce if drawing trails slows down the program too much. |
| flag_planets_orbits_only | bool | Set to *true* if you want to suppress orbits of minor bodies and moons. |
| flag_isolated_orbits | bool | Set to *true* if you want to see orbits only for selected planet. |
| flag_orbits_with_moons | bool | Set to *true* if you want to see also orbits of the selected planet. |
| line_thickness | int | Set the line thickness for grids and lines. Typical value: *1* |
| part_thickness | int | Set the line thickness for line partitions. Typical value: *1* |
| flag_azimutal_grid | bool | Display azimuthal grid |
| flag_equatorial_grid | bool | Display equatorial grid (of date) |
| flag_equatorial_J2000_grid | bool | Display equatorial grid (J2000) |
| flag_ecliptic_grid | bool | Display ecliptic grid (of date) |
| flag_ecliptic_J2000_grid | bool | Display ecliptic grid (J2000) |
| flag_galactic_grid | bool | Display galactic grid (System II) |
| flag_galactic_equator_line | bool | Display galactic equator line |
| flag_supergalactic_grid | bool | Display supergalactic grid |
| flag_supergalactic_equator_line | bool | Display supergalactic equator line |
| flag_equator_line | bool | Display celestial equator line (of date) |
| flag_fixed_equatorial_grid | bool | Display fixed equatorial (hour angle) grid |
| flag_fixed_equator_line | bool | Display fixed equator (hour angle) line |
| flag_equator_J2000_line | bool | Display celestial equator line (J2000) |
| flag_ecliptic_line | bool | Display ecliptic line (of date) |
| flag_ecliptic_J2000_line | bool | Display ecliptic line (J2000) |
| flag_longitude_line | bool | Display opposition/conjunction circle |
| flag_quadrature_line | bool | Display quadrature circle |

| | | |
|---|---|---|
| flag_meridian_line | bool | Display meridian line |
| flag_prime_vertical_line | bool | Display Prime Vertical line (East-Zenith-West) |
| flag_colure_lines | bool | Display colure lines (Celestial Pole-♈/♋/♎/♑) |
| flag_cardinal_points | bool | Display cardinal points |
| flag_ordinal_points | bool | Display intercardinal (or ordinal) points |
| flag_16wcr_points | bool | Display secondary intercardinal points |
| flag_32wcr_points | bool | Display tertiary intercardinal points |
| cardinal_font_size | int | Font size for cardinal points. Typical value: *24* |
| ordinal_font_size | int | Font size for intercardinal (or ordinal) points. Typical value: *18* |
| 16wcr_font_size | int | Font size for secondary intercardinal points. Typical value: *16* |
| flag_gravity_labels | bool | Set to *true* if you want labels to undergo gravity (top side of text points toward zenith). Useful with dome projection. |
| flag_moon_scaled | bool | Keep it *false* if you want to see the real moon size |
| moon_scale | float | Sets the moon scale factor, sometimes useful to correlate to our perception of the moon's size. Typical value: *4* |
| flag_planets_scaled | bool | Keep it *false* if you want to see the real planet size |
| planets_scale | float | Sets the planet scale factor, sometimes useful to show planets symbolically. Typical value: *150* |
| flag_sun_scaled | bool | Keep it *false* if you want to see the real sun size |
| sun_scale | float | Sets the sun scale factor, sometimes useful to correlate to our perception of the sun's size. Typical value: *4* |
| flag_minorbodies_scaled | bool | Set to *true* if you want to see minor bodies enlarged |
| minorbodies_scale | float | Set scale factor for minor bodies, to see them in unnatural detail. Typical value: *10* |
| flag_draw_moon_halo | bool | Display halo around the Moon |
| flag_draw_sun_halo | bool | Display Sun's glare |
| flag_draw_sun_corona | bool | Display Sun's corona when atmosphere is disabled |
| flag_fov_center_marker | bool | Set to *true* to enable drawing a field of view center marker |
| flag_fov_circular_marker | bool | Set to *true* to enable drawing a circular FOV marker |
| size_fov_circular_marker | float | size of the circular FOV marker, degrees |
| flag_fov_rectangular_marker | bool | Set to *true* to enable drawing a rectangular FOV marker |
| width_fov_rectangular_marker | float | width of the rectangular FOV marker, degrees |
| height_fov_rectangular_marker | float | height of the rectangular FOV marker, degrees |
| rot_fov_rectangular_marker | float | rotation angle of the rectangular FOV marker, degrees |
| flag_compass_marks | bool | Set to *true* to enable drawing compass marks |
| constellation_art_intensity | float | brightness [0...1] of the constellation art images. Typical value: *0.5* |
| constellation_art_fade_duration | float | time the constellation art takes to fade in or out, in seconds. Typical value: *1.5* |
| constellation_font_size | int | font size for constellation labels |
| constellation_line_thickness | int | thickness of constellation lines [1...5]. Typical value: *1* |
| asterism_font_size | int | font size for asterism labels |
| asterism_line_thickness | int | thickness of the asterism lines [1...5]. Typical value: *1* |
| rayhelper_line_thickness | int | thickness of the ray helper lines [1...5]. Typical value: *1* |
| flag_night | bool | Enable night mode (red-only mode) on startup |
| light_pollution_luminance | float | Sets the level of the light pollution simulation |
| use_luminance_adaptation | bool | Enable dynamic eye adaptation |

| | | |
|---|---|---|
| sky_brightness_label_threshold | float | Sky brightness [$cd/m^2$] to show infotext in black |
| flag_landscape_autoselection | bool | load fitting landscape after changing planet (use *zero* landscape when no fitting found). |
| flag_environment_auto_enable | bool | Enable/disable atmosphere, fog and cardinals for observer location when switching planet. |
| flag_show_selection_marker | bool | Enable/disable visibility of pointers for selected objects. |

## D.1.27 ⎡**DialogPositions**⎤

By default, GUI panels appear centered in the screen. You can move them to your favorite location, and on next start they will appear on that location instead. The entries in this section define the upper left pixel coordinate where panels are stored.

Examples:

| ID | Type | Example | Description |
|---|---|---|---|
| Help | int,int | 58,39 | Position of Help panel |
| DateTime | int,int | 1338,944 | Position of time panel |

## D.1.28 ⎡**DialogSizes**⎤

GUI panels can be resized by dragging on their lower corners or borders. Enlarged sizes are stored here, and on next start they will appear in this size. The entries in this section define the size.

Examples:

| ID | Type | Example | Description |
|---|---|---|---|
| Help | int,int | 895,497 | Size of Help panel |
| AstroCalc | int,int | 913,493 | Size of AstroCalc panel |

## D.1.29 ⎡**hips**⎤

This section defines the source list of the HiPS surveys, as well as other HiPS related options.

| ID | Type | Description |
|---|---|---|
| show | bool | show HiPS at startup? |
| sources/size | int | Number of HiPS survey sources |
| sources/*n*/url | string | uri of the *n*th source hipslist file ($n \in [1\ldots$ `sources/size` $]$) |
| visible/url | bool | HiPS configured to be displayed. (Stores current setting on program exit) |

## D.2  Solar System Configuration Files

The files[4] `ssystem_major.ini` and `ssystem_minor.ini` (in the `data/` subdirectory of the program directory, contain orbital and rotational data from which Stellarium configures the Solar System objects.

The minor bodies can be modified by placing a privately modified copy of `ssystem_minor.ini` into your own `data/` directory (see Chapter 5). You can edit the file either manually or with the Solar System Editor plugin (see Section 13.8). The private user file is automatically created by the Solar System Editor plugin.

Each object's data are described in its own section which is typically named after the object name. Some section names (e.g. those using diacriticals, spaces or other problematic characters) appear a bit mangled.

We list here examples for the major planets, larger moons with special coordinate functions, minor moons with generic orbital elements, minor planets and comets with elliptical and parabolic orbit elements.

All elements are stored in alphabetic order in the files, however it makes more sense to present the elements in another sequence which better reflects the meaning. The actual order of the objects in the files, and order of entries inside an object section, is irrelevant, but in case of duplicate entries the later entry is used.

### D.2.1  File ssystem_major.ini

#### D.2.1.1  Planet section

Example:

```
[jupiter]
name=Jupiter
type=planet
coord_func=jupiter_special
orbit_Period=4331.87

atmosphere=1
albedo=0.51
color=1., 0.983, 0.934
absolute_magnitude=-9.40

radius=71492
oblateness=0.064874
tex_map=jupiter.png #texture courtesy of Bj\xf6rn J\xf3nsson

# deprecated rotational elements
rot_equator_ascending_node=-22.203
rot_obliquity=2.222461
rot_periode=9.92491
rot_rotation_offset=-1 # use JupiterGRS patch

# WGCCRE rotational elements
rot_pole_ra=268.056595
rot_pole_ra1=-0.006499
rot_pole_de=64.495303
rot_pole_de1=0.002413
rot_pole_w0=284.95
rot_pole_w1=870.5360000
```

where

**name**  English name of the planet. May appear translated.

**type**  Mandatory for planets:

**parent**  =Sun. The body which this object is running around. Default: `Sun`

**coord_func**  The planet positions are all computed with a dedicated function (VSOP87 or DE43x).

---

[4]Before v0.16, there was a single file, `ssystem.ini`, with slightly different rules.

**orbit_Period**  number of (earth) days for how long the orbit should be made visible. Typically Stellarium shows one orbit line. The orbit slowly drifts, however.

**atmosphere**  (0 or 1) flag to indicate whether observer locations should enable atmosphere drawing.

**radius**  Equator radius, km.

**oblateness**  Flattening of the polar diameter. $(1 - r_{pole}/r_{eq})$

**albedo**  total albedo (reflectivity) of the planet. Used for "generic" magnitude computation, but the major planets usually have dedicated magnitude formulas, so the value is not evaluated unless you are observing from a location outside Earth.

**color**  Used to colorize halo. At least one of the components should be 1.

**tex_map**  File name of texture map in `textures` folder.

**halo**  Should be true to draw a halo (simple light disk) when object too small to draw a sphere. Default: `true`

### Elements for the Physical Ephemeris

Where known, Stellarium can properly model axis rotation with the `rot_...` entries in the element sets. Versions prior to 0.21 had rotational elements defined with respect to the equator of the parent object. While writing this documentation the origin and accuracy of this model is unfortunately untraceable. However, the IAU Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE) and modern sources like Urban and Seidelmann (2013) use rotational elements with respect to the ICRF (see section 18.2.2). Therefore, starting with version 0.21, Stellarium uses these more modern data and can now also show axes with precessional or other motions. Data for some planet moons are unfortunately still not available in this WGCCRE format, and therefore the old format can still be used, but should not be used for new entries.

**rot_equator_ascending_node**  *deprecated*

**rot_obliquity**  *deprecated*

**rot_rotation_offset**  *deprecated* longitude of prime meridian. For Planets, this used to be counted from the ascending node of the equator over the ecliptical plane at J2000.0. For moons, it is the longitude of the prime meridian counted from the ascending node of the moon's equator over the planet equator. A special value here indicates special treatment for the Great Red Spot.

**rot_periode**  *deprecated* Duration of one sidereal rotation, in earth hours.

**rot_pole_ra**  constant of axis right ascension in ICRF, degrees

**rot_pole_ra1**  change per century of axis right ascension in ICRF, degrees

**rot_pole_de**  constant of axis declination in ICRF, degrees

**rot_pole_de1**  change per century of axis declination in ICRF, degrees

**rot_pole_w0**  longitude of the prime meridian counted from the ascending node of the objects's equator through the ICRF equator, degrees

**rot_pole_w1**  change per day of axis rotation, degrees

In many cases, the attitude/rotation formulae for the North (or "positive") pole $(\alpha_0, \delta_0)$ are given like

$$\alpha_0 = \texttt{rot\_pole\_ra} + T * \texttt{rot\_pole\_ra1} \tag{D.1}$$

$$\delta_0 = \texttt{rot\_pole\_de} + T * \texttt{rot\_pole\_de1} \tag{D.2}$$

$$W = \texttt{rot\_pole\_w0} + d * \texttt{rot\_pole\_w1} \tag{D.3}$$

These cases are fully covered by the data in `ssystem_major.ini`. Corrections for solar system objects given by Archinal, A'Hearn, Bowell, et al. (2010), Archinal, A'Hearn, Conrad, et al. (2011), Archinal, Acton, A'Hearn, et al. (2018), Archinal, Acton, Conrad, et al. (2019), and Urban and Seidelmann (2013) have been implemented in the program.

### D.2.1.2  Moon section

All planet moons are defined only in `ssystem_major.ini`.

Moons are special in that they orbit another planet. Therefore, the rotational elements used to be specified relative to the equatorial plane of the parent planet, and `orbit_SemiMajorAxis` are specified in kilometers. However, as for the planets (see section D.2.1.1 above), current *IAU* reference material gives axis orientation with right ascension and declination values for the pole in ICRF coordinates, with some of them in motion. So again, if one of the `rot_pole_...` values exist, we assume the current standard, but keep the old elements available until we find new data. For more complicated motion, again some special functions are applied.

```
[amalthea]
name=Amalthea
type=moon
parent=Jupiter
iau_moon_number=JV

orbit_AscendingNode=141.5521520794674
orbit_Eccentricity=0.006175744402949701
orbit_Epoch=2454619.50000
orbit_Inclination=0.3864576103404582
orbit_LongOfPericenter=245.4222355150120000
orbit_MeanLongitude=224.7924893552550000
orbit_Period=0.5016370462116355
orbit_SemiMajorAxis=181994.8658358799

absolute_magnitude=7.4
albedo=0.09
color=1., 0.627, 0.492
radius=83.5
tex_map=amalthea.png
model=j5amalthea_MLfix.obj


rot_equator_ascending_node=213.7
rot_obliquity=15.5
# rot_periode=12.039289109079252
rot_rotation_offset=235.50
rot_pole_ra=268.05
rot_pole_ra1=-0.009
rot_pole_de=64.49
rot_pole_de1=0.003
rot_pole_w0=231.67
rot_pole_w1=722.6314560
```

where

**name**  English name of planet moon. No number, just the name. May be translated.

**type**  moon

**parent**  English name of planet or parent body.

**iau_moon_number**  a short label (string) consisting of the planet's initial and the moon's Roman number in order of discovery.

**coord_func**  Must be kepler_orbit (default, can be left away) for moons with orbital elements given, or <name>_special for

**orbit_AscendingNode**  $\Omega$

**orbit_Eccentricity**  $e$

**orbit_Epoch**

**orbit_Inclination**  $i$ [degrees]

**orbit_LongOfPericenter**

**orbit_MeanLongitude**

**orbit_Period**  [days]

**orbit_SemiMajorAxis**  $a$ [km]

**radius**  Equator radius, km.

**oblateness**  Flattening of the polar diameter. $(1 - r_{pole}/r_{eq})$ Bodies with non-ellipsoid shape, e.g. tri-axial geometry, cannot be modelled with this simple approach, but a 3D solid model can be shown, see below.

**albedo**  total reflectivity [0..1]

**color**  for drawing halo (default: 1,1,1)

**halo** [=true|false] to draw a simple diffuse dot when zoomed out. Default: `true`

**tex_map** name of spherical texture map. Many moons have been mapped by visiting spacecraft! For many other moons, Stellarium applies an inverted Lunar texture image.

**model** (optional) name of a 3D model for a non-spherical body in the `model` subdirectory of the program directory.

**rot_equator_ascending_node** *deprecated*

**rot_obliquity** *deprecated*

**rot_rotation_offset** *deprecated* longitude of prime meridian at J2000.0.

**rot_periode** *deprecated* Duration of one sidereal rotation, in earth hours. For moons in bound rotation (which always show one face towards their parent planet), it is best to omit this value: it defaults to `orbit_Period * 24`.

**rot_pole_ra** constant of axis right ascension in ICRF, degrees

**rot_pole_ra1** change per century of axis right ascension in ICRF, degrees

**rot_pole_de** constant of axis declination in ICRF, degrees

**rot_pole_de1** change per century of axis declination in ICRF, degrees

**rot_pole_w0** longitude of the prime meridian counted from the ascending node of the objects's equator through the ICRF equator, degrees

**rot_pole_w1** change per day of axis rotation, degrees

### D.2.1.3 Observers

Stellarium is great for excursions to the surface of any object with known orbital elements. Configuring a viewpoint away from a planet requires a special kind of location.

#### Solar System Observer

The Solar System Observer has been provided in earlier versions as a neutral view location high above the North pole of the Solar System. Meanwhile the location can be changed by keyboard interaction. See section 4.2.3.

```
[solar_system_observer]
name=Solar System Observer
parent=Sun
halo=false
hidden=true
orbit_SemiMajorAxis=30
type=observer
```

Note that it is `hidden` and has no `halo`. The observer is attached to the Sun, therefore the value for distance `orbit_SemiMajorAxis` is given in AU.

#### Planet Observers

There are other "observer" locations for all planets which have moons: Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. For example:

```
[earth_observer]
name=Earth Observer
parent=Earth
halo=false
hidden=true
orbit_SemiMajorAxis=149600000
type=observer
```

The distance `orbit_semiMajorAxis` has been preconfigured with a distance that gives a good view of the planet with its moons. Like for moons, the units are km from the planet.

## D.2.2 File ssystem_minor.ini

Orbital elements for minor bodies are always given for a particular *equinox* like J2000.0 (which indicates the coordinate reference system) and *epoch* (date). The other planets pull on the objects and change their orbits, most usually leading to the objects appearing too early or too late in their orbits, but also changing the other orbital elements. In addition, outgassing events of comets can act like jet propulsion and change orbits in unpredictable ways. It is heavily recommended to update the orbital elements on a regular basis (2×/year?),

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or at least before you go out and are actually observing minor bodies. Use the Solar System Editor plugin for this task (section 13.8).

You may find element sets for different equinoxes, like B1950.0. These have to be converted to equinox J2000.0 data before being useful in Stellarium. The conversion is outside Stellarium's scope.

**coord_func** is `kepler_orbit` by default. For compatibility and interoperability with older versions we will keep the old default of `comet_orbit` for some longer time.[5]

**parent** defaults to `Sun` and can be omitted.

**orbit_Epoch** JDE when these elements are valid. Defaults to 2451545.0 = the J2000.0 standard epoch.

**orbit_good** can be given in days to limit computation of the object to the time range epoch ± orbit_good. If specified as 0 there is no check for out-of-range dates. If specified as -1, half the orbital period is used. The main purpose of this parameter is to avoid an element clash or the inadvertent use of outdated comet orbit elements when a periodic comet reappears.

**orbit_ArgOfPericenter** $\omega$ [degrees]

**orbit_AscendingNode** $\Omega$ [degrees]

**orbit_Eccentricity** $e = 0$ circular, $0 < e < 1$ elliptic, $e = 1$ parabolic, $e > 1$ hyperbolic

**orbit_Inclination** $i$ [degrees] inclination against J2000 ecliptic

**orbit_SemiMajorAxis** $a$ [AU]

The other parameters are like those for the major planets.

### D.2.2.1  Minor Planet section

```
[4vesta]
type=asteroid
minor_planet_number=4
name=Vesta

coord_func=comet_orbit
parent=Sun
orbit_Epoch=2457000.5
orbit_MeanAnomaly=20.86389
orbit_MeanMotion=0.27154465

orbit_ArgOfPericenter=151.19843
orbit_AscendingNode=103.85141
orbit_Eccentricity=0.0887401
orbit_Inclination=7.14043
orbit_SemiMajorAxis=2.3617933
orbit_good=1325.46

color=1., 1., 1.
halo=true
oblateness=0.0

albedo=0.423
radius=280
absolute_magnitude=3.2
slope_parameter=0.32
tex_map=vesta.png
model=4vesta_21_MLfix.obj
```

**type** can be `asteroid`, `dwarf planet`, `cubewano`, `plutino`, `scattered disc object`, `Oort cloud object`. With the exception of Pluto (which is included in `ssystem_major.ini` and cannot be changed), all positions for minor bodies are computed with the orbiting elements given in this way.

Minor planets further specify

**orbit_Epoch** , JDE when these elements are valid. Defaults to J2000.0, i.e., 2451545.0.

**orbit_MeanAnomaly** $M$ mean anomaly, degrees.

---

[5]Previous editions used the name `comet_orbit`. Now the `coord_func` line can be left away, defaulting to `kepler_orbit`.

**orbit_MeanMotion**  $n$ mean motion [degrees/day].

   Visual magnitude is modelled from

**absolute_magnitude**  $H$

**slope_parameter**  $G$.

   Elements for rotational axis may be given just like for planets when they are known. It is recommended to use the modern specification (elements `rot_pole_...`).

**model**  A few asteroids have been visited by spacecraft, and for many other asteroids visual observations of stellar occultations by asteroids and light curve measurements have enabled researchers to derive 3D shape models of asteroids. If a model is available in the `models` subdirectory of the program directory, this can be configured with a `model` entry.

### D.2.2.2 Comet section

Comets are tiny, and their outgassing and close approaches to the major planets cause fast changes in their orbital elements, so that each apparition should be specified with a dedicated section in `ssystem_minor.ini`.

#### Naming schemes

Over just the past decades, the naming of comets has changed considerably. Starting in the 19th century, comets are usually named after their discoverer(s). In addition, they are given a catalog number. Traditionally, comets observations published by scientific organisations were sorted and labelled with Roman numerals after date of perihelion. When scientific communication became faster, comet discoveries were circulated by telegraphs, and a preliminary immediate labelling by sequence of discovery was used. After the year was over, the comet received again the Roman number indicating the position in the sequence of perihelon dates in that year.

   In 1994, a new scheme has been introduced[6]: When a comets is discovered, the discovery date governs a unique label: The 12 months of the year are split into half-months, for which 24 of the 26 letters of the alphabet are used (I and Z are omitted). After the letter, discoveries are enumerated in sequence. A letter before this number indicates what kind of comet the element set describes: **C** indicates a regular comet, **P** a periodic (recurring) comet, **D** is defunct (lost). **X** is one for which no reliable orbital elements can be given. **I** labels an interstellar object (an object on an orbit, or more accurately, a hyperbolic trajectory which only swings around the Sun one time). After a return, periodic comets receive a serial number before the P.

   This new scheme is also applied for old comets. However, for the sake of compatibility with older literature, Stellarium can use several optional entries in addition to the name:                          v 23.2

**name**  1P/Halley (First periodic comet, named after Edmund Halley, the astronomer who identified its recurrent nature)

**iau_designation**  1982 U1 (First comet discovered in 2nd half of October 1982)

**discovery_code**  1982i (9th comet discovered in 1982)

**perihelion_code**  1986 III (Third comet to go through perihelion in 1986)

   There is unfortunately divergent information about use of the new IAU discovery code for periodical comets like 1P/Halley. Some lists provide such codes for previous observations, while others use the modern code for Halley's own observation (P/1682 Q1) for every apparition, in which case identification of the proper apparition from just the name becomes impossible. IAU simply uses a periodic number with P and optional name (for comet Halley, "1P/Halley". Almost all periodic comets have names) to identify such a recurring object. While this can be used for predicted future passages through the inner Solar system, there cannot be a modern "discovery code" based label when the comet was at least in theory followed through aphelion. But also this format, using only periodic number, prevents disambiguation between apparitions. To make life simpler for us, we prefer to use a name entry like "1P/Halley (1986)" with year of perihel passage in brackets. A numbered comet may come without a discoverer name. In this case it is just shown with perihel year like "396P (2019)". The ini file should include a periodic number in front of the P in the name, however some data files are incomplete. Unnumbered comets follow the new IAU code, e.g., "C/1996 B2 (Hyakutake)". You can also provided separate `name` and `iau_designation` entries, in which case they will be combined.

   Most other elements are similar to minor planets. But note the specification of

**orbit_PericenterDistance**  $q$ [AU]

**orbit_TimeAtPericenter**  $T$ JDE of closest approach to the Sun

**orbit_Epoch**  JDE when these elements are valid (optional).

which is more typical for comets which may have no orbital period when they are on parabolic or hyperbolic orbits. Frequently orbital elements are given for a date very close to perihelion so that the perihel date

---

   [6]`https://minorplanetcenter.net/iau/lists/CometResolution.html`

*T* is used wherever `orbit_Epoch` is not given. However, this assumption does not always hold, so we recommend to state `orbit_Epoch` explicitly.

**ref**  Reference, e.g. some MPC Circular (optional). May be used in future versions.

### Comet magnitudes

Like for minor planets, visual magnitude is modelled from

**absolute_magnitude**  *H*

**slope_parameter**  *G*

but with a modified expression:

$$\text{mag} = H + 5 \cdot \log \Delta + 2.5 \cdot G \cdot \log r \tag{D.4}$$

The term `slope_parameter` may be a misnomer in case of comets. From the literature (Meeus, 1998) (equation 33.13) we find

$$\text{mag} = g + 5 \log \Delta + \kappa \log r \tag{D.5}$$

from which $\kappa = 2.5 \cdot G$. In any case, $\kappa$ is typically $[5 \dots 15]$ and specific for each comet. The standard value for *G* is 4 (therefore $\kappa = 10$).

Estimating and predicting comet magnitudes is very difficult, and values for *H* and *G* often differ between data sources like the Minor Planetary Center[7] and NASA/JPL Horizon[8]. When you think some comet magnitude is off, consider searching for other sources than MPC[9].

You can finetune the appearance of the comet, both when zooming in all the way to the core, or how the tails are represented.

**albedo**  (default: 0.075) is used to set the brightness for rendering the body, if you are close enough.

**model**  Some comets have been visited by spacecraft so that shape models of their cores may be available and can be configured with this entry.

**outgas_intensity**  (default:0.1) Intensity of a pseudo-outgas effect on the core, based on an inverse exponential Lambert shading, with the light at the viewing position.

**outgas_falloff**  (default:0.1) Exponent for falloff of outgas effect, should probably stay < 1.

**dust_brightnessfactor**  (default: 1.5) brightness of dust tail relative to the gas tail.

**dust_lengthfactor**  (default: 0.4) length of dust tail relative to the gas tail.

**dust_widthfactor**  (default: 1.5) width of dust tail relative to the gas tail.

Some historical depictions show huge comets. If painted correctly, you can try to recreate such paintings.

A large number of elements for historical comets is provided in the file `ssystem_1000comets.ini` in the installation directory. You can copy&paste what you need into your `ssystem_minor.ini` or add all with the Solar System Editor plugin (section 13.8).

With a clever combination of elements and `orbit_good` entries, it is possible to specify several sets of orbital elements for different epochs of one apparition.

### Periodic Comet

```
[1phalley]
type=comet
name=1P/Halley
iau_designation=1982 U1
discovery_code=1982i
perihelion_code=1986 III

orbit_ArgOfPericenter=111.7154
orbit_AscendingNode=58.8583
orbit_Eccentricity=0.968004
orbit_Inclination=162.2453
orbit_PericenterDistance=0.57136
```

---

[7]`https://www.minorplanetcenter.net/data`

[8]`https://ssd.jpl.nasa.gov/horizons/`

[9]One interesting website is `http://www.aerith.net/index.html` which provides magnitude predictions in terms of D.5 for current comets, sometimes even in intervals from perihel date as comets evolve. Just extract `absolute_magnitude` = *g* and `slope_parameter` = $\kappa/2.5$.

```
orbit_TimeAtPericenter=2446463.12979167
orbit_good=780

color=1.0, 1.0, 1.0
dust_brightnessfactor=1.5
dust_lengthfactor=0.4
dust_widthfactor=1.5

albedo=0.1
radius=5
absolute_magnitude=5.5
slope_parameter=3.2
model=1682q1halley_MLfix.obj [optional]
```

Note a rather short duration of `orbit_good`, which means the comet is only displayed 780 days before and after perihelion. (Actually, before and after `orbit_Epoch`, but this is not given explicitly, so it defaults to `orbit_TimeAtPericenter`.)

**Parabolic/Hyperbolic Comet**

```
[c2013us10%28catalina%29]
type=comet
name=Catalina
iau_designation=C/2013 US10

orbit_ArgOfPericenter=340.3533
orbit_AscendingNode=186.141
orbit_Eccentricity=1.000372
orbit_Inclination=148.8766
orbit_PericenterDistance=0.822958
orbit_TimeAtPericenter=2457342.20748843
orbit_good=1000

...

absolute_magnitude=4.4
slope_parameter=4
```

This has basically the same format. Note that eccentricity is larger than 1, this means the comet is following a slightly hyperbolic orbit. Stellarium shows data for this comet for almost 3 years (`orbit_good=1000` days) from the epoch (defaults to pericenter time).

### D.2.3  JPL Horizons

The *JPL Horizons*[10] on-line solar system data and ephemeris computation service provides access to key solar system data and flexible production of highly accurate ephemerides for solar system objects (Late 2023: 1,334,683 asteroids, 3,904 comets, 290 planetary satellites includes satellites of Earth and dwarf planet Pluto, 8 planets, the Sun, L1, L2, select spacecraft, and system barycenters). Horizons is provided by the Solar System Dynamics Group of the Jet Propulsion Laboratory.

#### D.2.3.1  How to manually look up a body

A comet discovered in early 2023, C/2023 A3 (Tsuchinshan-ATLAS), may become bright in October 2024. Let's find out its orbital elements for the most interesting time!

We use the Horizons web interface to look up the body we are interested in and find its orbital elements. The Horizons web interface will display something like this:

---

[10]`https://ssd.jpl.nasa.gov/horizons/`

```
1            Ephemeris Type: [Osculating Orbital Elements]
2   [Edit]   Target Body: C/2023 A3 (Tsuchinshan-ATLAS)
3   [Edit]   Coordinate Center: Sun (body center) [500@10]
4   [Edit]   Time Specification: Start=2024-07-03 TDB, Stop=2024-12-02, Step=5 (days)
5   [Edit]   Table Settings: custom
    [Generate Ephemeris]
```

1. Ephemeris Type *must* be set to [Osculating Orbital Elements].
2. Target Body is the body you want to add to Stellarium. Click [Edit] to look it up.
3. Center should be set to Sun for all heliocentric trajectories.
4. Time Specification: Use a short interval or discrete dates near the time you are most interested. The returned JDE date (Julian Day number) will be used as epoch in Stellarium.
5. Table Settings: We must [Edit] and select Output units: [au and days] to create data compatible with the appropriate fields in `ssystem_minor.ini`

The result begins with listing osculating elements for a certain epoch in the past and its own initial conditions and settings. Horizons then applies numerical integration and simulates the movement and gravitational interaction between all its solar system objects, including our comet. Then, for each requested time, orbital elements are listed. Here you could see the slight changes these elements undergo over weeks. However, in Stellarium, we can only use one particular element set and show the comet's movement under the assumption that these elements do not change. When we have read it will be brightest in October, let's take this section. The first number is the date (JDE) where these elements are valid, i. e., the element epoch.

```
2460584.500000000 = A.D. 2024-Oct-01 00:00:00.0000 TDB
 EC= 1.000086779013436E+00 QR= 3.914011809348247E-01 IN= 1.391089312570287E+02
 OM= 2.156049287759364E+01 W = 3.084955943429219E+02 Tp=  2460581.248532149941
 N = 3.253815615607083E-06 MA= 1.057967686457091E-05 TA= 1.819722055160837E+01
 A =-4.510320703532996E+03 AD= 9.999999999999998E+99 PR= 9.999999999999998E+99
```

Below you also find the keys:

```
   Symbol meaning:

   JDTDB    Julian Day Number, Barycentric Dynamical Time
     EC     Eccentricity, e
     QR     Periapsis distance, q (km)
     IN     Inclination w.r.t X-Y plane, i (degrees)
     OM     Longitude of Ascending Node, OMEGA, (degrees)
     W      Argument of Perifocus, w (degrees)
     Tp     Time of periapsis (Julian Day Number)
     N      Mean motion, n (degrees/sec)
     MA     Mean anomaly, M (degrees)
     TA     True anomaly, nu (degrees)
     A      Semi-major axis, a (km)
     AD     Apoapsis distance (km)
     PR     Sidereal orbit period (sec)
```

Now we can add an entry into our `ssystems_minor.ini`. We can leave the exponential writing style (trailing "E+02" etc.) or convert to the more human-readable as shown here. Symbols M1 and k1 are given only in the top list of initial elements. The symbols in brackets refer to the above table, do not enter those!

```
[c2023A3(tuchinshanatlas)]
iau_designation            = C/2023 A3
name                       = C/2023 A3 (Tsuchinshan-ATLAS)
type                       = comet
orbit_Epoch                = 2460584.5
orbit_ArgOfPericenter      = (W)     308.4955943429219
orbit_AscendingNode        = (OM)     21.56049287759364
orbit_Eccentricity         = (EC)      1.000086779013436
orbit_Inclination          = (IN)    139.1089312570287
orbit_PericenterDistance   = (QR)      0.3914011809348247
orbit_TimeAtPericenter     = (Tp) 2460581.248532149941
```

```
absolute_magnitude          = (M1)      6.1
slope_parameter             = (k1/2.5)  3.4
orbit_good                  = 1000
discovery                   = 2023-01-09 [Not given by JPL Horizons]
ref                         = JPL Horizons: JPL#25
```

JPL Horizons can also deliver osculating elements for a number of interplanetary spacecraft. To visualize
them, you should assign `type=interstellar object` (to make the orbit line stand out a bit more than
with `asteroid`) and invent your own magnitude, e.g., `absolute_magnitude=0` or even brighter, to make
them visible. Obviously, the shown trajectory is valid only around the given epoch and changes significantly
whenever a spacecraft encounters a larger solar system object or when operators fire its engines. An Example
for the Voyager 2 spacecraft may look like:

```
[voyager2]
name                        = Voyager 2 (after Neptune)
iau_designation             = Voyager 2
type                        = interstellar object
orbit_ArgOfPericenter       = 1.300872388863244E+02
orbit_AscendingNode         = 1.017840511971174E+02
orbit_Eccentricity          = 6.294338891686261E+00
orbit_Epoch                 = 2460554.5                 [Sept 1, 2024]
orbit_Inclination           = 7.895342038400214E+01
orbit_PericenterDistance    = 2.130818195968974E+01
orbit_TimeAtPericenter      = 2445446.868665616959
orbit_good                  = 12797
ref                         = JPL Horizons
absolute_magnitude          = 0
slope_parameter             = 4
```

The displayed trajectory should start at Voyager 2's encounter with Neptune on August 18, 1989 (JD
2447757.5). The value of `orbit_good`= (2460554.5 − 2447757.5 =) 12797 fulfills this idea.

# E. Planetary nomenclature

Planetary nomenclature, like terrestrial nomenclature, is a system of uniquely identifying features on the surface of a planet or natural satellite so that the features can be easily located, described, and discussed. Since the invention of the telescope, astronomers have given names to the surface features they have discerned, especially on the Moon and Mars. To standardize planetary nomenclature, the International Astronomical Union (IAU) was assigned in 1919 the task of selecting official names for features on solar system bodies[1].
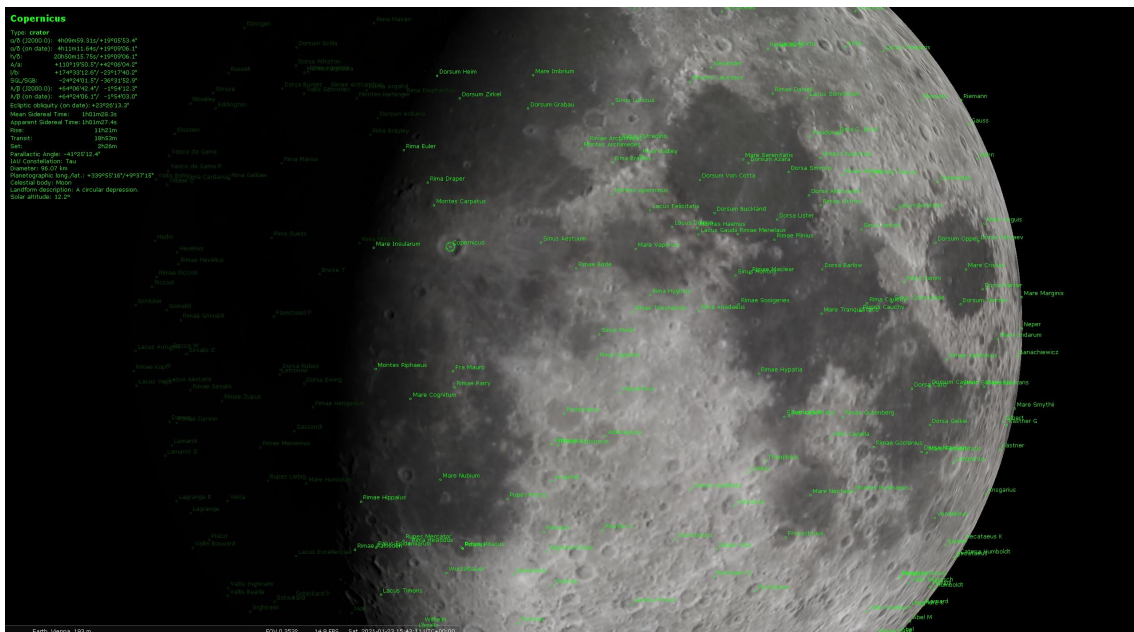


Figure E.1: Feature nomenclature of the Moon.

Since version 0.17.0 Stellarium supports planetary nomenclature, which allows using the planetarium for educational and informative purposes on the one hand, and as tool for recognition and targeting of the planetary features for advanced amateurs on the other hand, avoiding the need for additional cartographic software in the field.

All planetary nomenclature items are stored in a dedicated internal format, and all names are translatable to provide better understanding of those names by average users and newbies – for example in schools or universities. Of course all nomenclature items are available for finding in the Search Tool after enabling the

---

[1]History of Planetary Nomenclature – https://planetarynames.wr.usgs.gov/Page/History

display of nomenclature (this feature is rather costly in terms of computing power and therefore is by default disabled in the GUI).

*The information in sections E.3–E.6, included here for reference, has been taken from the "Gazetteer of Planetary Nomenclature" website by the International Astronomical Union (IAU) Working Group for Planetary System Nomenclature (WGPSN)*[2].

# E.1   Format of nomenclature data file

File `data/nomenclature.fab` is a plain text file in UTF-8 encoding and has a very simple data format:
   • One item per line;
   • Each item contains seven elements with white space ("space" or "tab" character) as delimiter.
File `data/nomenclature.dat` is a zipped `data/nomenclature.fab` file and used to minimize time of loading the data and reduce size of the installation package.

| Item | Type | Comment |
|---|---|---|
| planet name | string | English name of the planet, moon or minor body carrying the named feature |
| ID of planetary feature | integer | unique integer, equal to Feature ID obtained from Gazetteer of Planetary Nomenclature |
| translatable name of planetary feature | string | English name, containing context data for translators |
| type of planetary feature | string | 2-char code (see *designation* column in table in section E.6) |
| center latitude of planetary feature | float | decimal degrees |
| center longitude of planetary feature | float | decimal degrees |
| size of planetary feature | float | kilometers |

Example:

```
Vesta 15201 _("Caesonia","crater") AA 31.20117 249.93457 104.23
```

# E.2   Planetary Coordinate Systems

When we observe the Moon or another planet from Earth (or actually from anywhere), we can see only about half of the surface of the spheroid body at any time. Foreshortening further prevents us from observing surface features along the planet's visible limb. Therefore it is important to know the coordinates of the center of the apparent disk, given by the *central meridian* and latitude. In addition, we can also compute the *subsolar point*, where the sun is visible in the zenith, and which provides the center of the illuminated hemisphere. This is not the center of the visible disk! A part of the illuminated hemisphere is generally on the far side of the planet.

The north pole of the planets is the pole of rotation directed towards the north of the invariable plane (near the ecliptic) of the Solar system. Most planets are rotating in the same sense as they are moving around the sun. This is called *prograde*. Seen from the north side of the ecliptic, they rotate counterclockwise. Only a few objects, most notable Venus, are rotating clockwise, i.e., *retrograde*.

For historical reasons, there are several ways to count longitudes. Just like the terrestrial zero meridian has been defined as that one running through Greenwich observatory[3], the zero meridian on rocky bodies like the Moon or Mars is usually defined by some surface feature like a small crater. For the gas planets, the rotation of the magnetic field is usually given to define the central meridian. Starting from this central meridian, we can count longitudes in both directions. For the Moon, which shows always (almost, see 18.2.6) the same side towards Earth, we count western and eastern longitudes from the central meridian towards the trailing or leading edge of its daily motion, respectively. (Seeing the Moon through an unguided telescope, we first see the eastern longitudes from $\approx 90°$ to $0°$, then the western longitudes from $0°$ to $\approx 90°$.) Alternatively we can count the western longitudes as negative. The counting continues to the (invisible) far side of the Moon where one meridian has an Eastern longitude of $+180° = -180°$.

---

[2]`https://planetarynames.wr.usgs.gov`, visited on 2022-04-04

[3]In earlier times, at least each seafaring nation had its own zero meridian, usually running through an official observatory.

For other objects, historically, Mars was the first planet to be mapped with cartographic coordinates. Its rotational period of just over 24.5 hours allows to follow its rotation and observe only a slight change in appearance every day. It appeared natural to count the central meridian so that central longitude increased as time passed. Just like on Earth, as time passes, increasingly western longitudes receive sunlight and also become visible. Therefore these *planetographic* longitudes are counted towards the west on planets with prograde rotation. On planets with retrograde rotation like Venus, these longitudes are counted eastward.

In contrast, current convention on Earth is to count geographic longitudes eastward.

The information about coordinates for center and subsolar points in the information displayed for a planet is counted in this planetographic sense.

Another convention are *planetocentric coordinates* where longitudes are always counted positively towards the east. East is defined as going counterclockwise as seen from the north pole, which is itself defined as the one pole more closely aligned with Earth's north pole. The latest maps and data for Mars are using planetocentric data, i.e., eastern longitudes.

For clarity, therefore coordinates are often explicitly written with "E" and "W" instead of signed numbers.

Another difference between planetographic and planetocentric coordinates is that the latter model the planet as simple sphere, ignoring the (usually small) flattening of the planet bodies.

The surface coordinate systems defined by the WGPSN[4] and used in Stellarium follows are shown in table E.1[5]. However, given that the WGPSN publishes their data only with planetocentric latitudes, Stellarium provides planetocentric latitudes in the information panel for surface features.

## E.3  How names are approved by the IAU

When images are first obtained of the surface of a planet or satellite, a theme for naming features is chosen and a few important features are named, usually by members of the appropriate IAU task group (a commonly accepted planet-naming group). Later, as higher resolution images and maps become available, additional features are named at the request of investigators mapping or describing specific surfaces, features, or geologic formations. Anyone may suggest that a specific name be considered by a task group. If the members of the task group agree that the name is appropriate, it can be retained for use when there is a request from a member of the scientific community that a specific feature be named. Names successfully reviewed by a task group are submitted to the IAU Working Group for Planetary System Nomenclature (WGPSN). Upon successful review by the members of the WGPSN, names are considered provisionally approved and can be used on maps and in publications as long as the provisional status is clearly stated. Provisional names are then presented for adoption to the IAU's General Assembly, which met triennially in the past, and which now adopts nomenclature for planetary surface features as required. A name is not considered to be official – that is, "adopted" – until the General Assembly has given its approval.

## E.4  IAU rules and conventions

Names adopted by the IAU must follow various rules and conventions established and amended through the years by the Union. These include:

1. Nomenclature is a tool and the first consideration should be to make it simple, clear, and unambiguous.
2. In general, official names will not be given to features whose longest dimensions are less than 100 meters, although exceptions may be made for smaller features having exceptional scientific interest.
3. The number of names chosen for each body should be kept to a minimum. Features should be named only when they have special scientific interest, and when the naming of such features is useful to the scientific and cartographic communities at large.
4. Duplication of the same surface feature name on two or more bodies, and of the same name for satellites and minor planets, is discouraged. Duplications may be allowed when names are especially appropriate and the chances for confusion are very small.
5. Individual names chosen for each body should be expressed in the language of origin. Transliteration for various alphabets should be given, but there will be no translation from one language to another.
6. Where possible, the themes established in early solar system nomenclature should be used and expanded on.
7. Solar system nomenclature should be international in its choice of names. Recommendations submitted to the IAU national committees will be considered, but final selection of the names is the

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[4]IAU Working Group for Planetary System Nomenclature – `https://planetarynames.wr.usgs.gov/`
[5]`https://planetarynames.wr.usgs.gov/TargetCoordinates`, visited Jan.5, 2022

| Target | Coordinate Systems | | | Control Networks |
|---|---|---|---|---|
| Amalthea | Planetographic | +West | 0...+360 | |
| Ariel | Planetocentric | +East | 0...+360 | |
| Callisto | Planetographic | +West | 0...+360 | |
| Charon | Planetocentric | +East | 0...+360 | Charon |
| Deimos | Planetographic | +West | 0...+360 | |
| Dione | Planetographic | +West | 0...+360 | |
| Enceladus | Planetographic | +West | 0...+360 | |
| Epimetheus | Planetographic | +West | 0...+360 | |
| Europa | Planetographic | +West | 0...+360 | |
| Ganymede | Planetographic | +West | 0...+360 | |
| Hyperion | Planetographic | +West | 0...+360 | |
| Iapetus | Planetographic | +West | 0...+360 | |
| Io | Planetographic | +West | 0...+360 | Voyager/Galileo SSI |
| Janus | Planetographic | +West | 0...+360 | |
| Mars | Planetocentric | +East | 0...+360 | MDIM 2.1 |
| Mercury | Planetographic | +West | 0...+360 | MESSENGER Team |
| Mimas | Planetographic | +West | 0...+360 | |
| Miranda | Planetocentric | +East | 0...+360 | |
| Moon | Planetographic | +East | −180...+180 | LOLA 2011, ULCN 2005 |
| Oberon | Planetocentric | +East | 0...+360 | |
| Phobos | Planetographic | +West | 0...+360 | |
| Phoebe | Planetographic | +West | 0...+360 | |
| Pluto | Planetocentric | +East | 0...+360 | Pluto |
| Proteus | Planetographic | +West | 0...+360 | |
| Puck | Planetocentric | +East | 0...+360 | |
| Rhea | Planetographic | +West | 0...+360 | |
| Tethys | Planetographic | +West | 0...+360 | |
| Thebe | Planetographic | +West | 0...+360 | |
| Titan | Planetographic | +West | 0...+360 | |
| Titania | Planetocentric | +East | 0...+360 | |
| Triton | Planetographic | +East | 0...+360 | |
| Umbriel | Planetocentric | +East | 0...+360 | |
| Venus | Planetocentric | +East | 0...+360 | |

Table E.1: Coordinate systems used by the WGPSN

responsibility of the International Astronomical Union. Where appropriate, the WGPSN strongly supports an equitable selection of names from ethnic groups, countries, and gender on each map; however, a higher percentage of names from the country planning a landing is allowed on landing site maps.

8. No names having political, military or religious significance may be used, except for names of political figures prior to the 19th century.

9. Commemoration of persons on planetary bodies should not normally be a goal in itself, but may be employed in special circumstances and is reserved for persons of high and enduring international standing. Persons being so honored must have been deceased for at least three years, before a proposal may be submitted.

10. When more than one spelling of a name is extant, the spelling preferred by the person, or used in an authoritative reference, should be used. Diacritical marks are a necessary part of a name and will be used.

11. Ring and ring-gap nomenclature and names for newly discovered satellites are developed in joint deliberation between WGPSN and IAU Commission X2. Names will not be assigned to satellites until their orbital elements are reasonably well known or definite features have been identified on them.

12. Accessible and authoritative sources, including Internet sources, are required for adopted names. Wikipedia is not sufficient as a source, but may be useful for identifying appropriate sources.

In addition to these general rules, each task group develops additional conventions as it formulates an interesting and meaningful nomenclature for individual planetary bodies. Most of these conventions are self evident from study of the appendixes that follow.

## E.5   Naming conventions

Names for all planetary features include a descriptor term, with a few exceptions. For craters, the descriptor term is implicit. Some features named on Io and Triton do not carry a descriptor term because they are ephemeral.

In general, the naming convention for a feature type remains the same regardless of its size. Exceptions to this rule are channels (valles) on Mars and Venus, and craters on the Moon, Mars, and Venus; naming conventions for these features differ according to size. The categories for naming features on each planet or satellite (and the exceptions) are listed in Categories for Naming Features on Planets and Satellites[6]. One feature classification, regio, was originally used on early maps of the Moon and Mercury (drawn from telescopic observations) to describe vague albedo features. It is now also used to delineate a broad geographic region.

Named features on bodies so small that coordinates have not yet been determined are identified on drawings or images of the body that are included in the IAU Transactions volume of the year when the names were adopted. Satellite rings and gaps in the rings are named for scientists who have studied these features; drawings that show these names are also included in the pertinent Transactions volume. Names for atmospheric features are informal at present; a formal system will be chosen in the future.

The boundaries of many large features (such as terrae, regiones, planitiae, and plana) are not topographically or geomorphically distinct; the coordinates of these features are identified from an arbitrarily chosen center point. Boundaries (and thus coordinates) may be determined more accurately from geochemical and geophysical data obtained by future missions.

During active missions, small surface features are often given informal names. These may include landing sites, spacecraft impact sites, and small topographic features, such as craters, hills, and rocks. Such names will not be given official status by the IAU, except as provided for by Rule 2 above. As for the larger objects, official names for any such small features would have to conform to established IAU rules and categories.

When a satellite has been discovered through the efforts of a large scientific team, the list of individual team members may be too long to include all contributors. In such cases, credit for the discovery will go to the science team.

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[6]Surface Feature Categories – `https://planetarynames.wr.usgs.gov/Page/Categories`

## E.6 Descriptor terms (feature types)

Descriptor terms are intended to represent morphological characteristics, not geological origin. The WGPSN does not endorse any specific scientific hypotheses when assigning descriptors.

| *Feature* | *Designation* | *Description* |
|---|---|---|
| Albedo Feature | AL | Geographic area distinguished by amount of reflected light |
| Arcus, arcūs | AR | Arc-shaped feature |
| Astrum, astra | AS | Radial-patterned features on Venus |
| Catena, catenae | CA | Chain of craters |
| Cavus, cavi | CB | Hollows, irregular steep-sided depressions usually in arrays or clusters |
| Chaos, chaoses | CH | Distinctive area of broken terrain |
| Chasma, chasmata | CM | A deep, elongated, steep-sided depression |
| Collis, colles | CO | Small hills or knobs |
| Corona, coronae | CR | Ovoid-shaped feature |
| Crater, craters | AA | A circular depression |
| Dorsum, dorsa | DO | Ridge |
| Eruptive center | ER | Active volcanic centers on Io |
| Facula, faculae | FA | Bright spot |
| Farrum, farra | FR | Pancake-like structure, or a row of such structures |
| Flexus, flexūs | FE | A very low curvilinear ridge with a scalloped pattern |
| Fluctus, fluctūs | FL | Flow terrain |
| Flumen, flumina | FM | Channel on Titan that might carry liquid |
| Fossa, fossae | FO | Long, narrow depression |
| Fretum, freta | FT | Strait, a narrow passage of liquid connecting two larger areas of liquid |
| Insula, insulae | IN | Island (islands), an isolated land area (or group of such areas) surrounded by, or nearly surrounded by, a liquid area (sea or lake) |
| Labes, labēs | LA | Landslide |
| Labyrinthus, labyrinthi | LB | Complex of intersecting valleys or ridges |
| Lacuna, lacunae | LU | Irregularly shaped depression on Titan having the appearance of a dry lake bed |
| Lacus, lacūs | LC | "Lake" or small plain; on Titan, a "lake" or small, dark plain with discrete, sharp boundaries |
| Landing site name | LF | Lunar features at or near Apollo landing sites |
| Large ringed feature | LG | Cryptic ringed features |
| Lenticula, lenticulae | LE | Small dark spots on Europa |
| Linea, lineae | LI | A dark or bright elongate marking, may be curved or straight |
| Lingula, lingulae | LN | Extension of plateau having rounded lobate or tongue-like boundaries |
| Macula, maculae | MA | Dark spot, may be irregular |
| Mare, maria | ME | "Sea"; on the Moon, low albedo, relatively smooth plain, generally of large extent; on Mars, dark albedo areas of no known geological significance; on Titan, large expanses of dark materials thought to be liquid hydrocarbons |
| Mensa, mensae | MN | A flat-topped prominence with cliff-like edges |
| Mons, montes | MO | Mountain |
| Oceanus, oceani | OC | A very large dark area on the moon |

| Palus, paludes | PA | "Swamp"; small plain |
|---|---|---|
| Patera, paterae | PE | An irregular crater, or a complex one with scalloped edges |
| Planitia, planitiae | PL | Low plain |
| Planum, plana | PM | Plateau or high plain |
| Plume, plumes | PU | Cryo-volcanic features on Triton |
| Promontorium, promontoria | PR | "Cape"; headland promontoria |
| Regio, regiones | RE | A large area marked by reflectivity or color distinctions from adjacent areas, or a broad geographic region |
| Reticulum, reticula | RT | Reticular (netlike) pattern on Venus |
| Rima, rimae | RI | Fissure |
| Rupes, rupēs | RU | Scarp |
| Satellite Feature | SF | A feature that shares the name of an associated feature. For example, on the Moon the craters referred to as "Lettered Craters" are classified in the gazetteer as "Satellite Features" |
| Saxum, saxa | SA | Boulder or rock |
| Scopulus, scopuli | SC | Lobate or irregular scarp |
| Serpens, serpentes | SE | Sinuous feature with segments of positive and negative relief along its length |
| Sinus, sinūs | SI | "Bay"; small plain; on Titan, bays within seas or lakes of liquid hydrocarbons |
| Sulcus, sulci | SU | Subparallel furrows and ridges |
| Terra, terrae | TA | Extensive land mass |
| Tessera, tesserae | TE | Tile-like, polygonal terrain |
| Tholus, tholi | TH | Small domical mountain or hill |
| Unda, undae | UN | Dunes |
| Vallis, valles | VA | Valley |
| Vastitas, vastitates | VS | Extensive plain |
| Virga, virgae | VI | A streak or stripe of color |

## E.6.1  Chart of landform types

The graphical examples of some landform types were taken from a chart of landform types created in 1979 by Anne Gifford, then at the Air and Space Museum, Smithsonian Institution, Washington, D.C. [7]



**Lacus** [LC] and **Mare** [ME]   **Oceanus** [OC] and **Palus** [PA]   **Planitia** [PL] and **Planum** [PM]

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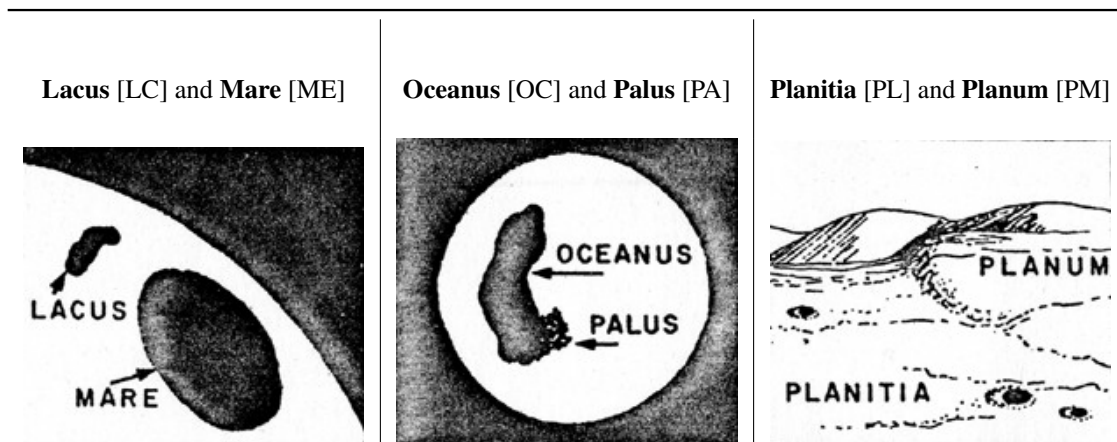
[7] https://planetarynames.wr.usgs.gov/images/Farouk_drawings_composite.pdf

| | | |
|---|---|---|
| "lake" (small irregular patch of dark, smooth material of the Moon) and "sea" (large, often circular, region of dark smooth material of the Moon) | "ocean" (vast, irregular, dark, smooth region – Oceanus Procellarum only) and "swamp" (small irregular area, on the Moon a mixture of mare and highland material) | low plain or large level expanse of lowlands and high plain or a plateau |

| **Catena** [CA] | **Cavus** [CB] | **Chaos** [CH] |
|---|---|---|
|  |  |  |
| chain; a string of closely spaced depressions | cavities; irregular steep-sided depressions usually in clusters | chaos; area of distinctive broken or jumped terrain |

| **Chasma** [CM] | **Crater** [AA] | **Dorsum** [DO] |
|---|---|---|
|  |  |  |
| chasm; steep-walled trough; large canyon | crater; any roughly circular depression resulting from impact or volcanic activity | ridge; elongate raised structure; wrinkle ridge |

| **Fossa** [FO] | **Labyrinthus** [LB] | **Mensa** [MN] |
|---|---|---|
|  |  |  |
| ditch; narrow linear trench (on the Moon called Rima) | labyrinth; an expanse of intersecting canyon-like troughs | mesa; flat-topped elevation with steep walls |

| **Mons** [MO] | **Patera** [PE] | **Promontorium** [PR] |
|---|---|---|
|  |  |  |

| mountain | "saucer"; shallow, complex crater with scalloped walls | promontory; extension of lunar mountains into mare |
|---|---|---|
| **Rima** [RI] | **Rupes** [RU] | **Scopulus** [SC] |
| channel; long narrow valley, fissure or channel on the Moon | linear scarp of cliff face | cliff; lobate or highly irregular scarp |
| **Sinus** [SI] | **Sulcus** [SU] | **Terra** [TA] |
| "bay"; semi-enclosed dark area opening into a mare on the Moon | complex area of sub-parallel furrows and ridges | uplands or highlands |
| **Tholus** [TH] | **Vallis** [VA] | **Vastitas** [VS] |
| dome; isolated domical mountain or hill | valley; canyon-like, often sinuous trough | "wasteland"; extensive plains of lowlands, only on Mars |
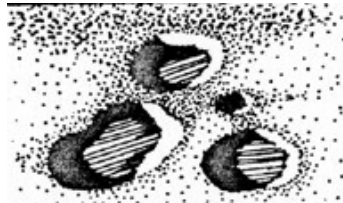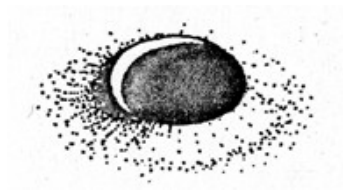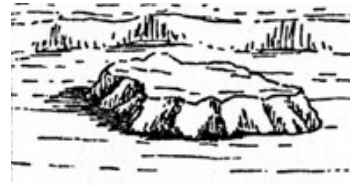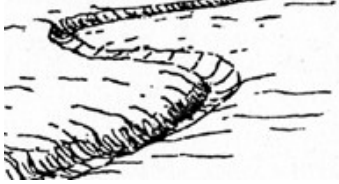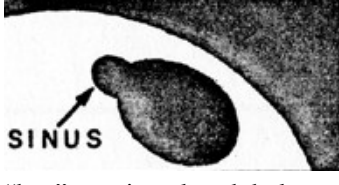
## Author and Acknowledgement

# F. Accuracy

Stellarium originally was developed to present a beautiful simulation of the night sky, mostly to understand what is visible in the sky when you leave your house, i.e., for present times. To save computation time, some concessions were made in astronomical accuracy by using simplified models which seemed acceptable at that time which was also close to the standard epoch of J2000.0. However, time is progressing, precession becomes noticeable when pointing telescopes to J2000.0 coordinates, and some users also started to overstress Stellarium's capabilities to simulate the historical sky of many centuries in the past, and found — or even worse: did not find, but simply published — the resulting inconsistencies and errors. Unfortunately, celestial motions are indeed more complicated than a simple clockwork, and the process of retrofitting detailed and accurate models which started around v0.11.0 (in 2011) has only recently (2021) come to a state where we as developers are beginning to be satisfied. Now, after implementation of annual aberration, Stellarium appears to deviate from reference solutions in the present time only by fractions of arcseconds, and by a few arcseconds in the remote past. Greater accuracy, including relativistic effects or the deflection of light by the Solar gravity field, may still be required for critical observations of stellar occultations by asteroids, grazing occultations of stars by the Moon or similar things. Stellarium does not compute these effects, and is definitely not usable for detailed planning of your spacecraft missions to the planets. There are more specialized programs for these topics, please use them.

Therefore, when using Stellarium for scientific work like eclipse simulation to illustrate records found in Cuneiform tablets, always also use some other reference to compare, and of course specify the program version you used for your work. (Use at least version 25.1 of Stellarium, which introduced the much improved star catalog!) You can of course contact us if you bring a solid background in fundamental astronomy and are willing and able to help improving Stellarium's accuracy even further!

## F.1 Date Range

The calendar dates are limited to a very wide interval of years, $-200,000\ldots+200,000$[1]. If you want to observe the other planets, this is way beyond what current ephemeris models are able to show, as explained in section F.3! Observe for example the Moon: you will find that it seems to run on a polar orbit around +78.000 and even retrograde on a highly elongated orbit a few millennia after that. A quick check in -180.000 places it in a highly elongated orbit beyond Jupiter that takes it through the solar system at up to more than 10% the speed of light. This is obvious nonsense, caused by excessively extrapolating mathematical models in inappropriate ways.

The extended date range is only useful to visualize the effect of stellar proper motions and the wobbling motion of Earth's axis known as precession. All other components of Stellarium have not made for this extended date range.

v 25.3

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[1]Before version 25.3, the date range was $-100,000\ldots+100,000$.

| Object(s) | Method | Notes |
|---|---|---|
| Mercury, Venus, Earth-Moon barycenter, Mars | VSOP87 | Accuracy is 1 arc-second from 2000 B.C. – 6000 A.D. |
| Jupiter, Saturn | VSOP87 | Accuracy is 1 arc-second from 0 A.D. – 4000 A.D. |
| Uranus, Neptune | VSOP87 | Accuracy is 1 arc-second from 4000 B.C. – 8000 A.D. |
| Pluto | ? | Pluto's position is valid only from 1885 A.D. – 2099 A.D. |
| Earth's Moon | ELP2000-82B | Fit against JPL DE200, which provides date range 1850–2050. Positions should be usable for some (unspecified) longer interval. |
| Galilean satellites | L2 | Valid from 500 A.D. – 3500 A.D. |

Table F.1: Orbit-centric accuracy of used algorithms

## F.2  Stellar Astrometry

Even though you can follow movements of stars on the sky for tens of thousands of years, please note that the precision of these predictions are limited by the precision of the data we have at the present time provided by Hipparcos for bright stars and Gaia. Most of the stars brighter than magnitude 10.5 have 3D position and 3D velocity data (i.e., 6D astrometry) in our star catalogs, thus their 6D astrometry are computed at any epoch by assuming linear motion with constant velocity. These calculation provides arcseconds level accuracy of stellar position, arcseconds per year level accuracy of proper motions, arcseconds level accuracy of parallax and km/s level accuracy of radial velocity in the previous and next tens of thousands of years. For stars fainter than magnitude 10.5 but brighter than magnitude 16.75, 2D computation is performed such that RA/DEC positions are computed from RA/DEC proper motions separately and assume constant proper motion. For stars fainter than magnitude 16.75, no astrometry propagation is performed hence their RA/DEC stay constant at any epoch.

The study of De Lorenzis and Orofino (2018) emphasized sky position errors with bright high proper motion stars like Arcturus, Dubhe, Sirius, Toliman and Vega which deviate noticeably from their correct locations even at around 2500BC with Stellarium 0.17.0 released on 21 Dec 2017. The star catalogs and astrometry propagation algorithms have been significantly improved since Stellarium 25.1, which has solved the problem outlined in the study.

A quick estimate: For Barnard's Star which is nearby and moving fast, the sky position uncertainty on the sky would be $\approx 0.05°$ (200000 mas) at year 200,000 using Gaia DR3 astrometries and associated uncertainies. The 2015 DR3 sky position uncertainty is $\approx 0.04$ mas.

## F.3  Planetary Positions

Stellarium uses by default the widespread VSOP87 theory (P. Bretagnon and Francou, 1988) to calculate the positions of the planets over time. This is an analytical ephemeris modeled to match the numerical integration run DE200 from NASA JPL, which by itself gives positions for 1850...2050. Its use is recommended for the years $-4000...+8000$. You can observe the sun leaving the "ecliptic of date" and running on the "ecliptic J2000" outside this date range. This is obviously a mathematical trick to keep continuity. Still, positions may be somewhat useful outside this range, but don't expect anything reliable 50,000 years in the past!

The optionally usable JPL DE431 and DE441 (see 5.5.3) deliver planet positions strictly for the year range -13000...+17000 only, and nothing outside, but likely with higher accuracy. Outside of this range, positions from VSOP87 will be shown again.

As far as Stellarium is concerned, the user should bear in mind the limits of the VSOP87 and other models (Table F.1). Accuracy values for VSOP87 are heliocentric as given by P. Bretagnon and Francou (1988).

## F.4 Minor Bodies

Positions for the Minor Bodies (Dwarf Planets, Asteroids, Comets) are computed with standard algorithms found in astronomical text books. The generally used method of orbital elements allows computing the positions of the respective object on an undisturbed Kepler orbit around the sun. However, gravitational, and in the case of comets, non-gravitational (outgassing) disturbances slowly change these orbital elements. Therefore an *epoch* is given for such elements, and computation of positions for times far from this epoch will lead to positional errors. Therefore, when searching for asteroids or comets, always update your orbital elements (See section 13.8), and use elements with an epoch as close to your time of observation as possible! Stellarium does not simulate gravitational perturbances and orbital changes of minor bodies passing major planets.

## F.5 Precession and Nutation

Since v0.14.0, Stellarium computes the orientation of earth's axis according to the IAU2006 Precession in a long-time variant developed by Vondrák, Capitaine, and Wallace (2011) and Vondrák, Capitaine, and Wallace (2012), and IAU2000B Nutation (McCarthy and Luzum, 2003). This also now allows proper depiction of the changes in ecliptic obliquity and display of "instantaneous precession circles" around the ecliptic poles. These circles are indeed varying according to ecliptical obliquity. Nutation is only computed for about 6000 years around J2000.0. Nobody could have observed it before 1609, and it is unclear for how long this model is applicable.

## F.6 Planet Axes

Where available, Stellarium uses  axis orientation and rotation data from the *IAU* Working Group on Cartographic Coordinates and Rotational Elements (*WGCCRE*). Orientation for some small moons is still simplified and based on the model originally available. (See section D.2.1.1)

## F.7 Eclipses

The moon's motion is very complicated, and eclipse computations can be tricky. One aspect which every student of history, prehistory and archaeology should know, but as it seems not every does, is at least a basic understanding of the irregular slow-down of earth's rotation known as $\Delta T$ (see section 18.4.3).

Eclipse records on cuneiform tablets go back to the 8th century BC, some Chinese records go back a bit further. Experts on Earth rotation have provided models for $\Delta T$ based on such observations. These are usually given as parabolic fit, with some recommended time span. Extrapolating parabolic fits to erratic curves too far into the past is dangerous, pointless and inevitably leads to errors or invalid results. Models differ by many hours (exceeding a whole day!) when applied too far in the past. This means, there was certainly an eclipse, and latitude will be OK, but you cannot say which longitude the eclipse was covering. The probability to have seen a total eclipse at a certain interesting location will be very small and should by itself not be used as positive argument for any reasonable statement. This is not a problem of Stellarium, but of current knowledge. To repeat, you may find a solar eclipse in the 6th millennium BC, but you cannot even be sure which side of Earth could have observed it!

**WANTED:** A model for $\Delta T$ that works in the Mesolithic!

## F.8 The Calendar

Stellarium follows the widely accepted convention that dates before the Gregorian calendar reform are given in the Julian calendar, introduced by JULIUS CAESAR in 46 BC. This calendar introduces a leap day every fourth year, which is a bit too much. If you want to show summer solstice in the year −2500, you will notice it is not on June 21st. This is not an error of Stellarium – the Gregorian reform had a reason! In prehistoric times, it may be more useful to work with solar ecliptic longitudes. For example, summer solstice is when the Sun is at $\lambda = 90°$.

JULIUS CAESAR introduced a Solar calendar to the Roman empire in 46 BC but was assassinated in March 44 BC=−43 (see below). His simple 4-year leap rule was then misapplied by the high priests of Rome by adding a leap day every third year. AUGUSTUS fixed the calendar by omitting a few leap days, and only 8 AD was the first correctly applied leap year as we know them (Ginzel, 1908, §186, §189). Be careful if you are working in Augustean and earlier times in the Roman world, maybe even related to named dates in

the pre-Julian Roman calendar: Stellarium, also its Calendars plugin (see section 13.10), does not model these issues!

Some authors (esp. for Mesoamerican dates) give dates in the proleptic Gregorian calendar (which means that they apply the Gregorian leap year rules before 1582). This is a convention, they may of course do that, but you must do the conversion to the Julian calendar to visualize the sky with Stellarium. If they also give Julian Day numbers (JD), you can use them with Stellarium as JD numbers are independent from calendar systems. Otherwise, you can utilize the Calendars plugin (see section 13.10).

Some users have noted and expressed confusion about a difference of one between dates given as BC (or BCE) versus Stellarium's negative years. Note that historical chronology does not know a year Zero! (Try to write this date in Roman numbers!) Year AD 1 (1 CE) was preceded by year 1 BC (1 BCE). Astronomers want to simplify computations and therefore use a year 0 (equivalent to 1 BC). It is simple: 1 BC=0, 2 BC=−1, ... 100 BC=−99 (Fig. F.1). Stellarium is an astronomy program and uses astronomical counting. Other programs may behave differently in this respect, e.g. may even use negative signs to indicate years BC. However, the Calendars plugin (see section 13.10) even allows displaying both counting systems.

|              |     |       |       | $\Longleftarrow$ negative | 0 | positive $\Longrightarrow$ |      |      |     |
|--------------|-----|-------|-------|------|------|------|------|------|-----|
| Astronomical | ... | -3    | -2    | -1   | 0    | 1    | 2    | 3    | ... |
| Historical   | ... | 4 BC  | 3 BC  | 2 BC | 1 BC | AD 1 | AD 2 | AD 3 | ... |
|              |     |       | $\Longleftarrow$ Before Christ | | | After Christ $\Longrightarrow$ | | | |

Figure F.1: Counting years around the beginning of the Common Era.

## F.9  Comparison to Reference Data

Tables F.2 and F.3 provide comparison data between JPL Horizons[2] and Stellarium. The JPL data were fetched in July 2021 by our attentive user Atque. These are apparent geocentric coordinates provided by JPL's solutions DE440/DE441 in J2000.0 equatorial coordinates, including JPL's corrections for nutation, light time, aberration, light deflection in the Solar gravity field, and other relativistic effects. The right part provides the respective values computed by Stellarium from DE440/DE441 files, with the current state of corrections for nutation, light time and aberration. The $\Delta T$ model was set to "JPL Horizons", but when using DE* files a slightly different model specialized to the DE ephemeris is used[3], resulting in differences in the effective value of $\Delta T$. Among the causes for differences we must take into account:

- Stellarium does not provide corrections for diurnal aberration (should not matter for geocentric positions)
- Stellarium does not provide corrections for light deflection in the Sun's gravitational field
- JPL Horizons uses slightly different models than Stellarium for precession and nutation[4]

The first item should not make a difference. The next two may cause differences in the range of a few arcseconds. The apparent drift that we can observe in the remote past may stem from different assumptions regarding $\Delta T$ (see 18.4.3) or from other reasons yet to be identified. Competent help welcome!

> **WANTED**
>
> If you can trace down hitherto unknown reasons for remaining inaccuracies and either provide a fix or a decisive hint to us, we can offer a reward in the EUR200–500 range from our donation fund. We, the developers, will judge and evaluate relevance, legal recourse is excluded.

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[2]`https://ssd.jpl.nasa.gov/horizons.cgi`

[3]For experts: The value for secular acceleration of the Moon in ELP2000-82B, $\dot{n} = -23.8946$, is replaced by $\dot{n} = -25.8$.

[4]`https://ssd.jpl.nasa.gov/?horizons_doc#specific_quantities`

Table F.2: An ephemeris comparison between Stellarium and JPL Horizons. Both are showing geocentric apparent coordinates from the JPL DE440/441 ephemerides (with slightly different models for precession, nutation and aberration; JPL results are also corrected for light deflection). While results for present times agree very well, results for the past seem to diverge a bit, presumably caused by differences in $\Delta T$ handling.

| UT Date Time | JPL Horizons (DE440/441) | | Stellarium 0.21.2$\beta$ | | |
| | RA J2000.0 | DE J2000.0 | $\alpha_{J2000.0}$ | $\delta_{J2000.0}$ | $\Delta T$ |
|---|---|---|---|---|---|
| **SUN** | | | | | |
| b2500-Jan-01 00:00 | 17h 24m 24.70s | -23° 43' 11.8" | 17h 24m 23.52s | -23° 43' 13.2" | 57938.45s |
| b2500-Jun-02 00:00 | 03h 06m 17.57s | +17° 54' 00.7" | 03h 06m 16.61s | +17° 53' 58.6" | 57927.29s |
| b2500-Nov-01 00:00 | 13h 11m 48.12s | -07° 48' 17.2" | 13h 11m 47.07s | -07° 48' 11.5" | 57916.12s |
| b2499-Apr-02 00:00 | 23h 26m 28.14s | -03° 42' 34.9" | 23h 26m 27.30s | -03° 42' 40.9" | 57904.96s |
| b0500-Jan-01 00:00 | 18h 25m 28.83s | -23° 37' 22.2" | 18h 25m 28.82s | -23° 37' 23.4" | 16704.77s |
| b0500-Jun-02 00:00 | 04h 09m 13.48s | +21° 17' 20.8" | 04h 09m 13.50s | +21° 17' 21.9" | 16698.78s |
| b0500-Nov-01 00:00 | 14h 04m 26.18s | -12° 48' 35.8" | 14h 04m 26.15s | -12° 48' 36.3" | 16692.79s |
| b0499-Apr-02 00:00 | 00h 21m 10.51s | +02° 19' 31.0" | 00h 21m 10.52s | +02° 19' 31.1" | 16686.79s |
| 0500-Jan-01 00:00 | 18h 53m 06.08s | -23° 04' 11.0" | 18h 53m 06.04s | -23° 04' 11.8" | 5413.20s |
| 0500-Jun-01 00:00 | 04h 39m 16.40s | +22° 19' 46.7" | 04h 39m 16.39s | +22° 19' 47.4" | 5409.79s |
| 0500-Oct-31 00:00 | 14h 29m 26.81s | -14° 52' 19.2" | 14h 29m 26.77s | -14° 52' 19.5" | 5406.38s |
| 0501-Apr-01 00:00 | 00h 46m 23.08s | +05° 01' 37.5" | 00h 46m 23.07s | +05° 01' 37.6" | 5402.97s |
| 0501-Aug-31 00:00 | 10h 41m 17.14s | +08° 22' 56.8" | 10h 41m 17.14s | +08° 22' 57.2" | 5399.56s |
| 1600-Jan-01 00:00 | 18h 43m 28.07s | -23° 06' 56.6" | 18h 43m 28.33s | -23° 06' 56.5" | 141.31s |
| 1600-Jun-01 00:00 | 04h 35m 37.18s | +22° 04' 25.0" | 04h 35m 37.43s | +22° 04' 25.6" | 140.84s |
| 1600-Oct-31 00:00 | 14h 21m 56.45s | -14° 09' 38.9" | 14h 21m 56.68s | -14° 09' 40.1" | 140.37s |
| 1601-Apr-01 00:00 | 00h 41m 18.48s | +04° 27' 19.4" | 00h 41m 18.70s | +04° 27' 20.8" | 139.90s |
| 1601-Aug-31 00:00 | 10h 36m 30.29s | +08° 48' 10.8" | 10h 36m 30.52s | +08° 48' 09.6" | 139.44s |
| 2021-Jan-01 00:00 | 18h 46m 53.59s | -22° 59' 57.2" | 18h 46m 53.59s | -22° 59' 57.2" | 65.79s |
| 2021-Jun-02 00:00 | 04h 40m 40.91s | +22° 11' 09.1" | 04h 40m 40.90s | +22° 11' 09.1" | 66.11s |
| 2021-Nov-01 00:00 | 14h 25m 34.78s | -14° 25' 31.0" | 14h 25m 34.78s | -14° 25' 30.9" | 66.43s |
| 2022-Apr-02 00:00 | 00h 45m 00.07s | +04° 50' 03.8" | 00h 45m 00.07s | +04° 50' 03.7" | 66.76s |
| **MERCURY** | | | | | |
| b2500-Jan-01 00:00 | 17° 07m 28.00s | -25° 22' 36.2" | 17h 07m 24.54s | -25° 22' 33.7" | 57938.45s |
| b2500-Jun-02 00:00 | 04h 57m 29.05s | +22° 59' 25.2" | 04h 57m 28.40s | +22° 59' 34.3" | 57927.29s |
| b2500-Nov-01 00:00 | 11h 56m 15.20s | +03° 10' 47.5" | 11h 56m 14.50s | +03° 10' 55.1" | 57916.12s |
| b2499-Apr-02 00:00 | 23h 03m 07.53s | -07° 14' 26.7" | 23h 03m 04.03s | -07° 14' 56.6" | 57904.96s |
| b0500-Jan-01 00:00 | 18h 40m 28.21s | -25° 26' 38.0" | 18h 40m 27.54s | -25° 26' 40.0" | 16704.77s |
| b0500-Jun-02 00:00 | 05h 38m 48.42s | +22° 19' 54.2" | 05h 38m 49.11s | +22° 19' 58.7" | 16698.78s |
| b0500-Nov-01 00:00 | 12h 56m 45.19s | -03° 57' 14.5" | 12h 56m 44.96s | -03° 57' 12.2" | 16692.79s |
| b0499-Apr-02 00:00 | 00h 21m 09.78s | +01° 53' 27.6" | 00h 21m 08.99s | +01° 53' 20.6" | 16686.79s |
| 0500-Jan-01 00:00 | 18h 23m 39.86s | -25° 14' 04.0" | 18h 23m 39.46s | -25° 14' 04.4" | 5413.20s |
| 0500-Jun-01 00:00 | 06h 29m 34.30s | +24° 32' 58.8" | 06h 29m 34.21s | +24° 33' 00.8" | 5409.79s |
| 0500-Oct-31 00:00 | 13h 28m 10.47s | -06° 51' 07.8" | 13h 28m 10.93s | -06° 51' 11.8" | 5406.38s |
| 0501-Apr-01 00:00 | 23h 55m 15.72s | -02° 45' 50.1" | 23h 55m 15.30s | -02° 45' 53.7" | 5402.97s |
| 0501-Aug-31 00:00 | 12h 03m 40.27s | -01° 48' 53.7" | 12h 03m 40.10s | -01° 48' 51.4" | 5399.56s |
| 1600-Jan-01 00:00 | 19h 16m 55.37s | -24° 27' 04.8" | 19h 16m 55.69s | -24° 27' 04.5" | 141.31s |
| 1600-Jun-01 00:00 | 05h 27m 00.75s | +22° 06' 49.9" | 05h 27m 00.88s | +22° 06' 49.8" | 140.84s |
| 1600-Oct-31 00:00 | 13h 24m 30.87s | -06° 45' 17.1" | 13h 24m 31.13s | -06° 45' 18.8" | 140.37s |
| 1601-Apr-01 00:00 | 00h 45m 30.34s | +03° 58' 05.0" | 00h 45m 30.64s | +03° 58' 07.2" | 139.90s |
| 1601-Aug-31 00:00 | 12h 08m 26.65s | -04° 19' 14.8" | 12h 08m 26.83s | -04° 19' 16.2" | 139.44s |
| 2021-Jan-01 00:00 | 19h 17m 59.43s | -24° 20' 58.1" | 19h 17m 59.41s | -24° 20' 58.2" | 65.79s |
| 2021-Jun-02 00:00 | 05h 35m 35.59s | +22° 40' 50.7" | 05h 35m 35.59s | +22° 40' 50.7" | 66.11s |
| 2021-Nov-01 00:00 | 13h 25m 55.55s | -06° 47' 18.8" | 13h 25m 55.54s | -06° 47' 18.7" | 66.43s |
| 2022-Apr-02 00:00 | 00h 43m 05.35s | +03° 21' 44.7" | 00h 43m 05.34s | +03° 21' 44.7" | 66.76s |
| **VENUS** | | | | | |
| b2500-Jan-01 00:00 | 14h 38m 40.01s | -10° 33' 46.3" | 14h 38m 40.01s | -10° 33' 46.8" | 57938.45s |
| b2500-Jun-02 00:00 | 01h 31m 36.91s | +08° 30' 50.3" | 01h 31m 35.42s | +08° 30' 41.0" | 57927.29s |
| b2500-Nov-01 00:00 | 14h 04m 33.57s | -13° 23' 07.7" | 14h 04m 31.93s | -13° 22' 58.4" | 57916.12s |
| b2499-Apr-02 00:00 | 02h 07m 22.90s | +16° 14' 49.7" | 02h 07m 21.78s | +16° 14' 43.3" | 57904.96s |
| b0500-Jan-01 00:00 | 15h 15m 48.26s | -13° 58' 19.4" | 15h 15m 48.35s | -13° 58' 20.3" | 16704.77s |
| b0500-Jun-02 00:00 | 02h 41m 50.72s | +14° 49' 02.0" | 02h 41m 50.54s | +14° 49' 01.5" | 16698.78s |
| b0500-Nov-01 00:00 | 15h 14m 41.57s | -18° 52' 17.3" | 15h 14m 41.35s | -18° 52' 16.9" | 16692.79s |
| b0499-Apr-02 00:00 | 03h 10m 27.71s | +21° 27' 17.2" | 03h 10m 27.72s | +21° 27' 17.6" | 16686.79s |
| 0500-Jan-01 00:00 | 20h 18m 43.11s | -15° 30' 09.1" | 20h 18m 43.83s | -15° 30' 09.4" | 5413.20s |
| 0500-Jun-01 00:00 | 02h 11m 10.44s | +11° 10' 10.0" | 02h 11m 10.33s | +11° 10' 09.7" | 5409.79s |
| 0500-Oct-31 00:00 | 14h 33m 32.68s | -14° 39' 03.4" | 14h 33m 32.50s | -14° 39' 02.8" | 5406.38s |
| 0501-Apr-01 00:00 | 03h 03m 13.09s | +18° 47' 05.5" | 03h 03m 12.97s | +18° 47' 05.1" | 5402.97s |
| 0501-Aug-31 00:00 | 09h 10m 52.83s | +08° 18' 44.4" | 09h 10m 53.44s | +08° 18' 40.8" | 5399.56s |
| 1600-Jan-01 00:00 | 17h 09m 26.57s | -18° 08' 55.1" | 17h 09m 26.71s | -18° 08' 55.3" | 141.31s |
| 1600-Jun-01 00:00 | 02h 28m 53.12s | +12° 50' 48.1" | 02h 28m 53.37s | +12° 50' 49.4" | 140.84s |
| 1600-Oct-31 00:00 | 14h 54m 13.53s | -16° 15' 03.3" | 14h 54m 13.79s | -16° 15' 04.6" | 140.37s |
| 1601-Apr-01 00:00 | 03h 18m 37.64s | +20° 06' 01.5" | 03h 18m 37.90s | +20° 06' 02.6" | 139.90s |

| UT Date Time | JPL Horizons (DE440/441) | | Stellarium 0.21.2$\beta$ | | |
| | RA J2000.0 | DE J2000.0 | $\alpha_{J2000.0}$ | $\delta_{J2000.0}$ | $\Delta T$ |
| --- | --- | --- | --- | --- | --- |
| 1601-Aug-31 00:00 | 07h 48m 52.93s | +16° 06' 13.5" | 07h 48m 53.14s | +16° 06' 13.3" | 139.44s |
| 2021-Jan-01 00:00 | 17h 18m 28.43s | -22° 26' 01.6" | 17h 18m 28.42s | -22° 26' 01.5" | 65.79s |
| 2021-Jun-02 00:00 | 05h 57m 01.46s | +24° 21' 39.2" | 05h 57m 01.45s | +24° 21' 39.2" | 66.11s |
| 2021-Nov-01 00:00 | 17h 40m 41.73s | -27° 05' 05.3" | 17h 40m 41.73s | -27° 05' 05.3" | 66.43s |
| 2022-Apr-02 00:00 | 21h 52m 25.36s | -12° 04' 41.5" | 21h 52m 25.35s | -12° 04' 41.5" | 66.76s |
| MOON | | | | | |
| b2500-Jan-01 00:00 | 00h 13m 40.60s | -00° 43' 59.3" | 00h 13m 13.41s | -00° 47' 44.2" | 57938.45s |
| b2500-Jun-02 00:00 | 12h 48m 51.83s | -04° 50' 11.6" | 12h 48m 20.00s | -04° 45' 50.3" | 57927.29s |
| b2500-Nov-01 00:00 | 02h 49m 20.95s | +19° 57' 17.4" | 02h 48m 49.83s | +19° 54' 22.0" | 57916.12s |
| b2499-Apr-02 00:00 | 15h 45m 48.47s | -25° 00' 31.4" | 15h 45m 11.61s | -24° 58' 11.1" | 57904.96s |
| b0500-Jan-01 00:00 | 02h 14m 28.99s | +14° 10' 37.4" | 02h 14m 20.11s | +14° 10' 05.8" | 16704.77s |
| b0500-Jun-02 00:00 | 15h 02m 34.83s | -16° 05' 08.5" | 15h 02m 24.07s | -16° 04' 39.3" | 16698.78s |
| b0500-Nov-01 00:00 | 05h 18m 41.70s | +19° 00' 42.7" | 05h 18m 32.17s | +19° 00' 41.6" | 16692.79s |
| b0499-Apr-02 00:00 | 18h 10m 41.75s | -18° 33' 49.1" | 18h 10m 31.22s | -18° 33' 56.3" | 16686.79s |
| 0500-Jan-01 00:00 | 05h 33m 09.71s | +28° 18' 25.7" | 05h 33m 02.93s | +28° 18' 25.0" | 5413.20s |
| 0500-Jun-01 00:00 | 19h 39m 46.24s | -24° 36' 20.7" | 19h 39m 38.25s | -24° 36' 48.8" | 5409.79s |
| 0500-Oct-31 00:00 | 08h 41m 09.22s | +19° 42' 14.7" | 08h 41m 03.32s | +19° 42' 46.3" | 5406.38s |
| 0501-Apr-01 00:00 | 22h 26m 23.71s | -07° 51' 05.2" | 22h 26m 17.20s | -07° 51' 54.1" | 5402.97s |
| 0501-Aug-31 00:00 | 11h 28m 24.37s | -00° 41' 25.5" | 11h 28m 19.05s | -00° 40' 44.2" | 5399.56s |
| 1600-Jan-01 00:00 | 07h 04m 55.02s | +24° 04' 37.3" | 07h 04m 56.39s | +24° 04' 33.9" | 141.31s |
| 1600-Jun-01 00:00 | 19h 54m 15.59s | -20° 26' 36.3" | 19h 54m 16.89s | -20° 26' 31.4" | 140.84s |
| 1600-Oct-31 00:00 | 10h 11m 24.53s | +07° 13' 09.4" | 10h 11m 25.66s | +07° 13' 02.2" | 140.37s |
| 1601-Apr-01 00:00 | 22h 46m 21.63s | -02° 54' 30.7" | 22h 46m 22.87s | -02° 54' 22.4" | 139.90s |
| 1601-Aug-31 00:00 | 12h 52m 10.20s | -10° 52' 36.0" | 12h 52m 11.39s | -10° 52' 43.0" | 139.44s |
| 2021-Jan-01 00:00 | 08h 23m 36.67s | +23° 01' 21.2" | 08h 23m 36.54s | +23° 01' 21.5" | 65.79s |
| 2021-Jun-02 00:00 | 22h 46m 54.03s | -13° 27' 21.8" | 22h 46m 53.93s | -13° 27' 22.4" | 66.11s |
| 2021-Nov-01 00:00 | 11h 18m 43.58s | +09° 57' 42.8" | 11h 18m 43.49s | +09° 57' 43.4" | 66.43s |
| 2022-Apr-02 00:00 | 01h 21m 51.21s | +05° 40' 00.7" | 01h 21m 51.14s | +05° 40' 00.1" | 66.76s |
| MARS | | | | | |
| 1601-Jan-01 00:00 | 19h 26m 56.21s | -23° 01' 42.7" | 19h 26m 56.45s | -23° 01' 42.4" | 140.18s |
| 1601-Jun-02 00:00 | 02h 59m 06.93s | +16° 41' 21.5" | 02h 59m 07.15s | +16° 41' 22.6" | 139.71s |
| 1601-Nov-01 00:00 | 09h 48m 48.55s | +15° 01' 38.0" | 09h 48m 48.75s | +15° 01' 37.2" | 139.25s |
| 1602-Apr-02 00:00 | 10h 25m 38.57s | +13° 17' 29.7" | 10h 25m 38.70s | +13° 17' 29.0" | 138.78s |
| 2021-Jan-01 00:00 | 01h 40m 18.14s | +11° 20' 41.2" | 01h 40m 18.14s | +11° 20' 41.1" | 65.79s |
| 2021-Jun-02 00:00 | 07h 45m 03.73s | +22° 37' 21.0" | 07h 45m 03.72s | +22° 37' 21.0" | 66.11s |
| 2021-Nov-01 00:00 | 13h 55m 54.00s | -11° 22' 08.1" | 13h 55m 54.00s | -11° 22' 08.1" | 66.43s |
| 2022-Apr-02 00:00 | 21h 31m 33.53s | -15° 56' 58.5" | 21h 31m 33.53s | -15° 56' 58.5" | 66.76s |
| JUPITER | | | | | |
| 1601-Jan-01 00:00 | 11h 33m 23.43s | +04° 18' 09.3" | 11h 33m 23.58s | +04° 18' 08.4" | 140.18s |
| 1601-Jun-02 00:00 | 10h 59m 49.52s | +07° 52' 18.0" | 10h 59m 49.67s | +07° 52' 17.1" | 139.71s |
| 1601-Nov-01 00:00 | 12h 39m 41.32s | -03° 02' 14.3" | 12h 39m 41.47s | -03° 02' 15.3" | 139.25s |
| 1602-Apr-02 00:00 | 13h 08m 44.17s | -05° 35' 33.6" | 13h 08m 44.30s | -05° 35' 34.4" | 138.78s |
| 2021-Jan-01 00:00 | 20h 20m 44.62s | -20° 00' 44.3" | 20h 20m 44.62s | -20° 00' 44.4" | 65.79s |
| 2021-Jun-02 00:00 | 22h 15m 51.65s | -11° 42' 45.3" | 22h 15m 51.65s | -11° 42' 45.3" | 66.11s |
| 2021-Nov-01 00:00 | 21h 41m 29.27s | -15° 01' 08.9" | 21h 41m 29.27s | -15° 01' 08.9" | 66.43s |
| 2022-Apr-02 00:00 | 23h 30m 29.23s | -04° 17' 08.2" | 23h 30m 29.24s | -04° 17' 08.2" | 66.76s |
| SATURN | | | | | |
| 1750-Jan-01 00:00 | 15h 46m 12.27s | -17° 54' 37.7" | 15h 46m 12.37s | -17° 54' 38.1" | 22.71s |
| 1750-Jun-02 00:00 | 15h 44m 23.78s | -17° 34' 00.9" | 15h 44m 23.87s | -17° 34' 01.3" | 22.52s |
| 1750-Nov-01 00:00 | 15h 59m 19.00s | -18° 50' 41.0" | 15h 59m 19.10s | -18° 50' 41.4" | 22.34s |
| 1751-Apr-02 00:00 | 16h 49m 11.72s | -20° 39' 30.2" | 16h 49m 11.82s | -20° 39' 30.5" | 22.15s |
| 2021-Jan-01 00:00 | 20h 15m 50.41s | -20° 10' 28.7" | 20h 15m 50.41s | -20° 10' 28.7" | 65.79s |
| 2021-Jun-02 00:00 | 21h 04m 25.24s | -17° 24' 46.6" | 21h 04m 25.24s | -17° 24' 46.6" | 66.11s |
| 2021-Nov-01 00:00 | 20h 39m 27.72s | -19° 14' 59.7" | 20h 39m 27.72s | -19° 14' 59.7" | 66.43s |
| 2022-Apr-02 00:00 | 21h 39m 14.50s | -15° 01' 42.2" | 21h 39m 14.50s | -15° 01' 42.2" | 66.76s |
| URANUS | | | | | |
| 1600-Jan-01 00:00 | 01h 41m 51.34s | +10° 01' 26.1" | 01h 41m 51.49s | +10° 01' 26.9" | 141.31s |
| 1600-Jun-01 00:00 | 02h 05m 21.58s | +12° 13' 45.6" | 02h 05m 21.73s | +12° 13' 46.4" | 140.84s |
| 1600-Oct-31 00:00 | 02h 04m 09.95s | +12° 05' 39.9" | 02h 04m 10.09s | +12° 05' 40.7" | 140.37s |
| 1601-Apr-01 00:00 | 02h 07m 08.63s | +12° 25' 31.5" | 02h 07m 08.78s | +12° 25' 32.4" | 139.90s |
| 1601-Aug-31 00:00 | 02h 28m 09.10s | +14° 11' 23.3" | 02h 28m 09.24s | +14° 11' 24.1" | 139.44s |
| 2021-Jan-01 00:00 | 02h 18m 27.82s | +13° 21' 27.5" | 02h 18m 27.83s | +13° 21' 27.5" | 65.79s |
| 2021-Jun-02 00:00 | 02h 40m 37.83s | +15° 11' 44.7" | 02h 40m 37.84s | +15° 11' 44.7" | 66.11s |
| 2021-Nov-01 00:00 | 02h 42m 31.60s | +15° 19' 13.5" | 02h 42m 31.60s | +15° 19' 13.5" | 66.43s |
| 2022-Apr-02 00:00 | 02h 42m 25.31s | +15° 22' 19.7" | 02h 42m 25.31s | +15° 22' 19.7" | 66.76s |
| NEPTUNE | | | | | |
| 1801-Jan-01 00:00 | 15h 07m 04.41s | -15° 44' 47.2" | 15h 07m 04.49s | -15° 44' 47.6" | 5.51s |
| 1801-Jun-02 00:00 | 15h 01m 57.08s | -15° 18' 05.9" | 15h 01m 57.15s | -15° 18' 06.2" | 5.42s |
| 1801-Nov-01 00:00 | 15h 07m 02.36s | -15° 46' 26.5" | 15h 07m 02.43s | -15° 46' 26.9" | 5.33s |
| 1802-Apr-02 00:00 | 15h 17m 01.46s | -16° 20' 15.8" | 15h 17m 01.54s | -16° 20' 16.2" | 5.24s |

| UT Date Time | JPL Horizons (DE440/441) RA J2000.0 | DE J2000.0 | Stellarium 0.21.2β $\alpha_{J2000.0}$ | $\delta_{J2000.0}$ | $\Delta T$ |
|---|---|---|---|---|---|
| 2021-Jan-01 00:00 | 23h 19m 18.38s | -05° 33' 12.4" | 23h 19m 18.39s | -05° 33' 12.4" | 65.79s |
| 2021-Jun-02 00:00 | 23h 36m 13.26s | -03° 46' 42.9" | 23h 36m 13.26s | -03° 46' 42.9" | 66.11s |
| 2021-Nov-01 00:00 | 23h 27m 30.35s | -04° 46' 19.7" | 23h 27m 30.35s | -04° 46' 19.7" | 66.43s |
| 2022-Apr-02 00:00 | 23h 38m 17.59s | -03° 34' 19.0" | 23h 38m 17.59s | -03° 34' 19.0" | 66.76s |
| IO(JI) | | | | | |
| 1601-Jan-01 00:00 | 11h 33m 30.36s | +04° 17' 19.7" | 11h 33m 30.51s | +04° 17' 18.9" | 140.18s |
| 1601-Jun-02 00:00 | 10h 59m 55.45s | +07° 51' 35.7" | 10h 59m 55.61s | +07° 51' 34.8" | 139.71s |
| 1601-Nov-01 00:00 | 12h 39m 41.63s | -03° 02' 20.8" | 12h 39m 41.81s | -03° 02' 22.0" | 139.25s |
| 1602-Apr-02 00:00 | 13h 08m 39.94s | -05° 35' 12.3" | 13h 08m 40.11s | -05° 35' 13.4" | 138.78s |
| 2021-Jan-01 00:00 | 20h 20m 41.43s | -20° 00' 57.7" | 20h 20m 41.43s | -20° 00' 57.7" | 65.79s |
| 2021-Jun-02 00:00 | 22h 15m 44.01s | -11° 43' 33.2" | 22h 15m 44.01s | -11° 43' 33.2" | 66.11s |
| 2021-Nov-01 00:00 | 21h 41m 21.65s | -15° 01' 52.3" | 21h 41m 21.65s | -15° 01' 52.3" | 66.43s |
| 2022-Apr-02 00:00 | 23h 30m 27.92s | -04° 17' 20.4" | 23h 30m 27.93s | -04° 17' 20.4" | 66.76s |
| EUROPA(JII) | | | | | |
| 1601-Jan-01 00:00 | 11h 33m 16.17s | +04° 19' 07.1" | 11h 33m 16.29s | +04° 19' 06.3" | 140.18s |
| 1601-Jun-02 00:00 | 10h 59m 53.24s | +07° 51' 59.3" | 10h 59m 53.37s | +07° 51' 58.7" | 139.71s |
| 1601-Nov-01 00:00 | 12h 39m 49.09s | -03° 03' 11.4" | 12h 39m 49.26s | -03° 03' 12.3" | 139.25s |
| 1602-Apr-02 00:00 | 13h 08m 40.13s | -05° 35' 20.4" | 13h 08m 40.28s | -05° 35' 21.3" | 138.78s |
| 2021-Jan-01 00:00 | 20h 20m 34.16s | -20° 01' 24.9" | 20h 20m 34.16s | -20° 01' 24.9" | 65.79s |
| 2021-Jun-02 00:00 | 22h 15m 55.57s | -11° 42' 23.5" | 22h 15m 55.57s | -11° 42' 23.5" | 66.11s |
| 2021-Nov-01 00:00 | 21h 41m 41.68s | -14° 59' 58.2" | 21h 41m 41.68s | -14° 59' 58.2" | 66.43s |
| 2022-Apr-02 00:00 | 23h 30m 29.10s | -04° 17' 03.2" | 23h 30m 29.11s | -04° 17' 03.3" | 66.76s |
| GANYMEDE(JIII) | | | | | |
| 1601-Jan-01 00:00 | 11h 33m 29.35s | +04° 17' 17.1" | 11h 33m 29.49s | +04° 17' 16.2" | 140.18s |
| 1601-Jun-02 00:00 | 11h 00m 04.63s | +07° 50' 38.0" | 11h 00m 04.78s | +07° 50' 37.2" | 139.71s |
| 1601-Nov-01 00:00 | 12h 39m 41.91s | -03° 02' 07.8" | 12h 39m 42.07s | -03° 02' 08.7" | 139.25s |
| 1602-Apr-02 00:00 | 13h 08m 24.28s | -05° 33' 17.7" | 13h 08m 24.40s | -05° 33' 18.6" | 138.78s |
| 2021-Jan-01 00:00 | 20h 20m 33.16s | -20° 01' 30.9" | 20h 20m 33.15s | -20° 01' 30.9" | 65.79s |
| 2021-Jun-02 00:00 | 22h 15m 57.19s | -11° 42' 07.4" | 22h 15m 57.19s | -11° 42' 07.5" | 66.11s |
| 2021-Nov-01 00:00 | 21h 41m 47.81s | -14° 59' 25.0" | 21h 41m 47.82s | -14° 59' 25.0" | 66.43s |
| 2022-Apr-02 00:00 | 23h 30m 31.22s | -04° 17' 01.0" | 23h 30m 31.23s | -04° 17' 01.0" | 66.76s |
| CALLISTO(JIV) | | | | | |
| 1601-Jan-01 00:00 | 11h 33m 15.59s | +04° 19' 21.5" | 11h 33m 15.73s | +04° 19' 20.6" | 140.18s |
| 1601-Jun-02 00:00 | 10h 59m 22.98s | +07° 55' 21.8" | 10h 59m 23.12s | +07° 55' 20.9" | 139.71s |
| 1601-Nov-01 00:00 | 12h 39m 17.32s | -02° 59' 27.6" | 12h 39m 17.47s | -02° 59' 28.8" | 139.25s |
| 1602-Apr-02 00:00 | 13h 08m 09.98s | -05° 32' 01.2" | 13h 08m 10.10s | -05° 32' 02.1" | 138.78s |
| 2021-Jan-01 00:00 | 20h 20m 42.72s | -20° 00' 56.3" | 20h 20m 42.73s | -20° 00' 56.3" | 65.79s |
| 2021-Jun-02 00:00 | 22h 15m 55.40s | -11° 42' 15.1" | 22h 15m 55.41s | -11° 42' 15.1" | 66.11s |
| 2021-Nov-01 00:00 | 21h 41m 58.24s | -14° 58' 23.9" | 21h 41m 58.25s | -14° 58' 23.9" | 66.43s |
| 2022-Apr-02 00:00 | 23h 30m 53.15s | -04° 14' 15.0" | 23h 30m 53.15s | -04° 14' 15.0" | 66.76s |

Table F.3: An ephemeris comparison between Stellarium and JPL Horizons, based on JPL DE440/441. Both are showing geocentric apparent coordinates (with slightly different models for precession, nutation and aberration; JPL results are also corrected for light deflection). This table shows ephemeris comparison in Dynamical time (TT), to avoid showing divergences which are only caused by differences in $\Delta T$ handling. (JPL's values for $\Delta T$ are listed for reference, but not used.)

| TT Date Time | JPL Horizons RA J2000.0 | DE J2000.0 | $\Delta T$ | Stellarium 0.21.2β $\alpha_{J2000.0}$ | $\delta_{J2000.0}$ |
|---|---|---|---|---|---|
| SUN | | | | | |
| b2500-Jan-01 00:00 | 17h21m25.18s | -23°40'30.1" | 58893.015756s | 17h21m26.91s | -23°40'34.2" |
| b2500-Jun-02 00:00 | 03h03m40.51s | +17°43'04.0" | 58881.693980s | 03h03m42.09s | +17°43'12.5" |
| b2500-Nov-01 00:00 | 13h09m12.65s | -07°32'06.5" | 58870.373294s | 13h09m14.12s | -07°32'16.5" |
| b2499-Apr-02 00:00 | 23h24m04.53s | -03°58'17.6" | 58859.053698s | 23h24m06.02s | -03°58'08.4" |
| b0500-Jan-01 00:00 | 18h24m36.63s | -23°37'53.7" | 16988.259557s | 18h24m37.49s | -23°37'54.4" |
| b0500-Jun-02 00:00 | 04h08m26.19s | +21°15'14.4" | 16982.002779s | 04h08m26.99s | +21°15'17.6" |
| b0500-Nov-01 00:00 | 14h03m40.03s | -12°44'27.5" | 16975.747099s | 14h03m40.76s | -12°44'32.1" |
| b0499-Apr-02 00:00 | 00h20m28.76s | +02°14'57.0" | 16969.492518s | 00h20m29.48s | +02°15'01.7" |
| 0500-Jan-01 00:00 | 18h52m48.93s | -23°04'32.9" | 5608.981515s | 18h52m49.49s | -23°04'32.9" |
| 0500-Jun-01 00:00 | 04h39m00.52s | +22°19'15.9" | 5605.028887s | 04h39m01.07s | +22°19'17.7" |
| 0500-Oct-31 00:00 | 14h29m11.35s | -14°51'03.8" | 5601.076499s | 14h29m11.84s | -14°51'06.7" |
| 0501-Apr-01 00:00 | 00h46m09.14s | +05°00'08.5" | 5597.124355s | 00h46m09.61s | +05°00'11.6" |
| 0501-Aug-31 00:00 | 10h41m02.87s | +08°24'23.2" | 5593.172456s | 10h41m03.36s | +08°24'20.5" |
| 1600-Jan-01 00:00 | 18h43m27.73s | -23°06'56.9" | 110.462079s | 18h43m27.90s | -23°06'57.0" |
| 1600-Jun-01 00:00 | 04h35m36.87s | +22°04'24.3" | 109.804702s | 04h35m37.03s | +22°04'24.8" |
| 1600-Oct-31 00:00 | 14h21m56.15s | -14°09'37.4" | 109.148794s | 14h21m56.30s | -14°09'38.2" |
| 1601-Apr-01 00:00 | 00h41m18.21s | +04°27'17.7" | 108.494367s | 00h41m18.35s | +04°27'18.6" |

| | | JPL Horizons | | | Stellarium 0.21.2β | |
| TT Date Time | RA J2000.0 | DE J2000.0 | ΔT | | $\alpha_{J2000.0}$ | $\delta_{J2000.0}$ |
|---|---|---|---|---|---|---|
| 1601-Aug-31 00:00 | 10h36m30.02s | +08°48'12.4" | 107.841429s | | 10h36m30.16s | +08°48'11.7" |
| MERCURY | | | | | | |
| b2500-Jan-01 00:00 | 17h02m08.10s | -25°14'54.4" | 58893.015756s | | 17h02m09.83s | -25°14'59.3" |
| b2500-Jun-02 00:00 | 04h55m00.41s | +23°03'30.5" | 58881.693980s | | 04h55m02.12s | +23°03'35.5" |
| b2500-Nov-01 00:00 | 11h54m04.49s | +03°27'59.5" | 58870.373294s | | 11h54m05.97s | +03°27'49.8" |
| b2499-Apr-02 00:00 | 22h57m59.14s | -07°54'02.4" | 58859.053698s | | 22h58m00.66s | -07°53'53.6" |
| b0500-Jan-01 00:00 | 18h38m56.17s | -25°28'13.0" | 16988.259557s | | 18h38m57.04s | -25°28'13.3" |
| b0500-Jun-02 00:00 | 05h38m38.91s | +22°22'48.0" | 16982.002779s | | 05h38m39.75s | +22°22'49.6" |
| b0500-Nov-01 00:00 | 12h55m48.65s | -03°50'09.1" | 16975.747099s | | 12h55m49.37s | -03°50'13.9" |
| b0499-Apr-02 00:00 | 00h19m39.97s | +01°41'26.3" | 16969.492518s | | 00h19m40.68s | +01°41'31.2" |
| 0500-Jan-01 00:00 | 18h23m11.76s | -25°14'05.2" | 5608.981515s | | 18h23m12.34s | -25°14'05.6" |
| 0500-Jun-01 00:00 | 06h29m15.56s | +24°33'46.9" | 5605.028887s | | 06h29m16.13s | +24°33'47.2" |
| 0500-Oct-31 00:00 | 13h28m09.82s | -06°51'31.3" | 5601.076499s | | 13h28m10.29s | -06°51'34.4" |
| 0501-Apr-01 00:00 | 23h54m49.90s | -02°49'01.2" | 5597.124355s | | 23h54m50.38s | -02°48'58.1" |
| 0501-Aug-31 00:00 | 12h03m21.92s | -01°46'20.3" | 5593.172456s | | 12h03m22.39s | -01°46'23.4" |
| 1600-Jan-01 00:00 | 19h16m54.82s | -24°27'05.8" | 110.462079s | | 19h16m54.99s | -24°27'05.7" |
| 1600-Jun-01 00:00 | 05h27m00.83s | +22°06'51.2" | 109.804702s | | 05h27m01.00s | +22°06'51.5" |
| 1600-Oct-31 00:00 | 13h24m30.45s | -06°45'14.3" | 109.148794s | | 13h24m30.59s | -06°45'15.2" |
| 1601-Apr-01 00:00 | 00h45m29.79s | +03°58'00.7" | 108.494367s | | 00h45m29.92s | +03°58'01.7" |
| 1601-Aug-31 00:00 | 12h08m26.49s | -04°19'13.1" | 107.841429s | | 12h08m26.63s | -04°19'14.0" |
| VENUS | | | | | | |
| b2500-Jan-01 00:00 | 14h37m07.30s | -10°25'08.5" | 58893.015756s | | 14h37m08.81s | -10°25'17.6" |
| b2500-Jun-02 00:00 | 01h28m34.06s | +08°11'02.7" | 58881.693980s | | 01h28m35.54s | +08°11'12.6" |
| b2500-Nov-01 00:00 | 14h01m18.60s | -13°03'41.8" | 58870.373294s | | 14h01m20.11s | -13°03'51.3" |
| b2499-Apr-02 00:00 | 02h04m39.28s | +15°58'24.8" | 58859.053698s | | 02h04m40.81s | +15°58'34.2" |
| b0500-Jan-01 00:00 | 15h15m08.22s | -13°55'20.5" | 16988.259557s | | 15h15m08.98s | -13°55'24.4" |
| b0500-Jun-02 00:00 | 02h40m55.02s | +14°44'15.5" | 16982.002779s | | 02h40m55.77s | +14°44'19.8" |
| b0500-Nov-01 00:00 | 15h13m42.04s | -18°47'53.8" | 16975.747099s | | 15h13m42.82s | -18°47'57.7" |
| b0499-Apr-02 00:00 | 03h09m40.90s | +21°23'39.0" | 16969.492518s | | 03h09m41.68s | +21°23'43.0" |
| 0500-Jan-01 00:00 | 20h18m48.52s | -15°30'50.9" | 5608.981515s | | 20h18m49.05s | -15°30'49.8" |
| 0500-Jun-01 00:00 | 02h10m53.15s | +11°08'35.0" | 5605.028887s | | 02h10m53.64s | +11°08'38.0" |
| 0500-Oct-31 00:00 | 14h33m13.65s | -14°37'22.9" | 5601.076499s | | 14h33m14.14s | -14°37'25.8" |
| 0501-Apr-01 00:00 | 03h02m54.73s | +18°45'37.5" | 5597.124355s | | 03h02m55.25s | +18°45'40.1" |
| 0501-Aug-31 00:00 | 09h10m56.37s | +08°17'52.4" | 5593.172456s | | 09h10m56.87s | +08°17'50.6" |
| 1600-Jan-01 00:00 | 17h09m26.64s | -18°08'55.7" | 110.462079s | | 17h09m26.80s | -18°08'56.1" |
| 1600-Jun-01 00:00 | 02h28m52.77s | +12°50'46.3" | 109.804702s | | 02h28m52.92s | +12°50'47.1" |
| 1600-Oct-31 00:00 | 14h54m13.16s | -16°15'01.5" | 109.148794s | | 14h54m13.31s | -16°15'02.3" |
| 1601-Apr-01 00:00 | 03h18m37.29s | +20°05'59.9" | 108.494367s | | 03h18m37.45s | +20°06'00.6" |
| 1601-Aug-31 00:00 | 07h48m52.75s | +16°06'13.4" | 107.841429s | | 07h48m52.90s | +16°06'13.2" |
| MOON | | | | | | |
| b2500-Jan-01 00:00 | 23h43m54.13s | -04°46'15.6" | 58893.015756s | | 23h43m55.61s | -04°46'06.1" |
| b2500-Jun-02 00:00 | 12h15m08.68s | -00°12'02.6" | 58881.693980s | | 12h15m10.14s | -00°12'12.5" |
| b2500-Nov-01 00:00 | 02h16m07.77s | +16°35'31.3" | 58870.373294s | | 02h16m09.31s | +16°35'40.6" |
| b2499-Apr-02 00:00 | 15h07m11.31s | -22°11'27.1" | 58859.053698s | | 15h07m12.93s | -22°11'35.4" |
| b0500-Jan-01 00:00 | 02h04m52.71s | +13°33'43.2" | 16988.259557s | | 02h04m53.45s | +13°33'47.8" |
| b0500-Jun-02 00:00 | 14h51m07.34s | -15°30'50.9" | 16982.002779s | | 14h51m08.09s | -15°30'55.1" |
| b0500-Nov-01 00:00 | 05h08m19.28s | +18°56'30.3" | 16975.747099s | | 05h08m20.10s | +18°56'32.5" |
| b0499-Apr-02 00:00 | 17h59m21.65s | -18°38'44.9" | 16969.492518s | | 17h59m22.47s | -18°38'46.1" |
| 0500-Jan-01 00:00 | 05h29m38.64s | +28°17'23.7" | 5608.981515s | | 05h29m39.22s | +28°17'24.9" |
| 0500-Jun-01 00:00 | 19h35m39.76s | -24°49'55.2" | 5605.028887s | | 19h35m40.33s | -24°49'54.6" |
| 0500-Oct-31 00:00 | 08h38m03.41s | +19°57'58.9" | 5601.076499s | | 08h38m03.95s | +19°57'57.5" |
| 0501-Apr-01 00:00 | 22h23m01.61s | -08°15'47.6" | 5597.124355s | | 22h23m02.11s | -08°15'45.1" |
| 0501-Aug-31 00:00 | 11h25m37.06s | -00°20'06.1" | 5593.172456s | | 11h25m37.53s | -00°20'09.0" |
| 1600-Jan-01 00:00 | 07h04m50.63s | +24°04'49.5" | 110.462079s | | 07h04m50.78s | +24°04'49.4" |
| 1600-Jun-01 00:00 | 19h54m11.52s | -20°26'52.9" | 109.804702s | | 19h54m11.67s | -20°26'52.7" |
| 1600-Oct-31 00:00 | 10h11m21.07s | +07°13'32.6" | 109.148794s | | 10h11m21.20s | +07°13'32.0" |
| 1601-Apr-01 00:00 | 22h46m17.79s | -02°54'56.8" | 108.494367s | | 22h46m17.91s | -02°54'56.1" |
| 1601-Aug-31 00:00 | 12h52m06.59s | -10°52'15.0" | 107.841429s | | 12h52m06.72s | -10°52'15.8" |
| MARS | | | | | | |
| 1601-Jan-01 00:00 | 19h26m55.96s | -23°01'43.2" | 108.881677s | | 19h26m56.12s | -23°01'43.1" |
| 1601-Jun-02 00:00 | 02h59m06.71s | +16°41'20.6" | 108.227856s | | 02h59m06.87s | +16°41'21.3" |
| 1601-Nov-01 00:00 | 09h48m48.40s | +15°01'38.7" | 107.575530s | | 09h48m48.55s | +15°01'38.1" |
| 1602-Apr-02 00:00 | 10h25m38.61s | +13°17'29.7" | 106.924708s | | 10h25m38.76s | +13°17'28.9" |
| JUPITER | | | | | | |
| 1601-Jan-01 00:00 | 11h33m23.43s | +04°18'09.3" | 108.881677s | | 11h33m23.57s | +04°18'08.4" |
| 1601-Jun-02 00:00 | 10h59m49.50s | +07°52'18.1" | 108.227856s | | 10h59m49.64s | +07°52'17.3" |
| 1601-Nov-01 00:00 | 12h39m41.26s | -03°02'14.0" | 107.575530s | | 12h39m41.40s | -03°02'14.9" |
| 1602-Apr-02 00:00 | 13h08m44.21s | -05°35'33.8" | 106.924708s | | 13h08m44.34s | -05°35'34.7" |
| SATURN | | | | | | |
| 1750-Jan-01 00:00 | 15h46m12.26s | -17°54'37.7" | 17.322273s | | 15h46m12.36s | -17°54'38.1" |

| TT Date Time | RA J2000.0 | JPL Horizons DE J2000.0 | $\Delta T$ | Stellarium 0.21.2$\beta$ $\alpha_{J2000.0}$ | $\delta_{J2000.0}$ |
|---|---|---|---|---|---|
| 1750-Jun-02 00:00 | 15h44m23.78s | -17°34'00.9" | 17.413029s | 15h44m23.88s | -17°34'01.3" |
| 1750-Nov-01 00:00 | 15h59m18.99s | -18°50'41.0" | 17.503706s | 15h59m19.09s | -18°50'41.4" |
| 1751-Apr-02 00:00 | 16h49m11.73s | -20°39'30.2" | 17.594270s | 16h49m11.82s | -20°39'30.5" |
| URANUS | | | | | |
| 1600-Jan-01 00:00 | 01h41m51.35s | +10°01'26.1" | 110.462079s | 01h41m51.49s | +10°01'26.9" |
| 1600-Jun-01 00:00 | 02h05m21.56s | +12°13'45.5" | 109.804702s | 02h05m21.71s | +12°13'46.3" |
| 1600-Oct-31 00:00 | 02h04m09.96s | +12°05'40.0" | 109.148794s | 02h04m10.11s | +12°05'40.8" |
| 1601-Apr-01 00:00 | 02h07m08.61s | +12°25'31.4" | 108.494367s | 02h07m08.76s | +12°25'32.3" |
| 1601-Aug-31 00:00 | 02h28m09.10s | +14°11'23.3" | 107.841429s | 02h28m09.25s | +14°11'24.1" |
| NEPTUNE | | | | | |
| 1801-Jan-01 00:00 | 15h07m04.41s | -15°44'47.2" | 18.261920s | 15h07m04.49s | -15°44'47.6" |
| 1801-Jun-02 00:00 | 15h01m57.08s | -15°18'05.9" | 18.107889s | 15h01m57.15s | -15°18'06.3" |
| 1801-Nov-01 00:00 | 15h07m02.35s | -15°46'26.5" | 17.952783s | 15h07m02.43s | -15°46'26.9" |
| 1802-Apr-02 00:00 | 15h17m01.46s | -16°20'15.8" | 17.797431s | 15h17m01.54s | -16°20'16.2" |
| IO(JI) | | | | | |
| 1601-Jan-01 00:00 | 11h33m30.35s | +04°17'19.8" | 108.881677s | 11h33m30.50s | +04°17'18.9" |
| 1601-Jun-02 00:00 | 10h59m55.42s | +07°51'35.9" | 108.227856s | 10h59m55.57s | +07°51'35.0" |
| 1601-Nov-01 00:00 | 12h39m41.55s | -03°02'20.3" | 107.575530s | 12h39m41.71s | -03°02'21.4" |
| 1602-Apr-02 00:00 | 13h08m39.95s | -05°35'12.3" | 106.924708s | 13h08m40.11s | -05°35'13.4" |
| EUROPA(JII) | | | | | |
| 1601-Jan-01 00:00 | 11h33m16.18s | +04°19'07.0" | 108.881677s | 11h33m16.31s | +04°19'06.2" |
| 1601-Jun-02 00:00 | 10h59m53.24s | +07°51'59.3" | 108.227856s | 10h59m53.38s | +07°51'58.6" |
| 1601-Nov-01 00:00 | 12h39m49.02s | -03°03'11.0" | 107.575530s | 12h39m49.17s | -03°03'11.8" |
| 1602-Apr-02 00:00 | 13h08m40.14s | -05°35'20.5" | 106.924708s | 13h08m40.29s | -05°35'21.4" |
| GANYMEDE(JIII) | | | | | |
| 1601-Jan-01 00:00 | 11h33m29.32s | +04°17'17.3" | 108.881677s | 11h33m29.46s | +04°17'16.4" |
| 1601-Jun-02 00:00 | 11h00m04.62s | +07°50'38.1" | 108.227856s | 11h00m04.77s | +07°50'37.3" |
| 1601-Nov-01 00:00 | 12h39m41.87s | -03°02'07.5" | 107.575530s | 12h39m42.01s | -03°02'08.4" |
| 1602-Apr-02 00:00 | 13h08m24.32s | -05°33'17.9" | 106.924708s | 13h08m24.46s | -05°33'18.9" |
| CALLISTO(JIV) | | | | | |
| 1601-Jan-01 00:00 | 11h33m15.60s | +04°19'21.4" | 108.881677s | 11h33m15.74s | +04°19'20.5" |
| 1601-Jun-02 00:00 | 10h59m22.96s | +07°55'21.9" | 108.227856s | 10h59m23.10s | +07°55'21.0" |
| 1601-Nov-01 00:00 | 12h39m17.27s | -02°59'27.3" | 107.575530s | 12h39m17.41s | -02°59'28.3" |
| 1602-Apr-02 00:00 | 13h08m10.01s | -05°32'01.4" | 106.924708s | 13h08m10.14s | -05°32'02.4" |

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# H. Acknowledgements

## H.1 Contributors to this User Guide

When not listed as chapter authors, the following were the main contributors to the User Guide, mostly for versions before V0.15:

| | |
|---|---|
| Matthew Gates | Primary author of the first User Guide (versions 0.9 to 0.12) |
| Paul Robinson | Sky guide; exercise ideas |
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| Rudy Gobits, Dirk Schwarzhans | Mac platform specifics |
| Barry Gerdes (†2014) | Windows platform specifics |
| | Customisation of .fab files |
| | Documentation Maintainer up to V0.12 |
| Sigma | Japanese translation; many corrections |
| Richard Powell | Figure 19.3 (colour/magnitude diagram) is a modification of his diagram; he kindly granted permission for it to be distributed under the FDL |
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| Alexander Wolf | New layout, many contributions for the 0.15+ editions |
| The rest of the Stellarium developer team | You know who you are... :-) |

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## H.2 Developers

Stellarium is not a company. It is a project created by a community of amateur and professional astronomers, software engineers, 3D graphics experts, cultural astronomers and experts in other related fields. Together we created something unique.

### H.2.1 Developers

**Project coordinator & lead developer** Fabien Chéreau
**Graphic/other designer** Martín Bernardi
**Developer** Guillaume Chéreau
**Developer** Georg Zotti
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**Developer** Henry Leung

**Sky cultures researcher** Susanne M. Hoffmann
**Tester** Khalid AlAjaji

## H.2.2 Former Developers

Several people have made significant contributions, but are no longer active. Their work has made a big difference to the project:

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**Doc author/developer** Matthew Gates
**Developer** Johannes Gajdosik
**Developer** Rob Spearman
**Developer** Bogdan Marinov
**Developer** Timothy Reaves
**Developer** Florian Schaukowitsch
**Developer** András Mohari
**Developer** Mike Storm
**Developer** Ferdinand Majerech
**Developer** Jörg Müller
**Developer** Marcos Cardinot
**OSX Developer** Nigel Kerr
**OSX Developer** Diego Marcos
**Continuous Integration** Hans Lambermont

## H.2.3 Contributors

Many individuals have made contributions to the project and their work has made Stellarium better. Alphabetically sorted list of all contributors:

Adam Majer, Adriano Steffler, Alec Clews, Alessandro Siniscalchi, Alex Gamper, Alexander Belopolsky, Alexander Duytschaever, Alexander Miller, Alexander V. Wolf, Alexandros Kosiaris, Alexey Dokuchaev, Alexey Sokolov, Allan Johnson, Andras Mohari, Andrei Borza, Andrew Jeddeloh, Andy Kirkham, Angelo Fraietta, Annette S. Lee, Antoine Jacoutot, Anton Samoylov, Arjen de Korte, Aspere, Atque, Barry Gerdes, Bernd K, Björn Höfling, Bogdan Marinov, Brian Kloppenborg, Cassy, Chi Huynh, ChrUnger, Chris Xiao, Clement Sommelet, Clepalitto, Colin Gaudion, Cosimo Cecchi, Dan Joplin, Dan Smale, Daniel, Daniel Adastra, Daniel De Mickey, Daniel Michalik, Danny Milosavljevic, Dark Dragon, David Baucum, Dempsey-p, Dhia, Diego Marcos, Dominik Maximilián Ramík, Edgar Scholz, Elaina, Eleni Maria Stea, Emmanuel, EuklidAlexandria, Fabien Chereau, Felix Z, Ferdinand Majerech, Florian Schaukowitsch, François Scholder, Freeman Li, FreewareTips, Froenchenko Leonid, Fòram na Gàidhlig, Georg Zotti, Gion Kunz, GitHaarek, Giuseppe Putzolu, Greg Alexander, Guillaume Chereau, Guillaume Communie, Gábor Péterffy, Hans Lambermont, Hector Quemada, Henry Leung, Hernan Martinez, Hleb Valoshka, Holger, Holger Nießner, Iceflower, Ivan Marti-Vidal, J.L.Canales, JAY RESPLER, JMejuto, Jack Schmidt, Jean-Philippe Lambert, Jocelyn GIROD, Johan Meuris, Johannes Gajdosik, Jonas Persson, Jörg Müller, Katrin Leinweber, Kenan Derviševic, Khalid AlAjaji, Kirill Snezhko, Konrad Rybka, Kutaibaa Akraa, Louis Strous, M.S. Adityan, Maciej Serylak, Marc Espie, Marcos Cardinot, Martin Bernardi, Martin Bernardi (Laptop), Matt Hughes, Matthew Gates, Matthias Drochner, Matwey V. Kornilov, Max Digruber, Michael Dickens, Michael Storm, Michael Taylor, Michal Sojka, Mike Boyle, Mike Garrahan, Minmin Gong, Mircea Lite, Miroslav Broz, Mykyta Sytyi, Nick Fedoseev, Nick Kanel, Nicolas Martignoni, Nidroide, Nir Lichtman, Norman Rasmussen, Oleg Ginzburg, Oscar Roig Felius, Paolo Cancedda (Pac), Paolo Stivanin, ParkSangJun, Patrick, Paul Krizak, Pavel Klimenko, Pawel Stolowski, Peter, Peter Hickey, Peter Mousley, Peter Neubauer, Peter Vasey, Peter Walser, Petr Kubánek, Pino Toscano, Pluton Helleformer, Qam1, RVS, Ralph Schäfermeier, Ray, Rob Spearman, Robert S. Fuller, Roland Bosa, Ross Mitchell, Rumen Bogdanovski, Ruslan Kabatsayev, Sam Lanning, Sebastian Jennen, Sergej Krivonos, Sergey, Shantanu Agarwal, Sibi Antony, SilverAstro, Simon Parzer, Song Li, Sripath Roy Koganti, Steven Bellavia, Sun Shuwei, Susanne M Hoffmann, Sveinn í Felli, Tanmoy Saha, Teemu Nätkinniemi, Teresa Huertas, Thilo, Thomas1664, Tig la Pomme, Timothy Reaves, Tomasz Buchert, Tony Furr, TotalCaesar659, Tuomas Teipainen, Tēvita O. Ka'ili, Vancho Stojkoski, Vicente Reyes, Victor Reijs, Vishvas Vasuki, Vladislav Bataron, Volker Hören, Wang Siliang, William Formyduval, Wolfgang Laun, Wonkyo Choe, Worachate Boonplod, Yaakov Selkowitz, Youssif Ghantous Filho, Yuri Chornoivan, Yury Solomonov, adalava, afontenot, bkuhls, bv6679, chithihuynh, colossatr0n, henrysky, leonardcj, luz paz, luzpaz, misibacsi, pkrawczun, rikardfalkeborn, riodoro1, sebagr, tofilwiktor, uwes-ufo, ysjbserver, zhu1995zpb, Łukasz 'sil2100' Zemczak.

# H.3 How you can help

We especially welcome contributions in shape of working program code for interesting features, but also bug reports, feature requests and other feedback through the usual channels (trackers, forums and so on):

**Stellarium on Github** `https://github.com/Stellarium/`

**Questions for Stellarium (FAQ)** `https://github.com/Stellarium/stellarium/wiki/FAQ`

**Current issues (FAQ)** `https://github.com/Stellarium/stellarium/wiki/Common-Problems-for-the-current-version`

**Google Group** `https://groups.google.com/group/stellarium`

Another form of support, donations, can be given via `https://opencollective.com/stellarium/donate`.

# H.4 Technical Articles

Stellarium would not look the same and work without these works from computer graphics and astronomy.

**The tone reproductor class** The class mainly performs a fast implementation of the algorithm from Tumblin and Rushmeier (1993), with more accurate values from Devlin et al. (2002). The blue shift formula is taken from Jensen et al. (2000) and combined with the Scotopic vision formula from Larson, Rushmeier, and Piatko (1997).

**The skylight class** The class governs sky colors and is a fast implementation of the algorithm by Preetham, Shirley, and Smits (1999).

**The skybright class** The class governs physical sky brightness values based on Bradley Schaefer's **VIS-LIMIT.BAS** basic source code (B. Schaefer, 1998). The basic sources are available on the Sky and Telescope web site (code "offered as-is and without support").

**The $\Delta T$ calculations** For implementation of calculation routines for $\Delta T$ we used the following sources:

1. $\Delta T$ webpage by Rob van Gent: `https://webspace.science.uu.nl/~gent0113/deltat/deltat.htm`
2. *Five Millennium Canon of Solar Eclipses: -1900 to +3000* (Espenak and Meeus, 2006) (`https://eclipse.gsfc.nasa.gov/SEhelp/deltatpoly2004.html`)
3. *Thousand Year Canon of Solar Eclipses 1501 to 2500* (Espenak, 2014) (`https://eclipsewise.com/help/deltatpoly2014.html`)
4. "On the system of astronomical constants" (Clemence, 1948)
5. "The rotation of the earth, and the secular accelerations of the sun, moon and planets" (Spencer Jones, 1939)
6. "Polynomial approximations for the correction delta T E.T.-U.T. in the period 1800-1975" (Schmadel and Zech, 1979)
7. "ELP 2000-85 and the dynamic time-universal time relation" (Borkowski, 1988)
8. "Empirical Transformations from U.T. to E.T. for the Period 1800-1988" (Schmadel and Zech, 1988)
9. "Historical values of the Earth's clock error $\Delta T$ and the calculation of eclipses" (Morrison and F. R. Stephenson, 2004) with Addendum (Morrison and F. R. Stephenson, 2005)
10. "Polynomial approximations to Delta T, 1620-2000 AD" (Meeus and Simons, 2000)
11. *Canon of Solar Eclipses -2003 to +2526* (Mucke and Meeus, 1983)
12. "The accelerations of the earth and moon from early astronomical observations" (Muller and F. R. Stephenson, 1975)
13. "Pre-Telescopic Astronomical Observations" (F. R. Stephenson, 1978)
14. "Long-term changes in the rotation of the earth - 700 B.C. to A.D. 1980" (F. R. Stephenson and Morrison, 1984)
15. "Long-Term Fluctuations in the Earth's Rotation: 700 BC to AD 1990" (F. R. Stephenson and Morrison, 1995)
16. *Historical Eclipses and Earth's Rotation* (F. Richard Stephenson, 1997)
17. *Astronomical Algorithms* (Meeus, 1998)
18. *Astronomy on the Personal Computer* (Montenbruck and Pfleger, 2000)
19. *Calendrical Calculations (The Millennium Edition)* (Reingold and Dershowitz, 2001)
20. $\Delta T$ webpage by V. Reijs: `http://www.iol.ie/~geniet/eng/DeltaTeval.htm`

**Precession:** "New precession expressions, valid for long time intervals" (Vondrák, Capitaine, and Wallace, 2011) with correction (Vondrák, Capitaine, and Wallace, 2012)

**Nutation:** "An abridged model of the precession-nutation of the celestial pole" (McCarthy and Luzum, 2003) This model provides accuracy better than 1 milli-arcsecond in the time 1995-2050. It is applied for years -4000..+8000 only.

**Martian polar caps:** Based on data from Smith et al. (2009) and Piqueux et al. (2015).

v 23.1    **Solar limb darkening:** Livingston (2002).

v 25.1    **Color of Neptune:** Irwin et al. (2024).

## H.5    Included Source Code

- Some computation of the sidereal time (`sidereal_time.h/c`) and Pluto orbit contains code from the libnova library (LGPL) by Liam Girdwood.
- The `orbit.cpp/h` and `solve.h` files were directly borrowed from **Celestia** (Chris Laurel; GPL license). They have now evolved a bit.
- Several implementations of IMCCE theories for planet and satellite movement by Johannes Gajdosik (MIT-style license, see the corresponding files for the license text)
- The tesselation algorithms were originally extracted from the glues library version 1.4 by Mike Gorchak `<mike@malva.ua>` (SGI FREE SOFTWARE LICENSE B).
- OBJ loader in the Scenery3D plugin based on glObjViewer (c) 2007 dhpoware
- Parts of the code to work with DE430/DE431 and DE440/DE441 data files have been taken from Project Pluto (GPL license).
- The `SpoutLibrary.dll` and header from the SpoutSDK version 2.005 available at `http://spout.zeal.co` (BSD license).

## H.6    Data

1. The Hipparcos star catalog From ESA (European Space Agency) and the Hipparcos mission. ref. ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200 `http://cdsweb.u-strasbg.fr/ftp/cats/I/239`
2. The solar system data mainly comes from IMCCE and partly from Celestia.
3. Polynesian constellations are based on diagrams from the Polynesian Voyaging Society
4. Chinese constellations are based on diagrams from the Hong Kong Space Museum
5. Egyptian constellations are based on the work of Juan Antonio Belmonte, Instituto de Astrofisica de Canarias
6. The Tycho-2 Catalogue of the 2.5 Million Brightest Stars Hog E., Fabricius C., Makarov V.V., Urban S., Corbin T., Wycoff G., Bastian U., Schwekendiek P., Wicenec A. Astron. Astrophys. 355, L27 (2000) `http://cdsweb.u-strasbg.fr/ftp/cats/I/259`
7. Naval Observatory Merged Astrometric Dataset (NOMAD) version 1 (`http://www.nofs.navy.mil/nomad`) Norbert Zacharias writes:

   "There are no fees, both UCAC and NOMAD are freely available with the only requirement that the source of the data (U.S. Naval Observatory) and original product name need to be provided with any distribution, as well as a description about any changes made to the data, if at all."

   The changes made to the data are:
   - try to compute visual magnitude and color from the b,v,r values
   - compute nr_of_measurements = the number of valid b,v,r values
   - throw away or keep stars (depending on magnitude, nr_of_measurements, combination of flags, tycho2 number)
   - add all stars from Hipparcos (incl. component solutions), and tycho2+1st supplement
   - reorganize the stars in several brightness levels and triangular zones according to position and magnitude

   The programs that are used to generate the star files are called **MakeCombinedCatalogue**, **ParseHip**, **ParseNomad**, and can be found in the util subdirectory in source code. The position, magnitudes, and proper motions of the stars coming from NOMAD are unchanged, except for a possible loss of precision, especially in magnitude. When there is no V magnitude, it is estimated from R or B magnitude. When there is no B or V magnitude, the color B-V is estimated from the other magnitudes. Also proper motions of faint stars are neglected at all.

8. Stellarium's Catalog of Variable Stars based on General Catalog of Variable Stars (GCVS) version 2013Apr. `http://www.sai.msu.su/gcvs/gcvs/` Samus N.N., Durlevich O.V., Kazarovets E V., Kireeva N.N., Pastukhova E.N., Zharova A.V., et al., General Catalogue of Variable Stars (Samus+ 2007-2012) `http://cdsarc.u-strasbg.fr/viz-bin/Cat?cat=B%2Fgcvs&`

9. Consolidated DSO catalog was created from various data:
   a. NGC/IC data taken from SIMBAD Astronomical Database `http://simbad.u-strasbg.fr`
   b. Distance to NGC/IC data taken from NED (NASA/IPAC EXTRAGALACTIC DATABASE) `http://ned.ipac.caltech.edu`
   c. Catalogue of HII Regions (Sharpless, 1959) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/20`)
   d. H-$\alpha$ emission regions in the Southern Milky Way (Rodgers+, 1960) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/216`)
   e. Catalogue of Reflection Nebulae (Van den Bergh, 1966) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/21`)
   f. Lynds' Catalogue of Dark Nebulae (LDN) (Lynds, 1962) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/7A`)
   g. Lynds' Catalogue of Bright Nebulae (Lynds, 1965) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/9`)
   h. Catalog of bright diffuse Galactic nebulae (Cederblad, 1946) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/231`)
   i. Barnard's Catalogue of 349 Dark Objects in the Sky (Barnard, 1927) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/220A`)
   j. A Catalogue of Star Clusters shown on Franklin-Adams Chart Plates (Melotte, 1915) from NASA ADS (`http://adsabs.harvard.edu/abs/1915MmRAS..60..175M`)
   k. On Structural Properties of Open Galactic Clusters and their Spatial Distribution. Catalog of Open Galactic Clusters (Collinder, 1931) from NASA ADS (`http://adsabs.harvard.edu/abs/1931AnLun...2....1C`)
   l. The Collinder Catalog of Open Star Clusters. An Observer's Checklist. Edited by Thomas Watson from CloudyNights (`http://www.cloudynights.com/page/articles/cat/articles/the-collinder-catalog-updated-r2467`)

10. Cross-identification of objects in consolidated DSO catalog was made with:
    a. SIMBAD Astronomical Database `http://simbad.u-strasbg.fr`
    b. Merged catalogue of reflection nebulae (Magakian, 2003) `http://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=J/A+A/399/141`
    c. Messier Catalogue from Wikipedia (includes morphological classification and distances) `https://en.wikipedia.org/wiki/List_of_Messier_objects`
    d. Caldwell Catalogue from Wikipedia (includes morphological classification and distances) `https://en.wikipedia.org/wiki/Caldwell_catalogue`

11. Morphological classification and magnitudes (partially) for Melotte catalogue from DeepSkyPedia `http://deepskypedia.com/wiki/List:Melotte`

# H.7 Graphics

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## H.7.1 Full credits for "earthmap" texture

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