

The Stellar Command Module
for
Integrating Astronomy and Art
User Guide

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Preface

Stellar Command is a software system that integrates *Stellarium* planetarium software with online astronomical data acquisition through *VizieR* database of astronomical catalogues [OBM00]. Stellar Command can be used as an interface mechanism for correlating music and sound generation, allowing Stellarium to be used as both a direct input interface for performance or composition, and as a remotely controlled derivative multimedia display output.

I hope you will have as much fun creating musical works with it as much as I have.

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Introduction

Musical composition and performance inspired or based on astronomy has been used in many cultures for millennia, with many civilizations creating songs and dances based on the astronomical calendar to reinforce the tracking of seasonal activities; such as planting and harvesting of crops, times of trade, and religious or cultural practices [R⁺15, dM15, Lim15]. More recently, composers have used scientific data obtained from individual stars to generate sounds and have created compositions directly correlated to that data [Fra14b, Bri13].

The advancement of computing power has made the availability of planetarium software for both desktop and mobile platforms very accessible to many people. These software packages are not only used for scientific and research activities; such as astronomy, education and general stargazing; they have also been used by artists in presenting multi-media artworks and installations [ZSW17, TIS⁺13].

Many composers have used the cosmos as inspiration or stimulus to their works, with many using scientific observations or data as input [Fra08b, Fra14b]. The *Quadrivium* linked astronomy, mathematics, geometry and music as a standard part of classical education up until the renaissance [LML⁺10]. Composers have been mapping mathematics and geometry to music since antiquity [Jam95, AF02]. Kepler stated "The heavenly motions are nothing but a continuous song for several voices, to be perceived by the intellect, not by the ear; a music which, through discordant tensions, through syncopations and cadenzas as it were, progresses toward certain pre designed six-voiced cadences, and thereby sets landmarks in the immeasurable flow of time." [RR79, cited in 286]. This notion inspired Rogers and Ruff to compose *The Harmony of the World* (1979), describing their work as "A Realization for the Ear" [RR79, p. 286] of Johannes Kepler's Astronomical Data from Harmonices Mundi 1619. More recently, composers have used measurements from online databases as inputs to automata or as stimulus to performers.

A system based on astronomical catalogues was the author's own musical composition and performance interface using naked eye and binocular astronomy [Fra14b]. A specific star was determined by calculating its azimuth and height above the horizon-known as its *altitude*-using accelerometer and magnetometer sensors, and calculating the exact location of the star on the celestial sphere using the sensor data, time and geographical location of the observer. This calculation returns the star's *right ascension (RA)*, which is based on its azimuth at Greenwich Meantime at the vernal equinox, and its *declination (Dec.)*, which is the stars north-south position at the same time [DSZ11, Fra14b]. The resultant RA and Dec. are added as input to the VizieR database of online catalogues, returning data about stars-such as brightness and colour-within the defined radius. Various works were created using this interface. In one performance, which was conducted in conjunction with

the Newcastle Astronomical Society on one of their field viewing nights, members of the public were enticed into viewing the night sky through high powered binoculars, while the sound generated, which was based on data from the stars they were viewing, was played through loudspeakers on the field [Fra14a]. Another set of performances was conducted with an improvising ensemble that featured various astronomical photos displayed as a slide show where the astronomical data was mapped as MIDI and functioned as inspirational impetus for the performers [Bri13].

Although both systems are innovative and impressive, they have identifiable boundaries. First, Machine 9 exists as an installation piece using unique piece of specialised hardware [spa16]. Furthermore, a publicly available API to convert the space debris to a musical transmission protocol like MIDI or OSC [WF⁺97] is not yet available for the wider computer music community. Secondly, although the binocular display has an awesome display—the actual night sky—“few people ventured outside to the astronomical equipment”[Fra14b, p. 50] because they were required to leave the room to look through binoculars while the ensemble played in a room. Furthermore, the work is severely bound by weather conditions and a clear view of the sky. In one of the performances, “the sky was completely covered with cloud and it rained, so there was nothing to see through the binoculars. The audience, however, enjoyed the ensemble performance with the NASA image slide show with samples fed from stored star tables.”[Fra14b, p. 50]. This weather constraint inspired the author to use planetarium software as the input and display mechanism as an alternative to binoculars.

Stellar Command enables composers to access astronomical data as input to their software using a common API. It also enables them to provide the audience an impressive planetarium software display that runs on a laptop computer without requiring the audience to leave the room. Furthermore, it facilitates creation of interactive celestial based installations. Stellar Command is available as open source software through GitHub [Fra19b].

Background

STELLARIUM

Stellarium is a software program designed to enable people to create a virtual planetarium using their home computer [ZW18]. It runs on Windows, OSX and Linux/Unix, including Raspberry Pi [ZW18, p. 6]. Stellarium calculates positions of the Sun, moon, stars and planets based on the time and location defined by the user, and renders them to the display. Stellarium is used by both amateur and professional astronomers, and is used by the European Organisation for Astronomical Research in the Southern Hemisphere to facilitate distribution and sharing of visual data among scientists [Ber08]. Stellarium has a very high quality graphical display, supporting spherical mirror projection that can be used with a dome [MC09] and is used in many schools and museums because it is both scientifically accurate and visually engaging [Ber08]. Moreover, Stellarium can display constellations from several different cultures and has labels translated to more than 40 languages, making Stellarium both culturally aware and inclusive [Ber08]. For example, Figures 1 and 2 display the same area of sky, however the first presents the constellations using the western sky lore while the latter presents them in the Tukano sky lore¹ [RD76]. A comparison reveals that *Scorpius* and *Crux* are referred to as the *Fer-de-lance* and the *Tortoise*. This feature can make Stellarium an extremely useful tool in facilitating multimedia presentations for ethnomusicology or composing in non-western contexts.

Many astronomers use Stellarium to display a prediction of the sky for a future time, such as organising a viewing night or planning an astro-photography session [Ash15]. Archaeoastronomers also use the feature to generate an astronomical display from a location for a period sometime in the past [Zot14]. Also, the landscape feature facilitates a connection between landscape and skyscape, so one can map the sky against a landscape for research or aesthetics [ZSW17].

Stellarium scripts are written in ECMAScript, also known as Javascript, and enables the programmer to generate and run an automated astronomy presentation, facilitating automation of all the functionality of Stellarium [ZW18].

Stellarium has a Remote Control plugin that enables third party programs to communicate with Stellarium via a REST client. This feature was used by the author to create an interactive spacecraft game using a sonic ball as a preliminary test of Stellarium's viability as a responsive performance interface [FB19]. The plugin also allows clients to query the status of Stellarium, including the area of sky currently being displayed. The exact celestial vector and field of view displayed are used as the input to the VizieR server in order to obtain data about stars in that location.

¹The Tukano tribes are indigenous peoples of the northwestern region of Brazil [Kno76].

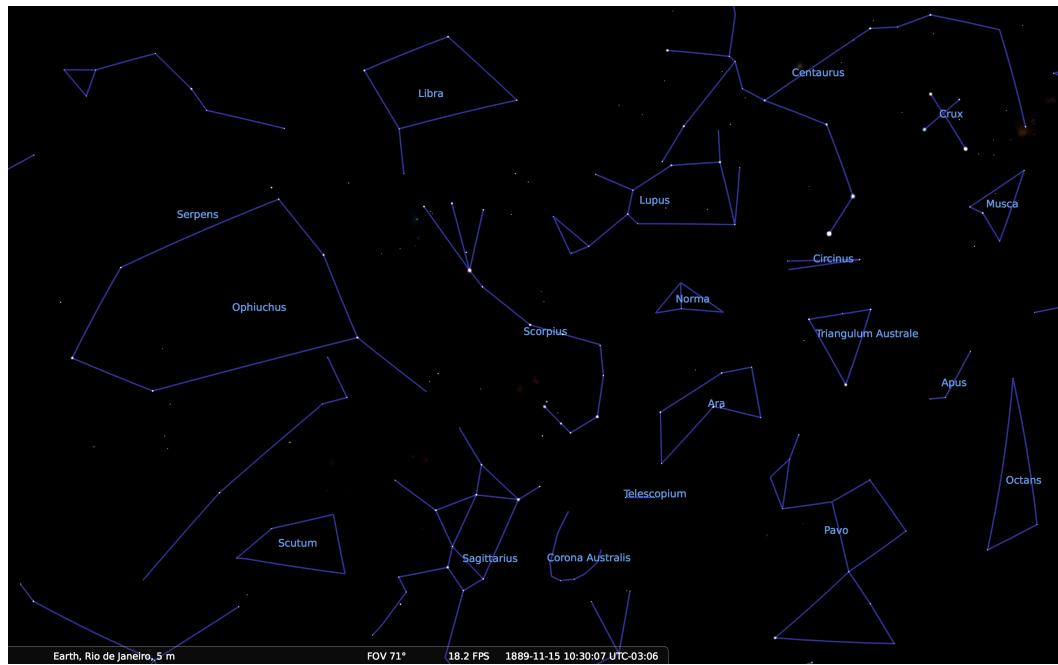


Figure 1: Constellations displayed in Western sky lore.

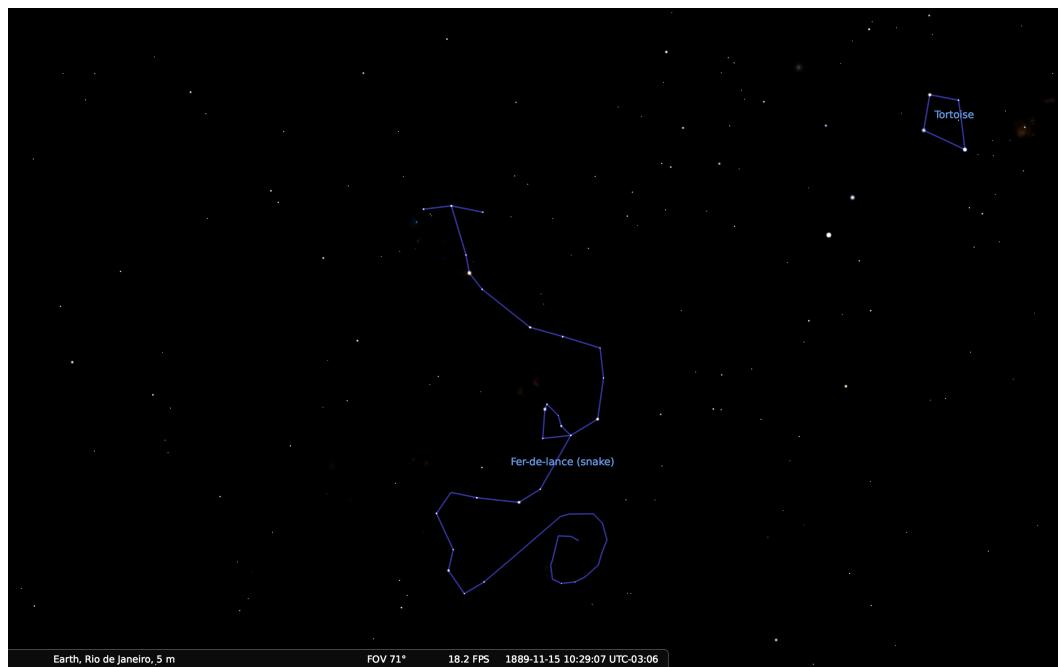


Figure 2: Constellations displayed in Tukano sky lore.

VIZIER

VizieR is an online database of high quality astronomical catalogues collected by the Centre de Données astronomiques de Strasbourg (CDS), one of whose main goals "is to promote the usage of the reliable astronomical catalogues to the astronomical community" [OBM00, p. 25]. One of the ways CDS ensures the reliability of their archives and catalogues is to only collect data that has been published or accepted in refereed scientific journals or literature. The number of catalogues available has grown from 3000 in 1999 [OBM00, p. 24] to currently 18000 [Viz18]. Catalogues can be selected by name or based on the wavelength, mission and astronomy type [Och10]. Wavelength dictates the frequency spectrum of the data in the catalogue, such as radio, infra-red, optical, x-ray, and Gamma-RAY. The mission indicates the purpose for which the catalogue was created or is used. For example, the purpose of the Kepler Mission is to "detect Earth-size planets in the habitable zone ... of solar-like stars... , determine their frequency, and identify their characteristics." [KBB⁺10, p. 2]; and so catalogues created or used within this mission can be specifically targeted. The type of astronomy indicates the subject area of research that the catalogue belongs to; for example, black holes, galaxy clusters, planetary nebulae, red shifts, and photometry.

Once a user has selected the database criteria to search, they must provide VizieR a search window that consists of a target centre and area around that point to search. The target centre is the point on the celestial sphere referenced to a celestial equinox², and can be defined by object name, RA and Dec., or by IAU-coordinates [viz17].

STELLAR COMMAND MODULE

Although it is possible to communicate directly to Stellarium and VizieR directly through the HTTP interface, the stellar position parameters between the two systems are different. Stellarium returns its position information as three dimensional spherical points, with a separate query for the field of view; whereas, VizieR requires the data as a two dimensional geometric point with a defined radius. The Stellar Command module abstracts this information from the client software and removes the requirement to perform these calculations by the client. Stellar Command directs VizieR to query the Hipparcos catalogue because it provides a "complete all-sky survey of astrometric and photometric parameters for one million stars down to magnitude 11" [VL97, p. 201]. An attempt was made using other photometric catalogues, however, it was difficult to obtain consistent results for all sky locations.

The interface required to control both Stellarium and VizieR was HTTP based, so a language that provided network functionality as a fundamental core feature was preferred. Also, it was imperative that third party users of the library should not have to learn a particular programming language, but instead, could easily interface with the library using their preferred music package such as Max MSP, SuperCollider or PD. Furthermore, it would be advantageous for users to be able to integrate the library into the programming language of their choice, such as C, C++, Python, Ruby, or Java.

Developing the system as a Java Archive (JAR) fulfilled all these requirements. Using a JAR file allowed instantiation from the command line, running as separate processes and using OSC to communicate with other programs. Additionally, many other programming languages can connect directly to a JAR through the Java Native Interface (JNI) [Lia99].

²The default equinox is J2000 [Och10].

Terminology

In all areas of research or vocation, there is terminology used that is specific to that field, and astronomy is no exception. Although this is not a treatise on the study of astronomy, it would serve you well to become acquainted with some of these terms.

DISCIPLINES OF RESEARCH

You will hear terms such as *astronomy*, *archaeoastronomy* and *ethnoastronomy*. These terms can sometime become confusing so I will provide short definitions for them.

Astronomy

Astronomy is one of physical sciences and involves the systematic study of celestial objects and phenomena that originate outside the Earth's atmosphere. Astronomic data from various missions are recorded in catalogues for use within the scientific community. Within the field of study, there are various terms used, which are important to know in order to query and interpret the astronomical data you will encounter.

Field of View

The *field of view* is the amount of sky that you are able to see and it is measured in degrees. If we zoom in, we reduce the field of view. If we compare Figures 3 and 4, we see the same point of sky is in the centre, however, the image that looks closer has a lower field of view.

Observation Location

The observer location is the geographical position from where the celestial observation is being made. These are defined using latitude and longitude. For example, if you were viewing the sky from Newcastle Australia, your geographical location would be 32.9283° South, 151.7817° East. Rather than using the terms south and east, northern latitudes are positive and southern are negative. Likewise, east is positive and west is negative. Therefore, the geographical location for Newcastle would be -32.9283, +151.7817. A western longitude can also be positive, however, the value is 360° - the western longitude. Eg, a longitude of -90° is also +270°.

It is also possible to set the planet or celestial body you are viewing from. For example, Figure 5 displays us looking at Jupiter with our observation location as its moon Io.

Time Zone

The time zone is the time difference between local time and Coordinated Universal Time (UTC) and does not change with daylight saving. The exact time is specified by the year,

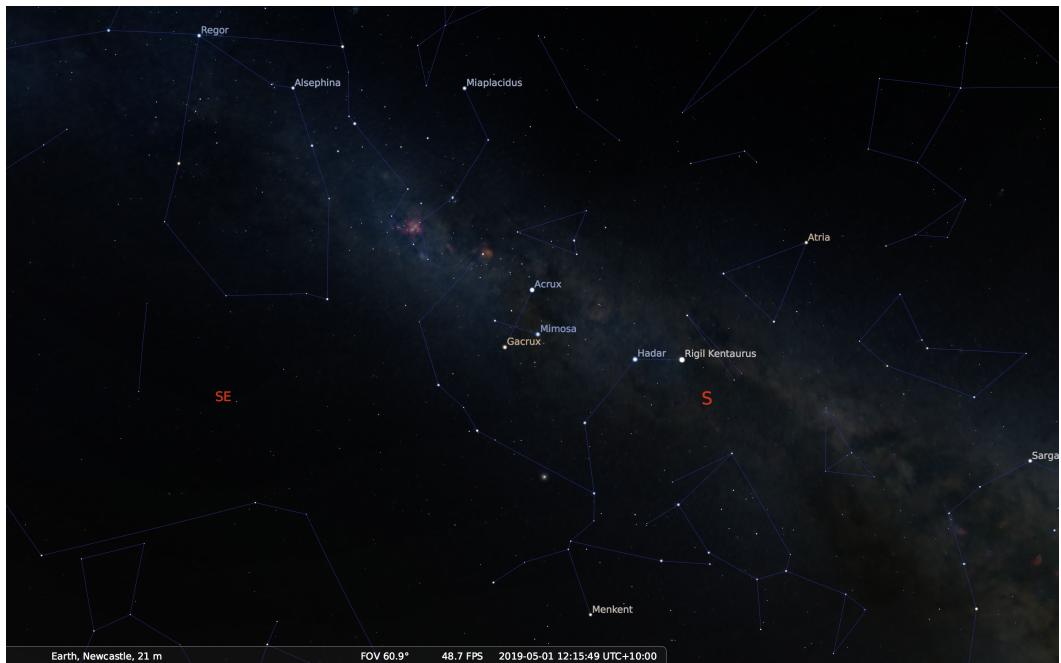


Figure 3: Stellarium displaying a 60° field of view.

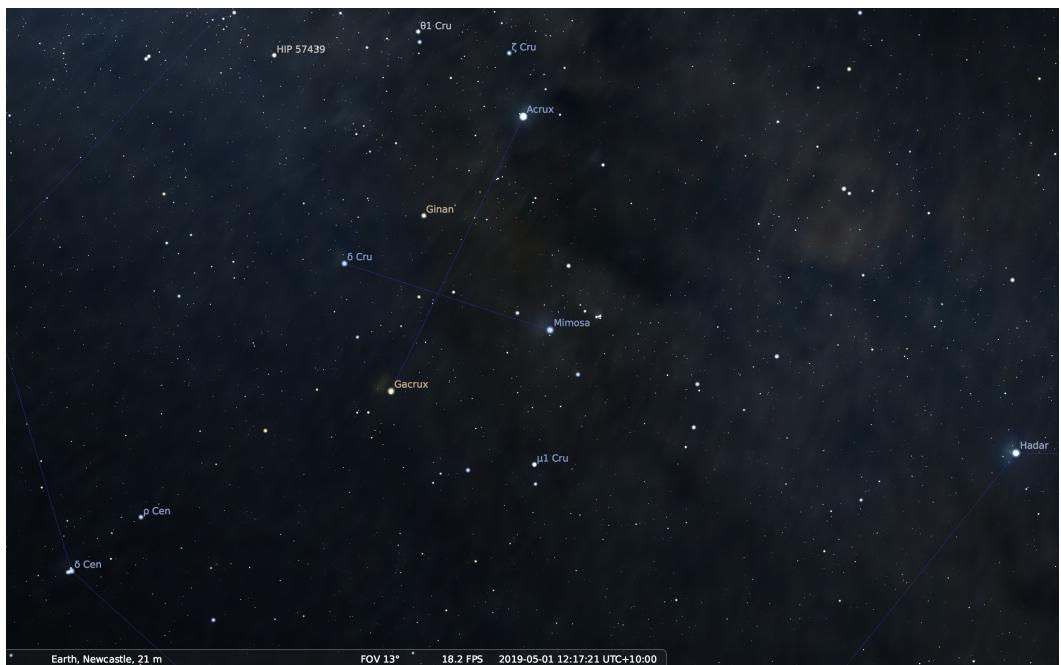


Figure 4: Stellarium displaying a 13° field of view.

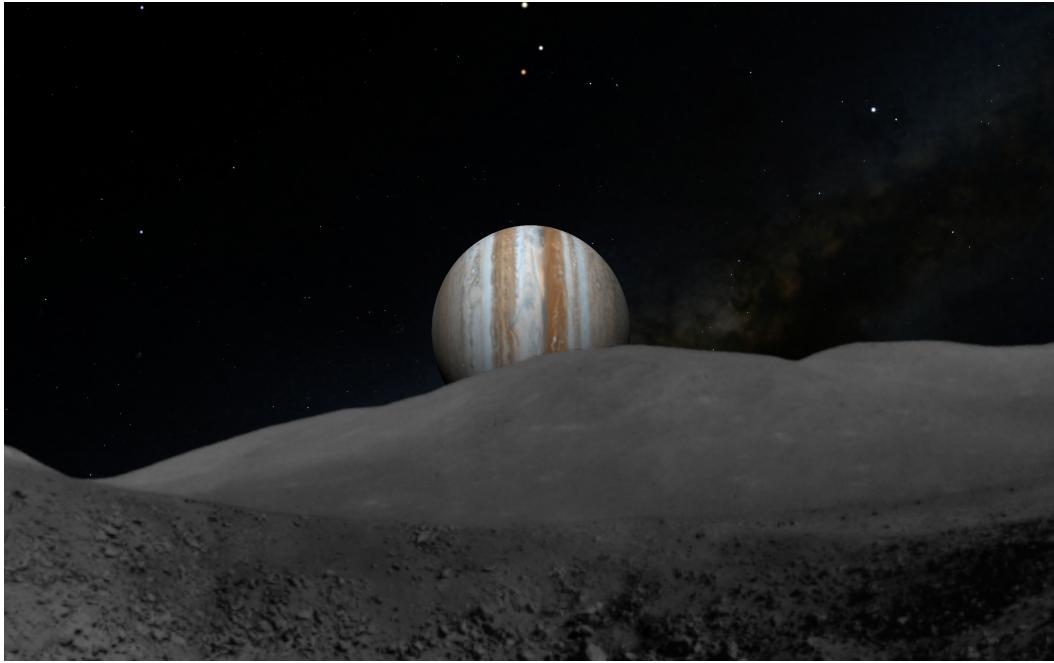


Figure 5: A simulation of Jupiter being viewed with Io as the observation location.

month, day followed by time in hours (24 hour code), minutes, seconds and the time zone. The time zone for UTC is "Z", with each hour time zone increasing by a letter of the alphabet, with "Z" being zero. For example, midday on January 1, 2000 at UTC would be defined as "2000-01-01T12:00:00Z". Likewise, "2019-06-01T14:13:00K" would be 1 June 2019 at 2:15pm, 10 hours later than UTC time (this is Sydney time). When daylight saving occurs, the local time changes, which results in a different letter for the time zone.

Celestial Coordinates

In the same way we can define an exact location on the Earth using latitude and longitude, we define the location of celestial objects using the celestial coordinate system. Instead of longitude and latitude, we use the terms *Right ascension* and *Declination*.

Right Ascension

Right Ascension, abbreviated to *RA*, is the angular distance from the east of the First Point of Aries (hereafter FPOA), and is measured in hours, minutes and seconds, and is similar to the longitude on earth, except on the celestial sphere. This is basically how long it takes from the time FPOA is on the meridian (directly north or south) for the RA in question to be overhead. For example, if an object had a Right ascension of 3 Hours, it would mean that it would appear on the meridian three hours after FPOA was. This is similar to the concept of time zones. In order to make calculations easier, we convert the RA to a digital angle by multiplying the number of hours by 15 (24 hours \times 15 = 360°). Furthermore, we use decimals instead of minutes and seconds. eg, $90^\circ 30'$ would be written 90.5° .

Declination

The declination is equivalent to the concept of latitude and is the angular distance a star is north or south of the celestial equator when it is on the meridian (in line with north / south).

Magnitude

The magnitude is how bright a star is. Higher magnitudes mean a lower brightness.

Atmosphere

Atmosphere is the gas that surrounds us and makes the sky appear like daylight. If there was no atmosphere, the sky would appear dark, as it does on the moon, and you would be easily able to see stars during the day. Stellarium gives us the option to hide the atmosphere, enabling us to see stars at any time. For example, Figure 6 shows the midday with normal atmosphere, whereas 7 shows the same sky without the atmosphere.



Figure 6: Midday showing the sky with atmosphere.

Ethnoastronomy

Ethnoastronomy is a social science belonging to the discipline of ethnology and examines the way astronomy is practised in the context of a particular culture [?].

Archaeoastronomy

Archaeoastronomy is the study of how ancient civilisations understood the cosmos and in a sense very similar to ethnoastronomy. “Broad public embrace of archaic astronomy



Figure 7: Midday showing the sky with atmosphere.

probably began in the eighteenth century with awareness of the summer solstice sunrise's affiliation with Stonehenge" [?, p. 263]. Archaeoastronomers have used Stellarium to generate an astronomical display from a location for a period sometime in the past [Zot14].

Astrology

"Astrology, from the Greek, astro-logos, is the assumption that the stars and planets contain meaning and significance for terrestrial affairs....Astrology appears to be a universal feature of human culture and may be understood as a form of cultural astronomy; an important contribution to the understanding of astronomy's cultural uses, applications, uses, and functions; and an indication of society's attitudes to the stars." [?, p. 104]. Stellarium has a feature whereby you can display constellation art, as shown in 8, which facilitates representing astrology in your works.



Figure 8: Constellation art.

One

Using Stellar Command with OSC

There are primarily two ways to use Stellar Command. The first is as a separate process that runs on the compute. The second method is to use Stellar Command as a library that you link to directly in your program. If you intend to use Stellar Command as a library, you can skip forward to chapter 2 – [Using Stellar Command as a Java Library](#).

1.1 LAUNCHING STELLAR COMMAND

makeidxstandalone The Stellar Command module is instantiated by executing Java with the name of the JAR file and the required program arguments that define communication, such as the network port to send OSC messages to, and the OSC address space. For example, to start the StellarCommand module so it sends OSC messages on UDP port 1234 using an OSC address space of /Stellar,¹ one would execute the following command:

```
java -jar StellarCommand.jar port=1234 osc=/Stellar
```

When the server starts, it will open the first available UDP port, and notify the client of this port. For example, if the command module opened port 4567, it will send an OSC message /Stellar/osc 4567 to the client on the localhost.

```
/Stellar/osc 4567
```

Allowing the command module to find its own port number removes the probability of port clashes as each client furnishes the other with a valid port number for communicating without requiring configuration in the command module. It is, however, possible to request the Stellar Command module try certain ports by adding the argument *tryport* with a comma separated list of ports. For example, the argument *tryport=3333,4444,5555* will cause Stellarium to sequentially try opening the ports listed, and if these all fail, will then open the first available port.

```
java -jar StellarCommand.jar port=1234 osc=/Stellar tryport=3333,4444,5555
```

The OSC client would receive the following OSC message:

```
/Stellar/osc 3333
```

¹In this instance, the OSC client and Stellarium are on the same computer.

The OSC client and the Stellarium server do not have to be on the same physical computer as the Stellar Command module. For example Figure 1.1, shows three OSC clients and a Stellarium server on a LAN, and a remote Stellarium server accessible from the internet through myserver.com.

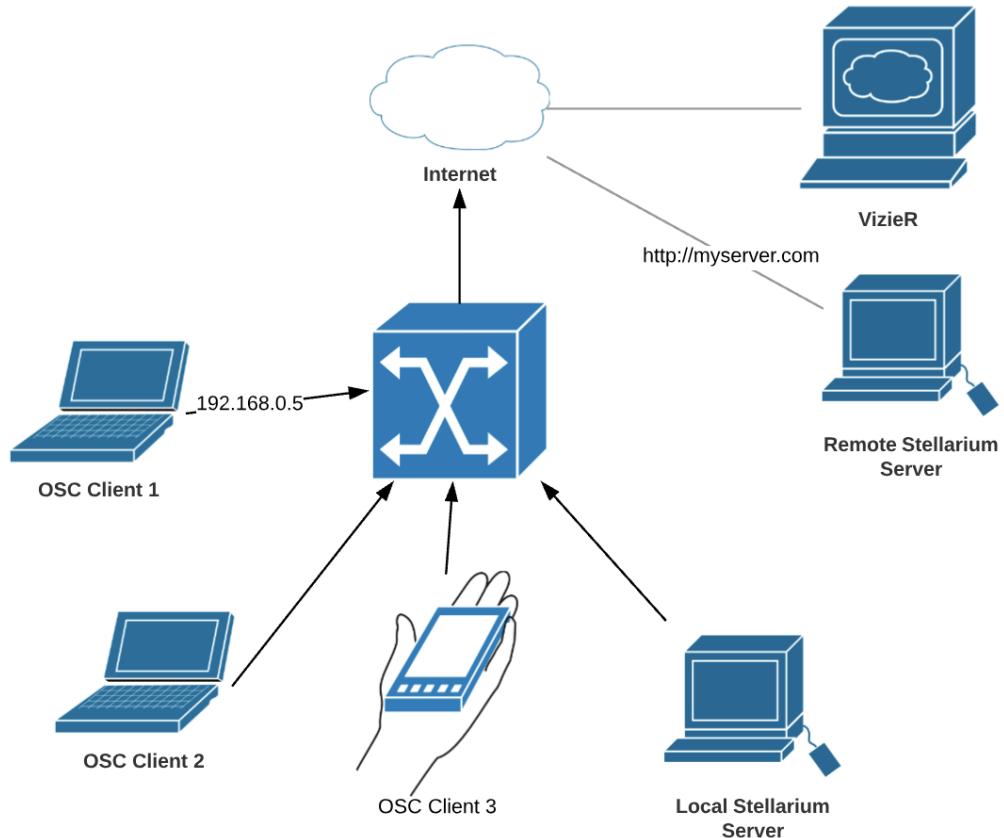


Figure 1.1: Remote Stellarium and OSC Clients.

Creating a connection between *OSC Client 1* and *Remote Stellarium Server* is effected by adding the arguments `client=192.168.0.5` and `stellarium=http://myserver.com` to the command line. This will cause the Stellar Command module to send OSC messages to “192.168.0.5” and Stellarium commands to `http://myserver.com` on HTP port 8090², effectively acting as a proxy between the two.

²The default Stellarium Remote Control port is 8090, however, this can be changed inside Stellarium. It is assumed that port forwarding when not using a local area network has been configured to send packages to the correct computer hosting Stellarium

```
java -jar StellarCommand.jar port=1234 osc=/Stellar \
client=192.168.0.5 stellarium=http://myserver.com
```

1.2 SENDING COMMANDS TO THE STELLAR COMMAND MODULE

You can provide instructions to Stellar Command in order to control Stellarium or to change the amount and type of data you want to receive. For example, you may want the Stellarium display to zoom in closer to a particular area of sky. You would do this by decreasing the field of view.³ Likewise, you may want to reduce the amount of astronomical data you are receiving by adding a filter threshold so VizieR will only receive stars within a certain magnitude range.

1.2.1 Field Of View

³Section 1.2.1 – *Field Of View* shows how to do this.

Two

Using Stellar Command as a Java Library

This chapter details how to use Stellar Command as a library that you call directly from within your programming environment. If you intend to use Stellar Command as a standalone server application and communicate to it with Open Sound Control Messages through your preferred music package—such as Max MSP, SuperCollider or PD—you can skip back to chapter 1 – [*Using Stellar Command with OSC*](#).

Three

Comments

3.1 ALGORITHMS

Over time we may use this section to explain, or list some of the algorithms for some of the macros in the class. The information may be useful to some.

3.1.1 Autoadjusting \marginparwidth

This algorithm is used within `\fixthelayout` unless the user have used `\setmarginnotes`.

```
if twocolumn then
    marginparwidth = min{inner margin,outer margin}
else
    if twoside then
        if marginpar always left or always right then
            marginparwidth = min{inner margin,outer margin}
        else if marginpar in outer margin then
            marginparwidth = outer margin
        else if marginpar in inner margin then
            marginparwidth = inner margin
        end if
    else
        if marginpar in left margin then
            marginparwidth = inner margin
        else
            marginparwidth = outer margin
        end if
    end if
end if
marginparwidth = marginparwidth - 2marginparsep
if marginparwidth < 1pt then
    marginparwidth = 1pt
end if
```

Notes

Bibliography

CTAN is the Comprehensive TeX Archive Network. Information on how to access CTAN is available at <http://www.tug.org>.

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Colophon

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