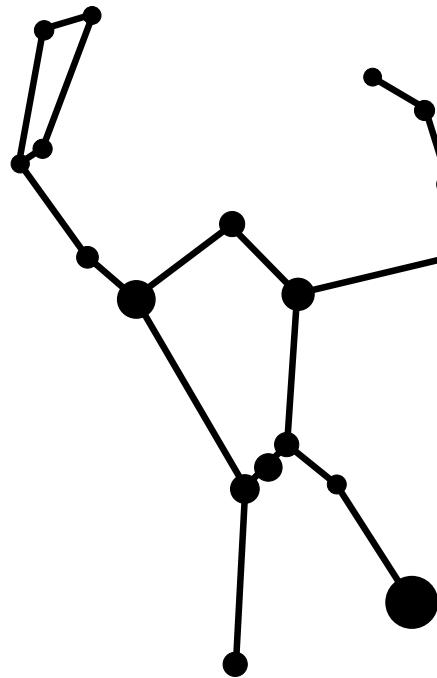


# Star Charts 101 and Practices

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This practice book is dedicated to all Astronomy enthusiasts and those aiming for cracking Star Charts part of Astronomy and Earth Science Olympiads. It is not a full star atlas but it will fulfill its duty as a practice book. I'll recommend students to **Print** it then solve problems. Keep it during your exam days as **only printed materials** are allowed in IOAA.

*Written from my experience of both being a participant of two international Olympiads as well as team leader for IOAA since 2018. I've also tried to mix my added experience as a stargazer/amateur astronomer into it!*

New versions can be found – <https://github.com/Rajit13/Star-Maps-101-and-Practices>

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## Contents

<b>1 Stars, Constellations, and Olympiads</b>	<b>3</b>
1.1 Constellation Names . . . . .	3
1.2 Star Names . . . . .	5
1.3 Constellation Figures . . . . .	8
<b>2 Exploring the Moon</b>	<b>32</b>
2.1 Moon's motion . . . . .	33
2.2 Moon's Phase . . . . .	33
<b>3 Deep Sky Objects</b>	<b>36</b>
3.1 Short Problems and Solutions on DSOs . . . . .	39
<b>4 Star Charts &amp; Positions of Stars</b>	<b>42</b>
4.1 Coordinate Lines . . . . .	42
4.2 Projections . . . . .	43
4.2.1 Horizon Views . . . . .	44
4.2.2 Round Maps . . . . .	45
4.3 Pole View Maps . . . . .	49
4.3.1 The precession of the Equinoxes . . . . .	50
4.4 Mercator Projections . . . . .	54
4.5 Monthly Sky Chats . . . . .	55
<b>5 Celestial Navigation</b>	<b>61</b>
5.1 Problem Solving Tips . . . . .	61
5.2 Naked Eye Observation . . . . .	62
5.3 Observing Planets . . . . .	73
5.3.1 Problem: Plotting the Moon and Planets . . . . .	74
5.4 Telescope Aided Observation . . . . .	79
5.5 Astrophotography . . . . .	89
5.6 Guessing the correct Magnitude . . . . .	89
<b>6 Practice Olympiad Problems</b>	<b>90</b>
6.1 General Instructions in typical IOAA . . . . .	90
6.2 How OBS Marking Works . . . . .	90
6.3 BDOAA . . . . .	93
6.3.1 2019 . . . . .	93
6.3.2 2021 . . . . .	94
6.3.3 2024 . . . . .	95
6.4 INAO . . . . .	96
6.4.1 2019 . . . . .	96
6.4.2 2018 . . . . .	97
6.4.3 2016 . . . . .	97
6.5 SAO . . . . .	98
6.5.1 P1: The night of Vernal Equinox . . . . .	98
6.6 Czech . . . . .	100
6.6.1 Observation using Simbad . . . . .	100

6.7	IOAA 2016 Observation Round . . . . .	101
6.7.1	Observational Map . . . . .	101
6.7.2	Observational Planetarium . . . . .	102
6.8	IOAA 2018 Observation Round . . . . .	105
6.8.1	O1 . . . . .	105
6.8.2	O2 . . . . .	106
6.8.3	O3 . . . . .	107
6.8.4	O4 . . . . .	108
6.9	IOAA 2019 Observation Round . . . . .	110
6.9.1	Task 01 . . . . .	110
6.9.2	Task 02 . . . . .	111
6.9.3	Task 03 . . . . .	112
6.10	GeCAA 2020 . . . . .	114
6.10.1	Problem 1 . . . . .	114
6.10.2	Problem 4 . . . . .	115
6.11	IOAA 2022 . . . . .	117
<b>7</b>	<b>Sources</b>	<b>120</b>

## Abstract

This book delves into the fundamental knowledge necessary for computations associated with studying the sky and the positions of celestial objects, specifically in observational astronomy—focusing on naked-eye observation. It elucidates practical examples that progressively increase in complexity. Initially, memorizing all the constellations might seem daunting for enhanced observational skills. However, contrary to this belief, memorization isn't required. Instead, this book systematically guides you in understanding the sky, allowing you to approach challenges as if solving a puzzle.

# 1 Stars, Constellations, and Olympiads

If you are aiming for Astronomy and Astrophysics Olympiad<sup>1</sup> or even Earth Science Olympiad<sup>2</sup> you may find a section where problems contains a star map. So what is a star chart i.e. Sky Map?

But before that, you should know some basic concepts i.e. what are Constellations? How stars move across the sky or it affects our observation?

**Constellations** represent apparent patterns formed by stars in the sky, often resembling figures or shapes perceived by humans. For instance, constellations might create recognizable figures like a Man (You may already guess the specific constellation I'm referring to!). They aid in identifying and recalling specific portions of the sky. However, it's important to note that creating random figures or personalized constellations is not officially recognized in Olympiads or by the International Astronomical Union (IAU). The IAU has officially acknowledged 88 constellations, while other popular patterns that are not part of these recognized constellations are referred to as Asterisms (e.g., Summer Triangle, Heavenly G, Big Dipper).

In a sky map, constellations are organized as their apparent orientation (projections) in the sky with respect to other celestial objects. In Olympiads question setters provides a sky map of a certain region (latitude  $\phi$ ) and ask students to determine some things or identify objects or constellation. Basics of Celestial Coordinate system is needed to understand the maps as well as solve the problems.

## 1.1 Constellation Names

Each Latin constellation name has two forms: the nominative, for use when talking about the constellation itself, and the genitive, or possessive, which is used in star names. For instance, Hamal, the brightest star in the constellation Aries (nominative form), is also called Alpha Arietis (genitive form), meaning literally, “the alpha of Aries”.

All modern constellations were codified in the European scientific subculture prior to the 19th century. As Latin was the international language of science up to that time, Latin governs the pronunciation of constellation names.<sup>3</sup> The Latin names of all the constellations, their abbreviated names and boundaries can be found in the table below. They are a mix of the ancient Greek patterns recorded by Ptolemy as well as some more “modern” patterns observed later by more modern astronomers.

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<sup>1</sup>IOAA/IAO

<sup>2</sup>IESO

<sup>3</sup>Source: <https://www.handprint.com/ASTRO/connames.html>

The IAU<sup>4</sup> adopted three-letter abbreviations of the constellation names at its inaugural General Assembly in Rome in 1922. The abbreviations devised by the IAU each have three letters which in the majority of cases are the first three letters of the constellation name, such as AND for Andromeda, EQU for Equuleus, HER for Hercules, ORI for Orion and so on. This trend is not strictly adhered to in cases where confusion may arise. This happens with the two constellations Leo (abbreviated LEO) and Leo Minor (abbreviated LMI). Similarly, because Triangulum (TRI) may be mistaken for Triangulum Australe, the latter is abbreviated TRA. Other instances occur with Sagitta (SGE) and Sagittarius (SGR) and with Canis Major (CMA) and Canis Minor (CMI) where the first two letters from the second names of the constellations are used. This is also the case with Corona Australis (CRA) and Corona Borealis (CRB) where the first letter of the second name of each constellation is incorporated. Finally, mention must be made of Crater (CRT) which has been abbreviated in such a way as to avoid confusion with the aforementioned CRA (Corona Australis).

In Olympiads, students are allowed to use star or constellation names based on their system, yet obtaining permission is necessary for IOAA/IAO/APAO/OWAO competitions. Typically, team leaders should inquire about this with the host jury. Therefore, students from countries like Bangladesh are advised to consistently utilize names designated by the IAU. However, for a comprehensive understanding of the Bangla names of stars and constellations, along with their background stories, students are encouraged to read the book “[Tara Porichity by Abdul Jobbar](#)”.

### Learning how to recognize constellations

1. Write down the list of all the constellations you want to remember (let's call this to be “C-List”)
2. Open the Stellarium app<sup>5</sup>,
3. Turn the constellation lines on, and the constellation names on.
4. Find all the constellation from the “C-list,” try to remember where they are situated and how they look
5. Turn the constellation names off (leave only the constellation lines on).
6. Try to find all the constellations from the “C-List” without the “Search” function. If you can find the constellation, you strike it out of the “C-list.” If not, find it with the “Search” function, try to remember where it is situated and how it looks.
7. Then, repeat all the previous steps with all the constellations left after the first striking-out. If you can find the constellation you strike it out of the “C-list”. If not, find it with the ”Search” function, try to remember where it is situated and how it looks
8. Repeat the striking-out rounds until you have no constellations left in your “C-list.”
9. If you every day repeat steps 1-8 (each day you start with blank “C-list” with no constellations struck out), just in 4-5 days you will be able to recognize the constellations lines and will have the basic knowledge about how they are situated on the night sky.
10. When you can strike all the constellations from the “C-list” in one striking out round, you can start repeating all the previous steps, but now with constellation lines turned off. If you repeat these steps every day, just in some days you will get good skills of determining the position of the constellation, and recognizing it by its picture or stars around.

<sup>4</sup>Source: <https://www.iau.org/public/themes/constellations/>

<sup>5</sup>Download from: <https://stellarium.org/>

## 1.2 Star Names

Most of the brighter stars were assigned their first systematic names by the German astronomer Johann Bayer in 1603, in his star atlas *Uranometria*. Bayer assigned a lowercase Greek letter, such as alpha ( $\alpha$ ), beta ( $\beta$ ), gamma ( $\gamma$ ), etc., to each star he catalogued, combined with the Latin name of the star's parent constellation in genitive (possessive) form. (See 88 modern constellations for the genitive forms later on the table.) For example, Aldebaran is designated  $\alpha$  Tauri (pronounced Alpha Tauri), which means "Alpha of the constellation Taurus".

A constellation's most brilliant star is often called Alpha, the first letter in the Greek alphabet. The letters are used with the Latin genitive form of the constellation name, so the Alpha star of Centaurus is called "Alpha Centauri." But there are few exceptions. For example, Gemini's brightest star is  $\beta$  and that of octans is  $\nu$ . Here is the lowercase Greek alphabet as used by astronomers:

$\alpha$ Alpha	$\iota$ Iota	$\rho$ Rho
$\beta$ Beta	$\kappa$ Kappa	$\sigma$ Sigma
$\gamma$ Gamma	$\lambda$ Lambda	$\tau$ Tau
$\delta$ Delta	$\mu$ Mu	$\upsilon$ Upsilon
$\varepsilon$ Epsilon	$\nu$ Nu	$\phi$ Phi
$\zeta$ Zeta	$\xi$ Xi	$\chi$ Chi
$\eta$ Eta	$\circ$ Omicron	$\Psi$ Psi
$\theta$ Theta	$\pi$ Pi	$\omega$ Omega

In Olympiad questions, when asked about a star's name examiners and Jury prefer these Greek letter titles (Flamsteed or Bayer Designation) rather than actual popular name. So it is a wise decision to remember star names by Greek letters.

A student should always know which star is the  $\alpha$ ,  $\beta$  star for a certain constellation. Specially exceptions. Sometimes you may have to remember special stars designated  $\gamma$  or  $\zeta$  etc.

### Knowing where the brightest constellation stars are situated

For learning where they are on the night sky, you can use the plan similar to the one for learning the constellations: You can learn their position with the same plan

1. Write down the list of all the stars you want to remember (let's call this to be "S-List")
2. Open the Stellarium app, try to find a star without turning the names and lines of the constellations on. If you managed to strike it out of the "S-List."
3. If not, turn on the constellation lines and try to find the star again. If you managed to find it, leave the star in the list without striking it out.
4. If not, find the star with the "Search" function, try to remember where it is situated and how it looks. Don't strike it out.
5. Repeat the striking-out rounds until you have no stars left in your "S-list."

If you every day repeat steps 1-5 (each day you start with blank "S-list" with no stars struck), just in a week, you will be able to recognize the stars on the night sky. You will also have a good knowledge of the relative positions of the constellations.

Table 1: Constellation Table

No.	Constellation	Location	Supposed Figure	Code	Brightest Star
1	Andromeda	N	Andromeda	And	Alpheratz ( $\alpha$ )
2	Antlia	S	The Air Pump	Ant	$\alpha$ Antliae
3	Apus	S	The Bird of Paradise	Aps	$\alpha$ Apodis
4	Aquarius	S/Eq	The Water Carrier	Aqr	Sadal Melik ( $\alpha$ )
5	Aquila	Eq	The Eagle	Aql	Altair ( $\alpha$ )
6	Ara	S	The Altar	Ara	$\beta$ Arae
7	Aries	N	The Ram	Ari	Hamal ( $\alpha$ )
8	Auriga	N	The Charioteer	Aur	Capella ( $\alpha*$ )
9	Boötes	N	The Herdsman	Boo	Arcturus ( $\alpha$ )
10	Caelum	S	The Graving Tool	Cae	$\alpha$ Caeli
11	Camelopardalis	N	The Giraffe	Cam	$\beta$ Camelopardalis
12	Cancer	N	The Crab	Cnc	Al Tarf ( $\beta$ )
13	Canes Venatici	N	The Hunting Dogs	CVn	Cor Caroli ( $\alpha$ )
14	Canis Major	S	The Great Dog	CMa	Sirius ( $\alpha*$ )
15	Canis Minor	N/Eq	The Little Dog	CMi	Procyon ( $\alpha*$ )
16	Capricornus	S	The Goat	Cap	Al Giedi ( $\alpha$ )
17	Carina	S	The Keel	Car	Canopus ( $\alpha*$ )
18	Cassiopeia	N	Cassiopeia	Cas	Schedar ( $\alpha$ )
19	Centaurus	S	The Centaur	Cen	Rigel Kentaurus ( $\alpha*$ )
20	Cepheus	S	Cepheus	Cep	Alderamin ( $\alpha$ )
21	Cetus	Eq	The Whale	Cet	Diphda ( $\beta$ )
22	Chamaeleon	S	The Chameleon	Cha	$\alpha$ Chamaeleontis
23	Circinus	S	The Pair of Compasses	Cir	$\alpha$ Circini
24	Columba	S	The Dove	Col	Phact ( $\alpha$ )
25	Coma Berenices	N	Berenice's Hair	Com	$\beta$ Comae Berenices
26	Corona Australis	S	The Southern Crown	CrA	$\alpha$ Coronae Australis
27	Corona Borealis	N	The Northern Crown	CrB	Gemma or Alphecca ( $\alpha$ )
28	Corvus	S	The Crow	CrV	Gienah ( $\gamma$ )
29	Crater	S	The Cup	Crt	$\delta$ Crateris
30	Crux	S	The Cross	Cru	Acrux ( $\alpha*$ )
31	Cygnus	N	The Swan	Cyg	Deneb ( $\alpha*$ )
32	Delphinus	N	The Dolphin	Del	Rotanev ( $\beta$ )
33	Dorado	S	The Goldfish	Dor	$\alpha$ Doradus
34	Draco	N	The Dragon	Dra	Eltanin ( $\gamma$ )
35	Equuleus	N	The Foal	Equ	Kitalpha ( $\alpha$ )
36	Eridanus	S/Eq	The River	Eri	Achernar ( $\alpha*$ )
37	Fornax	S	The Furnace	For	$\alpha$ Fornacis
38	Gemini	N	The Twins	Gem	Pollux ( $\beta*$ )
39	Grus	S	The Crane	Gru	Alnair ( $\alpha$ )
40	Hercules	N	Hercules	Her	Ras Algethi ( $\alpha$ )
41	Horologium	S	The Pendulum Clock	Hor	$\alpha$ Horologii
42	Hydra	S/Eq	The Water Snake	Hya	Alphard ( $\alpha$ )
43	Hydrus	S	The Lesser Water Snake	Hyi	$\beta$ Hydri
44	Indus	S	The Indian	Ind	$\alpha$ Indi

No.	Constellation	Location	Supposed Figure	Code	Brightest Star
45	Lacerta	N	The Lizard	Lac	$\alpha$ Lacertae
46	Leo	N/Eq	The Lion	Leo	Regulus ( $\alpha^*$ )
47	Leo Minor	N	Lion Cub	LMi	Praecipua
48	Lepus	S	The Hare	Lep	Arneb ( $\alpha$ )
49	Libra	S	The Scales	Lib	Zubeneshamali ( $\beta$ )
50	Lupus	S	The Wolf	Lup	$\alpha$ Lupus
51	Lynx	N	The Lynx	Lyn	$\alpha$ Lyncis
52	Lyra	N	The Lyre	Lyr	Vega ( $\alpha^*$ )
53	Mensa	S	The Table Mountain	Men	$\alpha$ Mensae
54	Microscopium	S	The Microscope	Mic	$\gamma$ Microscopii
55	Monoceros	Eq	The Unicorn	Mon	$\beta$ Monocerotis
56	Musca	S	The Fly	Mus	$\alpha$ Muscae
57	Norma	S	The Level	Nor	$\gamma$ Normae
58	Octans	S	The Octant	Oct	$\nu$ Octanis
59	Ophiuchus	Eq	The Serpent Bearer	Oph	Ras Alhague ( $\alpha$ )
60	Orion	Eq	The Hunter	Ori	Rigel ( $\beta^*$ )
61	Pavo	S	The Peacock	Pav	$\alpha$ Pavonis
62	Pegasus	N	Pegasus	Peg	Enif ( $\varepsilon$ )
63	Perseus	N	Perseus- Demi God	Per	Mirfak ( $\alpha$ )
64	Phoenix	S	The Phoenix	Phe	Ankaa ( $\alpha$ )
65	Pictor	S	The Painter's Easel	Pic	$\alpha$ Pictoris
66	Pisces	N/Eq	The Fish	Psc	Alphergh ( $\eta$ )
67	Pisces Australis	S	The Southern Fish	PsA	Fomalhaut ( $\alpha^*$ )
68	Puppis	S	The Stern	Pup	Naos ( $\zeta$ )
69	Pyxis	S	The Mariner's Compass	Pyx	$\alpha$ Pyxidis
70	Reticulum	S	The Net	Ret	$\alpha$ Reticuli
71	Sagitta	S	The Arrow	Sge	$\gamma$ Sagittae
72	Sagittarius	S	The Archer	Sgr	Kaus Australis ( $\varepsilon$ )
73	Scorpius	S	The Scorpion	Sco	Antares ( $\alpha^*$ )
74	Sculptor	S	The Sculptor	Scl	$\alpha$ Sculptoris
75	Scutum	S	The Shield	Sct	Ionnina
76	Serpens	Eq	The Serpent	Ser	Unukalhai ( $\alpha$ )
77	Sextans	Eq	The Sextant	Sex	$\alpha$ Sextantis
78	Taurus	N/Eq	The Bull	Tau	Aldebaran ( $\alpha^*$ )
79	Telescopium	S	The Telescope	Tel	$\alpha$ Telescopii
80	Triangulum	N	The Triangle	Tri	$\beta$ Trianguli
81	Triangulum Australe	S	The Southern Triangle	TrA	Atria ( $\alpha$ )
82	Tucana	S	The Toucan	Tuc	$\alpha$ Tucanae
83	Ursa Major	N	The Great Bear	UMa	Alioth ( $\varepsilon$ )
84	Ursa Minor	N	The Little Bear	Umi	Polaris ( $\alpha$ )
85	Vela	S	The Sail	Vel	Suhail ( $\alpha$ )
86	Virgo	Eq	The Virgin	Vir	Spica ( $\alpha^*$ )
87	Volans	S	The Flying Fish	Vol	$\beta$ Volantis
88	Vulpecula	N	The Fox	Vul	Anser

\* Indicates brightest stars in the sky

$\alpha$ And	$\beta$ Aur	$\alpha$ CMa	$\alpha$ Gem	$\alpha$ Ori	$\alpha$ Psc	$\beta$ UMa
$\beta$ And	$\alpha$ Boo	$\beta$ CMa	$\beta$ Gem	$\beta$ Ori	$\alpha$ Sco	$\alpha$ UMi
$\alpha$ Ari	$\beta$ Boo	$\alpha$ CMi	$\alpha$ Leo	$\alpha$ Oph	$\beta$ Sco	$\beta$ UMi
$\beta$ Ari	$\alpha$ Cap	$\beta$ CMi	$\beta$ Leo	$\beta$ Oph	$\alpha$ Ser	$\beta$ Cyg
$\alpha$ Aql	$\alpha$ Cas	$\alpha$ CrB	$\alpha$ Lep	$\alpha$ Per	$\varepsilon$ Sgr	
$\beta$ Aql	$\beta$ Cas	$\beta$ CrB	$\alpha$ Lib	$\beta$ Per	$\alpha$ Tau	
$\alpha$ Aqr	$\alpha$ Cep	$\gamma$ Dra	$\alpha$ Lyr	$\alpha$ Peg	$\beta$ Tau	
$\alpha$ Aur	$\alpha$ Cet	$\alpha$ Cyg	$\beta$ Lyr	$\beta$ Peg	$\alpha$ UMa	

Table 2: Suggested Bright Stars of interest

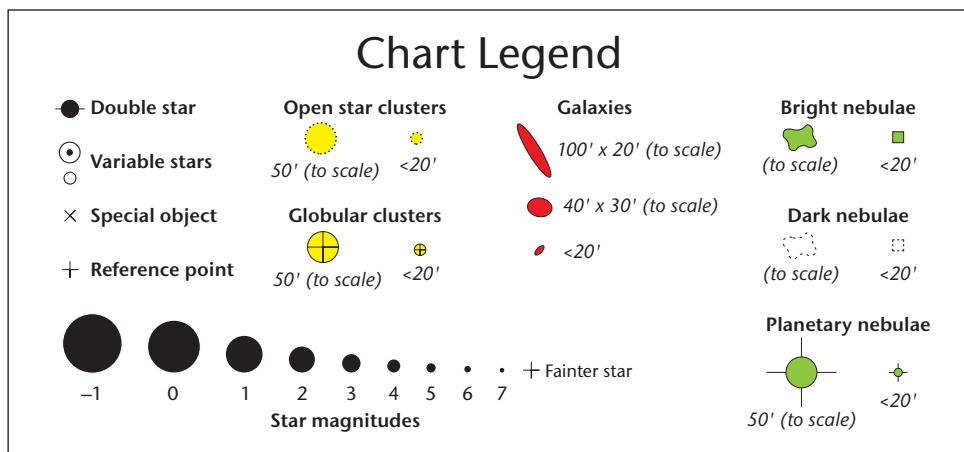
List of brightest natural objects in the sky- [https://en.wikipedia.org/wiki/List\\_of\\_brightest\\_natural\\_objects\\_in\\_the\\_sky](https://en.wikipedia.org/wiki/List_of_brightest_natural_objects_in_the_sky)

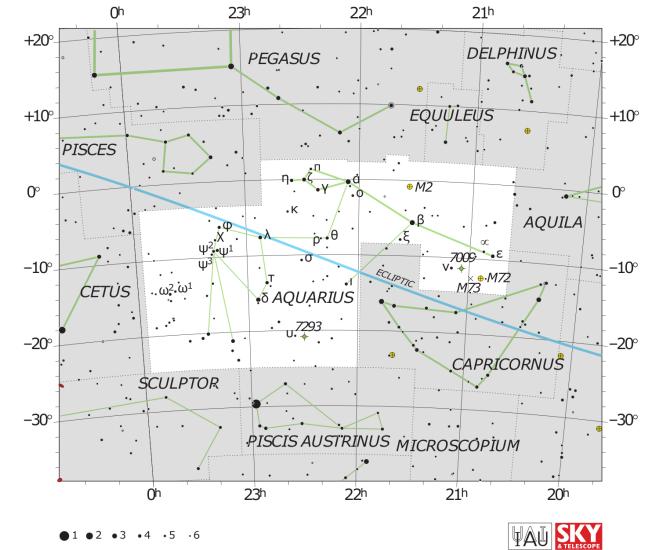
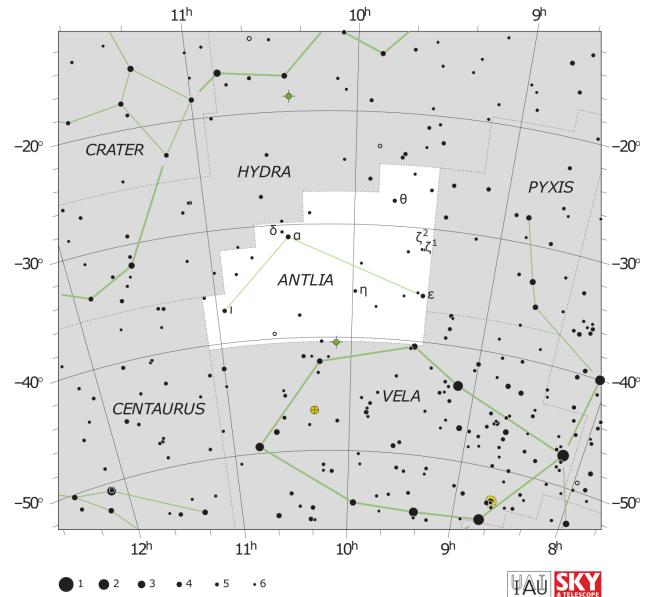
### 1.3 Constellation Figures

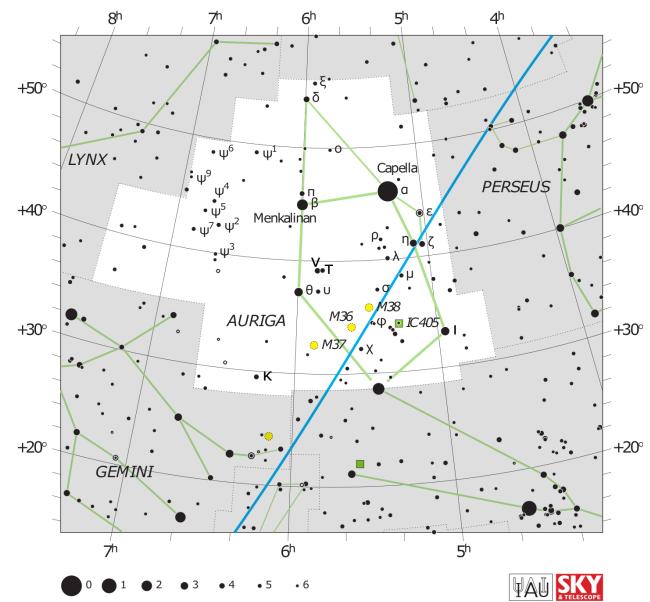
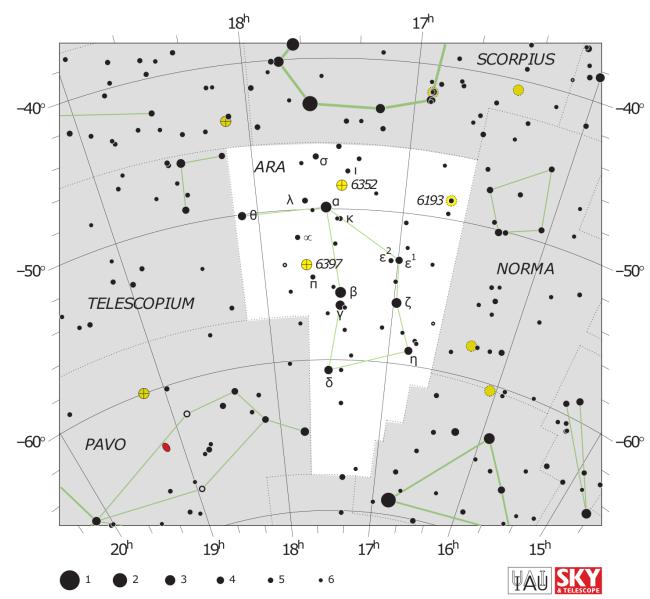
In star maps it is common to mark line “patterns” that represent the shapes that give the name to the constellations. However, the IAU defines a constellation by its boundary (indicated by sky coordinates) and not by its pattern and the same constellation may have several variants in its representation.

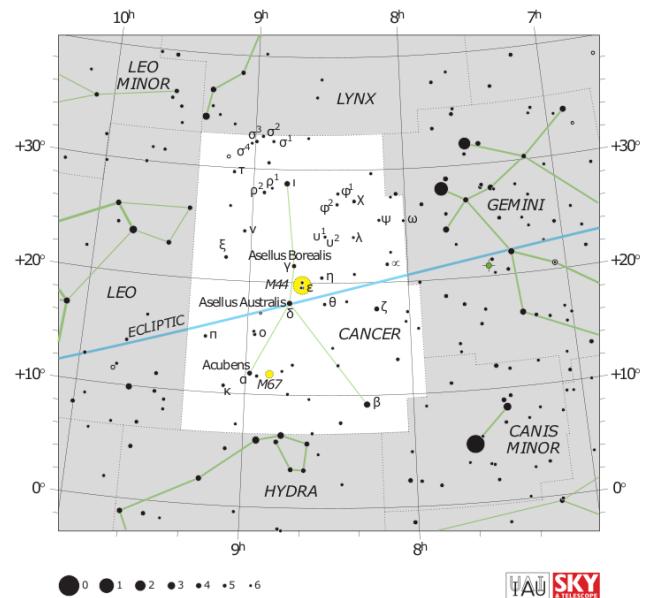
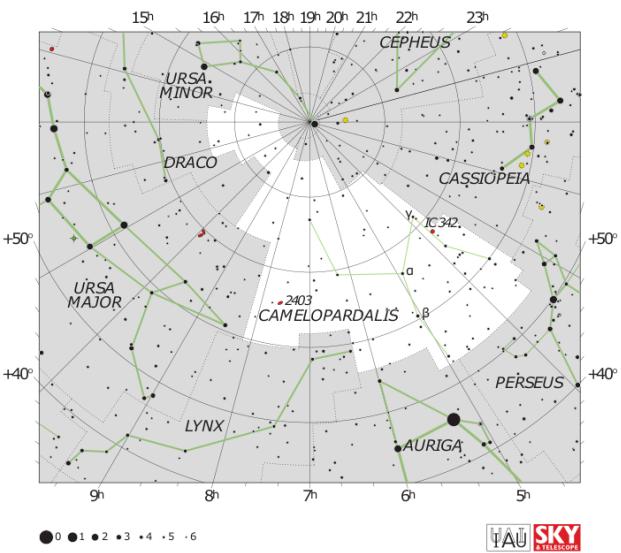
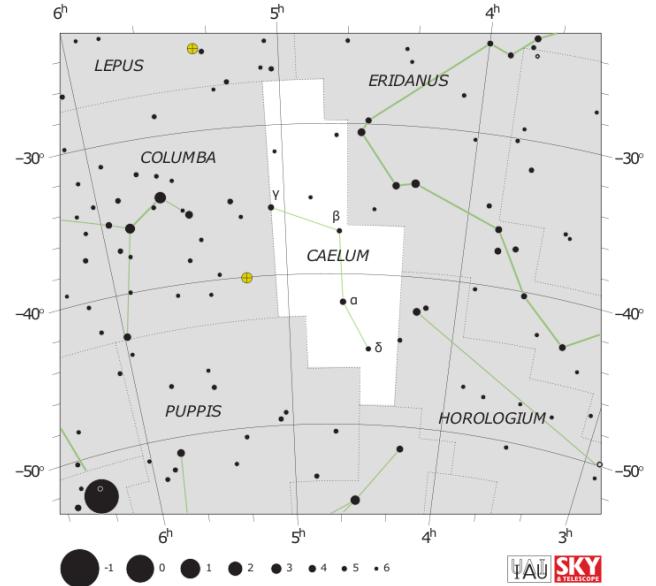
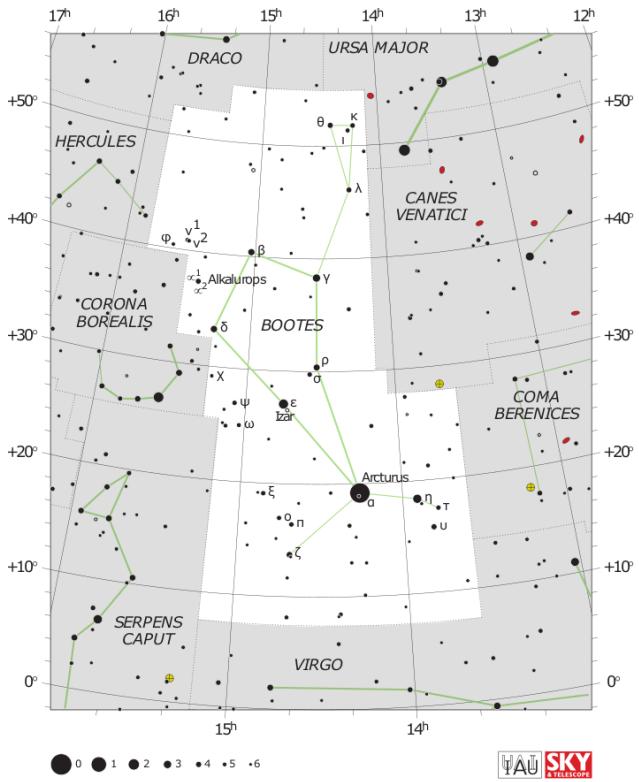
The constellations should be differentiated from asterisms. Asterisms are patterns or shapes of stars that are not related to the known constellations, but nonetheless are widely recognized by laypeople or in the amateur astronomy community. Examples of asterisms include the seven bright stars in Ursa Major known as “the Plough” in Europe or “the Big Dipper” in America, as well as “the Summer Triangle”, a large triangle, seen in the summer night sky in the northern hemisphere and composed of the bright stars Altair, Deneb and Vega. Whilst a grouping of stars may be officially designated a constellation by the IAU, this does not mean that the stars in that constellation are necessarily grouped together in space. Sometimes stars will be physically close to each other, like the Pleiades, but constellations are generally really a matter of perspective. They are simply our Earth-based interpretation of two dimensional star patterns on the sky made up of stars of many differing brightnesses and distances from Earth.

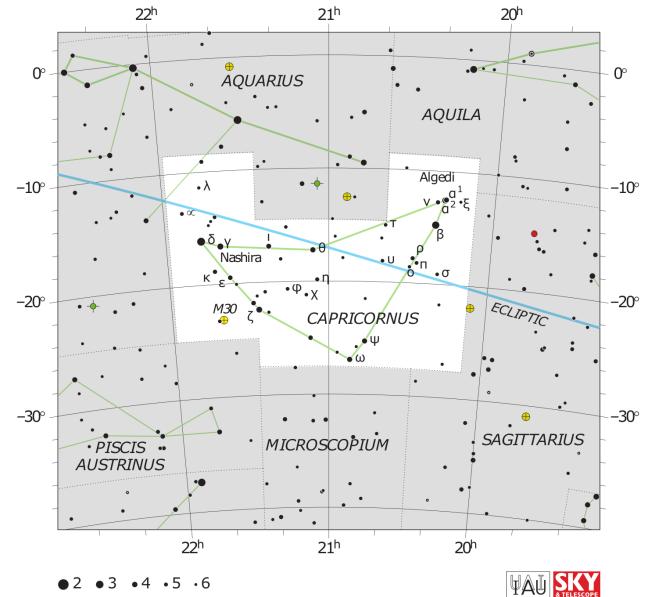
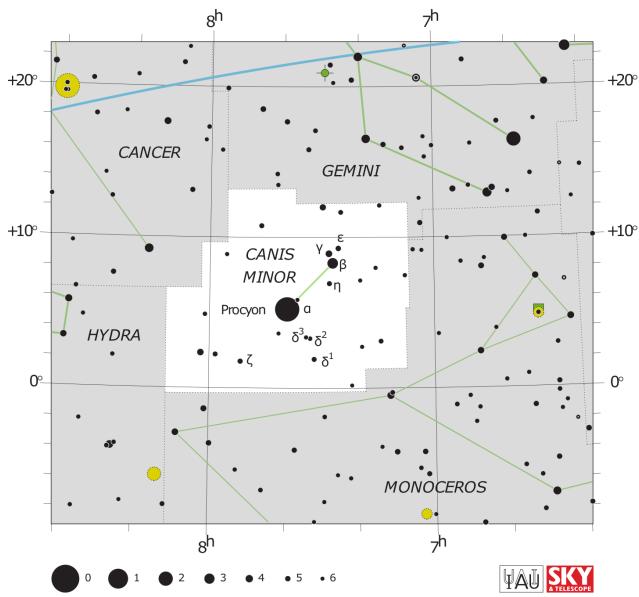
In the next page you’ll find the official figures from IAU. Notice that you should **only** remember constellation figures from IAU. You’ll find many shapes of same constellation on the internet which might differ due to distortion or variable conditions on their observations.

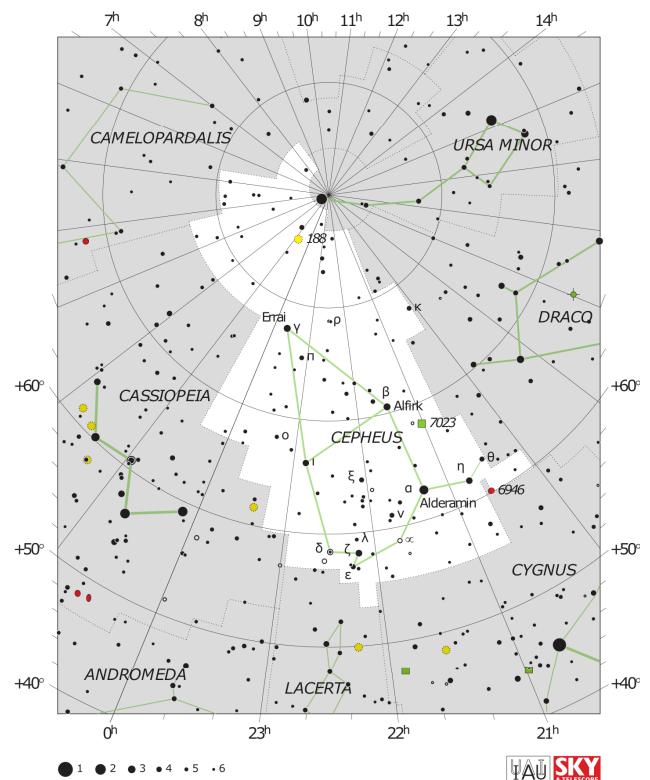
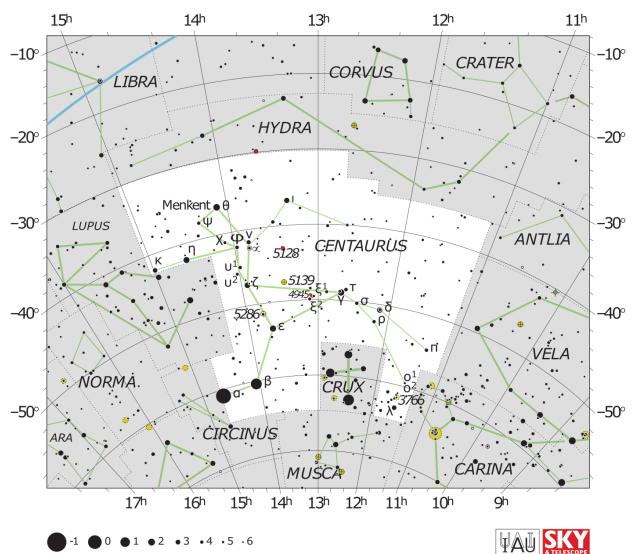
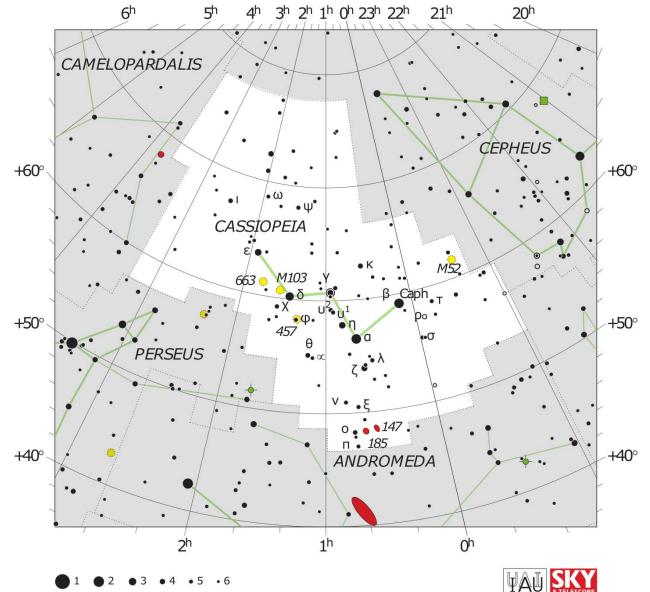
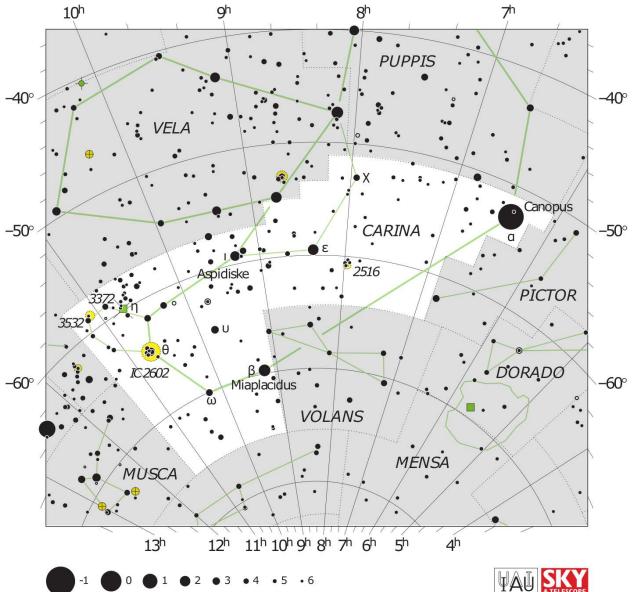


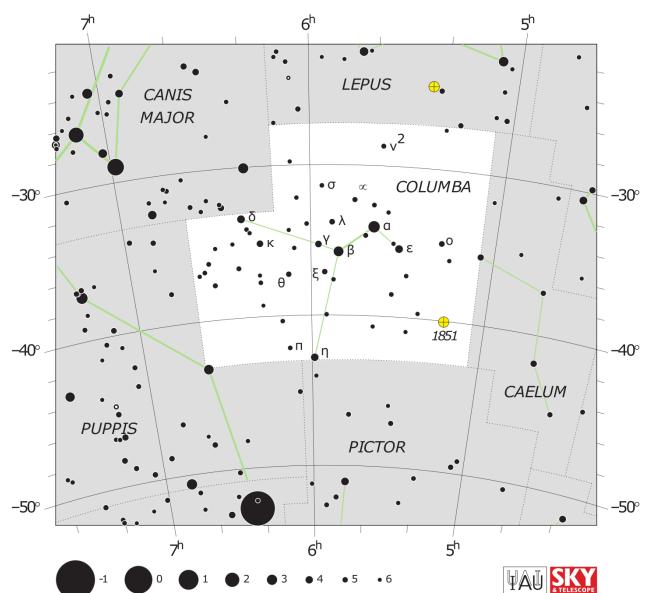
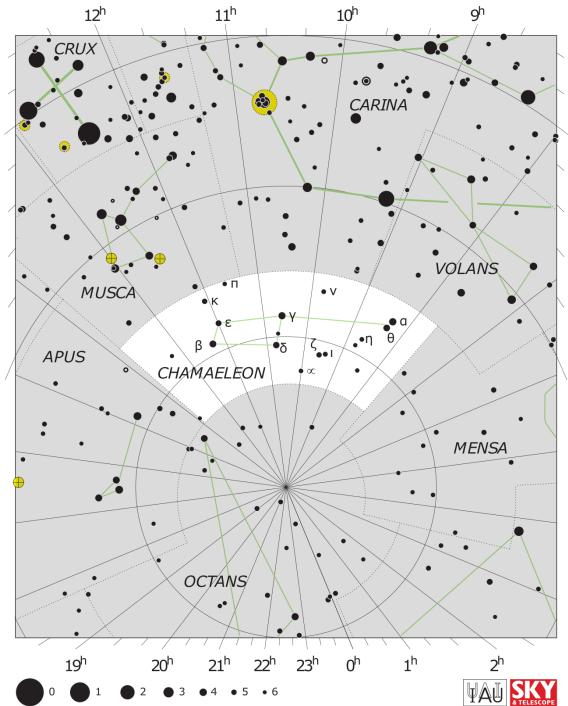


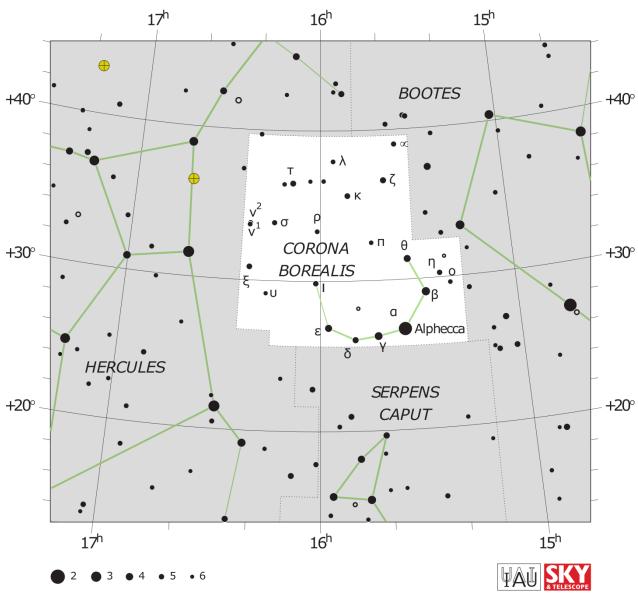




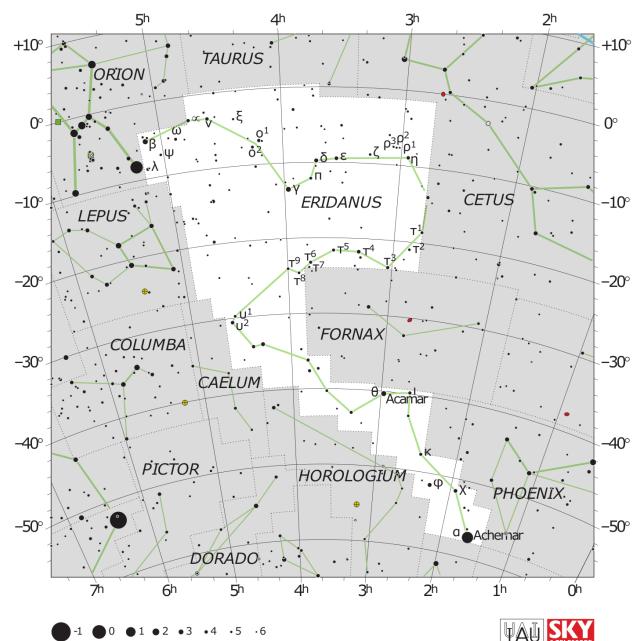
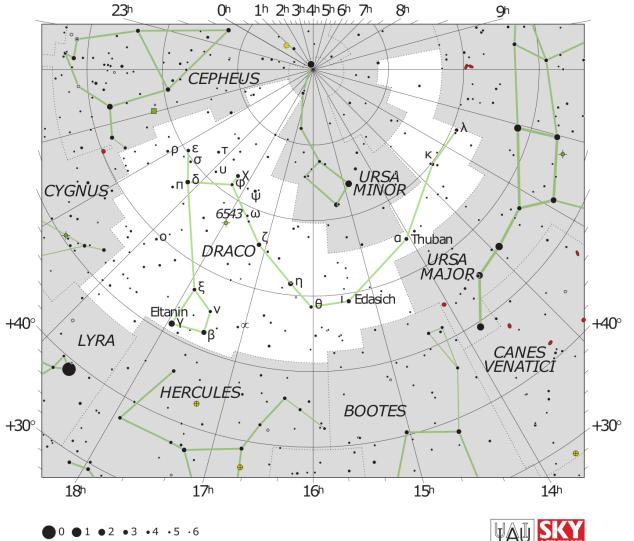


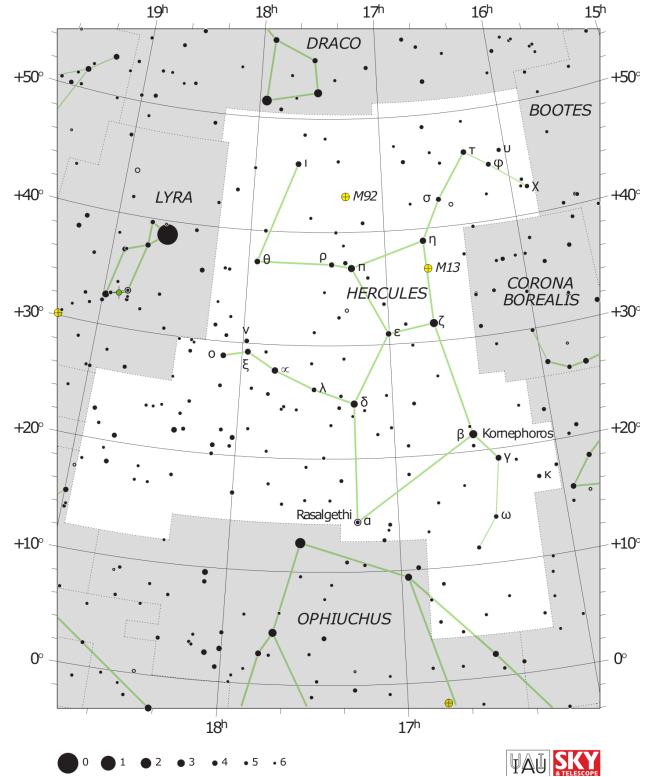




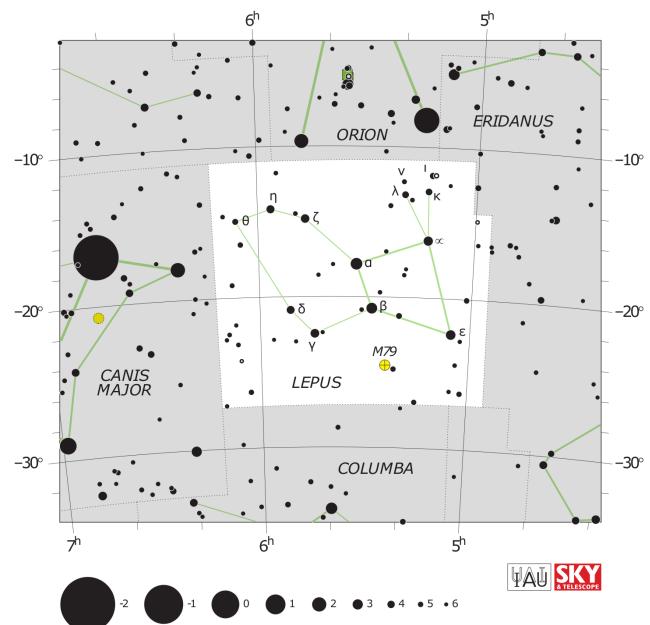
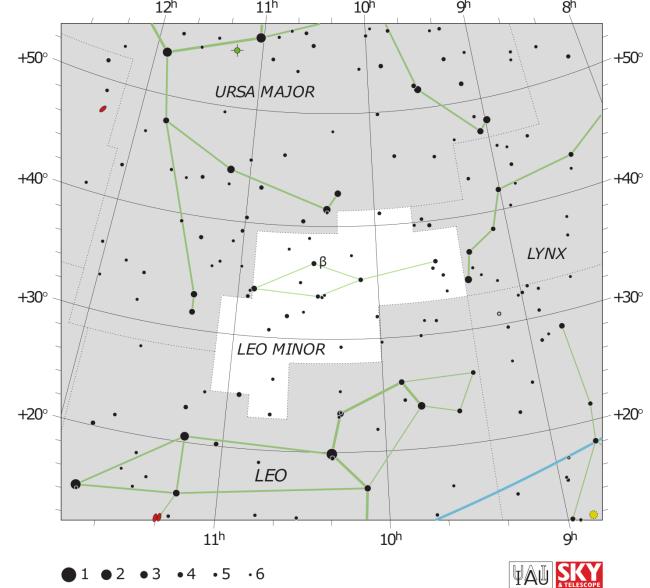




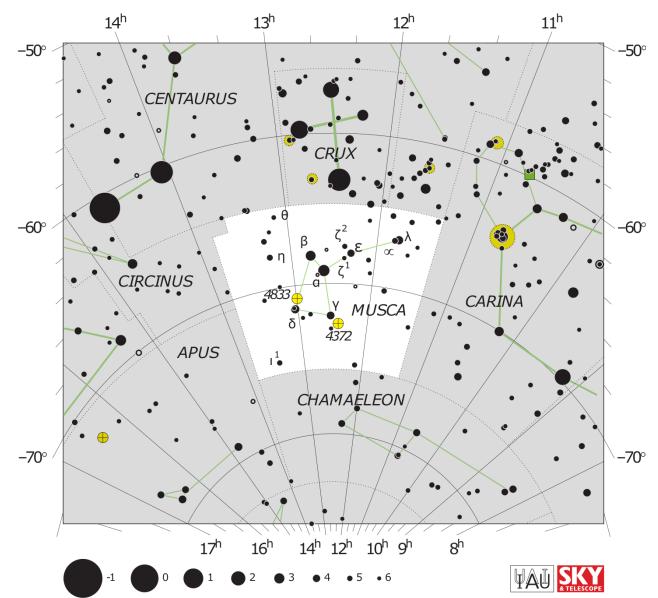
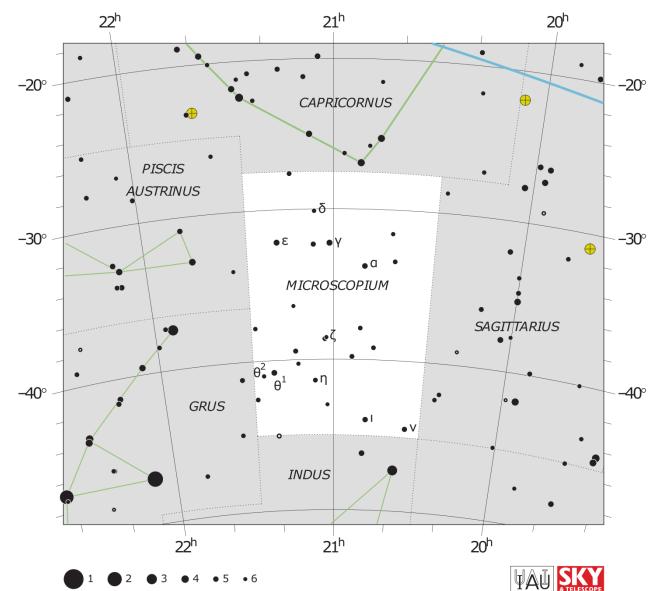


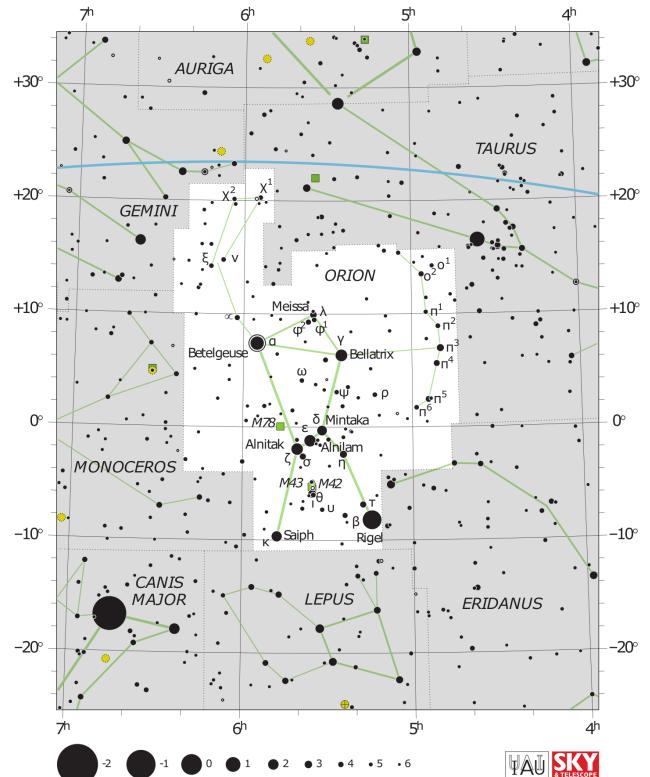
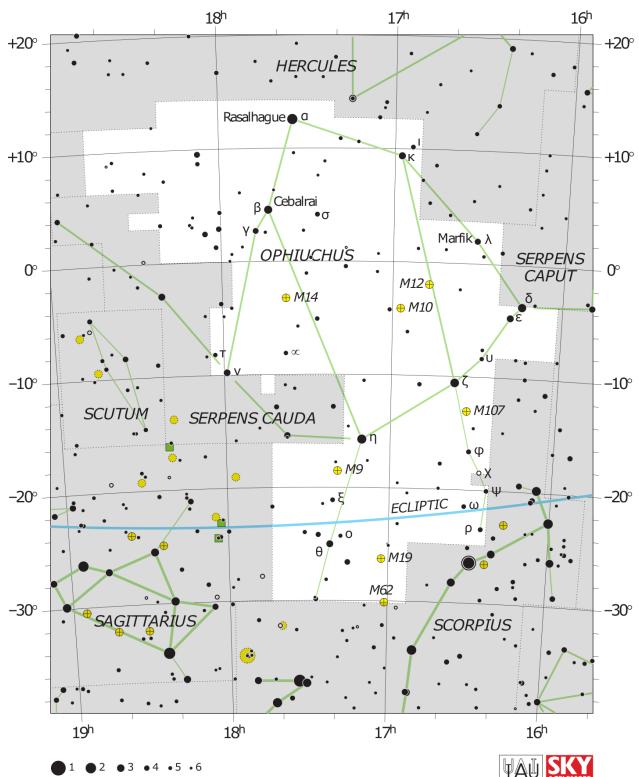


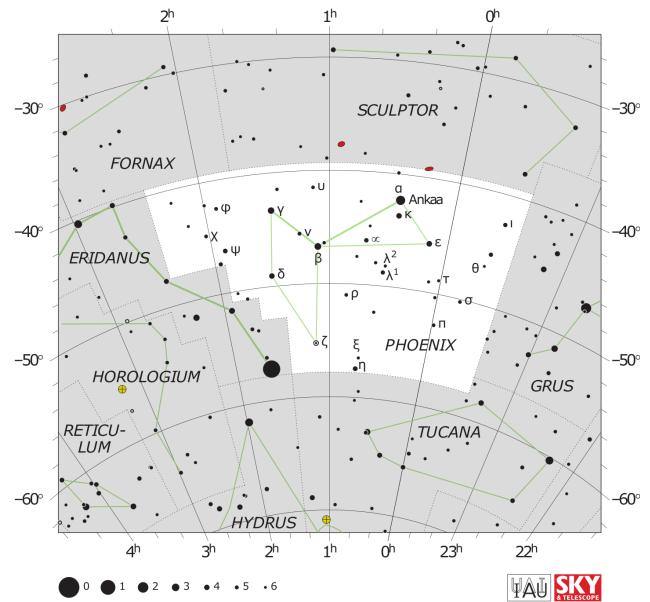
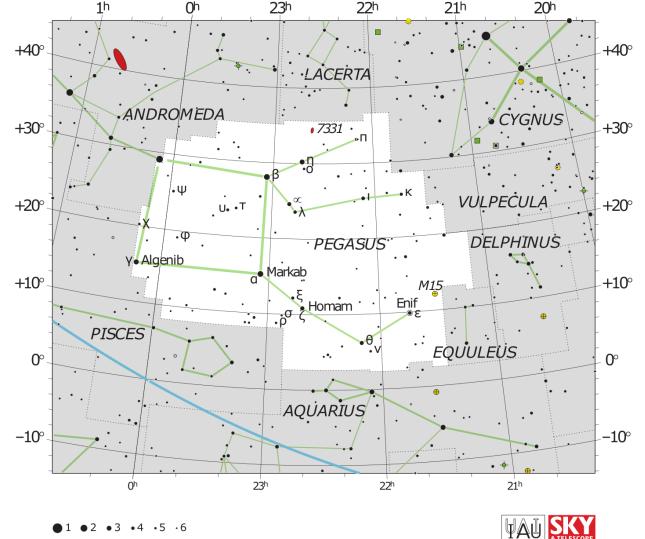


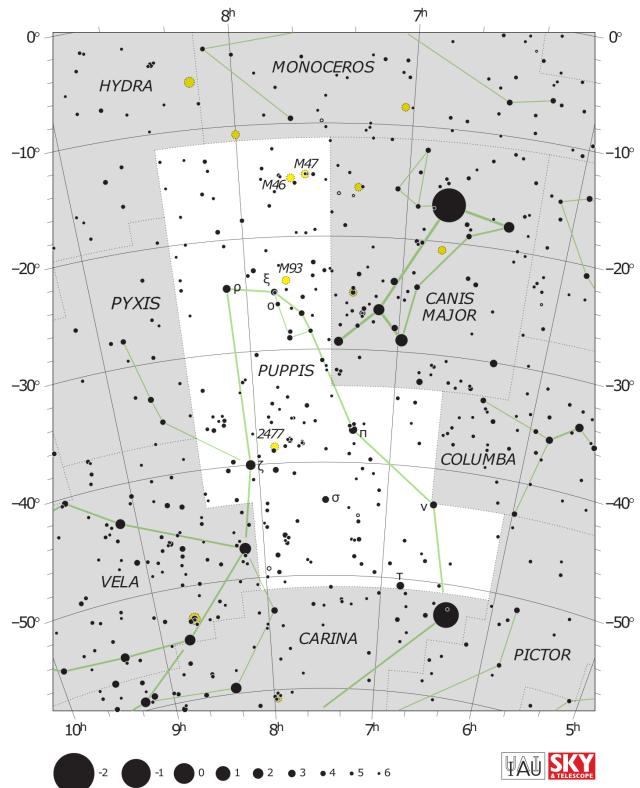
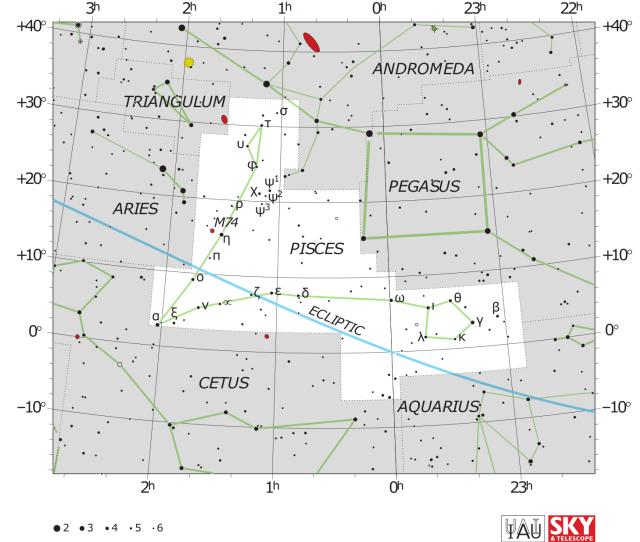


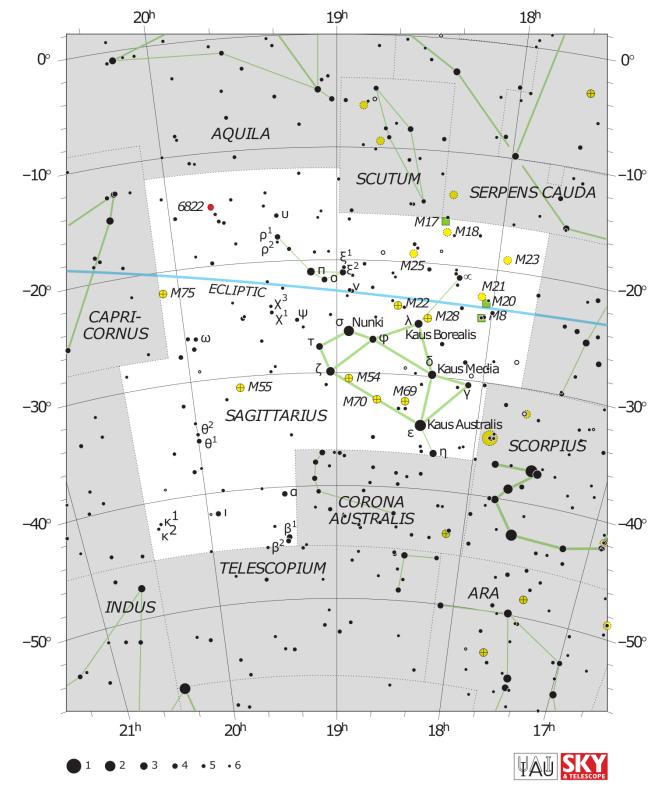
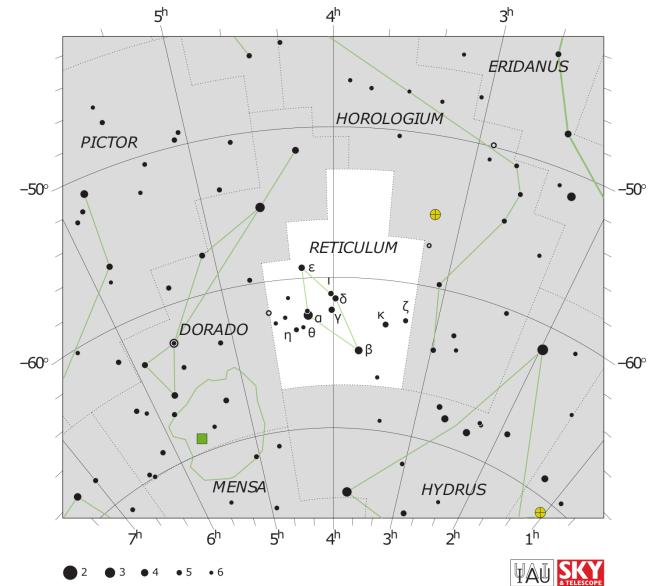


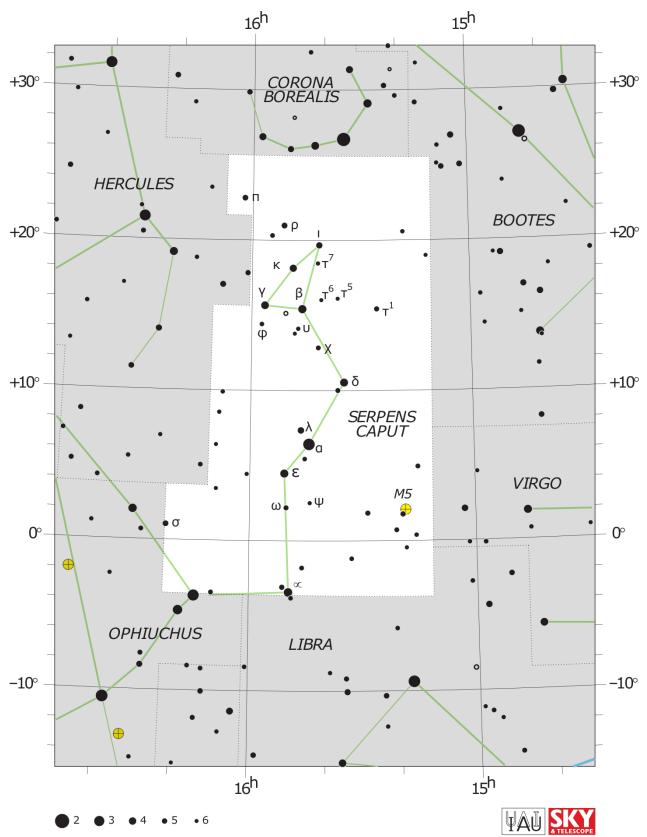
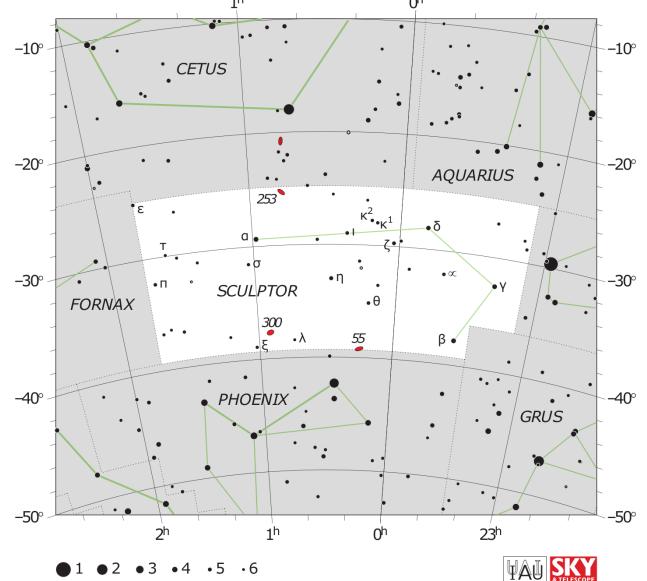
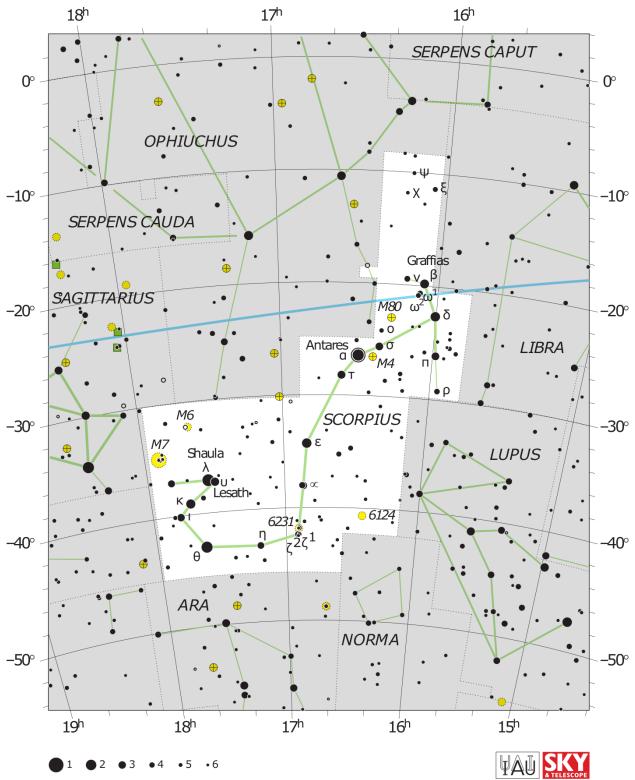


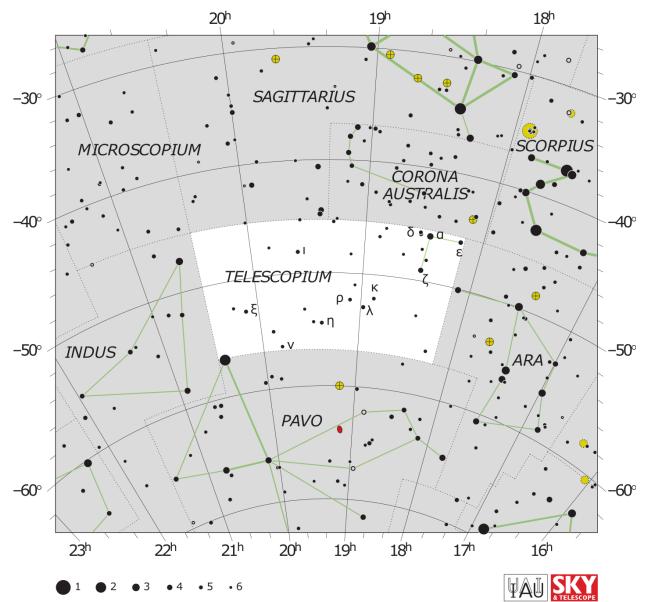
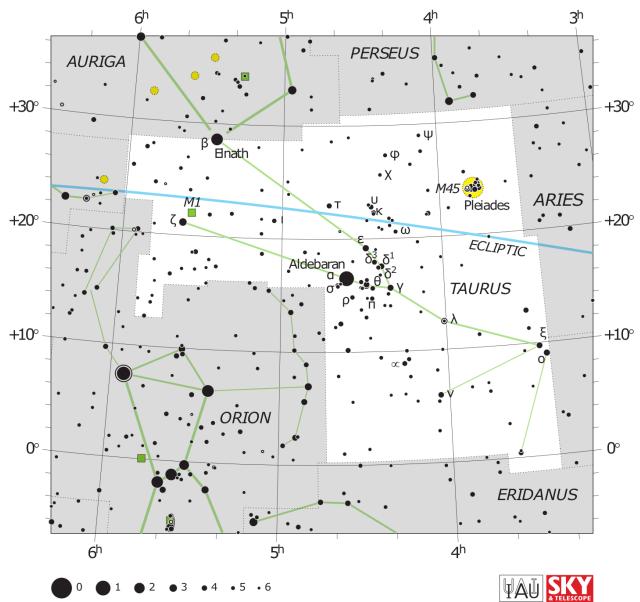
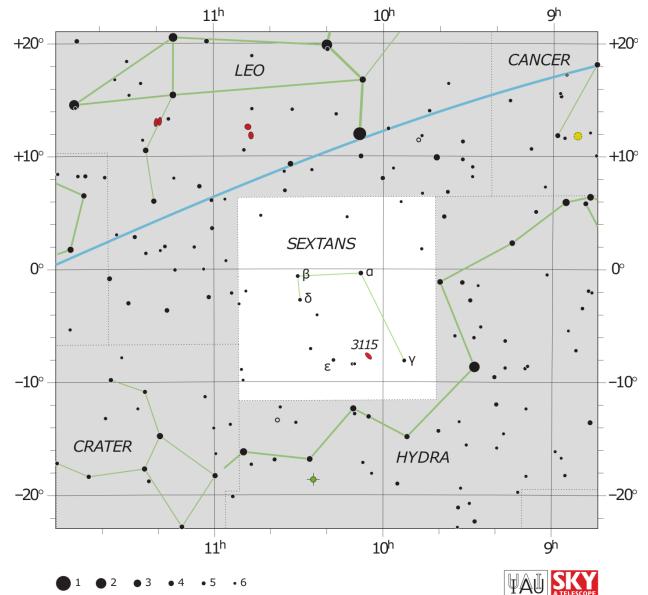
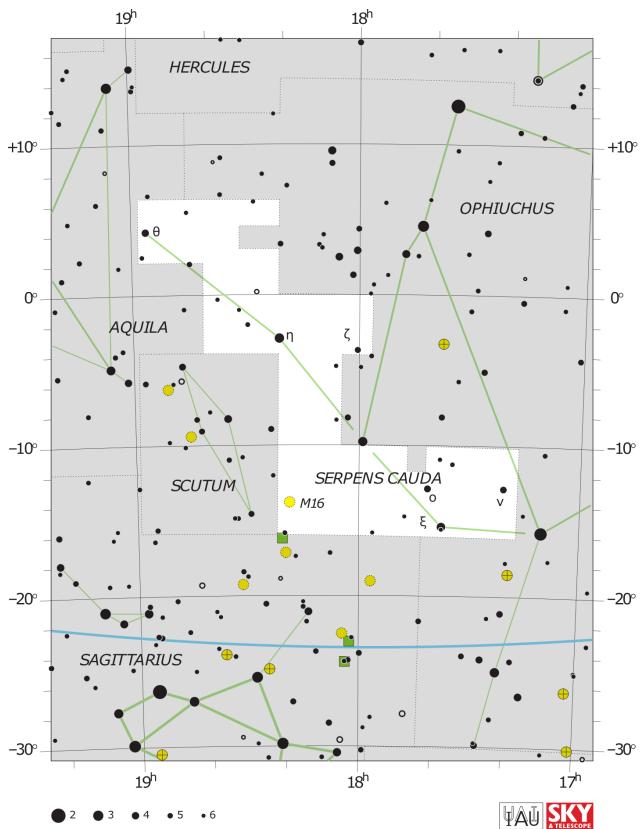


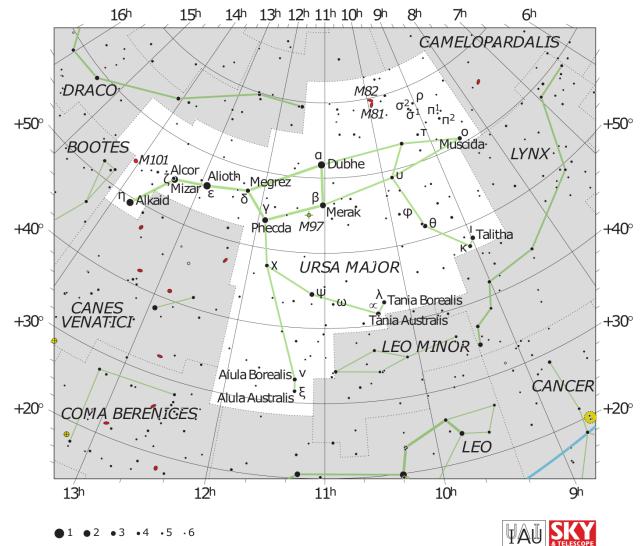
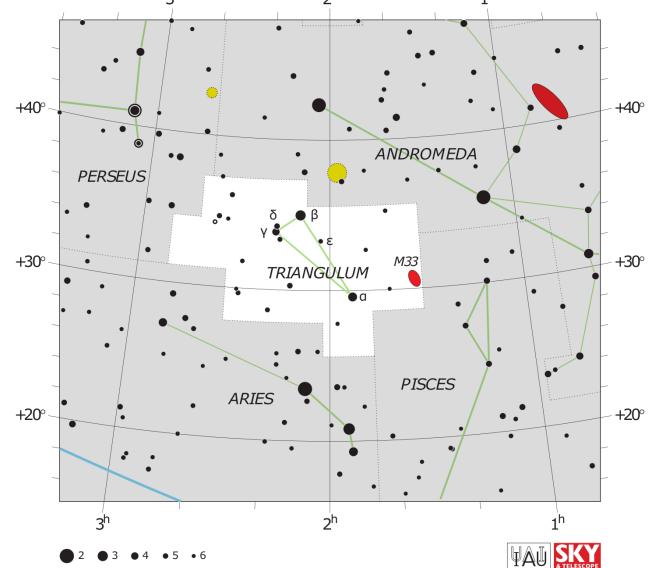


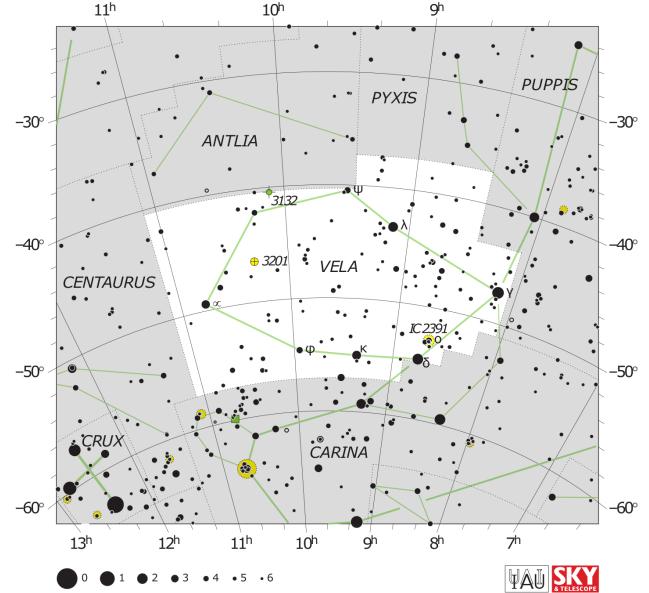
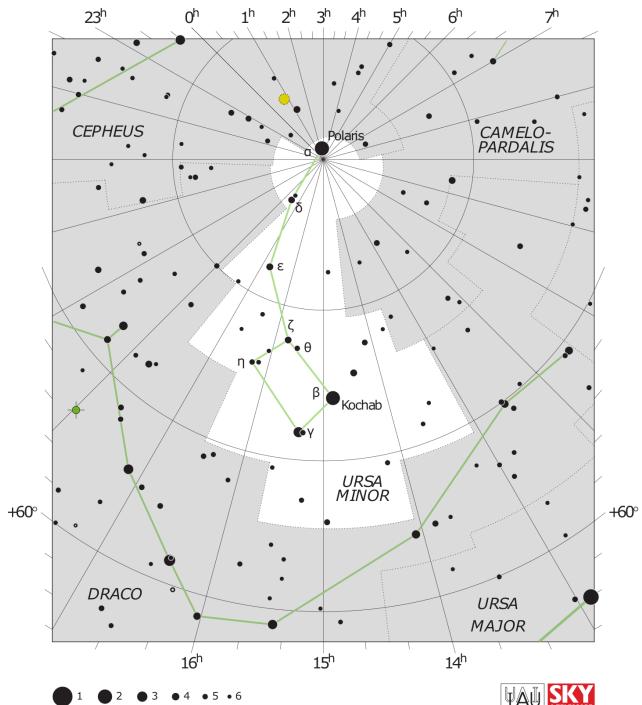












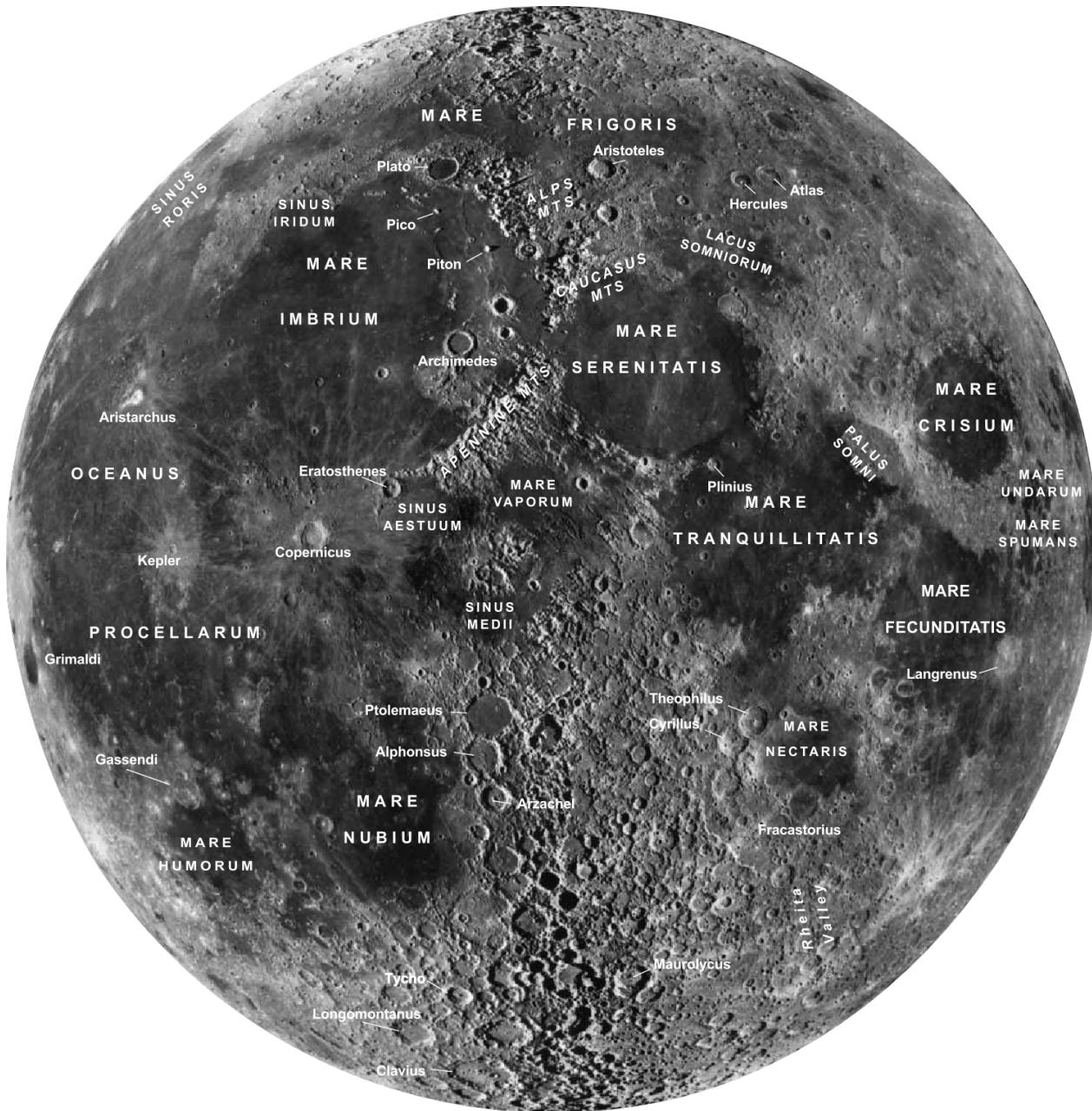


After printing use these constellation images to practice DSOs, planet positions, and angular sizes of a particular projection. Trust me it'll be helpful! A cartoon may describe it like—



## 2 Exploring the Moon

The Moon is by far the most rewarding celestial object for a small telescope. Even a very small instrument will reveal its bleak, blasted landscape of mountain ranges, plains, hills, valleys, and craters. Even binoculars show many features, and there are enough interesting sites on the Moon to keep a telescopic explorer busy forever.



You'll notice right away that except when the Moon is full, it is divided by the terminator, the line separating lunar day and night. Here is where detail shows best. When the Moon is a waxing (growing) crescent, we see the parts on the right edge of the map. At first-quarter phase we see the entire right half, and so on. To use this lunar map, turn the chart until it matches your view. Note: Some telescopes give a mirror image, which will not match this map no matter how you turn it.

Refractors and Cassegrain reflectors give mirror images when used with a star diagonal; so does any

other instrument containing an odd number of mirrors. If you find this to be a problem, take out the star diagonal and view “straight through.” A correct image is much easier to compare with any map.

Once the map is oriented, it will be simple to identify the major craters, mountains, and other features. In time, the geography of this alien world will become as familiar to you as that of our own.

## 2.1 Moon's motion

The Moon's orbital plane has an inclination of  $5^{\circ}9'$  in relation to the ecliptic. Although this angle remains approximately constant, the orbital plane is not fixed, moving such that its axis describes a complete circle around of the ecliptic axis in a period of 18.6 years.

Therefore, in relation to the Celestial Equator, the Moon's orbit has an inclination that varies from  $18.4^{\circ}(23.5^{\circ} - 5.15^{\circ})$  to  $28.7^{\circ}(23.5^{\circ} + 5.15^{\circ})$ .

Per day, the Moon moves  $\frac{360^{\circ}}{27.3 \text{ days}} \approx 13^{\circ}$  east in relation to the stars. This movement is a reflection of the Moon's revolution around the Earth, which completes every 27.3 days (sidereal month). The Sun moves  $\approx 1^{\circ}$  east per day, therefore the Moon is  $\approx 12^{\circ}$  east of the Sun per day. Because of this, the Moon crosses the local meridian  $12^{\circ} \cdot \frac{4 \text{ min}}{1^{\circ}} \approx 50$  min later than the previous day.

## 2.2 Moon's Phase

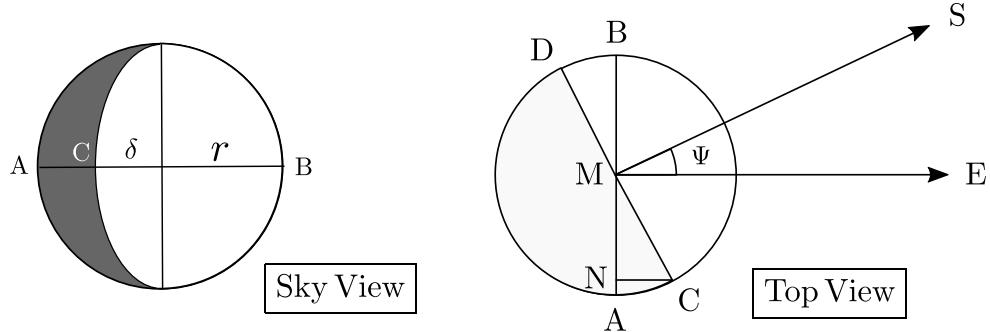


Figure 1: Lunar Phase Geometry

From the diagram,  $\angle SME = \Psi$  and  $MN = CM \cos \angle CMN = r \cos(90^{\circ} - \angle CME) = r \cos[90^{\circ} - (90^{\circ} - \angle SME)] = r \cos \Psi$ . So here  $\phi$  is phase of the moon, which is the ratio between illuminated part of lunar disk and total visible disk.

$$0 \leq \phi \leq 1$$

$$\begin{aligned} \phi &= \frac{BN}{AB} = \frac{r + MN}{2r} = \frac{r + r \cos \Psi}{2r} \\ \phi &= \frac{1 + \cos \Psi}{2} \\ &= \frac{\sin^2 \frac{\Psi}{2} + \cos^2 \frac{\Psi}{2} + \cos^2 \frac{\Psi}{2} - \sin^2 \frac{\Psi}{2}}{2} \end{aligned} \tag{1}$$

$$\phi = \cos^2 \frac{\Psi}{2} \tag{2}$$

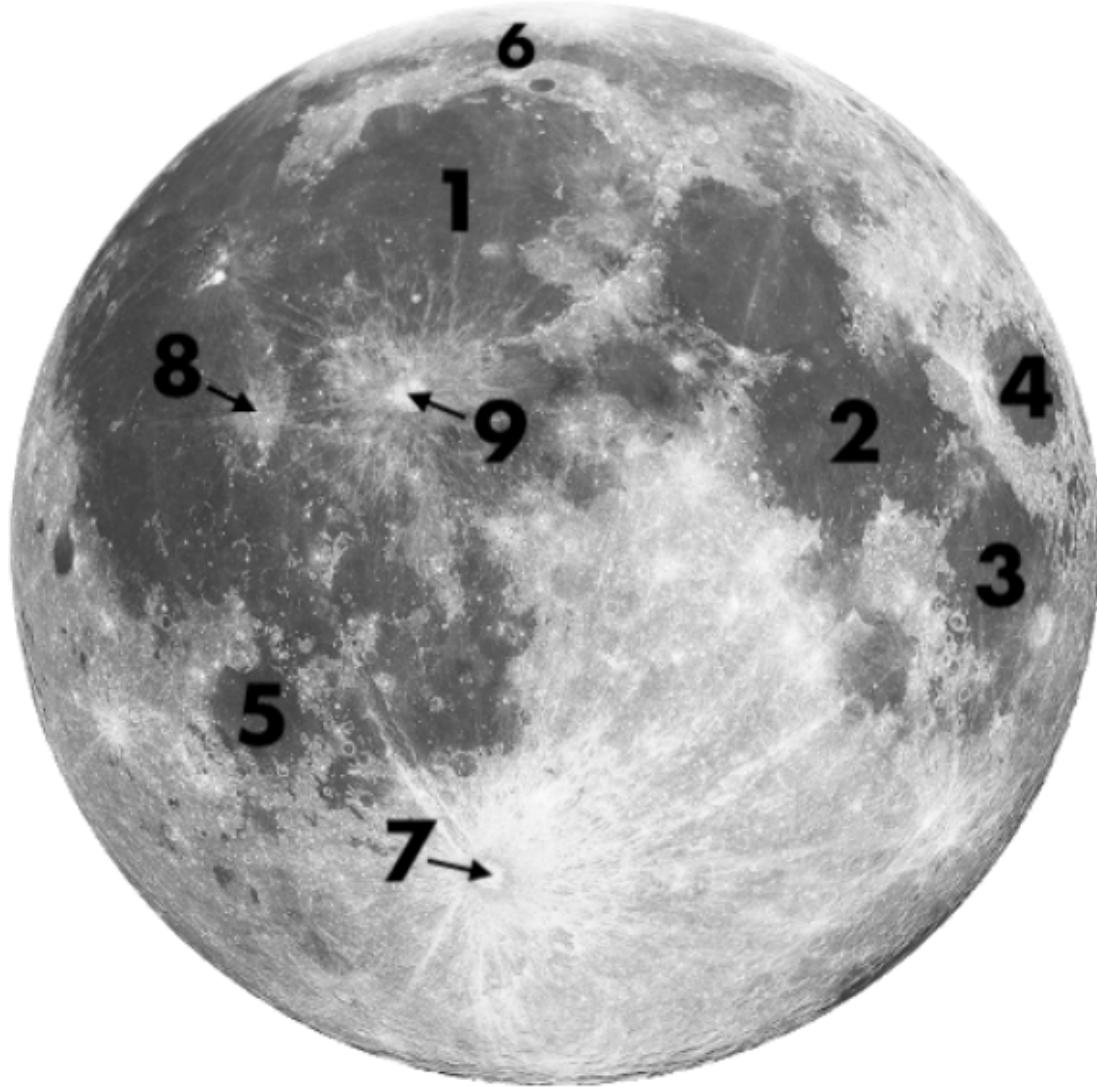


**Question** Name the Lunar Phase for Northern hemisphere!  
(Image inverted for printing purposes)

### Problem: Moon features

1. Match the selenographic objects numbered in the photo and their names and complete the table. Some of the designations of selenographic objects in the list superfluous.
2. Estimate the angular and linear size of the lunar sea No 4, as well as its area (in  $\text{km}^2$ ).
3. Mark the Moon's poles with signs • and label them with N (North) and S (South).

4. Mark the landing site for the Apollo 17 mission with an  $\times$ . Selenographic coordinates this point:  
 $20.2^\circ$  N. lat.,  $30.8^\circ$  E.



Sea (mare)	No	Sea	No	Crater	No
Vaporum		Nectaris		Aristotle	
Tranquility		Homorum		Kepler	
Clarity		Fecunditatis		Copernicus	
Frigoris		Imbrium		Tycho	
Crisium		Nubium		Eratosthenes	

Size	Answer
Angular	
Linear	
Area	

**Word Meaning** Vaporum = Vapour (Steam), Frigoris = Cold, Crisium = Crises, Nectaris = Nectar, Homorum = Moisture, Fecunditatis = Fertility, Imbrium = Rain, Nubium = Clouds.

### 3 Deep Sky Objects

**Deep Sky Objects** shortly DSOs are another interesting element of night sky observation as well as Observation round. Deep sky objects can galaxies, star clusters both open and globular or nebula. It is important to know which what and their perspective position in sky. So it is no wonder that someone has already classified these objects in night sky. The one classification now Astronomers widely follow is done by the French astronomer Charles Messier in his Catalogue des Nébuleuses et des Amas d'Étoiles (Catalogue of Nebulae and Star Clusters). Because Messier was only interested in finding comets, he created a list of those non-comet objects that frustrated his hunt for them. The compilation of this list, in collaboration with his assistant Pierre Méchain, is known as the Messier catalogue. This catalogue of objects is one of the most famous lists of astronomical objects, and many Messier objects are still referenced by their Messier number. You can find 3 kinds of catalogue on the star map— Messier Catalogue (M), New General Catalogue (NGC), Index Catalogue (IC)

For Olympiad a student must know the position and type of some DSOs. Here are some of these that I recommend—

**Most Important:** 1, 8, 13, 15, 20, 27, 31, 33, 41, 42, 44, 45, 51, 57, 63, 64, 81, 82, 101, 102, 104.

**Important:** 6, 7, 11, 16, 17, 18, 22, 40, 43, 67, 74, 76, 78, 83, 94, 97.

It is not customary to also remember how a particular DSO looks. But for the fascination of these and to know the structure, some examples should be remembered which are very popular. For instance, Andromeda galaxy, Pleiades or Ring Nebula. In the 12<sup>th</sup>, 2018 and nth15, 2022 IOAA recognizing DSOs by their image was a controversial question. So I'll suggest, *Be safe than sorry!*



In the next page the complete list Messier Objects is given.

Table 3: Messier Object List

Messier	English Name	Constellation	Status	Apparent Magnitude	Arc Size (In Minute)	Minimum Aperture	Coordinates Dec/RA
M1	Crab Nebula	Taurus	Supernova Remnant	8.4	6 × 4	50 mm	+22°00'/05h34m
M2		Aquarius	Globular Cluster	6.3	13	Naked Eye	-00°49'/21h33m
M3		Canes Venatici	Globular Cluster	6.2	16	Naked Eye	+28°22'/13h42m
M4		Scorpius	Globular Cluster	5.9	26	15 mm	-26°31'/16h23m
M5		Serpens	Globular Cluster	6.7	17	Naked Eye	+02°04'/15h18m
M6	Butterfly Cluster	Scorpius	Open Cluster	4.2	15	Naked Eye	-32°13'/17h40.1m
M7	Ptolemy Cluster	Scorpius	Open Cluster	3.3	80	Naked Eye	-34°47'/17h53m
M8	Lagoon Nebula	Sagittarius	Diffuse Nebula	6	90 × 40	Naked Eye	-24°23'/18h03m
M9		Ophiuchus	Globular Cluster	8.4	9	30 mm	-18°30'/17h19m
M10		Ophiuchus	Globular Cluster	6.4	15	Naked Eye	-04°05'/16h57m
M11	Wild Duck Cluster	Scutum	Open Cluster	6.3	14	Naked Eye	-06°16'/18h51.1m
M12		Ophiuchus	Globular Cluster	7.7	15	15 mm	-01°56'/16h47m
M13	Great Hercules Cluster	Hercules	Globular Cluster	5.8	17	Naked Eye	+36°27'/16h41m
M14		Ophiuchus	Globular Cluster	8.3	12	30 mm	-03°14'/17h37m
M15	Great Pegasus Cluster	Pegasus	Globular Cluster	6.2	12	Naked Eye	+12°10'/21h29m
M16	Eagle Nebula	Serpens	Stellar Nebula	7	7	Naked Eye	-13°49'/18h18m
M17	Omega Nebula	Sagittarius	Stellar Nebula	6	46 × 37	30 mm	-16°10'/18h20m
M18	Swan	Sagittarius	Open Cluster	7.5	9	15 mm	-17°08'/18h19.9m
M19		Ophiuchus	Globular Cluster	7.5	14	30 mm	-26°16'/17h02m
M20	Trifid Nebula	Sagittarius	Diffuse Nebula	6.3	28 × 28	30 mm	-23°01'/18h02m
M21		Sagittarius	Open Cluster	6.5	13	15 mm	-22°30'/18h04.6m
M22	Sagittarius Cluster	Sagittarius	Globular Cluster	5.1	24	Naked Eye	-23°54'/18h36m
M23		Sagittarius	Open Cluster	6.9	27	Naked Eye	-19°01'/17h56.8m
M24	Sagittarius Star Cloud	Sagittarius	Star Cloud	2.5	90 × 60	Naked Eye	-18°29'/18h17m
M25		Sagittarius	Open Cluster	4.6	32	Naked Eye	-19°15'/18h31.6m
M26		Scutum	Open Cluster	8	15	50 mm	-09°24'/18h45.2m
M27	Dumbbell Nebula	Vulpecula	Planetary Nebula	7.5	8 × 6	30 mm	+22°43'/19h59m
M28		Sagittarius	Globular Cluster	7.7	11	30 mm	-24°52'/18h24m
M29	Cooling Tower	Cygnus	Open Cluster	7.1	7	Naked Eye	+38°31'/20h23m
M30		Capricornus	Globular Cluster	7.7	11	30 mm	-23°10'/21h40m
M31	Andromeda Galaxy	Andromeda	Spiral Galaxy	3.4	190.2 × 60	Naked Eye	+41°16'9"/00h42m
M32		Andromeda	Elliptical Galaxy	8.1	8 × 6	30 mm	+40°51'/00h42m
M33	Triangulum Galaxy	Triangulum	Spiral Galaxy	5.7	70.8 × 41.7	Naked Eye	+30°39'/01h33m
M34		Perseus	Open Cluster	5.2	35	Naked Eye	+42°46'/02h42.1m
M35		Gemini	Open Cluster	5.5	28	Naked Eye	+24°21'/06h09.1m
M36		Auriga	Open Cluster	6.3	12	Naked Eye	+34°08'/05h36m
M37		Auriga	Open Cluster	6.2	24	Naked Eye	+32°33'/05h52m
M38	Starfish Cluster	Auriga	Open Cluster	7.4	21	Naked Eye	+35°51'/05h28m
M39		Cygnus	Open Cluster	5.5	32	Naked Eye	+48°26'/21h31m
M40	Winnecke 4	Ursa Major	Double Star	9.7	1	50 mm	+58°4'/12h22m
M41	Little Beehive	Canis Major	Open Cluster	4.5	38	Naked Eye	-20°46'/06h46.0m
M42	Orion Nebula	Orion	Diffuse Nebula	4	65 × 60	Naked Eye	-05°23'/05h35m
M43	De Mairan's Nebula	Orion	Diffuse Nebula	9	20 × 15	50 mm	-05°16'/05h35m
M44	Praesepe /Beehive	Cancer	Open Cluster	3.7	95	Naked Eye	+19°59'/08h40.4m
M45	Pleiades	Taurus	Open Cluster	1.6	110	Naked Eye	+24°07'/03h47m
M46		Puppis	Open Cluster	6.1	27	Naked Eye	-14°49'/07h41.8m
M47		Puppis	Open Cluster	4.2	30	Naked Eye	-14°30'/07h36.6m
M48		Hydra	Open Cluster	5.5	54	Naked Eye	-05°45'/08h13.7m
M49		Virgo	Elliptical Galaxy	9.4	97	50 mm	+08°00'/12h29m
M50		Monoceros	Open Cluster	5.9	16	Naked Eye	-08°20'/07h03.2m
M51	Whirlpool Galaxy	Canes Venatici	Spiral Galaxy	8.4	11 × 8	50 mm	+47°11'/13h29m
M52		Cassiopeia	Open Cluster	5	13	30 mm	+61°35'/23h24.2m
M53		Coma Berenices	Globular Cluster	8.3	13	30 mm	+18°10'/13h12m
M54		Sagittarius	Globular Cluster	8.4	9	50 mm	-30°28'/18h55m
M55		Sagittarius	Globular Cluster	7.4	19	Naked Eye	30°57'/19h39m
M56		Lyra	Globular Cluster	8.3	7	50 mm	+30°11'/19h16m
M57	Ring Nebula	Lyra	Planetary Nebula	8.8	1.3	50 mm	+33°01'/18h53m
M58		Virgo	Spiral Galaxy	10.5	5 × 4	50 mm	+11°49'/12h37m
M59		Virgo	Elliptical Galaxy	10.6	5 × 3	50 mm	+11°38'49"/12h42m
M60		Virgo	Elliptical Galaxy	9.8	7 × 6	50 mm	+11°33'/12h43m
M61		Virgo	Spiral Galaxy	10.2	6 × 5	50 mm	+04°28'/12h21m
M62		Ophiuchus	Globular Cluster	7.4	14	15 mm	-30°06'/17h01m
M63	Sunflower Galaxy	Canes Venatici	Spiral Galaxy	9.3	12 × 8	30 mm	+42°01'/13h15m
M64	Black Eye Galaxy	Coma Berenices	Spiral Galaxy	9.4	9 × 5	50 mm	+21°40'/12h56m
M65	Leo Triplet	Leo	Spiral Galaxy	10.3	10 × 3	30 mm	+13°05'/11h18m
M66	Leo Triplet	Leo	Spiral Galaxy	8.9	9 × 4	30 mm	+12°59'/11h20m
M67	King Cobra	Cancer	Open Cluster	6.1	30		+11°49'/08h51.3m
M68		Hydra	Globular Cluster	9.7	12	50 mm	-26°44'/12h39m
M69		Sagittarius	Globular Cluster	8.3	7	50 mm	-32°20'/18h31m
M70		Sagittarius	Globular Cluster	9.1	8	50 mm	-32°17'/18h43m
M71		Sagitta	Globular Cluster	6.1	7	50 mm	+18°46'/19h53m
M72		Aquarius	Globular Cluster	9.4	6	50 mm	-12°32'/20h53m
M73		Aquarius	Asterism	9	1	50 mm	-12°38'/20h58m54s
M74	The Phantom	Pisces	Spiral Galaxy	10	10 × 9	50 mm	+15°47'/01h36m
M75		Sagittarius	Globular Cluster	9.2	6	50 mm	-21°55'/20h06m
M76	Little Dumbbell Nebula	Perseus	Planetary Nebula	10.1	2 × 1	50 mm	+51°34'/01h42.4m
M77	Cetus A	Cetus	Spiral Galaxy	9.6	7 × 6	50 mm	-00°00'/02h42m

Messier	English Name	Constellation	Status	Apparent Magnitude	Arc Size (In Minute)	Minimum Aperture	Coordinates Dec/RA
M78		Orion	Diffuse Nebula	8.3	8 × 6	50 mm	+00° 00' / 05 <sup>h</sup> 46 <sup>m</sup>
M79		Lepus	Globular Cluster	8.6	9	50 mm	-24° 31' / 05 <sup>h</sup> 24 <sup>m</sup>
M80		Scorpius	Globular Cluster	7.9	9	50 mm	-22° 58' / 16 <sup>h</sup> 17 <sup>m</sup>
M81	Bode's Galaxy	Ursa Major	Spiral Galaxy	6.9	26 × 14	Naked Eye	+69° 3' / 09 <sup>h</sup> 55 <sup>m</sup>
M82	Cigar Galaxy	Ursa Major	Irregular Galaxy	8.4	11 × 5	30 mm	+69° 40' / 09 <sup>h</sup> 55 <sup>m</sup>
M83	Southern Pinwheel	Hydra	Spiral Galaxy	7.5	11 × 10	30 mm	29° 51' / 13 <sup>h</sup> 37 <sup>m</sup>
M84		Virgo	Elliptical Galaxy	10.1	5 × 4	50 mm	+12° 53' / 12 <sup>h</sup> 25 <sup>m</sup>
M85		Coma Berenices	Elliptical Galaxy	10	7 × 5	50 mm	+18° 11' / 12 <sup>h</sup> 25 <sup>m</sup>
M86		Virgo	Elliptical Galaxy	9.8	7 × 5	50 mm	+12° 56' / 12 <sup>h</sup> 26 <sup>m</sup>
M87	Virgo A	Virgo	Elliptical Galaxy	9.6	7	50 mm	+12° 23' / 12 <sup>h</sup> 30 <sup>m</sup>
M88		Coma Berenices	Spiral Galaxy	10.4	7 × 4	50 mm	+14° 25' / 12 <sup>h</sup> 31 <sup>m</sup>
M89		Virgo	Elliptical Galaxy	10.7	4	50 mm	+12° 33' / 12 <sup>h</sup> 35 <sup>m</sup>
M90		Virgo	Spiral Galaxy	10.3	10 × 5	50 mm	+13° 09' / 12 <sup>h</sup> 36 <sup>m</sup>
M91		Coma Berenices	Spiral Galaxy	11	5 × 4	60 mm	+14° 29' / 12 <sup>h</sup> 35 <sup>m</sup>
M92		Hercules	Globular Cluster	6.4	11	Naked Eye	+43° 08' / 17 <sup>h</sup> 17 <sup>m</sup>
M93		Puppis	Open Cluster	6	22	30 mm	-23° 52' / 07 <sup>h</sup> 44.6 <sup>m</sup>
M94	Cat's Eye Galaxy	Canes Venatici	Spiral galaxy	9	11 × 9	30 mm	+41° 07' / 12 <sup>h</sup> 50 <sup>m</sup>
M95		Leo	Spiral Galaxy	11.4	7 × 5	50 mm	+11° 42' / 10 <sup>h</sup> 43 <sup>m</sup>
M96		Leo	Spiral Galaxy	10.1	7 × 5	50 mm	+11° 49' / 10 <sup>h</sup> 46 <sup>m</sup>
M97	Owl Nebula	Ursa Major	Planetary Nebula	9.9	3	50 mm	+55° 01' / 11 <sup>h</sup> 14 <sup>m</sup>
M98		Coma Berenices	Spiral Galaxy	11	10 × 3	50 mm	+14° 54' / 12 <sup>h</sup> 13 <sup>m</sup>
M99		Coma Berenices	Spiral Galaxy	10.4	5	50 mm	14° 24' / 12 <sup>h</sup> 18 <sup>m</sup>
M100		Coma Berenices	Spiral Galaxy	10.1	7 × 6	50 mm	+15° 49' / 12 <sup>h</sup> 22 <sup>m</sup>
M101	Pinwheel Galaxy	Ursa Major	Spiral Galaxy	7.9	27 × 26	50 mm	+54° 20' / 14 <sup>h</sup> 03 <sup>m</sup>
M102	Spindle Galaxy	Draco	Elliptical Galaxy	10.7	6 × 3	50 mm	+55° 45' / 15 <sup>h</sup> 06 <sup>m</sup>
M103		Cassiopeia	Open Cluster	7.4	6	30 mm	+60° 42' / 01 <sup>h</sup> 33.2 <sup>m</sup>
M104	Sombrero Galaxy	Virgo	Spiral Galaxy	9	94	50 mm	-11° 37' / 12 <sup>h</sup> 39 <sup>m</sup>
M105		Leo	Elliptical Galaxy	10.2	5 × 4	50 mm	+12° 34' / 10 <sup>h</sup> 47 <sup>m</sup>
M106		Canes Venatici	Spiral Galaxy	9.1	18 × 8	30 mm	+47° 18' / 12 <sup>h</sup> 18 <sup>m</sup>
M107		Ophiuchus	Globular Cluster	8.9	10	30 mm	-13° 03' / 16 <sup>h</sup> 32 <sup>m</sup>
M108		Ursa Major	Spiral Galaxy	10.7	8 × 2	50 mm	+55° 40' / 11 <sup>h</sup> 11 <sup>m</sup>
M109		Ursa Major	Spiral Galaxy	10.6	8 × 5	50 mm	+53° 22' / 11 <sup>h</sup> 57 <sup>m</sup>
M110		Andromeda	Elliptical Galaxy	9	7 × 10	50 mm	+41° 41' / 00 <sup>h</sup> 40 <sup>m</sup>
M111	Western Part of Double Cluster	Perseus	Open Cluster	4.5	30	Naked Eye	-
M112	Western Part of Double Cluster	Perseus	Open Cluster	4.5	30	Naked Eye	-

For Table (3), In the next table here is the color code meaning–

Globular Cluster
Planetary Nebula
Stellar Nebula
Diffuse Nebula
Open Cluster
Spiral Galaxy
Elliptical Galaxy
Other

Table 4: Messier Object Color Code

### Some key facts about Messier Objects

- Only 34 out of 88 constellations contain Messier Objects
- Sagittarius contains the most about 35 where Virgo have 11, Coma Berenices have 8, Ursa Major and Ophiuchus with 7 each, Canes Venatici and Leo contains 5 each, and Scorpius contains 4.
- The list of 109 objects compiled by C. Messier contains many of the finest deep sky objects however observed from Paris. So far southern sky was lost to him. That's why 62 of his objects lie in these 8 constellations, famously known as Messier Northern Bias.

### 3.1 Short Problems and Solutions on DSOs

For data related to the problems below refer to the Messier Object List table.

**Question 1** The latitude of the location is 60° N. Questions 1.1 to 1.4 refer to the same location, but may not refer to the sky on the same day/night.

**Object of consideration:** Butterfly Cluster (M6), Trifid Nebula (M20), Wild Duck Cluster (M11), Ring Nebula (M57), Albireo, Arcturus, Rasalhague, M3.

**1.1 Which object/star cannot be seen at this location at any time of the year?**

- M6 as You cannot see any object below –30° declination.

**1.2 Which object below cannot be seen on the night of the vernal equinox at midnight?**

- Wild Duck Cluster (M11), At midnight of the Vernal Equinox, the meridian is 12h. As such, any object within 6h to 18h will not be able to be seen. That is apart from those that are circumpolar.

**1.3 If M3 is currently at the local meridian, in how many hours will Albireo set?**

- If M3 is at the local Meridian, then Albeiro would be just rising. As such, it will set in 12 hours.

**1.4 Which object will be closest to the zenith when it culminates on the local meridian?**

- Ring Nebula (M57), We look for the item with the declination is the closest to +60°, which is local zenith at that location.

**Question 2** A deep-sky object located directly at the celestial equator with an angular diameter of 10' is viewed from the eyepiece of a telescope with a true field of view of 0.8°. Object tracking on the telescope is disabled and the object is aligned at the edge of the field of view. Assuming the object moves along the diameter of the eyepiece before disappearing, calculate the time it takes for the object to drift out of view of the eyepiece.

- Objects on the Celestial Equator in the sky rotate once every sidereal day, that is, 360° in 23<sup>h</sup>56<sup>m</sup>4.1<sup>s</sup>. This gives 0.251°/min. The time it takes to drift out of the eyepiece is thus—

$$\frac{0.8^\circ}{0.251^\circ/\text{min}} = 3.19 \text{ min}$$

**Question 3** Imagine that you are in a post-COVID world without travel restrictions and are currently on a stargazing trip in a remote location at a latitude of 35° N. Capella (RA/DE: 5h 18m / +46 deg 01min) is currently 3 degrees above the western horizon. The following table shows a list of DSOs you have decided to try to observe for tonight.

**Object of consideration:** Heart Nebula, Omega Centauri, Black-Eye Galaxy, Dumbbell Nebula.

**In what order, from highest to lowest priority, should you arrange your observations so as to maximise your chances of seeing every one of the DSOs on your list?**

- Omega Centauri, Black Eye Galaxy, Dumbbell Nebula, Heart Nebula

A quick calculation ( $90^\circ - 61^\circ = 29^\circ$ ) shows us that the Heart Nebula is circumpolar and thus has lower priority. Ideally, one would want to view it when it is near the meridian, and judging by

the RA (which is earlier than Capella), it is around its lower culmination. The Dumbbell Nebula has a RA of 20h, indicating that it is on the eastern side of the sky and thus would have lower priority. Between Omega Centauri and the Black Eye Galaxy, the latter has a slightly earlier RA and thus is normally prioritized if we are near the equator. However, at northern latitudes, objects with more southern declinations spend less time above the horizon and thus set faster. While we normally need spherical trigonometry to ascertain which objects set earlier, there is a very small difference in RA between Omega Centauri and Black Eye Galaxy (31 minutes). Omega Centauri will set earlier and thus should be prioritized. (Note: Omega Centauri is very barely visible.)

**Question 4 Object of consideration:** Triangulum Galaxy, Andromeda Galaxy, Orion Nebula, Dumbbell Nebula and Eskimo Nebula where it has apparent magnitude of 10.1 and apparent size of  $0.8 \times 0.8$ .

**Calculate the surface brightness of each DSO in mag/arcsec<sup>2</sup>, and hence arrange them in order of increasing surface brightness.**

– Triangulum Galaxy, Andromeda Galaxy, Orion Nebula, Dumbbell nebula, Eskimo Nebula.

The calculated surface brightness of the objects are

- Triangulum: 23.3
- Andromeda: 22.5
- Orion: 21.87
- Dumbbell: 20.6
- Eskimo: 18.5

**\*Surface Brightness:** The total luminosity emitted by a column of linear area  $dA = \Omega r^2$ . Generally presented as,

$$\Sigma \approx \frac{F}{\Omega} \approx \frac{L}{4\pi d^2 \pi (R/d)^2} \approx \frac{L}{4\pi^2 R^2}; \quad \text{Unit : Wm}^{-2}\text{ster}^{-1}$$

Surface Magnitude: Logarithmic form of Surface brightness, generally presented as,

$$\mu = -2.5 \log \Sigma + C$$

Just like any other magnitude term you can't easily multiply, add or subtract  $\mu$ . The unit of  $\mu$  is mag/arcsec<sup>2</sup>. To understand this suppose a star has a surface magnitude of 13 mag/arcsec<sup>2</sup>, it is actually comparable to a star with angular area of 1 arcsec<sup>2</sup> to seem to have an apparent magnitude of 13<sup>m</sup>.

**Question 5** You are given a list of the following planetary nebulae for an upcoming observation session near the Equator.

**Object of consideration:** M27 (Dumbbell Nebula), M57 (Ring Nebula), M76 (Little Dumbbell Nebula), M97 (Owl Nebula), C39 (Eskimo Nebula), C63 (Helix Nebula).

**What are planetary nebulae? Briefly describe how they are formed.**

– They are emission nebulae surrounding the cores of old red giants. As these stars exhaust their fuel, the core contracts under its own gravity, increasing its temperature and increasing the luminosity. These conditions cause the red giant star to lose most of its outer layers to space, which are subsequently ionised by the hot remnant core/white dwarf to form these planetary nebulae.

A proper observation plan should be sorted by the time objects rise. Sort the objects in this list by the order in which they rise, with the earliest object first.

- M76 → C39 → M97 → M57 → M27 → C63

Suppose that during one night, you notice that the Owl Nebula is setting. Other than the Owl Nebula, what objects are above the horizon right now?

- M57, M27, C63.

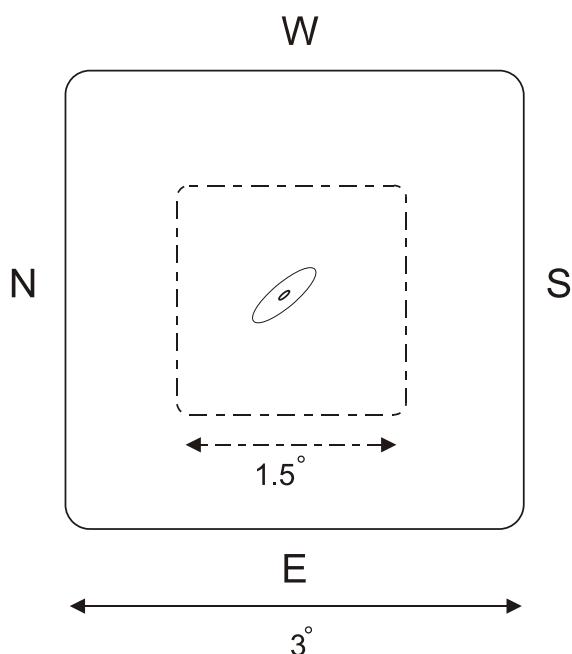
**Question 6** In a mildly light-polluted night sky with a surface brightness of 19.4 mag/arcsec<sup>2</sup>, which of the above objects are visible with the naked eye.

- Orion Nebula and Andromeda Galaxy,

Dumbbell Nebula and Eskimo Nebula are too small to be seen with the naked eye. Triangulum Galaxy requires very dark skies (around Bortle 2 and below, which is around a surface brightness of 21 and above). Surface brightness is not a completely reliable predictor of visibility. Other factor like the actual luminosity distribution of the object are more important in affecting visibility. For instance, both the Orion Nebula and Andromeda Galaxy have extremely bright central cores.

Note: This question would benefit those who have actually burnt midnight oil to go stargazing.

**Question 7** Observe the Andromeda Galaxy (M31) then draw the approximate shape and size of the galaxy that you see through the binoculars in the frame below with correct orientation.



**Caution:**

Correct shape and size (between 0.5 to 1 degrees) – **3 points**

Correct orientation (within  $23^\circ$  of the picture) – **2 points**

## 4 Star Charts & Positions of Stars

A star chart or star map is a map of the night sky. Astronomers divide these into grids to use them more easily. They are used to identify and locate astronomical objects such as stars, constellations and galaxies. They have been used for human navigation since time immemorial. Note that a star chart differs from an astronomical catalog, which is a listing or tabulation of astronomical objects for a particular purpose.

### 4.1 Coordinate Lines

To help with navigation, some star maps include coordinate lines that allow you to more accurately track down a faint fuzzy or an interesting object. The coordinates right ascension (RA) and declination (dec) – roughly equivalent to longitude and latitude on Earth – are sometimes marked on a star map. RA and dec (also represented by the Greek letter  $\delta$ ) are coordinates marking a star's (or galaxy's) position with respect to two points in the sky:

- The celestial equator (a line in the sky directly above the Earth's equator). This can be represented by a straight line or a curve depending on viewing position but one key point to remember is that this line always goes from East, *E* to West *W*.
- RA is measured as the angular distance along the celestial equator from the First Point of Aries, a position on the celestial equator in the constellation of Pisces. Rather than measure this angle in degrees, RA is measured in hours, minutes and seconds, so that the whole circle around the Earth is 24 hours.<sup>6</sup>

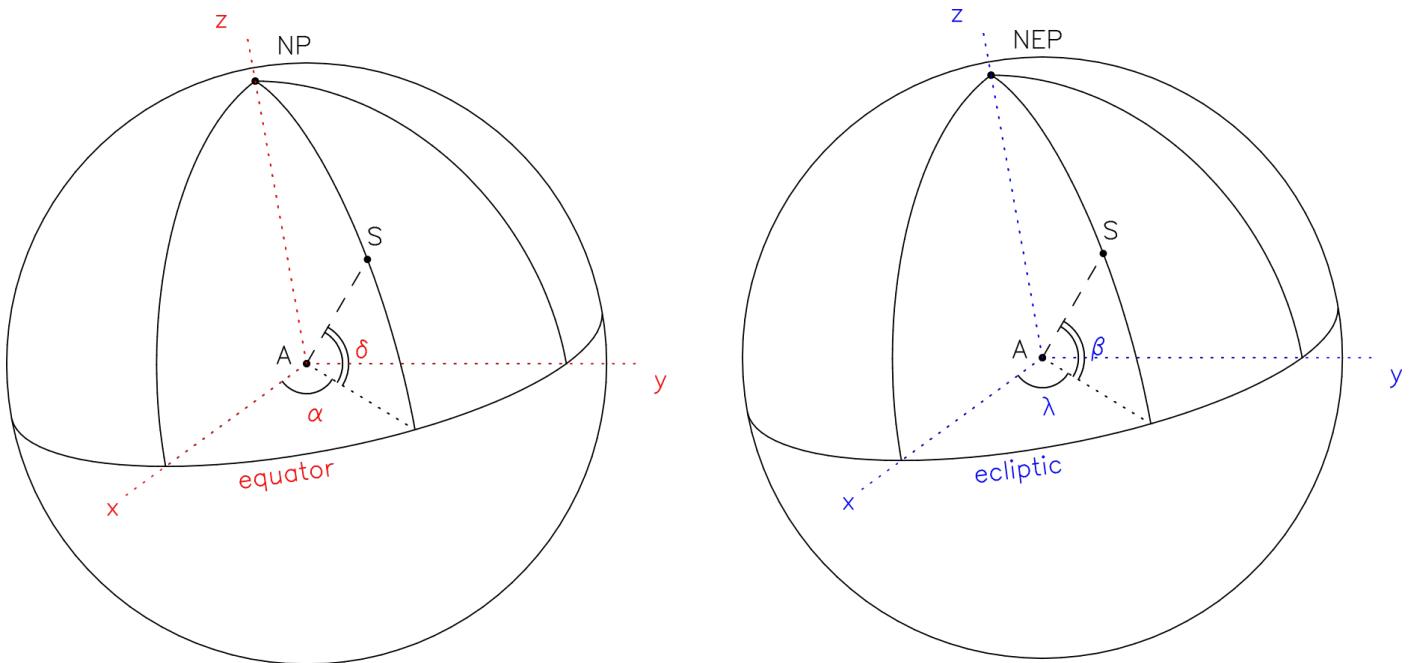


Figure 2: Celestial Sphere for EQS and ECS

<sup>6</sup>I'll cover very little of Celestial Coordinate system here so knowledge of the different coordinate system—their conversion and how to draw a celestial sphere is presumed here. We'll need some hardcore knowledge of the time keeping systems also. I would suggest you read “Astronomy Principles and Practice” by Roy and Clarke: Subchapters 8.1 – 8.5, 8.8 – 8.9, and 8.11

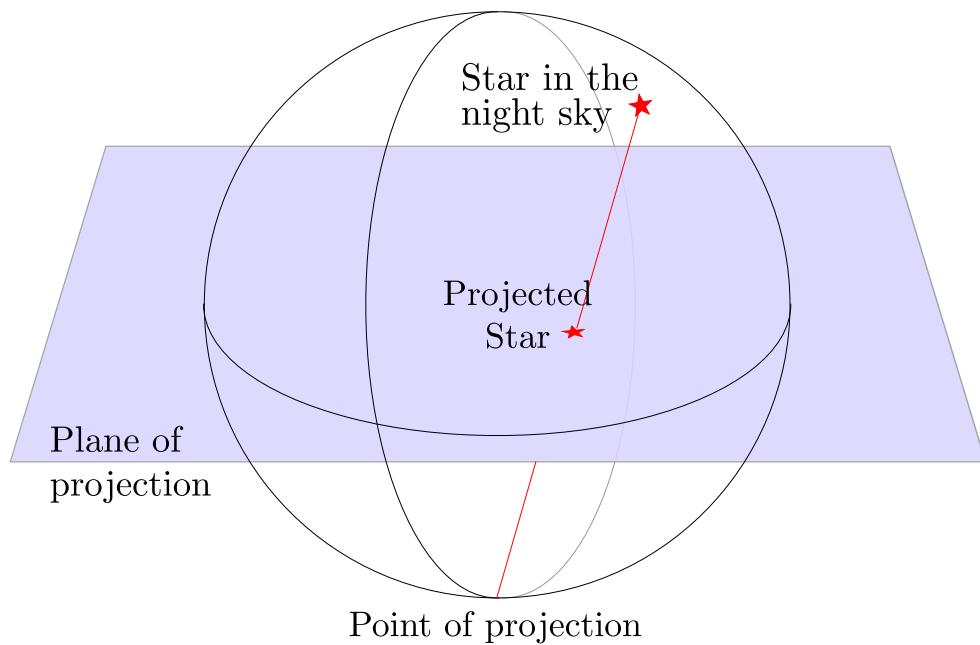
Therefore, when someone says that Canopus has an RA of  $06^h 24^m$ , it means that its RA coordinate is just over one quarter of the way around the sky ( $6^h$  is one-quarter of  $24^h$ ) from the First Point of Aries. RA is always measured eastward from the First Point of Aries.

System	Coordinates	Interval
Equatorial	$\delta$ : declination $\alpha$ : right Ascension	$-90^\circ \leq \delta \leq +90^\circ$ $0h \leq \alpha \leq 24h$
Horizontal	$a$ : altitude $Az$ : azimuth	$-90^\circ \leq a \leq +90^\circ$ $0^\circ \leq Az \leq 360^\circ$
Equatorial Time	$\delta$ : declination $HA$ : hour angle	$-90^\circ \leq \delta \leq +90^\circ$ $0h \leq HA \leq 24h$
Ecliptic	$\beta$ : ecliptic latitude $\lambda$ : ecliptic longitude	$-90^\circ \leq \beta \leq +90^\circ$ $0^\circ \leq \lambda \leq 360^\circ$
Galactic	$B$ : galactic latitude $L$ : galactic longitude	$-90^\circ \leq B \leq +90^\circ$ $0^\circ \leq L \leq 360^\circ$

Table 5: Summery of Celestial Coordinate Systems

## 4.2 Projections

A stereographic projection is mostly used, as is the convention for printed star maps. A planisphere is this type of star chart. But you might encounter different projects or a map of Horizon Views, showing the stars above the horizon as seen from a specified observing site at a given date and time. Another famous projection style which we also use for geographical position is Mercator projections. You'll encounter basically these 3 types of map projections. Now we will discuss each type of these maps and their pros and cons.



#### 4.2.1 Horizon Views

Horizon views shows the portion of the sky that is viewed by a Telescope Field of View (FOV) or Human eye. In astronomy, the field of view is the amount of sky you can see, whether with your unaided vision, binoculars, or a telescope. The FOV of a telescope varies due to usage of different telescope eyepieces whereas human eye spans approximately  $120^\circ$  of arc. So FOV is an important part of these maps as they also provide us with a crucial information—the Range of the Sky! Also, a telescope which has a much smaller field of view will have significant advantages, such as greater magnification and light-gathering power.

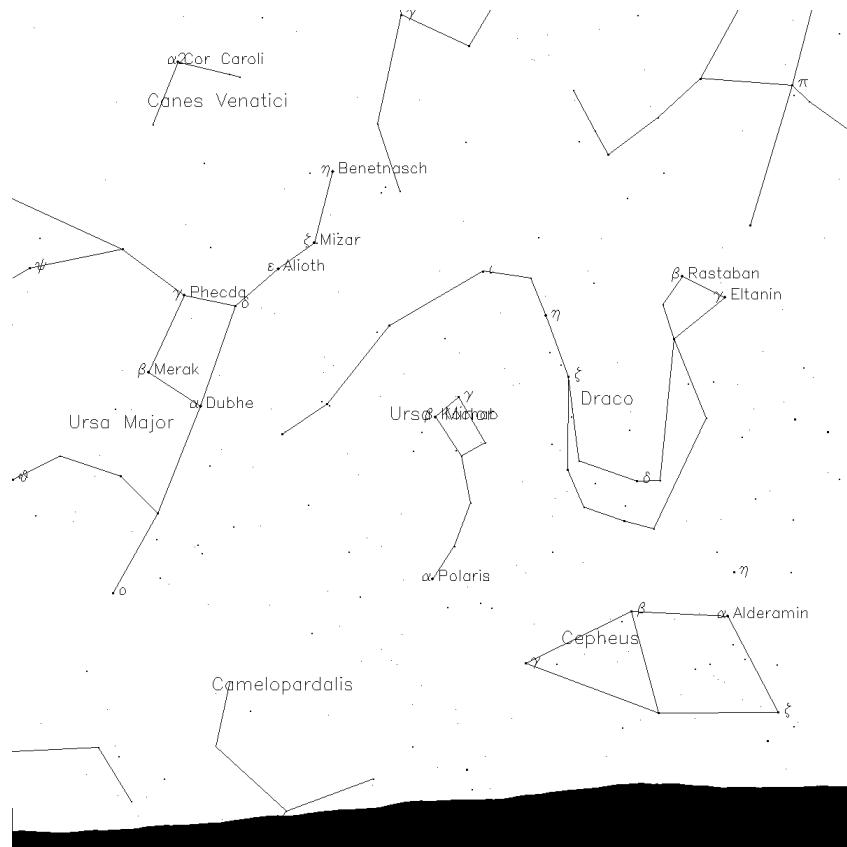


Figure 3: View toward horizon from  $23^\circ$  N  $89^\circ$  E, azimuth  $0^\circ$  (N) Wed 2022 Jan 26 0:27 UTC. Here the FOV is  $75^\circ$ .

To measure other information about the location of the observing place the chart should contain the *Pole star* or the Azimuth of the sky portion should be close  $0^\circ$ . As we know the altitude of the Pole star is equal to the latitude of the Observing place, this makes the whole procedure easy.

One might ask how can we know the scale of the image? Your scale is the Ursa Major/Minor constellation itself! But with this particular viewing the longitude of the observing place can not be determined easily. But using the Dipper clock orientation you can determine the current month of the observation provided that you know the time when it was observed. This is important as same sky viewing constellation will be present at night once a year. But another thing to remember is that if you've seen this portion of the sky at midnight today, you can find the same orientation after 6 months at midday [If there was no atmosphere which we can do using Stellarium].

You'll get the same result for 06-26-2022 at 12:27 UTC. Don't just believe me try it yourself! A clever

use of these type of maps are done in IOAA-18 O3 (See Figure 37).

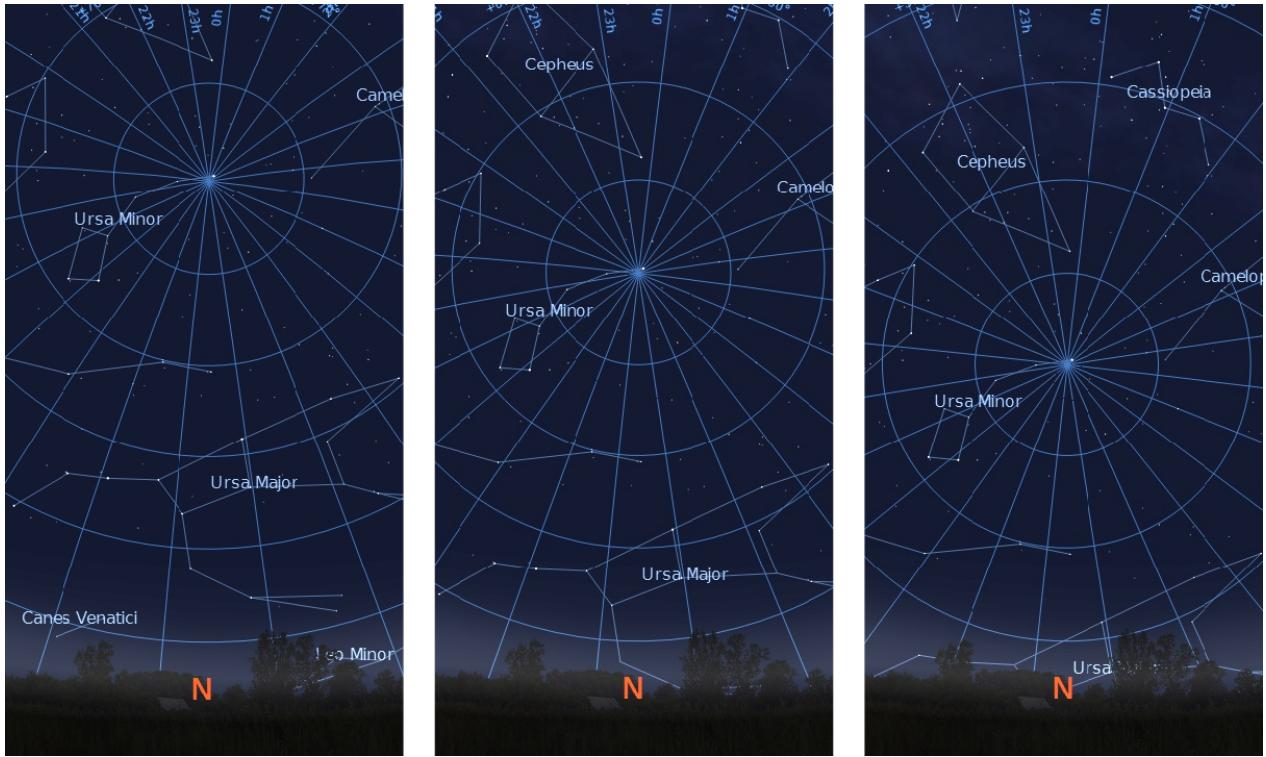


Figure 4: a)  $55^{\circ}$  N, b)  $45^{\circ}$  N, c)  $35^{\circ}$  N.

The effect of changing latitude on Horizon views. Travelling south causes constellations in the north to sink towards the horizon.

#### 4.2.2 Round Maps

Creating a star chart requires projecting the celestial sphere onto a two-dimensional plane. This section will focus on the most common projection method, called stereographic projection. The method works by setting the celestial sphere to a fixed radius and then placing an imaginary plane on top of the sphere (some textbooks will have the plane go through the sphere's center). We imagine a light source at the bottom of the celestial sphere, and notice that every light ray emitted intersects the sphere and the plane once. We project a point on the sphere by finding the corresponding light ray and mapping the point on the sphere to the intersection of this light ray and the plane. Finally, we scale the plane to the desired size, giving us a star chart. Note that stereographic projection cannot project the entire celestial sphere as points closer and closer to the observer's nadir will become infinitely far away on the plane (to remedy this one can move the light source down past the bottom of the sphere, but then we lose some of the nice properties of the projection). The round maps of stereographic projection shows a bird eye view of the sky. Let's see an example—

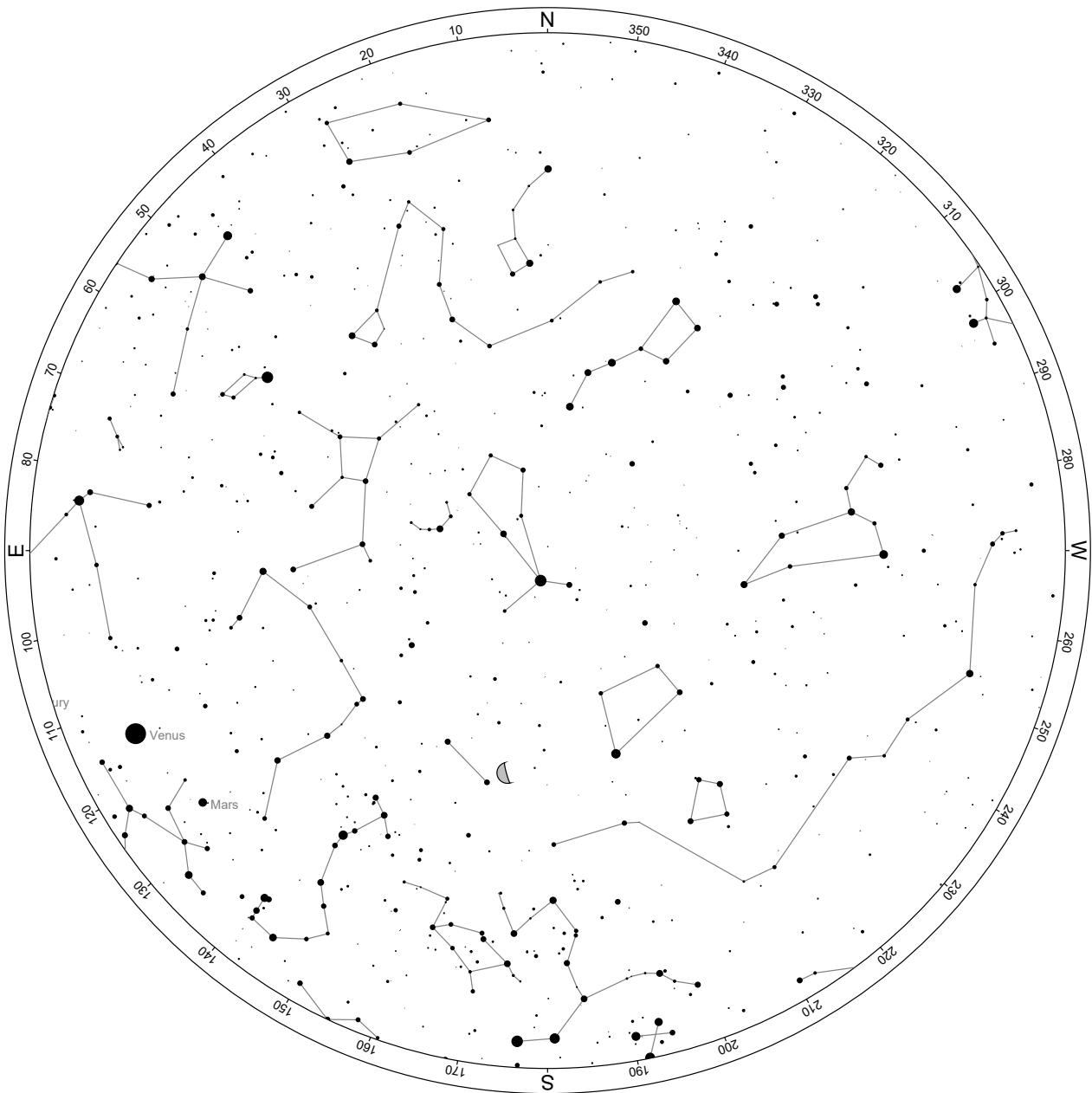


Figure 5: Stereographic projection of sky above 23.5° North

The round edge of each chart represents your horizon, with compass directions usually labeled. If not, then try to find the pole star. The line joining pole star and the center of the map reaches the both North and South cardinals. The side which is closest to Pole star is obviously your North. Turn the map around so the edge marked with the direction you're facing (north, east, or whatever) is right-side up. The stars above this horizon on the map will now match the stars you're facing. Ignore the rest of the map for now. The map's center is overhead (the zenith). So a star that's plotted halfway from the edge to the center can be found about halfway up the sky. That is, it will be halfway from horizontal to straight up. Dot sizes indicate star brightness — the larger the dot, the brighter the star. Example: Let's try the July/August chart. Turn it so the horizon labeled "Facing West" is right-side up. About halfway from there to the center is the bright star Arcturus. Go outside around one of the dates and times listed, face west, and look halfway from horizontal to straight up. There's Arcturus! To the right of Arcturus, in the northwest, is the Big Dipper. Turn the chart so the "Facing NW" horizon edge is right side up. When you hold the chart correctly, the Dipper's handle stretches toward the upper left

and its bowl is at lower right — just the way it looks in the northwestern sky. Nearly overhead, as you crane your neck up, is the bright star Vega. It's part of the little constellation Lyra. You'll notice that east is left of north on our charts, not to the right as on maps of the Earth. This is because the charts are used while looking up, not down. Note: In a stereographic projection, constellations near the edge of the sky chart are stretched and appear larger than if they were at the center of the chart

### Some key information to notice

- The celestial equator will always go from East to West. But this imaginary line in the sky can be an arc depending on the latitude of the observer. So you must know the constellations that resides on this path. One simple example is that celestial equator passes through the belt of Orion. So if you can first determine the cardinals, you can easily draw the equator with help of Orion.
- The ecliptic is the imaginary path in which the Sun moves throughout the year. The term zodiac comes from this concept. There are 13 constellations that lies in the ecliptic. But 12 are considered the famous Zodiac constellations. They are: Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius and Pisces. The Sun also passes through Ophiuchus, a constellation that has traditionally not been part of the zodiac family. It belongs to the Hercules family. One must also remember or be able to recognize this 12 constellations with their sequence. Then you can find the ecliptic.
- The intersection point of the equator and the ecliptic arc/line is the equinox point. So we have 2 equinox points  $180^\circ$  apart. One is known as the first point of Aries  $\Upsilon$  another is termed first point of Libra  $\omega$ . But the the names are misleading nowadays[!]. Yes the points are named using the constellation they were on. But due to some special effects like precessional rotation the equinoxes have shifted a bit. So the  $\Upsilon$  point now lies on Pisces and  $\omega$  currently resides on Virgo. It is helpful to also remember their approximate position compared to nearby constellations.

Now we'll revisit the figure 5 once again. Let's try to find how many things we can understand using this simple map. We will use above techniques to find out as many things as possible [See figure 6.]

1. The middle point of the map serves as the Zenith of the observer, shown by **Z** in figure 6.
2. The first thing, I've found is Big Dipper which is an asterism a part of big and famous constellation Ursa Major.
3. As you see it's a map of Northern hemisphere. How can I tell? I've found Ursa Minor and it's brightest star Polaris! From basic celestial sphere knowledge we know that the altitude of Polaris is equal to Observer's Latitude.
4. Using Polaris and **Z** point we can estimate the cardinals— N,S,E,W. Notice that E and W are mirror than what is supposed to be.
5. From Big Dipper using the star Alkaid, using an arrow we can find brightest star ( $4^{\text{th}}$  Brightest) of Bootes constellation, Arcturus! Shown using blue arrows, this is called star hopping. You can create your own star hopping shortcuts! We may discuss it later.
6. Again, It's obviously night sky of Summer Season! How can I tell? Using another famous asterism Summer Triangle!
7. Using the Zodiac Constellations—Cancer, Leo, Virgo, Libra, Scorpius, and part of Sagittarius, we can determine the approx. path of the Sun also known as Ecliptic. Green line in the figure 6.

8. Scorpius constellation is also known as Fish Hook asterism.
9. The first point of Libra  $\omega$ , where the Ecliptic intersects with the Equator is also a known location. This location was once above Libra but it has now shifted to Virgo. Shown using a circled cross in figure 6.

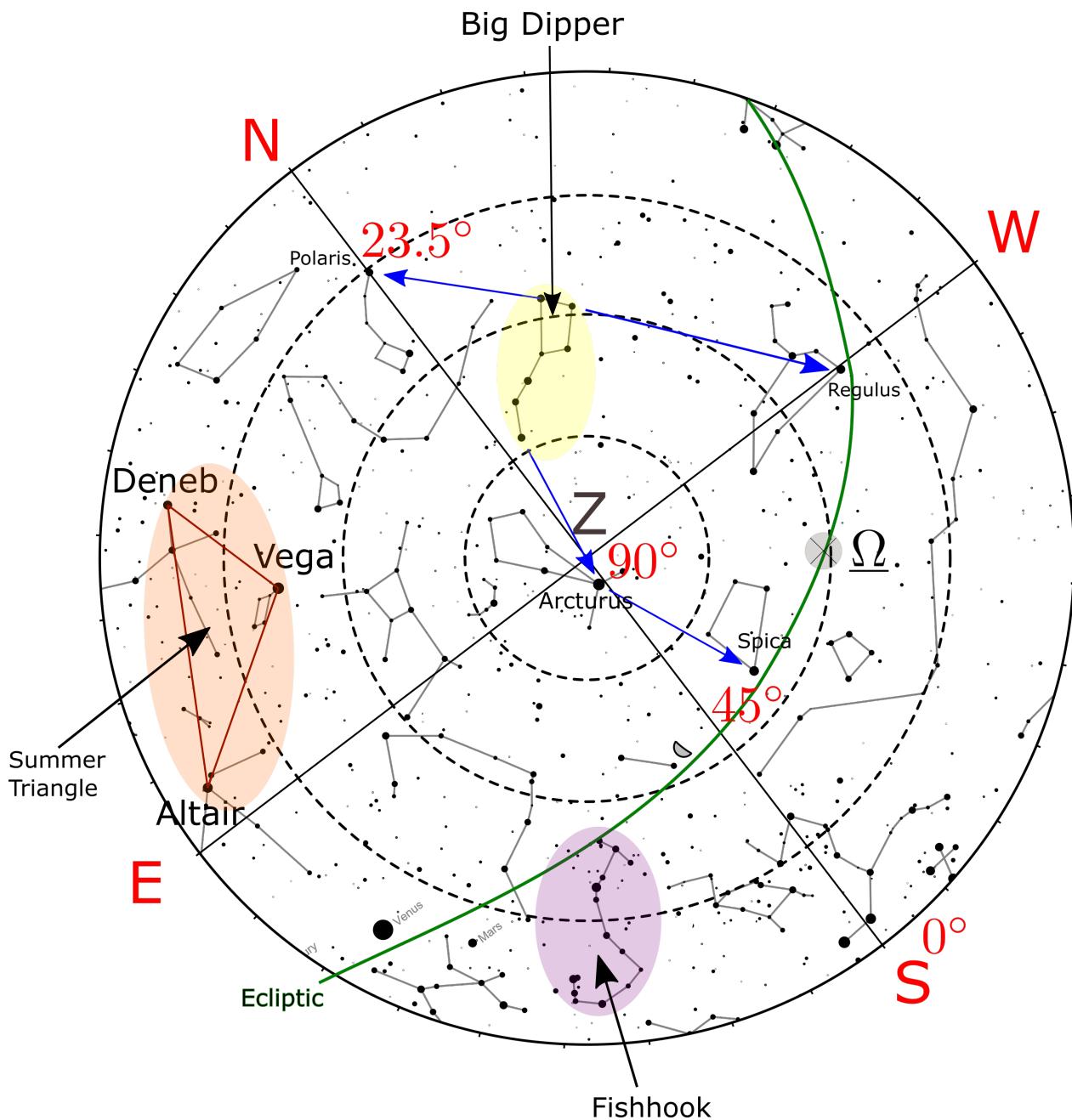


Figure 6: Solved Map for figure 5.

### 4.3 Pole View Maps

Pole view maps are interesting as here the edge of the map represents both the observing horizon in horizontal coordinate system and equator for equatorial coordinate system. So with this, one can determine the position of the star in both measuring system.



Figure 7: View from North Celestial Pole

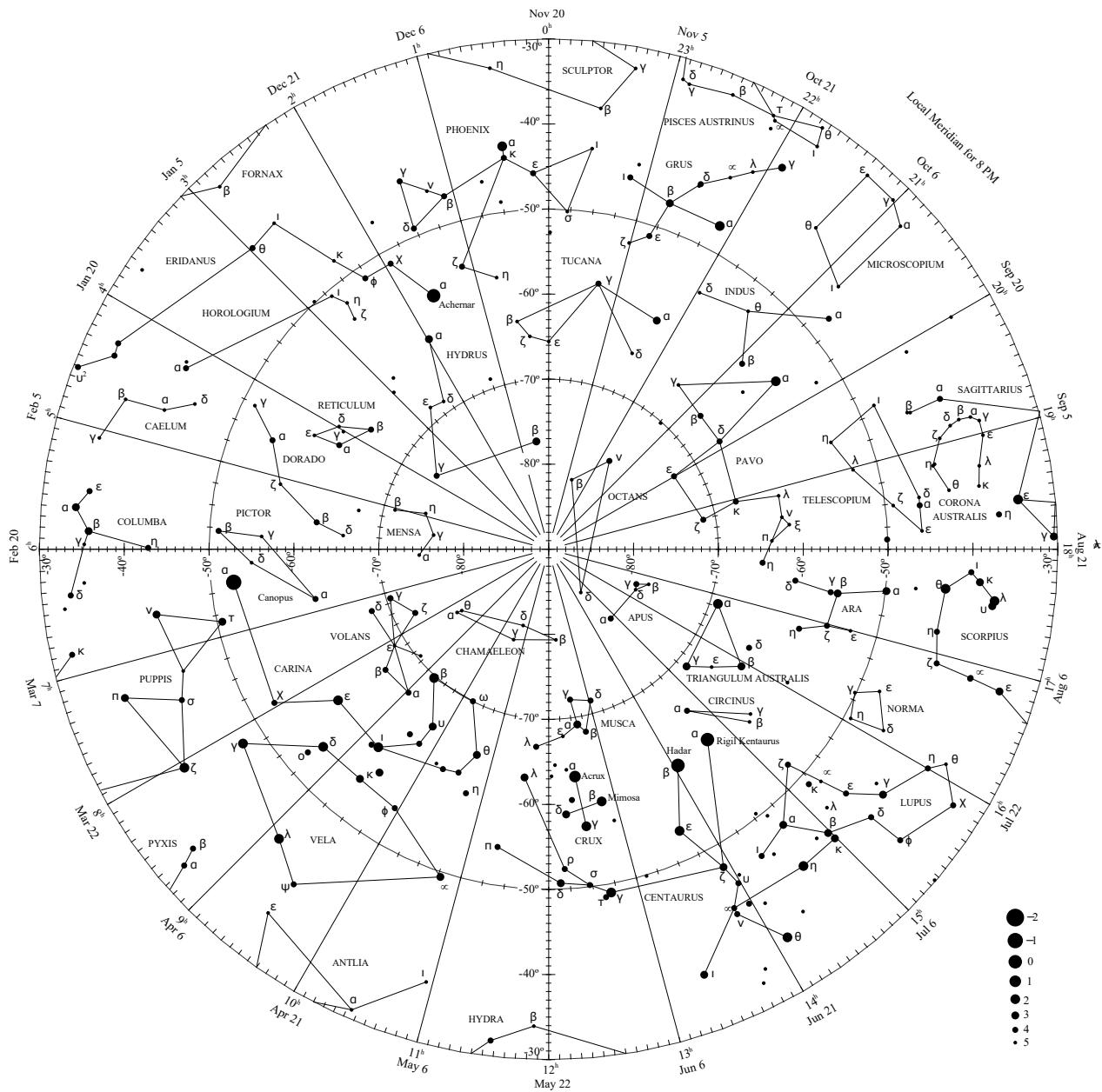


Figure 8: View from South Celestial Pole

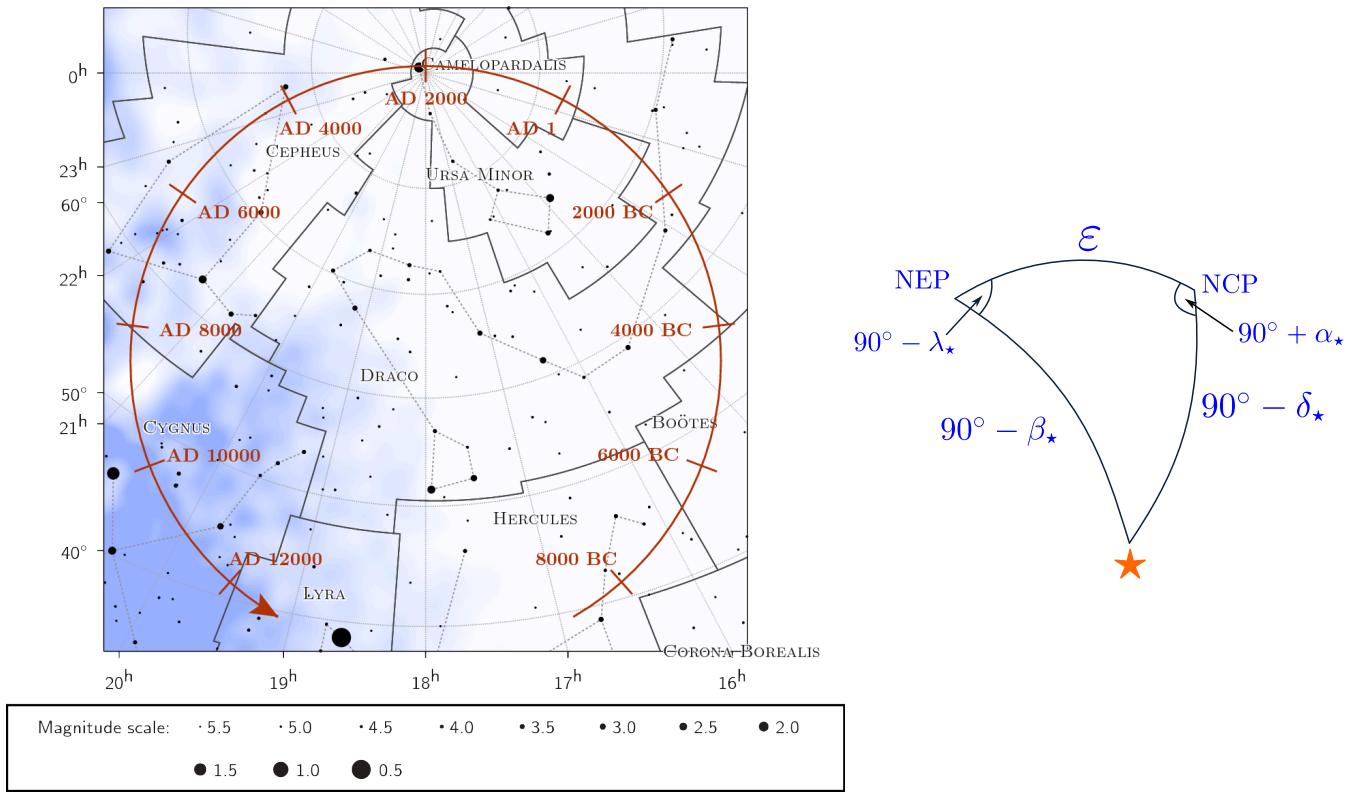
#### 4.3.1 The precession of the Equinoxes

The precession of the equinoxes is a gradual changing in the direction of the Earth's rotation axis, which causes the position of the celestial poles to drift westward through the constellations at a continuous rate of roughly  $50\frac{1}{4}''$  annually. Although this effect is small on short timescales, the accumulated drift adds up to about one Moon diameter per century.

The precessional motion causes the north and south rotational poles to trace out circles around the pole of the ecliptic (in  $T_{pr} \approx 25770$  year). Currently the Earth's north celestial pole points close to the star Polaris, but this will not always be the case. By 2500, Polaris will be several degrees away from the true celestial pole.

The precession of the Earth's rotation axis causes the ecliptic longitude to change linearly but the

ecliptic latitude remains constant. Suppose that at a certain point in time the star has coordinates  $(\alpha_{old}, \delta_{old})$  and  $(\lambda_{old}, \beta)$ . It is necessary to calculate its coordinates  $(\alpha_{new}, \delta_{new})$  and  $(\lambda_{new}, \beta)$  after time  $t$ :



(a) Precessional Circle

From spherical triangle shown above:

$$\begin{aligned}\cos(90^\circ - \beta) &= \cos \varepsilon \sin \delta_{old} + \sin \varepsilon \cos \delta_{old} \cos(90^\circ + \alpha) \\ \sin \beta &= \cos \varepsilon \sin \delta_{old} - \sin \varepsilon \cos \delta_{old} \sin \alpha_{old}\end{aligned}$$

Again,

$$\begin{aligned}\sin \delta_{old} &= \sin \beta_* \cos \varepsilon + \cos \beta_* \sin \varepsilon \sin \lambda_{old} \implies \sin \lambda_{old} = \frac{\sin \delta_{old} - \cos \varepsilon \sin \beta}{\sin \varepsilon \cos \beta} \\ \frac{\cos \lambda_{old}}{\cos \delta_{old}} &= \frac{\cos \alpha_{old}}{\cos \beta_*} \implies \cos \lambda_{old} = \frac{\cos \delta_{old} \cos \alpha_{old}}{\cos \beta}\end{aligned}$$

Now the new Ecliptic Coordinates after Precession:

$$\begin{aligned}\beta_{new} &= \beta_{old} \\ \lambda_{new} &= \lambda_{old} + \Delta\lambda = \lambda_{old} + \frac{t}{26000 \text{ years}} * 360^\circ\end{aligned}$$

Equatorial Coordinates after Precession (Similarly):

$$\begin{aligned}\sin \delta'_* &= \sin \beta'_* \cos \varepsilon + \cos \beta'_* \sin \varepsilon \sin \lambda_{old} \\ \delta_{new} &= \arcsin(\cos \varepsilon \sin \beta + \sin \varepsilon \cos \beta \sin \lambda_{new})\end{aligned}$$

$$\begin{cases} \sin \alpha_{new} = \frac{\cos \varepsilon \sin \delta_{new} - \sin \beta}{\sin \varepsilon \cos \delta_{new}} \\ \cos \alpha_{new} = \frac{\cos \beta \cos \lambda_{new}}{\cos \delta_{new}} \end{cases}$$

## Finding new Pole Star

Right now, Polaris ( $\alpha$  Ursae Minoris) is the “north pole star”, however Thuban ( $\alpha$  Draconis) was the “north pole star” when it was around 3000 BC.

- Q1. Mark Thuban on Figure 10
- Q2. We know that Thuban was passed by north celestial pole, and Polaris is also passed by north celestial pole. Based on this, we can find the north ecliptic pole. Find the north ecliptic pole!
- Q3. Measure the period of the precession.
- Q4. Find the equatorial coordinate of Polaris when Thuban was the “north pole star”.

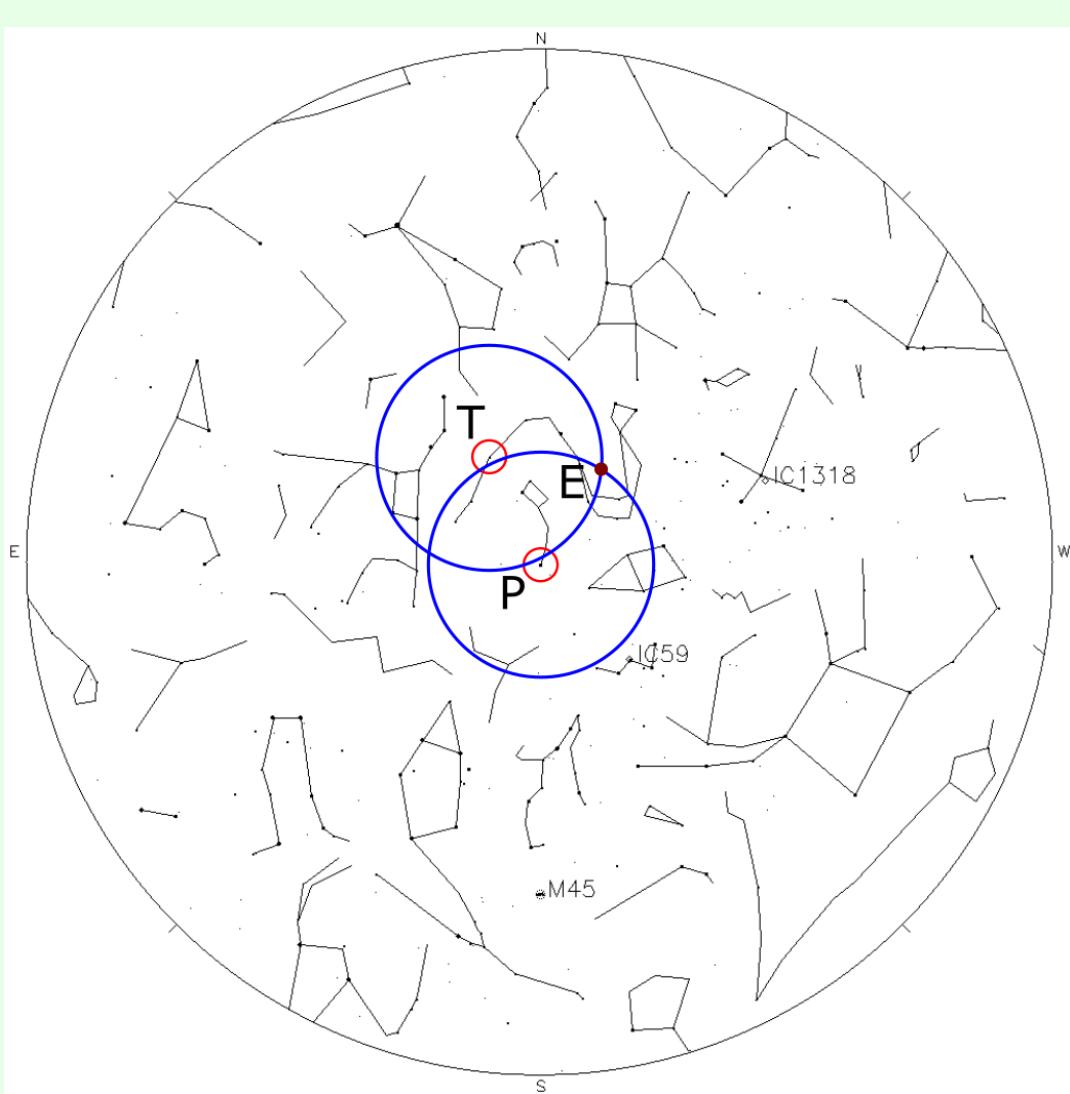


Figure 10: Thuban as North Pole

**Q2** We can find the north ecliptic pole by drawing two circles with its radius of  $23.5^\circ$  which the

center of each circle is on Polaris and Thuban. We will get 2 intersections, E and the other one. By considering the ecliptic line, we know that E is the north ecliptic pole (white circle), not the other one.

**Q3** First, we measure the angle of  $\angle PET$ . There are some ways to measure this angle. Some possible methods are:

- Measure PT  $\rightarrow$  PT =  $25.8^\circ$ . Using cosine rule we get  $\rightarrow \cos \angle PET = 0.361$  or  $\angle PET = 68.8^\circ$ .  
(for cosine rule in spherical geometry,  $\angle PET = 68^\circ$ )
- Direct method (using protractor)  $\angle PET = 69^\circ$  or  $70^\circ$  (need to be measured again)
- Get a line from T and tangential to line PE. The intersect is at F, then :  $\sin \angle PET = TF/TE$ . From this method we get  $\angle PET$  around  $66^\circ$ . (not really recommended)

Based from all these method, the range of  $\angle PET = 65 - 70^\circ$ . The time required to make this angle is =  $3000 + 20XX = 50XX$  years (XX = current year after 2000 CE). Thus the range of period of precession is: 25800-7800 years (These are only for the range, each team can get full mark if their answer is within this range)

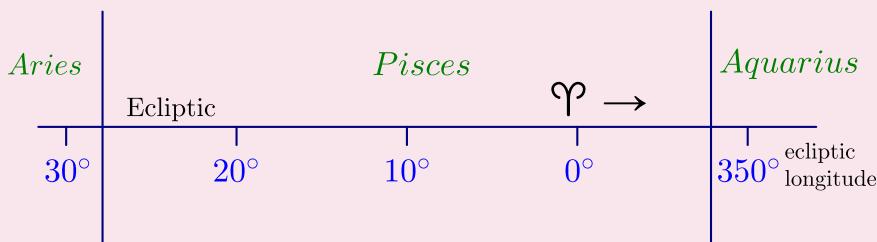
**Q4** PT =  $25.8^\circ$ , hence  $\delta_{\text{polaris}} = 90 - PT = 64.2^\circ$ .

From sin rule, we get  $\angle ETP = 58.1^\circ$  or  $3^h 52^m 30^s$ . (for sin rule in spherical geometry, it is  $58.2^\circ$ , still similar to flat one). We know  $\alpha_{\text{North Ecliptic Pole}} = 18^h$ . Now,

$$\begin{aligned}\alpha_{\text{polaris}} &= \alpha_{\text{North Ecliptic Pole}} + \angle ETP \\ \alpha_{\text{polaris}} &= 21^h 52^m 30^s\end{aligned}$$

Hence, the equatorial coordinate Polaris 6000 years ago is:  $(\alpha, \delta) = (21^h 52^m 30^s, 64.2^\circ)$

**Problem: Drifting Equinox** The Vernal Equinox occurs nowadays when the Sun is in the constellation of Pisces. Pisces covers a section of the ecliptic from longitude  $352^\circ$  to longitude  $28^\circ$ ; at longitude  $28^\circ$  the ecliptic passes into Aries.



How many years would we have to go back, to find the Sun at “the First Point of Aries” at the Vernal Equinox?

Because of precession, our framework of Right Ascension and declination is constantly changing. Consequently, it is necessary to state the equator and equinox of the coordinate system to which any position is referred. Astronomers will report the coordinates of an object based on the celestial equator and vernal equinox of a specific time and date; this is called the epoch. Certain dates (e.g. 1950.0, 2000.0) are taken as standard epochs, and used for star catalogues, etc.

## 4.4 Mercator Projections

**[To be completed]** Astronomical symbols are abstract pictorial symbols used to represent astronomical objects, theoretical constructs and observational events in European astronomy. The earliest forms of these symbols appear in Greek papyrus texts of late antiquity.

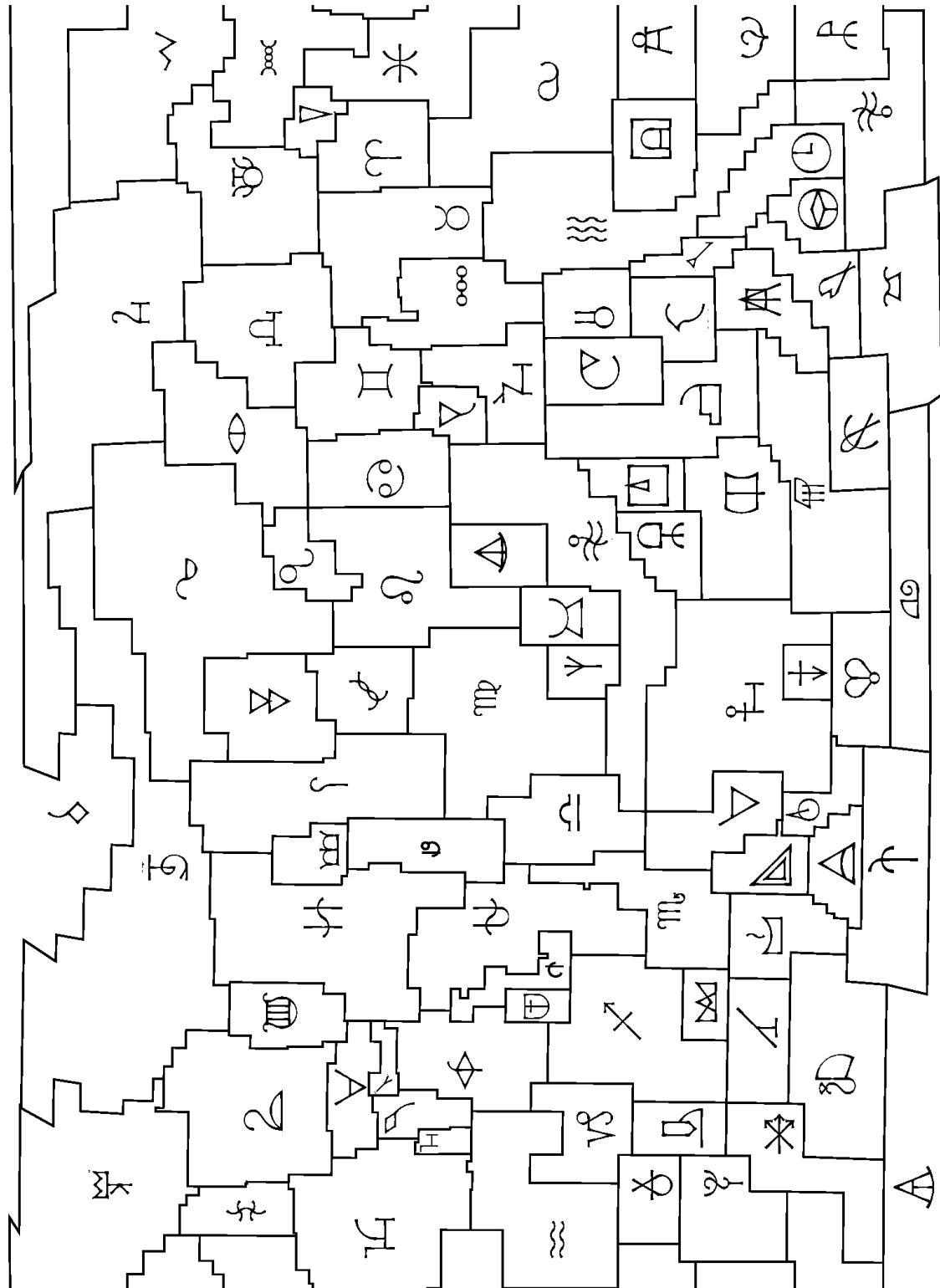


Figure 11: Mercator-projection sky map of constellations marked with symbols

## 4.5 Monthly Sky Chats

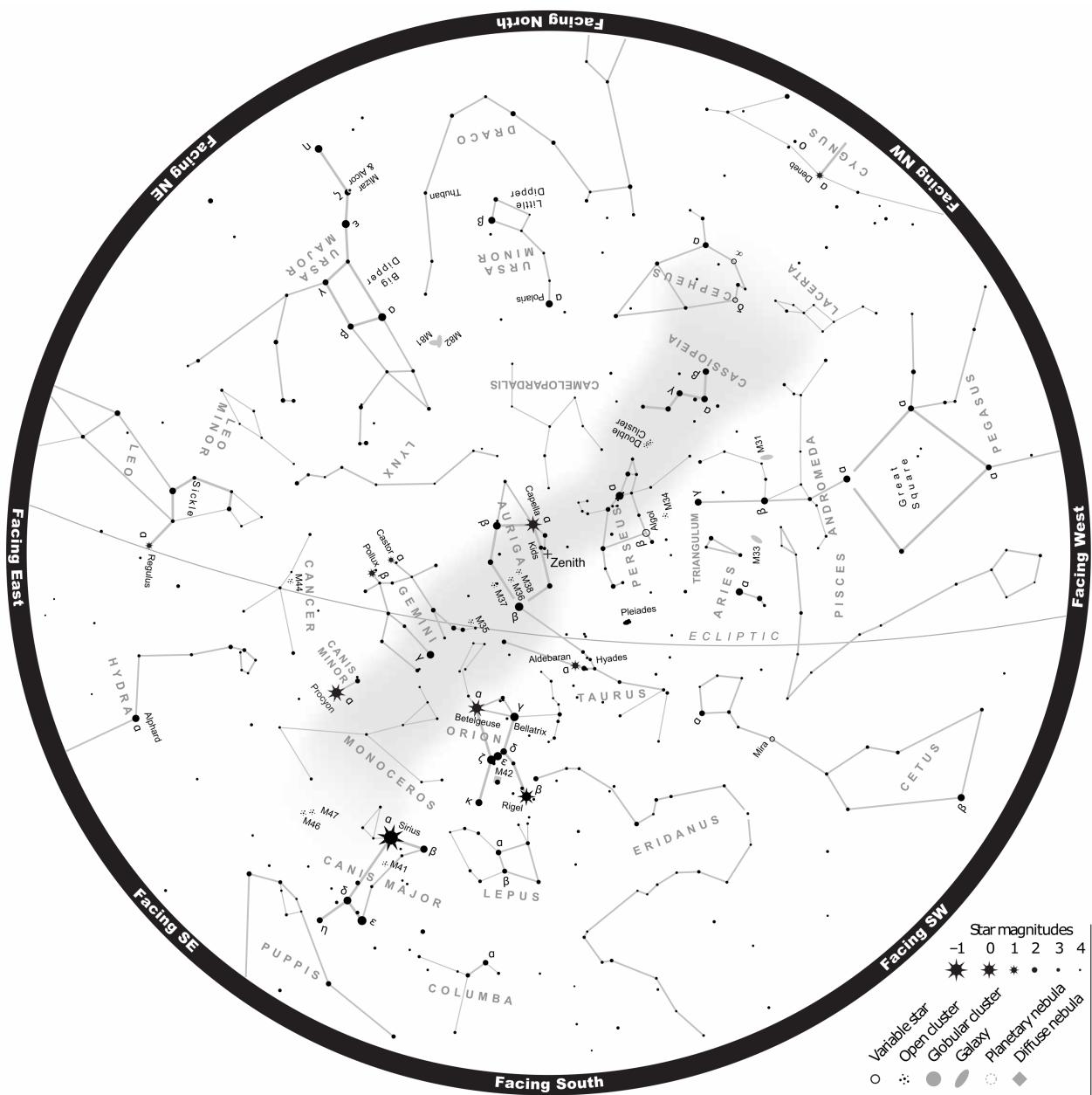


Figure 12: Jan/Feb Night Sky View for latitude 40° N

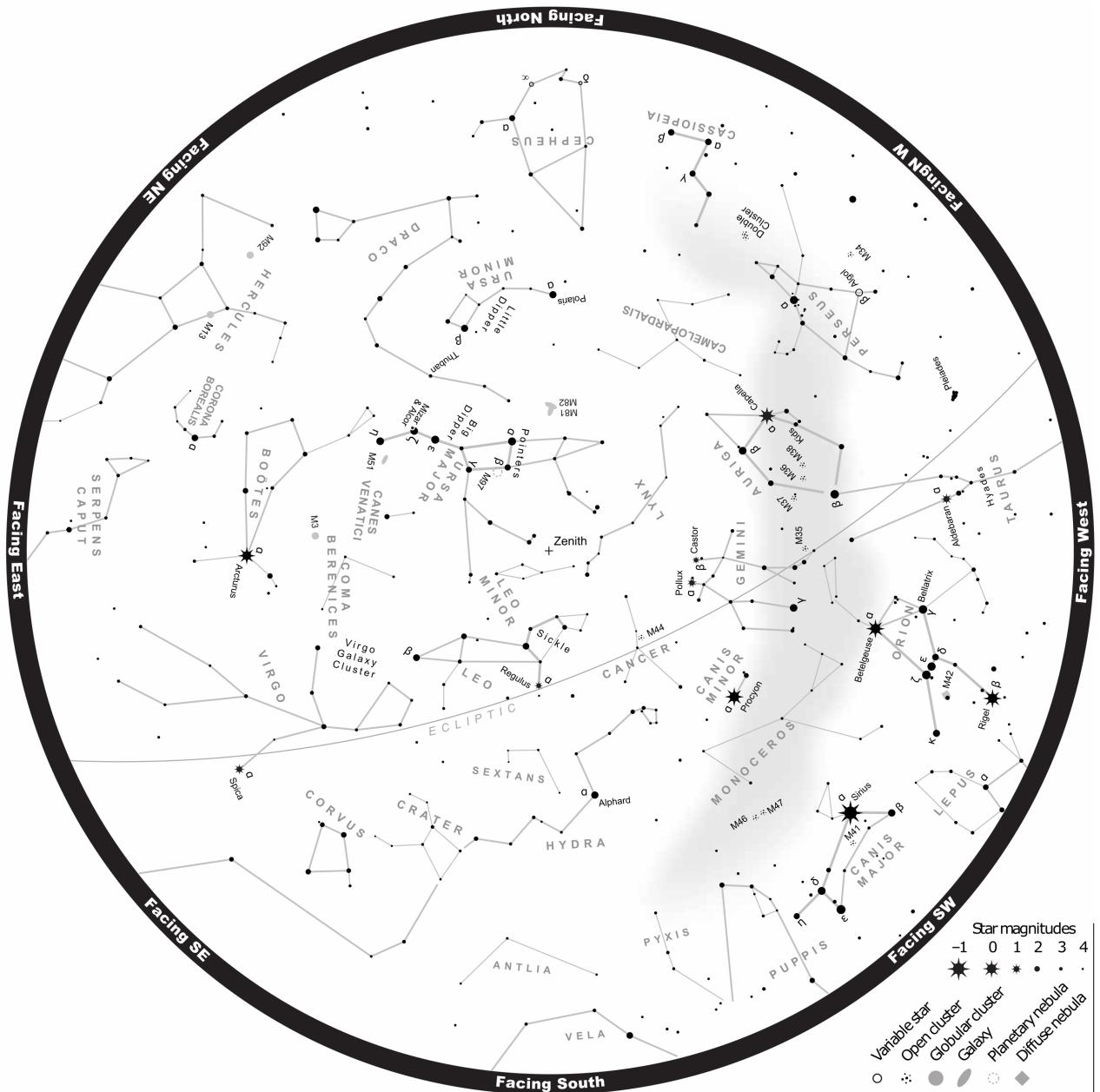


Figure 13: Mar/Apr Night Sky View for latitude 40° N

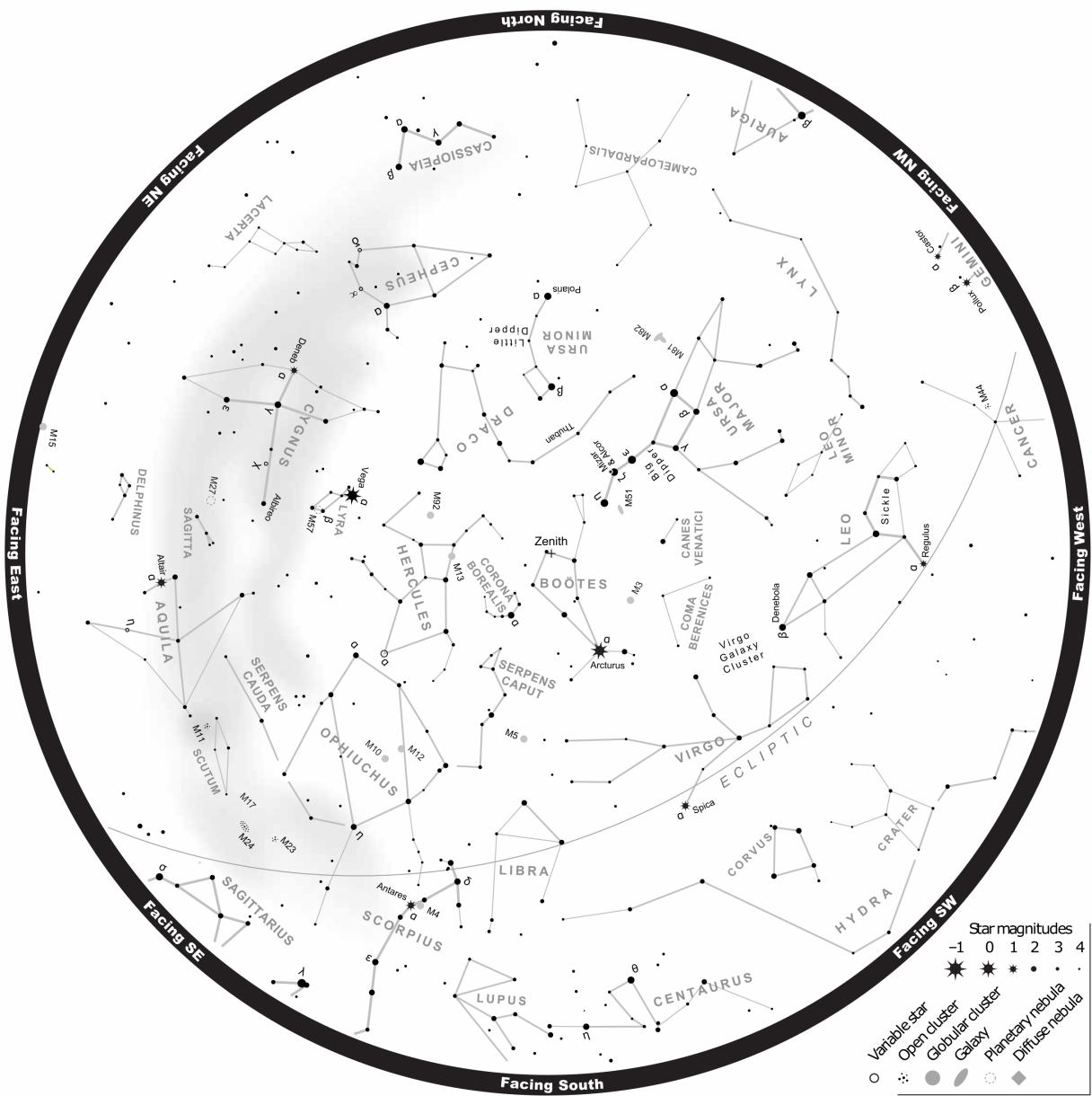


Figure 14: May/Jun Night Sky View for latitude 40° N

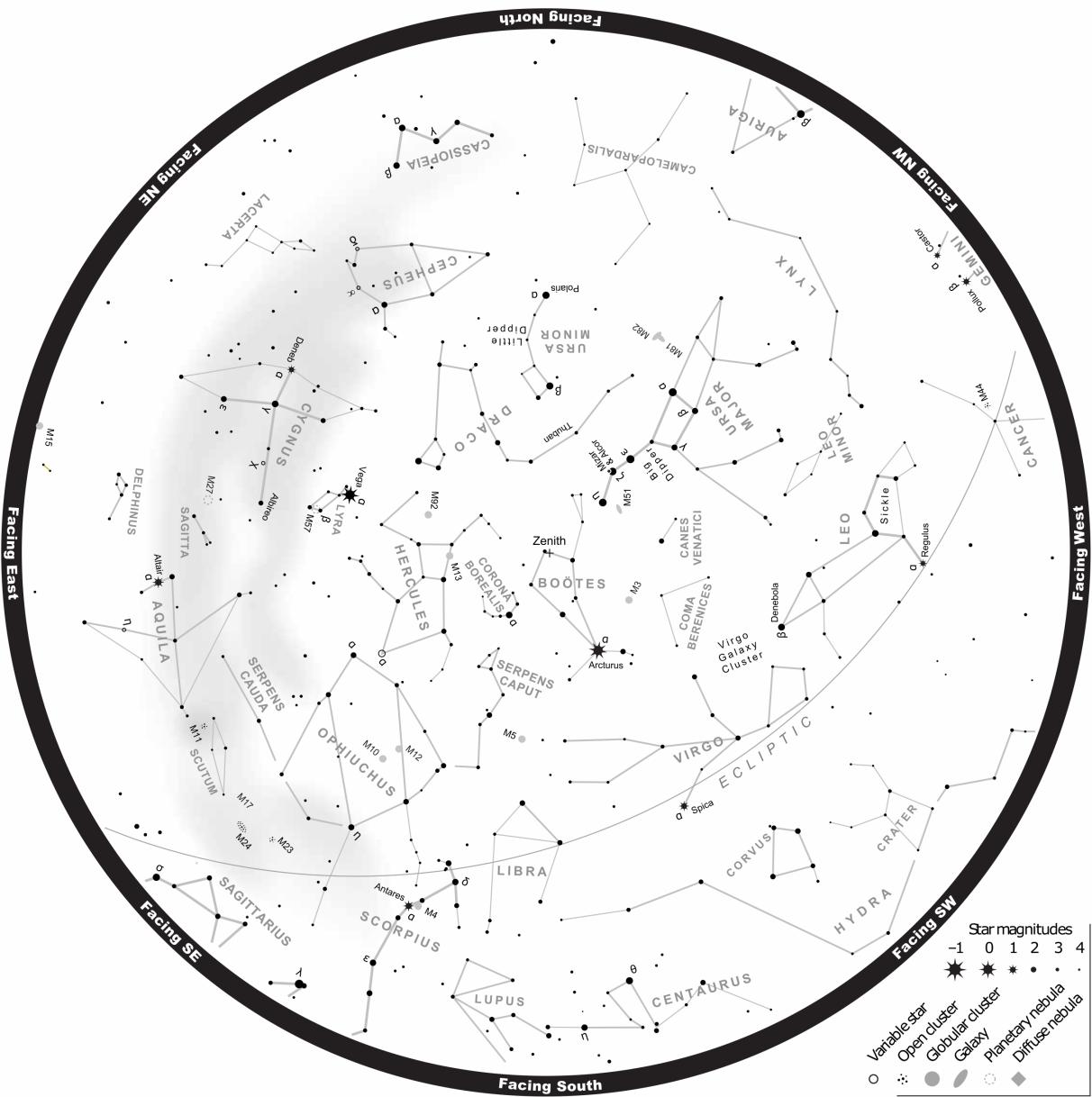


Figure 15: Jul/Aug Night Sky View for latitude 40° N



Figure 16: Sep/Oct Night Sky View for latitude 40° N

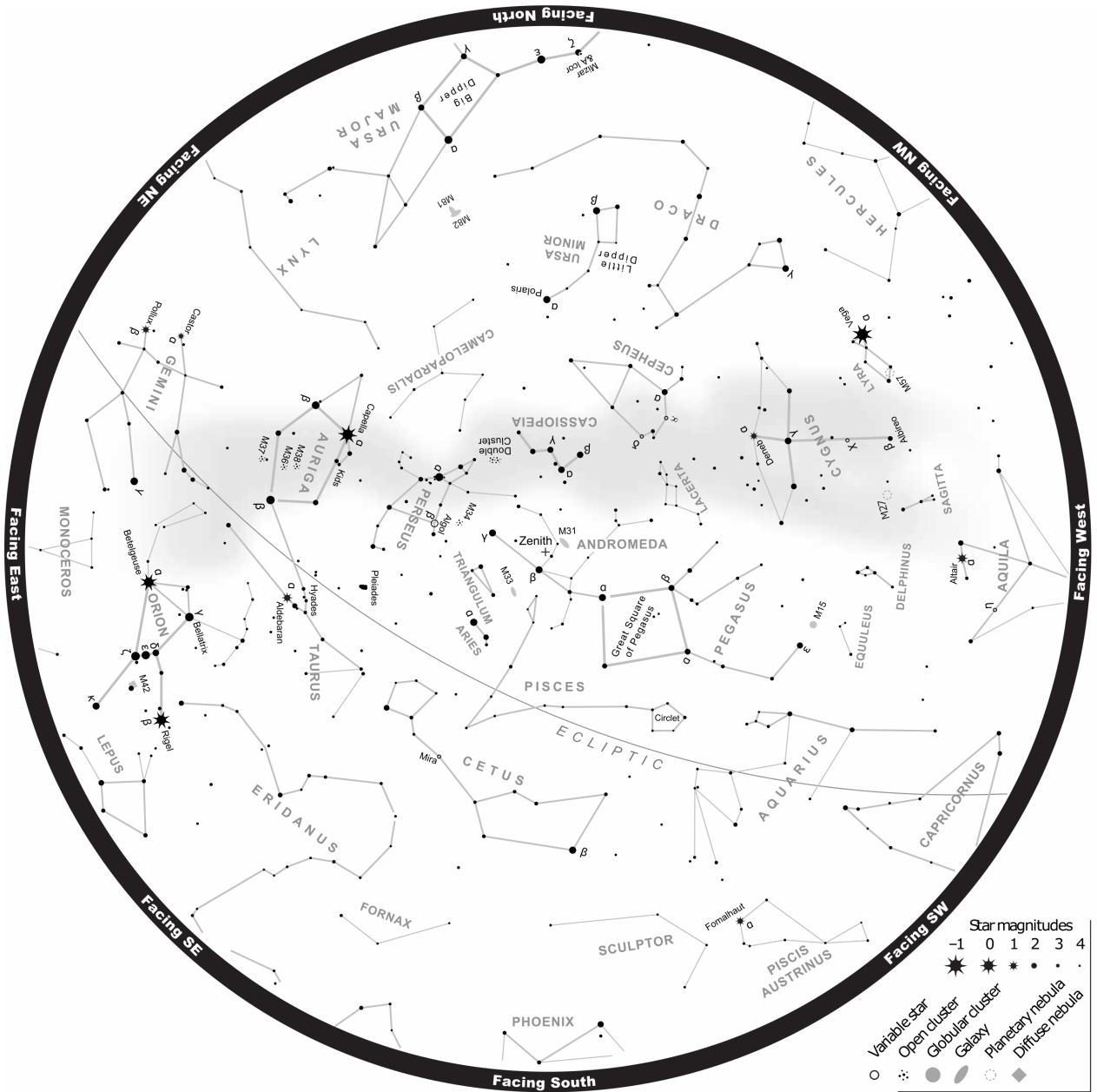
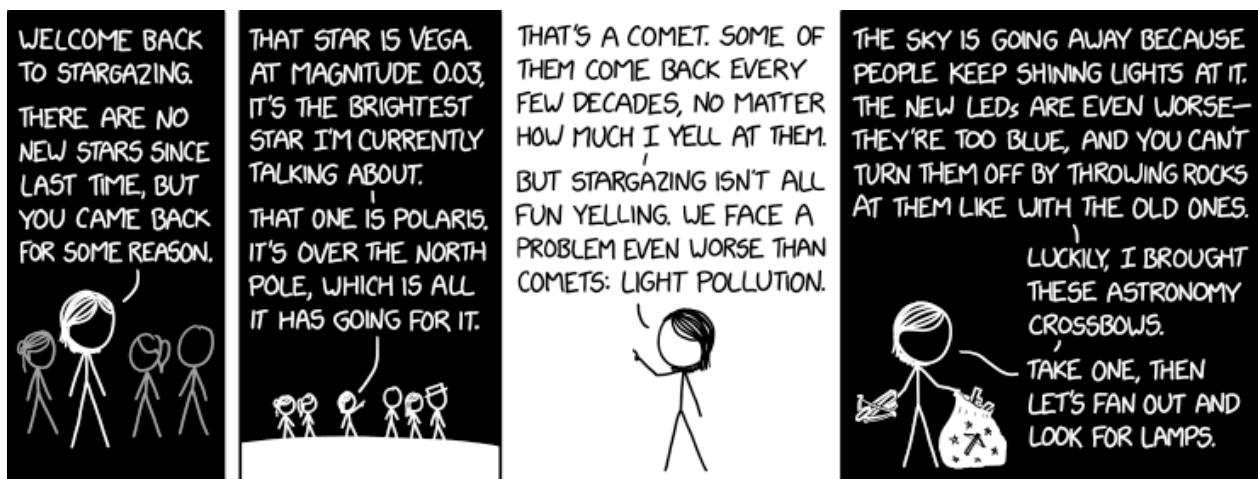


Figure 17: Nov/Dec Night Sky View for latitude 40° N

## 5 Celestial Navigation

Celestial navigation has a rich and interesting history. The navigator would use ‘sights’, or angular measurements taken between a celestial body (e.g., the Sun, the Moon, Polaris, or one of 57 other navigational stars and planets) and the visible horizon to locate one’s position in the world, on land as well as at sea.



Let us explore a simple application of Celestial Navigation using our wrist watch. To use our watch as a compass in the northern hemisphere, hold the watch horizontal and point the hour hand at the Sun. The halfway mark between the hour hand and the twelve o’clock mark is south. For example, if it is 8 o’clock, point the 8 on the watch face at the Sun. South would then be at the 10 o’clock position. If it is 4 o’clock, point the 4 on the watch face at the Sun. South would be in the 2 o’clock position.

### 5.1 Problem Solving Tips

Positional astronomy requires the use of methods that are not usually used in any other content seen in schools or in other Olympiads, and for this reason it can and will be a little difficult to advance through the problems in this topic, especially for students who are just starting out, but even those who have qualified for the more advanced phases can make fatal mistakes when solving these questions. However, there are some tips that can help progress in this field.

#### 1. Make a 3D drawing of the situation

The first step to solving any positional astronomy problem is to understand and visualize what is happening, and good drawing is fundamental in this process. In general, it is strongly recommended to make a three-dimensional drawing for all situations<sup>7</sup>, especially in questions of spherical trigonometry.

#### 2. In the drawing, represent values close to those in the statement

If the statement says that there is an observer with latitude  $\phi = -80^\circ$  observing a star with  $\delta = 50^\circ$ , it is recommended to make a drawing in which the PCS is relatively close to the zenith. This can help you identify particular cases and estimate the final answer<sup>8</sup>. Furthermore, in

<sup>7</sup>For meridian crossing problems, a 2D section of the celestial sphere is sufficient, however a 3D drawing can facilitate visualization

<sup>8</sup>For example, if the drawing shows that a star culminates close to the horizon, but its result is  $h = 80^\circ$ , something may have gone wrong.

questions of spherical trigonometry, this analysis is especially relevant for identifying the quadrant of certain angles. Certain trigonometric functions only work for certain quadrants, and therefore it is important to identify them before doing the math.

### 3. Not memorizing final formulas

Many results in positional astronomy are particular cases that are not taken into account in the formulas. For example, the equations obtained do not work for observers in the Southern Hemisphere or for stars in the Eastern Hemisphere. Therefore, the ideal is to understand the procedure used and adapt it according to each question - just memorize the three laws of spherical trigonometry.

### 4. Be careful with inverse trigonometric functions

In questions of spherical trigonometry, it is usually necessary to use inverse trigonometric functions to obtain numerical results. However, they do not provide unique values. Therefore, you may need to find both the sine and cosine of an angle to determine its value<sup>9</sup>. Furthermore, if your drawing is very well done, it is possible to identify which of the values is the true one.

## 5.2 Naked Eye Observation

### Upper and Lower Culmination

For an observer in the northern hemisphere, the altitude of a celestial body is maximum when it passes through the meridian, in the southern direction. In this case, the body is said to be in upper culmination and its hour angle is  $HA = 0^h$ . The altitude is minimum when the object is passing through the anti-meridian. Now, the body is said to be in lower culmination and its hour angle is  $HA = 12^h$ . In the derivation that follows, we consider only the case of an observer in the northern hemisphere, so  $\phi \geq 0^\circ$ .

I've used a 2D geometry of the situations described. I'll denote Upper culmination south of zenith as  $h_{U1}$ , Upper culmination north of zenith as  $h_{U2}$  and lower culmination as  $h_l$ .

Now for  $h_{U1}$  and  $\delta = -ve$ ,

$$\begin{aligned} 90^\circ &= \phi + (-\delta) + h_{U1} \\ h_{U1} &= 90^\circ - \phi + \delta \end{aligned}$$

Now for  $h_{U1}$  and  $\delta = +ve$ ,

$$\begin{aligned} 90^\circ &= \delta - \phi + h_{U11} \\ h_{U11} &= 90^\circ - \phi + \delta \end{aligned}$$

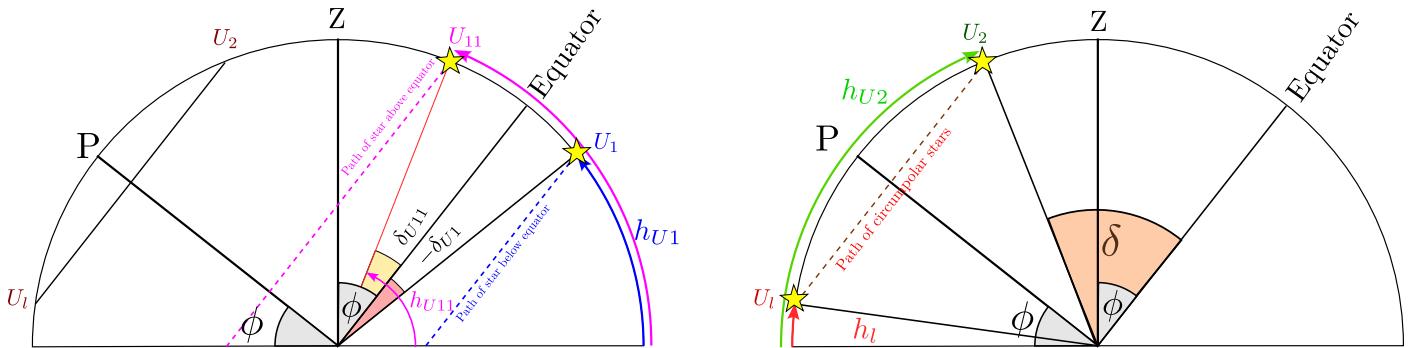
For, Upper culmination,  $h_{U2}$ , and we denote zenith angle of upper culmination,  $Z A_{U2} = \delta - \phi$  and  $\delta > 0$  always

$$\begin{aligned} 90^\circ &= \phi + PU_2 + ZA_{U2} \\ &= \underbrace{\phi + (90^\circ - \delta)}_{h_{U2}} + ZA_{U2} \\ h_{U2} &= 90^\circ - \delta + \phi \end{aligned}$$

So we can write in total

$$h_U = \begin{cases} 90^\circ - \phi + \delta, & \text{if the object culminates south of zenith;} \\ 90^\circ + \phi - \delta, & \text{if the object culminates north of zenith.} \end{cases} \quad (3)$$

<sup>9</sup>To do this, it would be necessary to use more than one law of spherical trigonometry



The altitude of lower culmination  $h_l$ , measured by convention from the northern horizon, is then:

$$\begin{aligned} 90^\circ &= h_l + PU_l + (90^\circ - \phi) \\ h_l &= 90^\circ - (90^\circ - \delta) - (90^\circ - \phi) \quad [:\ PU_l = PU_2] \end{aligned}$$

$$h_l = \delta + \phi - 90^\circ \quad (4)$$

Let us examine some special cases:

- when  $h_l > 0$  i.e  $\delta > 90^\circ - \phi$ , the object is circumpolar and it never sets;
- when  $h_U < 0$  i.e  $\delta < \phi - 90^\circ$ , it is never visible;
- $\phi - 90^\circ < \delta < 90^\circ - \phi$ , the object rises and sets

For a circumpolar star we can write,

$$\delta = \frac{1}{2}(h_U + h_l)$$

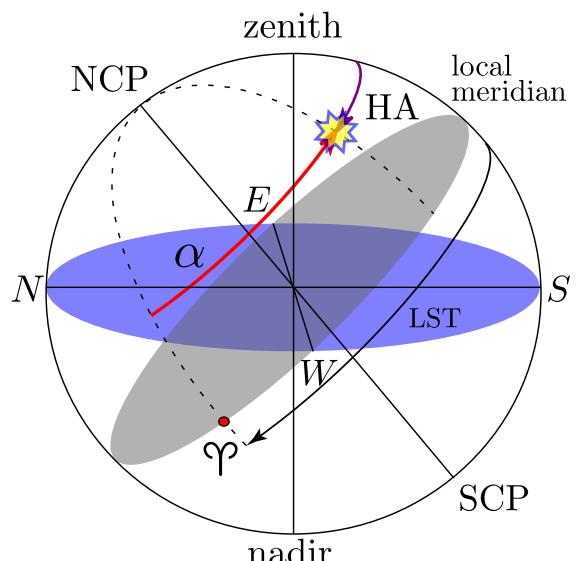
$$\phi = 90^\circ - \frac{1}{2}(h_U - h_l)$$

## Local Sidereal Time

Our wrist watches keep track of when the sun will be at transit. The solar time-keeping system we use ensures that our working day contains repeats with the rising and setting of the sun. Astronomers are however more interested in keeping track of the stars, since they want to observe them. They therefore use a sidereal time-keeping system to keep track of the vernal equinox (instead of the sun).

Once you know the time before or since the vernal equinox was at transit you can easily determine when any other star will be at transit. This is true, since there exists a simple relation between the hour angle of a celestial body and your local sidereal time which is given by:

$$LST = RA_\star + HA_\star = HA\gamma$$



## Coordinate Transformation

Coordinate conversion is very common in Olympiad questions and real academic research. For example, the position triangle plays the role of converting equatorial coordinates into horizontal coordinates or vice versa, in addition to making it possible to relate them to the hour angle of a star. This chapter will test your understanding of the previous chapters on spherical geometry and celestial coordinate systems. Fortunately, we only need two formulas - the cosine formula and the sine formula. You should also understand why the following simplifications are true:

$$\begin{array}{ll}
 \cos(-\theta) = \cos \theta & \sin(360^\circ - \theta) = -\sin \theta \\
 \sin(-\theta) = -\sin \theta & \cos(90^\circ - \theta) = \sin \theta \\
 \cos(360^\circ + \theta) = \cos \theta & \sin(90^\circ - \theta) = \cos \theta \\
 \sin(360^\circ + \theta) = \sin \theta & \cos(90^\circ + \theta) = -\sin \theta \\
 \cos(360^\circ - \theta) = \cos \theta & \sin(90^\circ + \theta) = \cos \theta
 \end{array}$$

If you are skeptical about any of the equations above, draw a triangle in a unit circle to experience the joy of discovery.

Now, let's just look at the conversion between horizontal and equatorial coordinates, since the relationships between other systems apply the same idea.

### Horizontal $\rightleftharpoons$ Equatorial Time

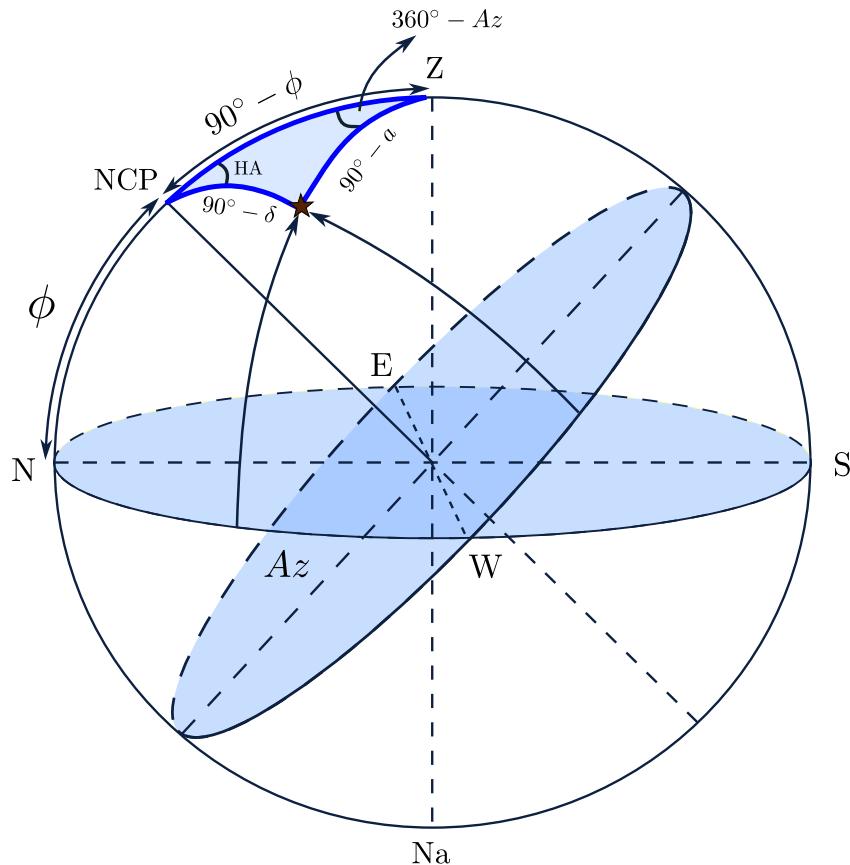


Figure 18: Celestial Sphere to get a Spherical Triangle

The coordinate conversion formulas can be easily derived from a celestial sphere diagram 18. Here we derive the formulas for a star  $X$  for an observer at latitude  $\phi$ . Note that we use  $P$  for North Celestial Pole (NCP) for conciseness.

If we wish to convert from horizontal coordinates to equatorial coordinates, we must know the altitude and azimuth of the star, and the latitude of the observer. We can then fully solve the spherical triangle  $PZX$  since we already have 3 known variables! We'll derive the relation in **3 Steps**

**Step 1** In a spherical triangle  $PZX$  by the **cosine** theorem

$$\begin{aligned}\cos PX &= \cos PZ \cos ZX + \sin PZ \sin ZX \cos PZX \\ \cos(90^\circ - \delta) &= \cos(90^\circ - \phi) \cos(90^\circ - a) + \sin(90^\circ - \phi) \sin(90^\circ - a) \cos(180^\circ - Az) \\ \boxed{\sin \delta = \sin a \sin \phi + \cos a \cos \phi \cos Az}\end{aligned}$$

**Step 2** In a spherical triangle  $PZX$  by the **sine** theorem

$$\begin{aligned}\frac{\sin ZX}{\sin \angle ZPX} &= \frac{\sin PR}{\sin \angle PZX} \\ \frac{\sin(90^\circ - a)}{\sin HA} &= \frac{\sin(90^\circ - \delta)}{\sin(360^\circ - A)} \\ \cos \delta \cos HA &= \cos a \cos Az \\ \boxed{\sin HA = -\frac{\sin Az \cos a}{\cos \delta}}\end{aligned}$$

**Step 3** Similarly we again move to **cosine** formula,

$$\begin{aligned}\cos ZX &= \cos PZ \cos PX + \sin PZ \sin PX \cos ZPX \\ \cos(90^\circ - a) &= \cos(90^\circ - \phi) \cos(90^\circ - \delta) + \sin(90^\circ - \phi) \sin(90^\circ - \delta) \cos(180^\circ - HA) \\ \boxed{\sin a = \sin \delta \sin \phi + \cos \delta \cos \phi \cos HA}\end{aligned}$$

Now, at the rising or setting of the celestial body, its height  $a = 0^\circ$ ,

$$\begin{aligned}\sin a &= \sin \delta \sin \phi + \cos \delta \cos \phi \cos HA \\ \cos HA &= \frac{\sin a - \sin \delta \sin \phi}{\cos \delta \cos \phi} \\ \boxed{\cos HA = -\tan \delta \tan \phi} &\implies \text{Sunrise Equation}\end{aligned}$$

the hour angle ( $HA$ ) is the time from the moment of the upper culmination.

- a. Calculate the height of the upper and lower culmination of the star El-Nat ( $\beta$  Tau) the city of Dhaka ( $\phi = 23^\circ 81'$ ). The declination of the star  $\delta = +28^\circ 37'$ .
- b. Under what conditions will the star never rise in St. Martin Island ( $\phi = 20^\circ 61'$ )?
- c. What time is the star Aldebaran ( $\alpha$  Tau,  $\delta = 16^\circ 33'$ ) is located above the horizon in Dhaka during the starry day?

More Coming....

## Practice Questions

1. Name the constellations where the Milky Way passes through that are visible from Northern and Southern hemisphere

The rotational Galactic Center of the Milky Way lies in the direction of Sagittarius, with the glowing band of hazy light then stretching all the way across to its anticenter in Auriga, before returning back to Sagittarius. From Earth, stargazers can see 30 constellations contained in this region of sky, some of which only faintly touch the region.

- Northern: Monoceros, Canis Major, Orion, Gemini, Taurus, Auriga, Perseus, Cassiopeia, Lacerta, Cepheus, Cygnus, Vulpecula, Sagitta, Aquila, Serpens, Sagittarius, Scutum, Ophiuchus, Scorpius.
- Southern: Norma, Lupus, Ara, Circinus, Triangulum, Crux, Musca, Carina, Vela, Pyxis, Puppis.

2. Write down any five constellations that lie on current celestial equator

- Virgo (Vir), Serpens (Ser), Ophiuchus (Oph), Aquila (Aql), Aquarius (Aqr), Pisces (Psc), Cetus (Cet), Libra (Lib), Hercules (Her), Scutum (Sct), Delphinus (Del), Equuleus (Equ), Pegasus (Peg).

3. How to find/point at the vernal equinox?

- The vernal equinox is located slightly south of the circlet of Pisces. There is no bright star near its exact location hence it can be identified only through practice.

4. In order to know your latitude from stargazing alone, what other piece(s) of information do you need?

- Stars' altitude and declination.

5. In the constellation Crux, the  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta$  stars are named in which order?

- Clockwise

6. Which of these stars cannot be observed by an observer at certain location?

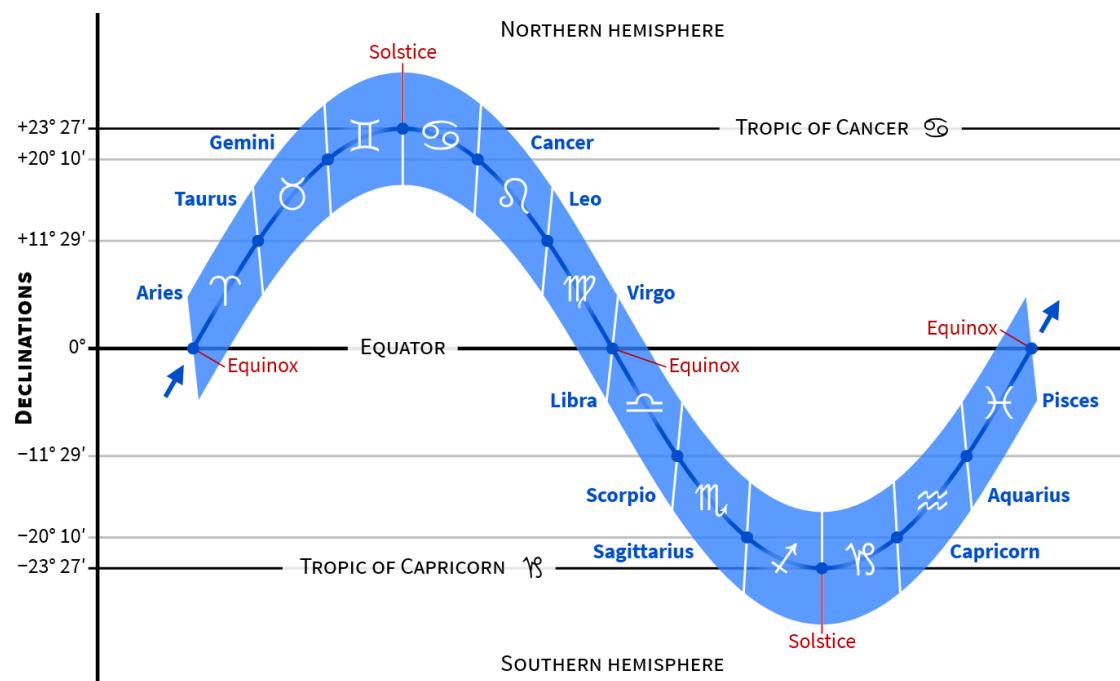
### Circumpolar Stars

This question relies on your comprehension of the night sky and rough idea of where the major stars are located. A concept introduced by this question is of circumpolar stars: they are stars that either never set or never rise. As the question asks the star that cannot be observed, it means that it asks for the lower circumpolar stars (stars that never rise) for an observer at certain location. The only challenge is to realize that lower circumpolar stars peak at an altitude of  $\delta + 90^\circ - \phi$ , where  $\delta$  is the declination of a star and  $\phi$  is the latitude of the observer. The condition for lower circumpolar stars would be that this altitude  $< 0^\circ$ . Therefore, the condition becomes  $90^\circ + \delta < \phi$ .

7. Name the Zodiac constellations according to sun's yearly path.

Spring	Aries, মেষ	♈	Autumn	Libra, তুলা	♎
	Taurus, বৃষ্টি	♉		Scorpio, বৃশিক	♏
	Gemini, মিথুন	♊		Sagittarius, ধনু	♐
Summer	Cancer, ককটি	♋		Capricornus, মকর	♑
	Leo, সিংহ	♌	Winter	Aquarius, কুম্ভ	♒
	Virgo, কন্যা	♍		Pisces, মীন	♓

Sign	Symbol	Astrology (Tropical)	Astronomy
Aries	♈	March 21 - April 20	April 19 - May 13
Taurus	♉	April 21 - May 21	May 14 - June 19
Gemini	♊	May 22 - June 21	June 20 - July 20
Cancer	♋	June 22 - July 22	July 21 - August 9
Leo	♌	July 23 - August 22	August 10 - September 15
Virgo	♍	August 23 - September 23	September 16 - October 30
Libra	♎	September 24 - October 23	October 31 - November 22
Scorpio	♏	October 24 - November 22	November 23 - November 29
Ophiuchus		-	November 30 - December 17
Sagittarius	♐	November 23 - December 21	December 18 - January 18
Capricorn	♑	December 22 - January 20	January 19 - February 15
Aquarius	♒	January 21 - February 19	February 16 - March 11
Pisces	♓	February 20 - March 20	March 12 - April 18



8. Give some practical advice for maximizing the number of meteors observed from a meteor shower during a short (3-4 hour observation session). Be specific and detailed.

- Observe during the peak night(s) of the specific shower!
- Observe from a dark location, preferably when the Moon is not up. This is so as to see as many meteors as possible
- Do not use a telescope/binoculars. Rather, just lie back and scan a large patch of sky (the larger the better) or
- In the Northern Hemisphere, where must one point the polar axis of the equatorial mount towards, such that moving the telescope in Right Ascension will most precisely mimic the motion of the sky over the course of a night?
- Generally, observe after local midnight as Earth would usually be moving into the stream of meteors then.
- If possible, observe when the radiant of the shower has a high altitude.

9. During an overnight observation session in December, a local astronomy club painstakingly recorded its observations. However, those notes ended being mixed up with observation logs from previous months. Which of the following objects is unlikely to have been observed during this December night?

- [Options]
  - A. Lagoon Nebula (M8) in Sagittarius
  - B. Orion Nebula (M42) in Orion
  - C. The Double Cluster (C14) in Perseus
  - D. The Andromeda Galaxy (M31) in Andromeda
  - E. Praesepe (M44) in Cancer

10. On a winter evening, Aquila the Eagle is found to be setting. You are given that Altair has a right ascension of  $19^h52^m$  and a declination of  $+8^\circ55'25''$ . Assuming that you are on the equator, what is the local sidereal time?

- Sidereal time is calculated from the Hour Angle + RA of a particular object, where the hour angle is the number of hours after the object has passed the meridian. In other words if  $0^h$  is the local meridian,  $18^h$  would be at the western horizon. In this case, it is given that  $19^h52^m$  is at that horizon. This means that the correct local sidereal time is  $1^h52^m$ .

11. Filters are often used in practical astronomy for image enhancement, especially when imaging deep-sky objects as they appear very dim even through a telescope. When imaging an emission nebula, which color/combination of filter(s) can be used to minimise light from background sources, thus allowing the nebula to stand out better?

- An emission nebula emits light that is dominated by the H- $\alpha$  spectral line (657 nm) of the Balmer series (ionized hydrogen emission). Hence, an emission nebula appears red. To enhance the image, one should minimize light from other background sources (non-red light) to enter the eye. Hence, one should use a red color filter to allow the nebula to stand out more. Yellow filters are generally used when trying to look at the yellow dust tails of comets and not DSOs. Stacking all of the filters listed defeats the purpose of using a color filter, which is to expose the sensor to light of a certain wavelength (color).

12. For an observer in the Northern Hemisphere, how does the right ascension of the Sun change from the start to the end of Summer?

*NB: we define the start of a season by its corresponding equinox/solstice. So the summer solstice marks the start of Summer.*

- Recall that during the northern vernal equinox, the Sun is at 0h by definition. The right ascension of the sun increases as the season progresses. Further, after 1 season, the Earth would have moved along 1/4 of its orbit, leading to From 6<sup>h</sup> to 12<sup>h</sup>.

13. Suppose your latitude is 45° N. What is the Sun's elevation above the southern horizon at noon on the summer solstice?

- The celestial equator is tilted at an angle equal to your latitude from the zenith. In this case, the celestial equator is 45° from your zenith and therefore 45° above the southern horizon. The Sun is 23.5° above the celestial equator on the summer solstice. Therefore the Sun is  $23.5^\circ + 45^\circ = 68.5^\circ$  above the southern horizon.

14. Let's consider stars for which it is true at the same time: (i) in their diurnal motion they cross the horizon, and (ii) their upper culmination occurs to the north of the zenith. Express the fraction of such stars as a function of latitude  $\phi$ . Assume that stars are distributed uniformly over the celestial sphere.

$$\text{Case 1: } \varphi \leq -45^\circ \implies -(90^\circ + \varphi) \leq \delta \leq 90^\circ + \varphi;$$

$$\text{Case 2: } -45^\circ \leq \varphi \leq 0^\circ \implies \varphi \leq \delta \leq 90^\circ + \varphi;$$

$$\text{Case 3: } 0^\circ \leq \varphi \leq 45^\circ \implies \varphi \leq \delta \leq 90^\circ - \varphi;$$

$$\text{Case 4: } \varphi \geq 45^\circ \implies \delta \in \emptyset.$$

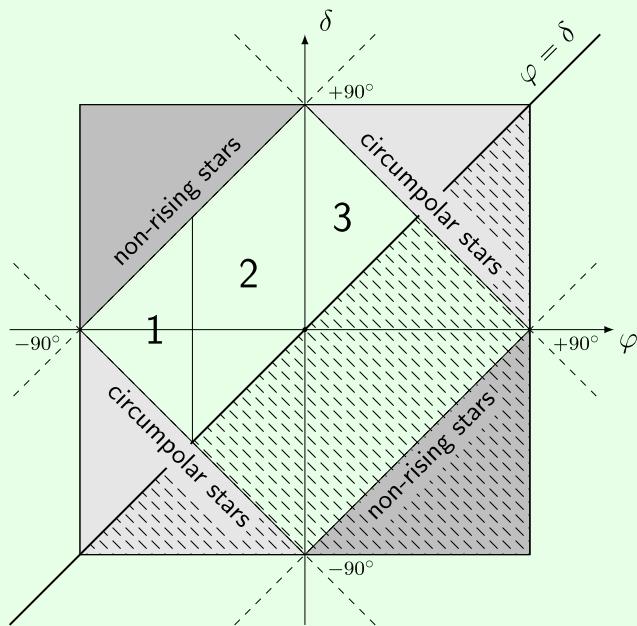


Figure 19: Selecting areas that meet the conditions of the problem

## 15. Estimating the Local Sidereal Time (LST) from Star Chart.

Method 1: Using RA of known object and estimating LHA to obtain LST

From the definitions of the following variables, the following equation relates LST, RA at meridian and local hour angle (LHA),

$$LHA_{\text{obj}} = LST - RA_{\text{obj}}$$

Then, find an object with known RA, and estimate its LHA. For an object on the meridian,  $LHA = 0$ . For rising and setting objects,  $LHA < 0$  or  $LHA > 0$  respectively.

e.g. Arcturus has a RA of  $14^h15^m$ ; it is estimated to have crossed the meridian (LHA) about 30 mins ago, i.e.  $LHA_{\text{Arcturus}} = 0^h30^m$ .

Hence,  $LST = LHA_{\text{obj}} + RA_{\text{obj}} = 14^h15^m + 0^h30^m \approx 14^{\text{h}}45^{\text{m}}$ .

Method 2: By first principles, definition of LST

By definition, the  $LST = LHA_{\text{Vernal Equinox}}$ , and  $RA_{\text{Vernal Equinox}} = 0^\circ$ .

In a tropical (calendar) year, there are 365.25 solar days, but 366.25 sidereal days. By definition, **at local noon** on the day of Vernal Equinox (usually around March 20-21), the vernal equinox is at the local meridian everywhere, thus  $LST = 0^h$ .

Thus, the  $LST$  at local noon every day after that increases by a small amount equal to the time required for the Earth to rotate an extra small angle due to its orbital motion, i.e. for each complete solar day the Earth completes a small fraction of the extra sidereal day. This amount is,

$$\Delta LST = \frac{1 \text{ day}}{366.25 \text{ day}} \times 24^h00^m = 3.93^m = 3^m56^s$$

If we take January 28, approximately 10 months and 7 days after Vernal Equinox (there is inaccuracy introduced here as each month is not of equal length),

$$LST_{\text{noon of 28 Jan}} = \left( \frac{10}{12} \times 365.25 + 7 \right) \times 3^m56^s = 1197^m = 20.40^h$$

If we do have a calendar, we can get a more accurate calculation, with 313 days between March 21 and January 28

$$LST_{\text{noon of 28 Jan}} = 313 \times 3^m56^s = 1231^m = 20.51^h$$

Now if we know time when any starchart is taken, Suppose the starchart was taken at 06:15 UTC, i.e. 6.15am at the Greenwich Meridian,

$$LST_{6.15 \text{ am on 28 Jan}} \approx 20.51^h - (12^h - 6.25^h) = 14.76^h \approx 14^{\text{h}}45^{\text{m}}$$

## 16. Estimating the Local Time (LT) from Star Chart.

For this you must know coordinates of a star lying on Celestial Equator. Recall that Orion lies along the celestial equator – and that one notable feature of the Belt of Orion are the declination of the belt stars, that is, their declination is close to  $0^\circ$ .

As an estimate, we take Mintaka's declination to be  $0^\circ$ , such that it would culminate at the zenith (center of the starchart) when the local sidereal time is equal to its right ascension. Now estimate whether Mintaka is to the east/west of the local meridian, i.e. if it has already culminated and thus its hour angle will be  $HA > 0$ . Thus, we measure Mintaka's distance from the center of the starchart (zenith), to estimate its hour angle,  $d = X$  cm. Then the fraction outward from the center of the starchart of radius is,  $f = d/r$ .

Then, to a first approximation, ignoring distortion from the stereographic projection, the hour angle  $HA$  of Mintaka from the zenith is approximately,  $HA = 90^\circ \times f$ . Then the local sidereal time at the time of the starchart is (right ascension of Mintaka  $\alpha = 5^h 33^m$ )

$$LST = HA + \alpha$$

Let's take a star chart that is dated 11 Mar, close to the vernal equinox 21 March, we can take the  $LST_{0000}$  at local solar midnight as approximately  $12^h - 10 \times 4^m = 11^h 0^m$ .

Then, to find the local sidereal time at local civil midnight, we need to introduce a correction as Observer's timezone (UTC+LT) is not in alignment with its longitude ( $\lambda$ ),

$$\begin{aligned} LST'_{0000} &= LST_{0000} - \Delta LST \\ &= LST - \left( LT - \frac{\lambda}{360} (24^h) \right) \end{aligned}$$

Therefore, the time before midnight  $\Delta T$  is simply the difference in the local sidereal times at the time of the starchart and at local civil midnight,

$$\Delta T = LST'_{0000} - LST$$

Therefore, the local time of the star chart is  $0000h - \Delta T = \text{ANSWER}$ .

## 17. Estimating the position of the Moon on certain local time on Star Chart after certain days.

At the same local (civil) time on the **next day**, the night sky would have rotated westward by an amount approximately  $4^m$  in RA.

However, due to the Moon's orbital motion about the Earth (anti-clockwise), it moves eastward relative to the fixed stars and its RA increases by approximately,

$$\begin{aligned} \Delta RA &= \frac{360^\circ}{T_{\text{sid}}} \\ &= \frac{360^\circ}{27.3 \text{ days}} \end{aligned}$$

$$= 13.19^\circ/\text{days}$$

$$\approx 53^m/\text{day}$$

Since the Moon's orbital plane is similar to the rest of the planets, it will thus appear eastward along the ecliptic by about 50 mins.

18. **Star-trails** Your task in this problem will be to take a photo of star-trails in the sky (stars) they draw due to the rotation of the Earth around its own axis. You can use either method to do this—several shorter exposures, which you then combine into a single image using appropriate software, or taking one long exposure.
- (a) Take a photo of the star-trails so that the image contains the North Pole. Try to be as long as possible so that arcs form, the corresponding hour angle should definitely exceed  $0^h 10^m$ . Describe in detail the procedure taking a picture. Record the time and place of acquisition, the length of individual exposures and parameters in the solution camera. Attach a printed photo in inverted colors to your solution.
  - (b) What curves do the stars plot in the photograph depending on the declination  $\delta_*$  of the star and also on declination  $\delta_c$  of the center of the frame? Justify your answer.

To solve this problem, we will assume for simplicity that the rays are coming from infinity as it passes through the lens does not change direction when passing through the optical center. Then it is clear that such rays from a given star describe the mantle of a cone during the day with an apex angle of  $180^\circ - 2\delta_*$ , the axis of which intersects the plane of the camera sensor at an angle  $\delta_c$ . The trajectories of the stars in the image will therefore be conic sections. If the star never sets below the sensor plane ( $|\delta_* - \delta_c| > 90^\circ$ ), this is generally an ellipse (in the special case, when the world pole is in the center of the image, i.e.,  $\delta_c = 90^\circ$ , the stars will draw circle). If the lower culmination of the star occurs in the plane of the sensor, it is a parabola ( $|\delta_* + \delta_c| = 90^\circ$ ). If the star falls below the plane of the sensor (but also rises above the plane of the sensor, i.e.,  $|\delta_* + \delta_c| < 90^\circ$  and  $|\delta_c - \delta_*| < 90^\circ$ ), it is generally a hyperbola. And in the special case when we have  $\delta_* = 0$ , the cone degenerates into a plane. Stars of the world therefore, the equator draws a line in the image.

Note: Star trails start becoming visibly apparent when a source that covers 1px stretches out to span 5px in any direction

### 5.3 Observing Planets

- Let us say we are observing sky from a dark location and all planets are visible in the sky. Arrange the planets of the solar system in the descending order of their apparent brightness as observed from the Earth.
  - Venus, Jupiter, Saturn, Mars, Mercury, Uranus and Neptune.

No penalty if Mars and Mercury's positions in the list are interchanged.
- Given Jupiter is the only solar system object visible on a star chart on Taurus constellation. Given that its elongation is currently  $150^{\circ}\text{W}$ , estimate the month this picture was taken in?
- What would be the maximum altitude of inner planets as seen in the western sky?

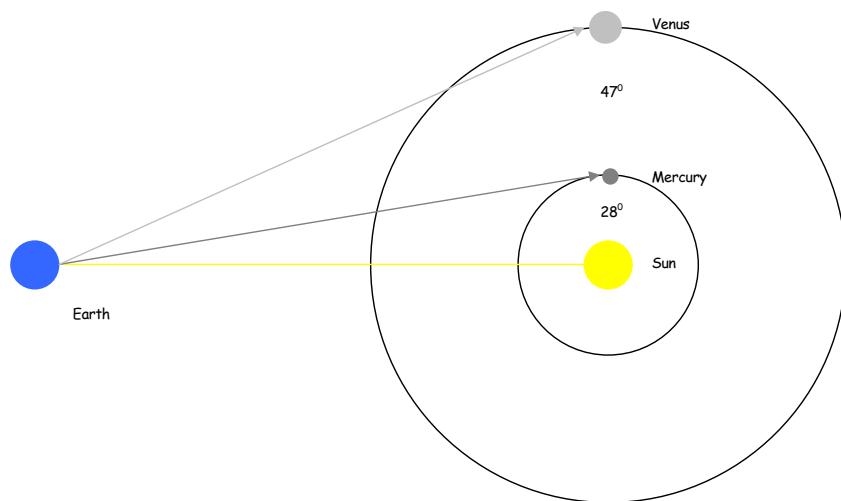


Figure 1. Inferior Planet Elongation.

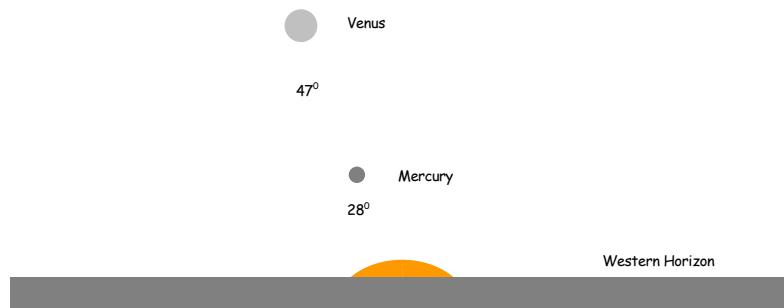


Figure 2. Mercury and Venus set shortly after the sun because of their low elongation.

- (INAO 2018) You were observing the sky from a location on the equator on the night of 20-21 March and you made following observations in her diary. Use the information given below to mark positions of the Sun, the Moon and the 5 planets on this circle at 11 am on the Vernal Equinox day (21<sup>st</sup> March).
  - Today is 11 days prior to the full Moon.
  - Saturn is seen in constellation of Sagittarius.
  - Jupiter is seen rising at the time of the Moon set.
  - Mars' position was coinciding with the center of Milky Way.

- Mercury set about 2 hours before the Moon.
- Venus was seen in the evening sky for about 2 hours after sunset.

### 5.3.1 Problem: Plotting the Moon and Planets

In this task, you have a map of the entire sky in the Mercator projection, in which the ecliptic coordinates are displayed as a rectangular grid. The map shows the ecliptic, the equator, and the position of the Sun. The local sidereal time is 14 h 30 min. Your task is to plot the positions of the planets and the Moon on the map, assuming that all of these objects are on the ecliptic at the given time. You can use the following information.

- **Mercury** is in the most ideal position possible to be observed in the morning before sunrise.
- **Venus** has a phase as in Figure 20 (the top of the image points north).
- The **Moon** is in the first quarter.
- The **Mars** is observed with an angular diameter of 17.92".

- We observe **Jupiter** with an angular diameter of 31.12"
- **Saturn** has an ecliptic longitude of 150°.
- **Uranus** has a right ascension of 12<sup>h</sup>
- **Neptune** is highest above the horizon

For each object, at least briefly justify your procedure.

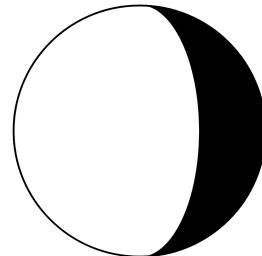


Figure 20: Venus Phase

#### Mercury

The ideal conditions for observing Mercury are when it is at maximum elongation. We observe it in the morning before sunrise, so it is west of the Sun, i.e. at maximum western elongation. Mercury's orbit has a large eccentricity, so the actual distance of Mercury from the Sun significantly affects the maximum angular distance it can reach from the Sun when viewed from Earth. We are interested in the ideal conditions, which occur at the greatest possible angular distance of Mercury from the Sun. Mercury must then be at aphelion, its distance from the Sun is

$$r_a = a_M(1 + e_M)$$

We calculate the angular distance of Mercury from the Sun based on Fig. 21

$$\sin \Delta\lambda = \frac{r_a}{r_\oplus} = \frac{a_M}{a_\oplus}(1 + e_M)$$

Therefore  $\Delta\lambda \approx 28^\circ$

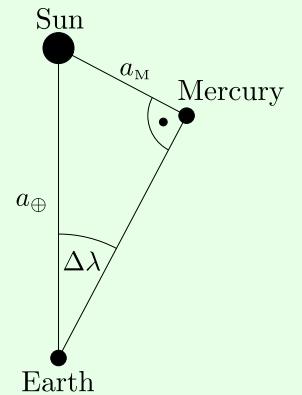


Figure 21

## Venus

From the photo of Venus we can find its phase angle, from which we can then determine the angular distance of Venus from the Sun. First we measure the diameter of the Venus disk  $2r$  and the distance  $r'$ . The radius of Venus in the image is  $r = 2.8 \text{ cm}$  (of course, it depends on the scale in which the image is printed). The distance of the boundary between light and shadow from the center of the Venus disk is  $r' = 1.3 \text{ cm}$ .

Figure 22 shows a schematic drawing of the view of Venus from Earth and from above. The angle  $\xi$  is calculated as

$$\xi = \frac{r'}{r}$$

The line pointing towards the Sun is perpendicular to the boundary between light and shadow, therefore the sum of the angle  $\xi$  and the phase angle  $\psi$  is equal to  $90^\circ$ . Therefore, for the phase angle,

$$\cos \psi = \frac{r'}{r}$$

Numerically we get  $\psi = 62^\circ$ .

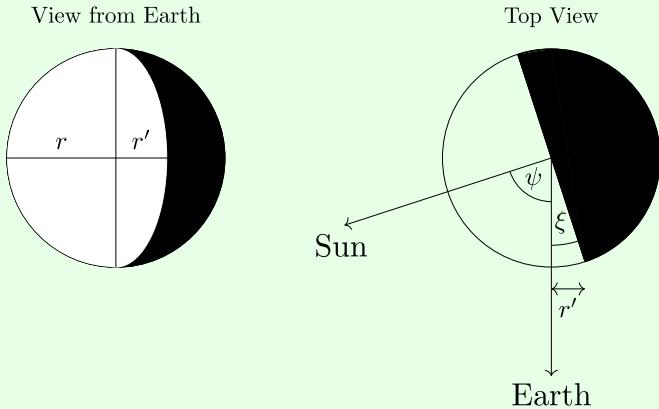


Figure 22: Calculation of the phase angle of Venus.

## Moon

The Moon is in first quarter, meaning it is located  $90^\circ$  east of the Sun.

## Mars

In the case of Mars and Jupiter, we only know their angular diameter. We will try to calculate their

The angular distance between Venus and the Sun can be obtained from the sine law for the Sun-Earth-Venus triangle, see Fig. 23

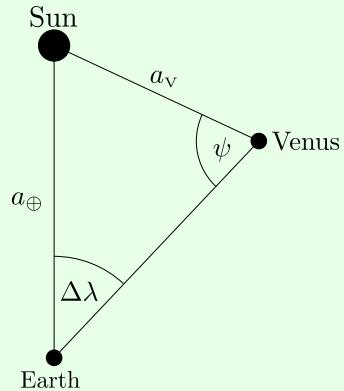


Figure 23

$$\frac{a_V}{\sin \Delta\lambda} = \frac{a_\oplus}{\sin \psi}$$

$$\Delta\lambda = \arcsin \left( \frac{a_V}{a_\oplus} \sin \psi \right) \approx 40^\circ$$

As stated in the assignment, the north is up in the image. The shadow is on the right, which means that Venus is west of the Sun.

angular diameters in significant aspects to see if they match the given values. We will try opposition and conjunction first, in which the planets have the largest and smallest angular diameters. For Mars, we get

$$\theta_{M,c} = \frac{2R_M}{a_M + a_\oplus} = 1.8 \cdot 10^{-5} \text{ rad} = 3.7'',$$

$$\theta_{M,o} = \frac{2R_M}{a_M - a_\oplus} = 8.66 \cdot 10^{-5} \text{ rad} = 17.9''.$$

We see that the angular diameter of Mars at the opposition matches the value given in the assignment. Mars is therefore  $180^\circ$  away from the Sun.

## Jupiter

The angular diameter of Jupiter in conjunction and opposition is

$$\theta_{Jup,c} = \frac{2R_{Jup}}{a_{Jup} + a_\oplus} = 1.51 \cdot 10^{-4} \text{ rad} = 31.1'',$$

$$\theta_{Jup,o} = \frac{2R_{Jup}}{a_{Jup} - a_\oplus} = 2.22 \cdot 10^{-4} \text{ rad} = 45.8''.$$

The given value matches Jupiter's angular diameter in conjunction, so Jupiter will be positioned in the same location on the map as the Sun.

## Saturn

Saturn has an ecliptic longitude of  $150^\circ$ , so on the map, you only need to measure the corresponding distance of  $150^\circ$ . Ecliptic longitude is measured from the vernal equinox towards the east. Since the distance from the vernal equinox to the edge of the map is insufficient, Saturn will be positioned at the right edge of the map.

## Uranus

Uranus has a right ascension of  $12^h$ , meaning it is located at the autumnal equinox. This point is in the constellation of Virgo, where the ecliptic intersects the equator.

## Neptune

From the given problem, we know that Neptune is currently culminating, meaning it is on the meridian. Its meridian position can either be estimated (less accurately) or calculated using spherical formulas. The hour angle of objects on the meridian is  $0^h$ , so its right ascension is equal to the sidereal time:

$$\alpha = 14^h 30^m = 217.5^\circ.$$

Right ascension is not the same as ecliptic longitude, but we can assume similar values for practical purposes. Neptune will be plotted at an ecliptic longitude of  $\lambda = 217.5^\circ$ . Both values should be approximately the same. To obtain the exact longitude  $\lambda$ , spherical trigonometry formulas must be used.

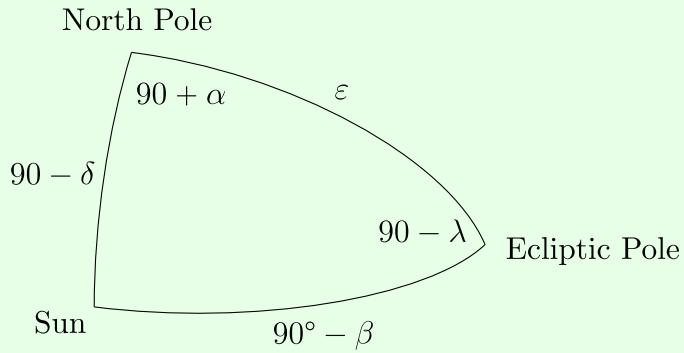


Figure 24: Ec-Eq Coordinate Transformation

In Figure 24, we have a spherical triangle used for converting between ecliptic and equatorial coordinates. The problem assumes that all planets lie precisely on the ecliptic, meaning their ecliptic latitude is  $\beta = 0^\circ$ . Since we know  $\beta$ ,  $\alpha$ , and the obliquity of the ecliptic  $\varepsilon$ , we apply the cosine rule:

$$\sin \beta = \sin \delta \cos \varepsilon + \cos \delta \sin \varepsilon \cos(90^\circ + \alpha),$$

which, using  $\sin \beta = 0$ , simplifies further to

$$\tan \delta = \tan \varepsilon \cos(90^\circ + \alpha).$$

Using the properties of sine and cosine, this expression can be further simplified:

$$\begin{aligned} \cos(90^\circ + \alpha) &= -\cos(90^\circ - \alpha) = -\sin \alpha, \\ \tan \delta &= \tan \varepsilon \sin \alpha. \end{aligned}$$

The declination of Neptune is  $\delta = -15^\circ$ . We calculate its ecliptic longitude using the sine rule (with additional simplifications using sine and cosine properties):

$$\cos \lambda = \frac{\cos \delta}{\cos \beta \cos \alpha}.$$

Using the arccos function on a calculator, we obtain  $\lambda' = 140^\circ$ , which is not the correct result—it should be close to the right ascension. Using the cosine property  $\cos x = \cos(360^\circ - x)$ , we find  $\lambda = 220^\circ$ . Since the difference from the right ascension is only  $2.5^\circ$ , we see that  $\lambda = \alpha$  is a reasonable approximation. When plotting on the map, this positional difference is negligible.

**Task:** Plot all planets and the Moon in Figure 25 on the next page!

The blue line on the map is the ecliptic and the green is the equator. Thanks to the Mercator projection, the ecliptic longitudes are displayed evenly, which greatly simplifies drawing objects on the map. All you need to do is determine the angular distance of the planets and the Moon from the Sun and convert it to the distance from the Sun in cm on the map.

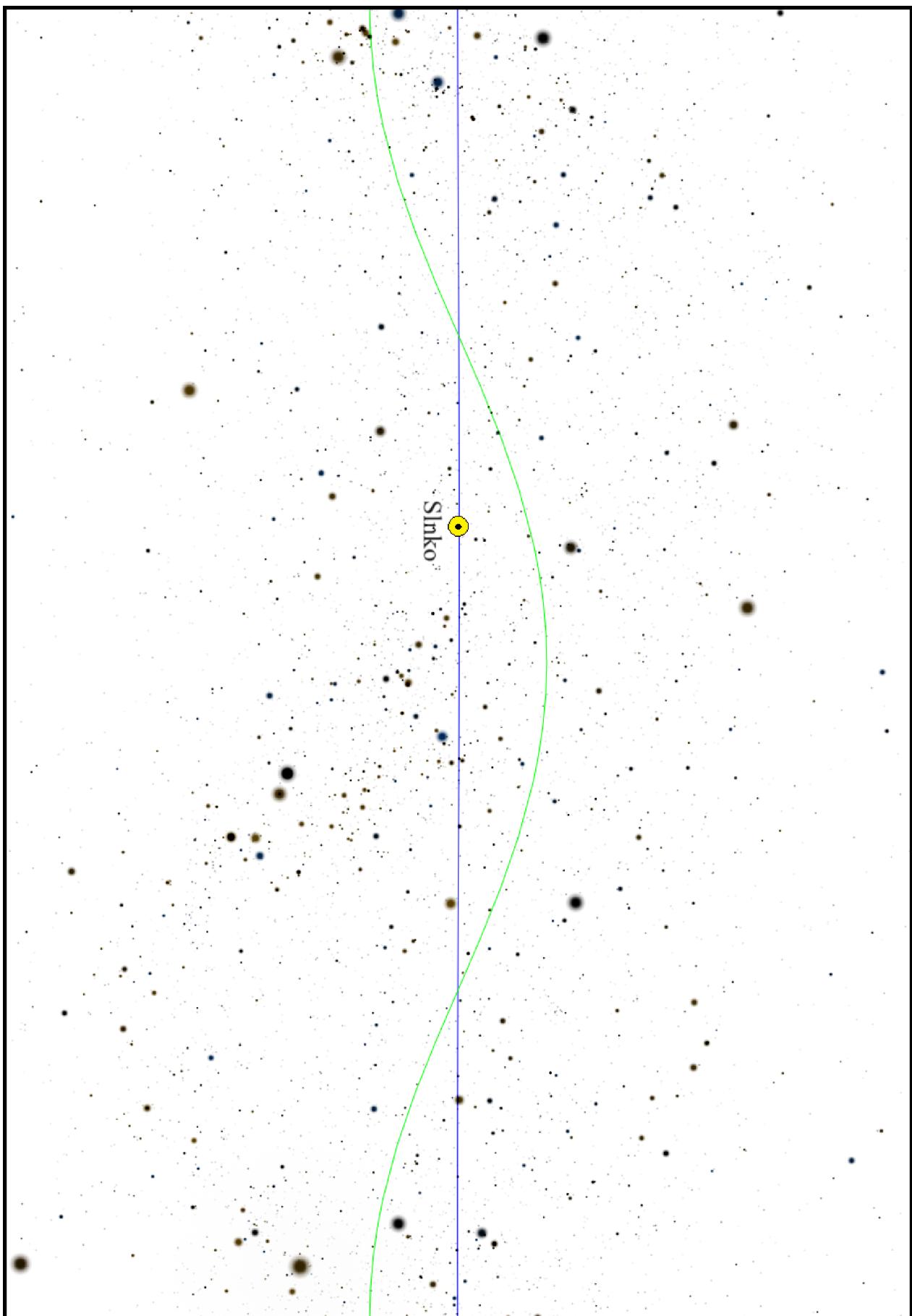


Figure 25: Planets Plotter

## 5.4 Telescope Aided Observation

Naked eye observations are fun (and necessary for the competition), but the real fun begins when we help our eye out by using telescopes - powerful instruments that reveal a whole new side to the starry sky! Telescopes can mainly be classified based on whether they use refraction or reflection for magnification, as well as their mounts and what coordinate system they are set up to follow. In this section, we will give a short introduction to all of these classifications that are necessary for you as a competitor in the IOAA to know.

### 1. Eyepiece

Lens placed near the focal point of the telescope.

*Determines:* magnification, apparent FoV, true FoV, and other specifications. Each eyepiece has a focal length just like the telescope.

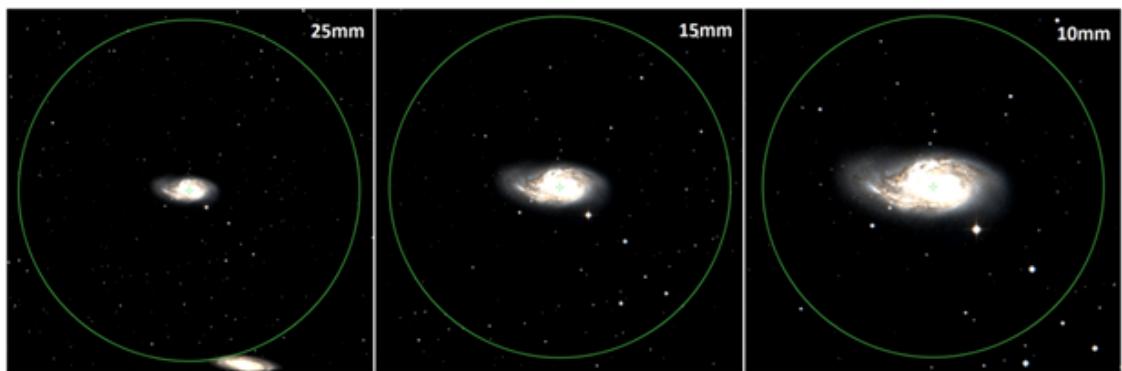
### 2. F-Number

Telescopes are often described by both their aperture size and f number. The f-number is the ratio of the focal length of the main lens or mirror to the aperture. In astronomy, as in photography, the aperture ratio is often denoted by  $f/n$  (e. g.  $f/8$ ), where  $n$  is the focal length divided by the aperture. For fast telescopes this ratio can be  $f/1\dots f/3$ , but usually it is smaller,  $f/8\dots f/15$ . These specifications are important because the brightness, size, and clarity of the image produced by a telescope depend on the aperture and focal length of its main lens or mirror. For example, a “150-mm (6-inch),  $f/8$  reflector” means the primary mirror is 150 mm (6 inches) in diameter and has a focal length of 1200 mm ( $8 \times 150$ ), or 48 inches ( $8 \times 6$ ).

If the aperture ratio is large, near unity, one has a powerful, “fast” telescope; this means that one can take photographs using short exposures, since the image is bright. A small aperture ratio (the focal length much greater than the aperture) means a “slow” telescope.

**Question** A special telescope features a  $3x$  optical scope with a diameter of 25mm, and a length of 120mm. Find the f-number of the scope.

### 3. Magnification



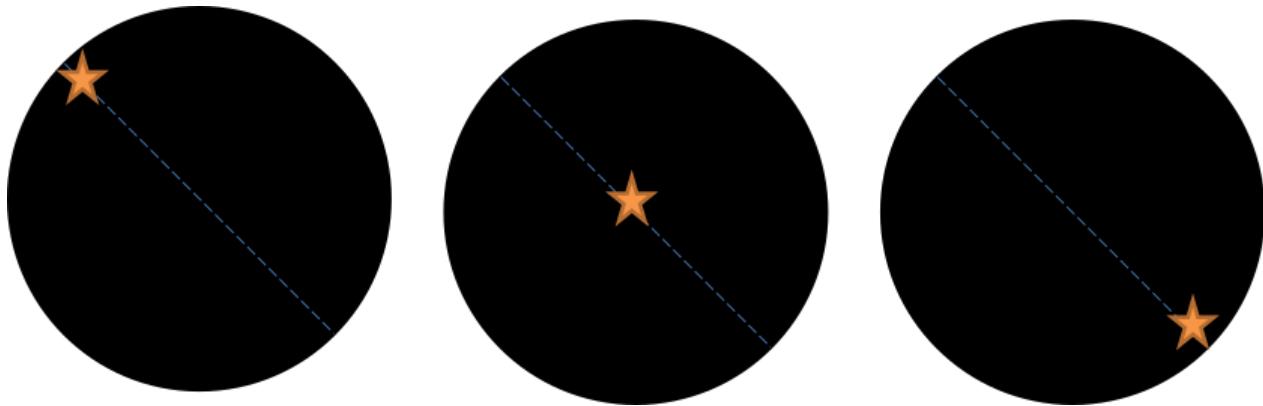
So for a given telescope, changing the eyepiece to another with a lower focal length will increase the magnification.

$$\text{Magnification} = \frac{\text{Telescope focal length}}{\text{Eyepiece focal length}} = \frac{\text{Aperture} \times \text{Focal Ratio}}{\text{Eye Piece Focal Length}}$$

#### 4. Field of View

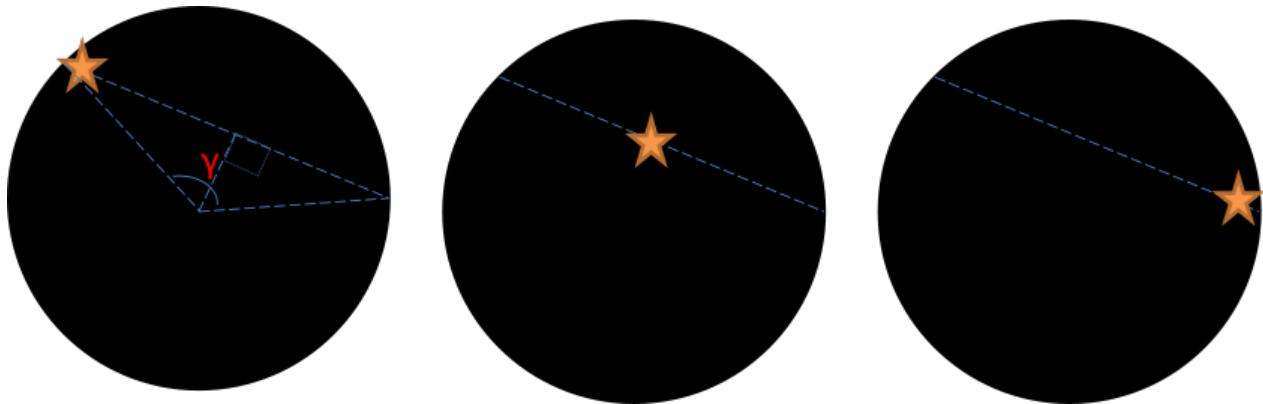
In general, the field of view (FOV) describes the area of a target (measured as an angle from the location of viewing) that can be seen on the chip of a CCD-camera or when looking through an eyepiece.

##### Equation of FOV



$$\text{FoV}[deg] = \omega \times t \times \cos(\text{declination}) = \frac{360^\circ}{23^h 56^m 4^s.1} \times t \times \cos \delta$$

If the star passes through the chord of the field of view, you can measure the magnitude of the central angle, which rests on this chord.  $t$  - is the time during which the star passes through this chord. Then this chord =  $vt \times \cos \delta$ . The same chord =  $a \cdot \sin \frac{\gamma}{2}$ .



**Actual/True field of view (TFOV):** the angular size of the amount of sky that can be seen through an eyepiece when used with a particular telescope, producing a specific magnification. It is typically between one tenth of a degree, and two degrees.

**Apparent field of view (AFOV):** it is a measure of the angular size of the image viewed through the eyepiece, in other words, how large the image appears (as distinct from the magnification). This is constant for any given eyepiece of fixed focal length, and may be used to calculate what the actual field of view will be when the eyepiece is used with a given telescope. The measurement ranges from 30 to

110 degrees.

If the apparent field of view is known, the actual field of view can be calculated from the following approximate formula:

$$\text{TFOV} = \frac{\text{AFOV}}{M}$$

For a telescope with focal length of  $f$ , object image size of  $d$ ,

$$\text{AFOV} = 2 \cdot \tan^{-1} \left( \frac{d}{2f} \right)$$

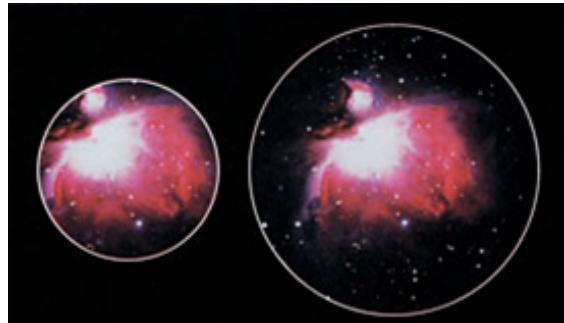


Figure 26: Same magnification but different AFoV and TFOV

**5. Planetary (color) filters:** Color filters are mostly used to enhance the color contrast differences between surface features on the moon or planets. The filters screw into a standard eyepiece barrel. The contrast differences are subtle and some observers report little or no observable differences. It may take patience and experience to recognize the differences.

**UHC** Ultra High Contrast filter. Increases the contrast of planetary and emission nebulas.

**OIII** Oxygen-III filter. Similar to UHC, but higher contrast on certain nebulas.

**H $\beta$**  Hydrogen Beta filter passes a particular colour of hydrogen light found in certain nebulas.

**Polariser** Darkening the moon and enhancing contrast on the planets.

**IR pass** Infrared pass filter is useful for getting steady views of the planets because IR is less disturbed by the atmosphere.

**Light pollution** A filter to increase contrast of objects when observing from urban areas. Darkens the sky by blocking street-lights whilst passing light from other colors.

## 6. Finderscope

Regardless of what kind of finder you are using you will have to align it with the telescope. The procedure is fairly simple and is best done during the day. The key thing is that you are aligning the finder to the telescope and not the other way around.

You want to do this during the day using a fixed land object. At night the things in the sky are moving which makes it more difficult to get the alignment correct.

During the day, set your telescope so that you can see a distant object, at least 1/4 mile away and farther is better. I prefer the cross arms on a telephone or power pole. That gives me a very well defined target right where the cross arm meets the pole. But the top of a chimney, a letter on a distant

sign, or something similar can work as well. This is your alignment target

Here are the steps to follow.

- Using your low power eyepiece point the telescope at the target and get it centered in the field of view of the eyepiece. Ignore the finder for now.
- Switch to a high power eyepiece and again, get that target centered
- Lock the scope into position in any way you can. You don't want it to move
- Look through the finder and spot the target
- Using the adjustments on the finder bracket adjust the finder until the target is centered in the finderscope.
- Go back to the eyepiece and make sure the scope has not moved. The target should still be centered
- Check the finder again and make any final adjustments

When the finder and the telescope both are lined up on the same point on your target, you are all set and ready to take your telescope out under the stars.

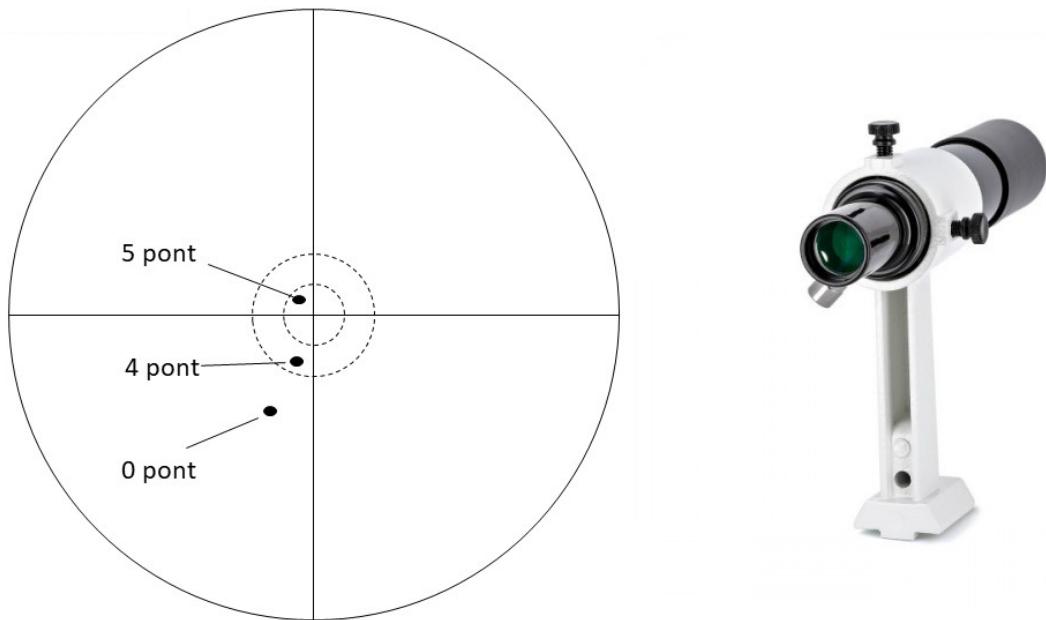


Figure 27: Left: Finderscope FOV and marking, Right: A typical finderscope.

## 7. Telescope Mount

There are two main types of telescope mount – equatorial and altitude-azimuth (“alt-az”)– with many variations.

*Equatorial:* This type of mount has been popular, almost universal, since telescopes achieved any sort of useful size. As we have seen, the equatorial system of co-ordinates ( $\alpha, \delta$ ) is based on the rotation of the Earth. A telescope with one axis aligned with the polar axis only needs to be driven around this axis at the sidereal rate to track astronomical objects.

*Alt-az* mounts are the simplest telescope mounts. Advantages: Cheap and simple to operate. Telescope moves up/down (altitude) and left/right (azimuth). Reflecting telescopes using this mount are known as *Dobsonians*. There are a couple of (minor) drawbacks to alt-az telescopes:

- The necessity for continuous rapid calculation of altitude and azimuth. This has been solved by the power of modern computers – so not really a problem at all.
- We have seen that the relationship between horizontal and equatorial co-ordinates can be expressed by two equations such as:

$$\sin a = \sin \delta \sin \phi + \cos \delta \cos \phi \cos H$$

and,

$$\sin A = -\frac{\sin H \sin \delta}{\cos a}$$

Note that, in the second equation, if the altitude ( $a$ ) approaches  $90^\circ$ , the azimuth ( $A$ ) approaches infinity. What this means, of course, is that for an object which passes through the zenith, as it does so, its azimuth jumps instantaneously from  $90^\circ$  East to  $90^\circ$  West (or from  $90^\circ$  to  $270^\circ$ ). In practice, it means that for objects near the zenith, it is very difficult to transform quickly enough and accurately enough from equatorial to horizontal co-ordinates and a small patch of sky near the zenith is effectively inaccessible, even though the telescope can easily point there. Simple observing program planning should avoid problems from this source.

## 8. Field Rotation

Alt-az mounts are to be avoided due to a phenomenon known as field rotation. Field rotation occurs due to the design of the alt-az mount. One axis, the azimuth axis, rotates around a vertical line passing from the center of the telescope to the zenith (left to right). The altitude axis rotates about a horizontal axis (up and down). Both axes must rotate at different rates to maintain the object in the field of view (FOV). As the Earth rotates about its axis, the central object in the field of view will remain centered but other objects in the FOV will appear to rotate with elapsed time. Field Rotation is an undesirable effect on time-exposure astrophotographs caused when an “Alt-Az” (“altitude-azimuth” or alt-azimuth) mount (sometimes called a “Dobsonian” or “fork mount”) is used to hold and point a telescope with a camera. It is also sometimes called Frame Rotation because the objects framed by the photograph seem to have rotated while the picture was taken.

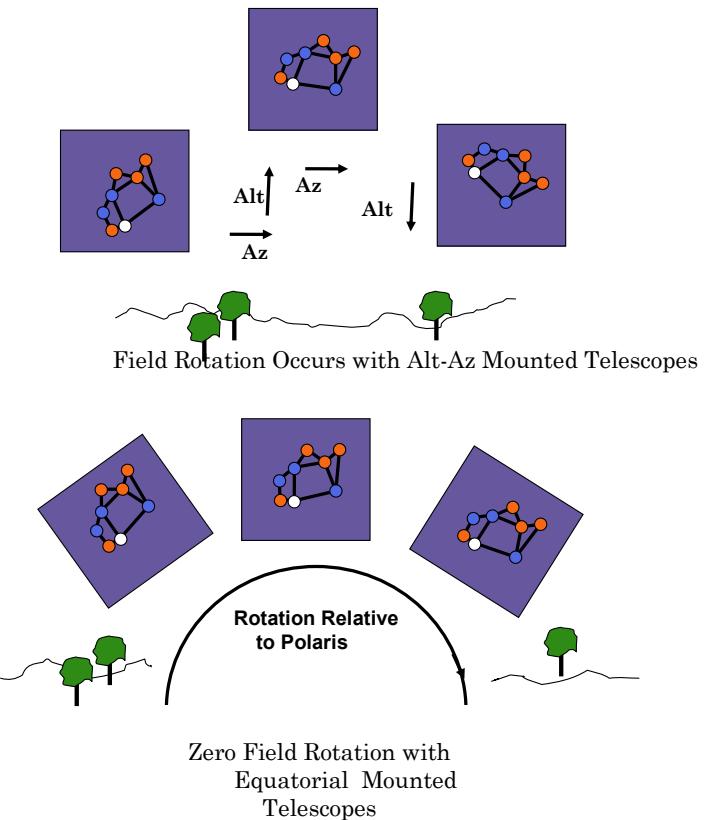


Figure 28: Field Rotation: Alt-Az and Equatorial Mounts

Let the FOV of the telescope be represented by a square and follow the motion of Sagittarius as it rises in the east. Because the alt-az mount can only move around the azimuth axis and the up and down on the altitude axis, the FOV remains fixed with the bottom parallel to the horizon. The objects in the sky, however, are rotating around the celestial pole star, Polaris. So asterisms and binary stars appear to rotate in the FOV. An equatorial mounted telescope does not suffer field rotation because the telescope is polar aligned and the FOV does not remain horizontal as it tracks; the telescope rotates. So the FOV matches the rotation of the object and it remains in the same fixed position.

**Mathematical Concepts Behind Field Rotation** Stars appear to rise in the east and set in the west, rotating about the north celestial pole star, Polaris. Rising stars will reach their highest elevation in the sky as they cross the local meridian, due south of the line between Polaris and the zenith. The altitude indicates the vertical position of the star with  $0^\circ$  at the horizon and  $90^\circ$  at the zenith. From direct observation, the following aspects are known about rate of rotation

1. The maximum rate of field rotation occurs as the star passes through the zenith.
2. The rate of field rotation is minimal when a star passes through the prime vertical at the horizon.
3. Considering the azimuth only, the rate of field rotation is highest when the star passes through  $0^\circ$  (N) and  $180^\circ$  (S), and lowest when the star passes through  $90^\circ$  (E) and  $270^\circ$  (W).
4. Regarding latitude, field rotation is highest at the Earth's equator and non-existent at the NCP and SCP.

$$\text{Rotation Rate} = \frac{\omega_{\oplus} * \cos(\text{Latitude}) * \cos(\text{Azimuth})}{\cos(\text{Altitude})} \quad (5)$$

where  $\omega_{\oplus} = 4.178 \times 10^{-3}$  degrees/second; Earth's rotation.

If we only consider changing the values of the azimuth in Equation 1, the least amount of field rotation (zero) is along the prime vertical (due east or west) because east is  $90^\circ$  from north ( $\cos 90^\circ = 0$ ) and west is  $270^\circ$  from north ( $\cos 270^\circ = 0$ ). Looking toward the other directions, the maximum rate of field rotation is when the star is due south ( $180^\circ$  from north;  $\cos 180^\circ = 1$ ) or directly north where  $\cos 0^\circ = 1$ .

$$\begin{aligned} \text{Least ROR}_{E,W} &= \frac{\omega_{\oplus} * \cos(\text{Lat}) * 0}{\cos(\text{Alt})} = 0; \quad (\text{Az} = 90 \text{ or } 270) \\ \text{MAX ROR}_{N,S} &= \frac{\omega_{\oplus} * \cos(\text{Lat}) * 1}{\cos(\text{Alt})}; \quad (\text{Az} = 0 \text{ or } 180) \end{aligned}$$

The altitude function deals with values between the horizon ( $0^\circ$ ) and the zenith ( $90^\circ$ ), so only considering changes to the values of the altitude in Equation 1 and using the trig values given above we get to following.

$$\text{RoR}_{\text{Horizon}} = \frac{\omega_{\oplus} * \cos(\text{Latitude}) * \cos(\text{Azimuth})}{1}; \quad \text{Alt} = 0$$

so the rate depends solely on the latitude and azimuth.

$$\text{RoR}_{\text{Zenith}} = \frac{\omega_{\oplus} * \cos(\text{Latitude}) * \cos(\text{Azimuth})}{0}; \quad \text{Alt} = 90$$

which is an undefined quantity and not allowed.

**Practice QnA**

**1. In what situation would polar alignment be necessary?**

- To track stars/to counter diurnal motion.

**2. What is the purpose of using a finderscope?**

- Find objects more easily due to larger FOV. Image is upside down and left-right inverted.  
Magnification:  $6 \times 30$ , or  $8 \times 50$  typically.

**3. When not in use, how should accessories (eyepieces, diagonals, binoculars, finderscopes, etc.) be stored?**

- Store in dry box/Ziploc bag to combat humidity, with foam/cushion to add stability and protection.

**4. A Newtonian needs to be well collimated (i.e., mirrors aligned to one another) to produce a sharp image. If you have set up a Newtonian Reflector outdoors, how can you quickly test if it is out of collimation?**

Perform a star test (i.e. defocusing a star at high magnification to make the diffraction rings more visible, and then checking if the diffraction rings are aligned or off-center).

**5. How do you polar-align your telescope near the equator, where Polaris cannot be seen most of the time?**

- Use compass to find magnetic North for alignment of azimuthal axis, then adjust mount's elevation/altitude to Singapore's latitude (less accurate), or

Drift alignment: observe North/South drift then adjust altitudinal axis, observe East/West (RA) drift then adjust azimuthal axis (more accurate).

**6. After assembling, if you can move the main optical tube easily, is the counter weight located at the correct or incorrect position?**

- Correct position. The counter weight should balance with the OT, so a little force should move it smoothly.

**7. Why do we need to align an equatorial telescope towards the North Celestial Pole / Polaris?**

- As stars revolve around Polaris every  $23^h 56^m$ , we can use only one knob to trace the star easily.

**8. Given a telescope with an aperture of 100mm and a focal length of 1600mm, when a 1.25-inch eyepiece of focal length 40mm is used, what is the effective magnification?**

- Telescope magnification is calculated by dividing the focal length of the telescope by the focal length of the eyepiece. So  $40\times$ . Again to find the magnification, we can use

$$\text{Magnification} = \frac{\text{Aperture} \times \text{Focal Ratio}}{\text{Eye Piece Focal Length}}$$

9. You would like to maximise your view of the Pleiades star cluster ( $110'$ ) in your eyepiece. Given the following details of your telescope, which eyepiece should you choose? (1 inch = 2.54cm)

Telescope: 5-inch aperture, f/6

Let the eyepiece focal length be  $x$  mm and apparent field-of-view be  $y^\circ$ .

$$\text{focal length} = (\text{aperture size}) \times (\text{focal ratio}) = 5 \times 2.54 \times 6 \times 10 = 762 \text{ mm.}$$

$$\text{magnification} = \frac{\text{focal length of telescope}}{\text{focal length of eyepiece}} = \frac{762}{x}$$

$$\text{true field-of-view} = \frac{\text{apparent field-of-view}}{\text{magnification}} \times 60 = \frac{y}{\text{magnification}} = \frac{60xy}{762} \text{ arcminutes}$$

Calculate for each option with the different values of  $x$  and  $y$ . This gives 35 mm focal length,  $40^\circ$  apparent field-of-view.

10. You brought out your club's 6" F/6 Newtonian telescope to observe M6. With a quick search you realize M6 is  $25'$  in angular diameter. Which eyepiece would you attach to the telescope to maximize your view of M6 while still ensuring the whole of M6 can be seen in the eyepiece? (FL =Focal length, AFOV = Apparent field of view, 1 inch = 2.54cm)

#### *Options*

A. FL: 32mm, AFOV:  $50^\circ$

D. FL: 7mm, AFOV:  $60^\circ$

B. FL: 40mm, AFOV:  $40^\circ$

E. FL: 4mm, AFOV:  $70^\circ$

C. FL: 13mm, AFOV:  $50^\circ$

Focal length = aperture  $\times$  Focal ratio =  $(6 \times 2.54) \times 6 \times 10 = 914.4$  mm.

$$\text{Magnification} = \frac{914.4}{x}$$

$$\text{TFOV} = \frac{\text{AFOV}}{M}$$

$$\begin{aligned} \text{TFOV [in arcmin]} &= \text{TFOV [in degrees]} \times 60 \\ &> 25' \end{aligned}$$

Option D matches the perfect condition.

11. The Celestron C8 is a Schmidt-Cassegrain reflective telescope with a focal ratio of 10 and a diameter of 203.2 mm. Using an objective lens (eyepiece) with a focus of 25 mm, a circular squirrel with a diameter of 25 cm fills the field of view completely. Assuming an apparent field of view of  $50^\circ$ .

The focal length of the telescope is 203.2 cm. Using the focal ratio, we can infer that the focus is ten times longer, i.e. 2032 mm.

$$\text{Using, } \text{FoV} = \frac{50}{M} = 50 \times \frac{f_{oc}}{f_{ob}} = 37'.$$

The distance from the squirrel to the observer is 2328 cm. The distance can be obtained using trigonometry. Specifically,  $d = \frac{h}{\tan \alpha}$ , where  $\alpha = 50^\circ$ .

The resolving power is  $0.68''$  from  $\theta = 1.22 \frac{\lambda}{D}$ .

12. The Celestron Advanced VX Y Go-To Reflector Telescope has an  $Y''$  optical tube assembly with specification  $f/5$ , where  $Y$  is an unknown value. The focal length of the optical tube is 1016 mm. Two eyepieces, one with diameter 8 mm and another with diameter 25 mm were provided. Determine the minimum size of a crater on the Moon that can be resolved by this telescope. Assume light of wavelength 550 nm.

The aperture diameter is determined by

$$D = \frac{f}{N} = \frac{1016}{5} = 203.2 \text{ mm}$$

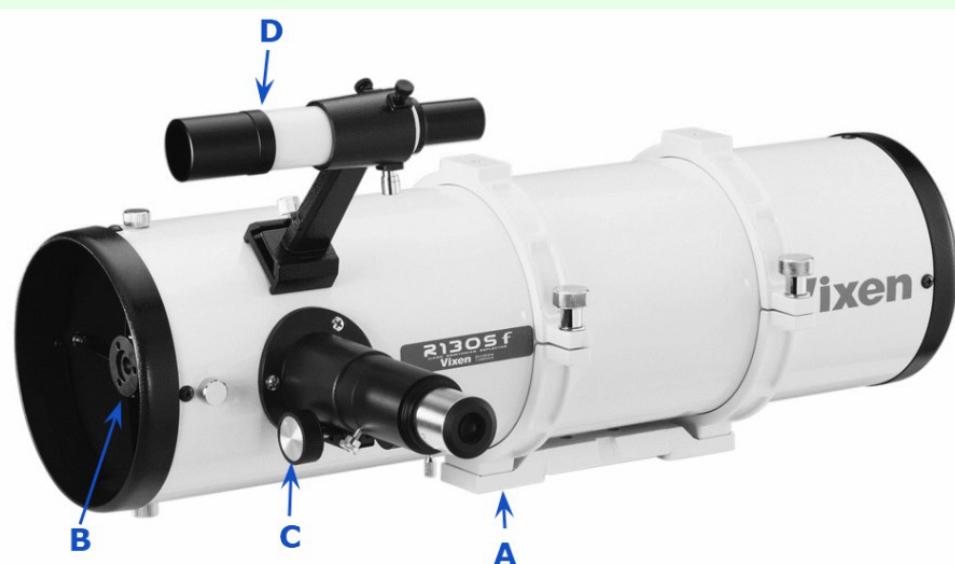
Using the formula for the Rayleigh criterion  $\theta = 1.22 \frac{\lambda}{D}$  with  $\lambda = 550 \text{ nm}$ ,  $D = 203.2 \text{ mm}$ , we get that the minimum angle that can be resolved is  $0.0001892^\circ$ .

Using  $s = r\theta$  and the Earth-Moon distance of  $3.843 \times 10^8 \text{ m}$ , we see that the minimum distance on the Moon that can be resolved is

$$s = 5.843 \times 10^8 \times \frac{0.0001892}{360} \times 2\pi = 1.27 \text{ km.}$$

13. The following is an image of a Newtonian Telescope. Label the following telescope parts in the image given above.

A: Dovetail      B: Secondary Mirror      C: Focuser Knob      D: Finderscope



### **Try Yourself**

- T1. Student A has just received a telescope from her professor. Her professor had performed some measurements on the telescope, and told her that it has an effective focal length of 1800mm, with an aperture of 90mm. Student A next chooses to use a 5 mm Plossl eyepiece, with an advertised apparent field of view (AFOV) of 40°.
- i. Calculate the f/ratio of this scope
  - ii. Calculate the resultant magnification that this setup provides
  - iii. Calculate the exit pupil of this setup.
  - iv. Calculate the true field of view (TFOV) for this setup.
  - v. Is this setup good for deep sky astrophotography? Justify your answer.  
(Hint: Think about highest useful magnification. Also, an average dark adapted human eye has an entrance pupil of about 7mm)
- T2. Upon further investigation, Student A discovered that a 3X Barlow lens had been left in the telescope's visual back. She thus removed the Barlow. She also changed the eyepiece to a 10mm Nagler, with an advertised 80° wide-view AFOV.

Calculate the new effective focal length, f/ratio, magnification, exit pupil and TFOV.

- T3. Chuan Ming is observing an unknown bright star through a refractor on an equatorial mount with a 2-degree true field-of-view. He observes that the star takes roughly 9.23 minutes to fully cross the diameter of the eyepiece field of view. Estimate the declination of the star. Assume the star is in the northern hemisphere.
- T4. A curious astronomer has observed two stars while they have been passing across the very center of telescope's field of view at the same time interval. One day, he noticed one of them rising and another setting simultaneously. Show that the stars will appear in exactly opposite directions on the horizon. Ignore any atmospheric effects.

## 5.5 Astrophotography

As the prices of DSLRs drop since their inception, more people now can take photographs of the night sky. The art of Astrophotography has caught on to become a serious pastime for amateur astronomers.

### Photography Jargon

Before we jump in, we should familiarise a little on some technical jargon that is commonly used in the photography community. The ultimate goal of a photographer is to control the amount of light captured by the sensor when taking a photo. It cannot be too much light else the photo will come out overexposed (too bright). The converse is true too, when the camera does not capture enough light. To achieve a good control over light, photographers concern themselves with 3 main settings:

Camera Settings	What it Controls
Shutter Speed / Exposure Length	The length of time the sensor is exposed to light. (e.g. 1/3s, 1/1000s, 1s, etc.)
ISO (pronounced “eye-soh”)	The Sensitivity of the sensor. Higher ISO = More Sensitive
f-Number/Ratio	Aperture size of the lens. Same definition with a telescope’s f-ratio.

These three settings are what a photographer uses to control the amount of light that hits the sensor.

The last setting is known as the Zoom. It controls how magnified the image will be. It is usually expressed as the focal length of the lens. (e.g., 18mm, 35mm, 120mm etc.)

## 5.6 Guessing the correct Magnitude

Conditions for comparing sight according to the Pickering method:

- a small angular distance of the comparison star from the variable star;
- the spectral classes of the comparison star and variable star must be adjacent on the Harvard scale of spectral classes

**IDEA** 1. Choose 2 stars with known magnitudes of more or less the same brightness,

**IDEA** 2. Divide the interval between them into 10 parts (or in the Neyland method - Blazhko into any number of parts, for example, into 5)

**IDEA** 3. Determine where the observed star is on the interval,

**IDEA** 4. By linearizing the scale, you determine the magnitude.

## 6 Practice Olympiad Problems

Practice problems are from Bangladesh Olympiad on Astronomy and Astrophysics (BDOAA), Singapore Astronomy Olympiad (SAO), Indian National Astronomy Olympiad (INAO), Czech Astronomy Olympiad (CzAO), International Earth Science Olympiad (IESO), and International Olympiad on Astronomy and Astrophysics (IOAA). Problem setters of respective questions are credited.

### 6.1 General Instructions in typical IOAA

You have XX minutes to read the questions and plan your observations. Do not talk to other participants. When you are shown the sign to ‘GO NOW’ by the supervisor, follow the directions to the telescope location taking with you the questions, clipboard and pen/pencil (a red light will be provided at the telescope). Keep your distance from other participants and do not talk to them. Show your badge and code to the assistant at your telescope.

You will have a total of XX minutes to complete the observing tasks, starting when all participants are ready. At the end of XX minutes take your papers and clipboard (leave the light) and wait until called to leave the observing location. Follow the directions back to the preparation hall. Keep your distance from other participants and do not talk to them.

You will have another XX minutes to process your observations and complete the answer sheet (there will be a calculator, geometrical instruments etc.). If you had any technical problems you can write a report for your team leader on the form in the answer sheets. At the end of XX minutes place your answer sheets and the report in the envelope and wait at your desk until directed to leave the hall.

### 6.2 How OBS Marking Works

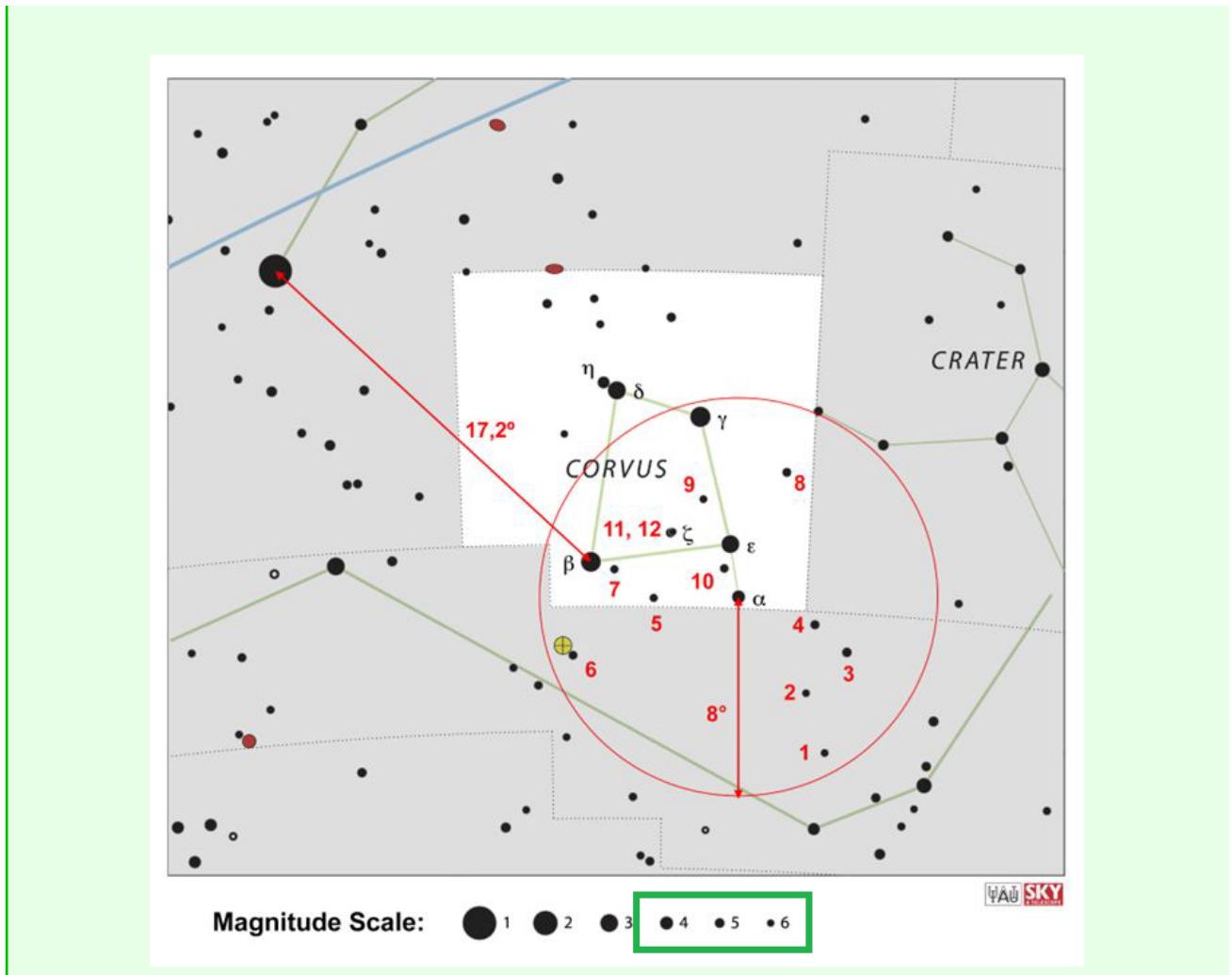
The observation/star chart round is all about **PENALTIES!** You can lose more points due to silly mistakes than the ones you earn from correct answers. This happened to one student from Bangladesh in IOAA 2024. When answering or drawing on star charts, keep the following in mind:

**Tip 1 Answer exactly what is asked.** For example, if the question specifies that star names should be written in IAU designation only, do so. Avoid writing something like: Alpha Ori/Rigel.

See the mistake? Instead of writing “ $\alpha$  Ori/Betelgeuse,” I wrote \*Rigel\* this will result in **0 points**. TRUST me, these kinds of blunders happen more often than you’d think! Better to write only  $\alpha$  Ori or Betelgeuse if you’re sure about the answer.

**Tip 2 Read the question carefully!** Words like *within, in between, inside, and boundary* may have subtler meanings than you initially understand. For example in IOAA 24 the question was

Consider that the angular distance between the stars Kraz (Beta Corvi) and Spica (Alpha Vir) is  $17.2^\circ$ . Using the Star Chart, draw the circumference and count which stars between magnitudes 4 and 6 exist **within** a radius of  $8^\circ$  from Alpha Corvi.



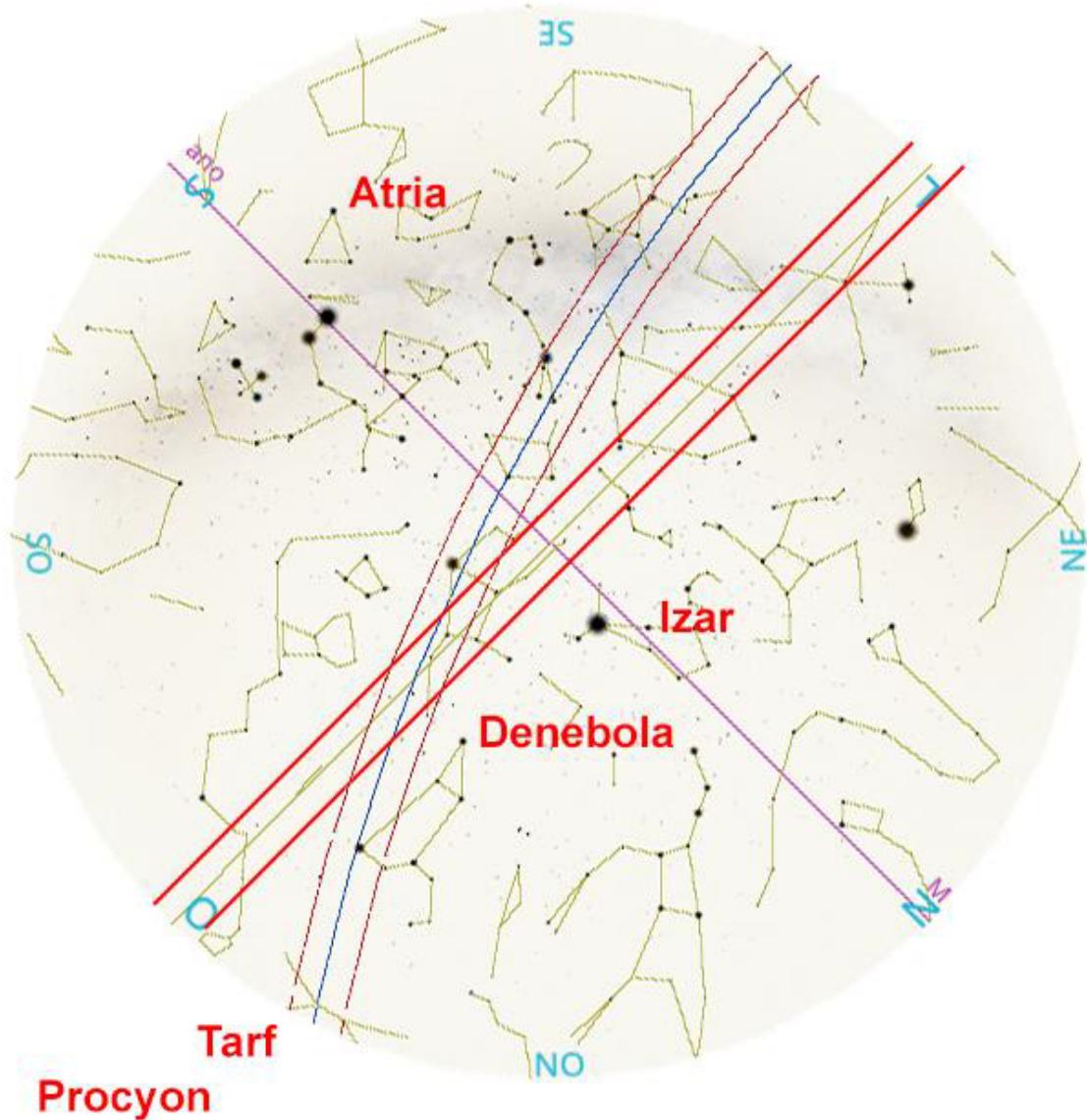
Some students in IOAA24 marked all the stars between  $4 \leq m \leq 6$  not only within the boundary but all over the map, loosing more points as penalty than earned!

**Tip 3** Observation accuracy in real/simulated sky. Suppose you're asked to calculate RA/DEC/Mag of a star. The right answer and the marking scheme would look like this,

1. Declination:  $+69^\circ 09' 11''$ 
  - (a)  $< \pm 1.5'$   $\Rightarrow$  4 points
  - (b)  $\leq \pm 3'$   $\Rightarrow$  2 points
  - (c)  $> \pm 3'$   $\Rightarrow$  0 points
2. Right ascension:  $9^h 55^m 54^s$ 
  - (a)  $< \pm 22.5 s$   $\Rightarrow$  4 points
  - (b)  $\leq \pm 45 s$   $\Rightarrow$  2 points
  - (c)  $> \pm 45 s$   $\Rightarrow$  0 points
3. Magnitude: 10.2 mag
  - (a)  $< \pm 0.4$  mag  $\Rightarrow$  2 points
  - (b)  $\leq \pm 0.8$  mag  $\Rightarrow$  1 points
  - (c)  $> \pm 0.8$  mag  $\Rightarrow$  0 points

So you see, you need to precise within arcseconds/seconds not arcminutes or several minutes! Recommended answers typically lies within  $\sim 5 - 10\%$  range. How to do that!?  $\Rightarrow$  PRACTICE your senses and buildup intuition, observe the sky in real time!

**Tip 4** Be precise with locations in charts. Most of the marks depend on your accuracy. Deviating too much from the correct position will result in penalties. Let me show you the boundaries for drawing equator, ecliptic and meridian line (IOAA 2024):



- 4 points (1 point for each Cardinal Point)
- 6 points (2 points for each line)

Each correct line drawing has full mark within the range, if you divert outside the recommended range some penalty ( $\sim 50\%$ ) will be applied. Answer outside the range will result in 0 points.

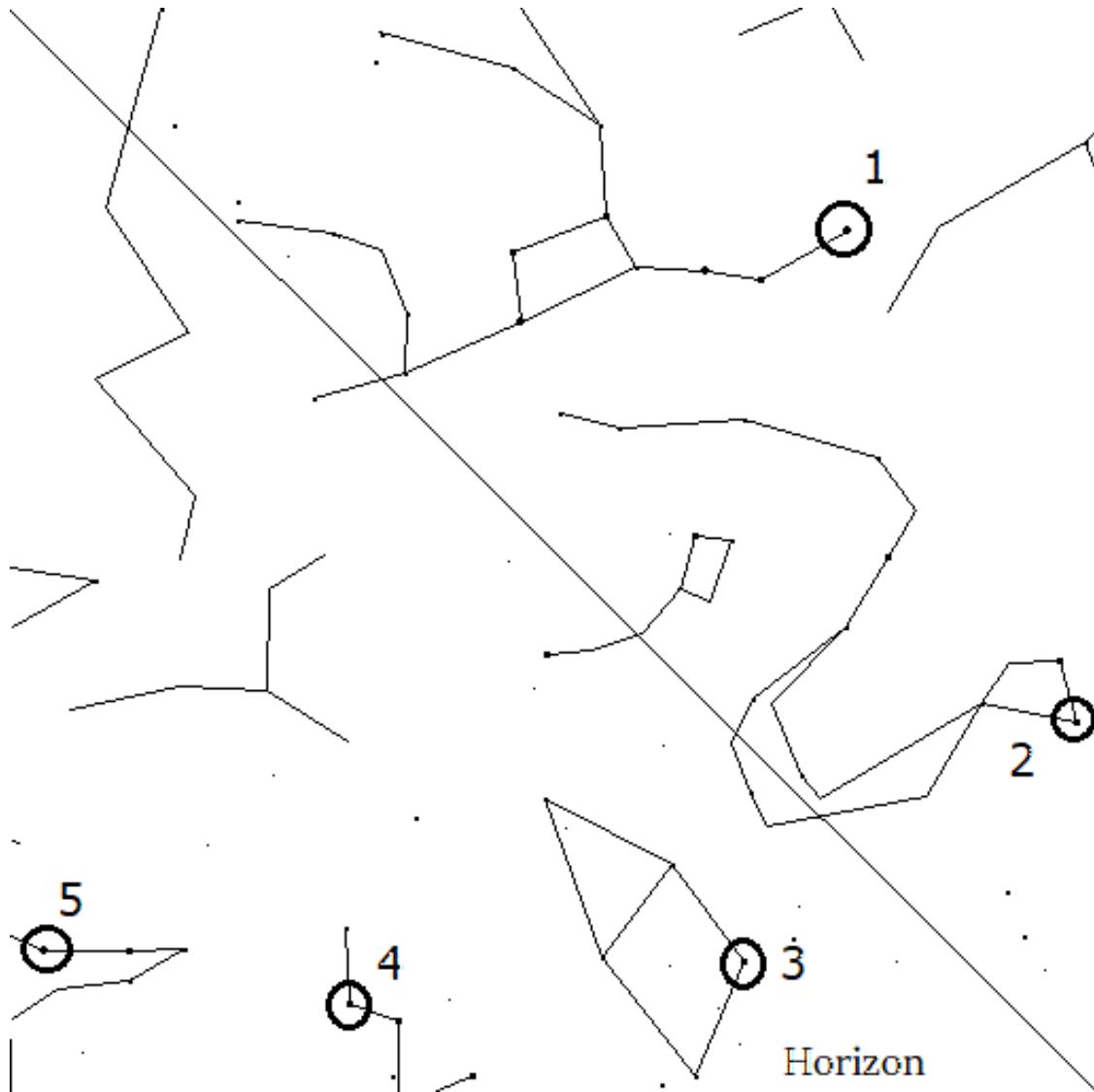
**Tip 5** Work with printed maps! Before IOAA be sure to create star maps of the host country for the duration of the event.

## 6.3 BDOAA

From my experience as an amateur Astronomer and IOAA team leader for 5 years I came across these things student should be aware and mindful about.

### 6.3.1 2019

On 23<sup>rd</sup> March, 2019, Mahmud and Fahim were observing their local sky with their IAU100 Bresser Telescope. According to their observation Mahmud made a sky map using “Your Sky” website. Now you’ve to find few things according to their map—

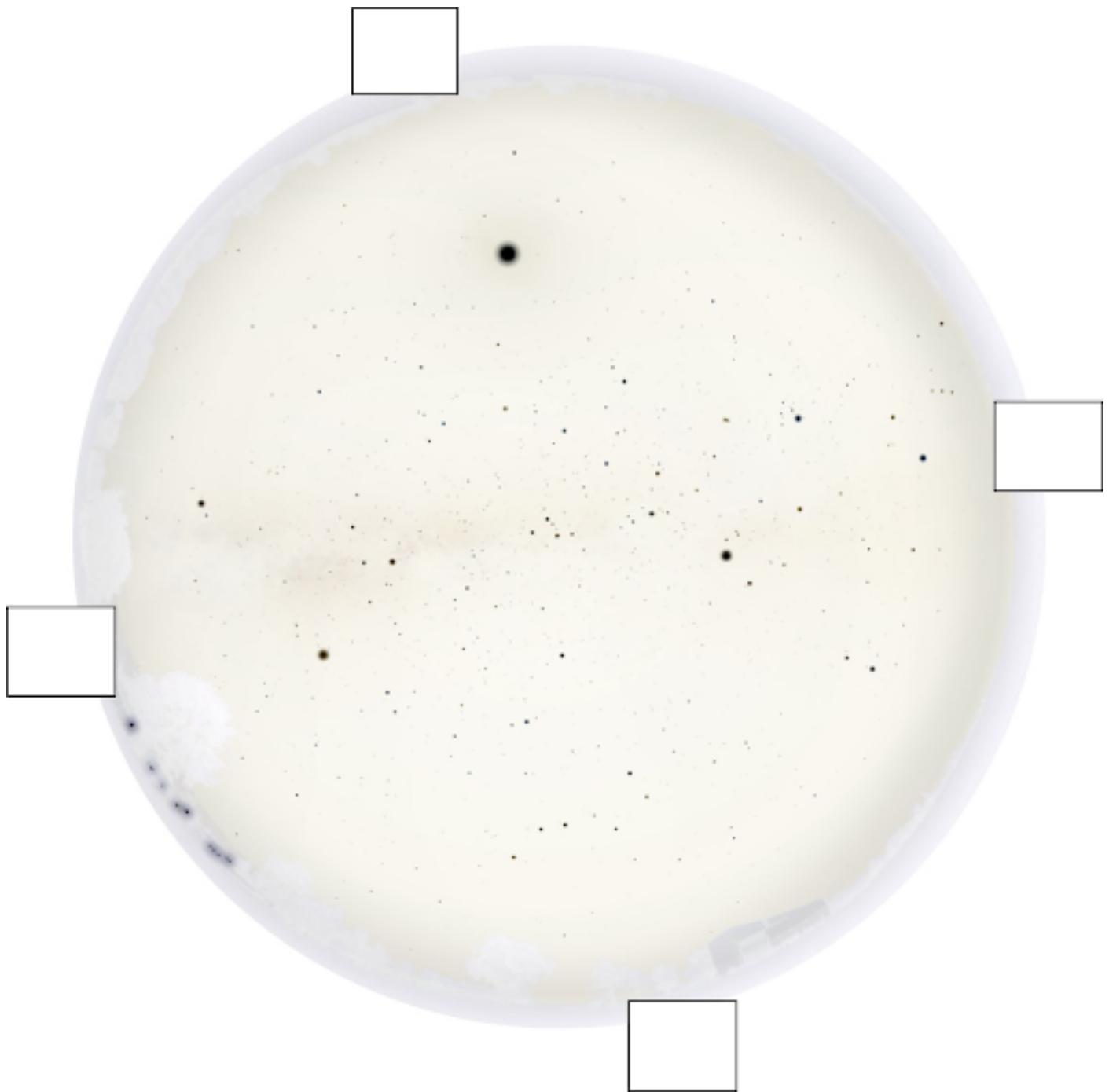


- Name the stars 1,2,3, 4, and 5 and their constellations.
- Draw a circle for the Circumpolar star region. [A circumpolar star is a star, as viewed from a given latitude on Earth, that never sets below the horizon due to its apparent proximity to one of the celestial poles.]
- If the Field of View (FOV) of this map is  $80^\circ$ , find the angular distance from  $\alpha$  Cassiopeia to  $\alpha$  Ursa Minor. [Hint: the line passes through the center of the eyepiece of the Telescope]

- d. Prove that if the right ascension of a star is equal to its altitude from one point/place then the magnitude of its longitude and declination is also equal from that point/place.

### 6.3.2 2021

Fahim is an Astronomer who likes to observe the sky. He travels the world with his telescope. Referring to the image of the night sky at an unknown location, Fahim was observing the sky.



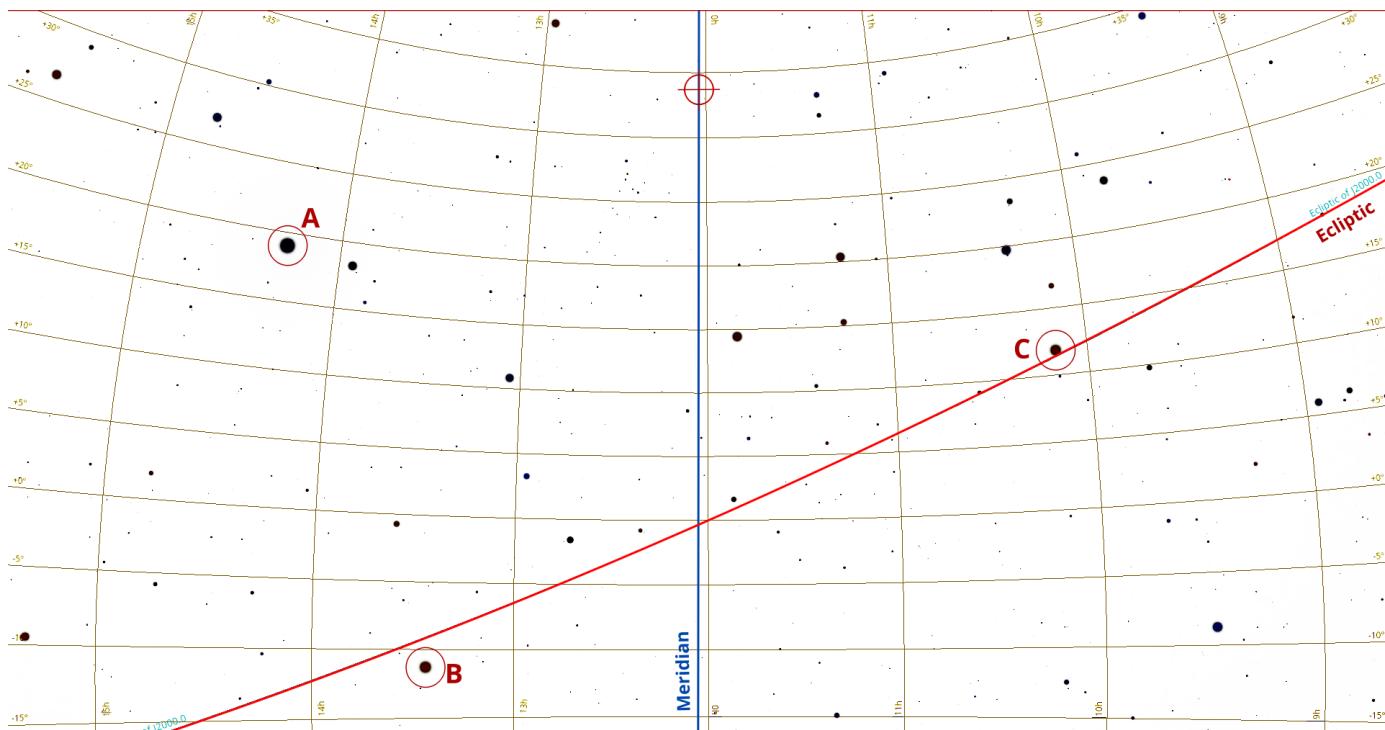
On the image, answer the following questions. [For this you can use any means to copy the image then draw everything necessary with computer paint or whatever you like]

- a. Identify the cardinal points.

- b. Trace out the ‘Little Dipper’ and label it accordingly.
- c. Trace the ‘Great Square of Pegasus’ and label it accordingly.
- d. Trace out two major complete IAU constellations that are visible (other than Cygnus, Ursa Major, and Ursa Minor).
- e. Mark the positions of two prominent nebulae that are visible and label them accordingly.
- f. Mark the positions of two prominent open clusters that are visible (except Hyades) and label them accordingly.
- g. Mark the approximate positions of two prominent galaxies that are visible and label them accordingly
- h. Approximately, what is the latitude of this location?

### 6.3.3 2024

This is the sky map at local solar midnight on the observation date. The crosshair ( $\oplus$ ) on the sky map indicates the Zenith. The inclined line represents the ecliptic and the vertical line going through the zenith represents the local meridian. The near-rectangular tiled grid on the sky is that of the equatorial coordinate system ( $\alpha$  and  $\delta$ ).



- (a) Draw the outlines of the two zodiac constellations that are visible in the sky map. [2]
- (b) Name the circled stars and estimate their equatorial coordinates ( $\alpha, \delta$ ). [4.5]
- (c) (i) Estimate the date of the observation. [2]

*Hint: On which constellation is the Sun located on the date? Remember that during the winter solstice,  $\alpha_{\odot} = 18^{\text{h}}$  and during the summer solstice  $\alpha_{\odot} = 6^{\text{h}}$ .*

- (ii) How long does Butch have to wait for the rescue team? [0.5]
- (d) Before the rescue team arrives, you have to be at the same place where you're now. Estimate the latitude of your current location. [1]  
*Hint: The Declination of Polaris is 90°.*

## 6.4 INAO

### 6.4.1 2019

The picture below was taken on 24<sup>th</sup> December 2019, from some place in India, showing the crescent of the Moon near the horizon (the horizontal dashed line marks the horizon of the place). Field of View (FOV) of the image is 60°.

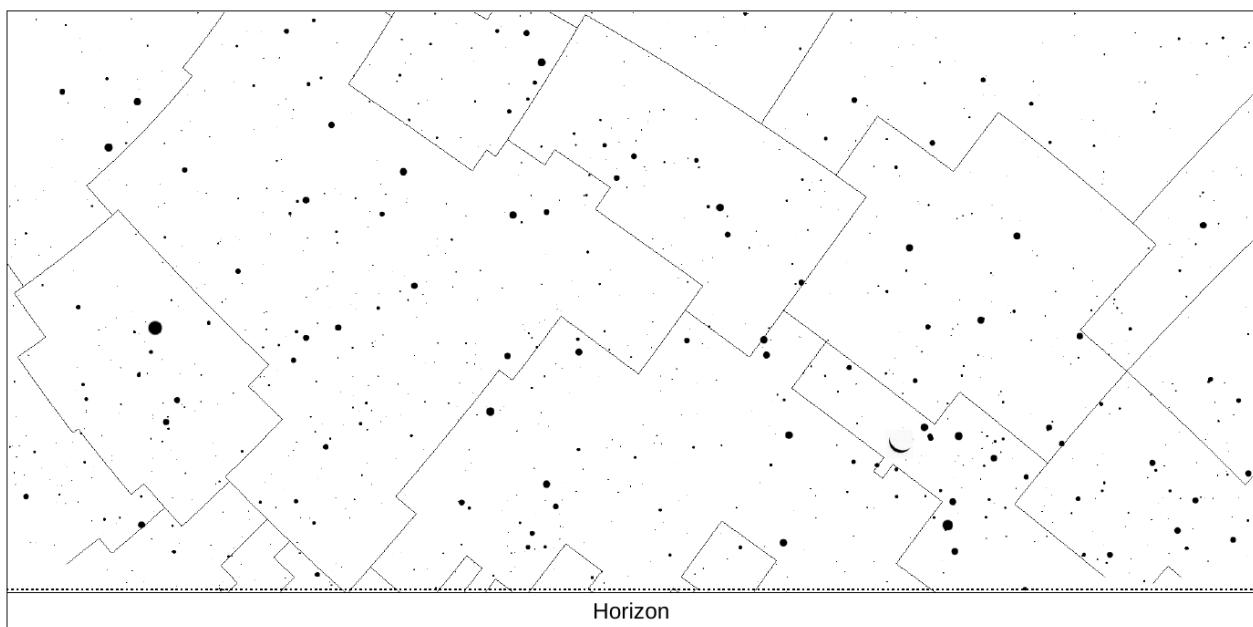


Figure 29: Negative image of certain patch of the sky on 24<sup>th</sup> December 2019

Note: The images printed are colour-inverted, i.e. the bright parts of the image appear black and dark parts appear white. Thus, the black dots are stars and planet and the dark crescent is actually bright crescent of the moon.

- At which of the following times this picture may have been taken? Give justification for your answer.  
18:00 hrs, 22:00 hrs, 01:00 hrs, 05:00 hrs.
- Write the names of the constellations present in the image of the sky.
- The map also includes a planet. Mark the planet on the map with a circle and label as 'P'.
- A zoomed-in image of the lunar crescent is given in the answersheet. On this image mark the approximate directions to the cardinal points. [East-West-North-South] Note: You may assume the box in the answersheet has a linear angular scale along the horizon.
- Find approximate latitude of the place. horizon.

#### 6.4.2 2018

Refer to 4

#### 6.4.3 2016

The skymap below [Figure 30] corresponds to sky above Nagpur ( $21^{\circ}$  N,  $79^{\circ}$  E) at 09:00 am on 1<sup>st</sup> February 2014. If you are not used to using sky maps, it is important to note that sky map is usually seen lying down on the ground (feet to the South), facing the sky with map in your hand. Thus, East is on the left of the map and West is on the right. Answer the following questions:

- a. Mark Polaris with letter ‘P’.
- b. Circumpolar stars for a given place are the stars, which will never go below the horizon. Draw boundary of this region and mark it by the letter ‘C’.
- c. The celestial equator is just a projection of the Earth’s equator in the sky. It will be the locus of points which are equidistant from the north and the south pole. Draw the equator on the map approximately and mark it with ‘Q’.
- d. The ecliptic is the imaginary yearly path of the Sun in the sky. Mark this approximately on the map and mark it with ‘E’.
- e. Mark approximate position of the Sun on the map as ‘S’.
- f. Yesterday was a new moon day. Mark the current position of the moon on the map as ‘M’.
- g. Which star was very close to the Zenith at 06:00 am today? Mark it on the map as ‘N’.
- h. Draw a line across sky showing horizon line as at 07:00 am today as ‘H’.

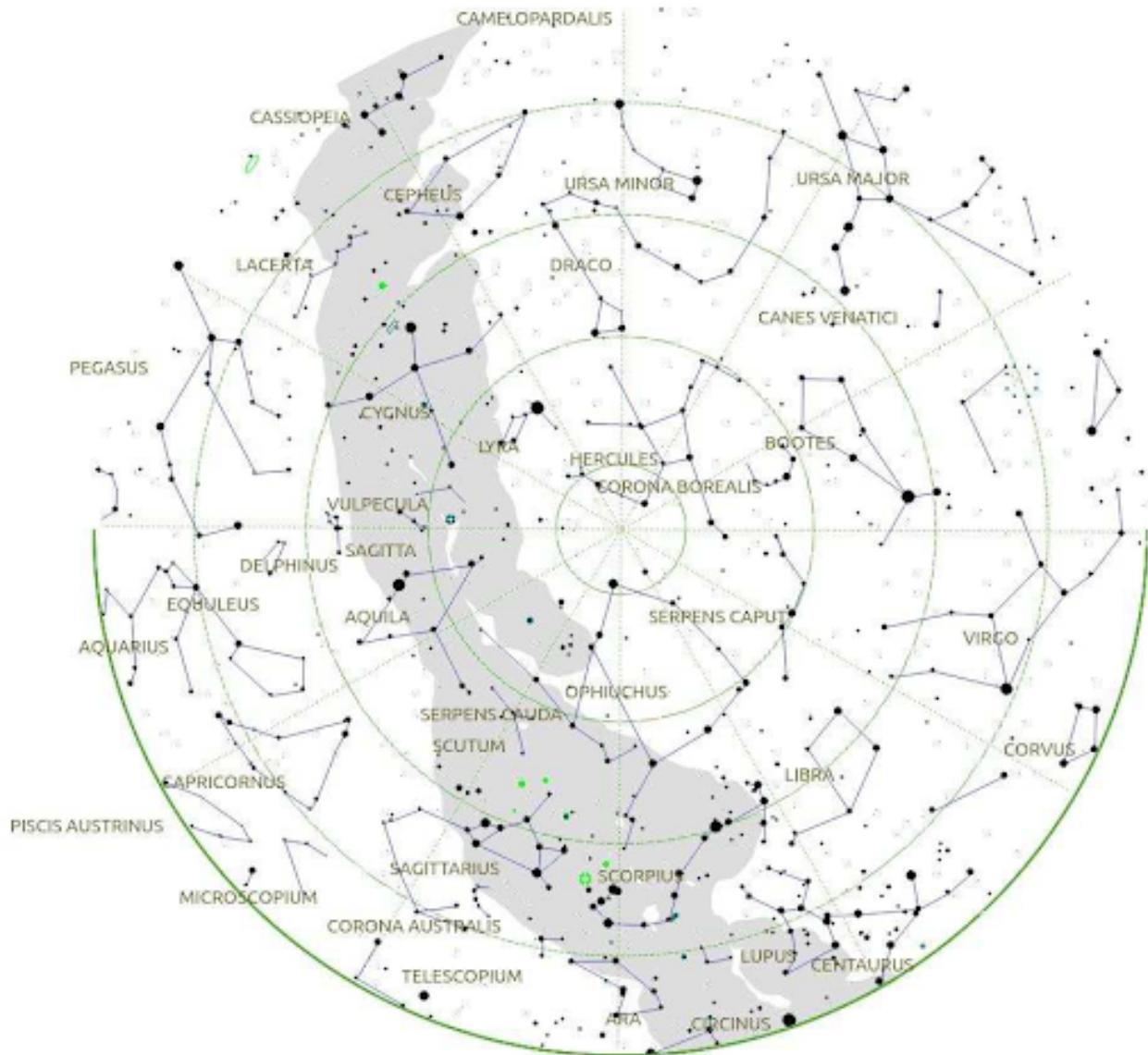


Figure 30: INAO 16 Map

## 6.5 SAO

### 6.5.1 P1: The night of Vernal Equinox

The star chart below shows the night sky at 0000h on the night following the Vernal Equinox (on 21 March 2018), from Singapore (UTC + 08:00), at latitude 1°17' N and longitude 103°51' E. Complete the questions on the following page. Note that the size of stars and objects are scaled by their brightness in the night sky, with brighter objects appearing larger.



Figure 31: SAO P1

- a. Along the horizon (circumference of the star chart), mark out the approximate location of cardinal West, with a cross  $\times$ .
- b. Trace out the local meridian with a solid arc, and label it **M**.
- c. Trace out the constellation of *Leo* with solid lines connecting its stars. Label its alpha star  $\alpha$  on the star chart.
- d. The pole star Polaris,  $\alpha$  Ursae Minoris, is visible. Mark out the star with an arrow  $\rightarrow$ . The tip of the arrow should point unambiguously at the star.
- e. The following four deep sky objects (DSOs) are visible in the star chart. Mark out any three of these DSOs, each with a hollow circle  $\circ$ , and write that DSO's catalogue designation adjacent to it. The centre of the hollow circle will be taken as the position of that DSO.

- (i) M41, an open cluster
- (ii) C80, the  $\omega$  Centauri Cluster
- (iii) C92, the Eta Carinae Nebula
- (iv) M51, the Whirlpool Galaxy

f. Calculate the **local hour angle** of the first point of Libra.

## 6.6 Czech

### 6.6.1 Observation using Simbad

In the blind map 32, 15 stars are highlighted in blue, 7 constellations in green and red in highlight 6 deep space objects. We could observe this night sky at midnight from a certain location on the 22nd day of a certain month this year. Select a month from the list.

Here is their list:

- |                |                   |                |                   |
|----------------|-------------------|----------------|-------------------|
| • M13          | • $\alpha$ Cygnus | • M31          | • Hounds          |
| • $\alpha$ Boo | • M33             | • $\beta$ Gem  | • Sirius          |
| • Hydra        | • Raven           | • $\alpha$ Lyr | • $\delta$ Cephei |
| • M45          | • Gemma           | • Cassiopeia   | • Big bear        |
| • Polar bear   | • $\alpha$ CMi    | • Capella      | • M42             |
| • $\alpha$ Leo | • Snake (head)    | • Rigel        | • Betelgeuse      |
| • Cancer       | • $\alpha$ Tau    | • Melotte 111  | • Spica           |

a. Calculate the location of Observing Place. [2]

b. Your task is to assign numbers 1 to 15 to the appropriate stars, designations S1 to S7 to the relevant constellations and the letters "a" to "f" to the relevant deep space objects. [7]

c. To the table then complete the required data (Object magnitude in filter V and Category) about the selected objects as is can be found in the SIMBAD database.<sup>10</sup> <http://simbad.u-strasbg.fr/simbad/> [6]

Object Code	Object Type	Visual Magnitude
a		
b		
c		
d		
e		
f		

d. Draw the galactic plane in the map. [2]

---

<sup>10</sup>How to use SIMBAD: 7 Min Video <https://www.youtube.com/watch?v=-x6B91DsGQ0>

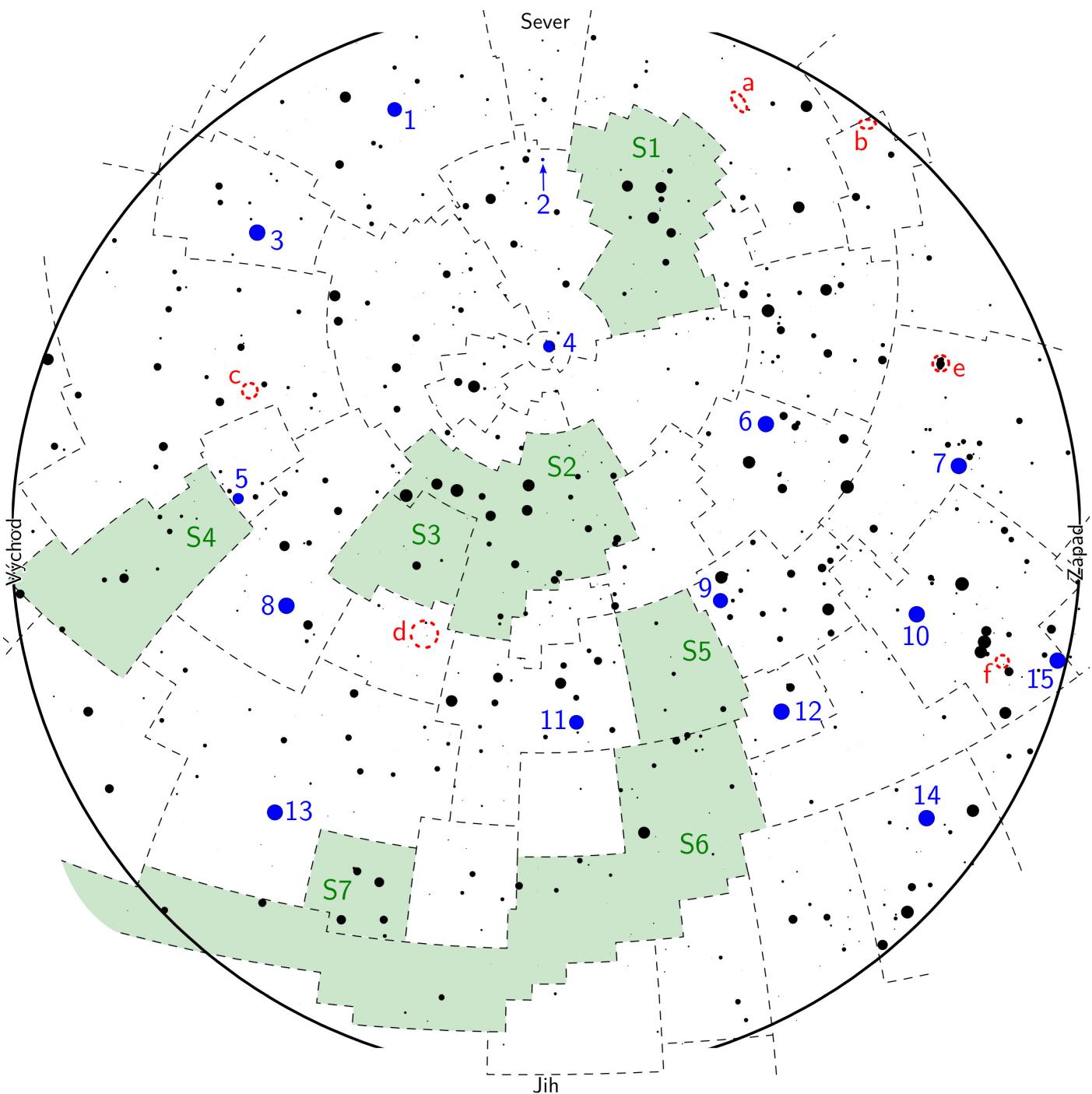


Figure 32: Czech P1

## 6.7 IOAA 2016 Observation Round

### 6.7.1 Observational Map

1. Mark any 5 (five) of the following stars on the map by putting a circle (O) around the appropriate star and writing its code next to it. If you mark more than 5 stars, only the first 5 in serial order will be considered.

<b>Code</b>	<b>Name</b>	<b>Bayer Name</b>
S1	Caph	$\beta$ Cas
S2	Asellus Australis	$\delta$ Cnc
S3	Acrux	$\alpha$ Cru
S4	Alphard	$\alpha$ Hya

<b>Code</b>	<b>Name</b>	<b>Bayer Name</b>
S5	Sheliak	$\beta$ Lyr
S6	Albireo	$\beta$ Cyg
S7	Rasalhague	$\alpha$ Oph
S8	Kaus Australis	$\epsilon$ Sgr

2. Mark location of any 3 (three) of the following galaxies on the map by putting a '+' sign at appropriate place in the map and writing its code next to it. If you mark more than 3 galaxies, only the first 3 in serial order will be considered.

<b>Code</b>	<b>Name</b>	<b>M number</b>
G1	Triangulum Galaxy	M 33
G2	Whirlpool Galaxy	M 51
G3	Southern Pinwheel Galaxy	M 83

<b>Code</b>	<b>Name</b>	<b>M number</b>
G4	Virgo A	M 87
G5	Sombrero Galaxy	M 104

3. Draw ecliptic on the map and label it as 'E'.
4. Show position of Autumnal Equinox (descending node of the ecliptic) on the map by a '+' sign and label it as 'A'.
5. Draw local meridian for Bhubaneswar on Winter Solstice day (22<sup>nd</sup> December) at local midnight and label it as 'M'.

Refer to the Map 33 for these problems<sup>11</sup>.

### 6.7.2 Observational Planetarium

**OP1:** Eight well known historical supernovae will appear in the projected sky one at a time (not necessarily in chronological order). You have to identify the appropriate map (Map 1 / Map 2) where a particular supernova belongs and mark it in the corresponding map with '+' sign and write codes 'S1' to 'S8' besides it.

<sup>11</sup>The digital copy of this map isn't available anywhere else. But fortunately I was a participant of IOAA-16 myself and I have my own script still now [2022!]. So I used my own work from IOAA and edited this image!

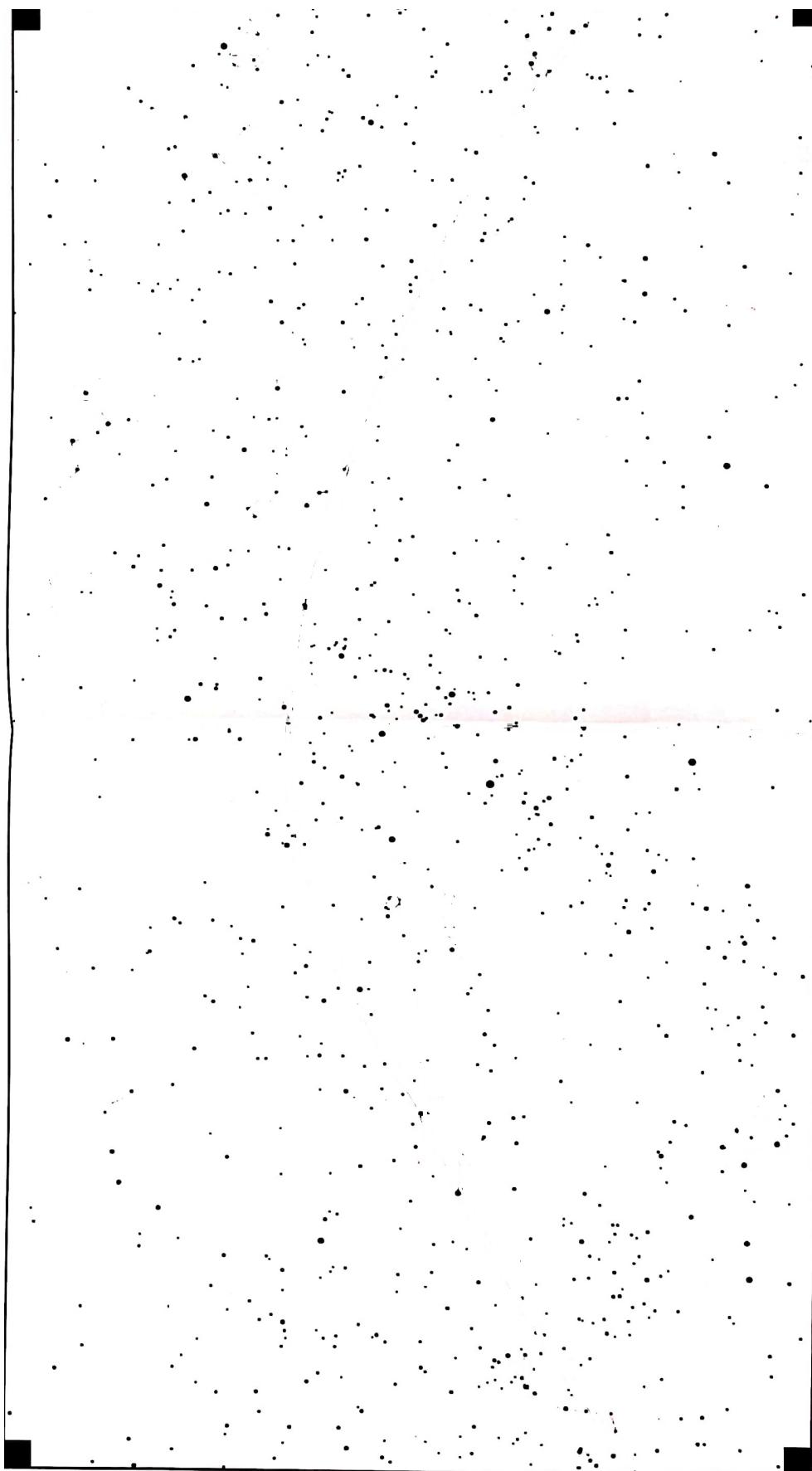


Figure 33: IOAA 2016 OM

Each supernova code will be projected on dome for 10 seconds, followed by appearance of supernova for 60 seconds and then 20 seconds for you to mark the answers.

- For S1, S2, S3, S4 and S5, the projected sky corresponds to the sky as seen from Rio de Janeiro on the midnight of 21<sup>st</sup> May
- For S6, S7 and S8, the projected sky corresponds to the sky as seen from Beijing on the midnight of 20<sup>th</sup> November. There will be a gap of two minute after S5 for change over and adaptation to new sky.

**OP2:** We are now projecting sky of another planet. The sky will be slowly rotated for 5 minutes . Identify the visible celestial pole of this planet and mark it with a '+' sign and label it as 'P' on the appropriate map (Map 1 / Map 2).

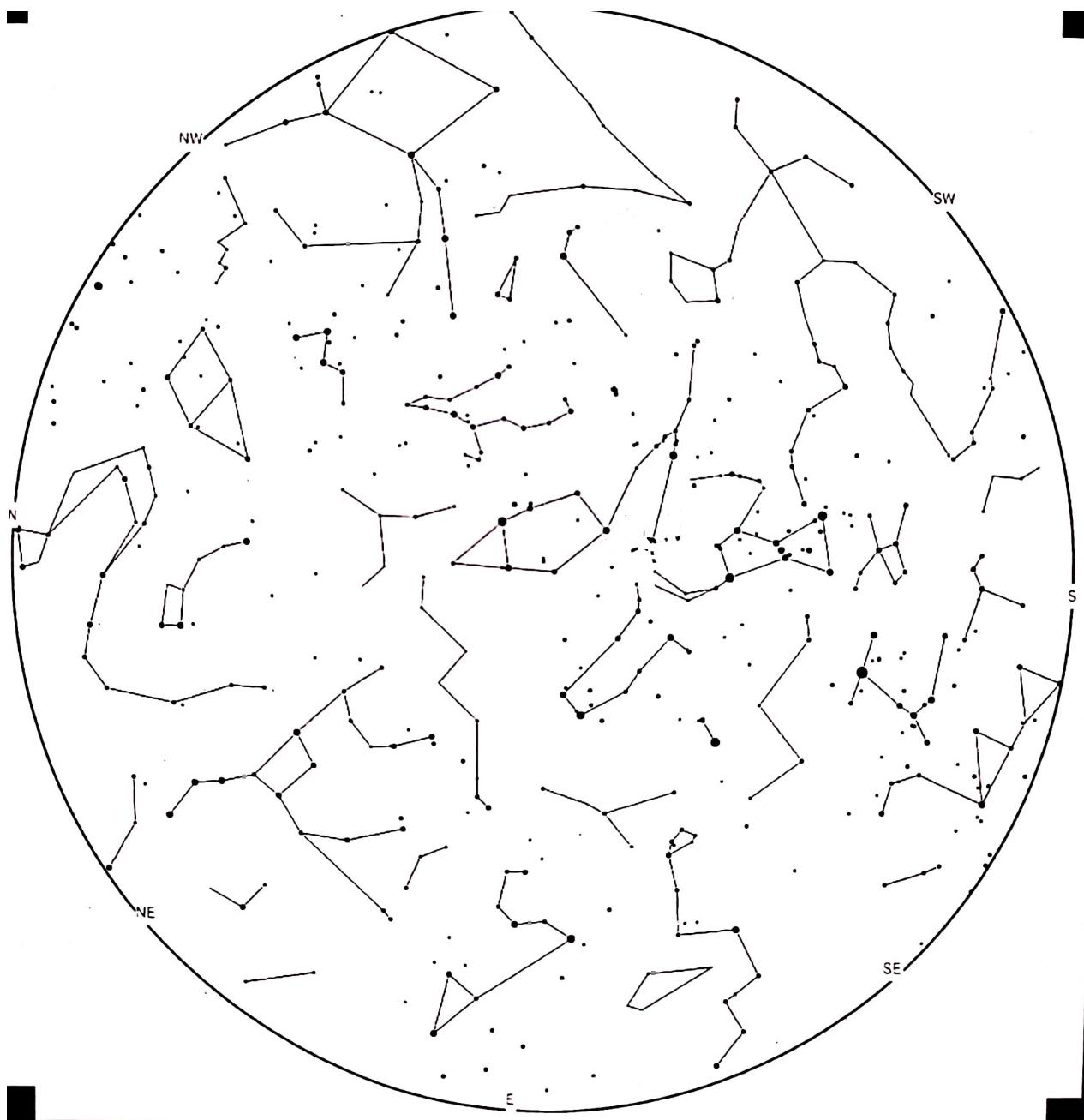


Figure 34: OP1 Map 2016

## 6.8 IOAA 2018 Observation Round

### 6.8.1 O1

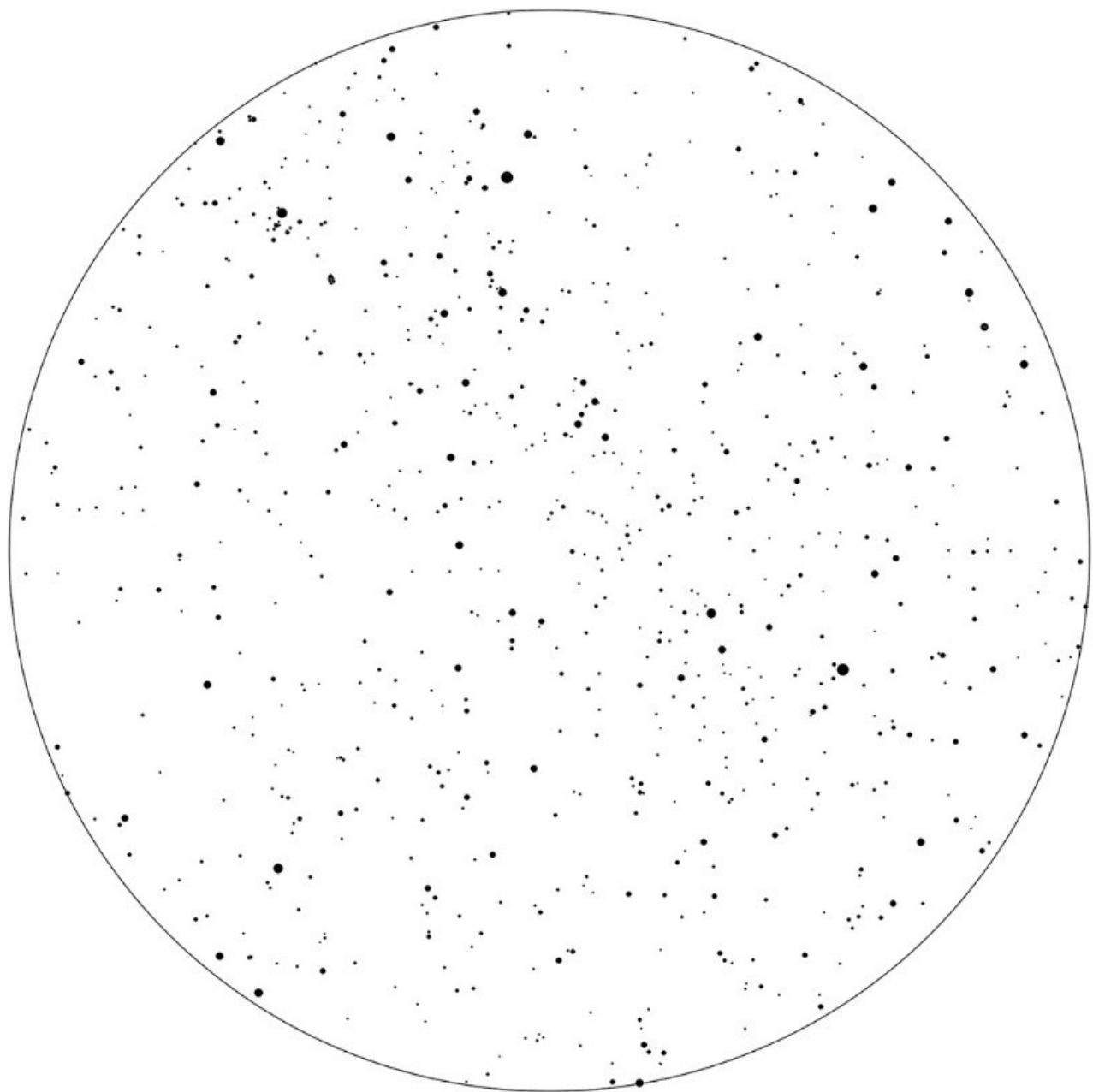


Figure 35: O1 Map

Figure 35 is a whole sky star chart of Yanqing, Beijing at 20:30 tonight (UTC+8) with the limit magnitude =  $5^m$  ( $m$  = magnitude). Four stars (about  $1^m - 3^m$ ) and one planet (brighter than  $2^m$ ) are missing in this chart. In the chart, the distance from the center is in proportion to zenith distance.

1. Draw a cross (X) on the location of each missing star and mark “T” on the chart, and draw a cross (X) on the location of the missing planet and mark “P” on the chart.

2. Please mark the orientation of the star chart with “N” “E” “S” “W” at the edge of the star chart.
3. On the chart, the celestial equator passes through many constellations. Please write down the name of any five of these constellations (IAU codes).
4. Using the star chart, estimate the altitude of Aldebaran ( $\alpha$  Tau), to the nearest degree.

### 6.8.2 O2

Figure 36 is a star chart of a recent opposition of Jupiter. The grid in the figure is the ecliptic coordinates. Please estimate the date of this opposition, to the nearest day.

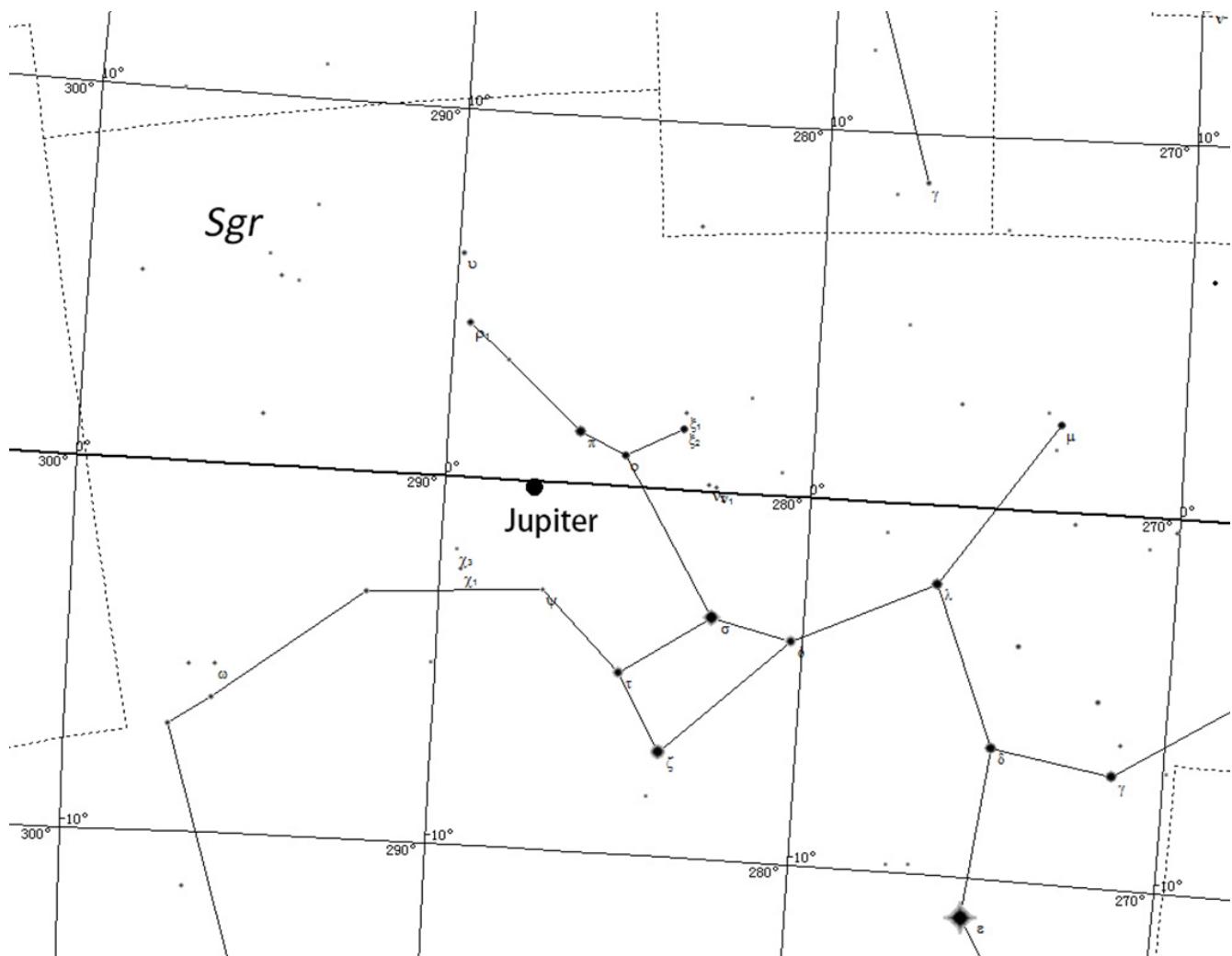


Figure 36: O2 Map

### 6.8.3 O3

Figure 37 is a star chart of a part of the sky on March 21, 2018. The longitude and latitude of the observation site is  $120^{\circ}\text{E}$ ,  $40^{\circ}\text{N}$  (UTC+8). The grid in the figure is an equatorial grid. The thicker vertical line in the centre is the meridian. Estimate the mean solar time to an accuracy of better than 0.5h.

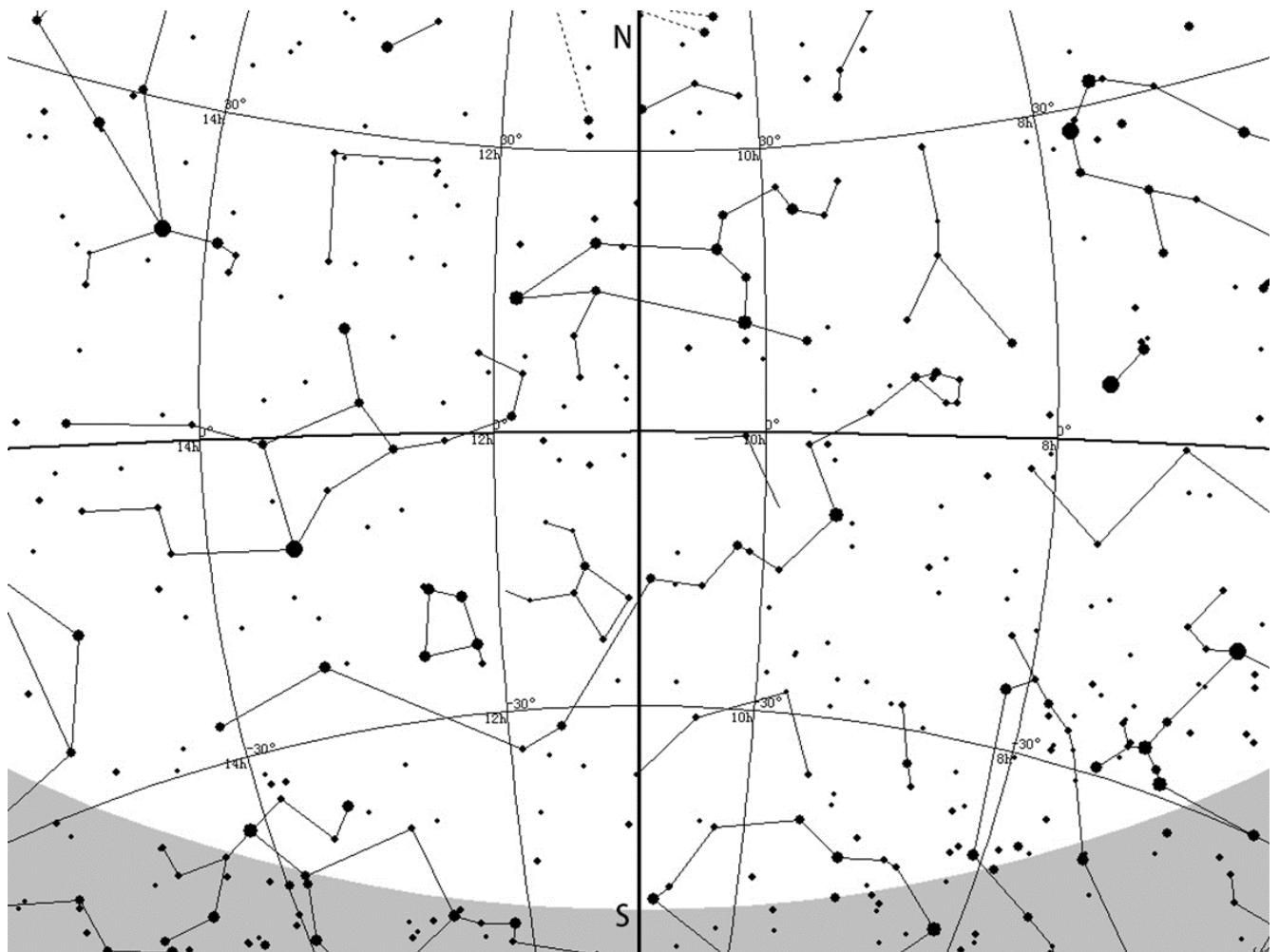


Figure 37: O3 Map

#### 6.8.4 O4

[Not Used during IOAA]

Students were supposed be given 2 star charts before the examination. They should read these star charts to know which star is  $\gamma$  Andromedae, and which star is  $\delta$  Cygni.

1. Figure 38 is a detailed star chart near  $\gamma$  Andromedae. Please draw a cross (X) on the map at the location of  $\gamma$  Andromedae, and mark North on the star chart with "N".



Figure 38: O4 Map

2. Figure 39 is a detailed star chart near  $\delta$  Cygni. Please draw a cross (X) on the map at the location of  $\delta$  Cygni.



Figure 39: O5 Map

## 6.9 IOAA 2019 Observation Round

### 6.9.1 Task 01

This is the sky above Keszthely at 24<sup>th</sup> (at an unknown date) The map does not show Solar System objects.

1. There are 3 novae on the projected sky at 2 magnitude. Find them, and label them by circles on your answer sheet's stellar map, at their right position. See the map on next page. (Each circle at wrong position(s) causes 1 point decrease.)
2. Mark all globular clusters with X signs on the stellar map attached to your answer sheet, which are members of the Messier catalogue and visible in the projected sky. Write the Messier number of these objects near the X labels.

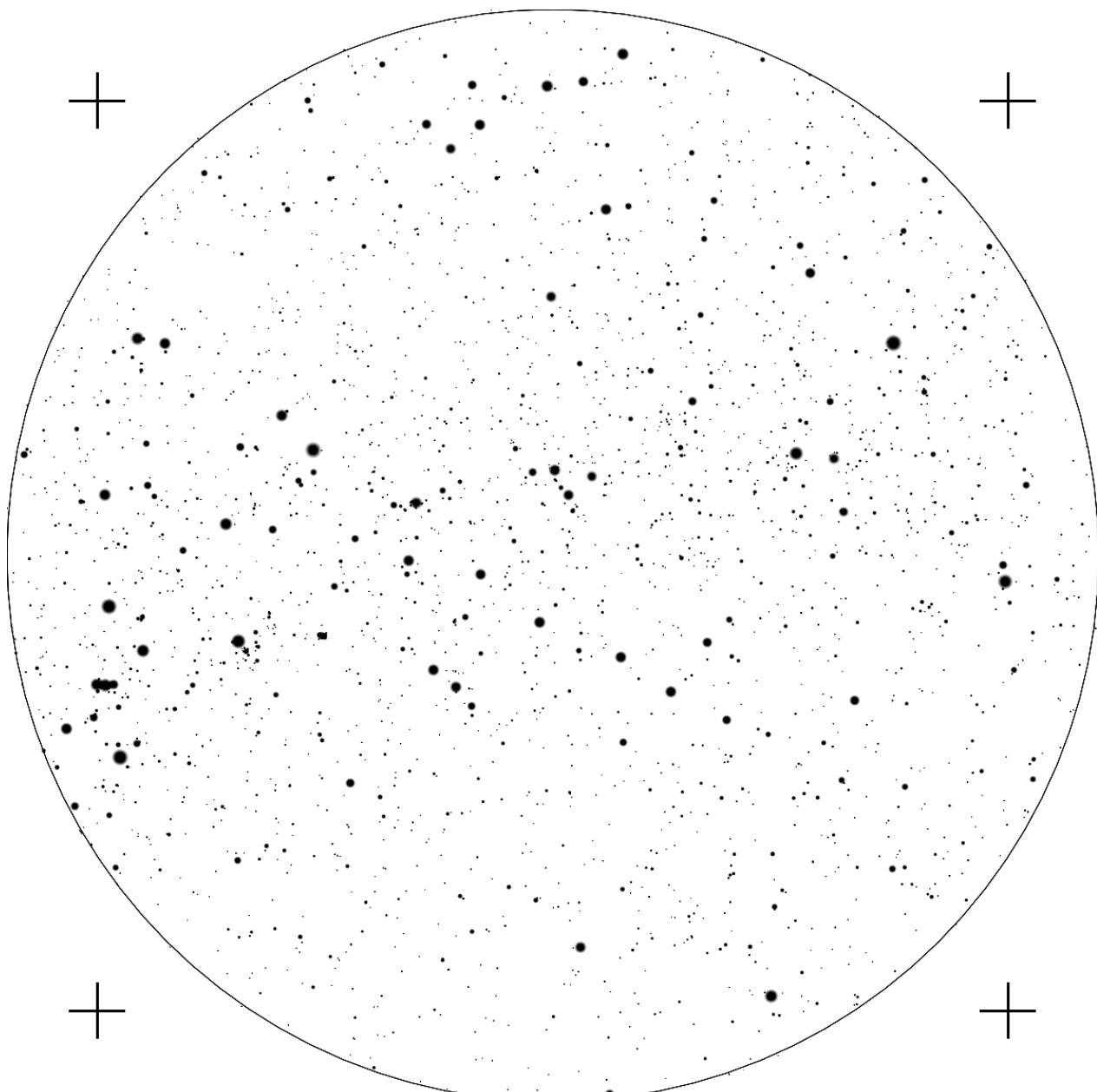


Figure 40: Task 01

3. In which month can you see these constellations (at midnight) in Keszthely?
4. What is the sidereal time? (To the accuracy of 15 minutes.)
5. List all zodiacal constellations, which partly or entirely can be seen in the shown sky. (Use the official IAU names or abbreviations.)

### 6.9.2 Task 02

We are standing somewhere on the Earth. The map does not show Solar System objects.

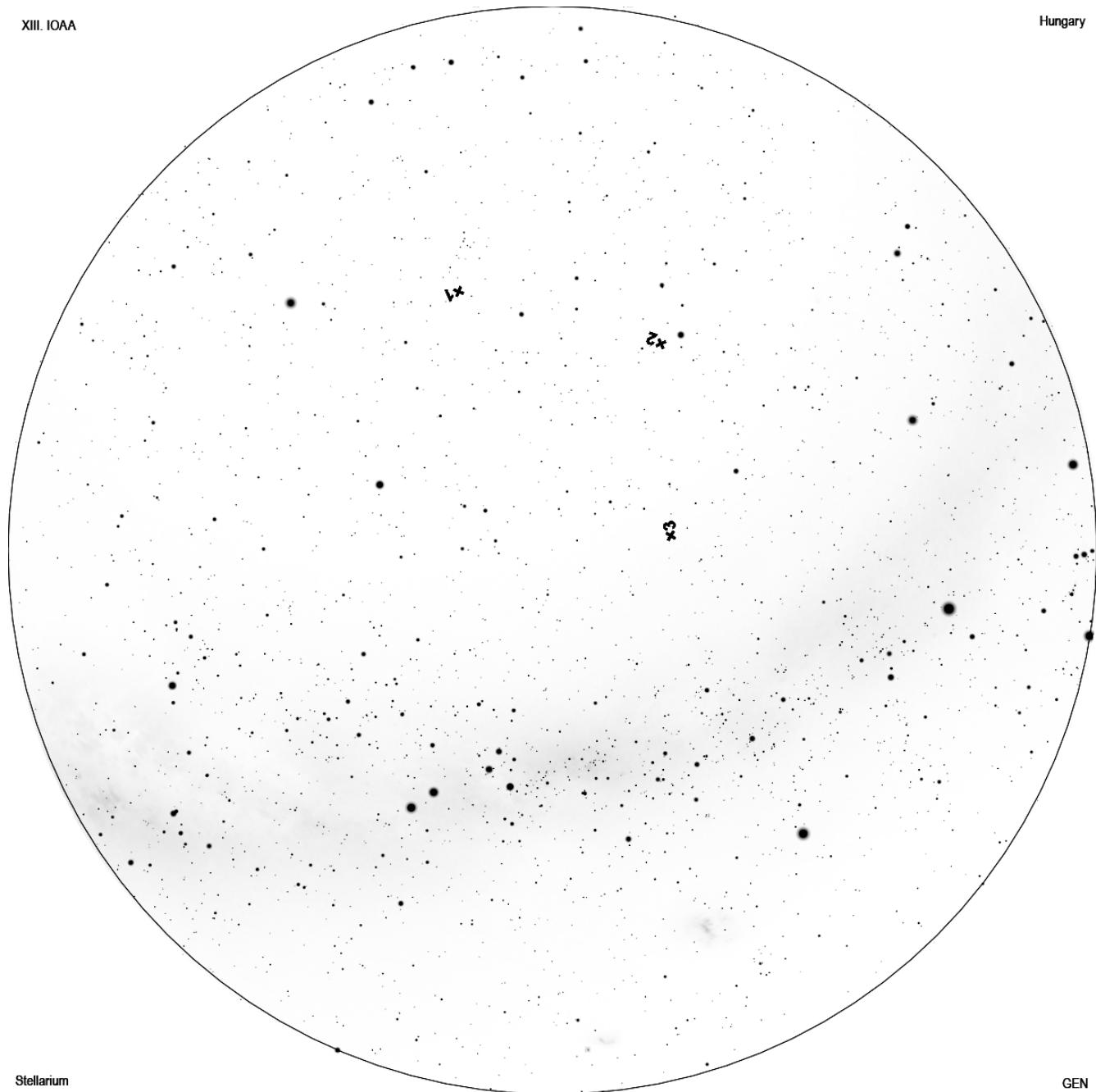


Figure 41: Task 02

1. Determine the geographical latitude of this observing site:      °. Its hemisphere: N / S (Circle the right one.)

2. Determine the Azimuth of the 3 brightest star on the projected sky. Azimuth is measured from North to the direction East 0-360°. Write the name of these stars in English or using their Bayer name onto the map, close to the position of the given stars. (Incorrect star position in a list or on the map causes 1 point decrease.)

Brightest Star	Name	Azimuth
1st		
2nd		
3rd		

3. Yellow  $\times$  signs show the positions of 3 comets. Which comet is in the closest position to ecliptic? (Write the number of nearest comet on the dotted line.)
4. List the circumpolar constellations seen from the given observing site, using their IAU abbreviations or ‘standard’ names.
5. Mintaka ( $\delta$  Orionis = delta Orionis) is setting at this moment. How many hours earlier did it rise? (To the accuracy of 15 minutes.)

### 6.9.3 Task 03

We are standing on the Moon now. As seen at this moment, the Earth centrally obscures the Sun (see the red circle on the sky). Consequently, the Moon is in one of its nodes now. Assume the longitudinal and latitudinal librations are exactly  $0^\circ$  at this moment.

1. Which season is taking place at this moment in Hungary?
2. There is a yellow circle on the projected sky (next to the red circle), which denotes minor planet Juno, which is at a distance of 3 AU from the Sun at this moment. Estimate its distance to the Moon now? (Rounded to 0.1 million km.) (Consider all orbits as circles.)
3. Estimate how much time after the projected event will  
the Sunset at your observing site? \_\_\_\_\_  
the Earth set at your observing site? \_\_\_\_\_
4. Estimate the distance of the observing site to the Apollo-11 landing place: \_\_\_\_\_ km.

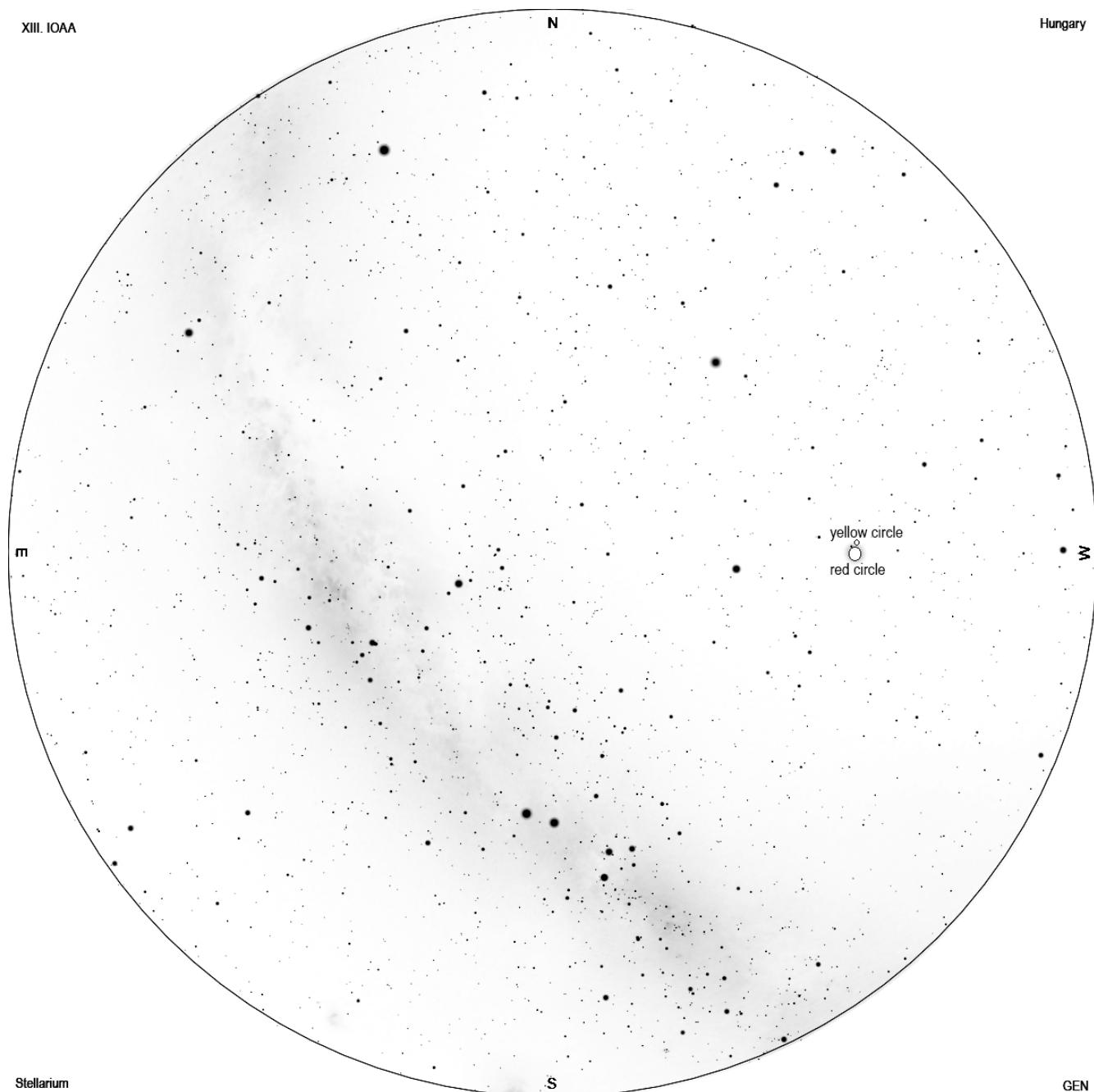


Figure 42: Task 03

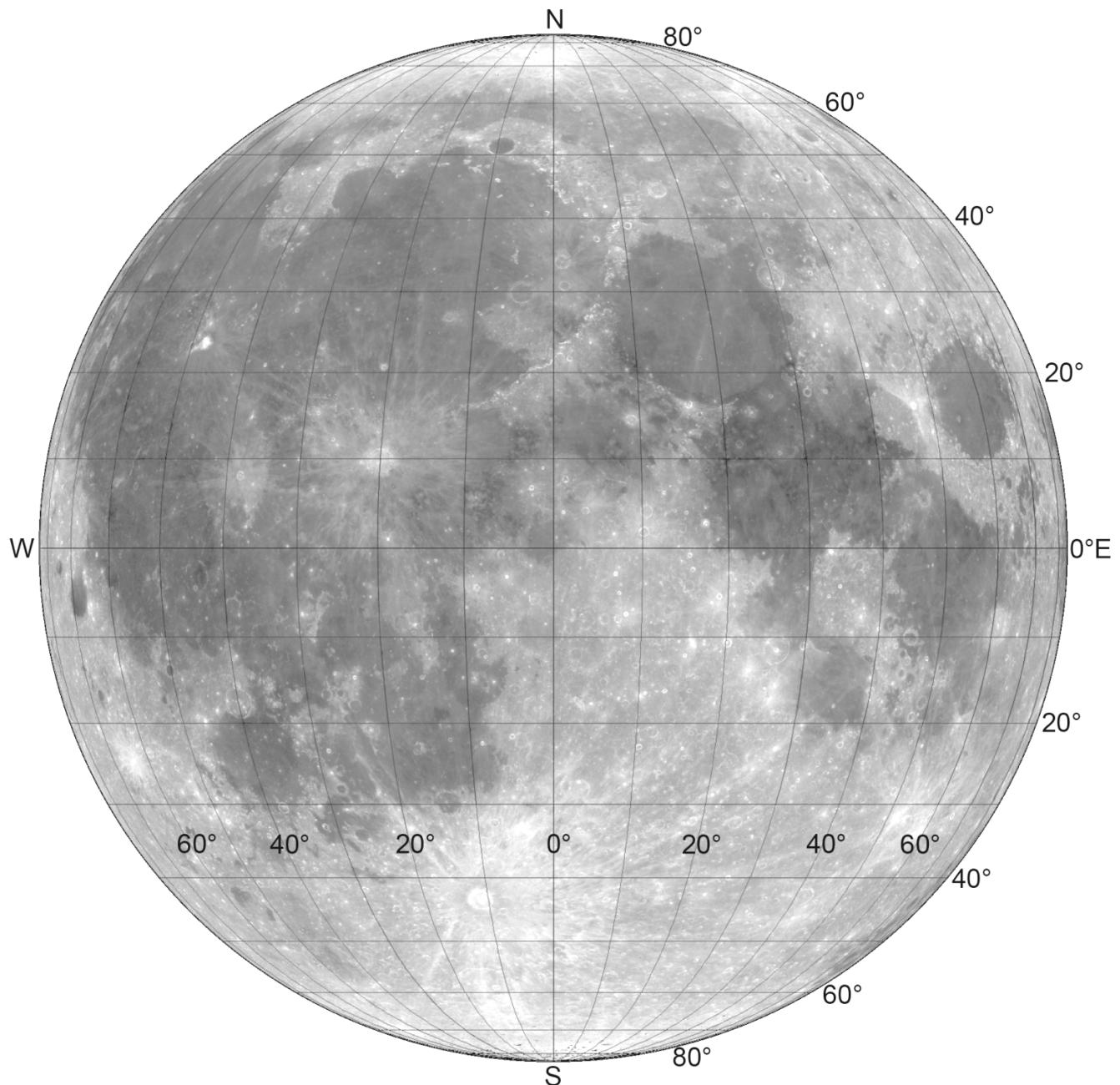


Figure 43: Task 03 - Lunar Map

## 6.10 GeCAA 2020

### 6.10.1 Problem 1

The figure 44 shows a star chart of the night sky. The location of comet C/2020 F3 Neowise on July 31<sup>st</sup>, 2020 is marked by a red dot.

- a. Name the five brightest stars in the field shown. Please use IAU star names in your answer (i.e. like Sirius or Rigel). Sort the brightest stars visible on the figure in descending order of brightness.
- b. Write the latin name abbreviation (you can find accepted abbreviated names<sup>12</sup> of the constellation in which the Sun is present on 31<sup>st</sup> July 2020.

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<sup>12</sup>[https://en.wikipedia.org/wiki/IAU\\_designated\\_constellations](https://en.wikipedia.org/wiki/IAU_designated_constellations)



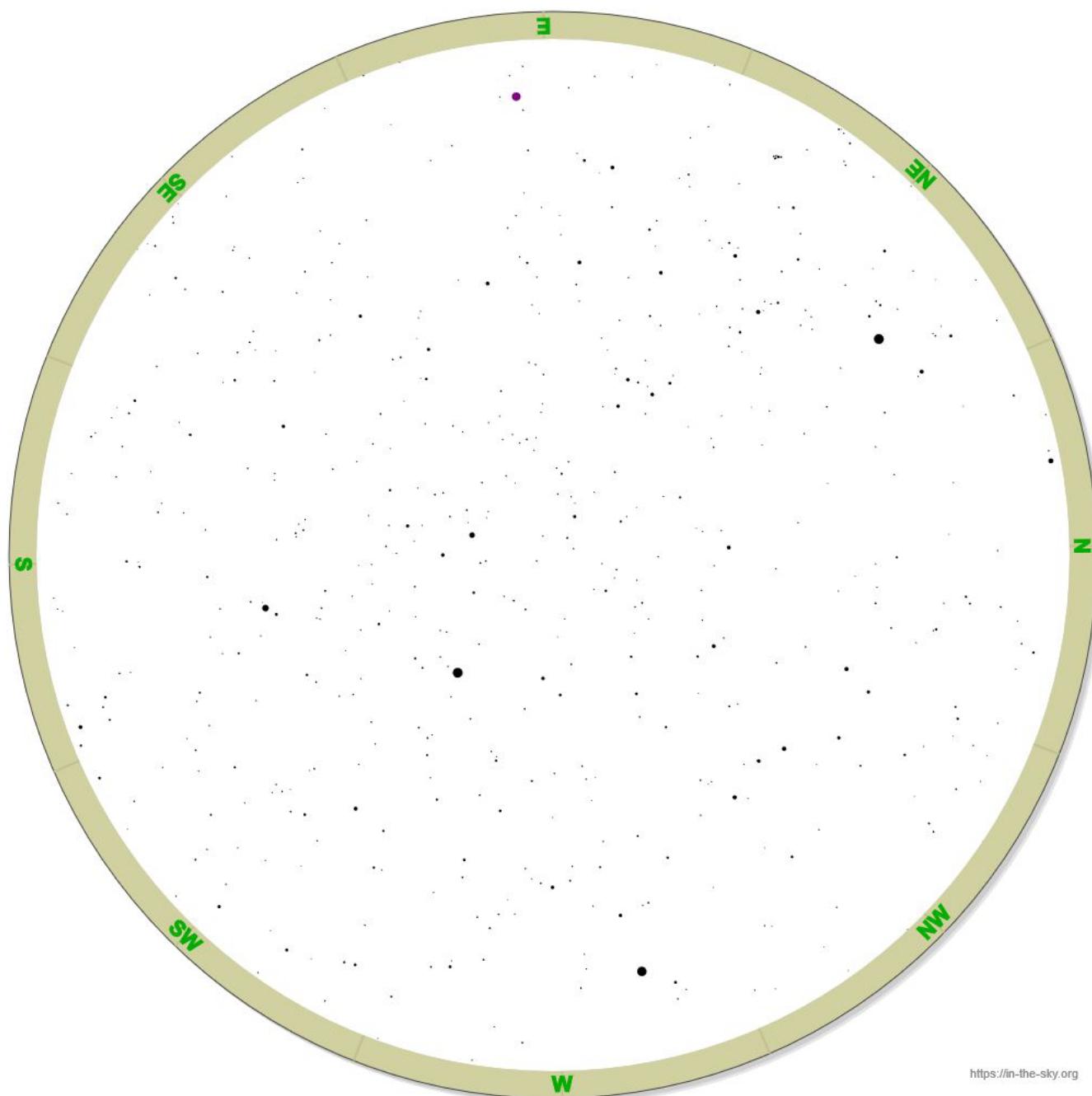
Figure 44: Comets in the “air”

- c. Mark the position of the Sun on the chart, in case it is not present on the chart, mark the direction to the Sun at the edge of the image.
- d. Mark which line on the chart corresponds most accurately to the position of the comet’s gas tail (1, 2, 3 or 4 as indicated on Figure 44). Write the correct number as your answer.
- e. Name the constellation in which the comet is seen in Figure 44. Write the answer using the IAU abbreviation

### 6.10.2 Problem 4

On the Figure 45, a star chart is shown for Tallinn, Estonia (Lat  $59.43^{\circ}$  N, Long:  $24.75^{\circ}$  E) on 14<sup>th</sup> September 2020 at 22:00 (UTC+3). The chart is not distorted and shows all latitudes from  $0^{\circ}$  to  $90^{\circ}$ . Stars to magnitude  $+4.7^m$  and one planet are shown.

- a. Four relatively bright (about  $1.5^m - 3.5^m$ ) stars in well-known constellations or asterisms are missing. Identify them (in any order) using the Bayer classification.
- b. Mark all the planets that should be visible at this time on this chart. Mars is marked as a red dot.
- c. Mark the missing stars indicating their rank order as greek letter with IAU Designation
- d. What is the RA of Mars (to nearest 10 minutes, write in format HH:MMm, where H and M-s are replaced with correct numbers, round answer to nearest 10 minutes, so it must end with “0” for example 12:10 )?

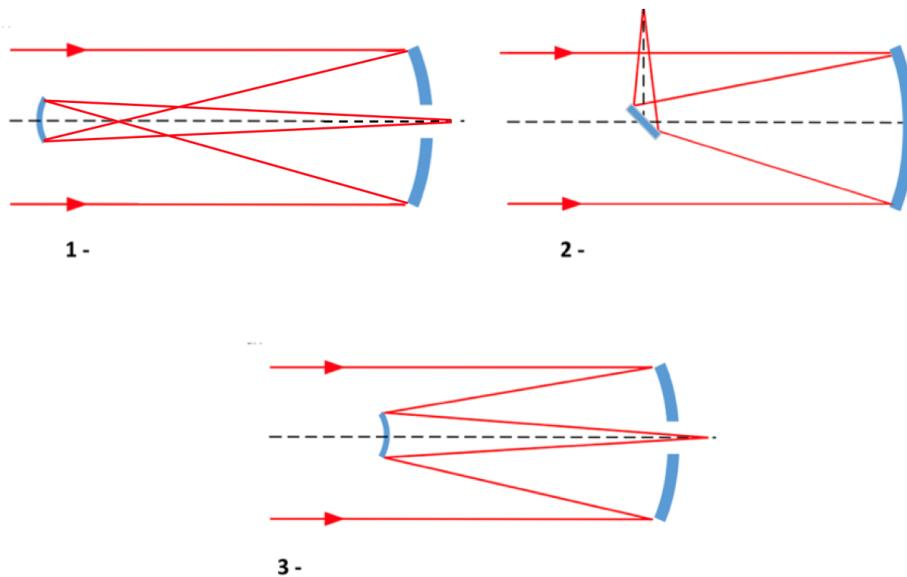


<https://in-the-sky.org>

Figure 45: GeCAA P4

## 6.11 IOAA 2022

**O5** The image below shows schematic representations of three different types of reflectors



For each one, choose the correct name from the list below.

(3 points each)

- (A) Newtonian (B) Pfund (C) Gregorian (D) Herschelian (E) Keplerian (F) Coudé (G) Galilean (H) Cassegrain

**O6** The equatorial constellations are listed below. Fill in the missing ones in the correct order. Use the IAU codes or official names accepted by the IAU.

1. Serpens (Ser) 2. Ophiuchus (Oph) 3. \_\_\_\_ 4. Aquarius (Aqr) 5. Pisces (Psc). 6. Cetus (Cet) 7. \_\_\_\_ 8. \_\_\_\_ 9. \_\_\_\_ 10. Monoceros (Mon) 11. Canis Minor (CMi) 12. \_\_\_\_ 13. \_\_\_\_ 14. \_\_\_\_ 15. Virgo (Vir)

Which of these 15 constellations are also on the ecliptic? If you give more than the required number of constellations, only the first ones you write (in order) will be considered.

**O8** There are three additional and two missing stars on the figure given below. Circle them and number them as 1, 2, 3 (additional stars), 4, 5 and 6 (missing stars).

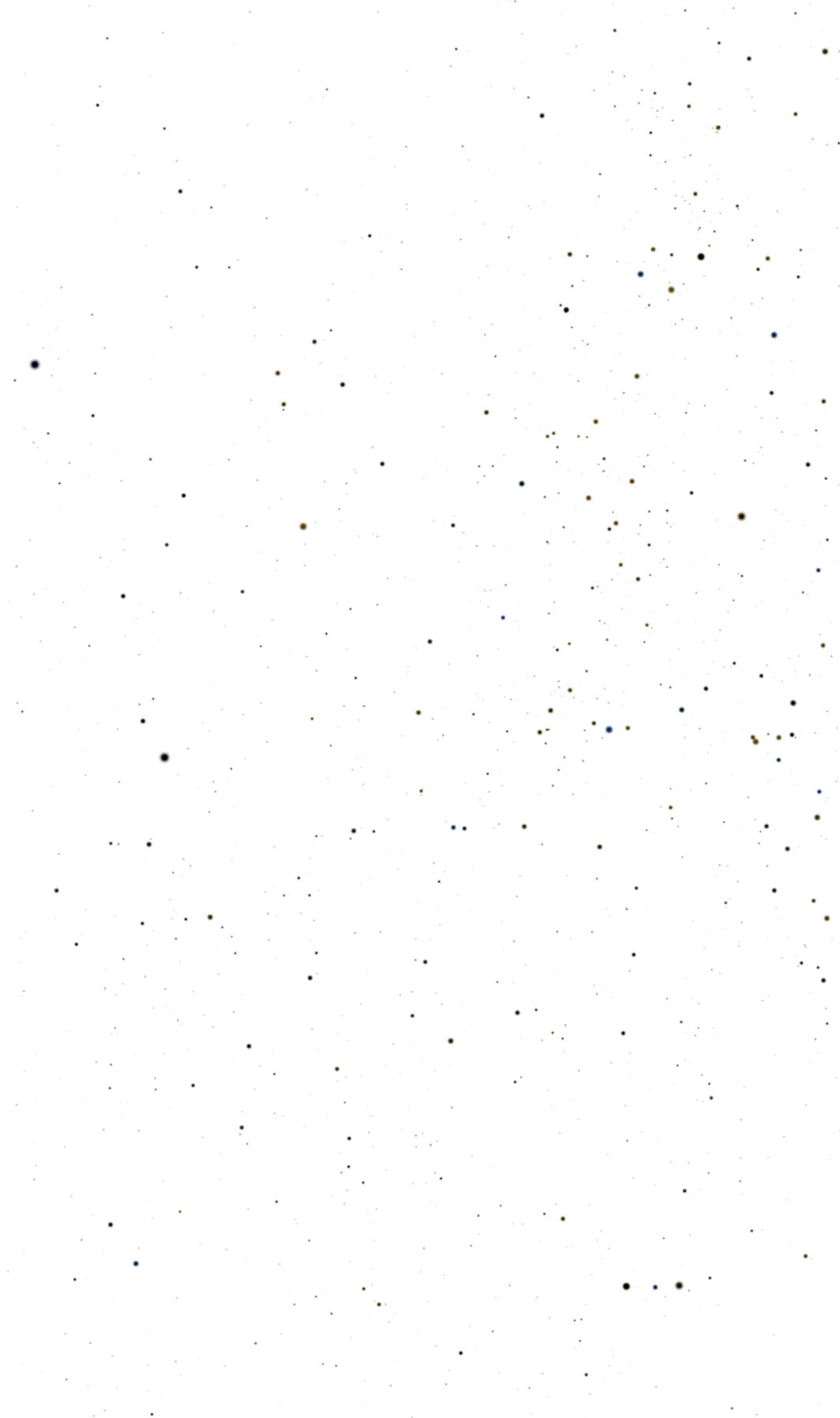


Figure 46: IOAA 2022 NO8

**O9** Calculate the time interval between the two figures given below if the first figure occurs earlier than the second one, and the time interval is less than one sidereal day.

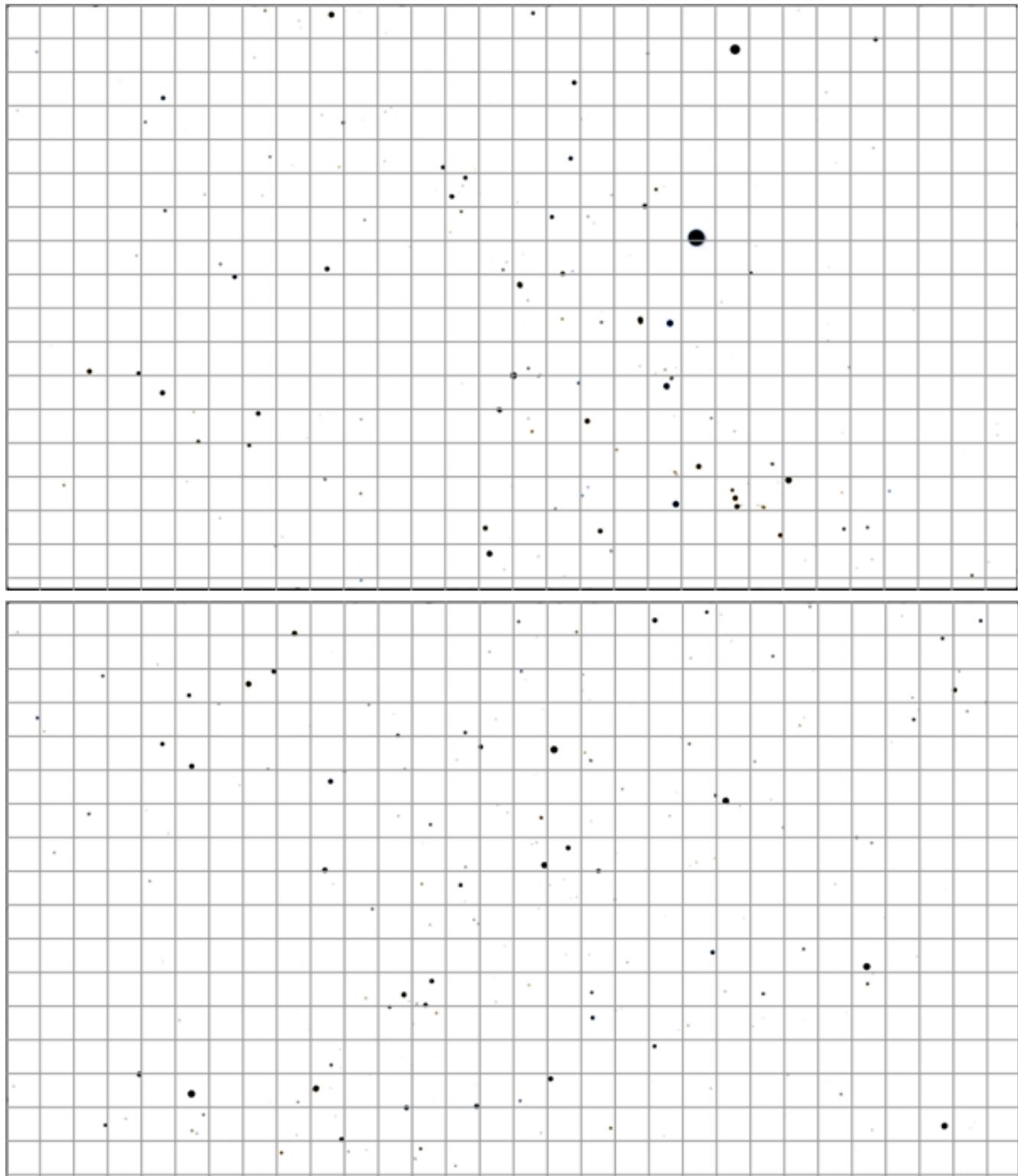


Figure 47: IOAA 2022 NO9

## 7 Sources

1. Wikipedia
2. IOAA (GeCAA)
3. International Earth Science Olympiad (IESO)
4. Bangladesh Olympiad on Astronomy and Astrophysics – <https://bdoaa.org/>
5. Singapore/Indian/Czech/Brazil/Russian/Slovak Astronomy Olympiad
6. **Your Sky** – <https://www.fourmilab.ch/yoursky/>  
Your sky is the most useful online tool for learning sky maps in an interactive way. You can personalize your own sky maps here for free. It is highly recommended. Most of the maps in this note are generated from here.
7. **Stellarium** – [www.stellarium.org/](http://www.stellarium.org/)  
Perhaps the best software you can find. But don't get too comfortable with only this, ok? But a bi-weekly visit is necessary if you want to actually learn about simulated sky.
8. **Heavens-Above** – <https://www.heavens-above.com/>  
This site has many features too. You can track satellites and make sky maps for their path.
9. **Skymaps.com** – [www.skymaps.com/](http://www.skymaps.com/)  
They provide monthly free sky maps based on North/South/Equator.