



THE NORWEGIAN ASTRONOMY AND ASTROPHYSICS
OLYMPIAD COMMITTEE

IOAA NOTES

Part 4: Observational Astronomy

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15th February 2026

1 Introduction and Resources

A big and special part of astronomy and astrophysics are night-sky observation and planetarium observations. We understand that many of our students in Norway haven't had the opportunity to do observation, and that this isn't covered by the curricula in Physics 1 and Physics 2. This is reflected in the fact that the observational questions are the ones where students mostly answer incorrectly, so in this document, we will provide the basics needed for you to build a foundation for observation. Once you're somewhat comfortable with the contents of this handout, the following resources can be of great use if you wish to practice:

- Stellarium: <https://stellarium.org/>
 - Stellarium is the go-to software for very nice visualisations, and is essentially a planetarium on your device.
- Cartes du Ciel / Skychart: <https://www.ap-i.net/skychart/en/start>
 - This software is a more "professional" piece of software as compared to Stellarium. It has a lot of functionality for skycharts and is extremely customisable. You can see the map of the sky from any given observation point at any given time (and that includes far into the past)!
- Heavens Above: <https://heavens-above.com/skychart2.aspx>
 - Heavens Above is a more user-friendly web UI for star charts, where you can still choose your location and time-and-date, like with Cartes du Ciel, just with substantially fewer features. Use this if you found Cartes du Ciel too daunting to begin with, but do make an attempt at using both!
- SkyAcademy: https://play.google.com/store/apps/details?id=digital.dong.skyacademy&hl=en_AU&pli=1 or <https://apps.apple.com/us/app/sky-academy-learn-astronomy/id1571488252>
 - Constellations are very important to have a hang of, and this app has been recommended by multiple previous participants on the Olympiad. It also teaches you the Messier Objects, which is also extremely useful for the Olympiad.

To be able to fully understand the contents of this handout, we recommend you being familiar with different coordinate systems. You can do this by reading through Part 2 of these IOAA notes. You should especially have an understanding of the ecliptic and the celestial equator. However, the best way to practice observations is by doing them, there's few other tricks to it. Use these resources, especially Stellarium, and spend some time learning how the night sky evolves throughout a night and where objects are located in relation to one another.

2 Basic Concepts

2.1 Apparent Magnitude

Before we actually look to the night sky or at a sky-chart, we should know what exactly we're looking for and looking at. If you look at the night sky, you will see that some celestial objects are bright, some dim, and many in between. We quantify the brightness we see with our eyes using apparent magnitude. The apparent magnitude of an object is a measure of its brightness in the sky given otherwise ideal observation conditions. (*Note: in this handout, we only focus on apparent magnitude for observation - for formulae and use in theoretical problems, see the handout on stellar properties (coming soon)*)

The reason we stress "otherwise ideal observation conditions" is that atmospheric effects and light pollution (just to name a couple) have a great effect on what we can see in the night sky and how bright they show up. One counter-intuitive thing to consider is that brighter objects will have lower apparent magnitudes. The magnitude system comes from Ancient Greece (as do many other things in astronomy) where they referred to the brightest stars being 1st magnitude, and the dimmest 6th magnitude, so apparent magnitude is a little bit like golf scores - the lower, the better (or in this case, brighter).

In modern astronomy, we have chosen the star Vega to be the reference for apparent magnitude. This means that Vega is defined to have apparent magnitude $m = 0$. Sometimes, you will be asked to estimate the magnitude of a certain object in the sky, and the way to do that is to find a couple that you very certainly know the magnitudes of, ideally one lower than the object of interest and one higher, and estimate the unknown magnitude to be in that range.

The brightest star in the sky is the Sun with an apparent magnitude of $m = -26.7$, but for the night sky, the star Sirius is brightest with magnitude $m = -1.46$. Not only stars have apparent magnitudes - anything we can see in the sky does! For example, Halley's comet had apparent magnitude $m = 2.1$ when it last was at its closest to our planet in 1986, the full moon has apparent magnitude $m = -12.74$. For objects in our Solar System, the apparent magnitude will vary based on where in our orbits we all are, but this effect isn't pronounced for far-away objects, such as stars. The planets will then have apparent magnitudes even lower than Sirius, the brightest being Venus at $m = -4.14$ on average.

2.2 Star Names

A lot of stars have common names that you should remember, but it is unrealistic (and frankly, unnecessary) to remember absolutely all of them. Luckily, stars are also named according to what constellation they're in. On the IAU (International Astronomical Union) website: <https://www.iau.org/public/themes/constellations/#and>, you can see a list of all accepted 88 constellations.

You should work as hard as you can to remember these 88, but what's important is knowing the abbreviations. Most of them are fairly straightforward, but some are a bit unexpected (e.g. Cnc for Cancer).

The stars you have to be aware of can all be named by the constellation they are in, in combination with a Greek letter. We call this the Bayer Designation. The general rule (with some exceptions mentioned below) is that the brightest star in the constellation is α , going further down the Greek alphabet as the stars get dimmer. As an example, Polaris is named α UMi, meaning that it's the brightest star in the Ursa Minor constellation.

Notable exceptions to this rule are:

- Orion: α Ori (Betelgeuse) is actually dimmer than β Ori (Rigel)
- Gemini: α Gem (Castor) is actually dimmer than β Gem (Pollux)
- Capricornus: α Cap (Algedi) is dimmer than both β Cap (Dabih) and δ Cap (Deneb Algedi)

2.3 Messier Objects

Messier (pronounced with a stress on the last syllable, not "more messy", like a student dorm :D) Objects are a set of 110 objects catalogued by the French astronomer Charles Messier. He was looking for comets, but on observing, he found objects that weren't comets, planets or stars, but looked like cloudy blobs in the sky. With today's astronomy knowledge, we know that these objects are galaxies, globular and open clusters, diffuse and planetary nebulae.

Other than being part of this catalogue, the Messier Objects have little-to-nothing in common with each other, which unfortunately means that the only way to learn them is by heart, since there is no system behind the number assignment and what gets on the list and what doesn't. We recommend you use SkyAcademy, provided in the resources list, to learn and practice.

All objects in the Messier Catalogue are marked as $M[\text{number}]$, with the number ranging from 1 to 110. When you learn them, you should know both their Messier numbers and names.

2.4 Constellations vs. Asterisms

Constellations are only constellations because they have been officially approved by the IAU (International Astronomical Union). There are, however, some sets of stars that make up very distinct and easy-to-find shapes in the sky, without being constellations.

Some famous asterisms are the Big Dipper, Orion's Belt, the Winter Hexagon, the Winter Triangle, the Summer triangle, and many more! Asterisms can either be contained within a constellation (for example, the Big Dipper is only a part of Ursa Major), or span multiple constellations (for example, the Winter Triangle consists of the three brightest stars from Orion, Canis Major and Canis Minor).

2.5 Angular Distances in the Sky

When we observe stars, and when we look at star charts, the separation between stars is often given in angular units, specifically degrees, arcminutes and arcseconds, where:

$$1 \text{ deg} = 60 \text{ arcmin} = 3600 \text{ arcsec} \quad (1)$$

There are some distances in the sky you should be aware of to help you orient yourself, but Figure 1 shows some rules-of-thumb for angular distances in the sky if you stretch your arm out fully. Another important thing to note is that the angular diameter of a Full Moon in the sky is approximately half a degree, or 30 arcsec, which you can use to "calibrate" yourself. This is only useful for practice, though, since a Full Moon will drown out a lot of the fainter objects in the sky, reducing what you can easily observe.

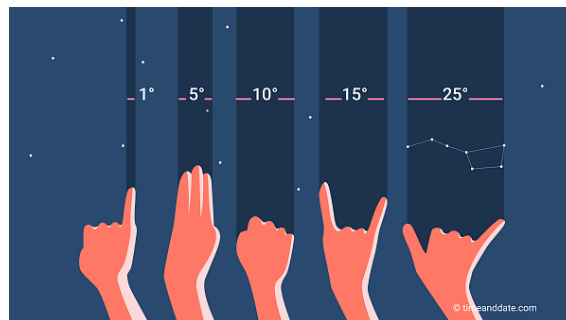


Figure 1: Good ways to remember angular separation in sky. Notice the angular separation of the Big Dipper asterism from end to end.

3 Star Map Reading

Another very specific thing for IOAA that you won't see in your textbooks or any other Olympiads are sky charts or star maps. These show the sky at a specific location at a specific point in time. Every star chart usually comes with a legend (or at least some information as to where and when it was taken, unless you are supposed to find that out yourself :)), and what you need to know about the charts presented in this document is that they are all of the night sky in Trondheim 2024 – 10 – 11 at 22 : 00 : 00 (CEST).

A basic star map can be seen in Figure 2. We understand this is a bit daunting, but even without knowing your way around the sky, we can appreciate certain important qualities of the map:

- the celestial bodies (planets and stars in this case) on the map are black dots sized according to their apparent magnitude, i.e. how bright they are for an Earth observer in ideal conditions.
- the circle surrounding it is the horizon at the observer's location
- the zenith is in the centre of the map, i.e. where the N-S and E-W lines cross (remember that this is 90° above the horizon)
- the cardinal directions north and south are as expected, but east and west are the opposite of what they are on a regular map of the Earth.
 - remember that any map of the Earth is viewing the Earth from the top and that's why you have the cardinal directions that you know; we are looking at the sky "from the bottom", so left and right will be flipped.
 - if you need an analogy, you can look at your right hand with the palm facing down; if you look at it from above, the thumb is on the left side, but if you look at it from below, keeping your hand in the same position, the thumb will be on the right!

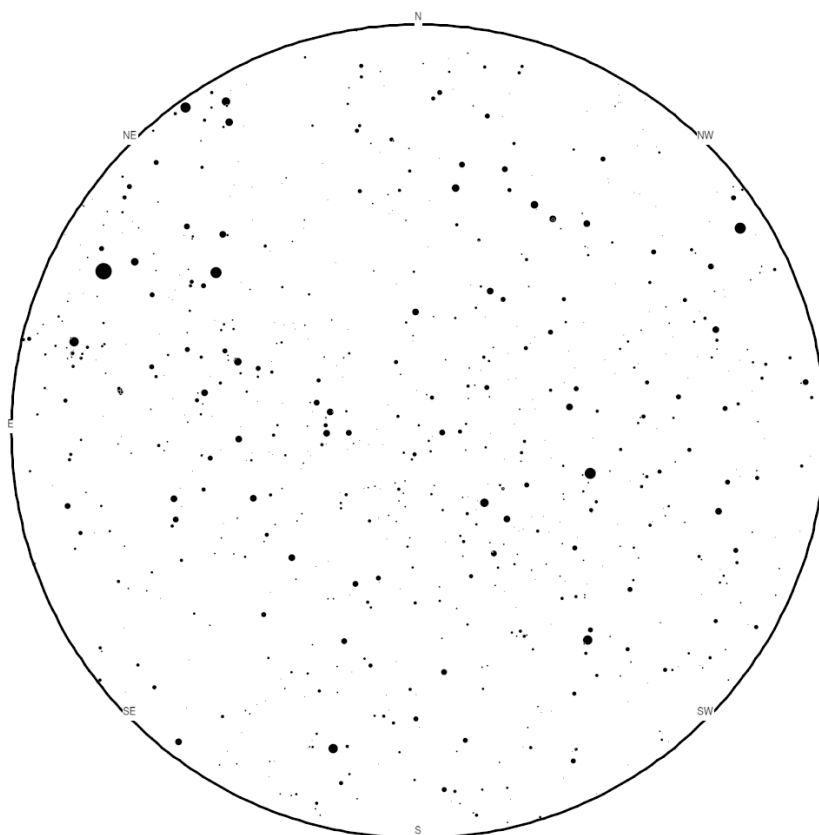


Figure 2: A blank sky chart with no labels.

Figure 3 shows lines you might be more familiar with, namely constellation lines, and labelled constellations. We recommend you print out some sky charts and practice labelling constellations. Throughout the document, you will learn which ones are most useful when it comes to orienting yourself in the sky.

Do consider that sometimes the cardinal directions won't be given and that you will be expected to find them yourselves. This also means that not all star charts you're presented with will have north up, south down, etc. You should be as comfortable as possible with using the stars themselves to find your way around.

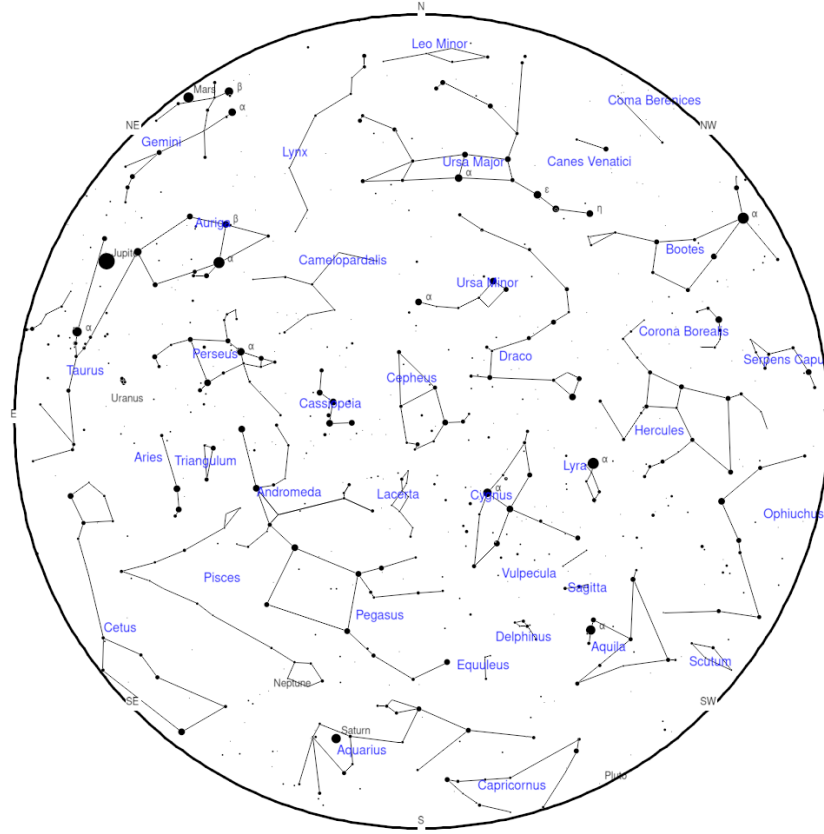


Figure 3: The same sky chart from Figure 2, with constellations and planets marked.

Now, we can also see Polaris, α UMi. We can use Polaris on a star chart in many different ways. To begin with, remember that it almost perfectly coincides with the North Celestial Pole. This means that the sky essentially rotates in a circle with Polaris in the centre. The rotation is going from east to west, and that can tell us a little bit about how the different celestial objects will move throughout the night.

Even unmarked, this is an alt-az projection of the sky. The altitude ranges from 0 at the horizon (the circumference of the circle) to 90° in the middle of the map, where zenith is. The azimuth can be read if we subdivide the circle into 360° as usual, with 0° being the cardinal north, and growing counterclockwise (so that east is 90° , south 180° and west 270°). The altitude of any star can easily be determined by the following relation:

$$\frac{a}{90^\circ} = \frac{d}{R}, \quad (2)$$

where R is the radius of the star map, d the distance between the horizon and the point of interest along the line connecting the point and zenith, and a the unknown altitude. The latitude of the observer corresponds exactly to the altitude of Polaris!

Remember that this is a star chart from a random day in October in Trondheim, so if you were anywhere else at any other time of year or day, the star chart would look differently!

3.1 Important Lines in the Sky

From the handout on coordinate systems, you might remember four important lines: the local meridian, the Celestial Equator (CE), the Ecliptic, and the Galactic Equator (GE). Knowing how to find these in the sky where you are can help you immensely in locating different celestial objects, just as long as you know where they are in relation to these lines.

The local meridian on a star chart is simply a straight line going from north to south! Celestial objects culminate on the meridian.

3.1.1 Celestial Equator

The Celestial Equator is a good starting point for the more involved lines. It is by definition the projection of Earth's Equator on the night sky. The Equator always goes from east to west, no matter where on Earth you are. On a sky chart, if the location of the observer is somewhere along Earth's Equator, the Celestial Equator will be a straight line from east to west. The further north you go, the more the CE will curve towards the south, and vice-versa. At the poles, the CE coincides exactly with the horizon.

Figure 4 shows the CE in Trondheim. How much does it curve, though? To know how to draw this, we can realise that the CE always goes through these constellations (not all of them will be visible, and you don't need to remember all of them, but knowing at least the ones in bold can help you substantially):

- | | | |
|-------------------|----------------|-----------------|
| • Aquarius | • Hydra | • Pisces |
| • Aquila | • Leo | • Serpens |
| • Canis Minor | • Monoceros | • Sextans |
| • Cetus | • Ophiuchus | • Taurus |
| • Eridanus | • Orion | • Virgo |

We can also use Polaris to approximately find the CE. On star charts, the CE will be south of Polaris, approximately the length of the radius of the star chart. You can use this fact to either help you start or to help you confirm what you have already found. In other words, the Celestial Equator is a curve whose top point is 90 degrees away from the celestial pole present in the sky chart.

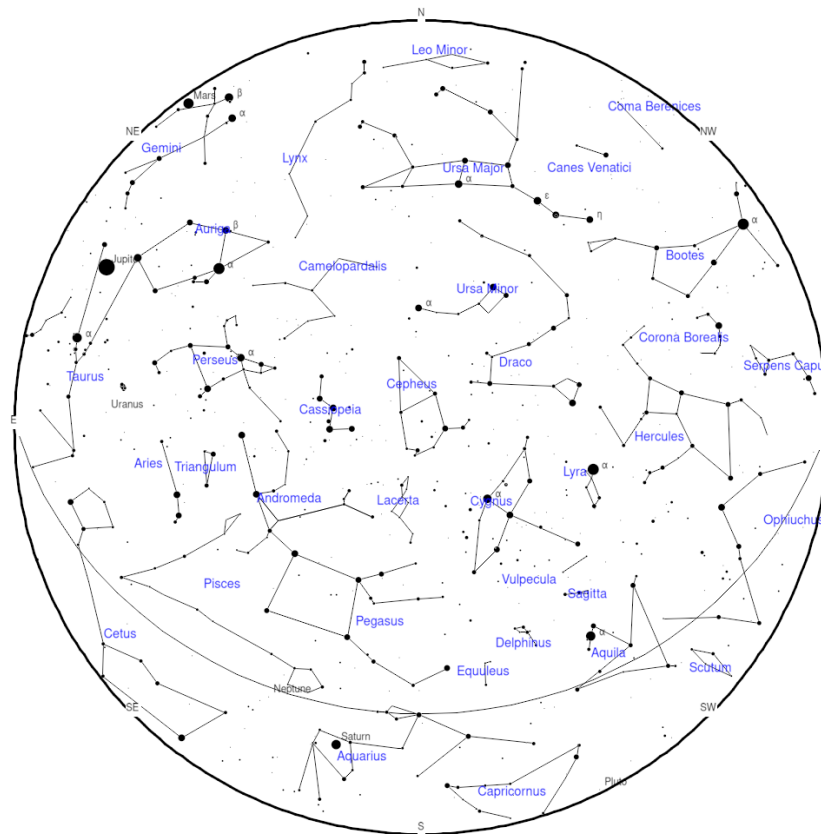


Figure 4: The same sky chart from Figure 3, with the Celestial Equator marked as a line from east to west, curving towards south.

3.1.2 Ecliptic and Zodiac

Now, remember that the ecliptic plane is the plane in which approximately all planets orbit the Sun. To find the Ecliptic on a star map, it can help to find the planets (that are substantially brighter than even the brightest star), and draw a curved line through them. We have done so in Figure 5.

The ecliptic has one more very important property, namely the fact that it passes through all the zodiacal constellations. The Zodiac is actually defined as the constellations the ecliptic passes through! The following constellations are all part of the Zodiac (don't worry, we won't be delving into any birth chart readings here :D).

- Capricorn (Jan)
- Gemini (Jun)
- Scorpio (Nov)
- Aquarius (Feb)
- Cancer (Jul)
- Sagittarius (Dec)
- Pisces (Mar)
- Leo (Aug)
- Taurus (May)
- Virgo (Sep)
- Libra (Oct)
- Ophiuchus (Nov/Dec)

If you're struggling to find the planets, you can try and find some parts of the Zodiac and try to look close to them, and vice-versa!

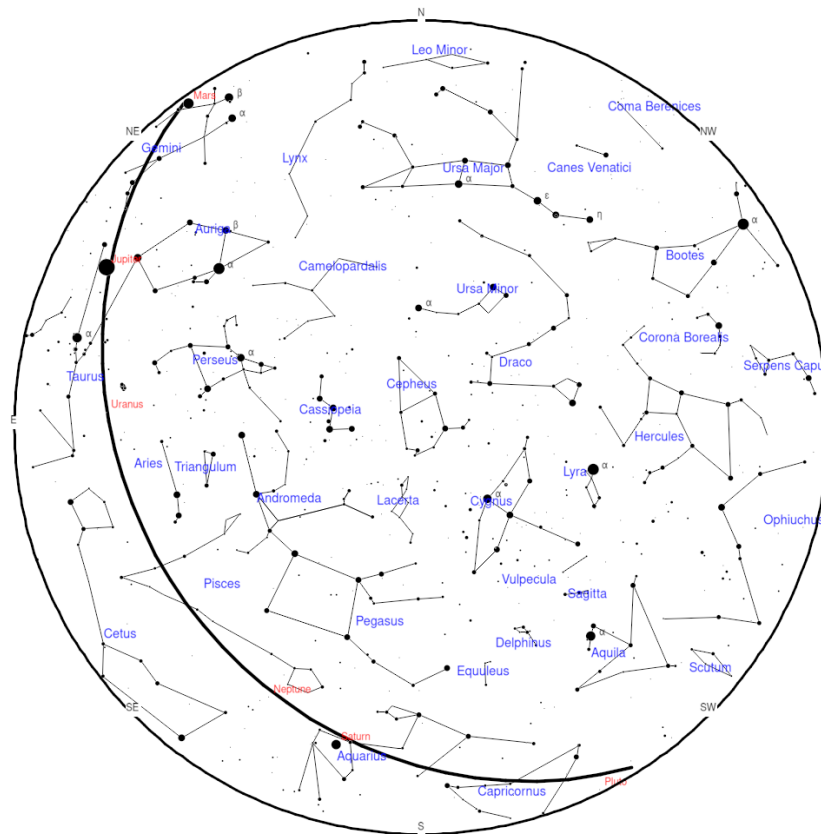


Figure 5: The same sky chart from Figure 3, with the Ecliptic clearly marked. Notice where the planets are located (their names written in red in the figure).

The Zodiac is actually incredibly useful on star charts, since it can not only help us determine where planets and constellations are, but also determine the month of the year of the star chart! You will have noticed in the bullet point list above that all 13 zodiacal constellations have been assigned a month. The month in question is approximately when these constellations are behind the Sun and therefore not visible in the night sky.

A constellation will culminate about six months after it has been behind the Sun. On the star charts given so far, we can clearly see several zodiacal constellations. Out of these, Pisces will culminate at midnight. Pisces corresponds to March in the list, and six months after March is October, which is exactly what the month is for the simulated sky!

3.1.3 Galactic Equator

Finally, the GE is a line passing through the Milky Way. In Figure 6, we have drawn in the GE along with the Milky Way.

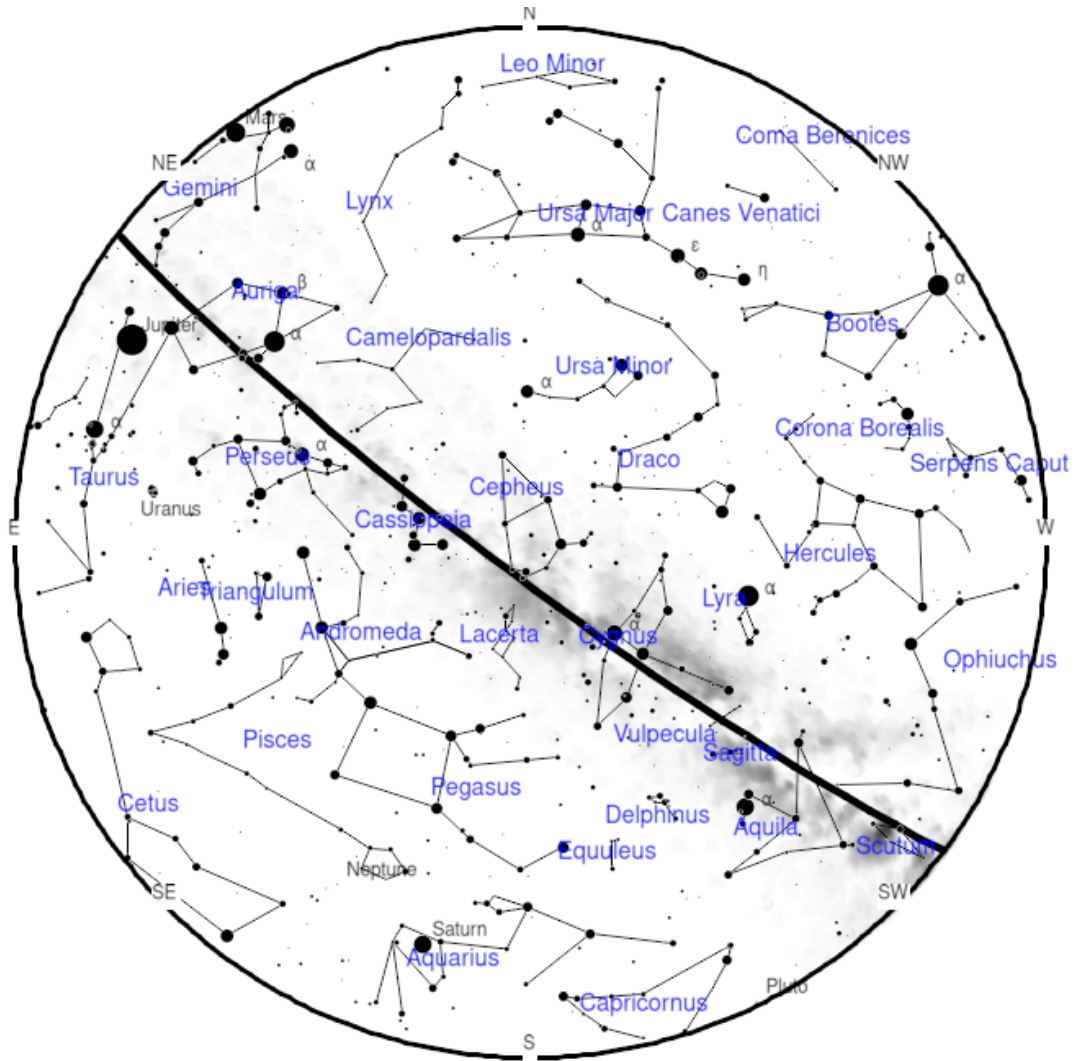


Figure 6: The same sky chart from Figure 3, with the Galactic Equator and Milky Way clearly drawn in.