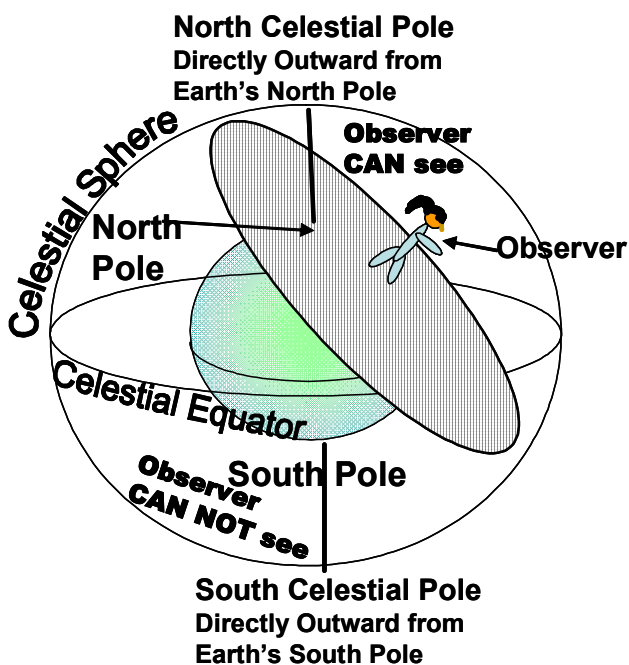


Chapter 3 How Earth and Sky Work- Effects of Latitude

In chapters 3 and 4 we will learn why our view of the heavens depends on our position on the Earth, the time of day, and the day of the year. We will explore views of the Earth, the sky, and an observer as seen from space and as seen from the surface of the Earth.



Today we know that the Earth is a sphere and we are tiny by comparison. The distance to every other celestial body is MUCH larger than the diameter of the Earth. Because we are so much smaller than the Earth, the Earth appears to take up half of all the directions we can look

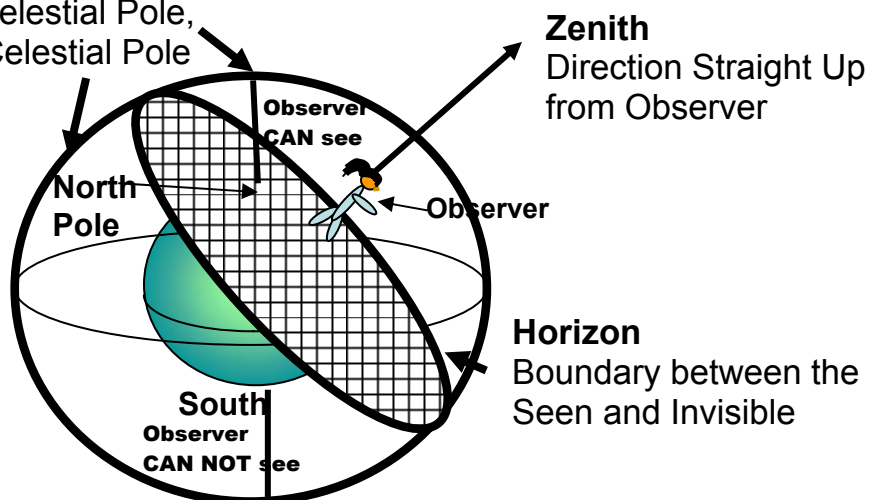
The Earth and the other planets orbit the Sun, while stars are at various distances and orbit the Milky Way galaxy. But we can use the idea of the **Celestial Sphere** to describe the appearance of the sky. The **Celestial Sphere** is an imaginary sphere surrounding the Earth. Stars, the Moon, the planets, the Sun, galaxies etc appear to be pasted on the Celestial Sphere. Straight up from Earth's north pole is a point called the North Celestial Pole. The Earth pole and Celestial Pole are lined up and remain lined up.

The figure shows our relation to the Celestial Sphere. The observer stands on the Earth. The stippled surface is the apparent (flat) surface of the Earth, bounding the half of the sky visible to the observer. As the Earth spins, different parts of the Celestial Sphere different parts may become visible. When the Earth turns so that a body comes onto the visible half of the Celestial Sphere, we say that it **rises**. When the Earth turns so that a body becomes blocked by the Earth, we say it has **set**.

We define the **zenith**, the **horizon**, and the celestial **meridian** to describe what an observer can see. These reference points depend on the observer's position. As Earth spins, the zenith and meridian change as the person moves with the Earth.

Meridian

Circle through Zenith, North Celestial Pole, South Celestial Pole



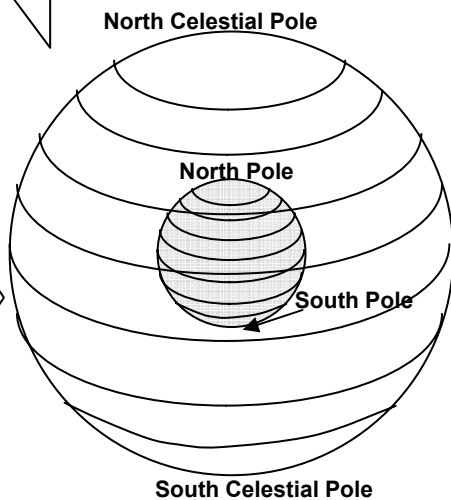
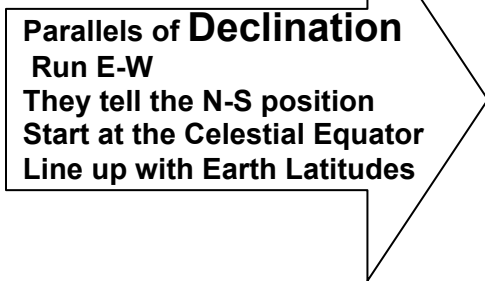
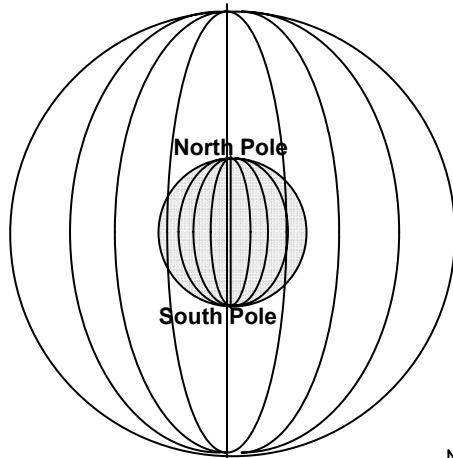
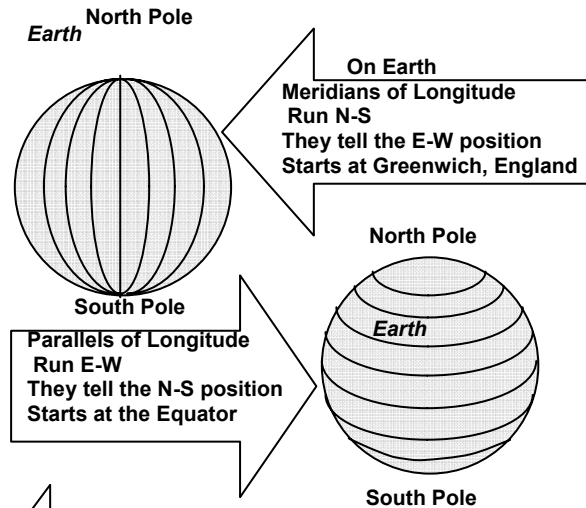
We have been considering what the observer can see. But this changes all the time. The Earth spins and the observer moves with it. The stars move but they do not go around the Sun or the Earth. Because stars are so far away, none of their individual motions of the stars is noticeable. Astronomers measure stars' motions by photographing them and comparing their relative positions over many years.

Because the stars move slowly it is useful to define stars' positions and patterns on the Celestial Sphere and to learn how the positions relate to their visibility. We do this using coordinates that are similar to Latitude and Longitude on Earth (other planets, moons and the Sun are also assigned their own Latitude and Longitude systems).

So first review Latitude and Longitude as shown in the figure.

Latitude is zero at the equator and $\pm 90^\circ$ at the poles. Longitude is zero at the Prime Meridian in Greenwich England. It goes East for 180° and west for 180° . The International Date Lines is approximately at the 180° line.

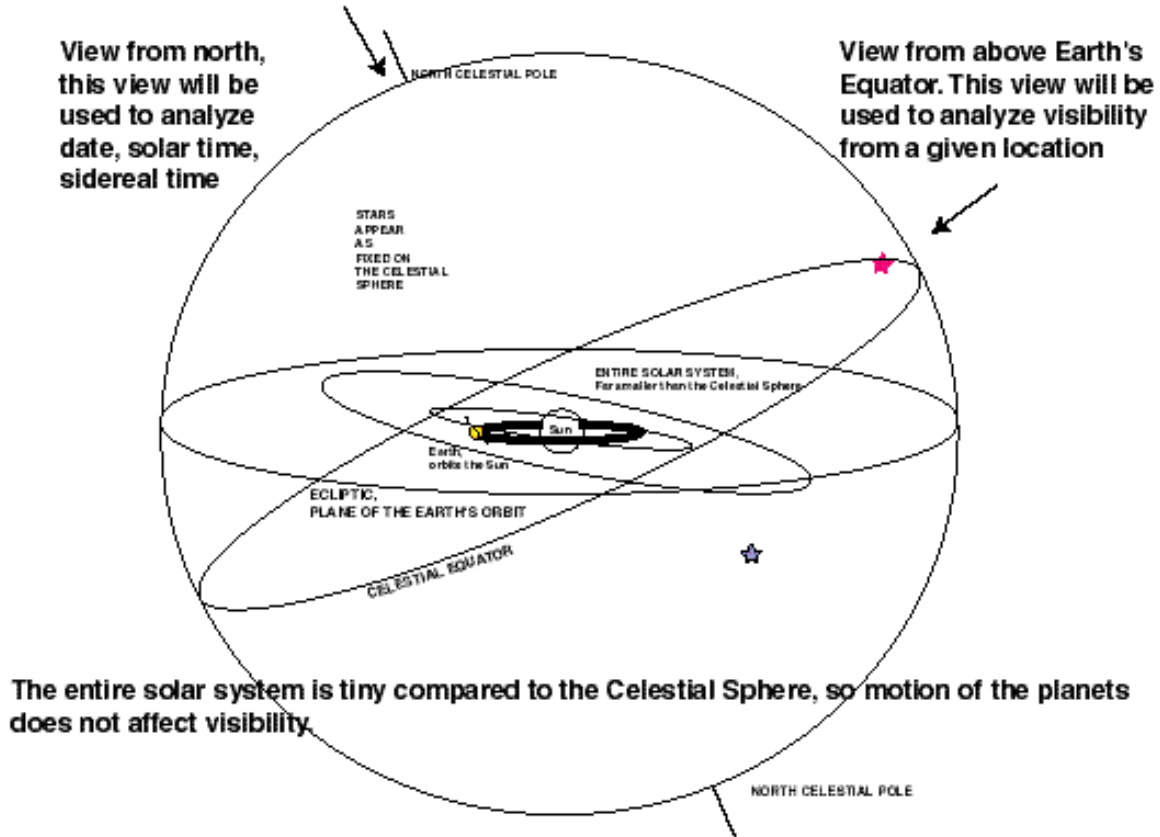
The coordinates for the Celestial Sphere are called **Right Ascension** and **Declination**. They are similar to **latitude** and **longitude** on the Earth. Each location on the Celestial Sphere, that is each direction in the sky, can be identified by its Right Ascension and Declination.



We think of the Celestial Sphere as fixed and the Earth spinning. As the Earth moves orbits and spins, the Earth's poles remain aligned with the poles of the Celestial Sphere and the parallels of latitude remain aligned with the parallels of declination. Meridians of longitude and of Right Ascension are parallel but there is no one-to-one alignment.

You may be wondering how the imaginary Celestial Sphere fits with the overall concept of the Universe, where the Earth orbits the Sun. The overall concept is in the figure below.

The Earth and Planets Orbit the Sun
Entire Solar System is within the Celestial Sphere
Solar System is so much smaller than Celestial Sphere that motions do not matter



The Celestial Sphere is so large that the Earth's orbital motion is insignificant by comparison.

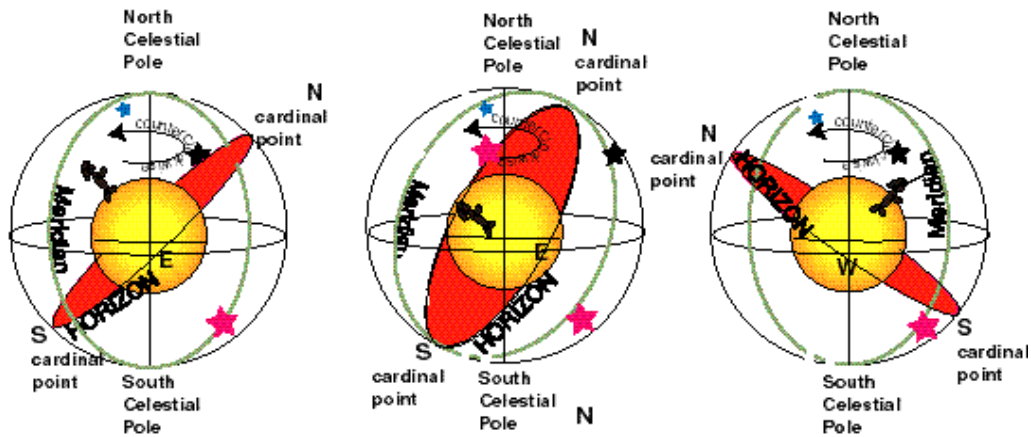
The Earth moves in three-dimensions, but to make it easier to draw, we will consider the appearance two dimensions at a time. First we will consider the view from the right of the image. When viewed from this direction, we see the effect of latitude on what can EVER be viewed.

Then we will look from above the North Pole of the Solar System. This will tell what can be seen at a given time and date, but will ignore the effect of latitude. The visibility curves at the end of chapter 4, combine both effects. In each situation, we will learn to compute what can be seen.

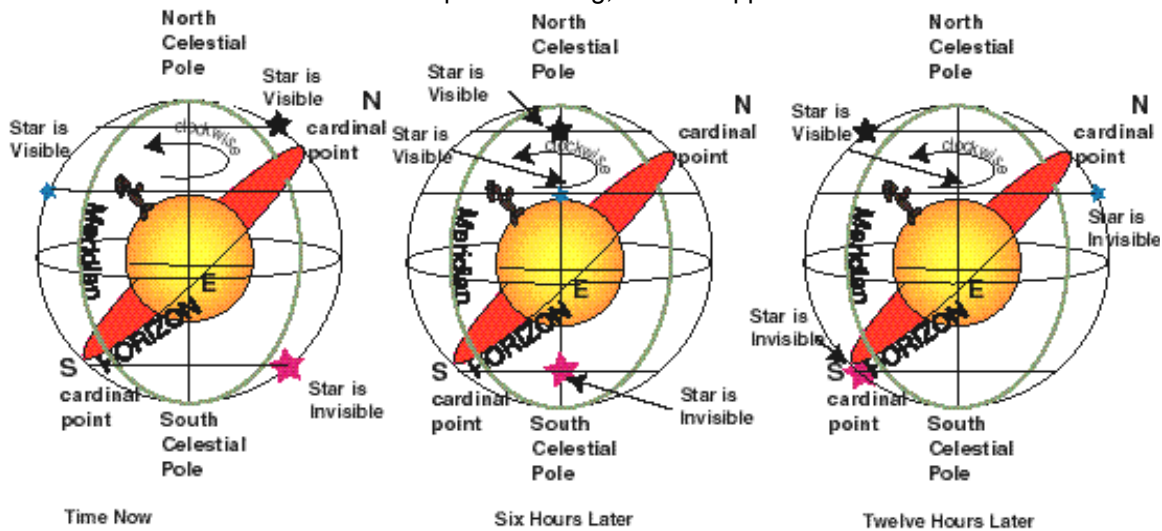
Finding the Effect of Latitude

Let's zoom out away from the Earth and the Celestial Sphere and see what happens as the Earth spins (every 23 hr 56 minutes) and the Celestial Sphere stays still, the observer and her/his horizon and meridian are carried along. Some stars rise and set, others are always seen.

6. Rotation of (Earth every 23 hours 56 minutes) moves the horizon, making bodies appear to move East to West



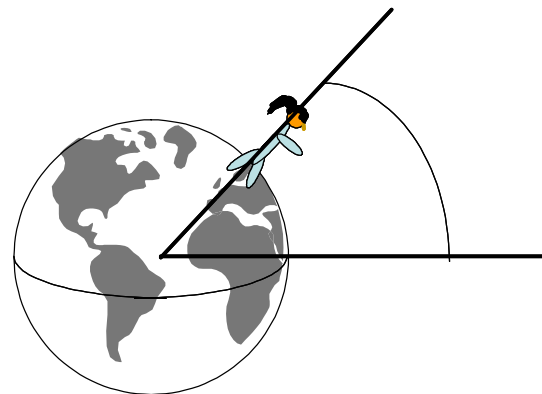
Even though the Earth is really spinning, the appearance is that the sky is moving. If the figure were redrawn to show the Celestial sphere moving, it would appear as follows.



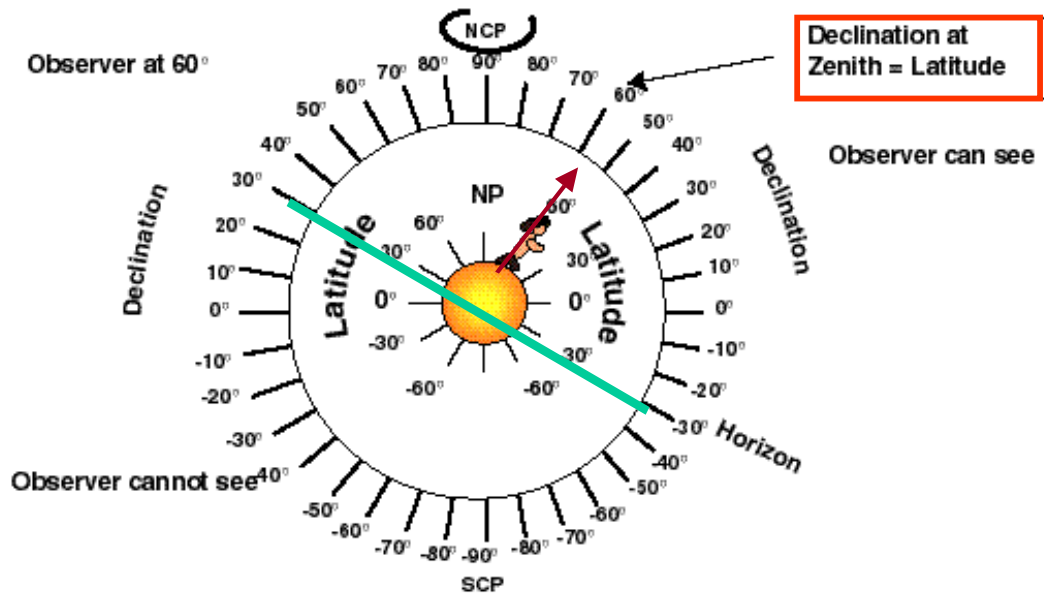
In 12 hours, the sphere moves half way around. Ignoring the depth, the stars, the Sun, the Moon and the planets appear to move **horizontally** from one side of the figure to the other, keeping the same declination. Over the next 12 hours they move back to their original positions. Bodies at some positions remain visible the entire time (**circumpolar** for this latitude); others remain invisible (**never seen**); yet others change from visible to invisible. Bodies at these positions are said to “**rise and set.**”

These pictures show the overall appearance of the sky, but do not provide a way to compute whether a star will be visible all the time, some of the time, or none of the time. To find this, we need to relate the declination horizon position on the sky and the observer’s latitude.

The observer’s latitude tells the angle from the equator to the observer. If we draw the Earth flat on and label the declinations above it, the



following picture results. North is toward the top. South is toward the bottom. The Declination values start at $+90^\circ$ at the northernmost point and progress lower and lower until they reach -90° .



Latitude on the Earth and Declination on the Celestial Sphere line up.
 The Declination at the Zenith equals the observer's latitude.
 The observer's horizon cuts 90° from the zenith at Declination $\pm(90^\circ - \text{latitude})$

The Latitudes on the Earth and the Declinations on the Celestial Sphere line up, so
Latitude = Declination at Zenith.

The observer always stands perpendicular (at a 90° angle) to his/her horizon. From the diagram, it is possible to tell which declinations can be seen by the observer.

To find the declinations where the horizon cuts the Celestial Sphere, count 90° north and 90° south of the zenith. This isn't the same as adding or subtracting 90° because the Declination system goes only from $+90^\circ$ to -90° . The horizon cuts the Celestial Sphere at two points that have the same declination value, but opposite signs. So

Declination at ends of Horizon = $\pm(90 - \text{latitude})$

Either you know the observer's latitude and can find the horizon, or you know something about the horizon so you can draw the horizon and can draw the observer 90° away.

There are **standard questions** that you can answer when the observer's latitude is known. These questions follow. The blank would have a number in it.

- What is the furthest north that an observer at latitude _____ can see?
- What is the furthest south that an observer at latitude _____ can see?
- What is the range of declinations that an observer at latitude _____ can see?
- What is the range of declinations that an observer at latitude _____ can NEVER see?
- What is the range of circumpolar declinations for an observer at latitude _____?

How do you find the answers? The following discussion is for an observer at latitude $+60^\circ$.

Circumpolar, the part of the sky that is always seen from your location. The circumpolar region starts at either $+90^\circ$ or -90° , whichever is above the horizon for the observer. The circumpolar region extends to the closest end of the horizon. The circumpolar region NEVER crosses the equator. The observer's latitude and the boundaries of the circumpolar region all have the same sign. Example. For an observer at $+60^\circ$, the circumpolar region is $+30^\circ$ to $+90^\circ$. If

declination is within the circumpolar region for an observer, EVERY location with that declination number is circumpolar.

Never seen- Starts either -90° or $+90^\circ$, whichever is not visible to the observer. It extends to the closest end of the horizon, the one with sign opposite the observer's latitude. It is just the opposite of the circumpolar region (that is the declination values are -1 times the values for the circumpolar region). For the observer at 60° , the never seen region would be -30° to -90° .

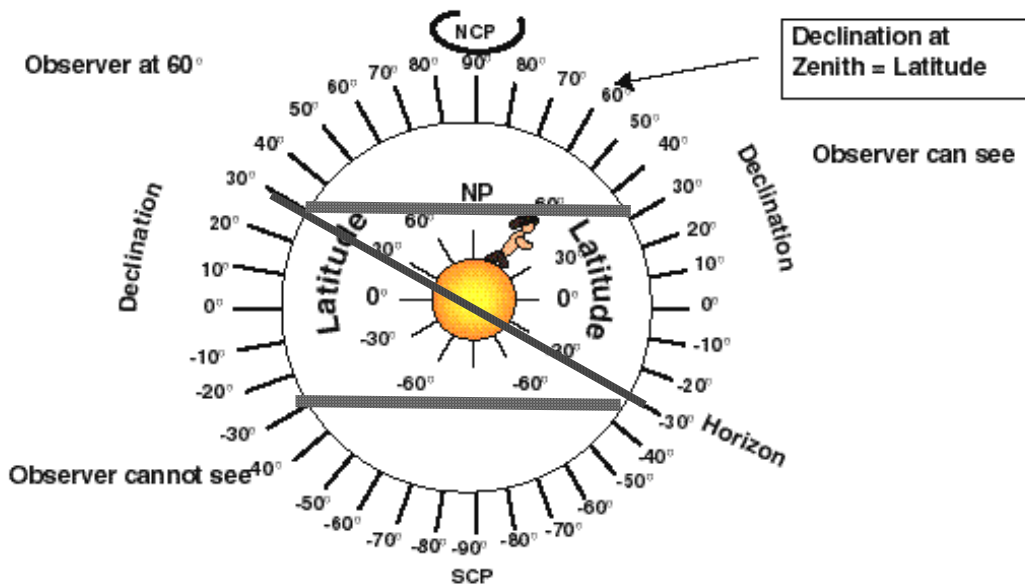
Rise and Set- Between $(90^\circ - |\text{latitude}|)$ and $-(90^\circ - |\text{latitude}|)$ This is what remains when the circumpolar and never seen regions are excluded.

Furthest North Seen – If the observer is in the northern hemisphere, $+90^\circ$,
If the observer is in the southern hemisphere $(90^\circ - |\text{latitude}|)$

Furthest South Seen - If the observer is in the northern hemisphere, $-90^\circ + \text{latitude}$
If the observer is in the southern hemisphere -90° .

The observer in the previous figure is at latitude 60° , so her zenith is at declination 60° . Her horizon is at 90° to the zenith direction at $\pm 30^\circ$. So what is the
Furthest north that an observer at latitude 60° can see?
Furthest south that an observer at latitude 60° can see?
Range of declinations that an observer at latitude 60° can see?
Range of declinations that an observer at latitude 60° can NEVER see?
Range of circumpolar declinations for an observer at latitude 60° ?

To determine whether a body can be seen some, none, or all the time, compare the declination to the limits of the circumpolar, never seen, and rise and set regions. Or use the diagram as follows. You will be drawing something like the letter Z.



Latitude on the Earth and Declination on the Celestial Sphere line up.
The Declination at the Zenith equals the observer's latitude.
The observer's horizon cuts 90° from the zenith at Declination $\pm(90^\circ - |\text{latitude}|)$

A. Draw the **horizon**. It goes through the center of the picture and through $\pm(90 - |\text{latitude}|)$ The horizon is always **at 90°** , a right angle, **to the observer's body**. It does NOT matter whether observer and the horizon are on the right or left of the picture so long as they are at 90° to one another.

B. Draw **horizontal** lines from the points where the horizon touches the Celestial Sphere to the Celestial Sphere on the other side of the picture. The declination is the **SAME** number at each end of the line. Your lines and the horizon make the shape Z or a reversed Z (NOT a sideward Z). These lines are the boundaries of the circumpolar and never seen regions.

C. Draw a horizontal line representing the daily apparent motion of the body the declination

D. Check whether the path of the star crosses the Z you drew before. If so, it rises and sets. If the path does not cross the Z and is always above the horizon as seen by the observer, it is circumpolar. If the path does not cross the Z and is never above the horizon as seen by the observer, it is Never Seen.

Lost at Sea- Finding Where You Are From What You Can See

In the problems we have been considering, there is only one free parameter, the observer's latitude. If we know the latitude, then we know the horizon and what can be seen, the circumpolar region etc. There is little variety.

On the other hand, an observer can **find his latitude** by noting the range of circumpolar bodies, the furthest south or north that can be seen etc. It is just a matter of using the information to find the horizon, then finding the location of the observer (90° from the horizon)

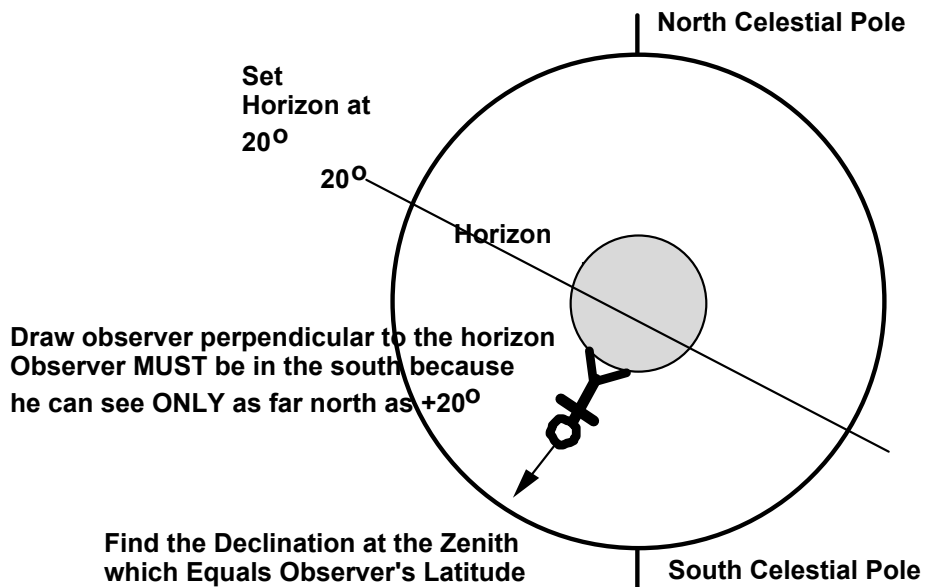
Example: You notice Vega at your Zenith, what is your latitude? Vega is a star and you can find its declination from a star map.

Answer: You know that Latitude of observer = Declination of zenith and the problem says that Vega, is at the zenith. So

Vega's declination = declination at the observer's zenith=observer's latitude = 39°

Example: If you can see as far north as 20° , what is your latitude?

Answer: The words imply that the horizon goes through 20° . It also goes through the center of the Earth and -20° . So draw the horizon. Draw the observer perpendicular to the horizon on the side such that he can see 20° and south of 20° . The latitude of the observer equals



the declination at the observer's zenith. How do you know whether the observer is in the North or the South? Be sure that your observer cannot see further north than 20° **Ans -70°**

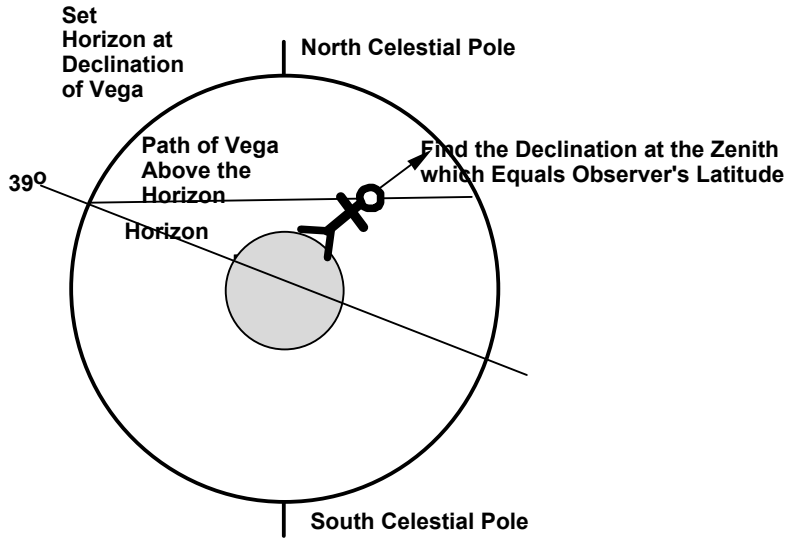
Example: You notice that Vega is circumpolar, but nothing further south is. What is your latitude?

Look up Vega's declination on a star map. If Vega is circumpolar, its entire path is above the horizon. Since nothing further south than Vega is circumpolar, the horizon must touch Vega's path on one side. It doesn't matter which side.

So draw the horizon though Vega's declination, the center of the Earth, and the negative of Vega's declination.

The observer will be perpendicular to the horizon. In this case, the observer will be in the northern hemisphere, since Vega is.

When you draw the line representing Vega's motion, you can simply draw the observer such that the entire path is above the horizon.



The Sky as We See It

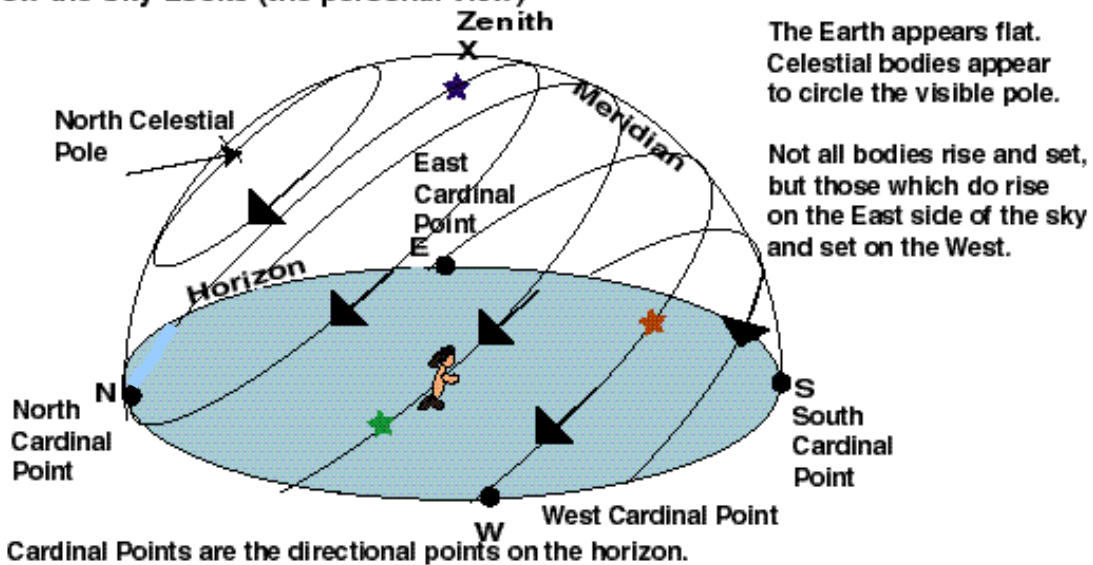
We have been making diagrams as though we are outside the Celestial Sphere. But how does the path of a star really look from the ground?

The figure below shows how celestial objects appear to move through the sky. It is drawn for a mid northern latitude location. Circumpolar objects appear to circle the pole, always remaining above the horizon. Objects that rise and set make arcs starting in the East and ending in the West. The never seen objects are, of course, never seen. The filled ellipse represents the ground.

As time goes by, the position of each object normally changes compared to the horizon and to the cardinal points (the N, E, S, W positions on the horizon).

The only points that don't appear to move are the North Celestial and the South Celestial poles. The North star, Polaris, is about 5/6 of a degree from the North Celestial Pole, changes its position a little. There is no bright star near the South Celestial Pole.

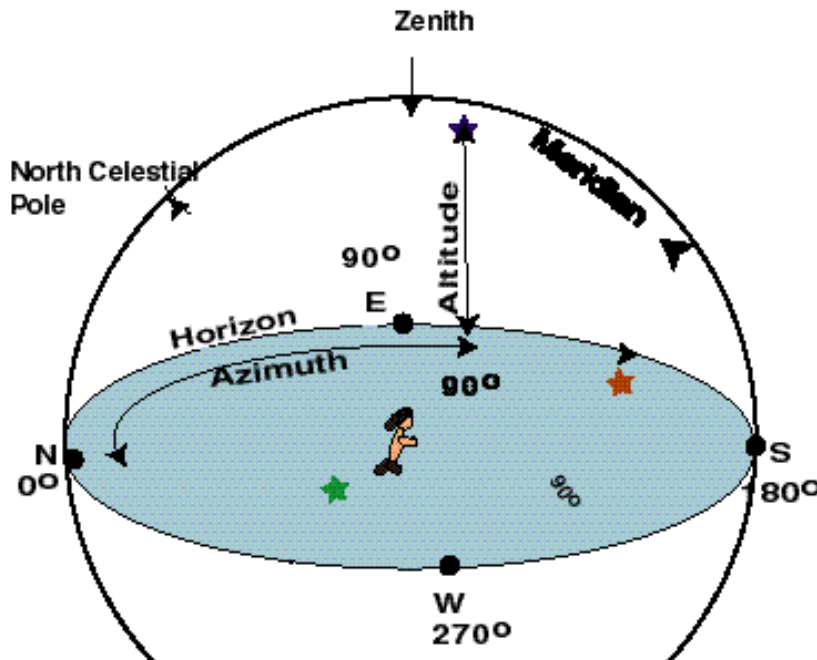
How the Sky Looks (the personal view)



Altitude/Azimuth System

Right Ascension and Declination are useful because they tell the position of a location on a star map. They don't correspond to a fixed direction compared to the observer's horizon and meridian. The Altitude and Azimuth system does.

Altitude is the angle from body to horizon. **Altitude** is 90° at the zenith, 0° at the horizon. Negative altitudes are sometimes used to describe positions below the horizon (invisible).



Azimuth is the angle from north to the point on the horizon below the object.

Azimuth runs from 0° at the North Cardinal Point, through 90° eastward and 180° to the south.

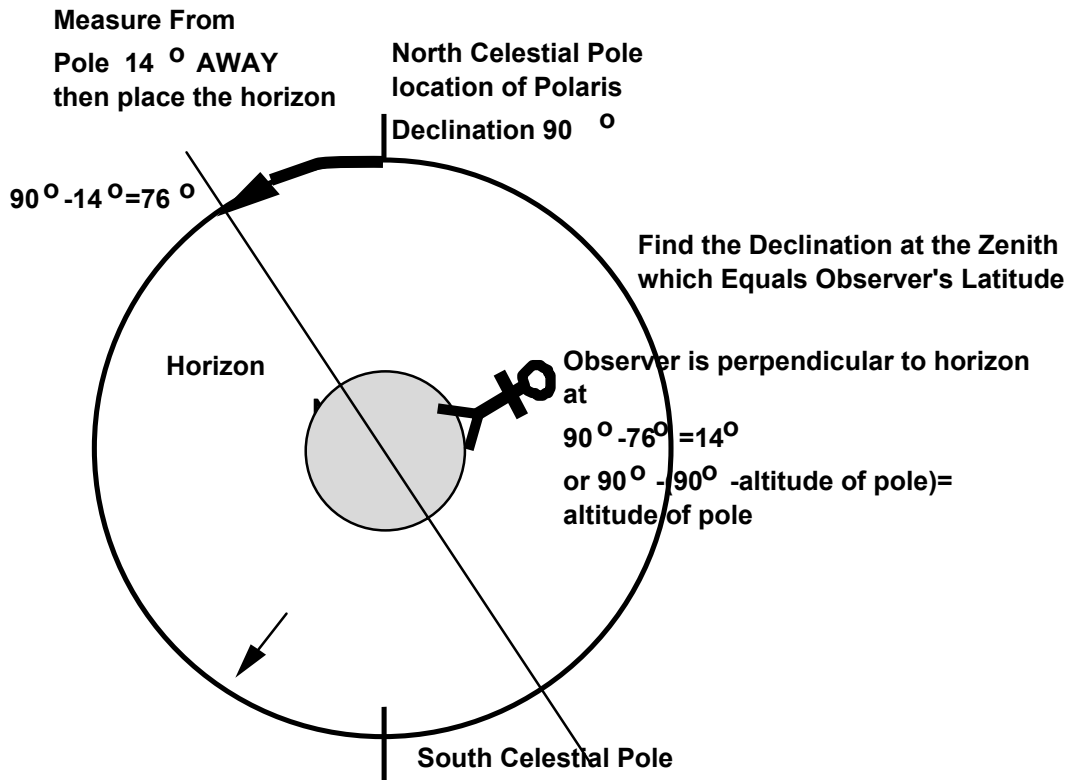
Altitude and Azimuth change as the objects rise and set. So there are no books of Altitude and Azimuth coordinates. But these coordinates are very useful for pointing out objects in the sky to nearby people. They are also used by some telescopes. But these

telescopes use a computer and a clock to figure out where the object is as it moves across the sky.

Altitude of the Celestial Pole

The altitude of the celestial pole, whichever one you can see, is equal to the latitude of the observer. Since the star Polaris is nearly at the North Celestial Pole, the altitude of Polaris equals the observer's latitude. This makes it easy to find latitude. **Latitude is equal to the altitude of Polaris.**

Ex. Polaris' altitude is 14° . Where are you?



Ans. Latitude 14° .

Example Polaris is at altitude 83° . What is your latitude?

Orientation Practice Problems Set I (you may look up declinations etc. on the star map)

- 1) What is the range of declinations that can be seen from latitude 20° ?
- 2) What is the range of declinations, which is circumpolar from latitude 20° ?
- 3) What is the furthest north that can be seen from latitude -43° ?
- 4) What is the furthest south that an observer at latitude at latitude -63° can see?
- 5) If you are at latitude 32° , what is the range of declinations that are circumpolar ?
- 6) When the altitude of the North Celestial Pole is 14° , where are you?
- 7) If you are at latitude -30° , what is the altitude of the SCP? of the NCP?
- 8) What is the furthest south latitude you can be so that the star Vega will be circumpolar for you?
- 9) What is the range of declinations that are visible from -60° ?
- 10) Regulus is circumpolar. It just grazes the horizon at its lowest point, what is your latitude?
- 11) You are lost at sea. Antares just comes above the horizon at culmination(its highest point), What is your latitude?
- 12) If you notice that Betelgeuse is circumpolar, but nothing further south is, what is your latitude?
- 13) If Deneb just rises and nothing further north is visible, what is your latitude?
- 14) When Antares is circumpolar and nothing further north is, what is your latitude?
- 15) What latitude allows the observer to see the largest variety of celestial objects?

Answers 1) from 90° to -70° 2) $+70^\circ$ to $+90^\circ$ 3) $+47^\circ$ 4) -90° 5) 58° to 90° 6) $+14^\circ$ 7) SCP 30° altitude, NCP -30° altitude, below the horizon 8) Vega at 36° , latitude of observer 54° 9) $+30^\circ$ to -90° 10) Regulus at $+12^\circ$, observer $+78^\circ$ 11) Antares at -26.5° , observer at 63.5° 12) Betelgeuse at 7° , observer at 83° 13) Deneb at 45° you at -45° 14) Antares at -26.5° , observer at -63.5° 15) The equator, latitude 0°