

Earth-Sky Relationships and the Celestial Sphere

Almost everyone who has looked up at the night sky has imagined that the Earth is in the middle of a large sphere on which the stars and planets move across the night sky. This model, while not literally correct, is a useful way to describe what we see in the night sky, and a useful way of describing the Earth in relationship to other celestial objects. The name we give this imaginary sphere on which the sun, other stars and planets move is called the *celestial sphere*. In class, we will use models of celestial spheres to understand the earth's relationship to space.

Let's start by considering the image of the celestial sphere below.

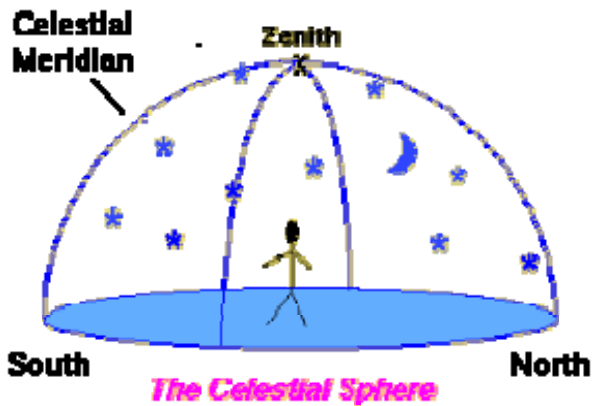


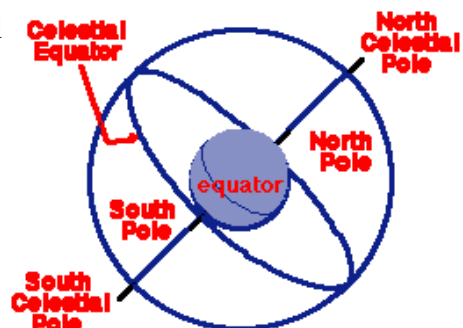
image courtesy University of Tennessee at Knoxville Astronomy Dept.

This image allows you to imagine that we are standing on the Earth looking up at the sky; from our vantage point, it appears as if the sky is a huge sphere and we are at its center.

One of the ways in which we can imagine how the sky looks from different places on the Earth, or how the sky looks at different times of the day or the year, is to use the celestial sphere. As you review the celestial sphere, notice there are a number of features to help us use the sphere.

The metal bands: There are two metal bands of importance here; one is parallel to the ground and represents the horizon. Objects above this band are above the horizon (and potentially visible); objects below the band are below the horizon. The second band, running vertically, has degree markings on it. These markings will help you set the sphere for the proper latitude on the Earth.

Celestial Equator and Celestial North Pole: We all know that the Earth has an equator and North Pole. When we imagine the celestial sphere, we imagine the Earth's equator and North Pole superimposed on the sky. So, if we could take the Earth's equator and stretch it so it expands to encircle the sky, we



would be able to divide the sky into a Northern and Southern Hemisphere. We call this dividing line on the sky the Celestial Equator, and it is represented on your celestial sphere as the “seam” between the bottom and top halves of the sphere.

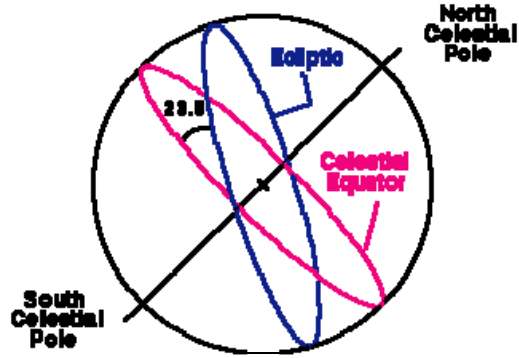
We know that the poles of the Earth are the points on the Earth that are the center of our daily rotation. Similarly, the Celestial poles are those points on the celestial sphere that are the center of rotation of the celestial sphere. Our celestial spheres show this clearly: the metal spike runs through the North and South Poles of the Earth, and extend into space. The North Celestial Pole is that point on the sky that is directly above the North Pole of the Earth. As you rotate the celestial sphere, notice that all the stars move around the North Celestial Pole (NCP) in circular paths.

There is no star exactly at the NCP, however, the bright star Polaris is very close to the NCP. (By the way, Polaris is not the brightest star in the night sky, contrary to much popular belief. It is approximately the 20th brightest star in the night sky, but is the brightest star near the NCP.)

Lines of Celestial Latitude and Longitude: If you look carefully at the celestial spheres, you can see lines inscribed on its surface. Notice that these lines run both horizontally and vertically, similar to lines of latitude and longitude on the Earth. In fact, these lines serve the same purpose on the celestial sphere: just as we can specify the location of a place on the Earth by its latitude (number of degrees north or south of the equator) and longitude (number of degrees east or west of the Greenwich meridian), we can locate the position of any celestial object by its celestial latitude (number of degrees north or south of the celestial equator) and celestial longitude (a measure of east-west distance from a specific point...in this case the Vernal Equinox). [See the web site <http://condor.stcloudstate.edu/~physcrse/astr106/ra.html> for a nice illustration of this geometry.] Just like terrestrial latitude, we describe celestial latitude in degrees north or south. While longitude on the Earth is measured in degrees, celestial longitude is measured in hours.

If you look carefully on your spheres, you should find some number inscribed on the surface, indicating degrees of latitude (technically called declination) and hours of longitude (technically called right ascension). So, if you look at your celestial spheres and find the bright star Aldebaran (in the constellation Taurus), you should be able to estimate that its declination is slightly more than 15 degrees, and its right ascension is between four and five hours. (The more exact figures are 16.5 degrees dec, 4 hrs 36 mins RA).

Setting the day of the year: Notice the white knob connected to a yellow sphere by a metal wire; not surprisingly this sphere represents the sun. Notice that as you rotate the knob, the sun moves along a certain path. If you look carefully, you should see inscribed into the sphere a series of grid marking showing days of the year. Notice that the path the sun seems to take (we say ‘seems to take’ since of course it is the Earth that moves) cuts across the Earth’s equator. This path lies in a plane called the ecliptic, and the ecliptic is the plane of the Earth’s orbit around the sun. The name derives from the fact that solar and lunar eclipses can only occur when the moon lies on the ecliptic and is at the proper lunar phase.



SETTING THE LATITUDE: Usually, the first step you will want to take is to set the celestial sphere to show the sky for a particular place in the world. This means adjusting the sphere for the proper latitude. The concept behind this is that the Earth's North Pole should be set such that the altitude (angle of star above the horizon) of the north star (Polaris) is equal to the latitude of the observer. For example, if you are on the North Pole of the Earth, then the North Pole of the sky is directly above you, and you should set the celestial sphere so that the NCP is pointing straight up. If you were on the equator, for instance, you would see the North Star on the horizon. In this case, the altitude of the North Star is zero (zero degrees above the horizon), and you should set the sphere so that the metal spike is directly horizontal.

We can use the degree marking along the metal strip to set the latitude, but we have to be careful. If you want to set the celestial sphere for a latitude of X degrees, you must adjust the sphere so that the angle marker intersecting the horizon is $90 - X$ degrees. In short, if you want to set the sphere for the latitude of Chicago (42 degrees North), you must adjust the sphere so that $90 - 42 = 48$ degrees is the number on the metal strip that intersects the horizon ring.

IN SETTING THE CELESTIAL SPHERE FOR LATITUDE, ALWAYS MAKE SURE THE NORTH POLE OF THE SKY IS TILTED TOWARD THE NORTHERN HORIZON OF THE EARTH AS SHOWN ON THE BASE OF THE SPHERE.

1. Set the sphere for each of the following locations:
 - a) Chicago, latitude 42 degrees
 - b) Leningrad, latitude 60 degrees
 - c) equator, latitude 0 degrees
 - d) north pole, latitude 90 degrees

SETTING THE DAY

Setting the day is easily done by moving the sun. Notice the path the sun takes as you turn the solar knob. If you look carefully on the sphere, you will see the days of the year

marked off. To see the sky as it would look on a certain day, simply turn the solar knob until the sun lines up with the day in question.

2.

- a) Set the sphere for the first day of summer (June 20) in Chicago.
- b) Set the sphere for the first day of winter (21 December) in Chicago. See how much more daylight you receive in summer and how much higher in the sky the sun is during June than in Dec..
- c) Set the sphere for the first day of summer in Leningrad. How many hours of daylight does Leningrad receive this day?
- d) Set the sphere for the first day of winter in Leningrad. How many hours of daylight are there?

The Arctic Circle is at latitude 66.5 degrees North (and the Antarctic Circle is at latitude 66.5 South). Above these latitudes it is possible to get 24 hours of daylight or of darkness depending on the season. Set the sphere for 70 degrees and observe how much daylight or darkness you get on the first day of summer and the first day of winter.

The tropics are those places on the Earth with latitudes less than 23.5 degrees. At these locations, the sun can be seen directly overhead once or twice a year. Set the sphere for 23.5 degrees for the first day of summer and rotate the globe until the sun is directly above the Earth. Now set the sun for the same location but for 21 December; see that the sun never gets directly overhead. Now, set the sphere for Chicago and see that even on the first day of summer, the sun is never directly overhead.

THE STARS IN THE SKY

You can see what the sky should look like from any location by setting the sphere to the proper latitude and day, and turning the sphere until the sun goes below the horizon. Looking through the back of the sphere toward the North, you can see what constellations should be visible at a given time of night.

For today's date (in Chicago), what stars are rising just as the sun sets? What stars are rising at midnight? What stars are visible just before sunrise.

Set the sphere for six months from now, what stars are visible then?

CIRCUMPOLAR STARS

Some stars never rise or set; these are called circumpolar stars. If you set the sphere for Chicago for any night, you will see that certain stars rise (they come from below the horizon ring to above it) and set (go from above to below the horizon ring). In Chicago, what constellations are circumpolar? At the North Pole, what constellations are circumpolar? At the equator, what constellations are circumpolar?

RISING AND SETTING OF STARS IN THE MIDLATITUDES AND IN THE TROPICS

If you set the sphere for the midlatitudes (30-60 degrees), you will notice that stars rise and set at appreciable angles to the horizon. However, near the equator (in the tropics) stars rise almost perpendicularly to the horizon. This led many tropical cultures to develop horizon based astronomy, since where objects rose on the horizon gave you a good idea as to where you could find the star in the sky later in the night.