Coordinate Systems in Celestial Mechanics

By Brad Young, Astronomy Club of Tulsa

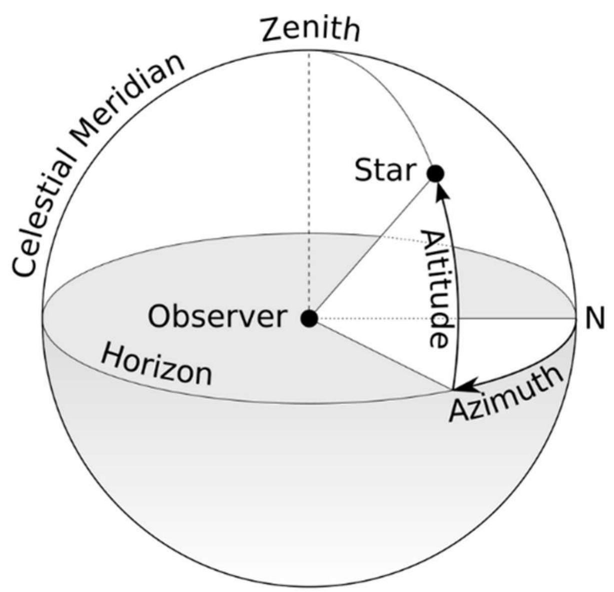
New technologies in optics, imaging and guiding systems have significantly shortened the learning curve for amateur astronomers. When I first began as an amateur, we did not have go to telescopes but instead had to use physical setting circles to determine where an object was in the sky. This meant not only knowing its coordinates but also the sidereal time. Although finding yours is not that difficult to do, the new technology now does all the work for you in finding objects and some of the knowledge you needed in the past is no longer required. This is wonderful in that it saves you steps and lets you spend more time with the eyepiece or imaging, but it also means that fundamental ideas about how the sky works are not picked up as part of the normal growth of an amateur. There are many things we don't get exposed to early on that may help down the road, and it is important to help fill in those gaps if we see them among new members.

In this article, I'd like to discuss fundamental celestial mechanics. Celestial mechanics is a math-based study of how the sky and all the astronomical objects in it move. There are four coordinate systems that are often used in astronomy. Each one of these coordinate systems are useful in their own way. Understanding how your equipment finds and tracks objects is a way of helping you learn where objects are in the sky, and how we determine their position whether done manually or through computer systems. And, if your technology isn't working quite right, this knowledge may help you troubleshoot.

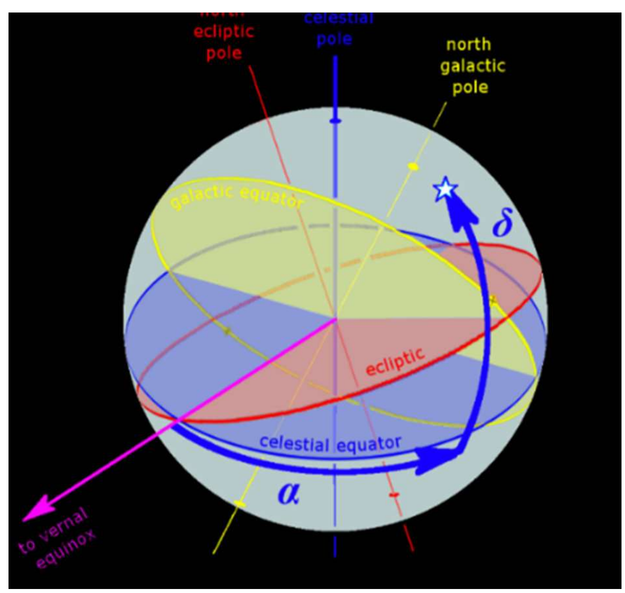
There are two types of mounts for most amateur telescopes. The first is what's known as a horizontal or alt azimuth mount, which is one that moves up and down and rotates around the base, but is parallel with respect to the ground. The other type is an equatorial amount which is inclined to the ground by an angle determined by your latitude on Earth. For instance, our latitude here in Tulsa is 36 degrees north so the equatorial mount would have the telescope tube fixed at a 36° angle up from the horizon. It's important to note that your telescope, through either manual or automatic controls, will determine the location of the object you want to observe based on the type of mount it uses.

The first coordinate system is the simplest horizontal or alt azimuth. As described above regarding the mount that uses it for coordinates, it is a simple up and down (altitude) and a circle coplanar with the ground (parallel to it, azimuth) . This type of coordinate system is simple and the most intuitive. Altitude is measured in degrees from zero to 90 at the zenith and azimuth from zero to 360 running clockwise from North. The symbol for altitude is theta [θ] and that for azimuth is phi [ϕ]. One way to look at this system is that the point you look at never moves, but the objects in the sky do. This was how ancient peoples saw the universe; it appeared that the Sun, for instance, rotated around the Earth.

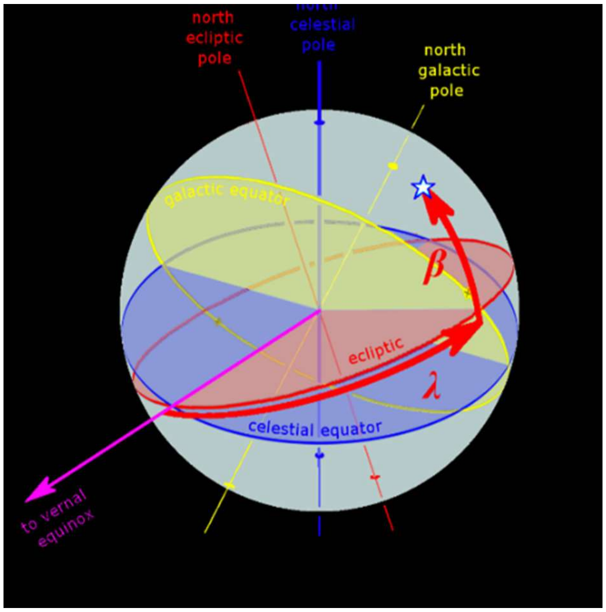
The next coordinate system is closely tied to navigation and uses some of the same principles as the horizontal system. However, the equatorial coordinate system sets zero degrees in latitude as the great circle projection of earth's equator onto the sky. The corollary of latitude is declination [δ] in this coordinate system, in degrees. The projection of longitude can be measured in degrees, using the symbol [α]. Longitude is also called right ascension and is measured in hours, minutes and seconds. This is explained by its navigational roots; each hour of Right Ascension is 15° and represents the rotation of the earth in that period at any point on its surface. This is also why the equatorial coordinate system is often referred to as "RA Dec".



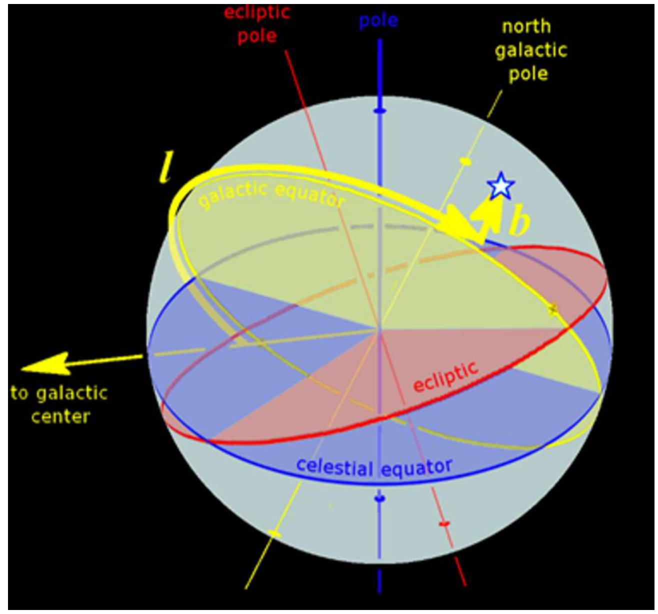
Horizontal Coordinate System
Star is at this position for only a moment.



Equatorial Coordinate System
Star is always at this RA Dec but that point rises and sets.



Ecliptic Coordinate System



Galactic Coordinates

This coordinate system is essentially the map of the sky projected onto the coordinate system we used on Earth. So, for instance, the bright star Sirius is always located at Right Ascension 6 hours and 45 minutes and declination -16˚.7. This coordinate system has the advantage of every object in the sky except for those within our solar system being at the same RA and Dec for decades. It is like the situation of a city on a map. Tulsa is located at 36˚ north and 96˚ west longitude and this will not change substantially in the foreseeable future. The only difficulty here is that you must know a reference Right Ascension point to know what portion of the sky is projected onto the coordinate system. Astronomy uses the point in the sky known as the First Point of Aries, located at zero hours and zero degrees declination, which is a point now located in the constellation Pisces. If you'd like to know why that point moves over the last few thousand years look up "precession of the equinoxes".

Now, instead of watching the stars change in the sky in reference to a point, we see it is the point in the sky that rises and sets because of the Earth's rotation. This makes it easier to record where objects are and find them again. Using Sirius as example again, we learned that stars culminate (reach their highest point in either due south or north) 4 minutes earlier each night. This is the result of our revolution around the sun in about 365 days, very close to 360 degrees around a circle. 1 degree is 24 hrs a day x 60 min per hr / 360 degrees = 4 minutes. So, if Sirius culminated at 12 a.m. last night, it will tonight at 11:56 p.m., at the same spot in the sky.

The other two coordinate systems build off the same idea, but instead of using a projection of terrestrial latitude and longitude they build their system off ecliptic or galactic coordinates. The ecliptic system sets longitude 0 at the First Point of Aries again but instead of using the equator of the earth projected into the sky, it uses the path followed by the Sun (known as the ecliptic) as zero latitude [β] with longitude [λ] again measured to the east. Sirius is located at λ = 104˚ and β = -39˚.6 Similarly, galactic coordinates use a point identified by l and b, starting at the center of the Milky Way.

Each type of coordinate system has its best use. Horizontal is a simple way to identify location in the sky based on cardinal directions. The equatorial system uses a star map which is projected onto the sky. Telescopes that use an alt azimuth mount find the altitude and azimuth of the object of interest from its Right Ascension and Declination and convert one to the other. Equatorial mounts determine the declination and Right Ascension from the current time and after alignment typically with two stars to determine the current projection of terrestrial coordinates on the sky. The other two coordinate systems are useful in studying the movement of planets and the location of objects within our galaxy but are less useful to amateur astronomers.

It is possible to transform from one set of coordinates to one of the others, if each are in the same epoch, although this can also be fixed, using a separate step. Those calculations are found in Meeus, below.

BIBLIOGRAPHY:

Astronomical Formulae for Calculators, Jean Meeus, 1982.

Astronomy Made Simple, Meir Degani, 1956.

The Stars in Their Courses, Sir James Jeans, 1931.

The Milky Way: An Autobiography of Our Galaxy, Moiya McTier, 2022.

Astrophysical Concepts, Martin Harwit, 1988.

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