

Lesson 28 - Coordinate Systems in Astronomy

When an observer (an astronomer) looks at the night sky, the essential goal is to know where look and how to describe the location of whatever you are looking at.

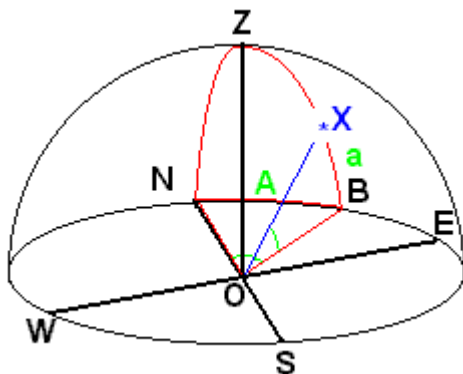
For Earth based astronomers there are two practical and commonly used coordinate systems they can employ. The first, the horizon coordinates, refer to an astronomer's local position; the local horizon. The second, the equatorial system, refers to the coordinate system of the whole Earth.

Coordinates in the horizon system make sense to anyone at a given location at a given moment in time. The equatorial coordinates are the same for any observer anywhere on the Earth.

Measurements of star positions are made first in the local horizon system and then converted to the equatorial system when they are reported for general consumption. When looking for a known object, the equatorial coordinates must be converted into horizon coordinates before you start pointing your telescope.

The Horizon Coordinate System

The horizon marks the apparent edge of the local plane centered on the observer's location. This plane is bounded by the four cardinal directions; **N**, **E**, **S** and **W**. The



point in the sky that is straight overhead is called the zenith point, **Z**.

If you are standing in a field with a pair of binoculars looking for the Andromeda Nebula, you need information about its location relative to reference marks you can see. The primary reference mark is **N**. For this you can use the north star, Polaris.

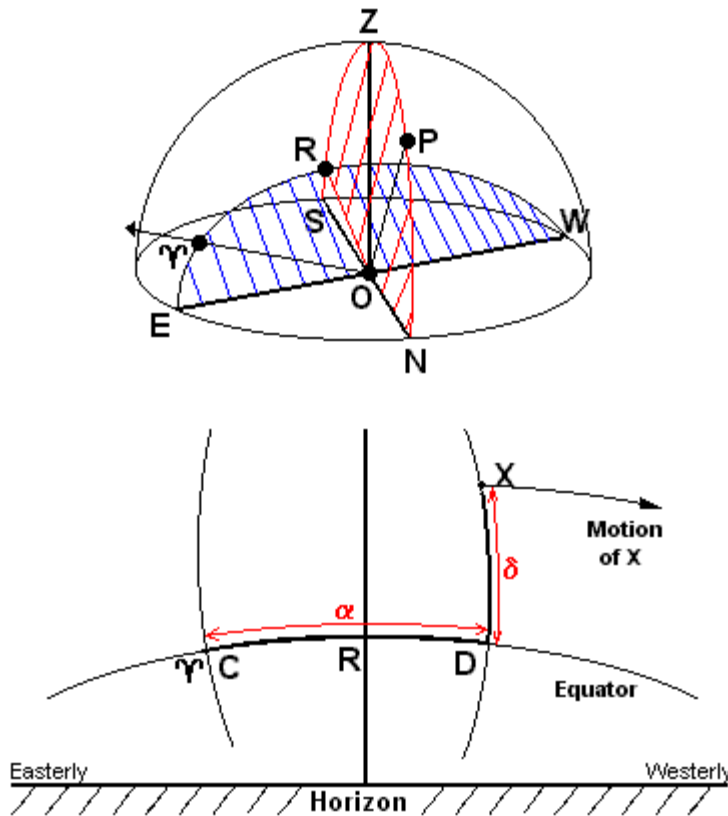
After you identify **N**, the point on the horizon directly below Polaris (approximately), you need to know how far around to the right (clockwise direction) to rotate so you will be facing in the proper direction. This is called the *azimuth* of the object. Its symbol is the capitol letter **A**. The *azimuth* is measured in degrees (from 0° to 360°) clockwise from due north. If the *azimuth* is 90° , for example, then you need to face due east. If the *azimuth* is 225° , then you need to face southwest, etc.

Next, you need to know how high up in the sky to look. The angle above the horizon where the object can be found is known as its *altitude*. Its symbol is the small letter a . This is not the same as the altitude of an airplane. This astronomical *altitude* is an angle measured from 0 to 90°; between the horizon and the zenith point.

The Equatorial Coordinate System

While the horizon system works well for finding astronomical objects while standing in a field and even when working with a telescope, it is not generally useful if you want to tell someone else how to find the same object when they are standing in their own field, or even if they are standing in your field at a different time.

What we need is a coordinate system that does not move with time the way the rotating Earth does, or, more realistically, moves so slowly that we only need to update the table of positions every decade or two; not every minute or two.



For this purpose, the equatorial system offers a good compromise that everyone can live with. First, it is relatively easy to convert back and forth between the equatorial and horizon systems. Second, in the age of the atomic clock we have a good method for knowing the time. Third, we also have a worldwide system of latitude and longitude that allows us to uniquely identify any location on the surface of the Earth according to its geographic coordinates.

The reference point in this coordinate system is called the *first point of Ares*. It is marked on sky charts with the symbol, Υ . The *first point of Ares* lies on a line on the celestial sphere created by

extending the plane of the Earth's equator out onto the celestial sphere.

If we extended the Earth's orbital plane, called the ecliptic, onto the celestial sphere we would get a second line on the celestial sphere. These two lines on the celestial sphere cross at two points. The first point of Ares is one of these points in the sky where the equator and the ecliptic cross.

The *first point of Ares* moves very slowly. It takes about 26,000 years for it to move once around the circle of the equator. That means it moves less than one minute of arc each year. It is slow enough that we can update its true position to the correct current value if we know where it was at any specific time in the past and how fast it is changing.

The *first point of Ares* appears to rotate once each day around the Earth. In this it is like the Sun, the Planets and the stars. However, relative to those objects it is barely moving at all. Therefore, by using it as our reference point we automatically get a coordinate system in which the stars, at least, hardly move at all. The planets move at a pace consistent with their orbital progress around the sun.

The first equatorial coordinate is known as the *right ascension*. Its symbol is the lower case Greek letter α . It is measured in hours rather than degrees. Just remember that one hour of *right ascension* equals 15° and you will have no trouble with *right ascension*. The *right ascension* is always measured in hours east of the *first point of Ares*.

Imagine that the *first point of Ares* is due south of you at a given instant. The *right ascension* tells you how many hours, minutes and seconds you must wait until the object of interest is due south of you. This works for any point on the Earth.

The other equatorial coordinate is known as *declination*, δ . It measures the angle above the equator (+angles: up to $+90^\circ$ at the North Pole) or below the equator (–angles: down to -90° at the South Pole) where an object can be found.

A Word about Time

Historically, astronomers have always measured time using what is called Greenwich Mean Time (GMT). This is the time at the Prime Meridian. The Prime Meridian runs north and south through the Greenwich Observatory in England. Technically, GMT has now been replaced by what is sometimes called Coordinated Universal Time. Coordinated Universal Time is based on a system of atomic clocks. The system is redundant in the sense that there are numerous atomic clocks in the system. Even when one or several must be removed for repair or service, the system marches on without a hitch. GMT was based on a continuing series of Sun observations and was subject to the usual observational uncertainties. The atomic clocks are accurate to within a second every billion years, or so. The system is also flexible. As newer and more accurate atomic clocks are developed, they can be slowly being integrated into the system.

Coordinated Universal Time is nearly identical to GMT by design but it does not depend on making the Sun sights. The primary reason to go to Coordinated Universal Time is that the rotation rate of the Earth is slowing down. Earthquakes, volcanic eruptions, weather patterns, continental drift, among others, affect the Earth's rate of rotation. Over longer periods the gravitational interaction between the Earth and the Moon causes the Moon to move farther from the Earth and the Earth's rotation to slow. GMT assumed the Earth's rotation was the ultimate constant clock. Universal Coordinated Time assumes that a collection of atomic clocks is the ultimate constant clock.

Occasionally, you will hear that we have've had a leap second added to the time. That means that one second has been added to all the clocks in the Coordinated Universal Time network so that they will agree with GMT; to within a second, at least. There is a debate going on right now about whether or not to continue this practice. If we do not, then we will have completely separated the system of making astronomical observations from the rotational system of the Earth.

For most purposes it is sufficient to use GMT as the shorthand name even when you are technically referring to Coordinated Universal Time. Coordinated Universal Time comes closest of any timekeeper yet developed to producing what astronomers call Ephemeris Time. Ephemeris Time, the ideal, is time that flows uniformly. Time based on the rotation of the Earth, the orbits of the planets or any mechanical clock yet devised has greater inherent error and more quirks than the atomic clocks now in use. However, even these are not perfect and the search is still on for better clocks capable of providing ephemeris time of the required stability for studying the universe in increasingly finer detail.

Another Word about Time

It's too bad that the Earth has to go around the Sun. It complicates the calculations for astronomers. Our whole system of time is all messed up. GMT is based on the idea that the Sun should be due South of the Greenwich Observatory at noon. A twenty-four hour day has been established as the time between one solar transit of the Greenwich meridian and the next.

If we used a more distant star as our reference, however, the day would be 3m 56s shorter. During a year of 365.25 solar days, the Earth actually rotates on its axis, relative to a distant star, 366.25 times. One day is overlooked because we make one additional rotation in revolving around the Sun. The short day is called Sidereal time.

Astronomers use Sidereal time in their calculations because it removes Earth's motion from the calculations. The two clocks agree once a year, at the autumnal equinox. Between one autumnal equinox and the next, the sidereal clock gets a full 24 hours ahead of our solar clocks.