Mounts and Coordinate Systems

Part 1: Measuring the Sky

By Dan Lessmann

Hi again. For the last few months we've been looking at telescopes, how they work and how we work with them. For the next few months we're going to talk about what goes under them. I'm referring to mounts and how they relate to the coordinate systems we use to find our way around the sky.

To understand what goes on below our scopes we need to understand how we measure things up above. Lyn thinks I talk too much and makes me break these things up into parts. So let's talk about coordinate systems this month and we'll talk about mounts next month.

Some Coordinate System Basics

We use coordinate systems to be able to define a point in space. A coordinate system accomplishes this by defining a point in relation to another known point along at least one, but for our purposes, two fixed axes. Most of us will remember an example of this from school.

Cartesian Coordinates

The Cartesian coordinate system, as shown in Figure 1, is a two dimensional or planar grid with an origin and two axes, the X axis and the Y axis, perpendicular to each other. Knowing the distance and the direction, positive or negative, from the origin along these two axes allows us to define any point in the plane. Each distance and direction is known as an *ordinate* and these ordinate pairs taken together are a *coordinate*. So, the coordinate (4, 4) is a point that is 4 units positive along the X axis and 4 units positive along the Y axis. Simple enough.

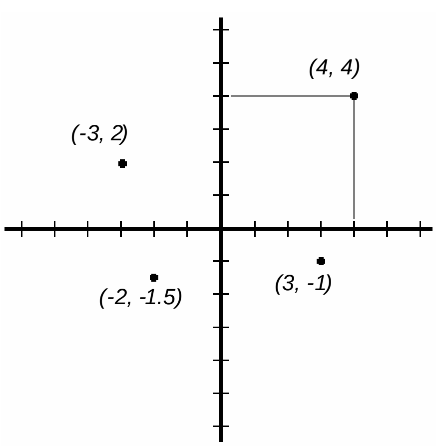

Figure 1— Cartesian Coordinates.

Polar Coordinates

Now let's look at another way to define a point. Suppose instead of measuring along two linear axes, we measure the angle from one axis and the direct, or *radial* distance from the origin as shown in Figure 2.

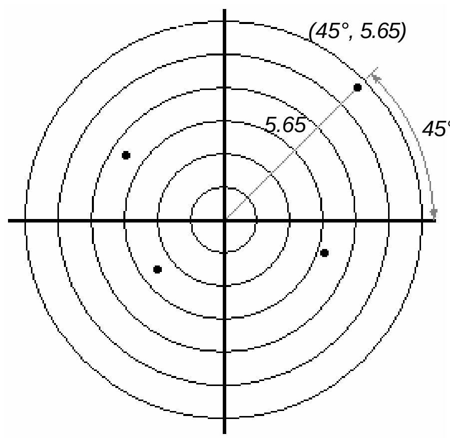

Figure 2— Polar Coordinates

As with Cartesian coordinates the polar coordinate system can define any point on the plane. Now instead of two linear ordinates we have one angular ordinate and one radial ordinate. The first ordinate will generally be from 0° to 360° and is measured positive in a counter clockwise direction. The second is the radius measured linearly and is simply the direct distance from the origin to the point. Degrees are further subdivided into *arcminutes*, *arcseconds* and fractions of arcseconds and are designated as D° M' S.SS". There are 60 arcminutes in a degree and 60 arcseconds in an arcminute. Both arcminutes and arcseconds are commonly referred to as minutes and seconds but don't confuse them with time units. These are angular units. So what was coordinate (4, 4) in the Cartesian plane is coordinate (45°, 5.65) in the polar plane. Still simple.

Geographic Coordinates

Planar coordinates are fine for a plane but the appearance of the sky is not planer. It's like looking at the inside of a ball or it's *spherical*. Let's look at one more coordinate system that we need to be familiar with, spherical coordinates as they relate to the surface of the earth or *geographic coordinates*. Here we attempt to wrap the Cartesian plane onto the surface of the sphere. This is a *spherical projection*.

Figure 3 shows how the Cartesian plane is projected. It doesn't fit so well does it? Notice how measurements along what was the X axis bunch up at the poles.

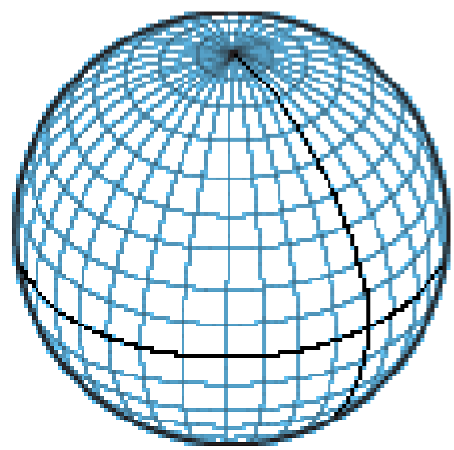

Figure 3— Spherical Projection

As with planer coordinate systems, everything is measured from a known origin point along two axes in some direction. But because we're dealing with a sphere, it's convenient to define those ordinates angularly along two circular axes. These axes are *great circles*; a circle on the surface of a sphere where the center of the circle is the center of the sphere.

The first great circle is the *equator*, a circle around the circumference of the earth exactly halfway between the north and south poles and perpendicular to its axis of rotation. *Small circles*, circles on a sphere whose centers are *not* at the center of the sphere, are projected parallel to the equator both north and south and that's what they are called, *parallels*.

The second axis is an arbitrary arc projected from the North Pole around the circumference of the earth to the South Pole. This arc passes through the Royal Observatory in Greenwich, England and is known as the *prime meridian*. Other arcs from the North to the South Pole are projected in the same way and are simply called *meridians*. Note that meridians are not parallel to each other except at the equator. As they approach the poles, they bunch up closer and closer and eventually meet at the pole itself.

By specifying the number of degrees measured along these axes and a direction, we define the coordinate of any point on the surface of the earth. The ordinate measured along the equator is the *longitude* and is measured in degrees east or west of the prime meridian from 0° to 180°. The ordinate measured along the prime meridian is the *latitude* and is measured in degrees north or south of the equator from 0° to 90° in both directions. Geographic coordinates are always expressed in longitude and latitude order. For example, American Horse Lake is located at the coordinate 98° 30' 30" W longitude by 35° 37' 45" N latitude.

How Long Is A Degree and Which Way Is North?

The length of one degree depends on where you are on the surface of the earth but, at the equator and at sea level, one minute of one degree in both latitude and longitude is exactly one nautical mile so a degree is 60 nautical miles in length or about 69 statute miles. At either pole, this is not the case. Where the meridians meet, the distance of one degree of longitude to another can't be measured. At our latitude of around 35° N a degree of longitude is about 56 statute miles in length. A degree of latitude is the same linear length anywhere on the globe.

Cardinal directions and longitude have less and less relevance as you approach either pole. All directions are north when standing at the South Pole and the longitude is all longitudes. So the cardinal directions and longitude have no useful meaning at the poles. This is why polar explorers use polar coordinates for navigating around on the ice.

The World is Flat After All

You'll note that all of these coordinate systems require only two ordinates and two directions of measure. This is because we're dealing with two dimensions in all of these systems. No consideration of altitude is made in the geographic coordinate system and there are only two dimensions in a plane. Two dimensions require only one ordinate pair to define the location of a point.

Looking Up

Over the years a variety of coordinate systems have been developed to define the location of objects in the sky but two systems, *altitude-azimuth* and *equatorial*, are the ones we use the most and the ones that best relate to our various telescope mounts. Let's start with the most common one.

Altitude-Azimuth Coordinates

The alt-az coordinate system is popular only because it's the system many of our mounts use but that's about all it's got going for it. Well, that's not entirely true. It's also easy to use. But there are several things not so good about this system. I'll get to the alt-az grinch list later but let's first define the system. Figure 4 shows this coordinate system from the east side looking in.

The origin for the alt-az coordinate

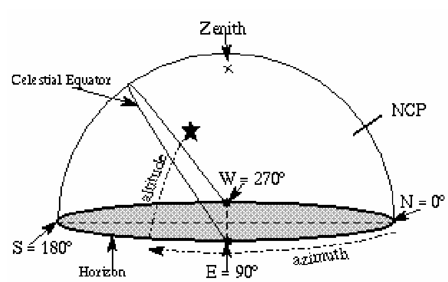

Figure 4—Alt-Az System From the East

system is where you're currently standing. In the figure, that would be where the dashed lines from north to south and east to west intersect.

The axes are provided by the horizon and true north. The ordinates are the number of degrees above the horizon, or altitude and the heading or azimuth. So, the star in the figure has alt-az coordinates of somewhere around 45°, 120°. That is, 45° above the horizon and 120° east of due north. Let's look closer.

Altitude

This is the number of degrees above the horizon from 0°, on the horizon to 90° overhead at the *zenith*. Objects below the horizon are designated with a negative altitude and can be as low as -90° or straight down at the *nadir*. So the range of altitudes can be from -90° to +90°.

Azimuth

Figure 5 shows the alt-az system looking down from the zenith. Like the polar coordinate system, we use the angle from a fixed axis for this ordinate. The azimuth starts at a heading of 0°, due north, through east, 90°, then south, 180°, on to west, 270° and finally back to due north. One degree west of due north is 359° there being 360° in a circle.

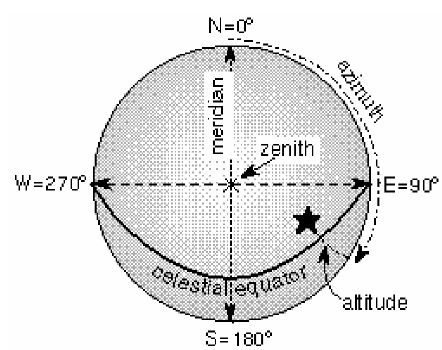

Figure 5—Alt-Az System From Above

For both axes, your fist held out at arm's length is approximately 10° of arc wide. The *local meridian* or simply meridian is an arc passing from due north, through the zenith to due south.

My Alt-Az Grinch List

There are a few things not so good about the alt-az coordinate system.

The origin isn't fixed temporally. It's *whenever* you happen to be at the time. The star I mentioned above at 45°, 120° is no longer there. In the time it took you to read to here it's moved a bit. The earth rotates under the sky at a rate of 1° every 4 minutes from west to east so the apparent motion of the sky is that same degree from east to west.

The origin isn't fixed geographically. It's *wherever* you happen to be at the time. Even at the same time, two observers at different locations will have different relative alt-az coordinates for the same object. You can't call up your buddy a few counties over that-a-way and tell him to look at alt-az coordinate such and such for a cool view. His coordinate such and such will not be the same point in the sky as yours.

This is known as a *local coordinate system*. So to be able to use alt-az coordinates you must know a couple of extra pieces of information. You must know where you are on the surface of the earth and you must know the exact time at the time of the observation.

Despite these problems our brains seem to be wired for alt-az coordinates and many of our scopes are mounted on alt-az mounts. SCTs commonly use alt-az coordinates and Dobs are almost always alt-az. I can also say it's easier to use because my experience shows that most people get confused by the alternative which we'll look at next. So despite the disadvantages of alt-az, we continue to use this system.

Equatorial Coordinates

This coordinate system, also called *polar coordinates,* is also a spherical projection of two axes but this time the axes are not fixed relative to the surface of the earth. Instead they are projected on to the apparent dome of the sky or the *celestial sphere*, and are fixed to the sky. These axes are *right ascension* and *declination* or R.A. and Dec.

We Need A Few References

Before we can define the axes, we need to define a few other references. Figure 6 shows an earth-

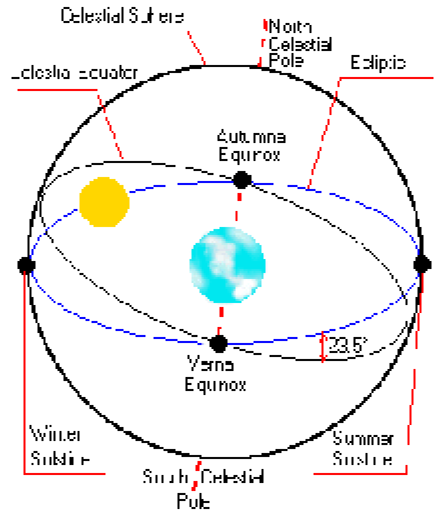

Figure 6—Equatorial Coordinate References

centric view of the celestial sphere with the Sun over on the left.

The *ecliptic* is the plane established by the path of the earth's orbit around the sun. With the exception of Pluto, all of the planets and the earth's moon orbit more or less on the plane of the ecliptic.

The *Celestial Equator* is a projection of the earth's equator onto the celestial sphere.

The *North and South Celestial Poles* are the earth's true north and south poles projected on to the celestial sphere. These are commonly abbreviated as NCP and SCP.

The *Vernal Equinox* is the point of intersection between the ecliptic and the celestial equator that the sun passes through on about March 21st. This event defines the first day of spring.

The second point where these intersect is called the *Autumnal Equinox* and the sun's passage through this point defines the first day of autumn on about September 22nd.

The angle between the two great circles of the ecliptic and the celestial equator is about 23 ½° and is the tilt of the earth's axis relative to the plane of its orbit. Without this tilt, we wouldn't have seasons.

The points at which the apparent position of the sun are farthest north and south of the celestial equator are the *summer and winter solstices*. The summer solstice occurs on about June 21st and marks the first day of summer and the longest day of the year in the northern hemisphere. The winter solstice occurs about December 21st and marks the first day of winter, the shortest day of the year in the northern hemisphere.

The position of the sun at the solstices is marked by two latitudes on the surface of the earth. The Tropic of Cancer lies at 23 ½° N latitude. This latitude is the farthest north you can be for the sun to pass directly overhead through the zenith. The Tropic of Capricorn lies at 23 ½° S latitude. This latitude is the farthest south you can be for the sun to pass through the zenith.

The tropics are named for the constellations the sun was in at the time they were discovered but the sun is no longer in these constellations at these times. This is because of a phenomenon known as *precession of the equinoxes* or simply precession. The earth doesn't quite rotate exactly on its axis. It's got a small amount of wobble like a top does as it slows down. This causes the earth's axis to rotate in a circle of a radius of 23 ½° every 25,800 years. Right now Polaris is less than a degree away from the north celestial pole but it won't stay there. In about 4000 AD the best pole star will be Gamma Cephi in Cepheus. Deneb and Vega will both be reasonable pole stars some time after that. Figure 7 shows the effect of precession on the NCP.

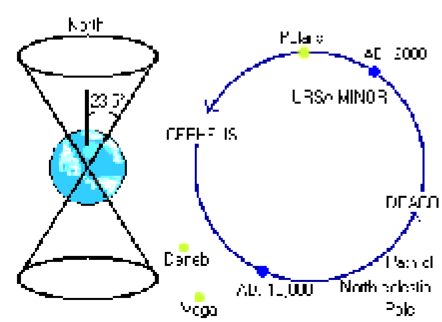

Figure 7—Precession of the Equinoxes

Precession not only changes the location of the north and south celestial poles. It also changes the orientation of the celestial equator and the position of the Vernal Equinox. So though this coordinate system is based in the sky, it's not quite constant. Okay, let's define the two axes as shown in Figure 8.

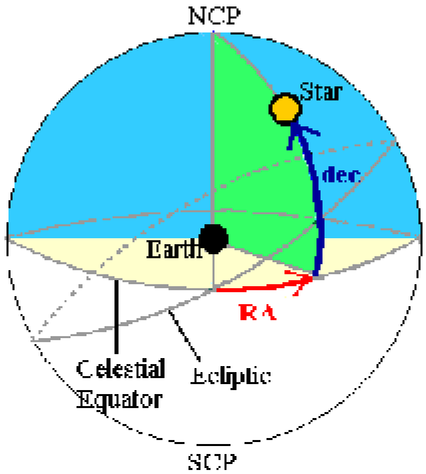

Figure 8—Equatorial Coordinate Axes

Right Ascension

R.A. is the number of hours, minutes, seconds and fractions of seconds measured from an arbitrary meridian, the *celestial meridian.* This meridian passes from the north celestial pole through the Vernal Equinox currently in Pisces to the south celestial pole.

As with the earth's day, there are 24 hours along this axis. Don't confuse R.A. hours with hours of time. The two are totally independent of one another but right ascension is based on the hours of the day. R.A. hours are simply a circle divided into 24 parts of 15° each.

Also don't confuse the minutes and seconds of R.A. with arcminutes and arcseconds. *They are not the same*. There are 60 minutes in one R.A. hour so each R.A. minute is ¼°.

We use hours to designate right ascension for timing convenience. A star that is overhead at Greenwich at midnight will be overhead here about 6 ½ hours later or at about 6:30 AM *Greenwich Mean Time* or GMT, which is also *universal time* or UT. So, the farther east you travel, the later the hour of the day. The same is true with R.A. hours. Traversing east from the celestial meridian increases the hours of R.A. from 0h to 23h and back to 0h.

In the same way, a star that is one R.A. hour east of the meridian right now will cross the meridian one hour from now. An object one R.A. hour west of the meridian will cross the meridian 23 hours from now.

The value of the R.A. ordinate currently overhead at the local meridian is the current *sidereal time*. Knowing this "time" will come in handy when we locate objects using this coordinate system.

Declination

Declination is simply the number of degrees, positive to the north or negative to the south, from the celestial equator. 0° is at the celestial equator. 90° is at the north celestial pole up by Polaris and -90° is at the south celestial pole. This is identical to the latitudes of the earth.

Equatorial Advantages

By far the greatest advantage of this coordinate system is that the coordinate of a celestial object is constant allowing for precession. The Vernal Equinox is always at 0h, 0° no matter where you are on the surface of the earth or the current time and date. This is why star charts always define object locations in equatorial coordinates.

Now, instead of objects moving relative to a local or terrestrial based coordinate system, we move relative to a fixed celestial coordinate system. This means you can now call your buddy in the next county and tell him to take a look at equatorial coordinate such and such and he'll be able to find the object you'd like him to see. In fact, you can tell him weeks later and he can be on the other side of the world.

Equatorial Coordinate Epochs

Because of precession of the equinoxes and other relativistic motions, new official equatorial coordinates published in star charts and other data have to be adopted from time to time. The last time this happened was in January of 2000. This created a new epoch known as J2000 for the time of its adoption. Star charts that are printed for this epoch are said to have J2000 coordinates.

Sidereal Motion and Tracking

Sidereal motion is the combined motion of the earth's rotation about its axis and its motion in its orbit around the sun. Because the earth rotates from west to east and moves in its orbit in the same direction, kind of like it rolls its way around the sun, a *sidereal day* is about four minutes shorter than a solar day. That is, on average, the solar day, the time it takes for the sun to return to a particular point in the sky from day to day, is 24 hours long. But the time it takes a star to return to a particular point in the sky is 23 hours, 56 minutes and 4 seconds long.

Sidereal tracking is the motion tracking telescopes make to compensate for sidereal motion and remain pointed at the same location in the sky. Alt-az mounts do this by tracking in both altitude and azimuth axes simultaneously but an equatorial mount needs to sidereal track only in right ascension. You'll see why next month when we take a look at an equatorial mount.

Circumpolar Objects

Depending on where you're located on the surface of the earth, some objects in the night sky are *circumpolar* meaning they never set. Here in Oklahoma City, any object that has a declination greater than about 55° will be circumpolar. At the equator, no object is circumpolar with the exception of the NCP and SCP itself both of which will always be exactly on the north and south horizons. At the equator, Polaris is never more than about 45 minutes above the northern horizon. Here in our latitudes, it's never less than 34° above the northern horizon. Many of our northern constellations never set. These include Ursa Minor, Cassiopeia, Cepheus, most of Draco and Camelopardalis, a big chunk of Ursa Major and a little chunk of Lynx.

Likewise, many objects are never visible from Oklahoma City. These objects are always hidden by the southern horizon. Any object with a declination of about -54° or further south can never be observed from our northern latitude.

That's it for this month. Next month we'll add some hardware to our look at coordinate systems. Until then… Clear skies!