ASTRONOMICAL COORDINATES: DECLINATION AND RIGHT ASCENSION

Link to: physicspages home page.

To leave a comment or report an error, please use the auxiliary blog.

Reference: Carroll, Bradley W. & Ostlie, Dale A. (2007), *An Introduction to Modern Astrophysics*, 2nd Edition; Pearson Education - Chapter 1, Problems 1.4 - 1.6.

Although objects visible in the sky are all at different distances from Earth, for the purposes of observing them from Earth-bound telescopes we can treat the objects in the sky as if they were all on the surface of a sphere whose centre is at the centre of the Earth. This sphere is known as the *celestial sphere*. The coordinates of an object in the sky can then be specified using only two coordinates, analogous to the latitude and longitude used to identify places on Earth. We can get celestial latitudes by simply projecting Earth's latitudes onto the celestial sphere. The celestial latitude is called *declension* (Dec for short) and is measured in degrees ranging from -90° at the south celestial pole (the point in the sky that is a projection of Earth's south pole onto the celestial sphere) to $+90^{\circ}$ at the north celestial pole.

When we try to specify celestial longitude we can't just project Earth's longitude onto the celestial sphere since Earth rotates relative to the stars so the longitude of a point on the Earth's surface that is directly under some particular star changes continuously over the course of a day. A set of longitude lines is therefore specified that is fixed relative to the stars' positions on the celestial sphere. This 'celestial longitude' is called *right ascension* and, rather than being measured in degrees as terrestrial longitude is, it is measured in hours, minutes and seconds, with values ranging from 0 hours around (in an easterly direction) to 24 hours.

Although right ascension (or RA as it is more commonly abbreviated) is measured in units of time, we need to be careful in relating RA time to terrestrial time. The 24 hours of RA correspond to one complete rotation of Earth *relative to the stars*, NOT the Sun! To see the difference, picture the Earth in its orbit about the Sun. Over the course of one complete orbit about the Sun, Earth goes through 360°. As the year is 365.25 days, Earth travels just under 1° of its orbit each day. That means that Earth must rotate about 361° between successive times at which the Sun is on the meridian (that is, at its highest point in the sky for a given day). However, Earth needs to rotate only 360° between successive times at which some particular distant star is on the meridian. The former time interval (which is what we think of as an ordinary day) is called a *solar day*, while the latter time interval is a *sidereal day*. A solar day is about 4 minutes longer than a sidereal day, as that's how long it takes Earth to rotate through 1°. The units of RA measure sidereal time, not solar time, so the time it takes for one complete rotation of the celestial sphere (that is, the time taken to run through one complete cycle of RA from 0 hours up to the next 0 hours) is about 4 minutes less than 24 hours measured by your wristwatch. Another way of putting it is that any given star rises about 4 minutes earlier each day. It is this mismatch between sidereal and solar time that causes the constellations we see in the night sky to shift slowly over the course of a year.

The zero hour of RA is defined as the RA coordinate at the point where the Sun crosses the celestial equator heading north, which is the spring or vernal equinox in the northern hemisphere, and the autumnal equinox in the southern hemisphere and occurs around March 21. This point (0 hours RA and 0° Dec) is called the first point of Aries although confusingly it is actually located in Pisces. [The shift is due to Earth's precession, or wobble in its axis, which we'll get to eventually. A long time ago, this point actually was in Aries. Incidentally, if you believe in astrology, you should know that the dates of the various star signs are based on the positions of the constellations several thousand years ago. For example, the star sign of Aries runs from March 21 to April 19, during most of which time the Sun is actually in Pisces. The Sun doesn't actually enter Aries until around April 17. Yet another reason, if one were needed, not to take horoscopes seriously.]

Due to the tilt of the Earth's axis of around 23.5°, the path of the Sun across the sky (known as the *ecliptic*) varies between extremes of declination of $+23.5$ (around June 21, at which point the Sun's coordinates are $RA = 6^h$; $Dec = +23.5^\circ$) through the equinox around September 21 ($RA = 12^h$; $Dec = 0^\circ$) to the winter (summer) solstice in the northern (southern) hemisphere around December 21 ($RA = 18^h$; $Dec = -23.5^\circ$).

The altitude (angle relative to the horizon) of an object depends on the latitude from which it is observed. At the north pole, the north celestial pole is directly overhead, so an object with $Dec = 90^\circ$ is directly overhead. In general, an object with Dec δ has altitude δ when seen from the north pole. At the north pole, the altitude of any given object is a constant; it just rotates around the sky in a circle around the zenith (the point directly overhead).

As we move south, the celestial north pole moves downwards, so that at latitude L the altitude of the celestial north pole is also L. Since objects rotate around the celestial north pole, an object with Dec δ has an altitude that depends on where in the sky it is. When it's on the meridian, its altitude is highest and at that point, the altitude is $90 - L + \delta$. This means that an object with $L=\delta$ is directly overhead on the meridian. The highest point in the sky reached by the Sun (on the summer solstice) at a given latitude is thus

$$A=90-L+23.5=113.5-L \tag{0.1}$$

For latitudes less than 23.5, this gives a value greater than 90 which just indicates that the Sun appears past the zenith at an angle with the zenith of $A-90$. For my latitude of +56.5 north, the highest the Sun gets is 57°.

At the other extreme (the winter solstice), the Sun's Dec is -23.5 so the altitude is

$$A=90-L-23.5=66.5-L \tag{0.2}$$

For my latitude, the winter sun thus never gets more than 10° above the horizon on December 21.

Since the north celestial pole has an altitude L at latitude L, any objects with declinations in the range $90-L<\delta<90$ will never set as seen from that latitude and are known as *circumpolar*. Similarly, stars with declinations $-90<L<L-90$ will never rise and are permanently invisible from that latitude. At the north pole, all stars with $\delta>0$ are circumpolar, and only the northern half of the sky is ever visible. At the equator, no stars are circumpolar, but all stars are visible at some point.

Midnight sun at the summer solstice therefore occurs when the Sun, at declination $\delta=23.5$, is circumpolar, which occurs for latitudes $66.5<L<90$. At the vernal equinox the Sun's declination is $\delta=0$, so it will never set only at the north and south poles, where it will just skim the horizon all the way round.

PINGBACKS

Pingback: Angular distances on the celestial sphere
Pingback: Kepler's third law and satellite orbits
Pingback: Solar irradiance