Notes – Naked-Eye Astronomy

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The Celestial Sphere - some basics

Looking at the Sky – technical terms and tips

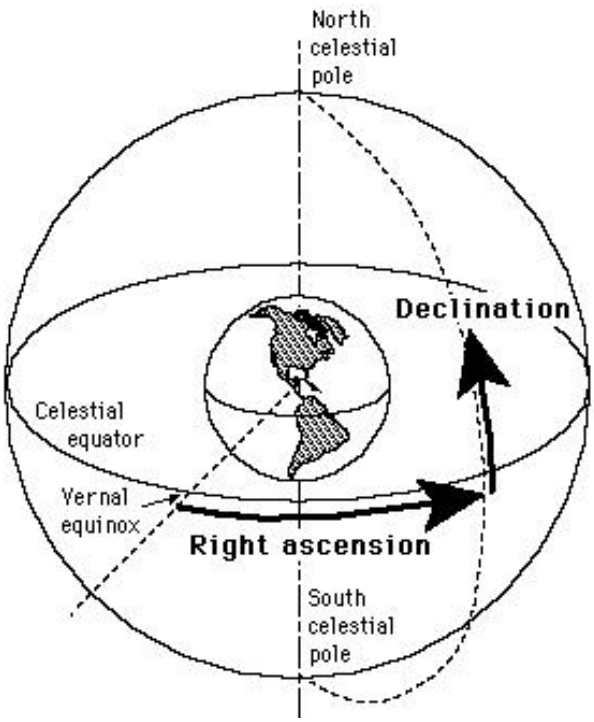


Figure 1 – Right Ascension and Declination.

Generally a star or planet's location is given by its declination and its right ascension which are measurements that are not that useful when you are trying to orientate yourself underneath the dome of the sky. However, they provide a fixed reference point so that a star can be located on the celestial sphere.

Declination

In astronomy, declination is one of the two coordinates of the equatorial system, the other being either right ascension or hour angle. Declination is comparable to latitude, projected onto the celestial sphere, and is measured in degrees north and south of the celestial equator. Therefore points north of the celestial equator have northern declination while those to the south have southern declination.

Right Ascension

RA is the celestial equivalent of terrestrial longitude. Both RA and longitude measure an east-west angle along the equator and both measure from an arbitrary zero point on the equator. For longitude, the zero point is the Prime Meridian (0^0 Longitude). For RA, the zero point is known as the vernal equinox point (also known as the First Point of Aries), which is the place in the sky where the Sun crosses the celestial equator at the March equinox.

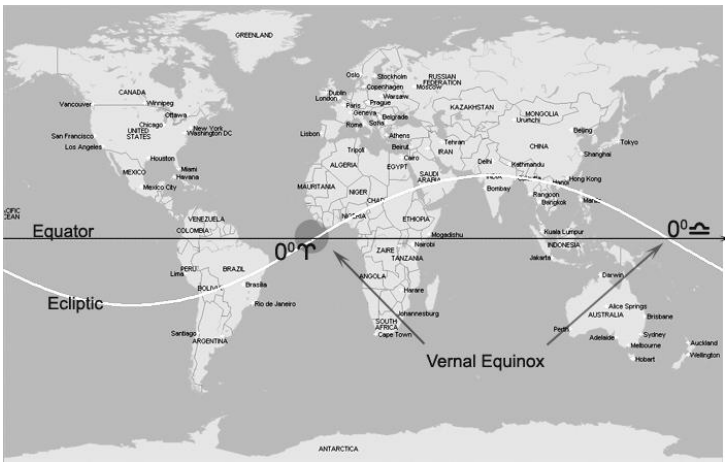


Figure 2 – Right Ascension is measured from the spring vernal equinox.

RA is measured in hours, minutes, and seconds eastward from the vernal equinox (sometimes it is also given in degrees). Being closely tied with sidereal time, it is both a unit of time and of angle. An hour of right ascension is equal to 15 degrees of arc, a minute of right ascension equal to 15 minutes of arc, and a second of right ascension equal to 15 seconds of arc. RA can be used to determine a star's location and to determine how long it will take for a star to reach a certain point in the sky. For example, if a star with RA = 01:30:00 is at your meridian (culminating), then a star with RA = 20:00:00 will be on the meridian 18.5 sidereal hours later.

However, declination and its right ascension of a star or planet is not helpful when you are standing out under a night sky trying to understand what you are seeing. Finding a star which has the coordinates of RA 13 hours 25 minutes and declination of $11^0 12'$ south, which is the location of the star Spica, may locate the star on the celestial sphere but does not locate the star in the night sky for you.

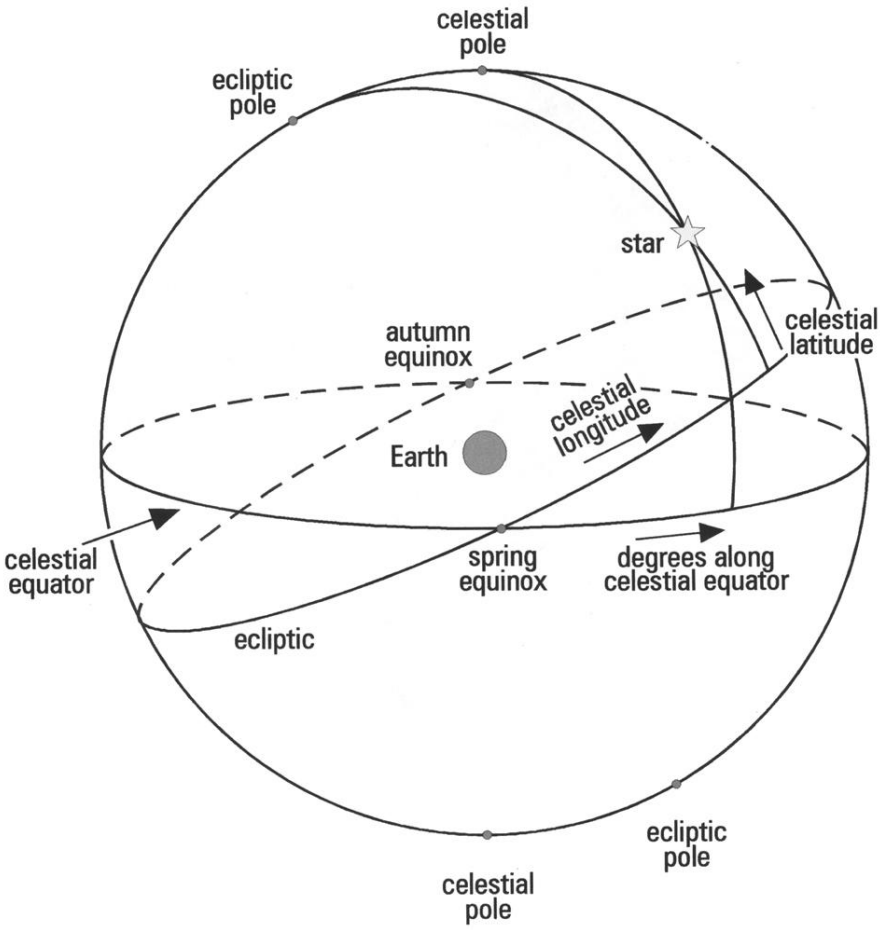
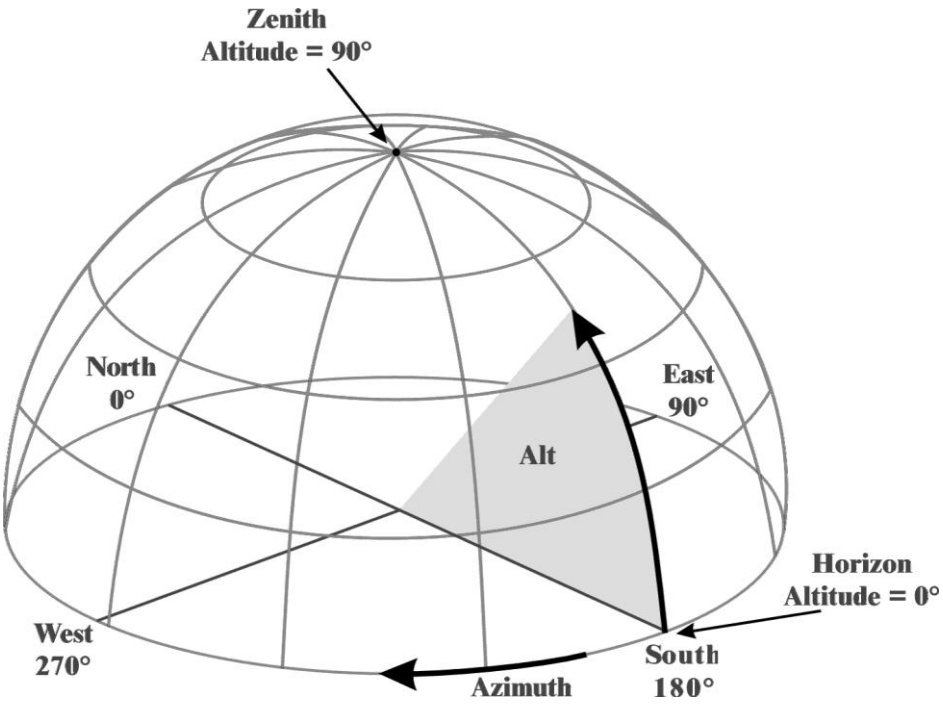


Figure 3 – The celestial sphere.

Finding an object in the sky

If we know the date, place and time, then at any single moment we can measure the location of a object in the heavens via its azimuth and altitude.



Azimuth is simply the compass direction, measured around the horizon, starting from the point on the horizon due north and moving toward the east. It is usually expressed in degrees.

Altitude is the measurement of the elevation of a star above the horizon and is normally measured in degrees.

Figure 4 - Local Horizon showing Azimuth, Altitude and the Zenith.

Example - The location Pleiades over Stonehenge (Latitude 51N10. 44 and Longitude 1W49. 34.) at sunset on the winter solstice (21 December, 2010) at the time of civil twilight is approximately azimuth 85^0 altitude 27^0. So starting from north you would move 85^0 along the horizon in an easterly direction – you would be thus looking at 5^0 to the north of due east. Once you have located your direction along the horizon then you raise your eyes 27^0 above the horizon – see using your hand as a measuring device later in these notes – you will now be looking at the Pleiades. As time passes the Pleiades will move higher in the sky changing both its azimuth and altitude. When its azimuth is 180^0, or due south, it will be culminating. It will culminate at an altitude of 63^0. After culmination it will start to move lower in the sky as it begins to set. It will eventually set at an azimuth of 312^0.

Zenith is the point directly above your head at an altitude of 90^0 to the local horizon. If your are trying to learn to recognize the constellations then the zenith is a good place to start as you can always locate it. Lie on the ground and look straight up.

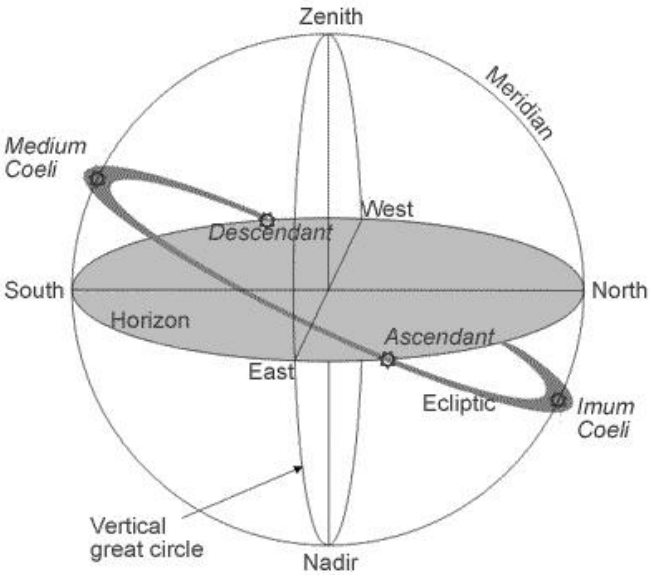
Meridian

In the sky, a meridian is an imaginary great circle on the celestial sphere. It passes through the north point on the horizon, through the celestial pole, up to the zenith, through the south point on the horizon, and through the nadir, and is perpendicular to the local horizon *(see figure 4).* As a star rises for your location it

will eventually cross over the local meridian when it will be culminating after which it begins to set.

The points of the astrological horoscope as located in the dome of the sky

Once you are outside you need to look for the ecliptic. If your latitude is south of 23^0 South, then the ecliptic will be located in the north. If you are north of 23^0 North, then it will be located in the south. Look for a zodiac sign that you know should be above the horizon, or look for planets or the Moon – these will be roughly on the line of the ecliptic.



Ascendant and MC (Midheaven) - Where the ecliptic cuts the horizon in the east is the ascendant and where the ecliptic cuts the local meridian is the MC.

If you are in the northern hemisphere then the MC, which is located on the ecliptic, will be in the south. However, in the southern hemisphere where the ecliptic is in the north, the MC will be located in the north.

Figure 5 –The angles of a astrological horoscope (northern hemisphere).

Celestial Poles are the imaginary points where the Earth's spining axis intersects the imaginary rotating sphere of stars called the celestial sphere.

As the Earth spins, the poles remain fixed in the sky and all other points are seen to rotate around them. The celestial poles have declinations of 90^0N (North Pole) and -90^0S (South Pole)

Locating the Celestial Pole

If you are in the northern hemisphere, then face due north and the north celestial pole will be located at an altitude which is identical to your latitude. For example, when in London the north celestial pole is located in the sky by looking due north and then at an elevation of 51^0. For the southern hemisphere, at let us assume a latitude of 33^0 South, then face due south and look up to an altitude of 33^0. You will be looking at the south celestial pole *(see figure 6)*. See discussion on other era with other pole stars [1]

Figure 6 – The stars moving around the south celestial pole

[1] "Thuban Was Once the Pole Star," *The Science News-Letter* 26, no. 691 (1934): http://www.jstor.org/stable/3910830.

Using your hand as your personal sky instrument.

You can use your hand to help to measure the degrees of azimuth and altitude.

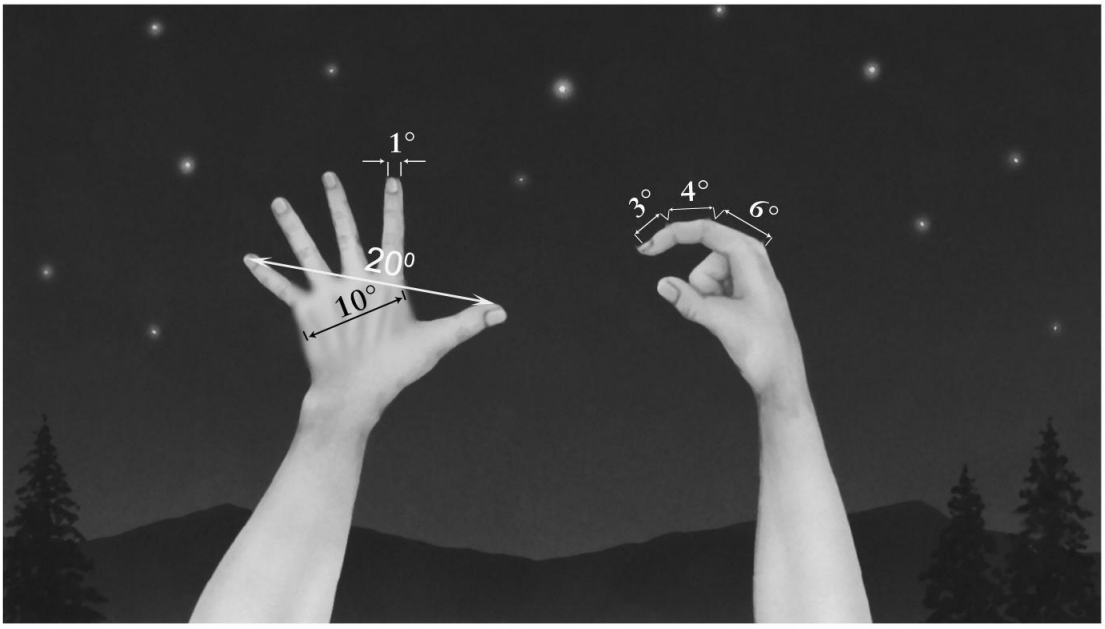


Figure 7 – Your hand and the sky

The movement of the Sun

As the sun moves along the ecliptic, the azimuth of its rising and setting will transcribe a regular arc for a given landscape. This moment is not affected by precession. However, it is affected by nutation which is a slight irregular motion of the earth's movement. (This does influence the azimuth of sun rises and setting over thousands of years so it is applicable to the study of the archaeoastronomy of megalithic sites).

This arc is influenced by the latitude of the observer and the local landscape where hills may delay the appearance of the orb of the sun.

In the northern hemisphere at the summer solstice the sun will rise in the north east. It will rise for several days at its extreme north east position, and will move across the sky at a particular angle, possible rolling up hills or forming a particular relationship to the line of the horizon. Once past the solstice the sun will rise at a position moving closer to due east. At first the position of the sunrise will move slowly along the horizon, only changing it azimuth a little from one day to the next. However as the date moves towards the equinox the azimuth of each sunrise will move more rapidly towards the due east. At the time of the spring or autumn equinox the sun will rise due east. From this period onwards sun rise each day will occur on the horizon at a azimuth further south until eventually at the summer solstice the sun will rise at a point in the south east. *(see Figure 8)*

A similar situation occurs for sun set throughout the year.

Figure 8 – The changing position on the horizon of sunrises for a location in the northern hemisphere

Thus for any location there are four key points of azimuth. *Figure 9* is for Chartres Cathedral, France located at a latitude of 48N24. The graduated circle is the azimuth degrees on the horizon. The red dots are the position of sun rise and the blue dots are the position of sun set. The red dot at the top of the diagram is the summer solstice sun rise at an azimuth of 51^0 51'. The sun rise at this point on the horizon and travel across the cathedral (the red path), culminating due south at an altitude of 65^0 and eventually sets at an azimuth of 307^0 58'. The winter solstice sun rise occurs at 125^0 48', (the blue path) culminates due south at an altitude of 18^0 and sets at an azimuth of 234^0 06'. At the time of the equinox the sun will rise due east and set due west. This pattern is repeated annually.

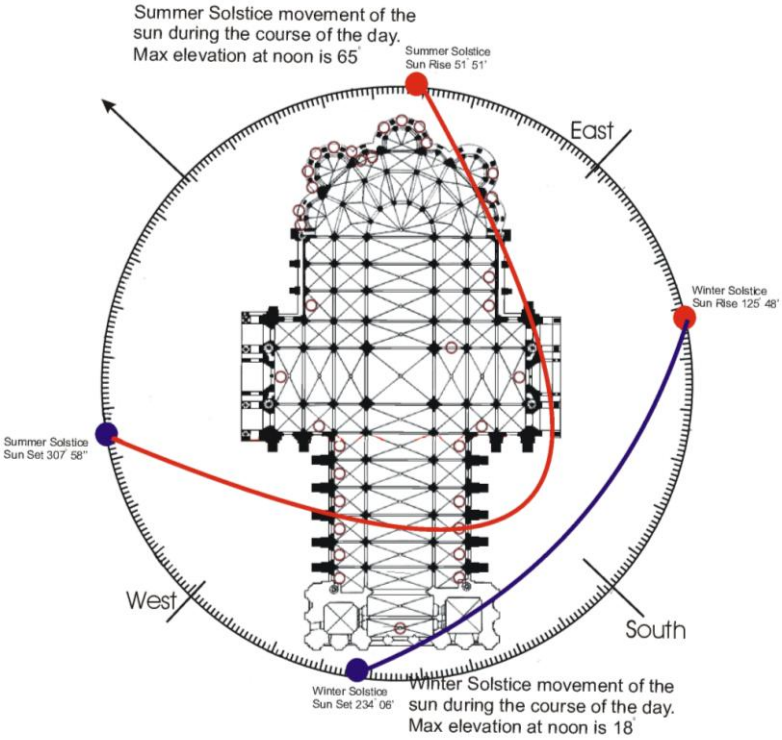


Figure 9 – Extremes of sun rise and sun set for Chartres Cathedral, France latitude 48N24

Twilight

There are three phases to twilight which occur either at dawn or at sun set. The actual measurements of twilight are influence by the latitude and the altitude of the observer.

Civil twilight is when the sun is below the horizon by not more then 6^0. During civil twilight, the sky is has become bright or if in the evening is still bright and only the very brightest stars or planets can be seen. In some countries, the end of evening civil twilight is also referred to as "lighting up time".

Nautical twilight is when the sun is between 6^0 - 12^0 below the horizon. Generally this is the period when navigation at sea via the horizon is no longer possible. The bight stars are sill visible and at and is often called “first light” as one can start to precise the illumination of the rising sun, or the last rays of the setting sun.

Astronomical twilight is when the sun is between 12^0 - 18^0 below the horizon. The sun is no longer illuminating the sky.

The length of twilight is dependent therefore on how quickly the sun can move below the horizon. At equatorial latitudes the ecliptic tends to form a 70^0 - 90^0 angle to the horizon, thus the sun quickly moves through the minus elevation degrees to produce the effect of night suddenly falling, or little time between dawn and full daylight. However, in the summer months at higher latitudes the sun is on a section of the ecliptic which never gains to much minus elevations below the horizon. Thus twilight can linker for hours, and the dawn can take a long time to turn into full daylight *(see Figure 10).*

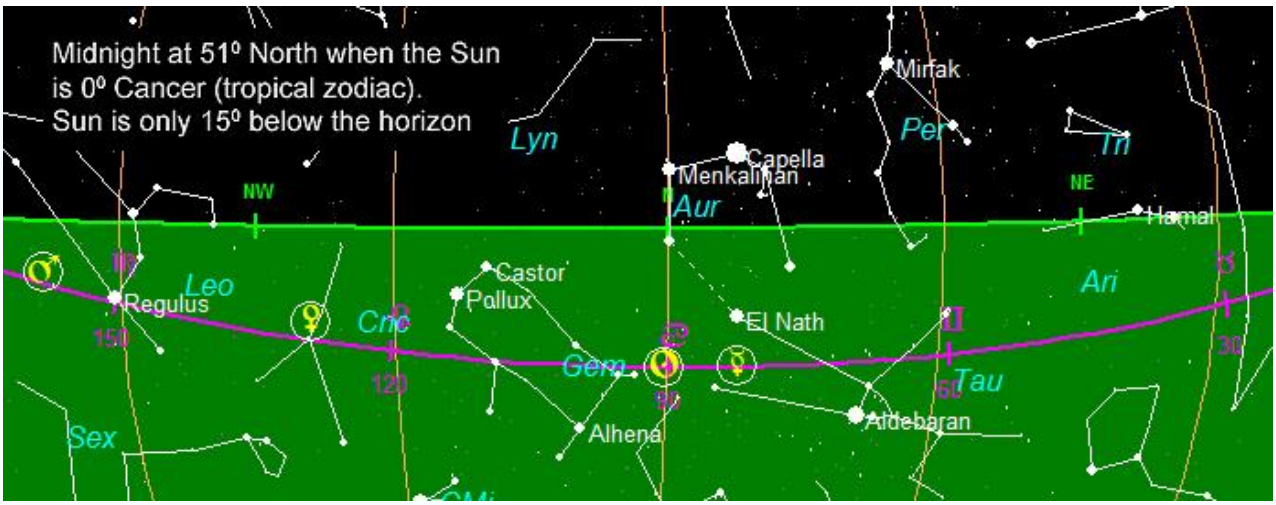


Figure 10 – The sun (☉) at midnight on the summer solstice at a latitude of 51N. The maximum elevation below the horizon that the sun can gain is only 15^0.

The movement of the Moon

The Moon also follows the ecliptic although it does move north and south of the ecliptic which leads to the concept of lunar standstills which will be discussed separately.

Just as the sun, throughout the course of a year, shifts its rising and setting positions as well as the height it reaches in the sky at culmination so too does the moon. However, the moon covers the entire pattern in the course on one month.

The moon in the northern hemisphere starts its cycle by rising in the south-east. When it rises from this position, it will only gains a small amount of altitude before it sets. (This is the dotted red line in the diagram which happens every month when the Moon is in the tropical zodiac sign of Capricorn). The next night it will rise a little closer to due east and it will rise a little higher in the sky. It then sets a little further towards due west. Every night its arc moves. Half-way through this rhythm it rises close to due east, sweeps a "middling" arc through the sky and then sets close to due west. (This is the white line in the diagram which happens every month when the Moon is in the zodiac signs of Aries or Libra). After this the Moon begins its time of *high-flying*. Every day it keeps rising further towards the north and each time it climbs higher and higher in the sky. (This is the yellow line in the diagram which happens every month when the Moon is in zodiac sign of Cancer). Eventually it turns in its rising position and repeats the whole cycle again.

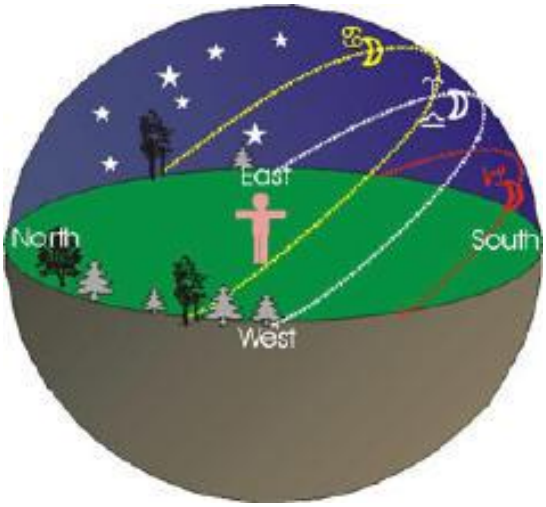


Figure 11 - The monthly rhythm of the Moon as it sweeps its arc through the sky [For the southern hemisphere reverse the signs of Cancer and Capricorn and swap north and south.]

Thus at the time of the summer solstice (Sun entering zodiac sign Cancer) the full moon will occur in Capricorn. Therefore in the month when the Sun is high and the days are long, the full Moon will rise but keep low in the sky, and set quickly. However, at the time of the winter solstice when the Sun is entering Capricorn, the days will be short but the full Moon will be in Cancer and will thus rise at sun set and climb to its maximum height for that latitude and be visible throughout the night.

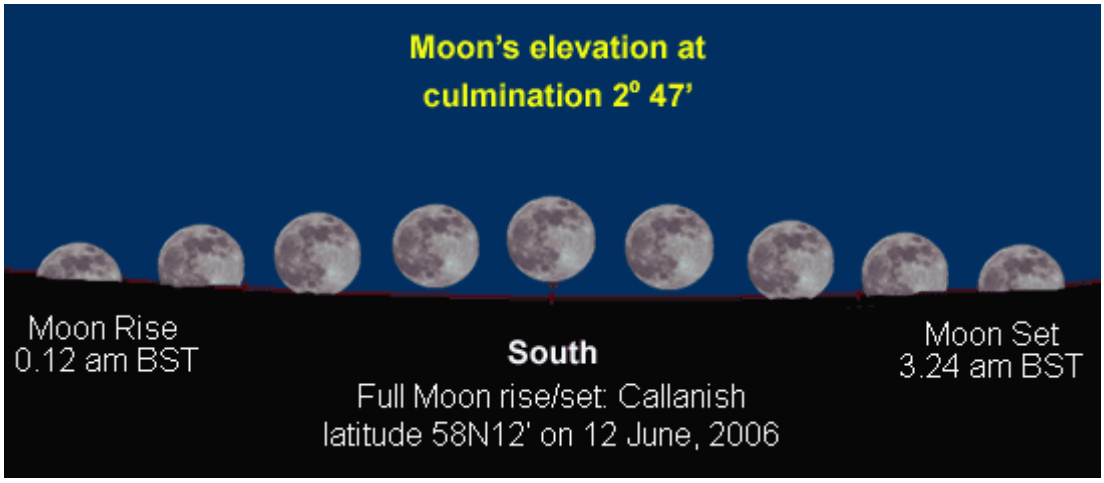


Figure 12 – The full moon rising over Callanish, Scotland on 12 June 2006. The Moon also had southern declination, thus was located south of the ecliptic. The visual impact of such low full moons is that they can be seen to roll along the horizon, or other feature in the landscape.

Star movements

This relationship between the sky and land is part of the meaning of the term "fixed" that we apply to the stars. The earth rotates on its axis and every day the whole sky, stars, planets, ecliptic, sun and moon appear to rise and set. Yet unlike the planets, the stars are fixed in their place in the dome of the sky and therefore, since the dome of the sky appears to rotate, they will, for any given place always rise in the same place on the horizon, set on the same place on the horizon, and culminate at the same degree of elevation above the horizon.

Figure 13 - For the observer, and ignoring for the moment the slow effect of precession, this star will <u>always</u> rise over the same place in the landscape, every single day of the year. As well, for any given calendar date, the star will not only rise in the same place but will also rise at the same time of the day.

Stars are therefore *fixed* in their relationship to place and calendar and do not wander around the sky, changing their times and positions of rising, setting and culmination like the planets. The stars are fixed in their relationship to place.

For example, in *figure 13* the time is set to pre-dawn with the sun just below the horizon. Let us say that the calendar date is 10th June. For this location, on 10th June, the star will rise just before dawn in exactly the same place on the line of the horizon. Later in the year the star will be seen to rise at exactly the same place on the line of the horizon. The only difference is that it will be seen to rise at some other time during the night but always the time of rising will be linked to the calendar date.

Stars have two fixed relationships to space;

- They will always rise and/or set touching the same place on the line of the horizon; and,
- The time in the day or night when a star is seen to rise, set or culminate is fixed to a particular calendar date (ignoring precession).

So just as the Sun is linked to time giving us our calendar - so the stars are linked to place. The sun and the stars come together in what is known as star phases[2].

These star phases were observed and used as part of the religious calendar of the old kingdom period in Egypt where the star phases gave a pulse or beat to a place. Additionally the Romans and the Greeks used parapegma[3], which were calendars based on measuring the course of the year by the stars and the horizon line.

Atmospheric Refraction

The variation of air density causes by altitude can bend the light rays of a rising or setting object so that they appear higher in the sky they actually are. When considering the movement of a planet or a star close to the horizon this is a factor which needs to be taken into account.

Other topics still to be covered.

Venus – the phases of Venus and its unique pattern in the sky.

Working with Shadows, the pointer of the sun. – Future notes.

Astrolabes – Their cultural importance and link to calendar and their use in understanding the sky's movement for any given latitude.

[2] Bernadette Brady, *Brady's Book of Fixed Stars* (Maine, USA: Samuel Weiser, Inc., 1998), p. 317-33.

[3] Daryn Lehoux, "The Parapegma Fragments from Miletus," *Zeitschrift fur Papyrologie und Epigraphik* 152(2005).

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Globe at Night Project, part of the International Dark Sky Association. This web site allows you to take part at star counting at set dates for your location, you then report this figure to a central database. This is similar to other environmental projects which may count birds or insects for a given day.

http://www.globeatnight.org/ Accessed 25 January 2010.

URLs

http://inkido.indiana.edu/a100/celestialsphere.html - a good web sit covering many issues of the movement of the sky. Accessed 20 January 2010.

http://www.umich.edu/~lowbrows/guide/eye.html David Snyder from Michigan State University focuses on naked-eye astronomy. Accessed 26 January 2010

http://www-personal.umich.edu/~dgs/alway/planisphere.htm - how to make a planisphere. Accessed 20 January 2010

The **UK Telegraph's** report on dark skies gaining World Heritage Site status.
http://www.telegraph.co.uk/earth/environment/3513334/Could-New-Zealand-host-the-first-world-heritage-site-in-the-sky.html 15 December 2009