Fundamentals Of Astronomy

Part 2: The Interplay of Earth and Sky

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To begin understanding the movement of the stars and planets in the sky, we must first consider our place on Earth. We live on a rotating planet, a satellite of a single star, the sun, some 93 million miles from us. As the Earth rotates, we find ourselves facing towards the sun for about 12 hours; then we are carried across into the dark half of our planet for another 12 hours or so.

The Celestial Sphere: ***We observe the sky as it looks, not as it is.***

On a night when the stars shine brightly and the moon hangs low in the sky, venture outside for a moment of wonder. Seek out a quiet spot, far from the glare of city lights, where the canopy of the universe can stretch before you unbroken. Find a place with a clear view of most of the sky and, if possible, away from direct light. As you settle into this tranquil space. Lift your gaze to the heavens…

The sky seems like a grand hemispherical dome, with stars seemingly anchored to its inner surface. If Earth were transparent, you would be able to observe the stars on the opposite half of this star-filled dome beneath your feet, giving you the sensation of being at the center of a smooth black sphere adorned with stars. Astronomers refer to this as the celestial sphere. Although it appears that the stars are attached to this celestial dome, they are actually located at varying distances. However, this depth is not something you can perceive just by gazing up at the sky.

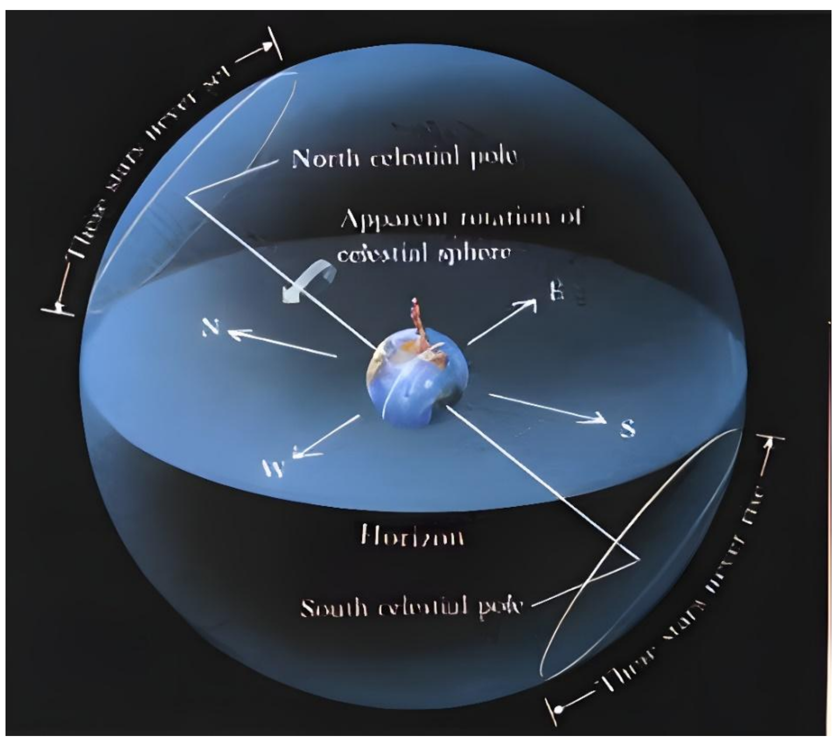

Figure 1: Earth at the center of the Celestial Sphere

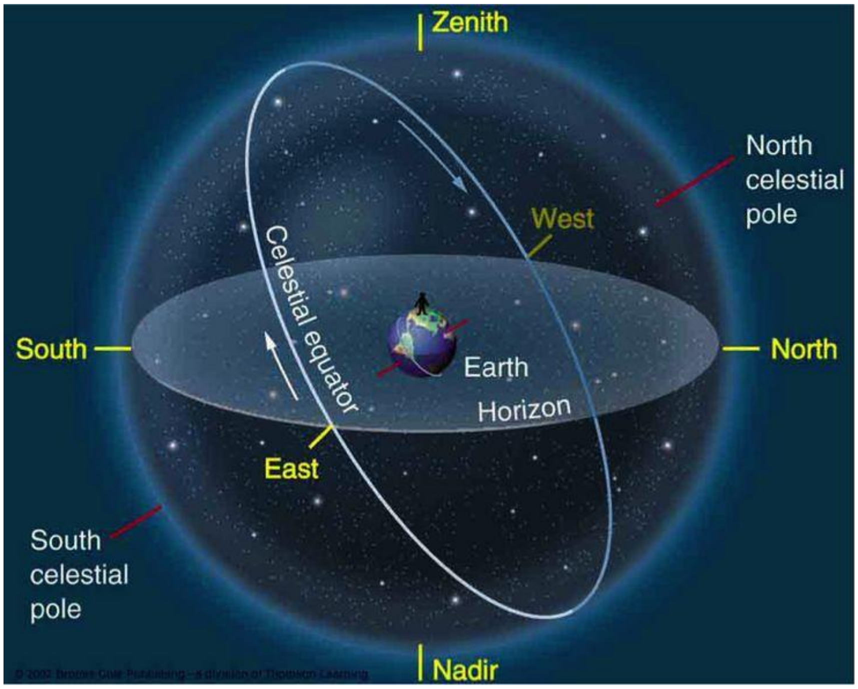

Figure 2: The Celestial Spheres showing key points.

We may perceive ourselves as being on top of the Earth, but this is merely an illusion. This sensation stems from gravity pulling you toward the Earth's center. For instance, at this moment, you are positioned at a particular latitude (your location along the arc that extends from the Earth's equator to the rotational pole). To illustrate this point, let’s assume your latitude is 45° North, which places you halfway between the equator and the North Pole. The latitude of the North Pole is 90°, while that of the equator is 0°.

The Earth seems to exist at the heart of this imaginary sphere. Now, imagine being at the center of this sphere, looking outward. Directly above you is your zenith, while directly beneath you is your nadir—both are specific points on the celestial sphere. The great circle of the horizon lies in between, formed by an imaginary plane that is tangent to the Earth at your feet. Everything above the horizon is visible in the sky, while everything below it remains hidden from view.

The celestial sphere is inclined in relation to the observer just like the Earth itself. The continuation of the Earth's rotation axis into the sky establishes the North and South Celestial Poles (NCP and SCP), while the extension of the Earth's equatorial plane defines the celestial equator. The North Celestial Pole is located in the constellation Ursa Minor (the Little Bear), near the direction of the star Polaris, commonly known as the North Star.

The South Celestial Pole is situated within the modern constellation Octans, also known as the Octant, generally near the dim southern pole star Sigma Octantis (Polaris Australis). The celestial meridian is the circle that extends through the North Celestial Pole, Zenith, Nadir, and the South Celestial Pole. The points where the celestial meridian intersects with the horizon establish the north and south directions, while the intersection of the celestial equator with the horizon defines east and west.

The point where the celestial meridian meets the celestial equator (represented by the uppercase Greek letter Sigma) is located below the zenith at an angle equivalent to the observer's latitude. The Earth rotates around its poles from west to east (counterclockwise when viewed from above the North Pole), creating the appearance of the sky rotating in the opposite direction around the North and South Celestial Poles, in line with the celestial equator. The altitude of the North Celestial Pole above the horizon always matches the observer's latitude. In the Southern Hemisphere, the South Celestial Pole is visible above the horizon, while the NCP lies below it.

A star on the celestial sphere appears to trace a daily path around the observer. The perpendicular angle of a star relative to the celestial equator is defined by its declination. A star is said to set when it drops below the horizon, and it rises when it ascends above it. Stars situated on the celestial equator rise directly in the east and set directly in the west. As the declination increases, the star rises and sets further north of west. If a star is positioned far enough north, it can become circumpolar, meaning it remains continuously visible. Conversely, if the declination is sufficiently south, the star never rises above the horizon and remains unseen.

Figure 3: Star trails showing the apparent movement of the stars from east to west Around the celestial north pole - the dot at the center of the circle.

The Ecliptic: *The path of the Sun, Moon, and Planets*

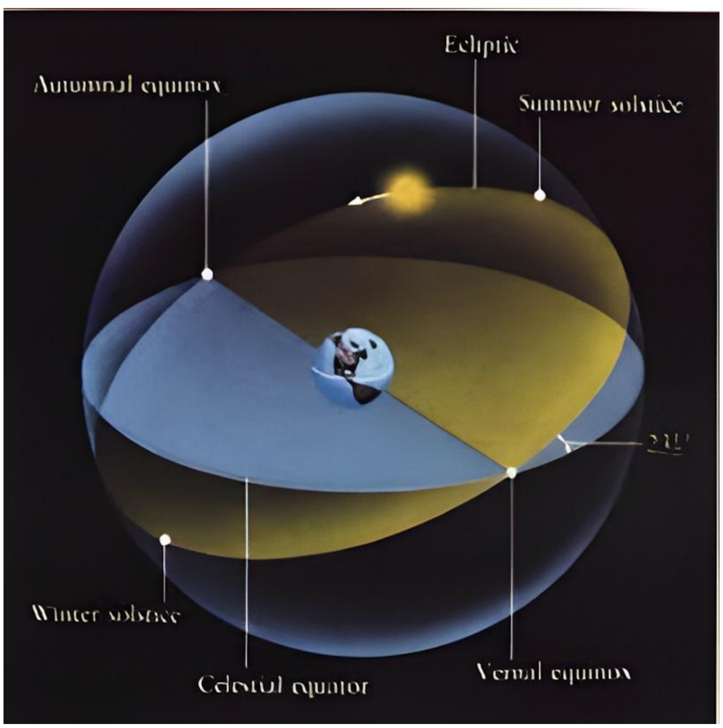

Figure 4: The Celestial Sphere showing the Ecliptic, the equinoxes and solstices.

Although the Earth orbits around the Sun, we perceive ourselves as stationary, leading to the illusion that the Sun travels around the Earth once a year in a counterclockwise direction (from west to east, opposite to its daily movement across the sky) along a consistent path known as the ecliptic. Since there are 365 days in a year and a full circle comprises 360°, the Sun shifts eastward at a gradual rate of just under one degree per day. Simultaneously, it appears to move from east to west due to the Earth's rotation, but this movement is slightly slower than that of the stars due to its concurrent eastward progression.

The poles of the ecliptic are defined at a right angle to the ecliptic plane: the North Ecliptic Pole is situated in the constellation Draco, while the South Ecliptic Pole is located in Dorado.

The Earth's axis is tilted at an angle of approximately 23.5° in relation to the ecliptic poles. This tilt creates a separation between the celestial and ecliptic poles by the same angle, resulting in the circle of the ecliptic being inclined with respect to the celestial equator by this same angle. This phenomenon is referred to as the obliquity of the ecliptic.

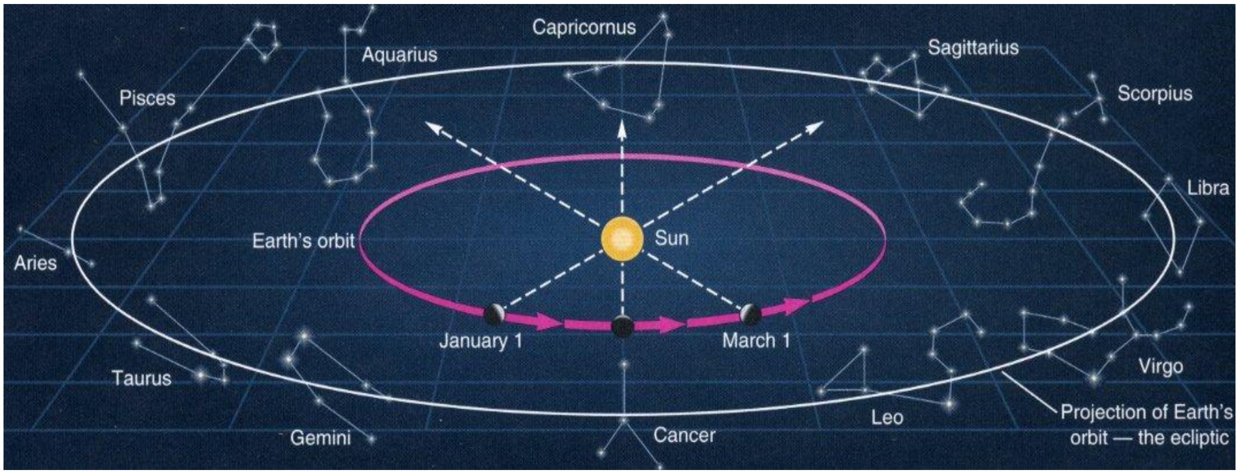

Figure 5: The Zodiacal constellations

As the Sun travels along the ecliptic against the backdrop of stars - still present even if obscured by the blue sky. It seems to shift north and south of the celestial equator. It appears to move across a band of 12 ancient constellations known as the Zodiac. Below, these constellations are presented in their traditional sequence, along with the average date on which the Sun enters each one.

Aries	**Taurus**	**Gemini**	**Cancer**	**Leo**	**Virgo**
April 19	May 15	June 21	July 21	August 11	September 17
Libra	**Scorpius**	**Sagittarius**	**Capricornus**	**Aquarius**	**Pisces**
November 1	November 24	December 18	January 20	February 17	March 12

These dates are determined according to the official boundaries established by the International Astronomical Union in 1930, though minor variations may occur due to leap years.

Notably, Ophiuchus, also known as the Serpent Bearer, is situated between Scorpius and Sagittarius. This constellation is crossed by the ecliptic, making it an unofficial thirteenth member of the Zodiac—though it does not have a place in the classical Zodiac. The Sun enters Ophiuchus on November 30.

Seasons: equinoxes and solstices

Twice a year, the Sun crosses the celestial equator. Sometime around March 20 at a point called the Vernal Equinox, and on September 23 at the Autumnal. On these dates, the Sun has a declination of 0°, it rises exactly east and sets exactly west. It is up for 12 hours and down for 12 hours, hence the term equinox. The equinox passages respectively announce the beginning of northern-hemisphere spring and autumn (and southern hemisphere autumn and spring).

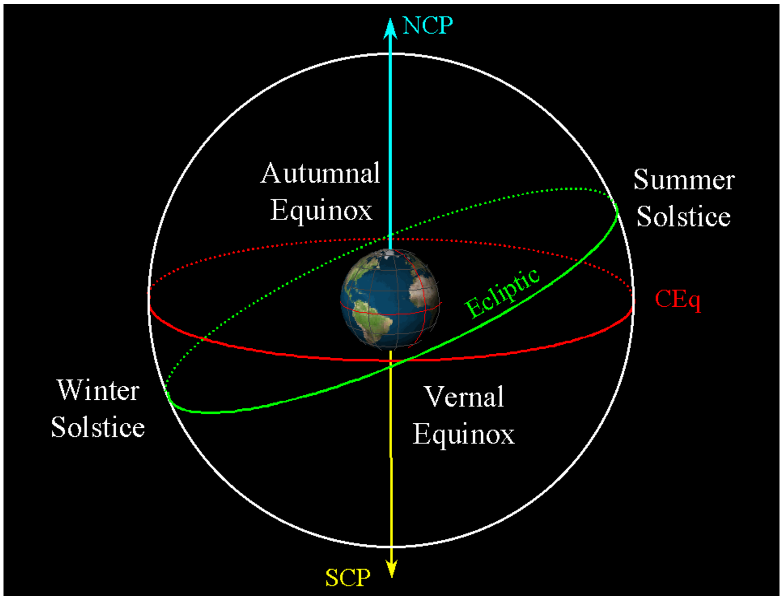

Figure 6: equinoxes and solstices

Point	Usual Date	Right Ascension	Declination	Constellation
Vernal Equinox	March 20	0 hours	0°	Pisces
Summer Solstice	June 21	6 hours	23.5°N	Gemini
Autumnal Equinox	September 23	12 hours	0°	Virgo
Winter Solstice	December 22	18 hours	23.5°S	Sagittarius

As the Sun moves north of the equator from the Vernal Equinox, it rises and sets progressively more to the north of east and west. Days gradually become longer than 12 hours, nights shorter.

On June 21, the Sun reaches its most northerly extent, at a declination of 23.5 degrees north at the Summer Solstice, to begin northern-hemisphere summer (and southern-hemisphere winter). It then rises as far north of east and sets as far north of west as possible. The Northern hemisphere days are now the longest of the year, nights the shortest, the extent of the effect dependent on latitude.

Conversely, following the autumnal equinox, as the Sun moves south, it rises and sets progressively farther south of east and west. The Northern hemisphere days now get shorter, nights longer. On December 22, the Sun reaches its most southerly at a declination of 23.5 degrees south, at the Winter Solstice to begin northern-hemisphere winter (southern hemisphere summer). It then rises as far south of east and sets as far south of west as possible. Northern-hemisphere daytime is now minimized, nighttime maximized. All the effects are reversed in the southern hemisphere, while at the Earth's equator, days and nights are always equal at 12 hours.

When at the Summer Solstice, the northern-hemisphere Sun crosses the celestial meridian as high as possible, while at the Winter Solstice it crosses as far south as possible. In the summer, sunlight spreads over a smaller area of ground than it does in winter, and thereby heats the ground more efficiently, yielding more heat, so it is hot in the summer, cold in the winter. This effect is the sole cause of the Seasons.

Above the Arctic Circle at latitude 66.6° north and below the Antarctic Circle, latitude 66.6° south, the Sun can be circumpolar in the summer, yielding 24 hours of sunlight and a midnight Sun. The farther north of the Arctic Circle or south of the Antarctic Circle, the more days of the midnight Sun you will see. In between the Tropic of Cancer and the Tropic of Capricorn, the Sun will be overhead on June 21 at the former, on December 22 at the latter.

Precession causes the celestial poles to move in circles around the ecliptic poles, which changes the pole stars. In ancient Egyptian times, for example, the North Celestial Pole pointed close to Thuban in Draco. Precession also causes the plane of the Earth's equator to wobble, which changes the directions of the equinoxes and solstices against the background stars, continuously altering the right ascensions and declinations of stars, though in a precisely known way. In ancient times, the Vernal Equinox was in Aries, which is why that constellation tops the classical list. In classical times, the summer and Winter Solstices were in Cancer and Capricornus, hence the names "Tropic of Cancer" and "Tropic of Capricorn."

Due to the effects of precession, by around 1990, the Summer Solstice shifted across the contemporary boundary from Gemini to Taurus, with Taurus now officially marking the position. However, since the Summer Solstice is still nearer to the traditional depiction of Gemini than to that of Taurus and given that Gemini occupies a quarter of the ecliptic, it continues to be regarded as the celestial home of the Solstice in traditional contexts.

Time and Coordinates

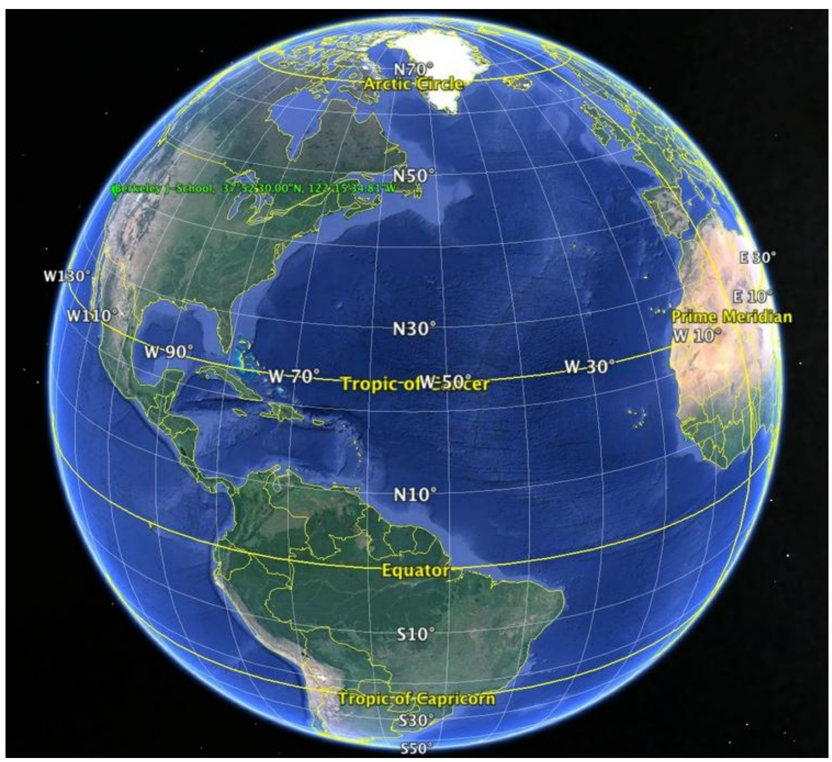

Figure 7: Longitude and Latitude

Your location on Earth is defined by your latitude and longitude. Longitude indicates your position in the east-west direction. A great circle that extends from the North Pole through your location to the South Pole is known as a meridian. The meridian passing through Greenwich, England, is referred to as the prime meridian. Pay attention to where these two meridians intersect the equator; your longitude is determined by the angle between these intersections. For instance, Greenwich's coordinates are 51° 29' North latitude and 0° longitude, while Buenos Aires is situated at 34° 35' South latitude and 58° 29' West longitude. Remember that there are 60 minutes (') in a degree of angle and 60 seconds (") in a minute.

The angular displacement of a star westward from the celestial meridian (measured along the celestial equator, similar to longitude) is known as the hour angle. This angle is typically expressed in time units, with a rate of 15° per hour. Apparent solar time is calculated by adding 12 hours to the hour angle of the Sun, which establishes the start of a "day" at midnight. However, due to the Earth's orbital eccentricity and the tilt of the ecliptic, apparent solar time does not remain constant. Corrections for these factors result in mean solar time, which can differ from apparent solar time by as much as 17 minutes. The hour angle of the Sun, and thus the time of day, shift continuously with longitude, where differences in longitude directly correspond to time differences. Standard times correspond to the mean solar times of nearby standard meridians, which are positioned at 15° intervals from Greenwich; however, political boundaries can cause discrepancies.

Sidereal time is determined by the positions of stars in the night sky. A sidereal day refers to the time it takes for a specific star to complete its journey and return to the same point in the sky. This duration is slightly shorter than a mean solar day, lasting approximately 23 hours, 56 minutes, and 4.1 seconds. A sidereal day is divided into 24 sidereal hours, with each hour further subdivided into 60 sidereal minutes, and so forth.

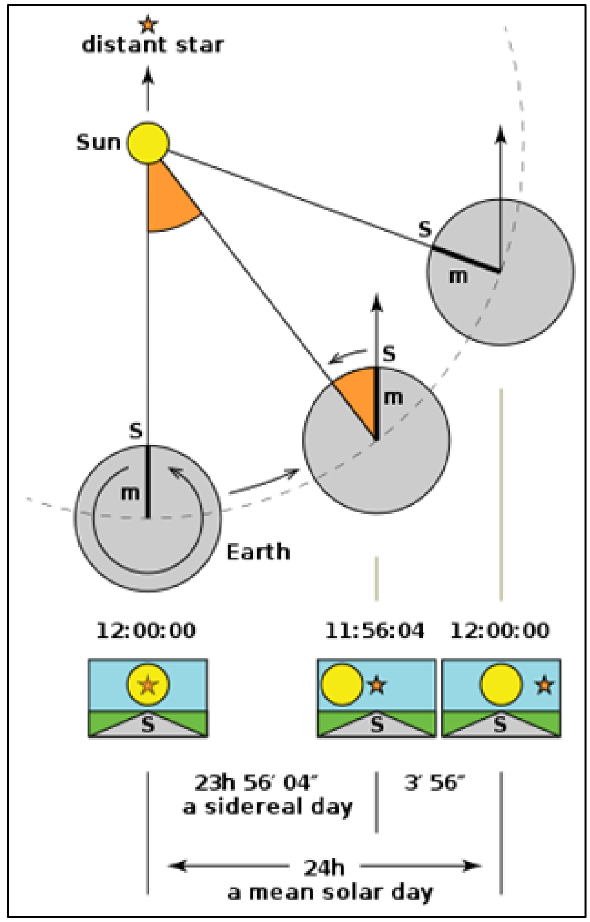

Figure 8: Solar and Sideral Day

Sidereal days are shorter because, in addition to rotating on its axis, the Earth is also orbiting the Sun. Both movements occur in a counter-clockwise direction when viewed from above the North Pole. To illustrate this, you might consider drawing a diagram.

Start by representing the Sun as a point. Next, draw the Earth and indicate that it's noon for an observer on the surface by sketching a stick figure standing on the Earth, with their feet on the ground and their head tilted toward the Sun, which is directly overhead at this time. Draw a line from the Earth to the Sun and extend it beyond the Sun to place a star along this line. From the observer's perspective, the star would also appear to be overhead, albeit hidden by the Sun.

Now, visualize how, during a mean solar day, the Earth moves in its orbit while rotating. Draw the Earth in this new position along its orbit. It's okay to exaggerate this movement for clarity. Notice that in this new position, the observer, still facing the Sun, is no longer pointing at the star—suggesting that more than one sidereal day has passed!

The right ascension of a star or any celestial object is defined as the angle it makes with the vernal equinox, measured eastward along the celestial equator, and is commonly expressed in time units. The right ascension and hour angle of a celestial body together sum to equal the sidereal time. By knowing the sidereal time and the right ascension of a celestial object, you can calculate its hour angle. This, along with the object's declination, allows you to align a telescope and locate anything in the night sky.

Thus, two coordinates are needed to locate an object on the celestial sphere: Dec*lination and Right Ascension.*

The equatorial coordinate system

Right Ascension

Like longitude, right ascension specifies the location of a celestial object relative to the celestial equator. The Vernal Equinox Point serves as the reference point for right ascension, defined as 0h or 24h. As you move eastward, this value increases. Given that a complete circle of 360° corresponds to 24 hours, a right ascension of 15° is equal to 1 hour.

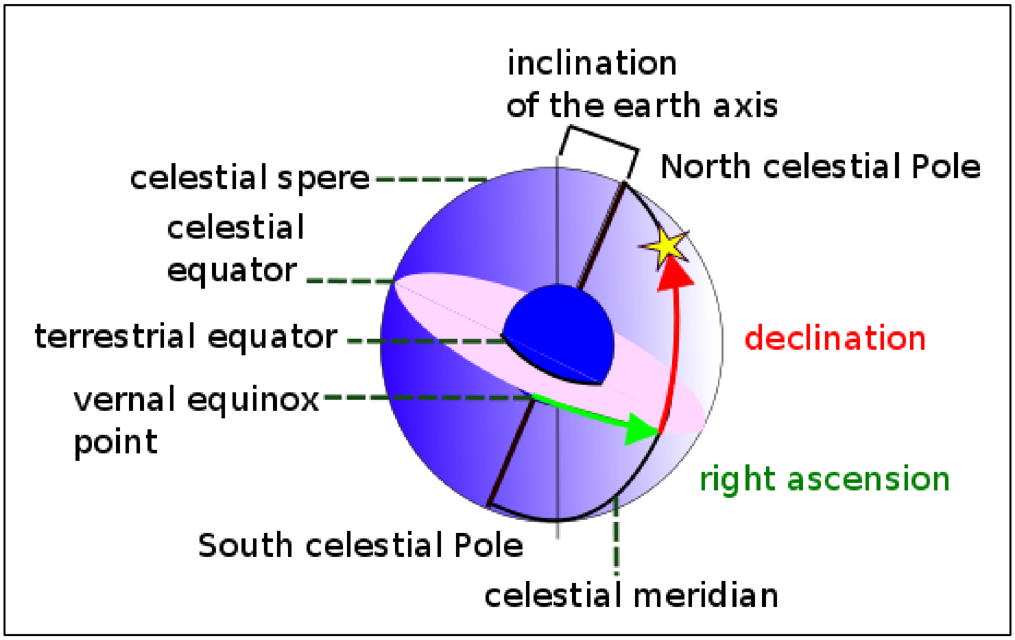

Figure 9: Right Ascension and Declination

Declination

Declination is the angle measured north or south of the celestial equator. It is defined as 0° at the celestial equator, +90° at the north celestial pole, and -90° at the south celestial pole, mirroring the way latitude is defined on Earth.

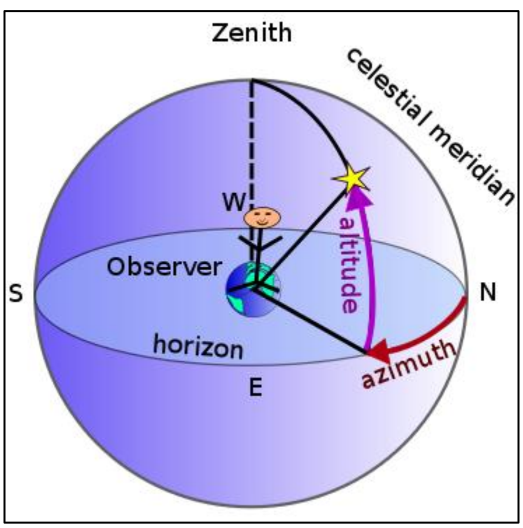

Figure 10: Altitude and Azimuth - ALTAZ

The horizon Coordinate system

The horizon or "local" coordinate system defines a star's position on the celestial sphere in relation to the observer's celestial horizon and zenith.

The azimuth represents the angle between a reference point (north) and the star's position projected onto the horizon.

Meanwhile, the altitude is the angle formed between the star and the horizontal plane. Together, the star's Coordinates are specified by its azimuth and altitude.