

Time

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Some Definitions:

Celestial Sphere is an imaginary sphere of infinite radius centered on the center of the earth to which the stars are fixed and is a useful construct in positional astronomy where we are primarily concerned with the direction of objects in the sky as it appears to an observer on earth.

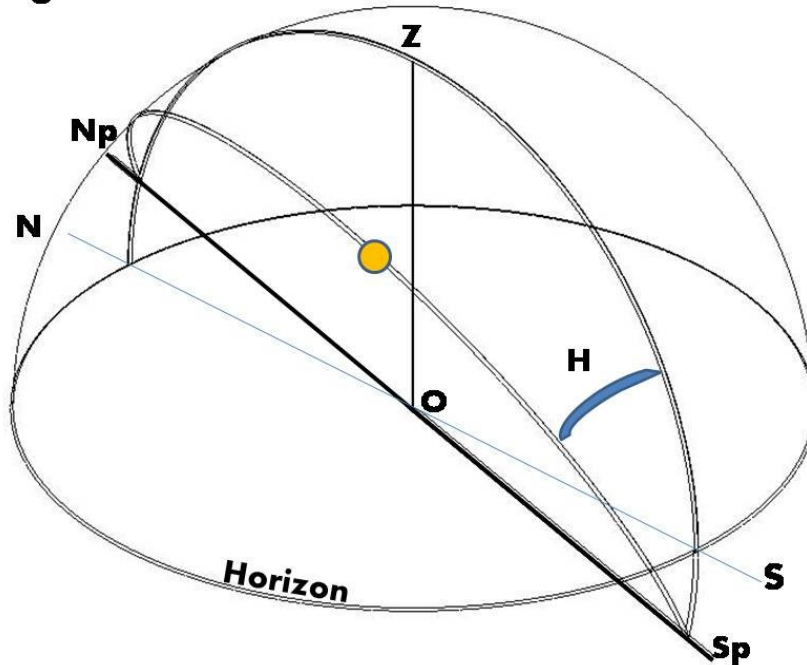
Meridian is the imaginary line through the zenith (point right overhead) in the north-south direction.

The **celestial equator** is the plane of the earth's equator projected on to the celestial sphere.

Ecliptic is the plane of the earth's orbit or the apparent orbit of the sun relative to the earth. Over a year the sun seem to move relative to the stars in the sky along the projection of the ecliptic on the celestial sphere.

Hour angle of an object in the sky is the angle through which the earth has rotated since the object was on the meridian. In other words it is how far to the west it is from the meridian. This can be expressed in degrees or in time units, where one degree is equal to four minutes. See diagram 1.

Diagram. 1

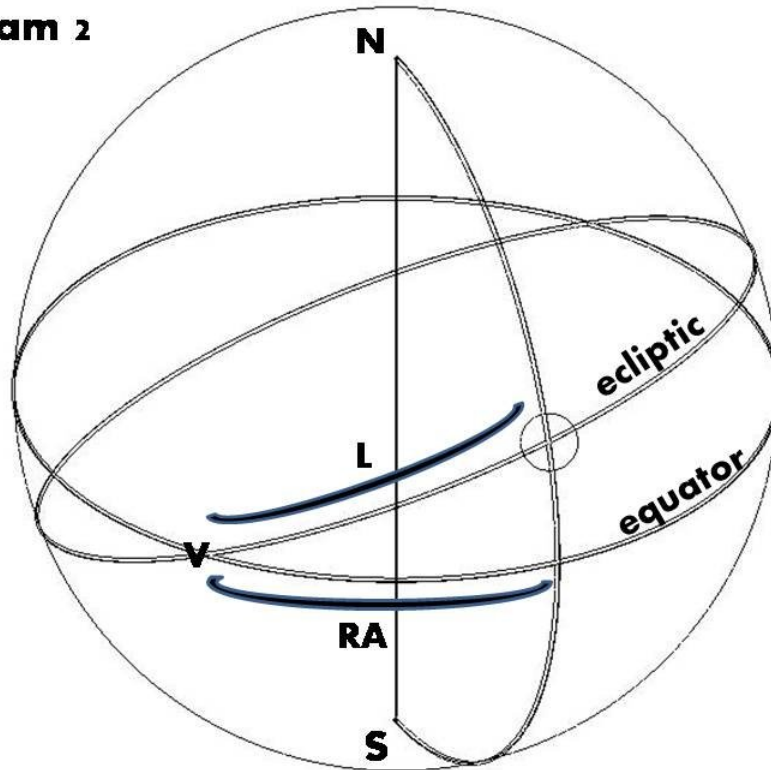


The so called **First Point of Aries** or point of **vernal equinox** is the point on the celestial sphere where the sun moving along the ecliptic crosses the celestial equator from south to north in March.

The First Point of Aries is the datum relative to which position of objects on the celestial sphere are measured. **Right Ascension** is the angular separation of the object east of the First Point of Aries and **Declination** is the angular separation of the object in the northward sense from the First Point of Aries or the equator. The right ascension and declination are analogous to the geographical longitude and latitude respectively on earth. Right ascension or RA is usually given in time units like the hour angle and so range from zero to 24 hours. Note that while the hour angle is measured westward from the local meridian, the RA is measured eastward from the First Point of Aries which is fixed to the celestial sphere. Declination is always given in degrees and if the object is south of the First Point of Aries it is given a negative sign.

Longitude of the sun is the angle through which the sun has moved along the ecliptic from the point of vernal equinox. See diagram 2.

Diagram 2



Time:

The definition of time in the present context is tied to the day-night cycle which we experience on earth due to the rotation of the planet about a north-south axis through its center. This is also called “civil time” as it regulates human business on earth. In other words the period of rotation of the earth relative to the sun is the basis of civil time. Unfortunately the sun is not fixed to the celestial sphere like the other stars but seem to move along the ecliptic. And further the ecliptic plane is not perpendicular to the axis of rotation of the earth. (See diagram 2). Then again the sun does not go along the ecliptic at a constant rate. All of this can be explained by the fact that the earth is orbiting the sun along an elliptical path (at varying speed) and the axis of rotation of the earth is pointing 23.44 degrees away from the perpendicular to the orbital plane. But it does complicate the exact measurement of the earth’s rotation relative to the sun. In fact until the advent of modern electronics it would have been

impossible to make a time measuring device which would run in synchronism with the sun ! If we could just agree to measure time based on the rotation of the earth with respect to the fixed stars matters would be very simple. The stars do transit the meridian at regular intervals of 23 hours 56 minutes and 4 seconds. Indeed astronomers use a **Sidereal Time** based on the hour angle of the First Point of Aries. However it would throw human affairs out of gear if 2 PM is in the afternoon in March and 2 PM is in the dead of night in September. So the civil time has to relate to the real sun which regulates life on earth. To overcome the problems with the real sun, astronomers have invented a concept called a "**mean sun**" which moves uniformly round the celestial equator in the eastward sense, completing one round in the same time as the real sun completes a circuit round the ecliptic. The position of the mean sun is to coincide with that of the real sun at the point of vernal equinox. "**Mean Time**" is the time based on the mean sun. When the mean sun is on the local meridian it is 12 noon, mean time. The mean sun being a fiction cannot of course be observed, but as it starts out from the First Point of Aries at the instant the real sun is there and moves at a constant rate along the celestial equator its right ascension can be readily computed.

A of mean sun =

(days elapsed since vernal equinox) / (365.2422 days) X (24 hours)

Computing the RA of the real sun is not so easy. First compute the longitude of the real sun (see notes on elliptical orbit) using the following data :-

Sun is at perigee on January 3

Longitude of perigee is 282.94719 degrees

Orbital period is 365.257 days (sidereal year)

Once the longitude 'L' of the sun is known we can calculate its RA using the relation:-

$$\tan (RA) = \tan L \times \cos 23.44$$

So also the declination is calculated from the longitude of the sun using the relation:-

$$\sin(\text{dec}) = \sin(L) \times \sin 23.44$$

Where 23.44 is the inclination of the ecliptic to the celestial equator in degrees. The ambiguity as to the quadrant of RA (whether it is between 0 & 90 degrees or 180 & 270 degrees when tan L is positive or whether RA is between 90 & 180 degrees or between 270 & 360 degrees when tan L is negative) can be resolved if we remember that RA has to be in the same quadrant as L because RA and L are identical at 0, 90, 180, & 270 degrees.

The difference in the RA of the real and mean sun is of course the difference between mean time (clock time) and time shown by a simple sun dial. Or by how far the real sun is behind the mean sun in crossing the meridian. This value (for some reason) is known as the **Equation of Time**. The value of the equation of time can be positive or negative. For example it is negative by 16 minutes and 24 seconds at the beginning of November (3rd or 4th). This just means the real sun is ahead of the mean sun by over 16 minutes and you feel the sun setting a bit early for the season. On the other hand by second week of February (12th) the equation of time is plus 14 minute 24 seconds and the real sun lags behind the mean sun.

$$\text{Equation of time} = \text{RA of real sun} - \text{RA of mean sun}$$

$$= \text{mean time} - \text{apparent solar time}$$

(the RA is measured eastward from point of vernal equinox. The vernal equinox point is on the celestial sphere which seems to rotate westward as seen from earth. So the greater the RA, the latter it transits the meridian.)

The **Standard time** is just the mean time corresponding to a particular longitude on earth which has been fixed for a country or zone. This is of course a necessary step to ensure that all citizens agree on train timings etc. The **Greenwich Mean Time or**

GMT is the mean time on the datum meridian passing through Greenwich observatory near London. **Indian Standard Time** is the mean time on 82.5 degrees longitude east of Greenwich, approximately going through the middle of India. So if you are on longitude 77 degrees east (Trivandrum for example) your local mean time is 22 minutes behind IST. Remember one degree of longitude makes a difference of four minutes in local time.

The earth goes round the sun in 365.256366 days. But the apparent north-south oscillation of the sun in the sky and the consequent cycle of seasons have a period of 365.242199 days. The disparity may seem trivial, but over a period of 13 centuries the seasons would drift by as much as six months if we adopt the period of the earth's orbit as the mean year. So the mean civil year has been defined as the duration between the successive transits of the sun across the celestial equator from south to north at the point of vernal equinox, which is of course 365.242199 days. This is called the "**Tropical Year**". According to the Gregorian calendar devised by a team of astronomers commissioned by Pope Gregory in 1582, a year has 365 days except the years which can be divided by 4 (without leaving a remainder) which have 366 days by adding a day to February. These years are called "leap years". However the years ending in two zeros (end of centuries) which are of course divisible by 4 are not leap years if they are divisible by 400. Thus 1900 was a leap year, but 2000 was not a leap year. All these adjustments makes the year 365.2425 days long, which is a good approximation of the tropical year. The reason for the difference between the tropical year and the period of the earth's orbit round the sun (365.256366 days) is that the point of vernal equinox is drifting westward at the rate of about 50 arc seconds (an arc second is 1/3600 of a degree) per year so that the sun (going eastward along the ecliptic) crosses the point a bit earlier than if it had remained strictly fixed to the celestial sphere. And that in turn is because the earth's axis of spin has a wobble, technically known as "**Precession**" of the axis. The period of this precession is about 26000 years. This of course is the time in which the vernal equinox would drift through one complete round of the celestial equator. Currently the point of vernal equinox also known as the first point of Aries (for historical reasons) is in Pisces just below the square of Pegasus.

Incidentally, the period of the earth's orbit is called the "**Sidereal Year**". From an observational point of view it is the time taken for the sun to return to the same point on the star background or the celestial sphere.

Sometimes the time of an astronomical event is given in "**Julian Days**".

This is just the time elapsed in days from the noon over Greenwich meridian of January 1st of 4713 BC. For example an event at 6 PM, IST, of 2nd June 2010 will have a Julian date 2455168.02083. The fraction 0.02083 comes in because Julian date of the noon Greenwich mean time (GMT) of 2nd June 2010 is 2455168.00 and our IST is ahead of GMT by 5 ½ hours so that 6 PM, IST is 12.30 PM GMT and 30 minutes is 0.02083 day. By the way Julian was just the father of Joseph Scaliger (French) who introduced the system of time reckoning back in 1582 probably to avoid the confusions of the new Gregorian calendar. It is still used mainly because it makes the computation of time elapsed between widely spaced events easy.

Though the rate of rotation of the earth relative to the stars is practically uniform, there is a secular slowing down due to the tidal action of the moon amounting to the order of milliseconds in a century. Then there are unpredictable variations of the order of a few milliseconds per day which cancel out over long periods which is due to the fact that the earth is not all solid and there is some exchange of angular momentum between the liquid core and solid outer mantle and even the oceans. These things came to light as modern atomic clocks came into use which are more accurate than the earth's rotation. So now there is an "**Ephemeris Time**" base on celestial dynamics. If there are just two bodies orbiting around their common center of gravity their orbital period would be precisely constant in ephemeris time. But such an ideal is not available and it takes a lot of painstaking observations of the solar system with its eight planets and their tens of satellites, not to mention the millions of Asteroids, comets , and other junk, to track ephemeris time. Now atomic clocks adjusted to be within a second of ephemeris time is used to fix the ephemeris or location of bodies in the solar system and for guiding manmade space craft on interplanetary flights.
