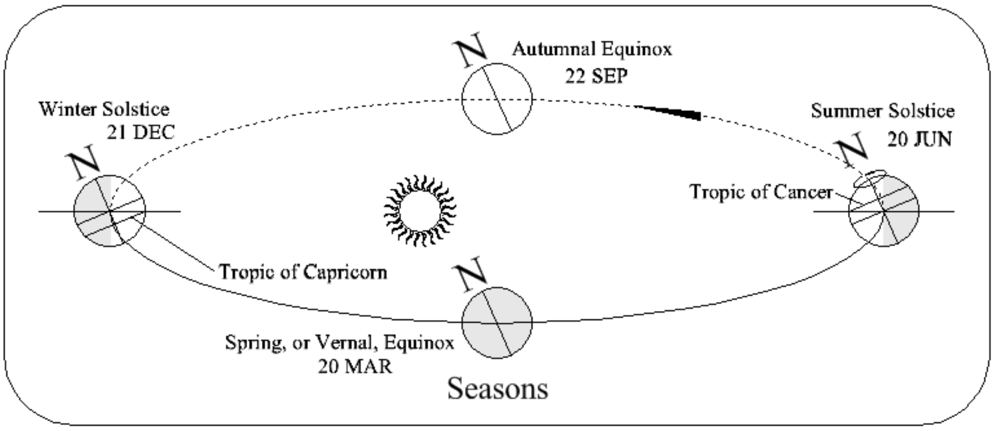
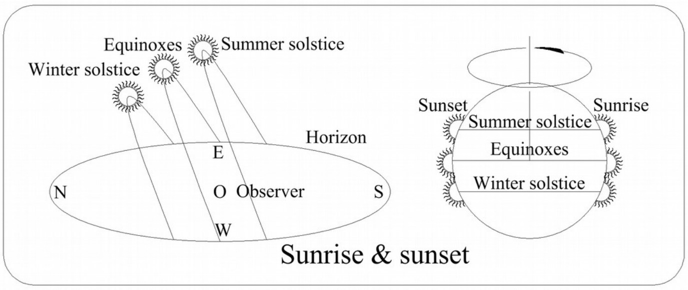
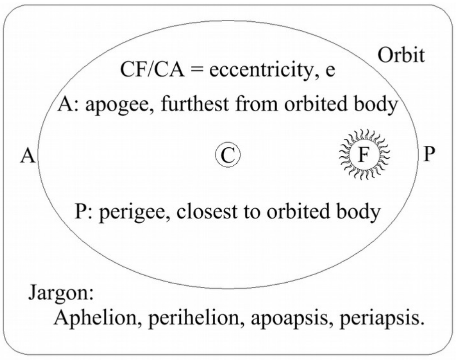
# Astronomy

## The Seasons




The seasons are caused by the inclination of the Earth's axis: when a hemisphere is tipped toward the Sun, the Sun is more directly above it. At the Summer Solstice the tilt is most directly towards the Sun, it's midsummer & the days are longest. The opposite occurs at the Winter Solstice. (The drawing has the terminology applied to the northern hemishere; the opposite is happening in the southern.) Halfway between, at the Equinoxes, the days & nights are of equal duration. From the point of view of an observer, the following drawing shows what happens throughout the year.

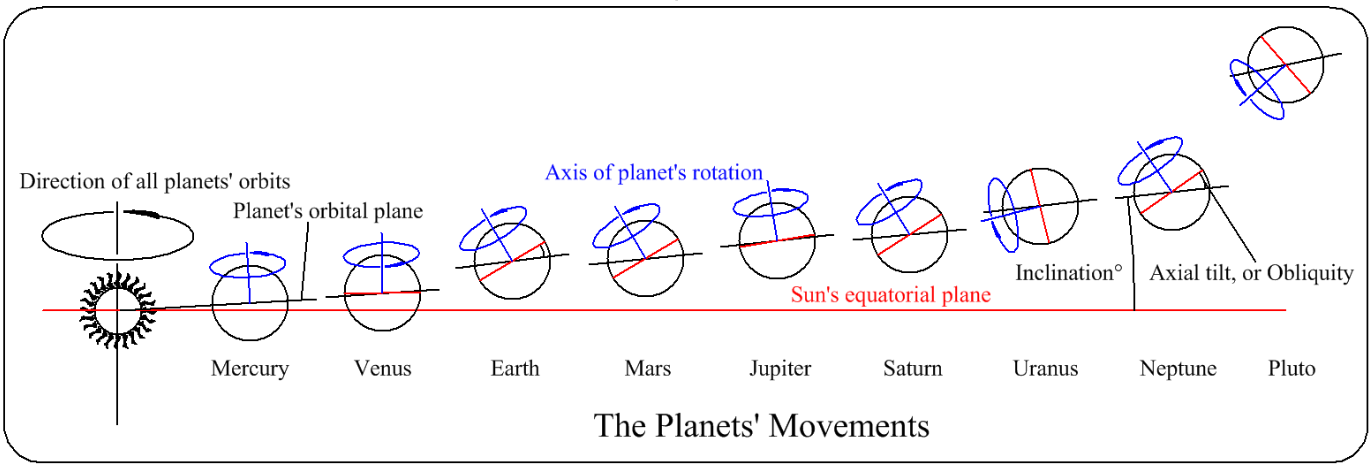



All orbits are ellipses. Ellipses have two focal points, & the orbited body is at one of these. That means that the Earth varies its distance from the Sun as it orbits, but the eccentricity is so small that the variation has negligible effect on the heat reaching Earth.

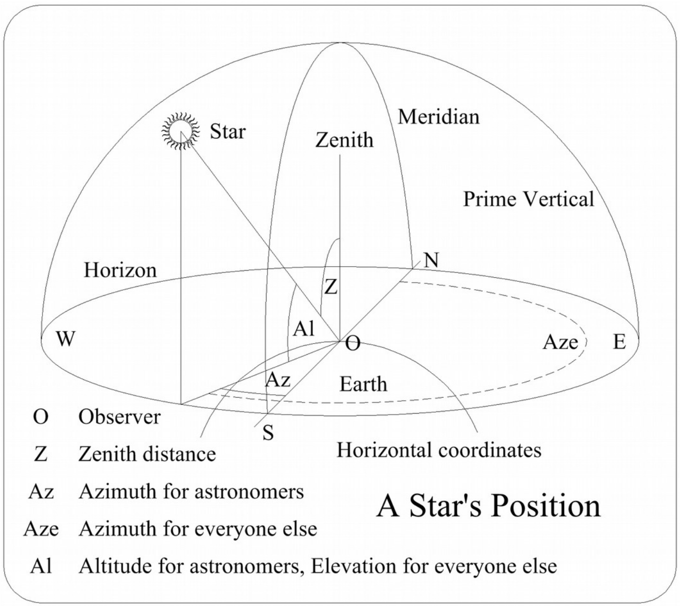
## The Planets

Notice that the Inclination is the angle between the planet's *orbital* plane the




Sun's *equatorial* plane.

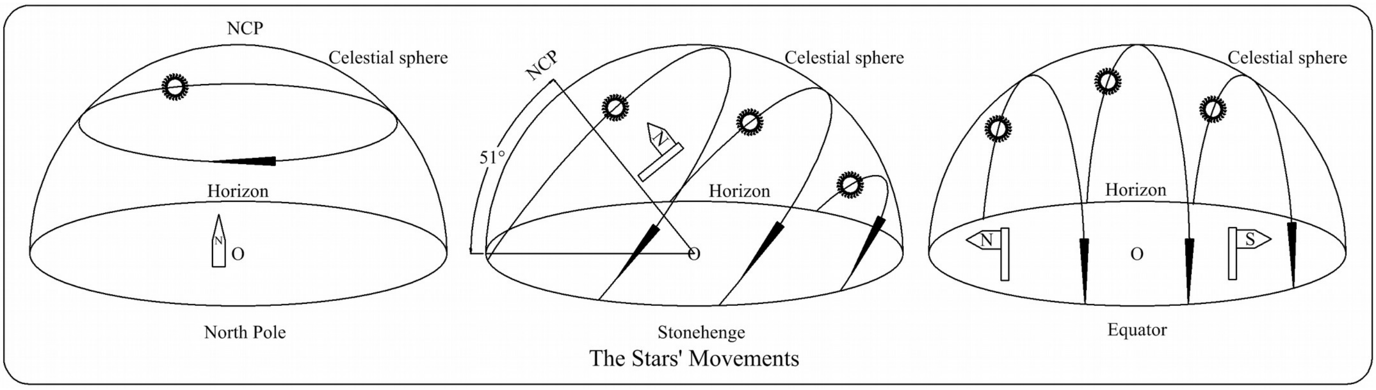
## The Stars



A Star's Position

It is necessary to know the position of a star. For any observer a star’s position can be specified as shown in the drawing. But this position is relative to the observer’s place on the Earth’s surface, & only valid at a particular time. Something better is needed; Something to let everyone, at any time, know how to find that star.

Before moving on, notice how the stars apparently move; knowing what to expect helps one to understand. The Earth rotates around an axis defined by the North & South Poles. An observer at a pole will see the stars apparently rotating around the pole. As the obsever travels toward the equator the stars’ apparent

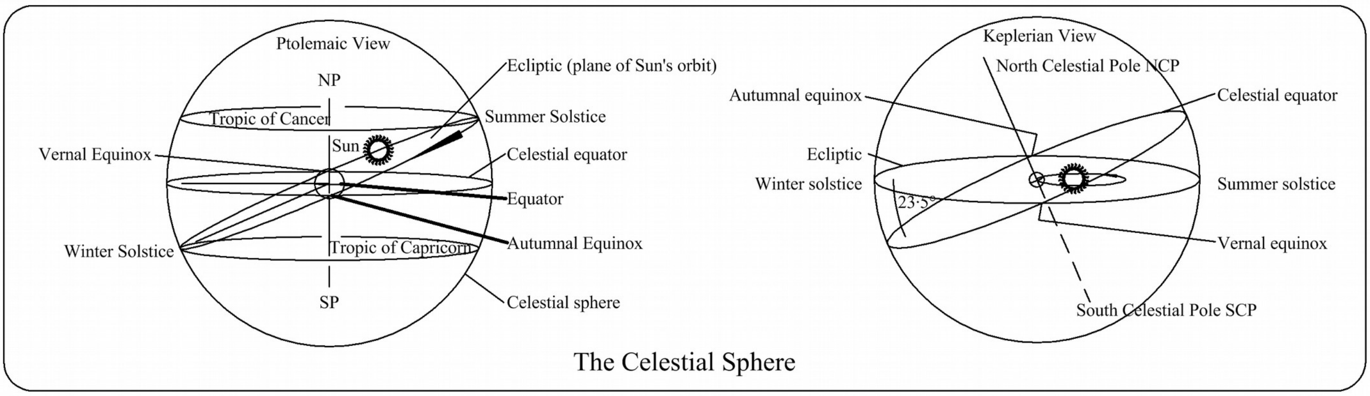


The Stars' Movements

movement will change: the drawing shows how.

## The Celestial Sphere

Imagine a perfect sphere centred on the Earth & expanded out to infinity. This sphere is called the Celestial Sphere. The stars are so far away that they appear as little lights on this huge surface. Just for interest, the Ptolemaic view is shown; it assumes that the Earth is at the centre of the universe, & that everything revolved



The Celestial Sphere

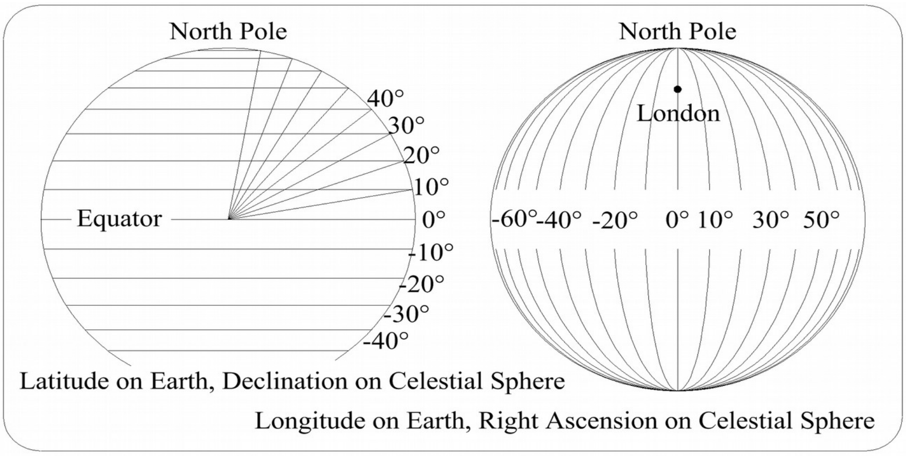
around it in circles. The correct view is the Keplerian.

Note that the Ecliptic is defined incorrectly in the Ptolemaic view. To ensure no confusion, the Ecliptic is the plane of the Earth’s orbit.

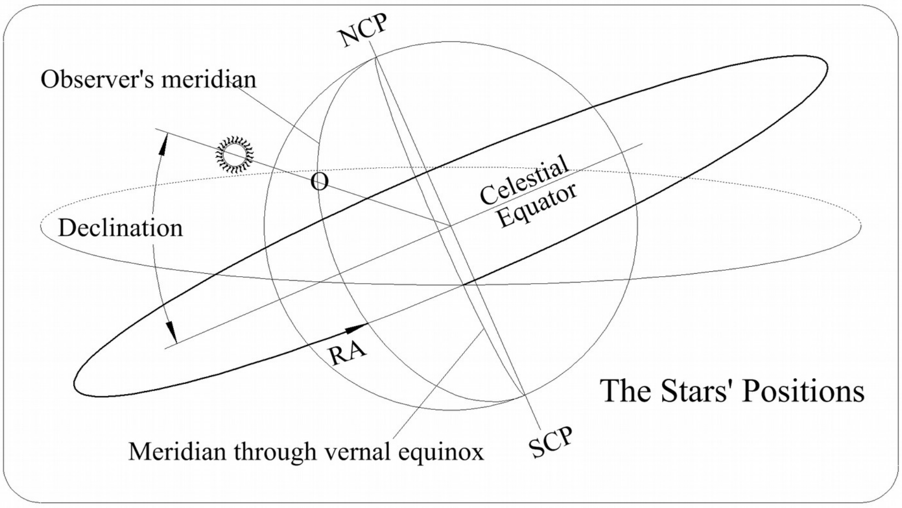
The poles, on the sphere, are called the North & South Celestial Poles (NCP &

SCP). The equator is called the Celestial Equator. The equinoxes & solstices now have precise locations: the eqinoxes occur when the Earth crosses the intersections of the ecliptic & the celestial equator, & the solstices are 90° around the ecliptic.

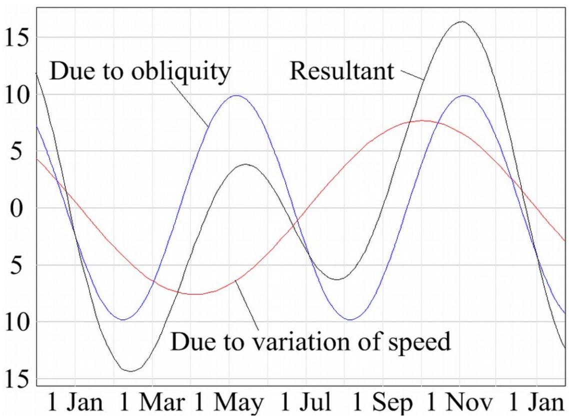
## Location on Celestial Sphere




To define a position on Earth lines of latitude & longitude, as shown in the drawing, are used. For any particular point on Earth, the longitude line is called its Meridian. Latitude is the distance from the equator towards one of the poles, measured as shown. Longitude is the distance around the Earth, also measured as shown  On the celestial sphere the latitude is called Declination & is similarly measured (from the celestial equator), but the longitude is called the Right Ascension, RA, & is subtly different. These are Equatorial coordinates.




In the drawing the observer is shown on the surface of the Earth. When he discovers a star he records its declination & the time that the star is on his zenith (crossing his meridian). The RA is measured from the meridian of the vernal equinox eastward, so his RA, at the rcorded time, must be ascertained. Then that is the star’s RA.




## Days

If  the intervals between successive noons are measured, a complicated pattern of differences between these intervals emerges. .

These differences have two causes - first, because the Earth moves along its orbit as it rotates, it must rotate slightly more than one rotation between successive noons, & second, the Earth's orbit is elliptical and the Earth moves faster along its orbit when closer to the Sun. An average of the intervals is called the Mean Solar Day, & this is the day in everyday life.

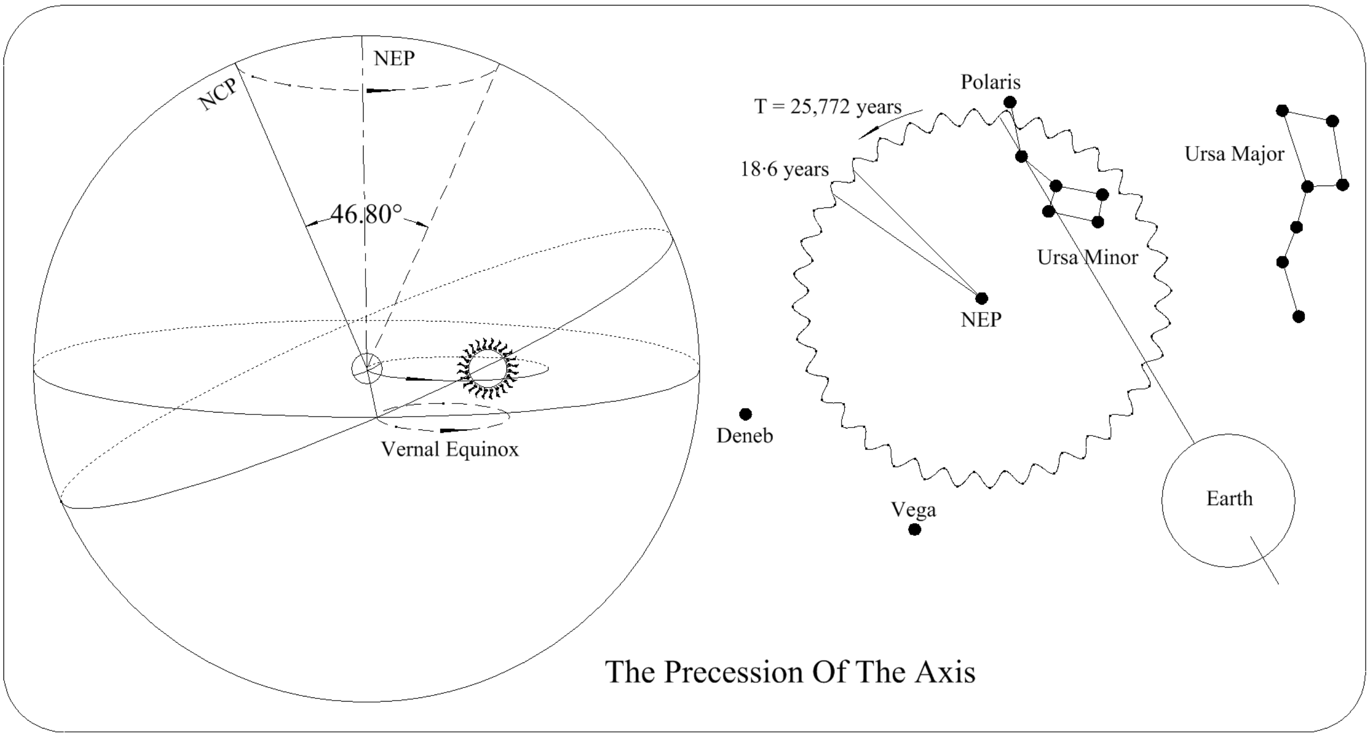
Over a year the Earth makes one orbit taking 365•242 198 79 solar days, but it doesn’t rotate 365... times; it rotates 366... times. So the time, in mean solar days, is 365...  / 366... = 23h 56m 4•091s. This is one Sidereal Day, which gives Apparent Sidereal Time.

## The Earth Moves

The Earth’s movement in the solar system is mostly an ellipse around the Sun. However, all the things in the system have a gravitational effect. The most effective are the Sun, the Moon & Jupiter. The largest effects are the movements of the Earth’s axis relative to the stars.

The drawing shows the axis moving such that it traces a cone, & this movement is called precession. As the axis moves so must the equator, so the celestial equator nust move, hence the vernal equinox moves. This gives rise to the phrase “precession of the equinoxes” to describe this movement.

Superimposed on the precession is a wobble, called nutation. Precession & nutation are only the major effects.

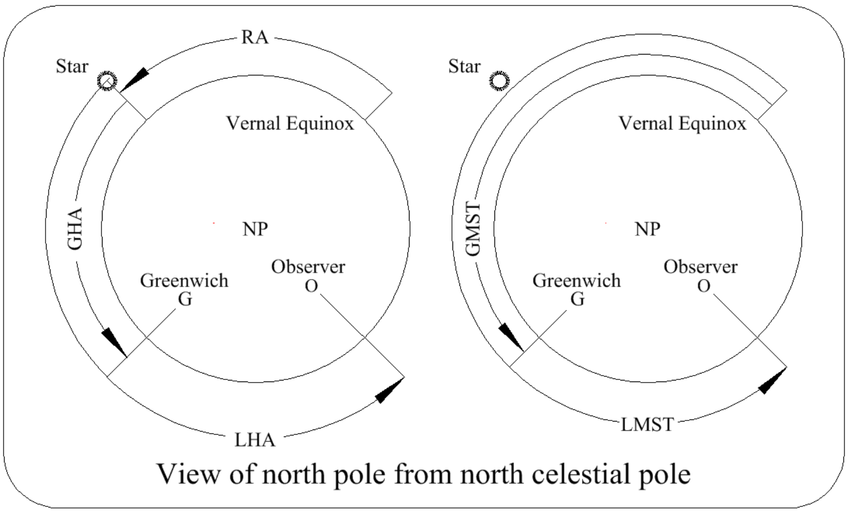


The Precession Of The Axis

The stars’ coordinates are, therefore, constantly changing, & astronomers must regularly update them  If the axis of the ecliptic was projected to the celestial sphere it would intersect it at the Ecliptic Pole, & coordinates referenced to that, ecliptic coordinates, would be much more stable. But the gravitational effects cause even that to move.

Apparent sidereal time must also be corrected if it is to define when a position on the Earth points to a star as it did one sidereal day before. The correction for nutation yields Mean Sidereal Time, MST,: 23h 56m 4•090 530 832 88s.

The MST is used on the RA axis of telescopes & is the RA of stars & the vernal equinox in astronomical tables.



View of north pole from north celestial pole

The Way Around The Celestial Equator

The drawing is self-exlanatory apart from LHA, Local Hour Angle, & GHA, Greenwich Hour Angle.

The former is the difference in MST between any two points of interest, the latter the difference between a point of interest & Greenwich.

# Appendix

## Time

MST is measured from the vernal equinox. This precesses & a correction yields the Stellar Day, 23h 56m 4•098 903 691s.

The International Earth Rotation and Reference Systems Service, IERS, is the best source of data.

## Time of Orbit

| | |
|---|---|
| M | primary’s mass |
| m | satellite’s mass |
| G | gravitational constant |
| a | semi-major axis |
| e | eccentricity |
| T | orbital period |
| r | separation |
| C | circumference |

Average orbital speed, $Va = (2\pi a/T)v(1 - 1e^2/4 - 3e^4/64 - 5e^6/256 - 175e^8/16384...)$
Instantaneous speed, $V = v[Gm(2/r - 1/a)]$
If e is low & m << M, $Va \approx 2\pi a/T$, or $Va \approx v(Gm/a)$
If e is low & m <<<< M, $Va \approx v(Gm/r)$
If e is low & m & M are comparable, $Va \approx v[G(M + m)/r]$
$C = (2\pi a)[1 - (1/2)^2e^2/1 - (1.3/2.4)^2e^2/3 - (1.3.5/2.4.6)^2e^2/5...]$
So average $r = a[1 - (1/2)^2e^2/1 - (1.3/2.4)^2e^2/3 - 1.3.5/2.4.6)^2e^2/5...]$
With such low values of e in the solar system, $r \approx a$.

## TheEarth

Earth bulges at the equator. South of the equator the bulge is ~ 15m higher than it is north of the equator. The south pole is ~ 30m closer to the centre of the earth than the north pole. The circumference of Earth at the equator is about 40,075 km, but from pole-to-pole - the meridional circumference - Earth is only 40,008 km around.

## Constellations

| | | |
|---|---|---|
| Capricornus | 19 JAN | 15 FEB |
| Aquarius | 16 FEB | 11 MAR |
| Pisces | 12 MAR | 18 APR |
| Aries | 19 APR | 13 MAY |
| Taurus | 14 MAY | 19 JUN |
| Gemini | 20 JUN | 20 JUL |
| Cancer | 21 JUL | 9 AUG |
| Leo | 10 AUG | 15 SEP |
| Virgo | 16 SEP | 30 OCT |
| Libra | 31 OCT | 22 NOV |
| Scorpius | 23 NOV | 29 NOV |
| Ophiochus | 30 NOV | 17 DEC |
| Sagittarius | 18 DEC | 18 JAN |