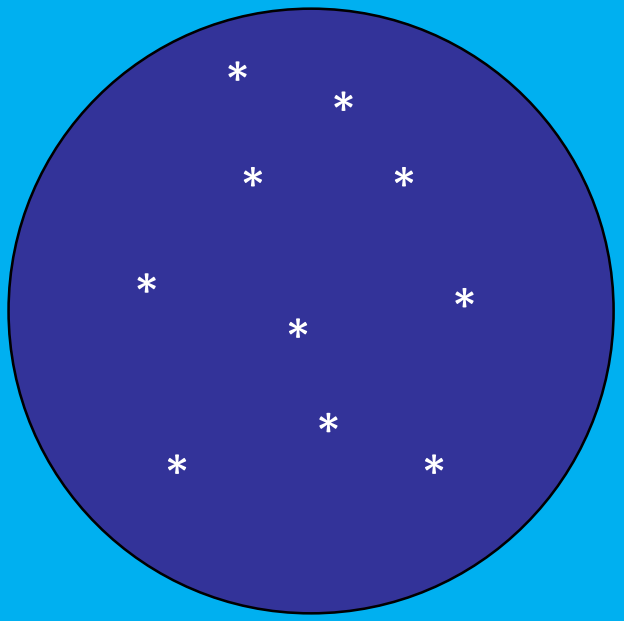
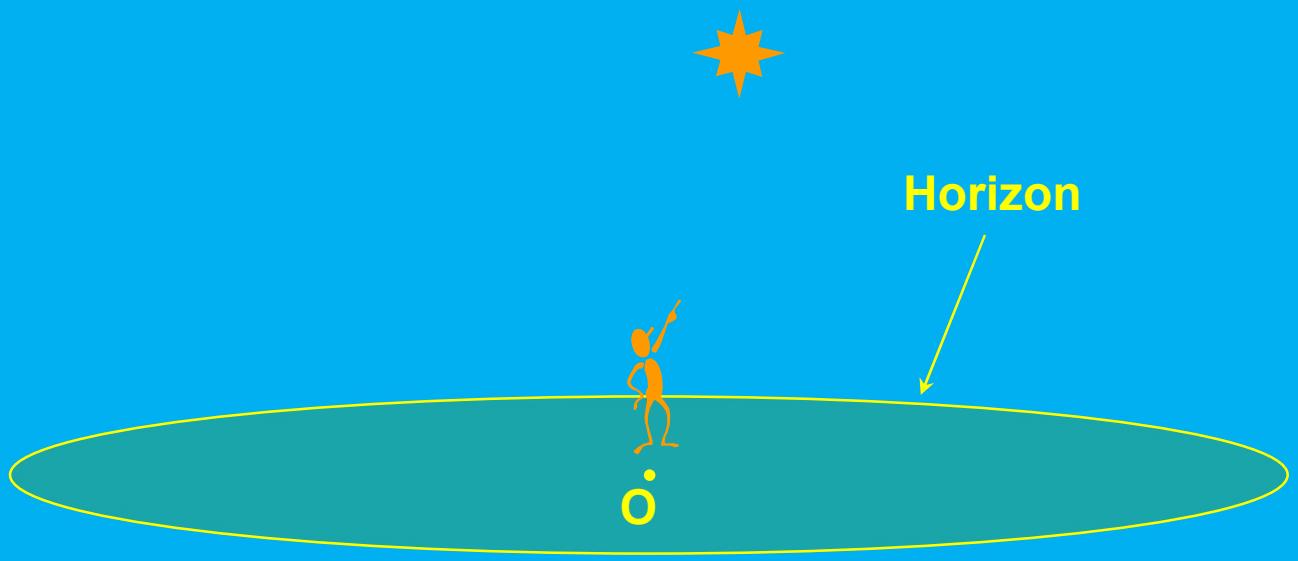
# The Celestial Sphere

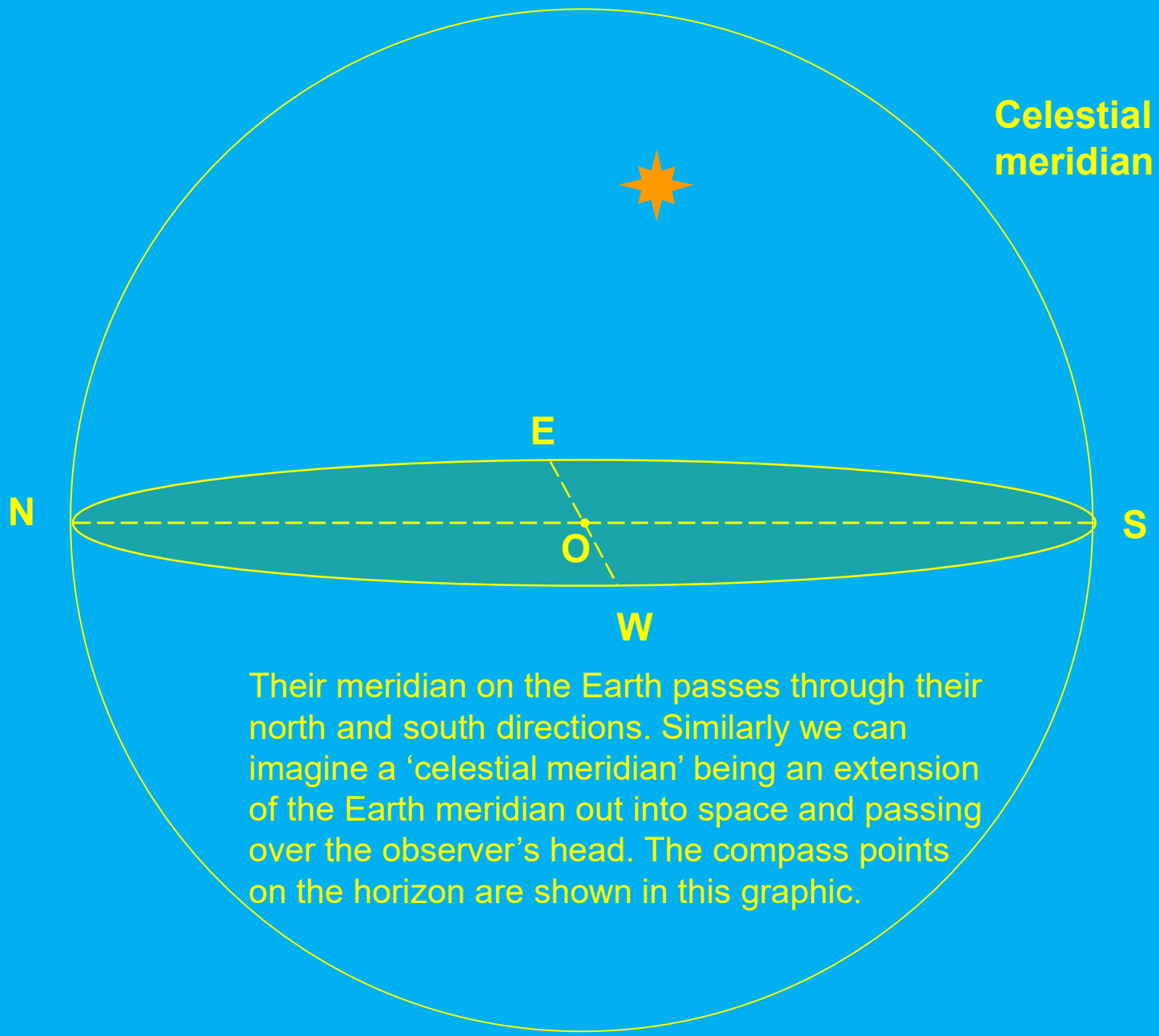


This presentation is about the celestial sphere, an imaginary sphere of infinite radius around us which contains the stars and all other celestial objects. It is useful as a concept to facilitate understanding their positions and apparent motions, and forms the basis for mathematical calculations relating to spherical astronomy.

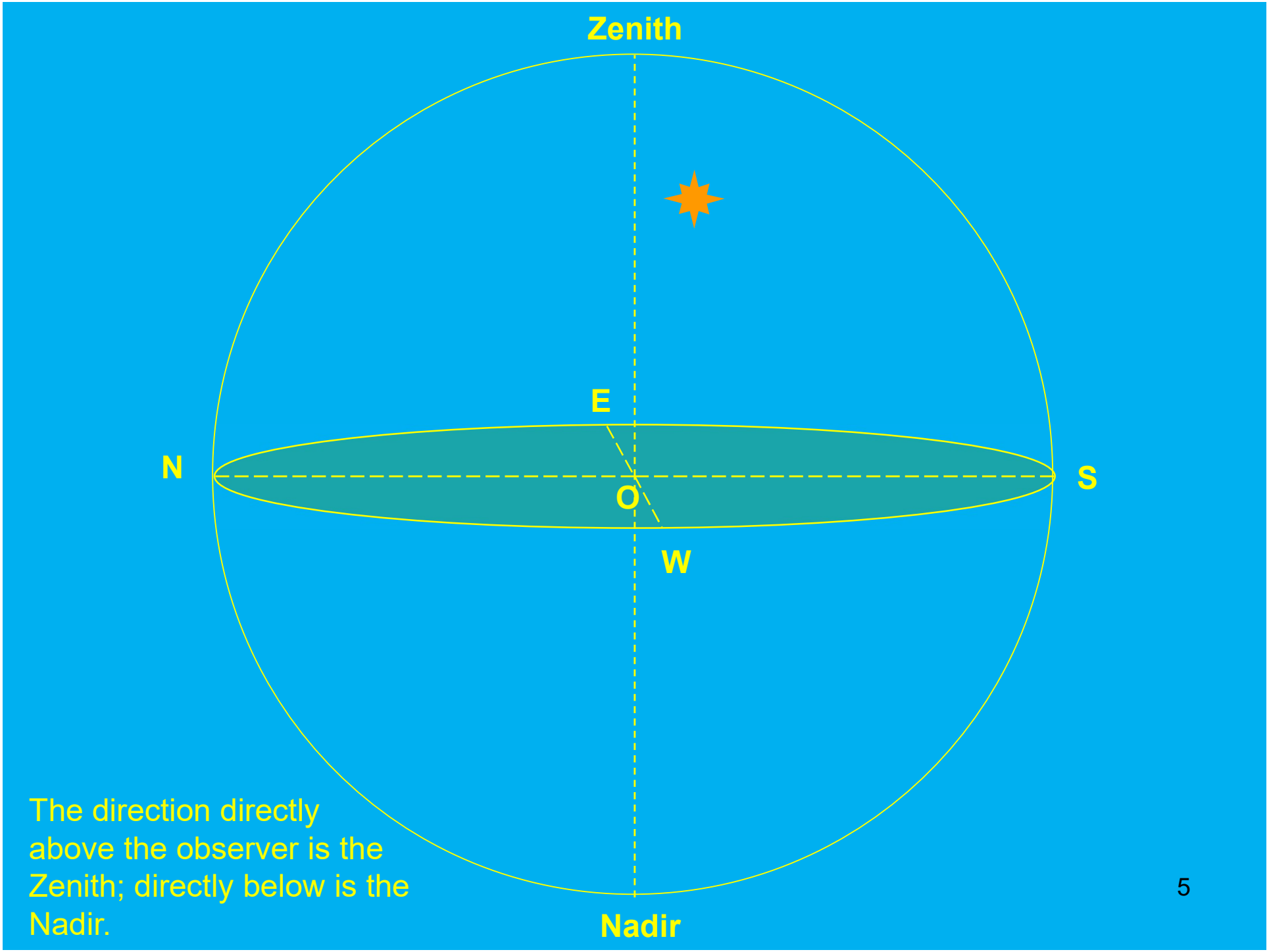
Let’s first have a short introductory course in celestial mechanics.



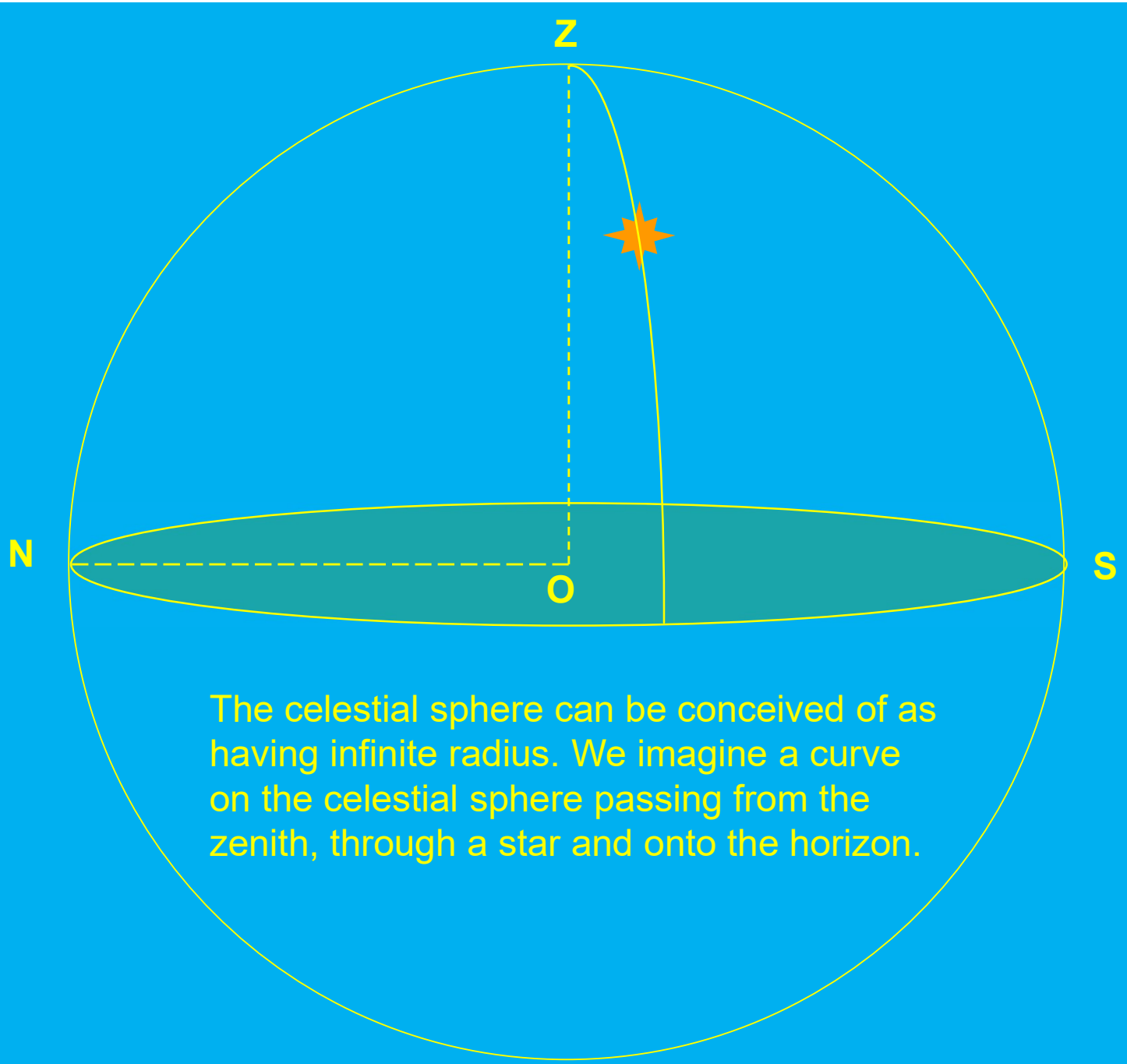

We imagine an observer standing on the Earth at the position O.
They perceive that they are standing on a flat surface with a 360 degree horizon.



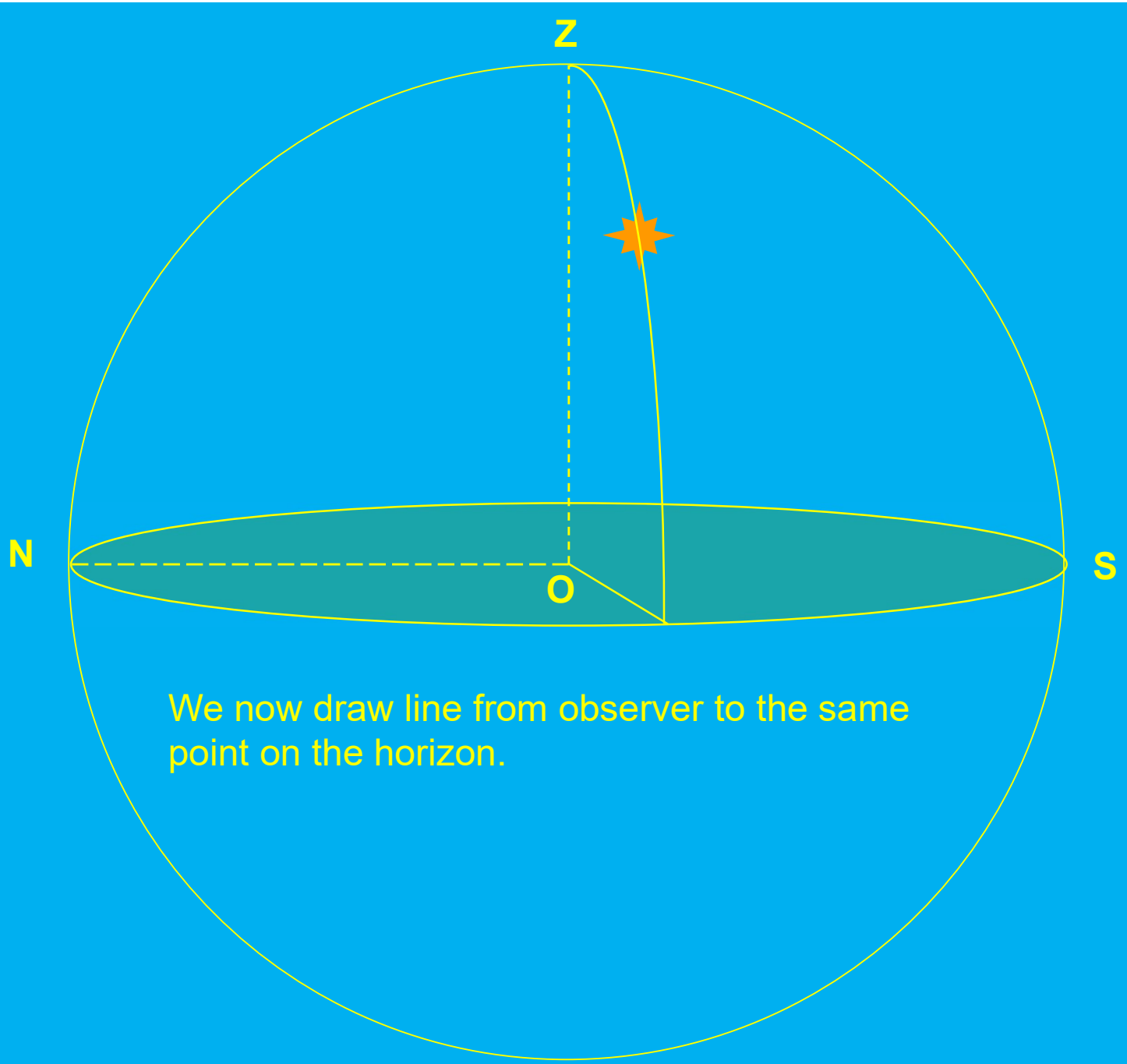

Their meridian on the Earth passes through their north and south directions. Similarly we can imagine a ‘celestial meridian’ being an extension of the Earth meridian out into space and passing over the observer’s head. The compass points on the horizon are shown in this graphic.



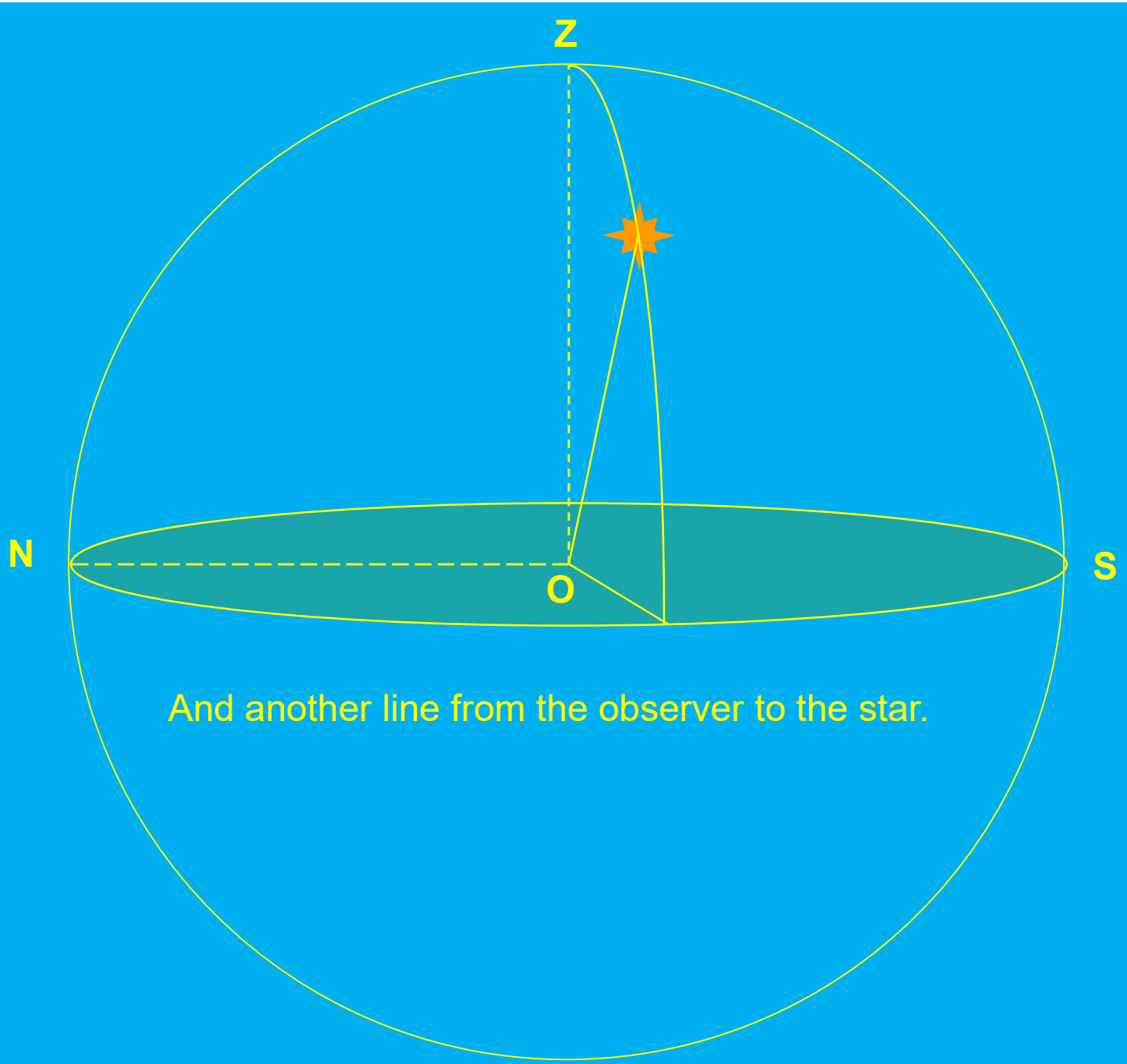

The direction directly above the observer is the Zenith; directly below is the Nadir.



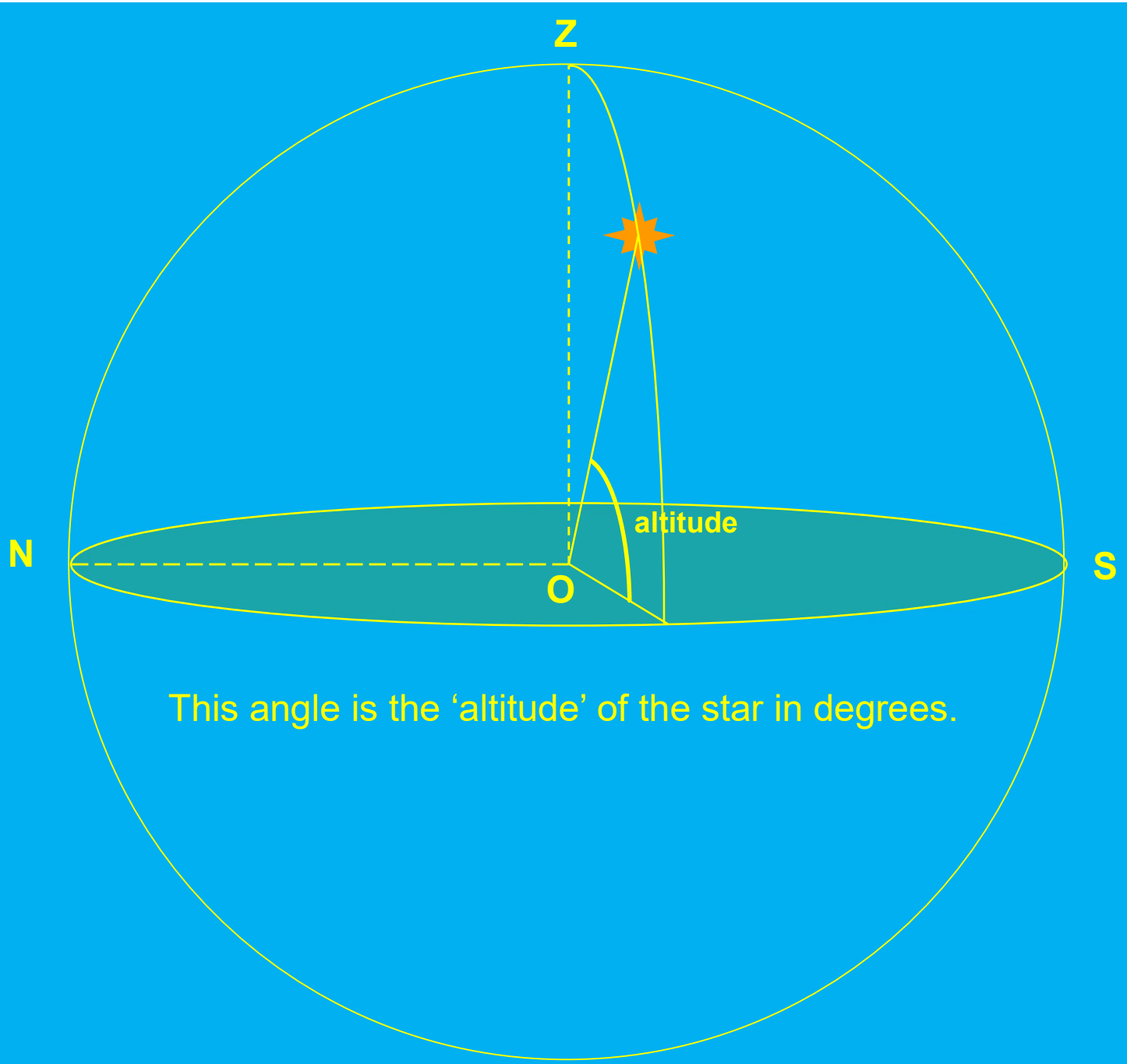

The celestial sphere can be conceived of as having infinite radius. We imagine a curve on the celestial sphere passing from the zenith, through a star and onto the horizon.



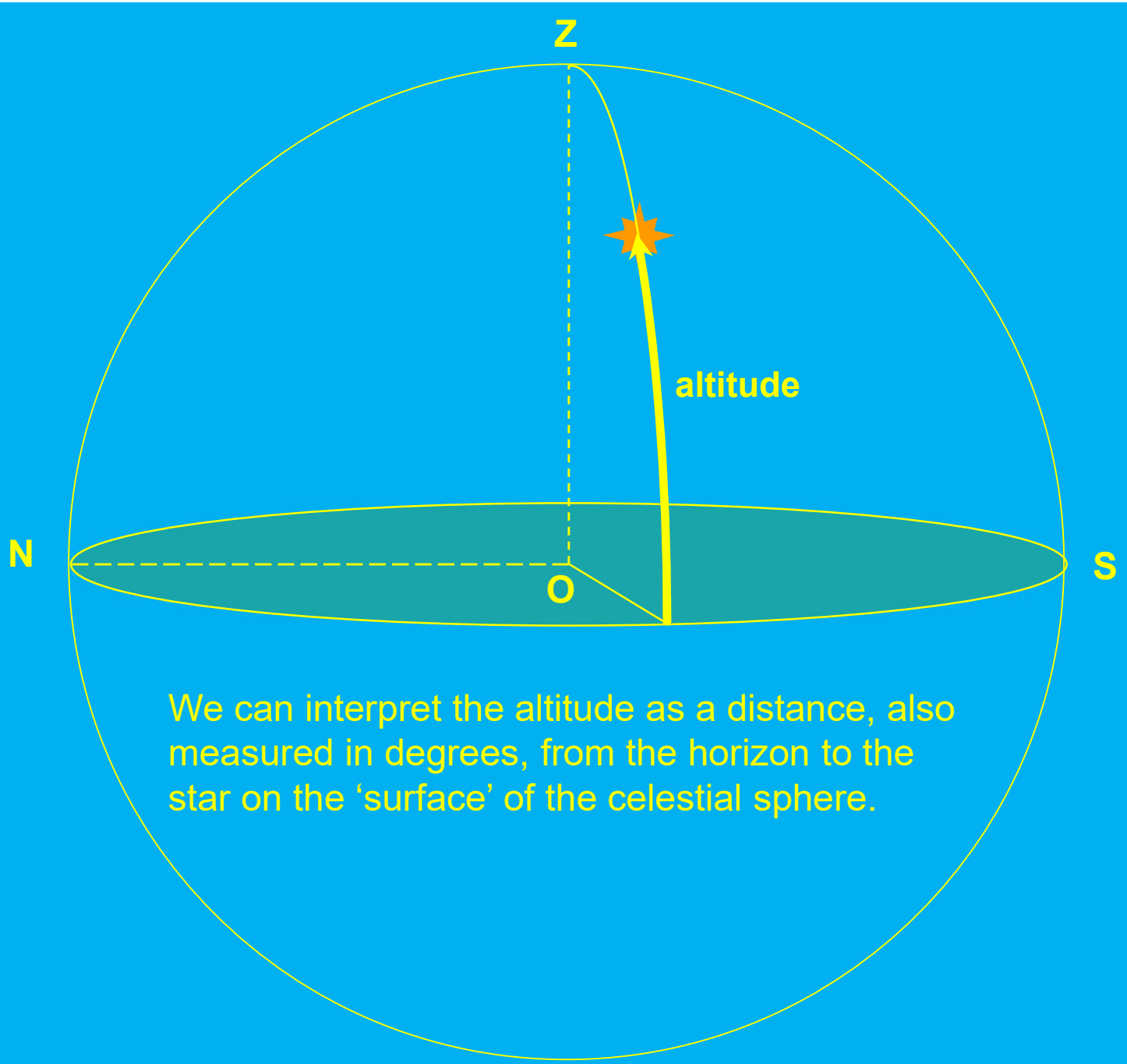

We now draw line from observer to the same point on the horizon.



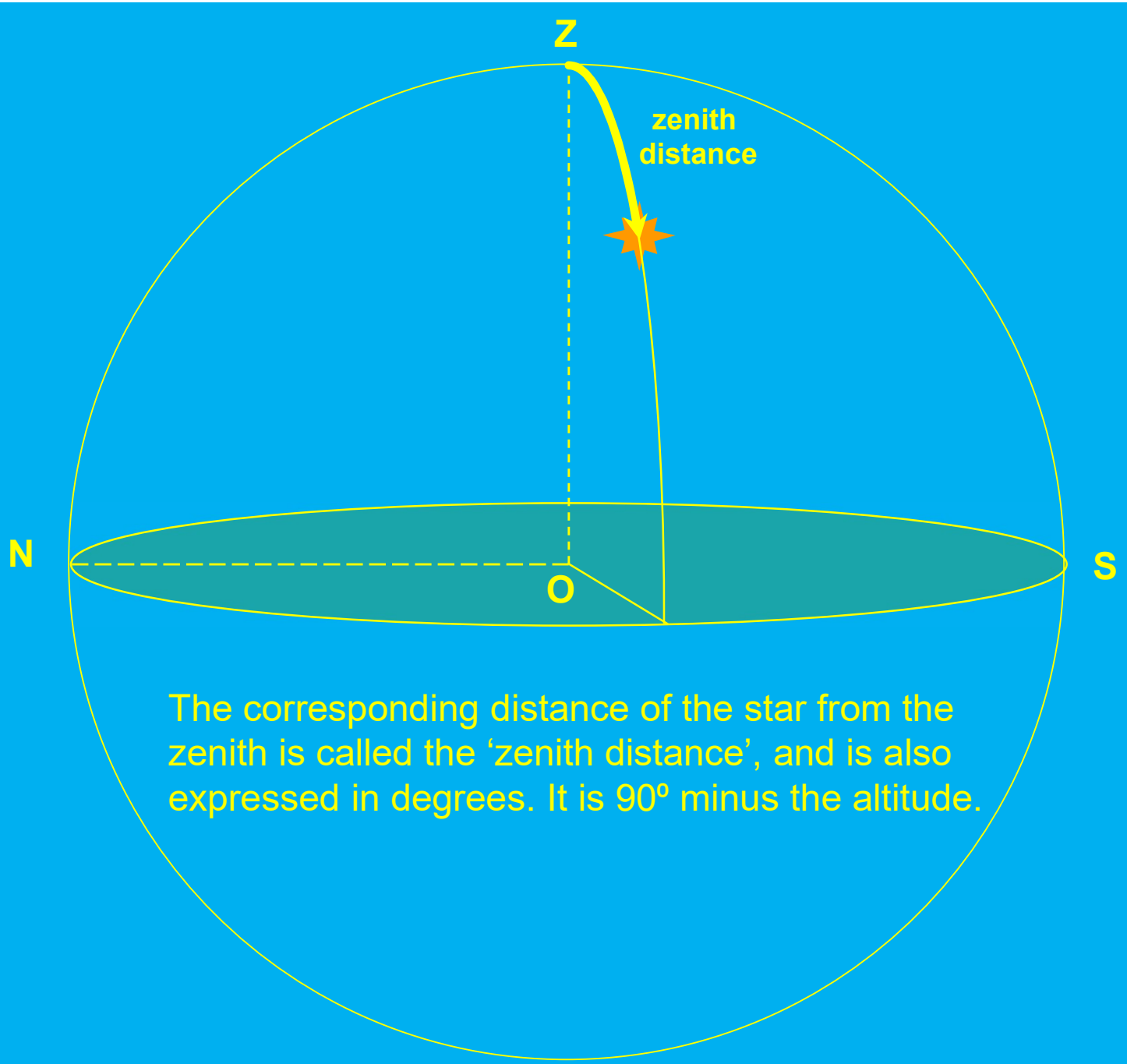

And another line from the observer to the star.



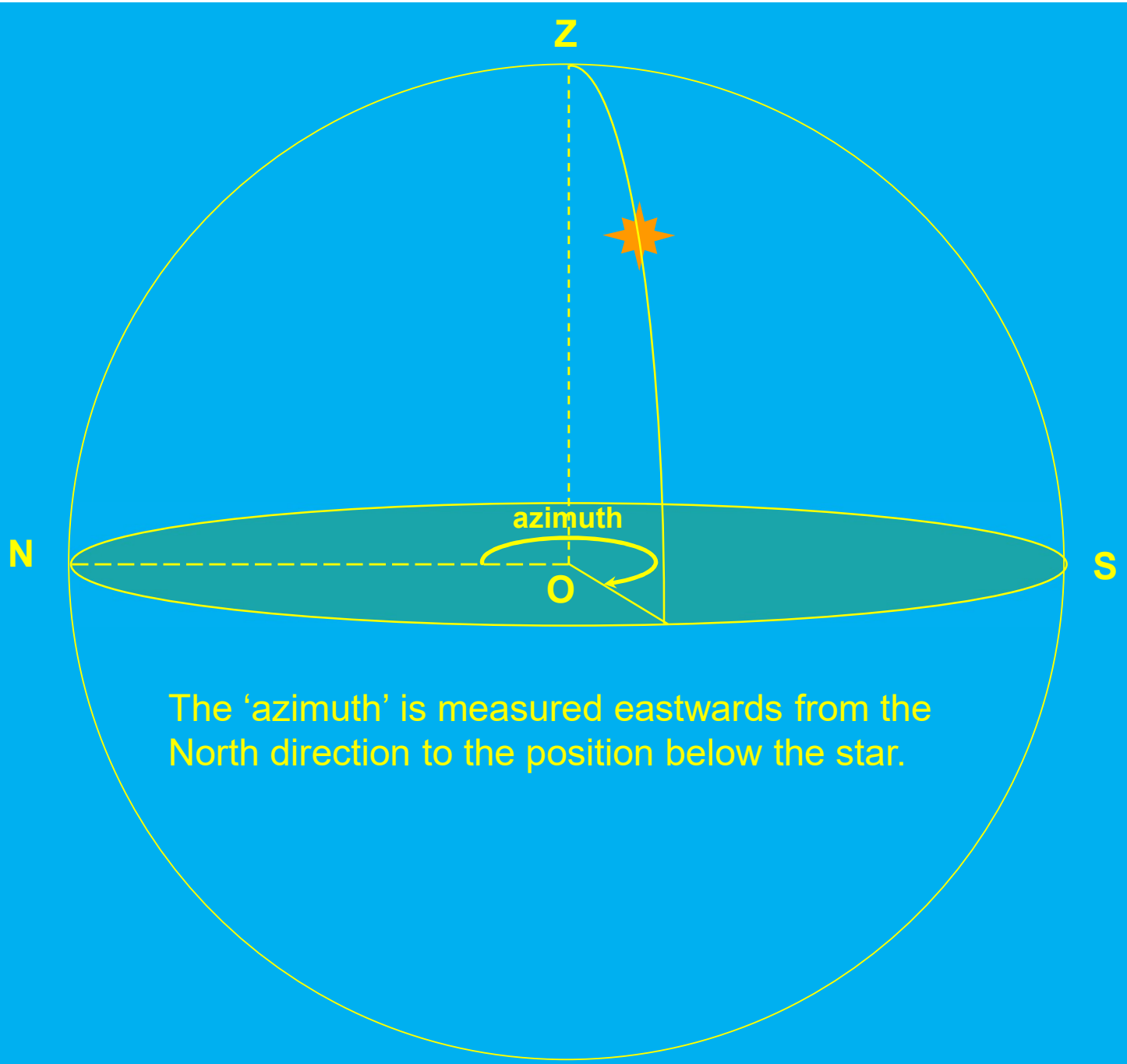

This angle is the ‘altitude’ of the star in degrees.




We can interpret the altitude as a distance, also measured in degrees, from the horizon to the star on the ‘surface’ of the celestial sphere.

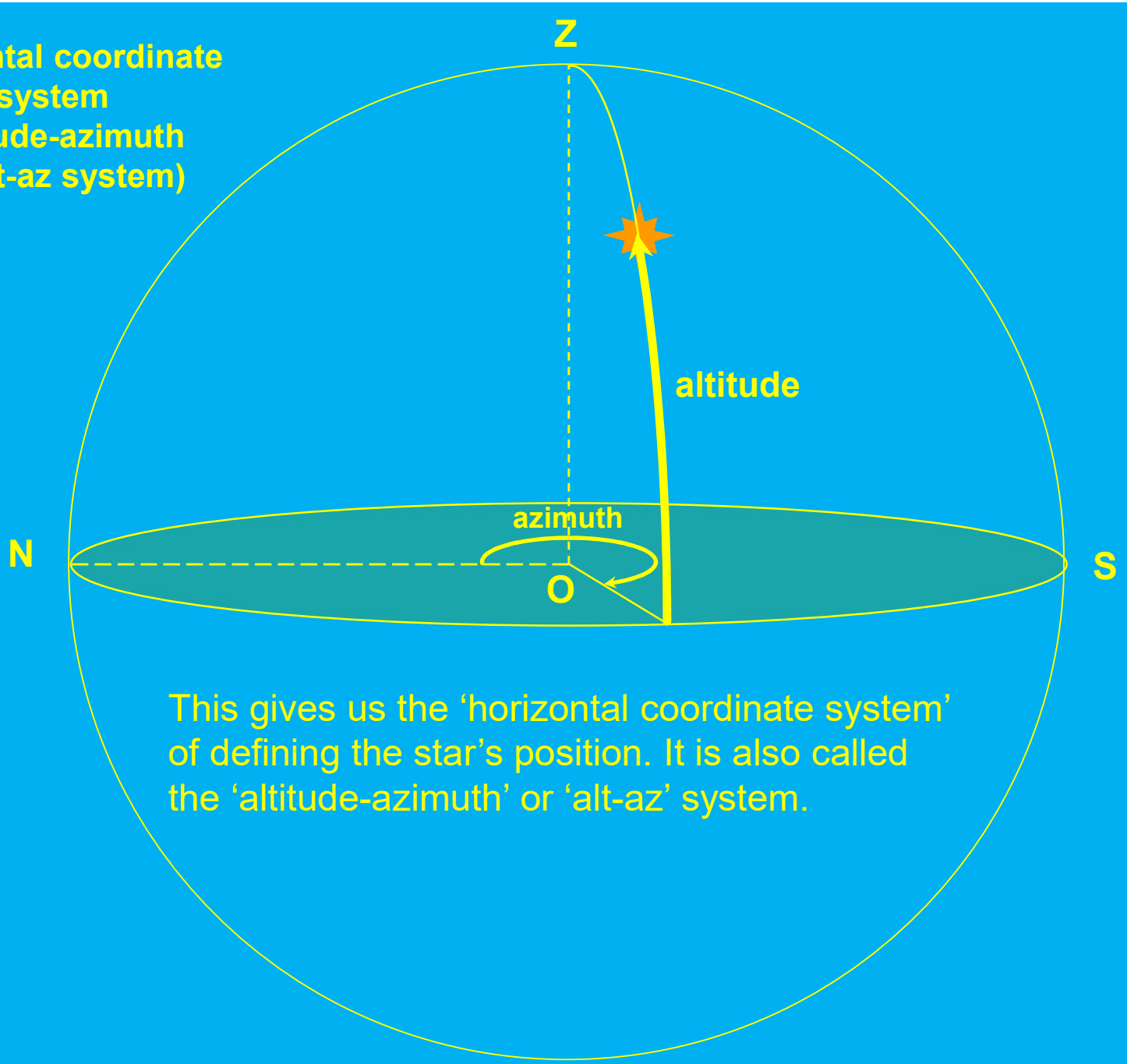



The corresponding distance of the star from the zenith is called the ‘zenith distance’, and is also expressed in degrees. It is 90º minus the altitude.

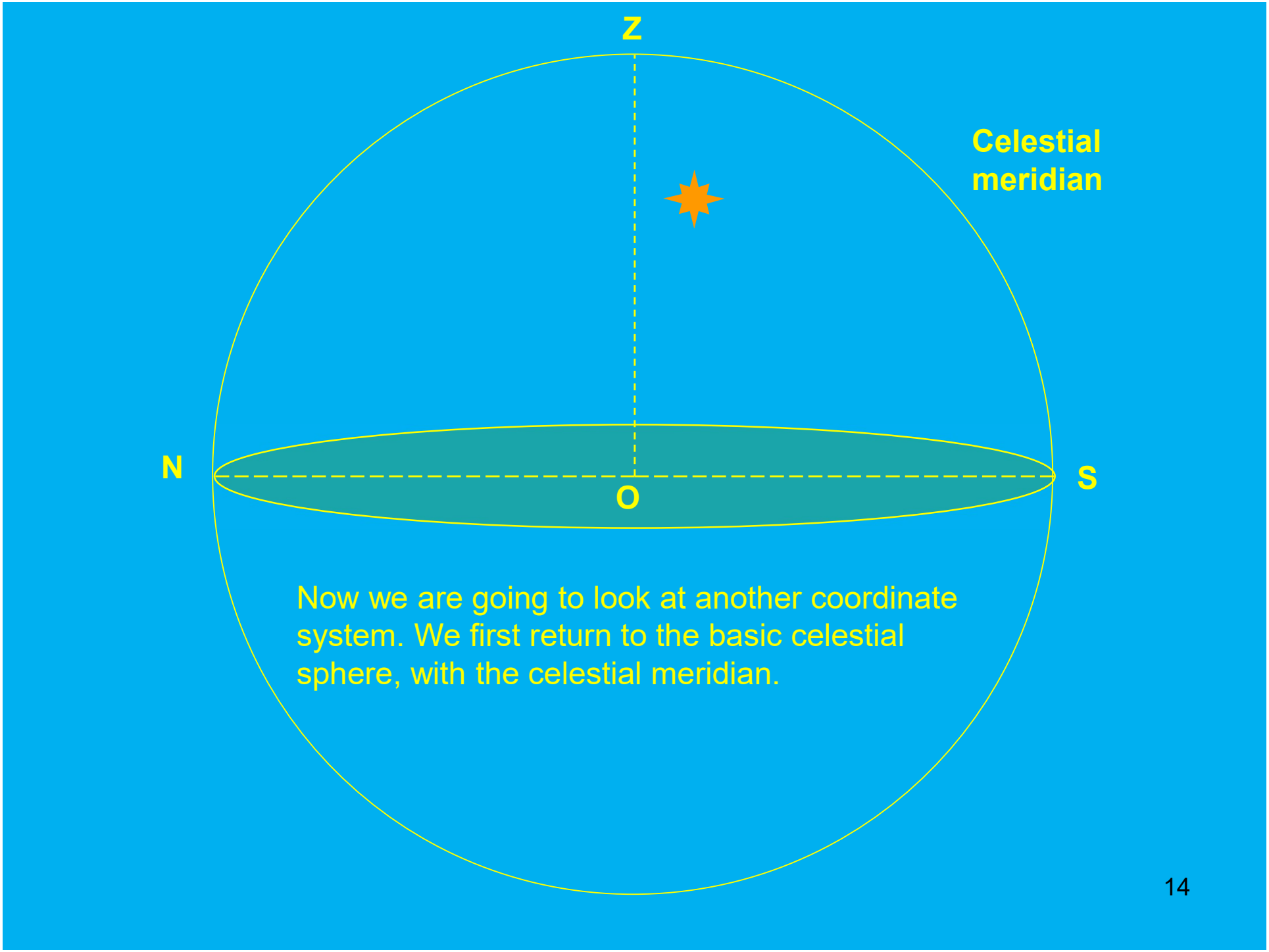


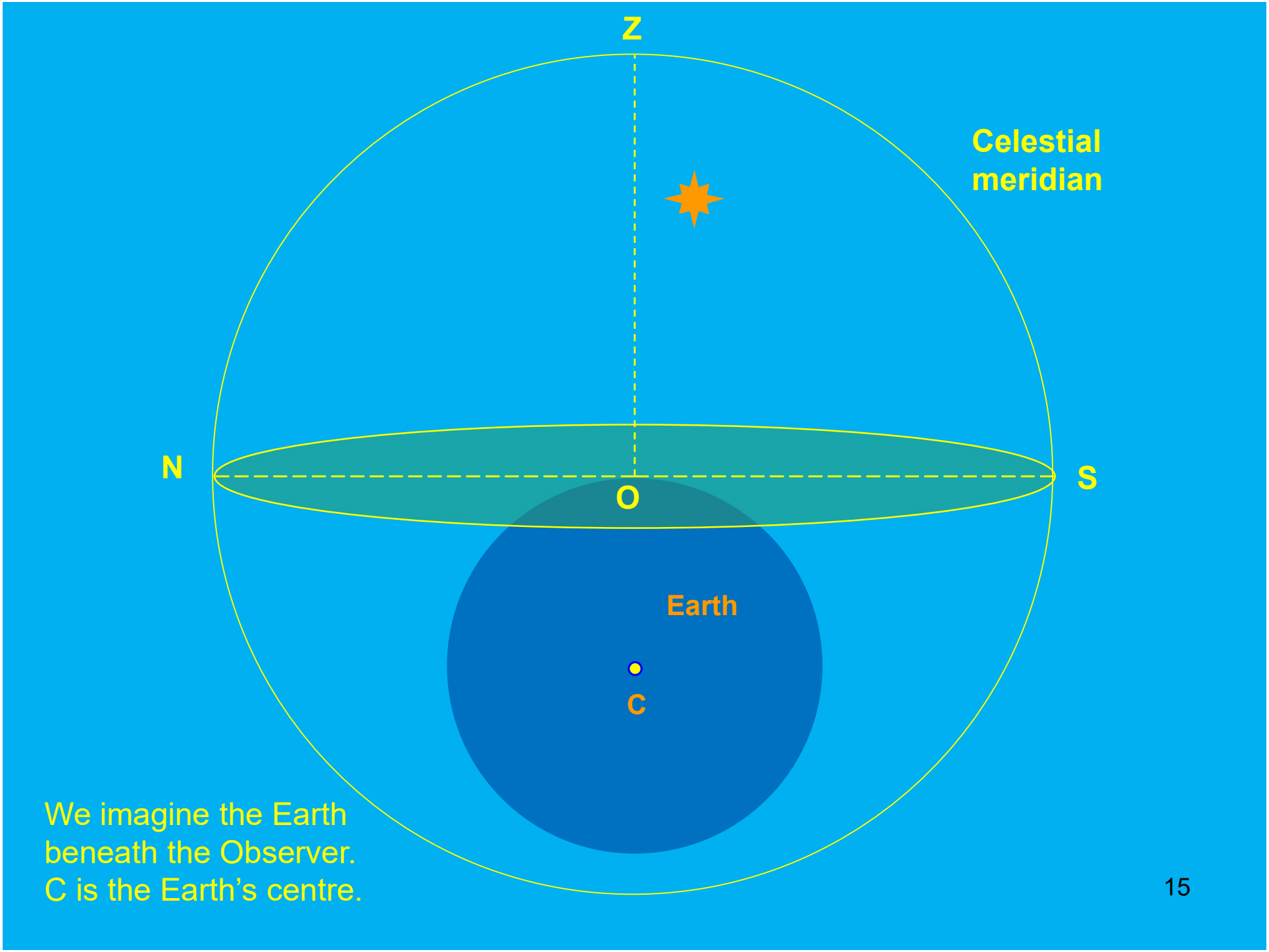

The ‘azimuth’ is measured eastwards from the North direction to the position below the star.

**Horizontal coordinate system (altitude-azimuth Or alt-az system)**

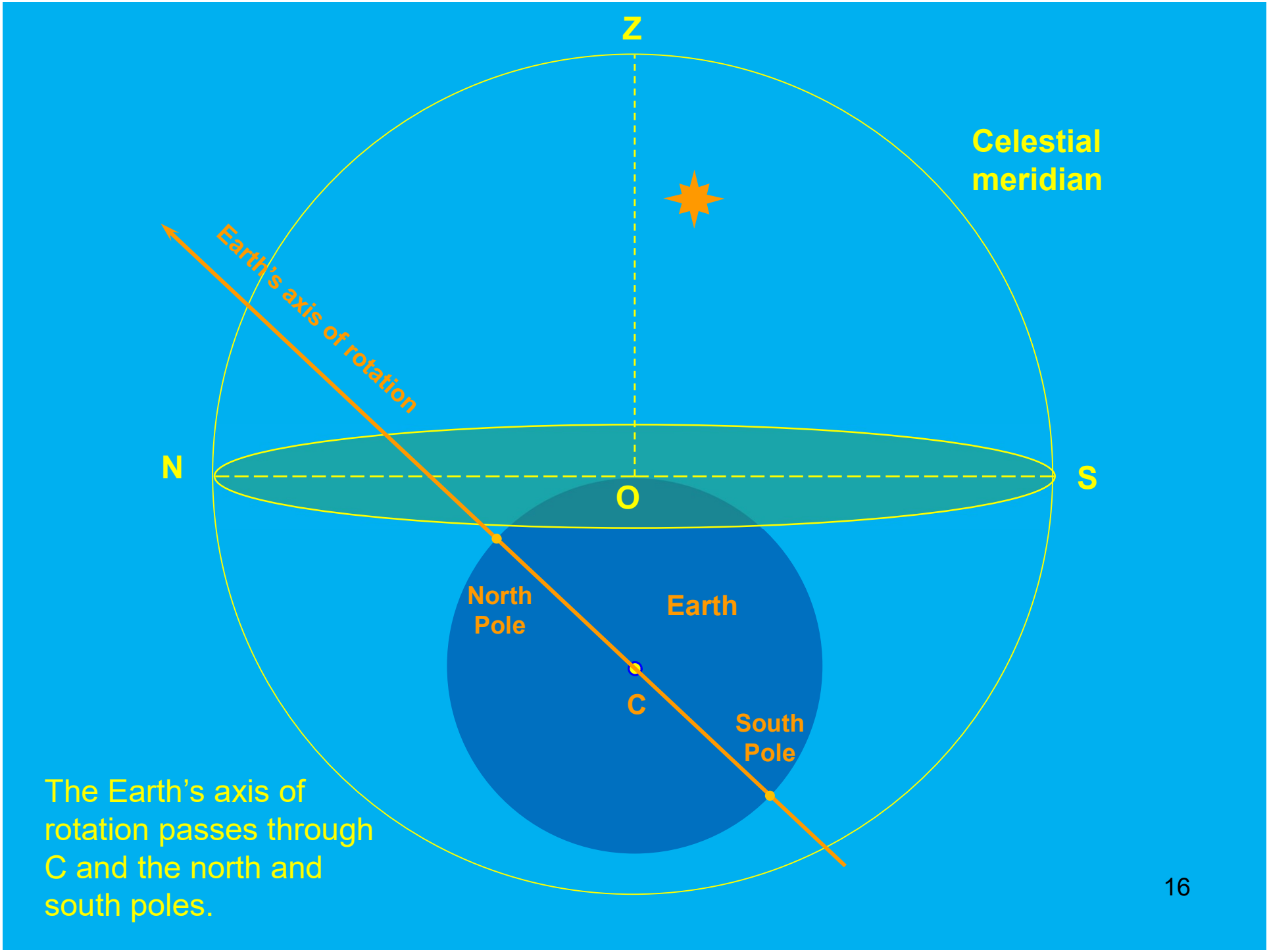



This gives us the ‘horizontal coordinate system’ of defining the star’s position. It is also called the ‘altitude-azimuth’ or ‘alt-az’ system.

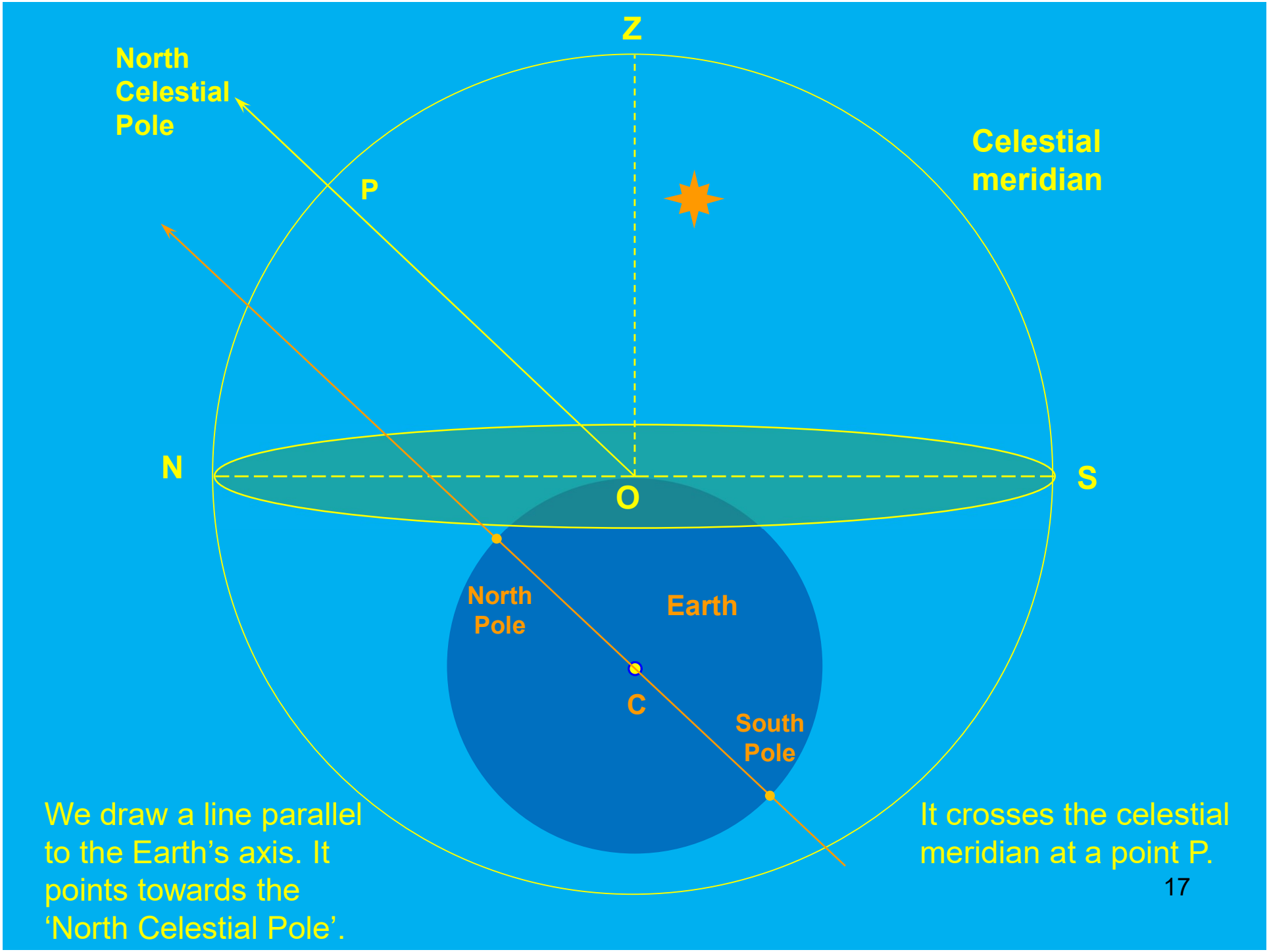

Z
Celestial
meridian
N
S
O
Now we are going to look at another coordinate system. We first return to the basic celestial sphere, with the celestial meridian.




We imagine the Earth
beneath the Observer.
C is the Earth's centre.

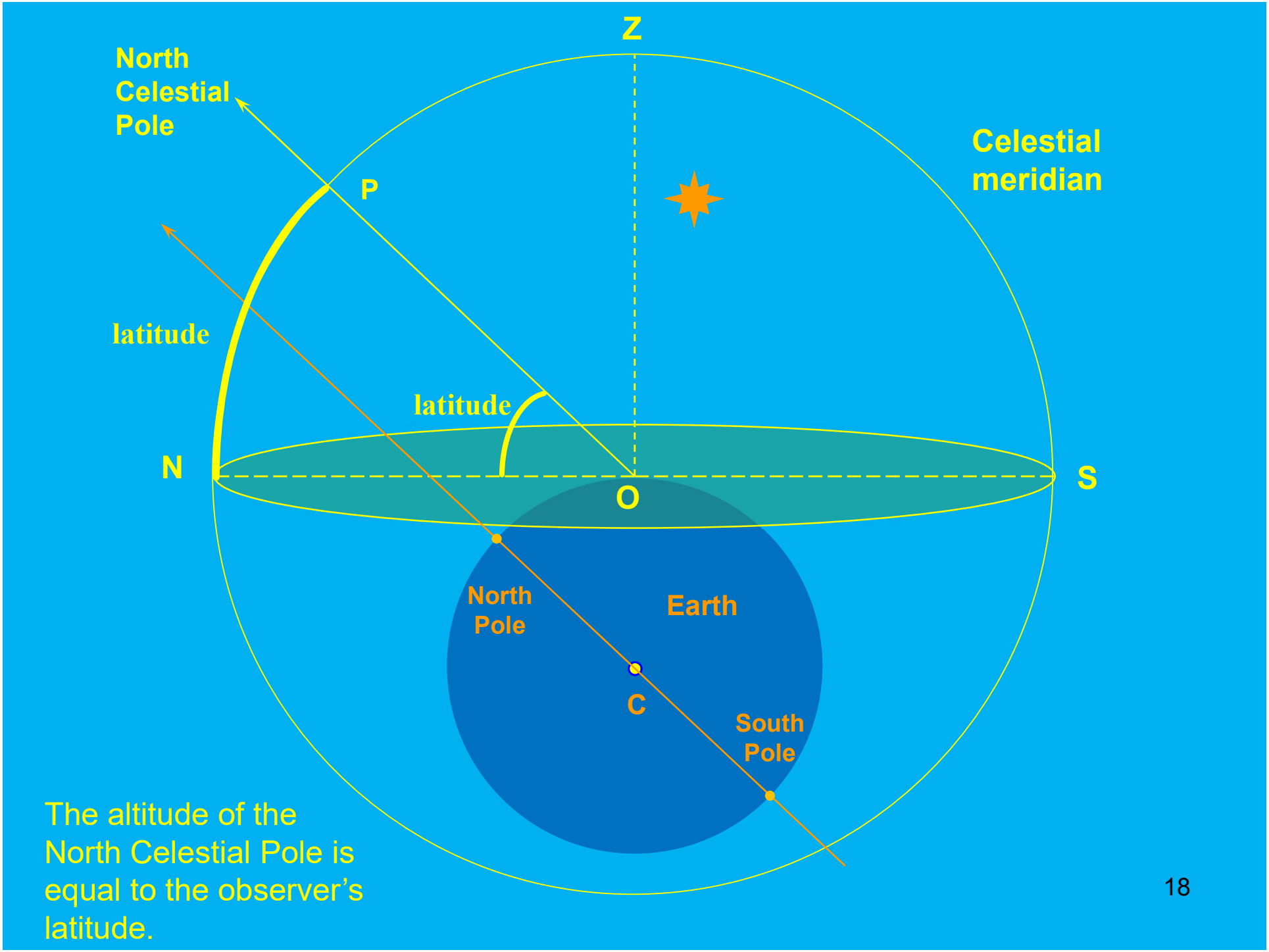



The Earth's axis of rotation passes through C and the north and south poles.

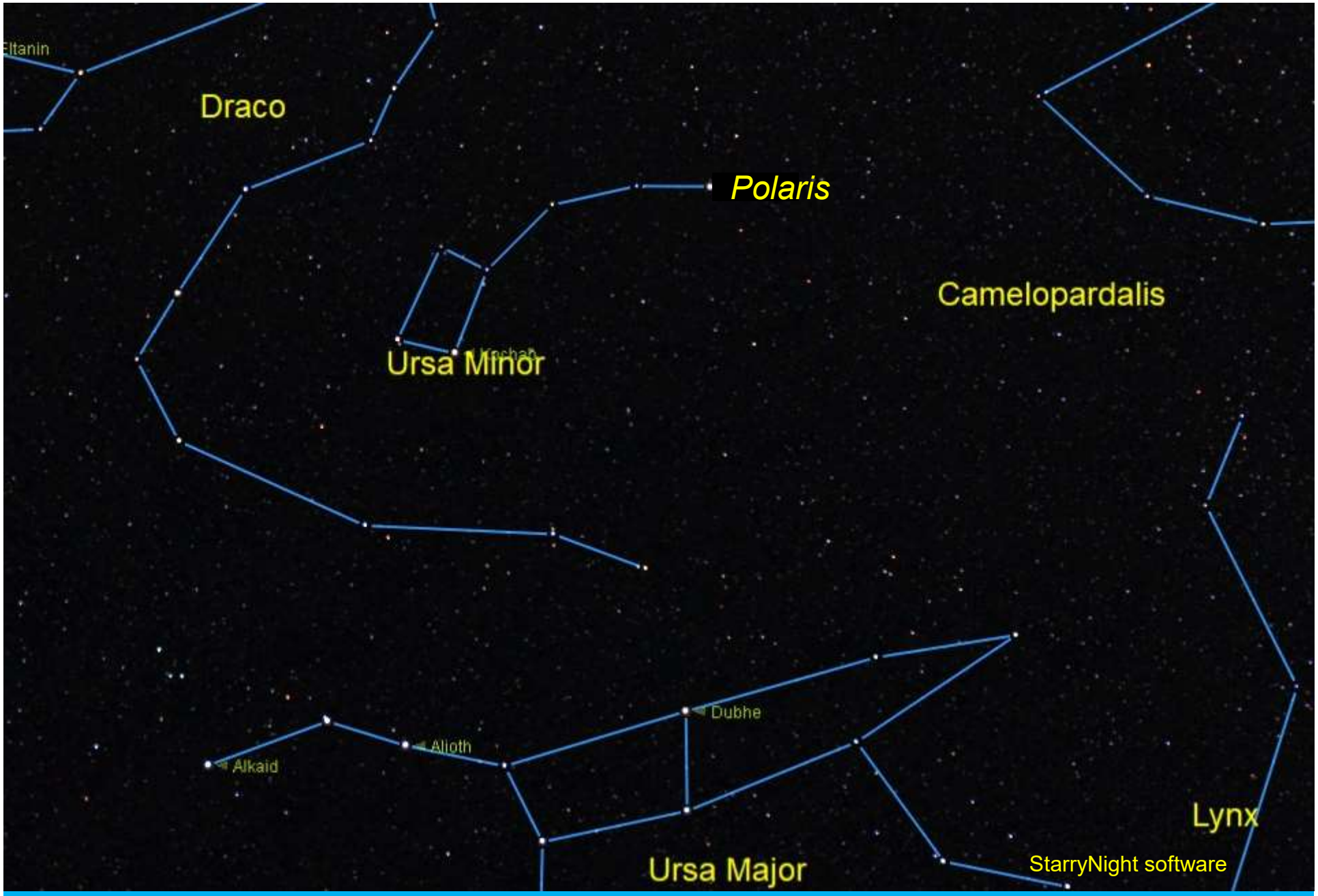



We draw a line parallel to the Earth's axis. It points towards the 'North Celestial Pole'.

It crosses the celestial meridian at a point P.

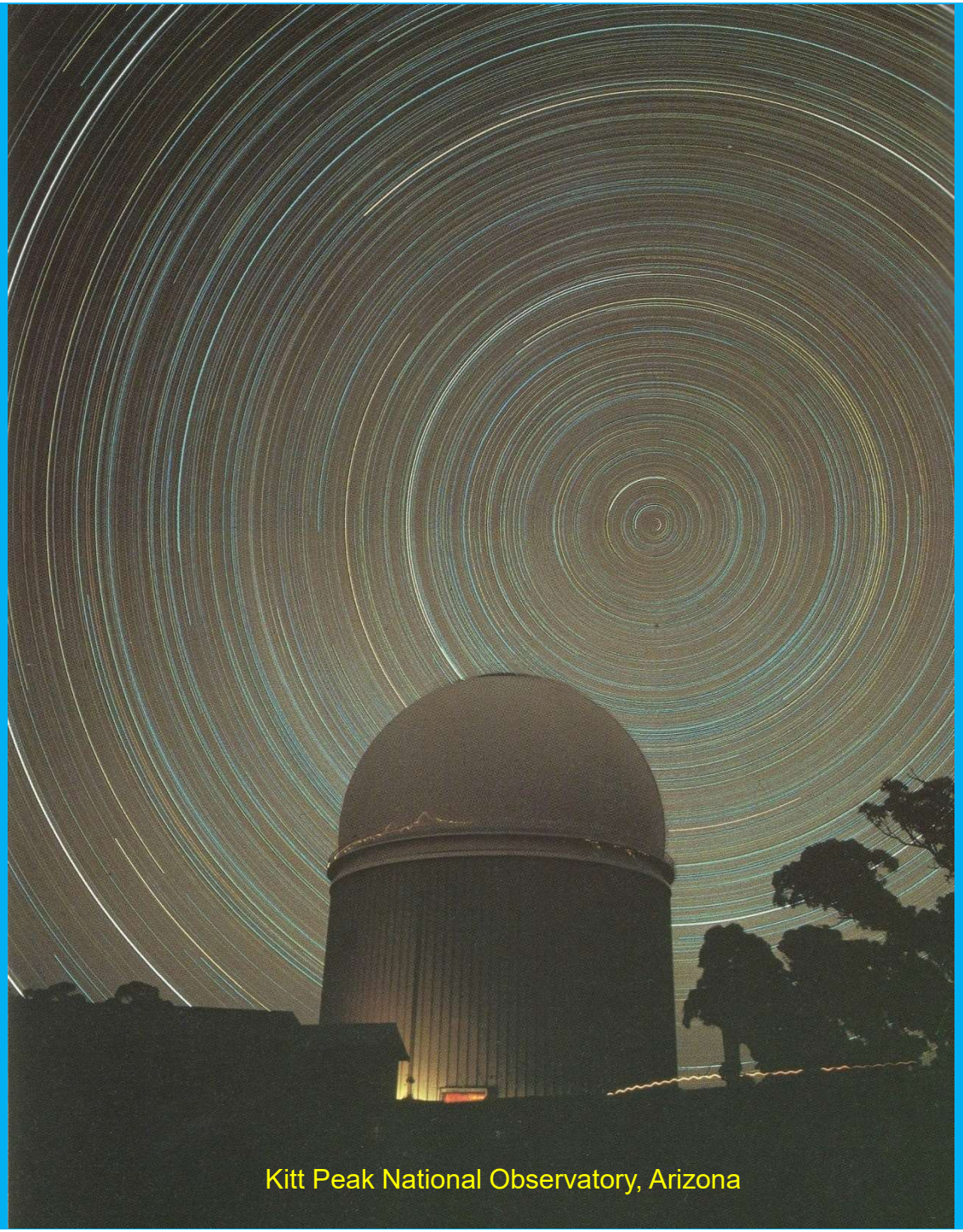



The altitude of the North Celestial Pole is equal to the observer's latitude.

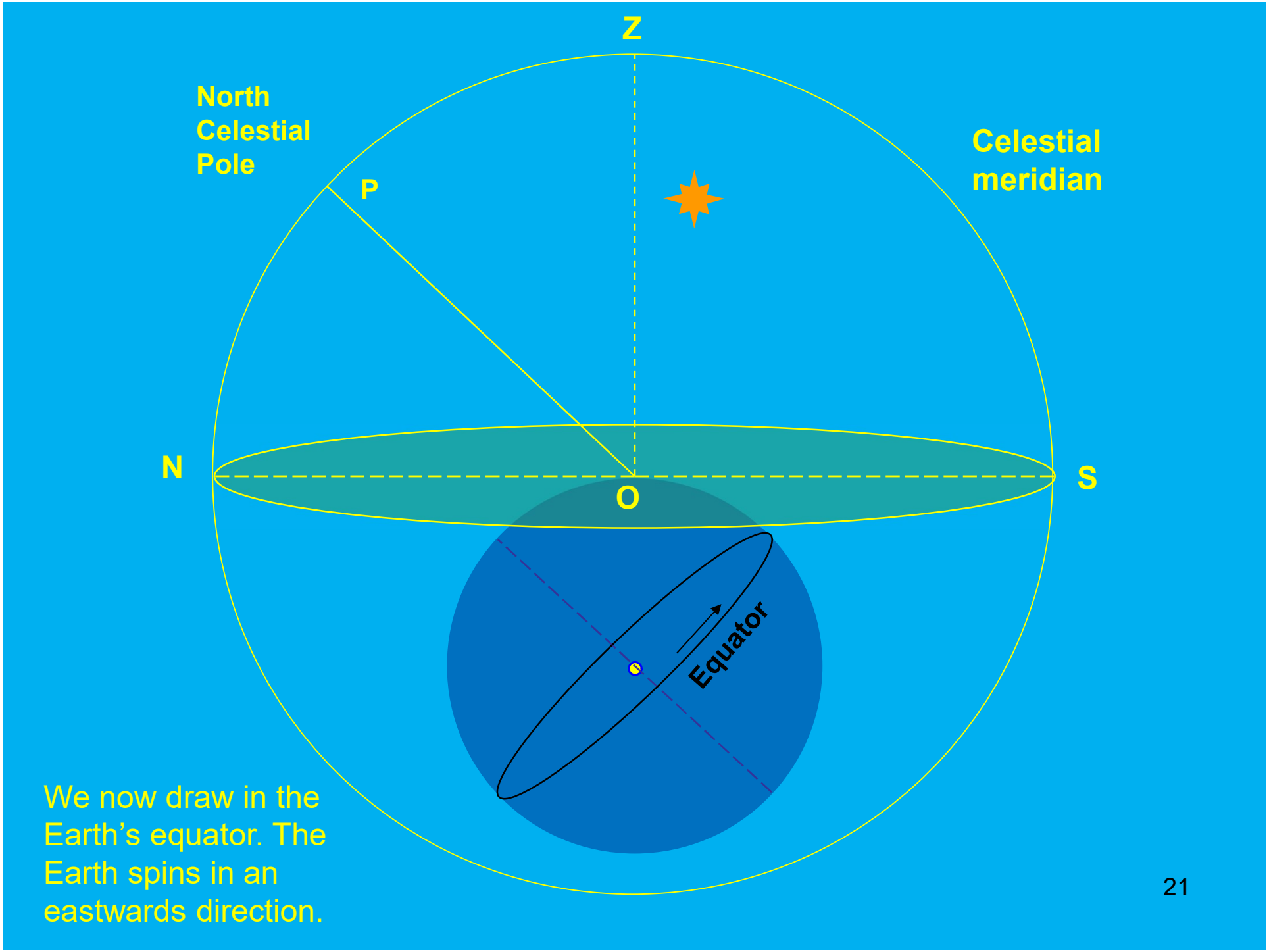



The North Celestial Pole happens to be marked very closely by the North Star, Polaris.

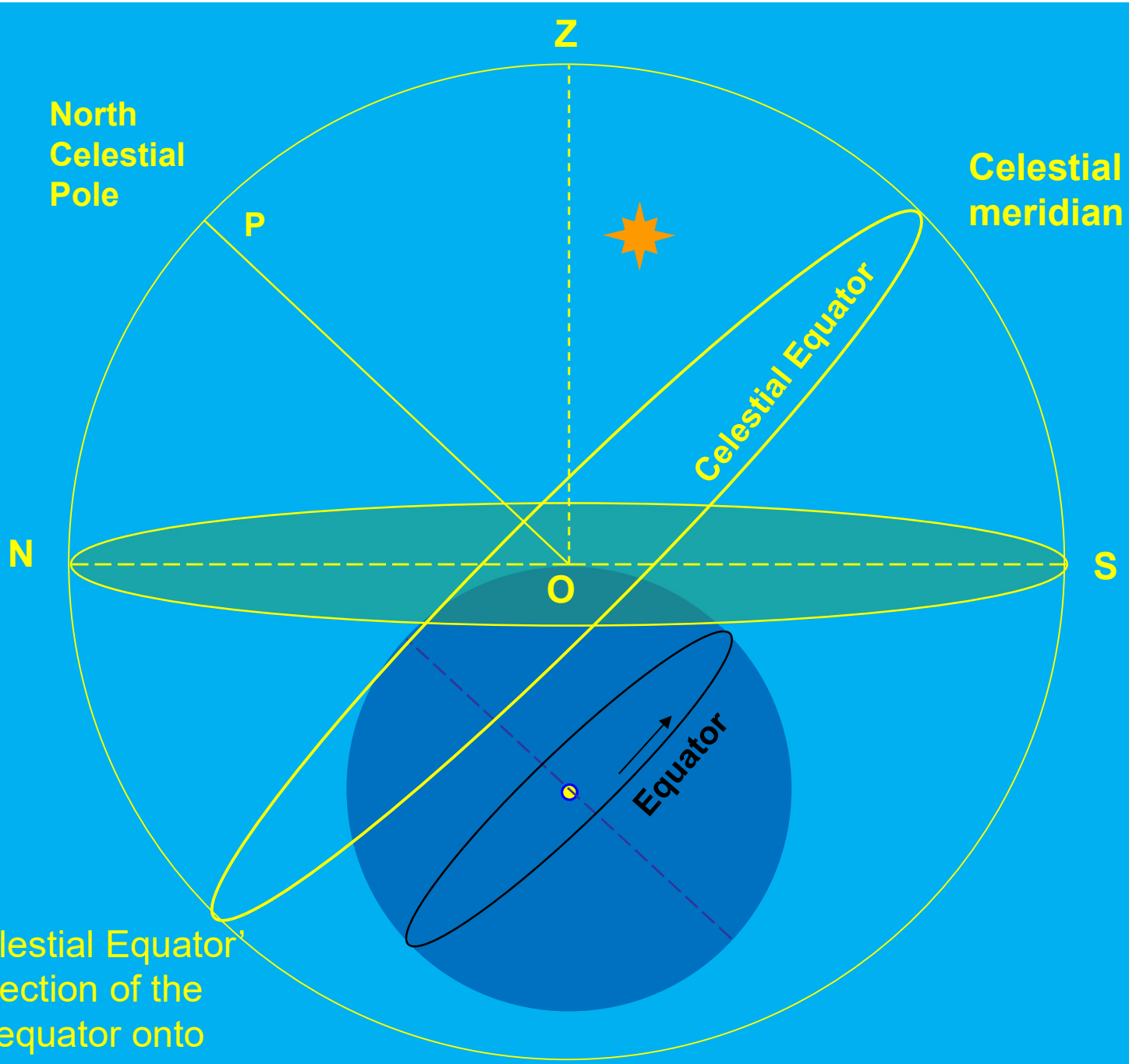
The rotation of the Earth makes the stars appear to circle the North Celestial Pole, as shown in this time exposure taken over several hours.



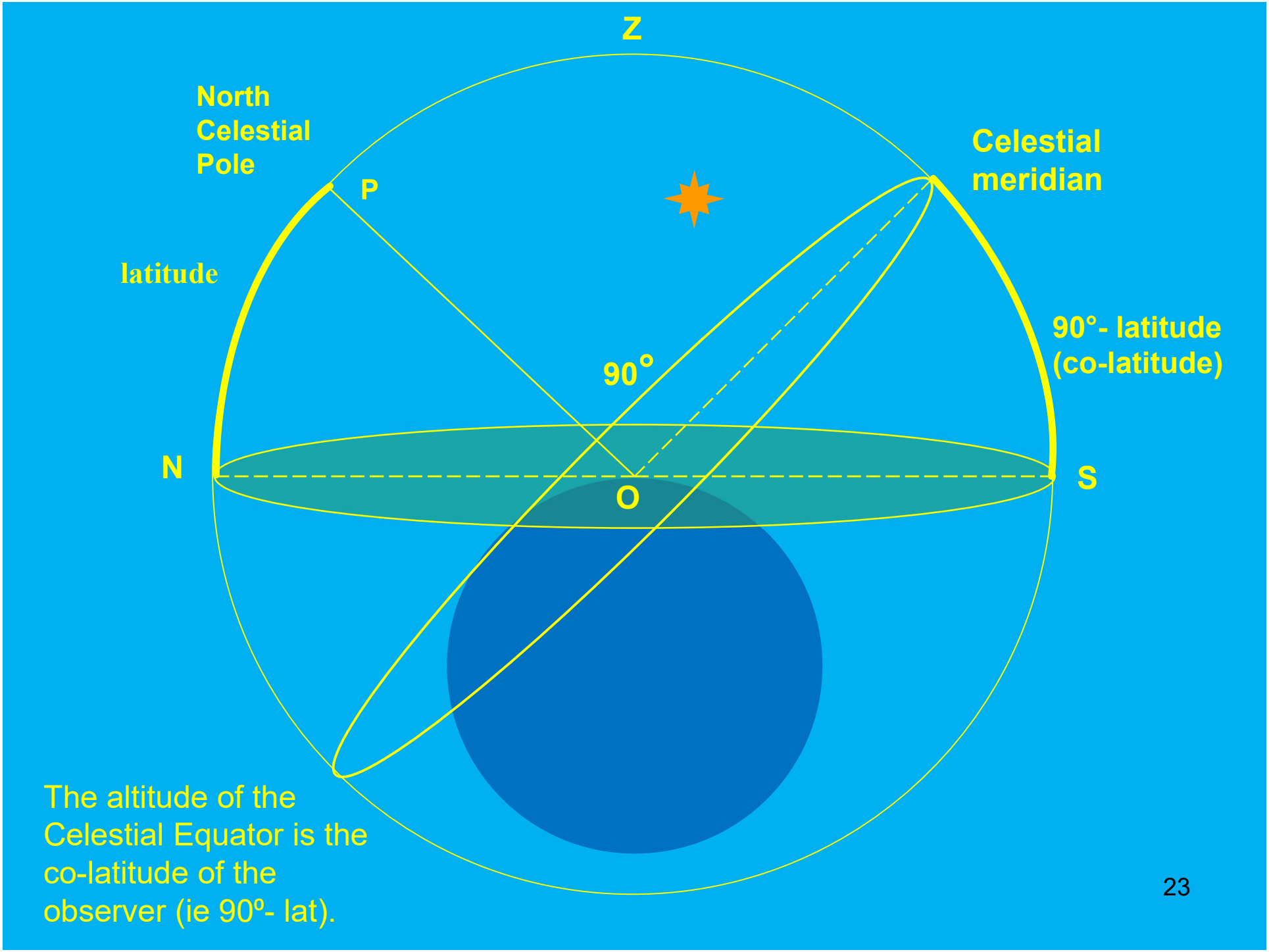
Kitt Peak National Observatory, Arizona



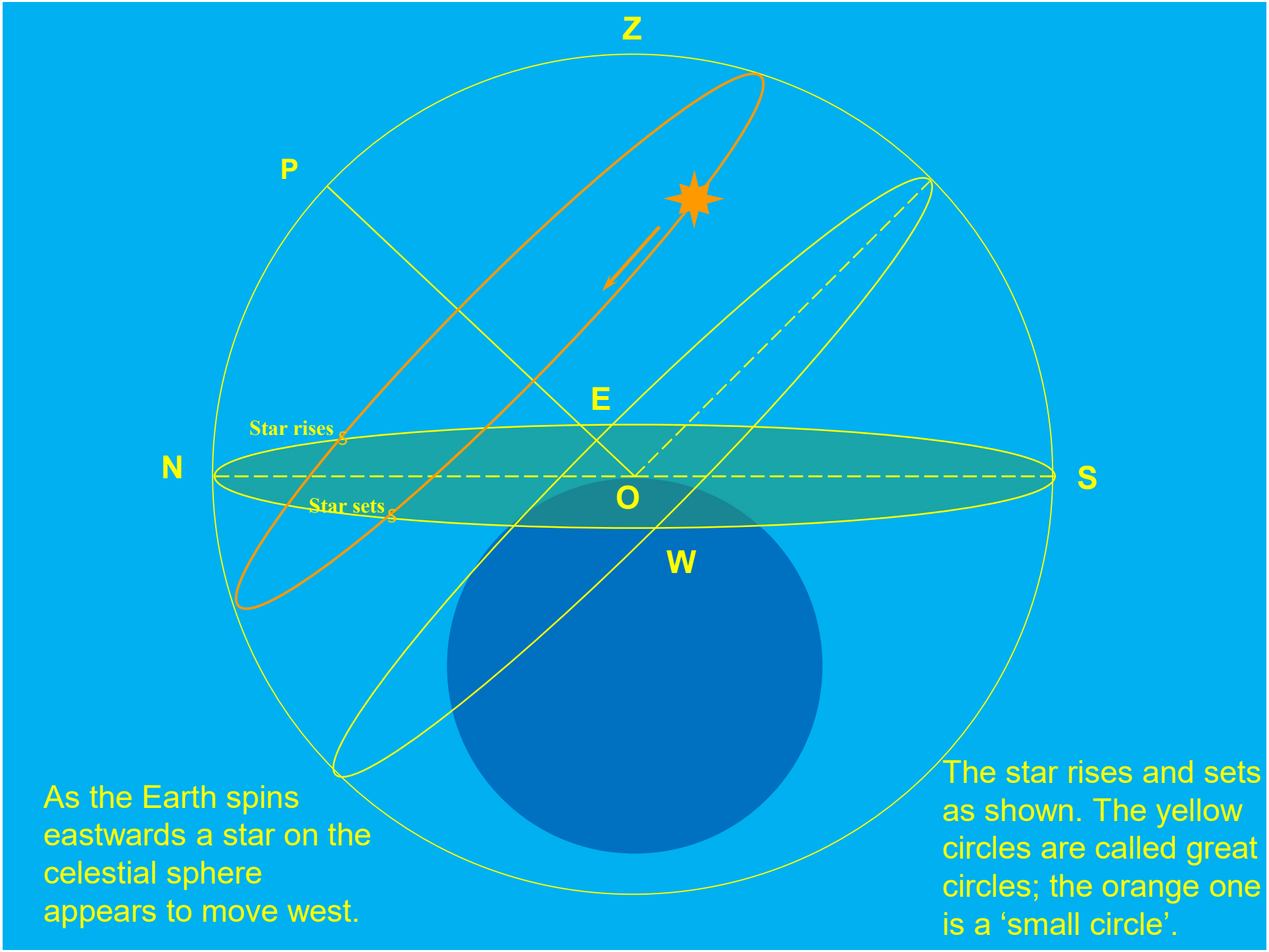

We now draw in the Earth's equator. The Earth spins in an eastwards direction.




The ‘Celestial Equator’ is a projection of the Earth’s equator onto the celestial sphere.

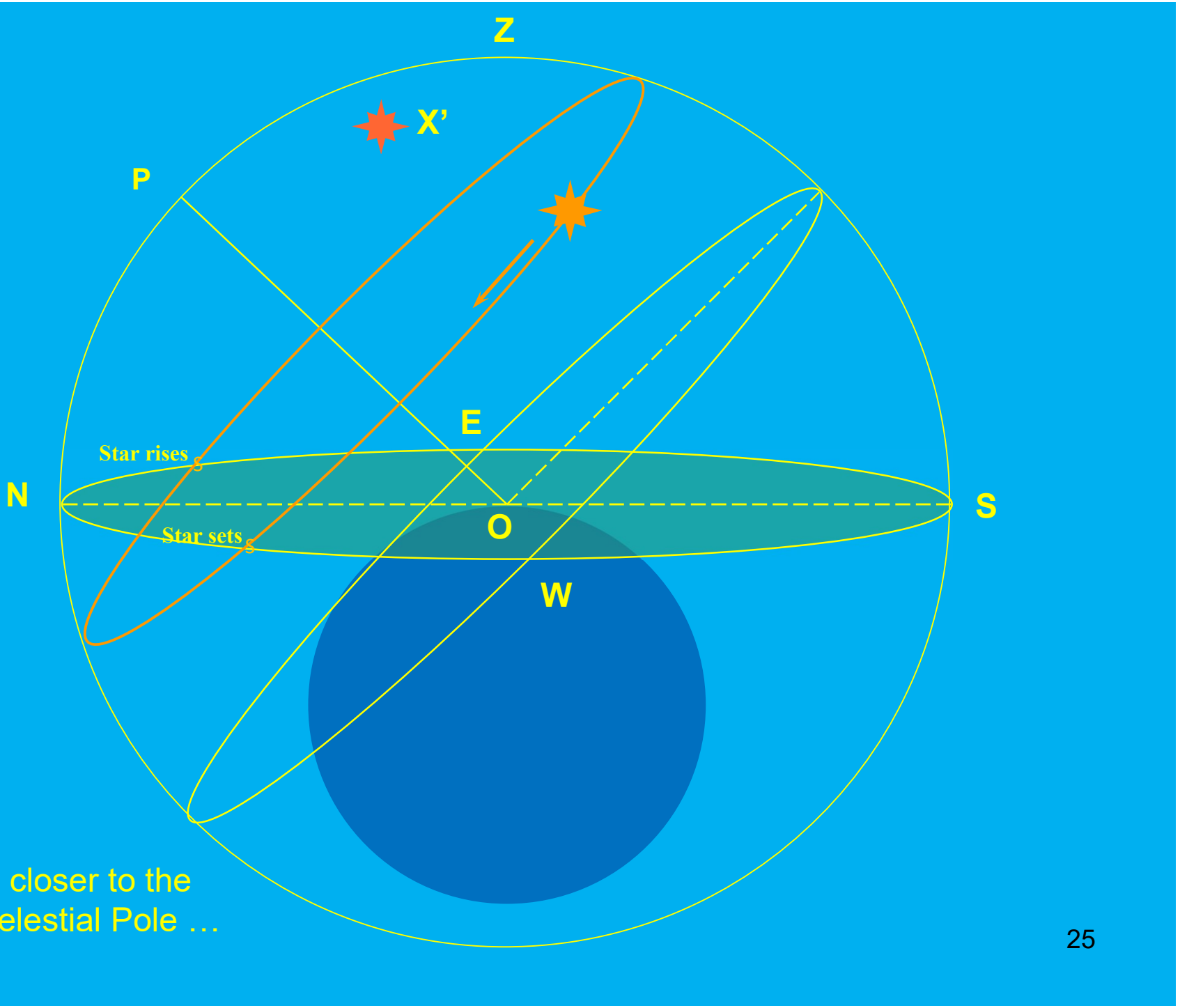



The altitude of the Celestial Equator is the co-latitude of the observer (ie 90º- lat).



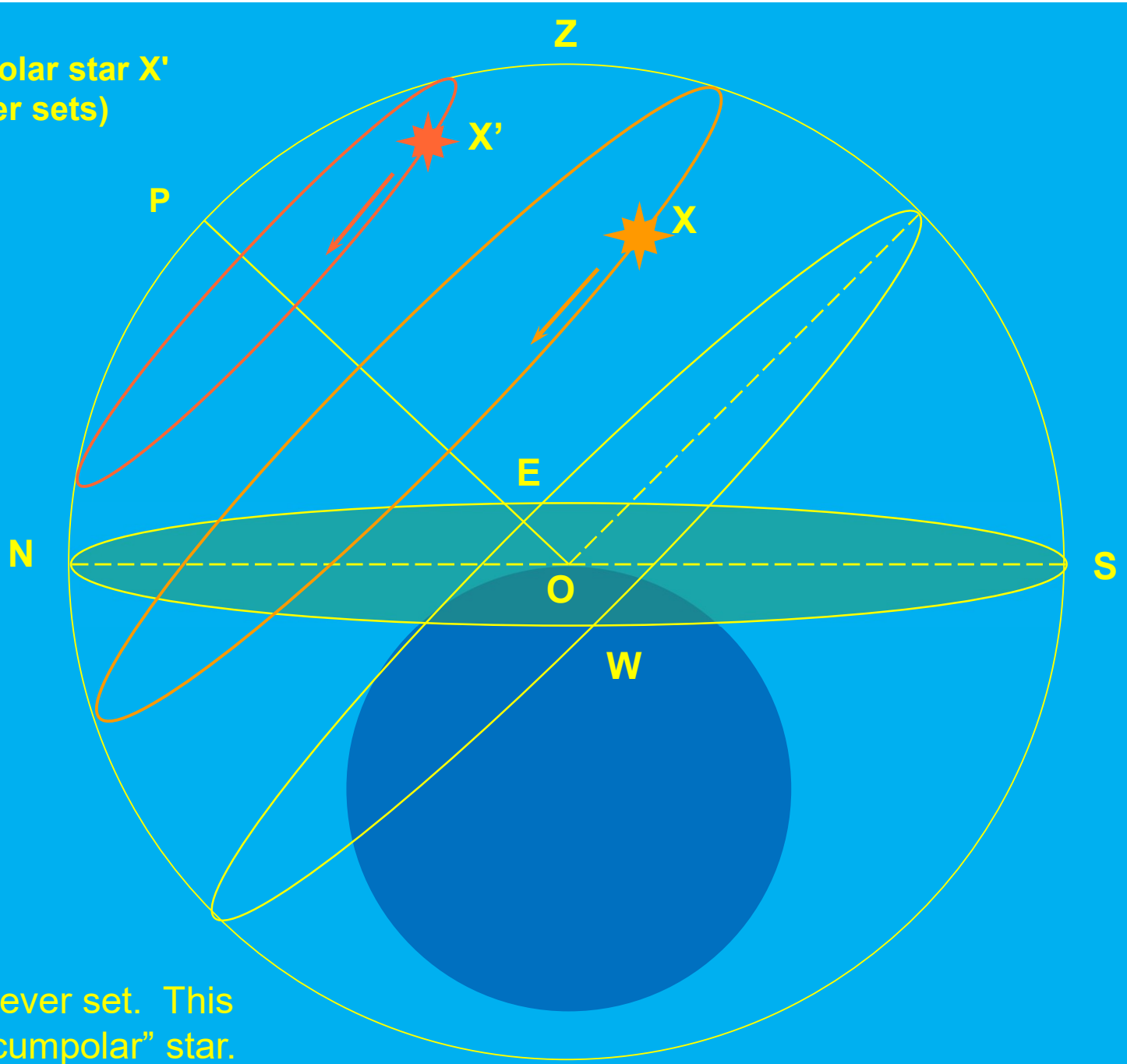

As the Earth spins eastwards a star on the celestial sphere appears to move west.

The star rises and sets as shown. The yellow circles are called great circles; the orange one is a ‘small circle’.

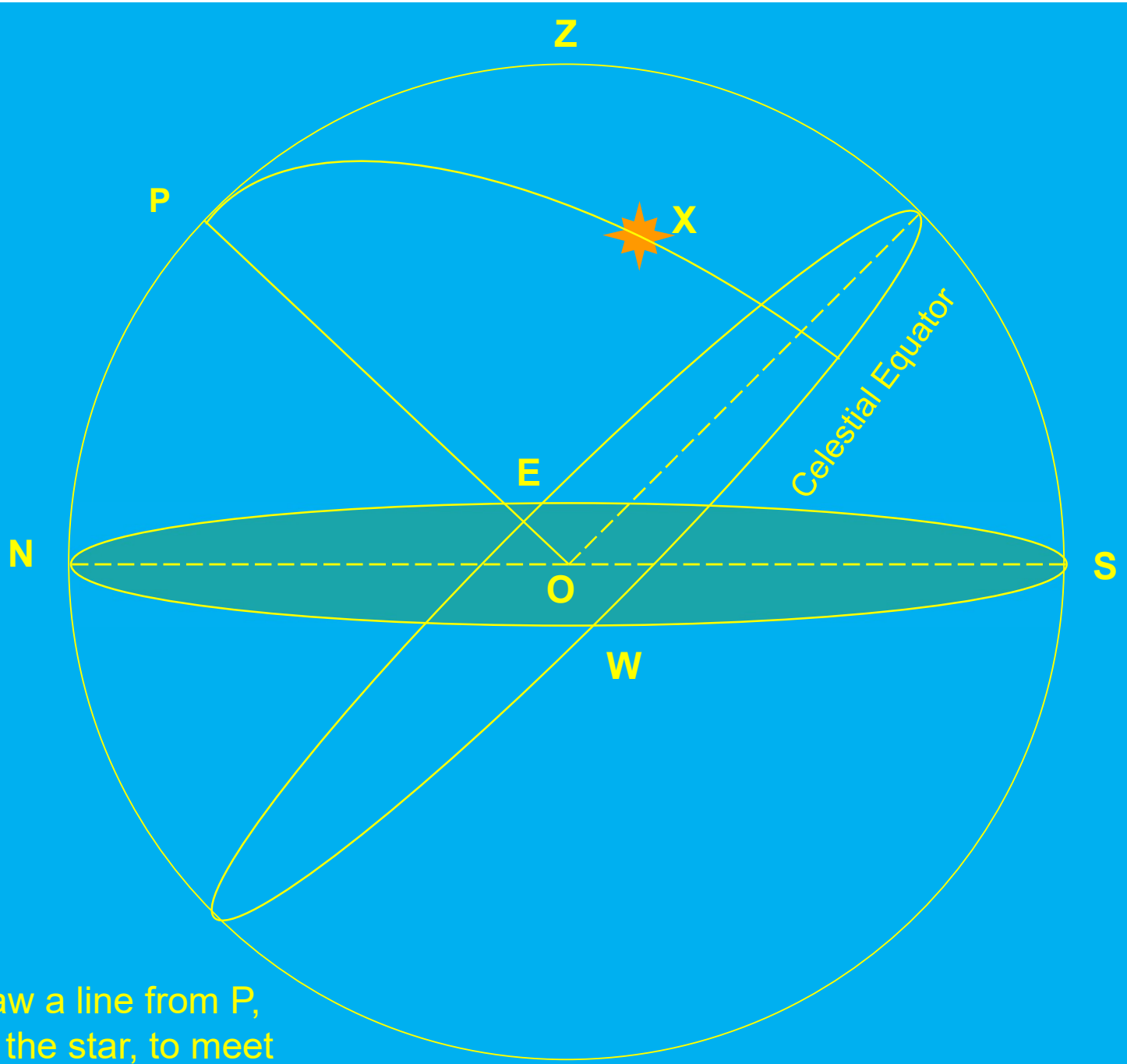



A star x' closer to the North Celestial Pole …

**Circumpolar star X'**
**(never sets)**

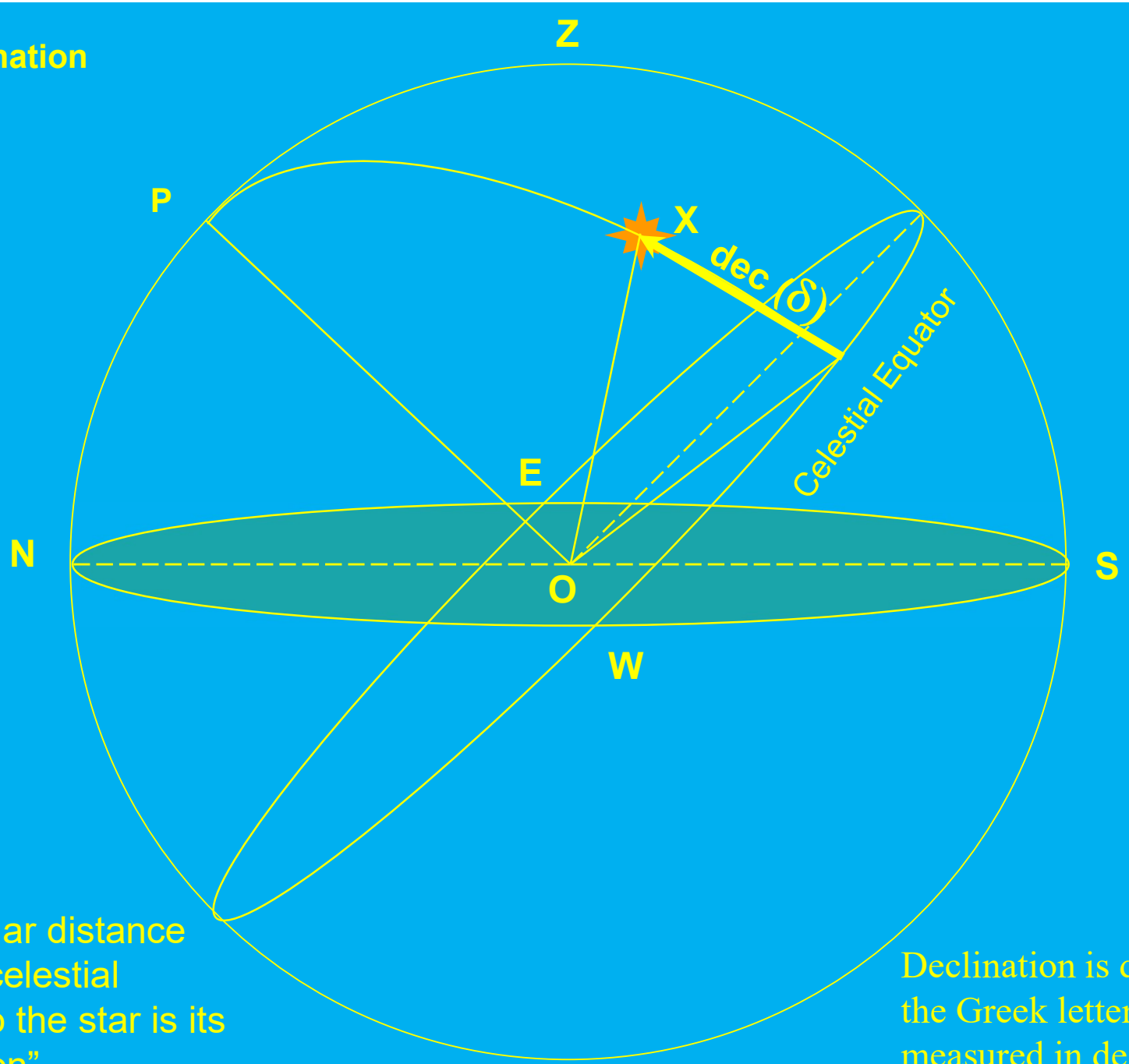



… will never set. This is a “circumpolar” star.




Now draw a line from P, through the star, to meet the celestial equator.

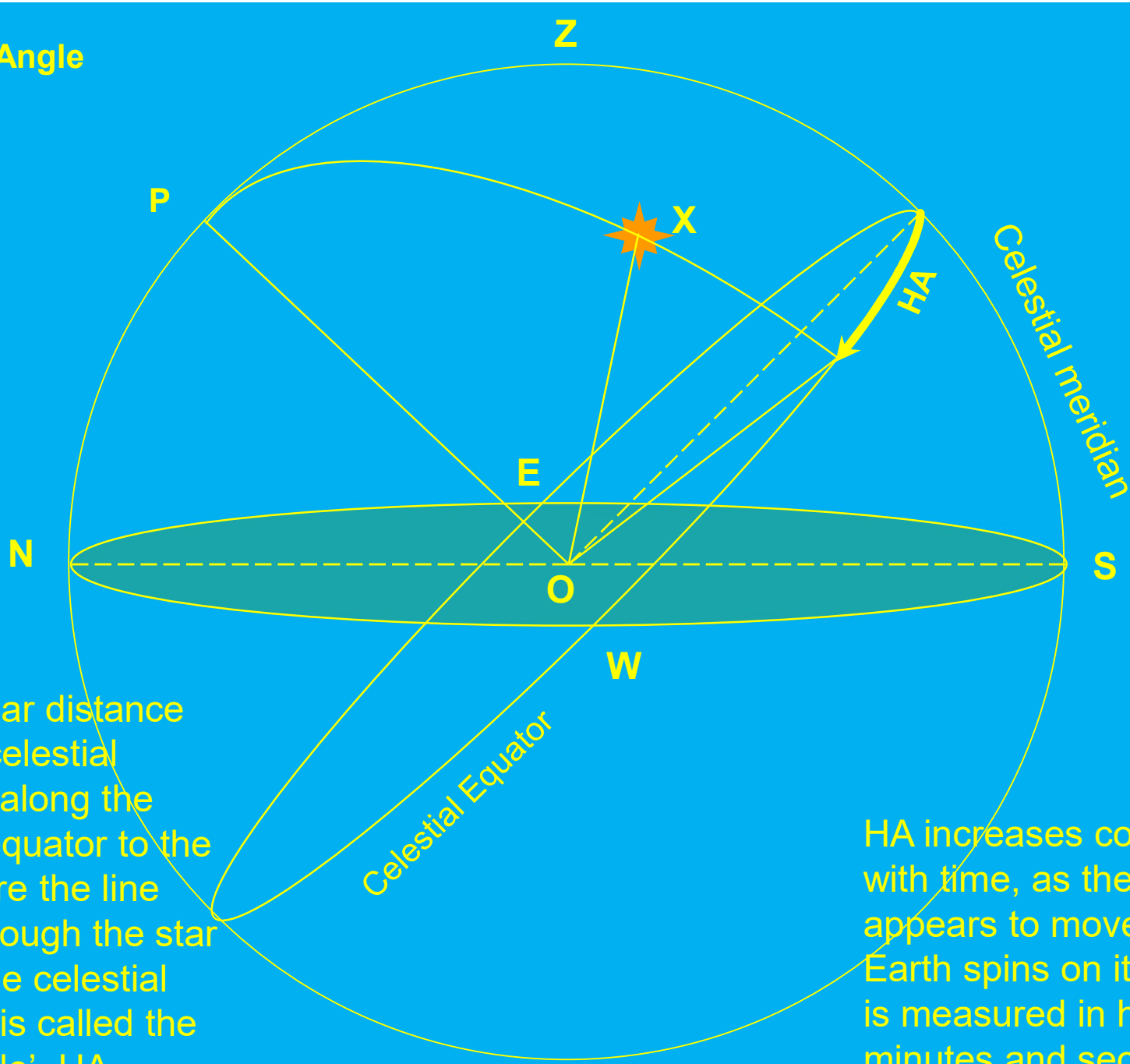
## Declination




The angular distance from the celestial equator to the star is its "declination".

Declination is denoted by the Greek letter δ, and is measured in degrees.

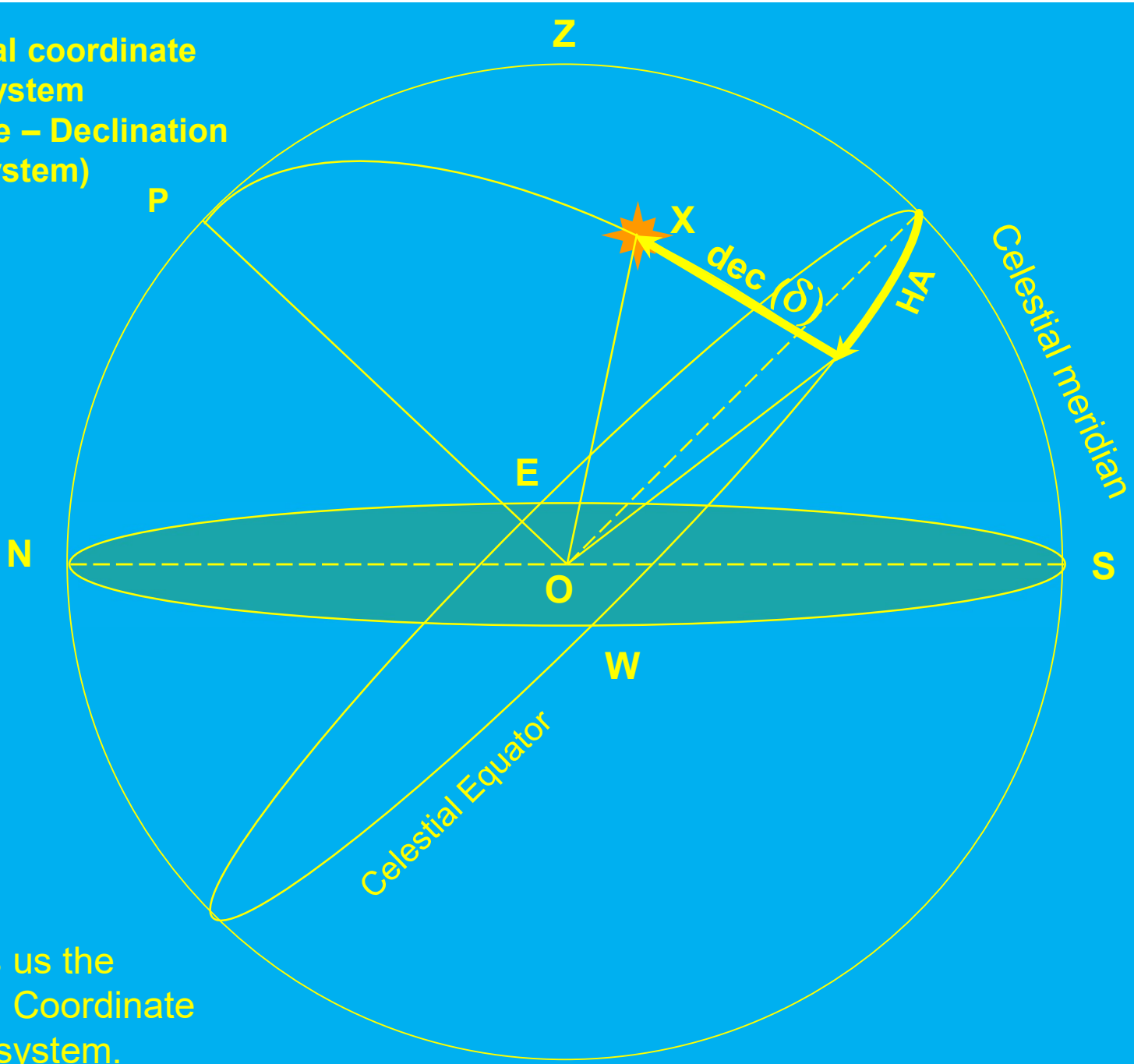
# Hour Angle




The angular distance from the celestial meridian, along the celestial equator to the point where the line from P through the star to meet the celestial meridian, is called the ‘Hour Angle’, HA.

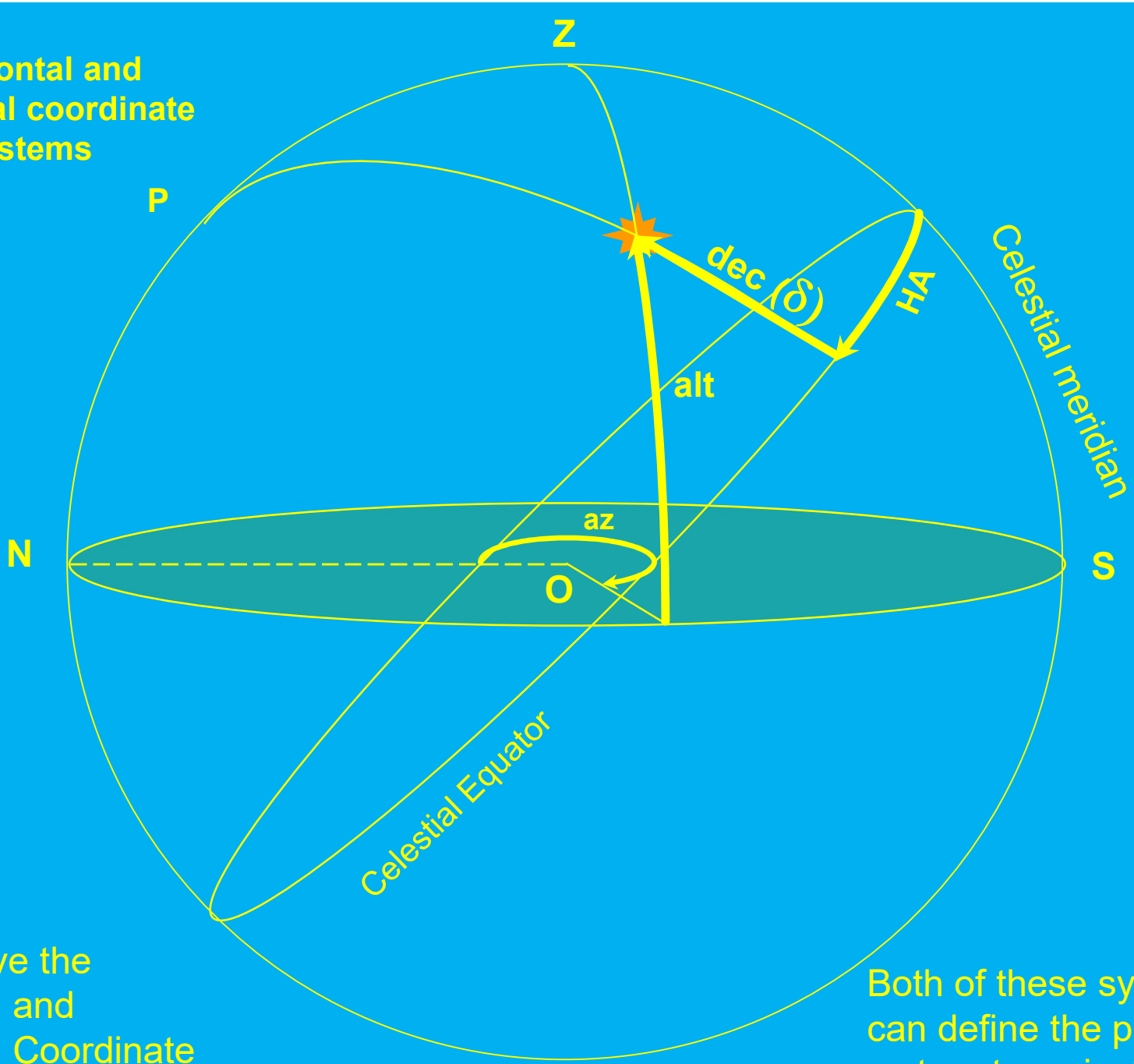
HA increases constantly with time, as the star appears to move as the Earth spins on its axis. It is measured in hours, minutes and seconds.

**Equatorial coordinate System (Hour Angle – Declination System)**




This gives us the Equatorial Coordinate (HA-dec) system.

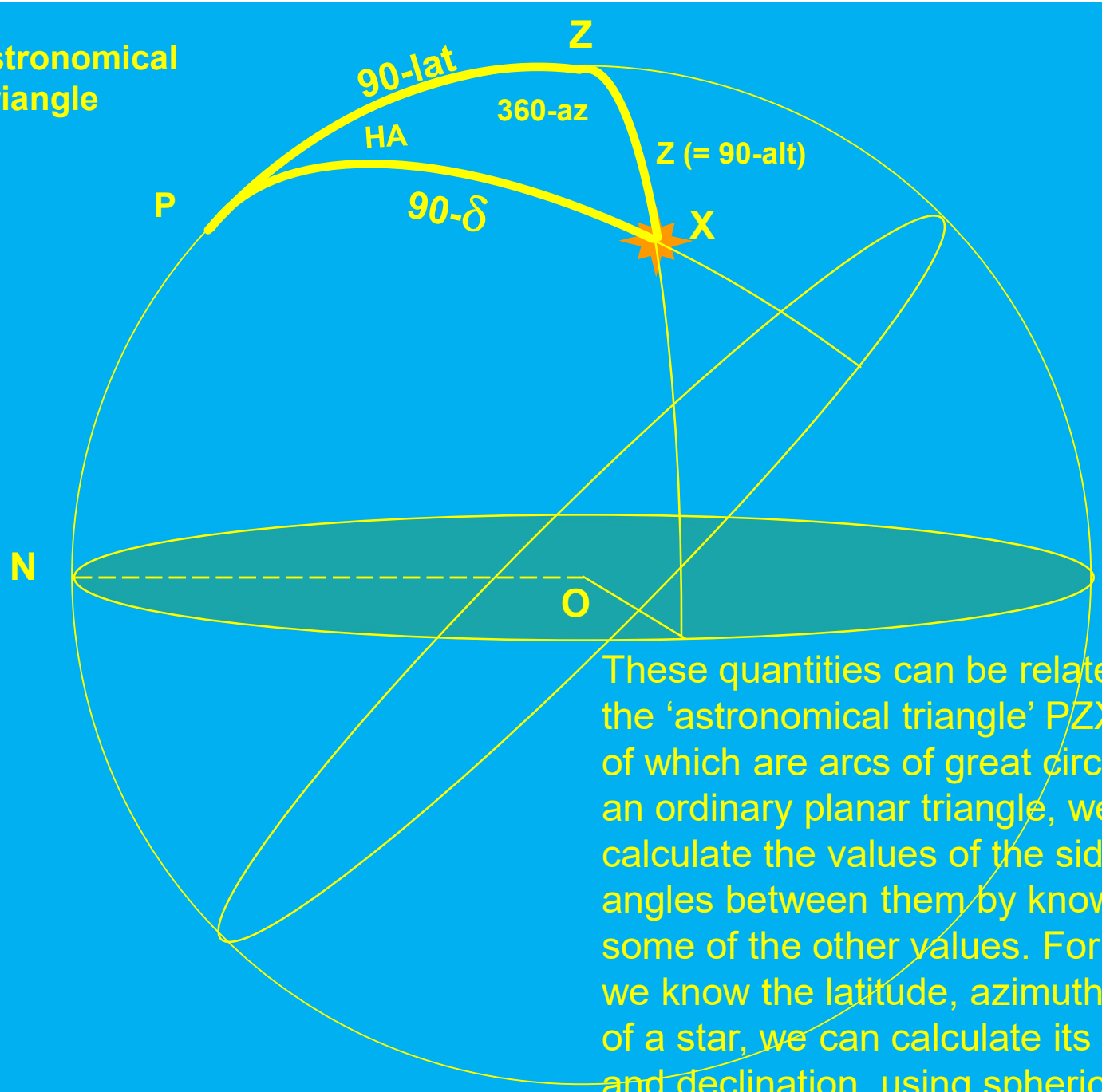
# Horizontal and equatorial coordinate systems




So we have the Horizontal and Equatorial Coordinate systems.

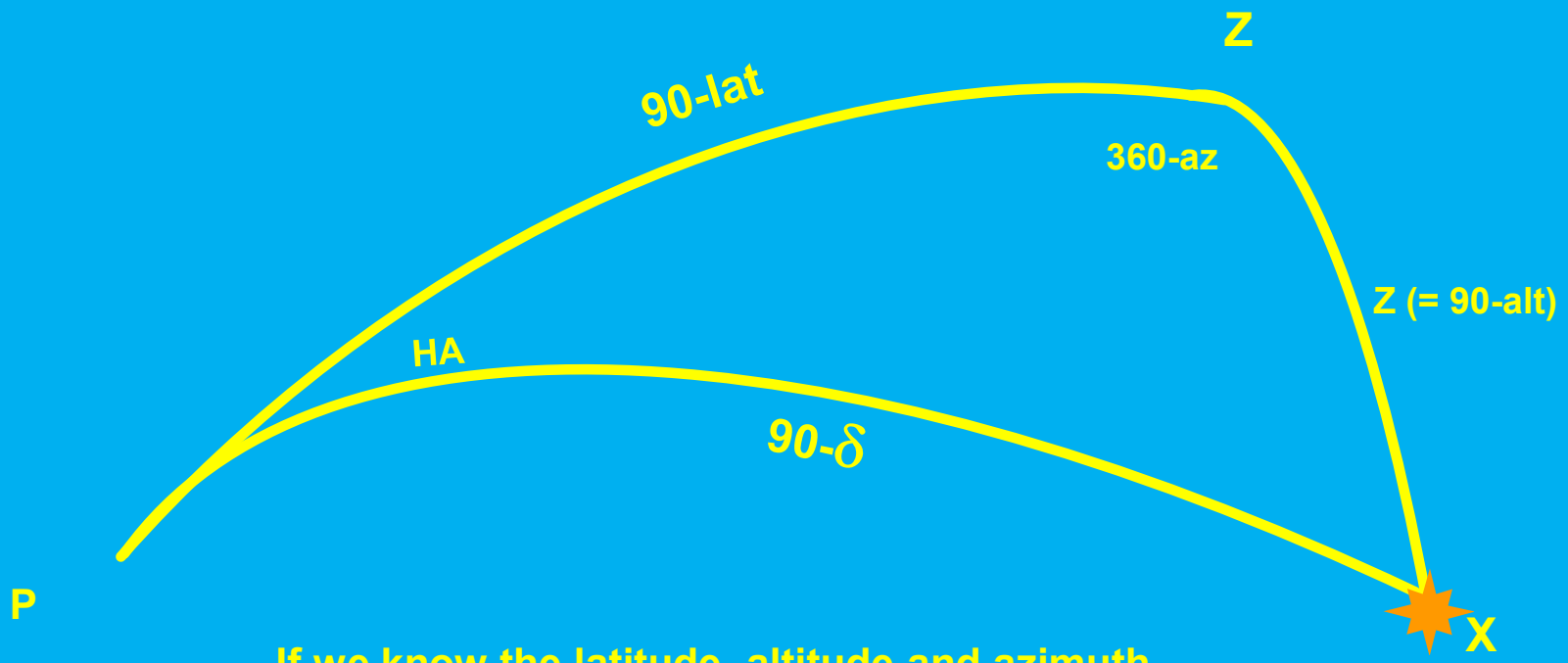
Both of these systems can define the position of a star at any instant.

## The astronomical triangle




These quantities can be related through the ‘astronomical triangle’ PZX, the sides of which are arcs of great circles. As with an ordinary planar triangle, we can calculate the values of the sides and the angles between them by knowledge of some of the other values. For example, if we know the latitude, azimuth and altitude of a star, we can calculate its Hour Angle and declination, using spherical trigonometry.

## The astronomical triangle
## Conversion between the horizontal and equatorial coordinate systems

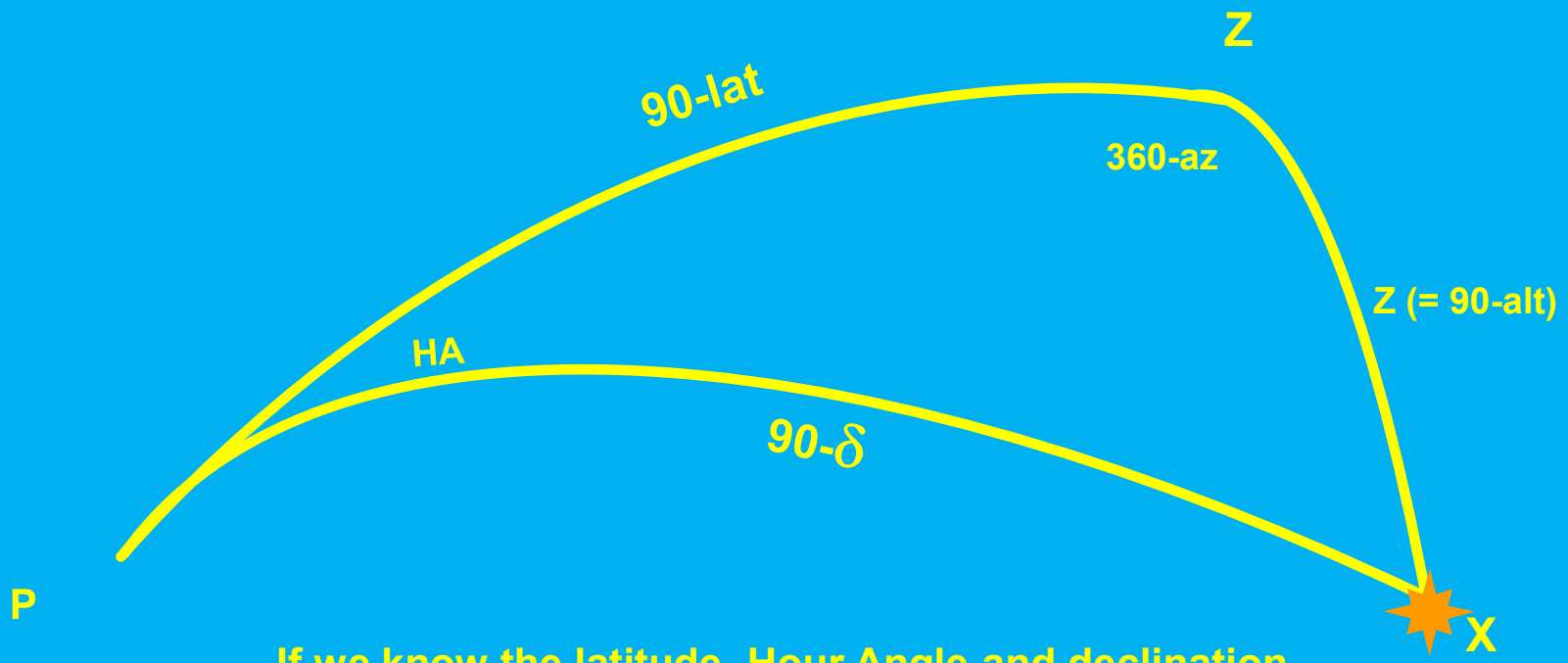



**If we know the latitude, altitude and azimuth**

**we can calculate the declination:** $\sin \delta = \sin(\text{lat}) \sin(\text{alt}) + \cos(\text{lat}) \cos(\text{alt}) \cos(\text{az})$

**and then the Hour Angle:** $\cos(\text{HA}) = \dfrac{\sin(\text{alt}) - \sin(\text{lat}) \sin(\delta)}{\cos(\text{lat}) \cos(\delta)}$

## The astronomical triangle
## Conversion between the horizontal and equatorial coordinate systems



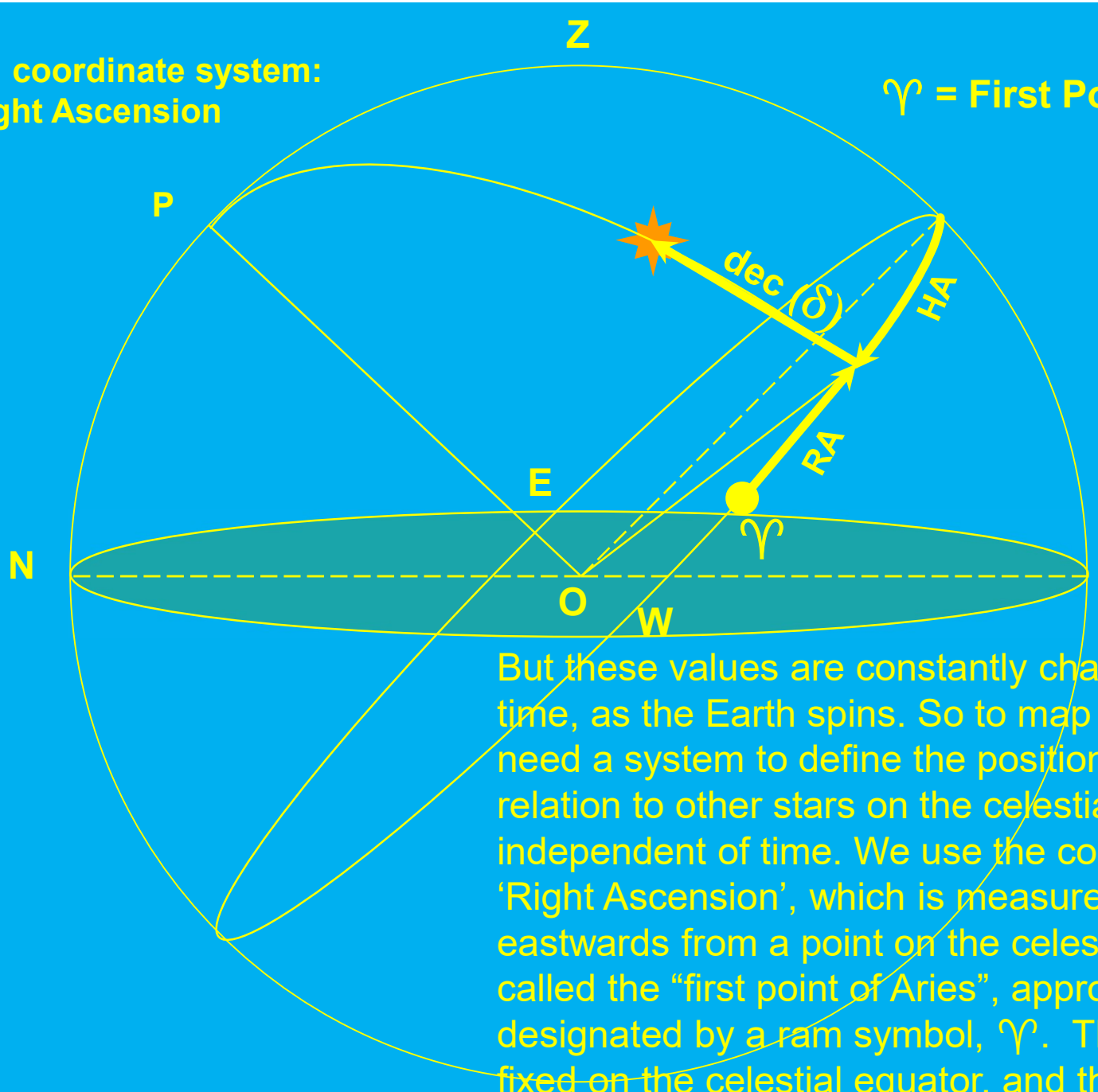

**If we know the latitude, Hour Angle and declination**

**we can calculate the altitude:** $\cos(\text{alt}) = \sin(\text{lat})\sin(\text{dec}) + \cos(\text{lat})\cos(\text{dec})\cos(\text{HA})$

**and then the azimuth:** $\cot(\text{az}) = \dfrac{\cos(\text{lat})\tan(\delta) - \sin(\delta)\sin(\text{HA})}{\sin(\text{HA})}$

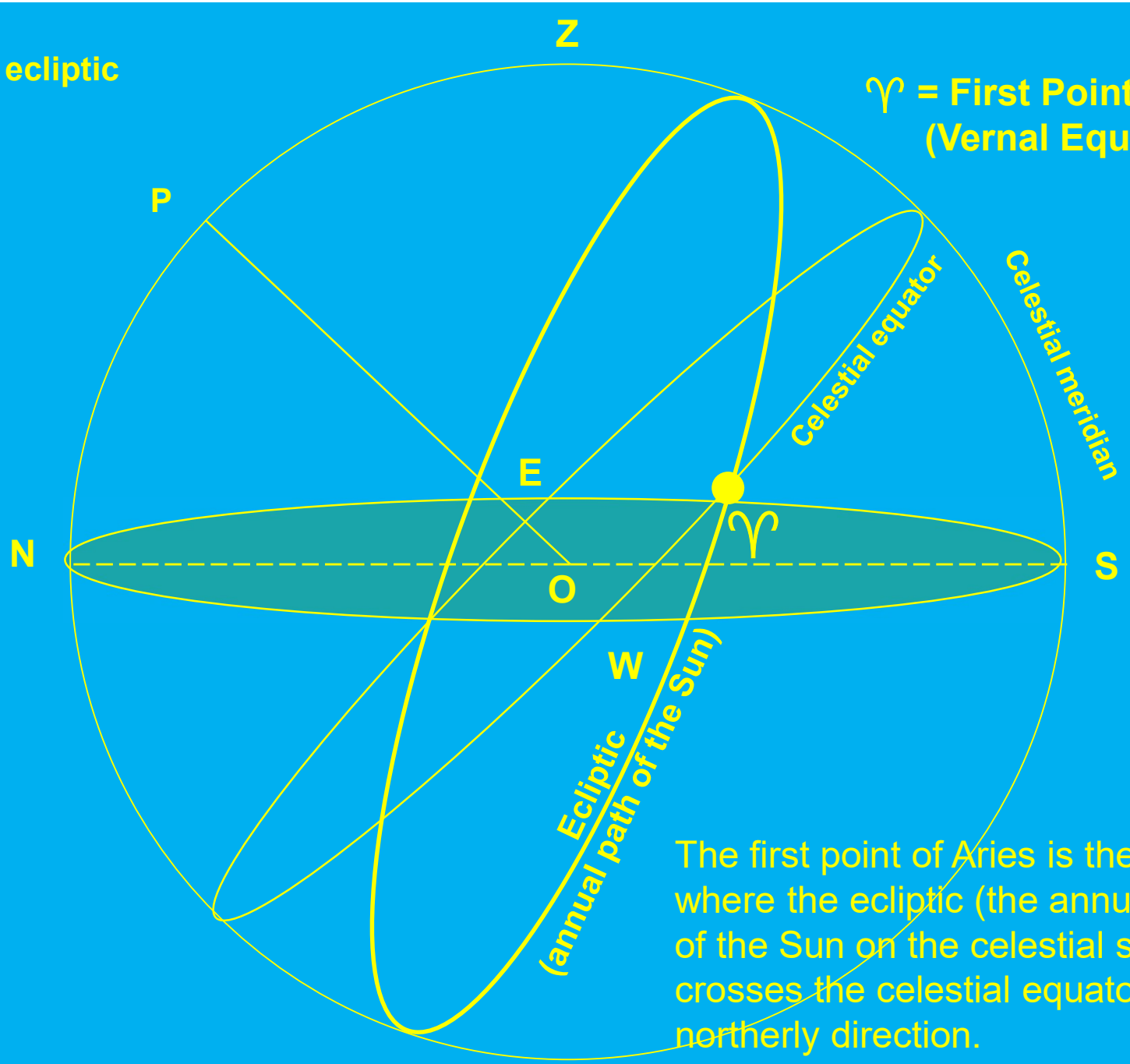
## Equatorial coordinate system: Right Ascension

♈ = First Point of Aries



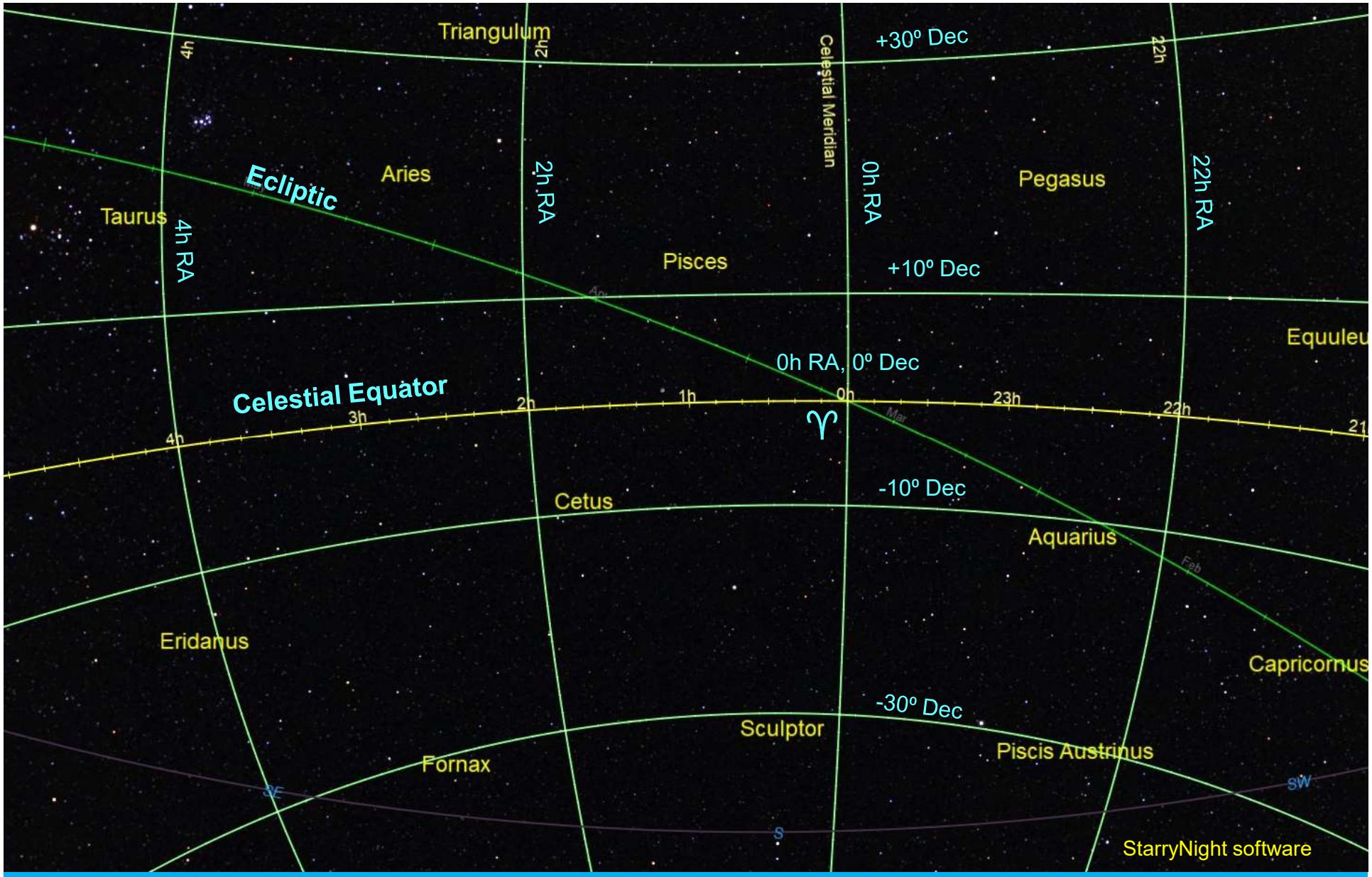

But these values are constantly changing with time, as the Earth spins. So to map stars we need a system to define the positions of stars in relation to other stars on the celestial sphere, independent of time. We use the concept of 'Right Ascension', which is measured eastwards from a point on the celestial equator called the "first point of Aries", appropriately designated by a ram symbol, ♈. This point is fixed on the celestial equator, and therefore rotates with it.

# The ecliptic




♈ = First Point of Aries
(Vernal Equinox)

The first point of Aries is the point where the ecliptic (the annual path of the Sun on the celestial sphere) crosses the celestial equator in a northerly direction.

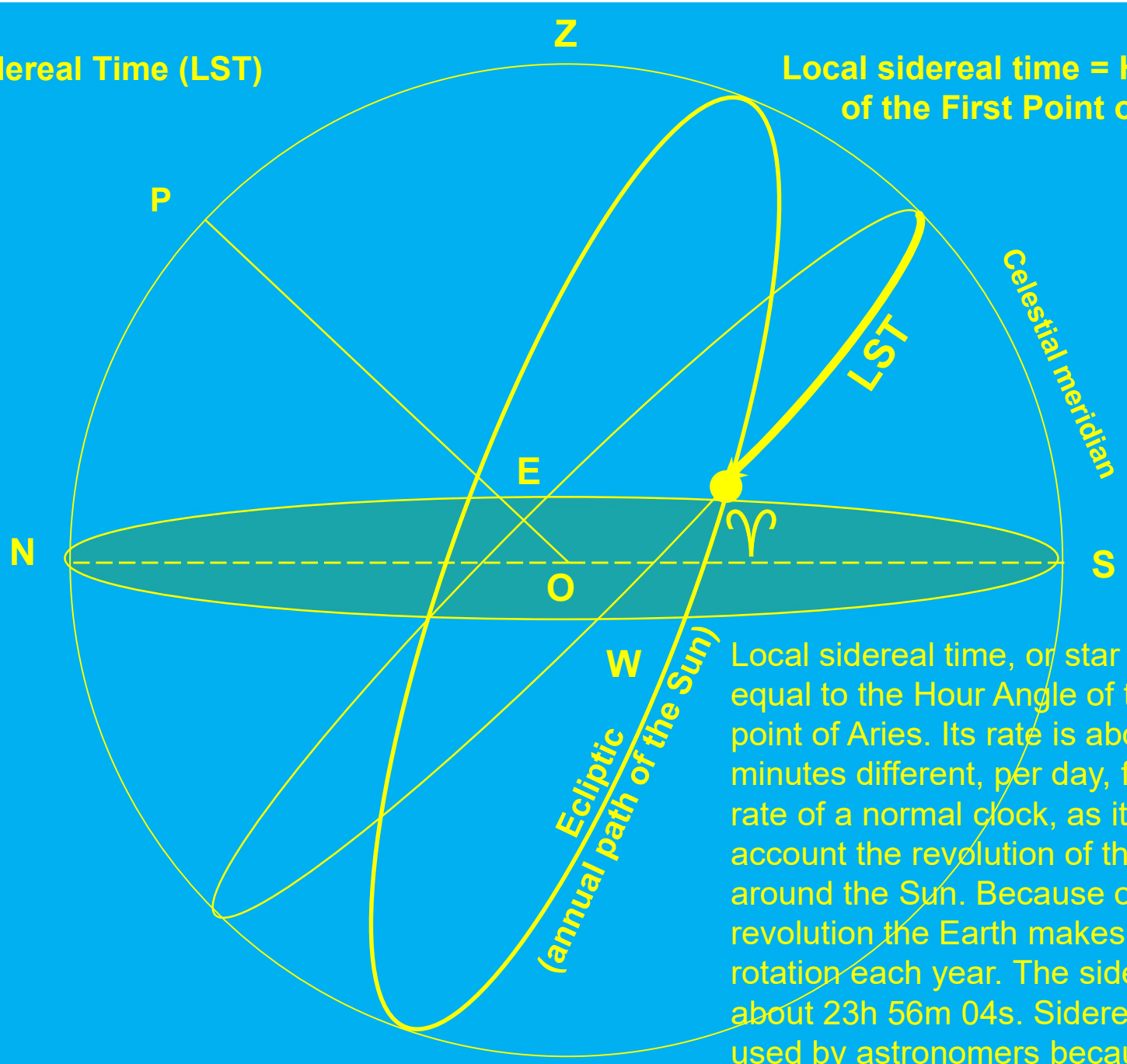



Star maps show the RA – Dec Equatorial Coordinates.

The point marked 0h RA and 0º Dec is the First Point of Aries (♈).

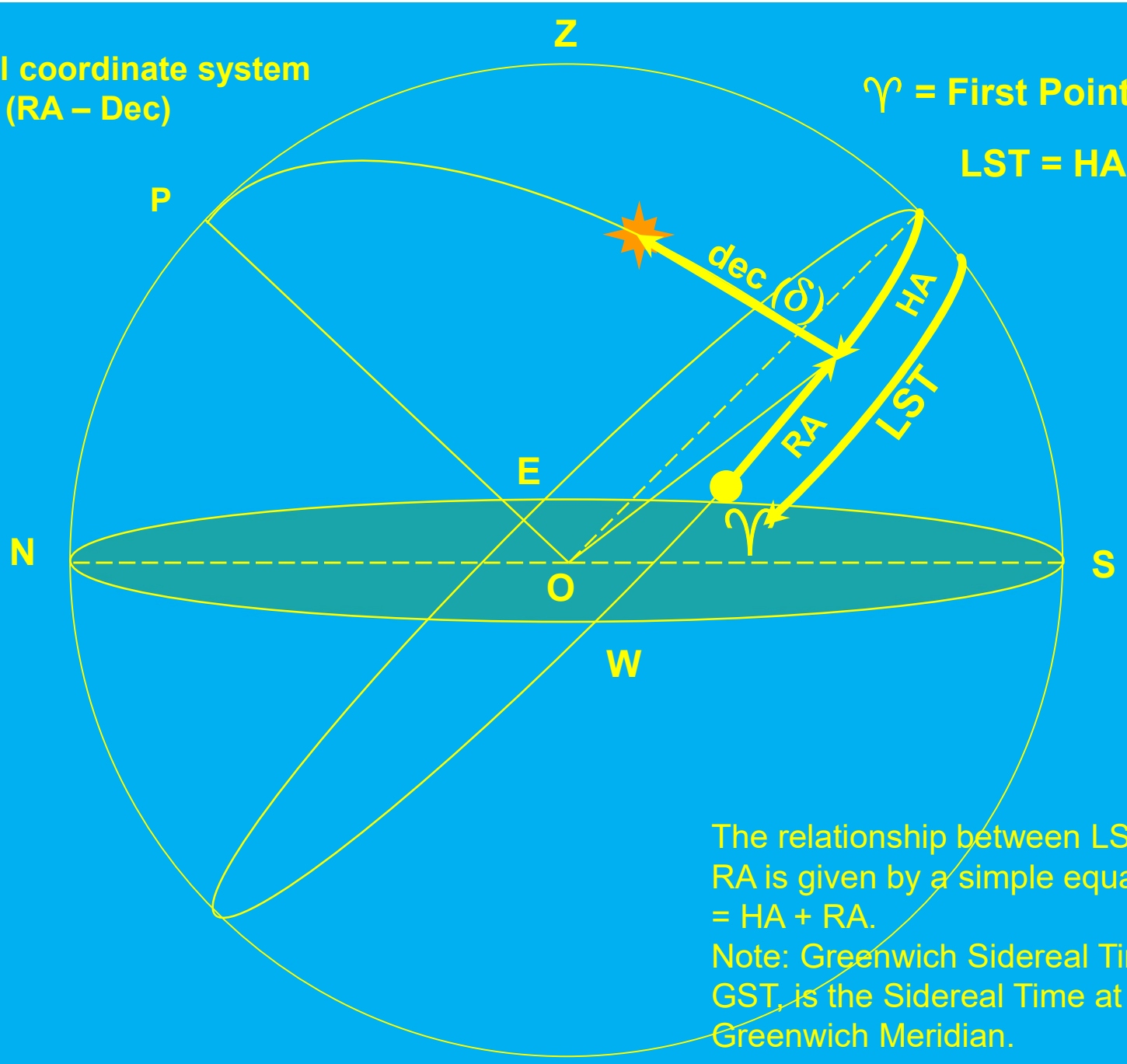
# Local Sidereal Time (LST)

**Local sidereal time = Hour Angle of the First Point of Aries**




Local sidereal time, or star time, is equal to the Hour Angle of the first point of Aries. Its rate is about four minutes different, per day, from the rate of a normal clock, as it takes into account the revolution of the Earth around the Sun. Because of this revolution the Earth makes an extra rotation each year. The sidereal day is about 23h 56m 04s. Sidereal time is used by astronomers because it relates to the stars, not the Sun.

## Equatorial coordinate system (RA – Dec)




♈ = First Point of Aries

LST = HA + RA

The relationship between LST, HA and RA is given by a simple equation: LST = HA + RA.

Note: Greenwich Sidereal Time, or GST, is the Sidereal Time at the Greenwich Meridian.

**Congratulations. You are now a celestial sphere expert!**

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