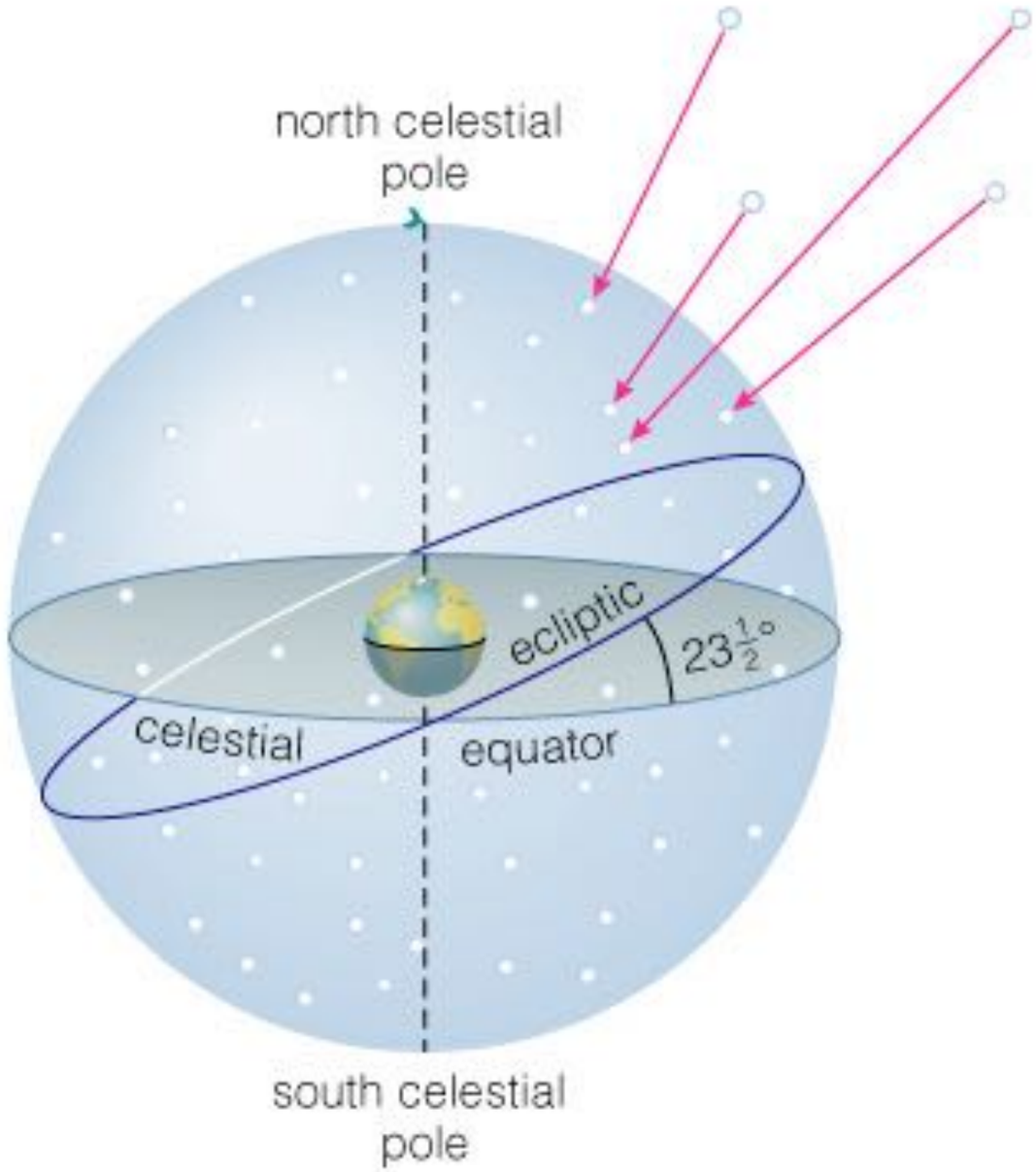
Today

- Appearance of the Sky
- Orientation
- Motion of sky
- Seasons
- Precession (?)

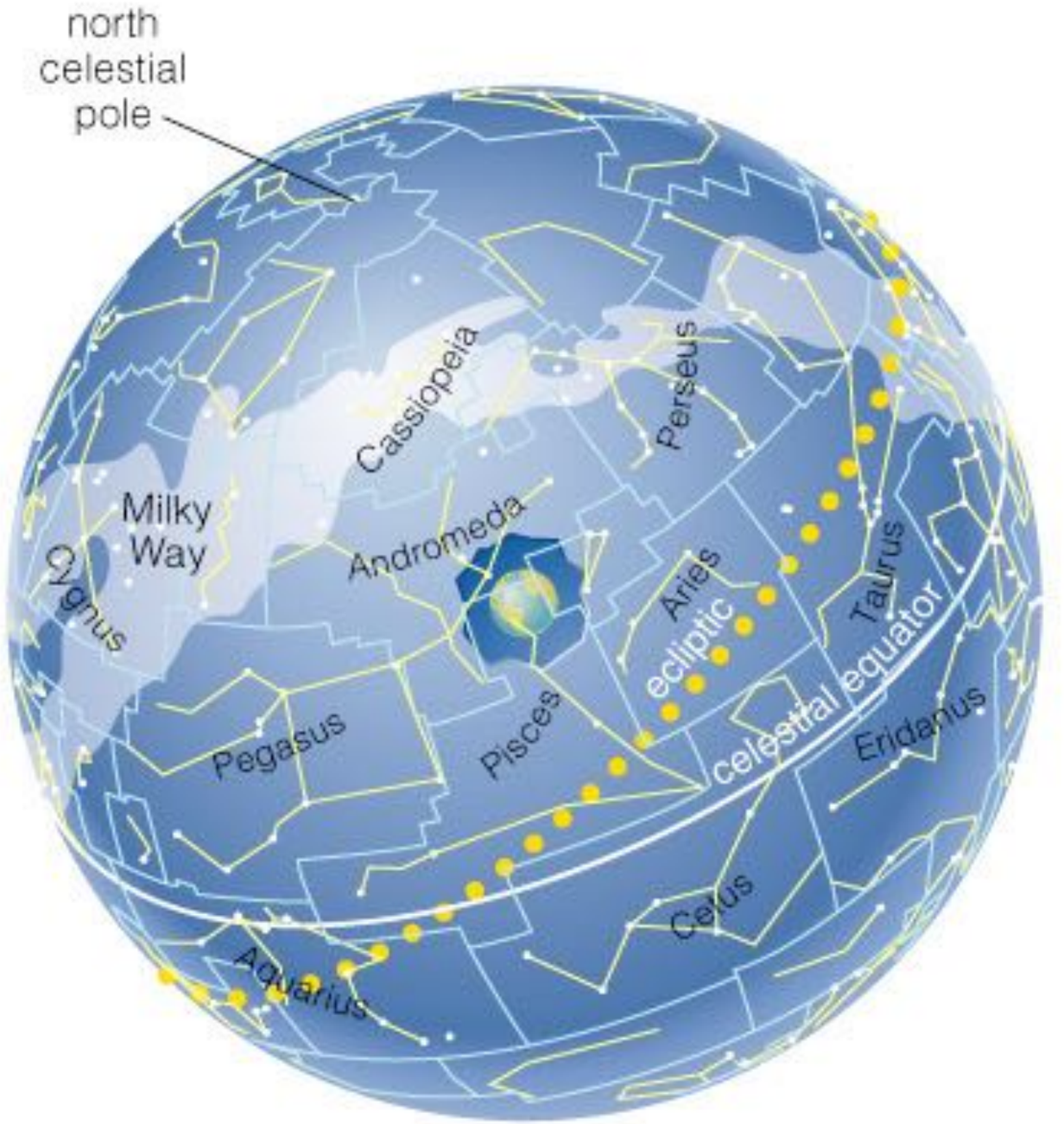
The Celestial Sphere



Stars at different distances all appear to lie on the celestial sphere.

The ecliptic is the Sun's apparent path through the celestial sphere.

The Celestial Sphere



The 88 official constellations cover the celestial sphere.

The celestial sphere is like a globe of the earth - the 2D surface of a sphere that maps where things are.

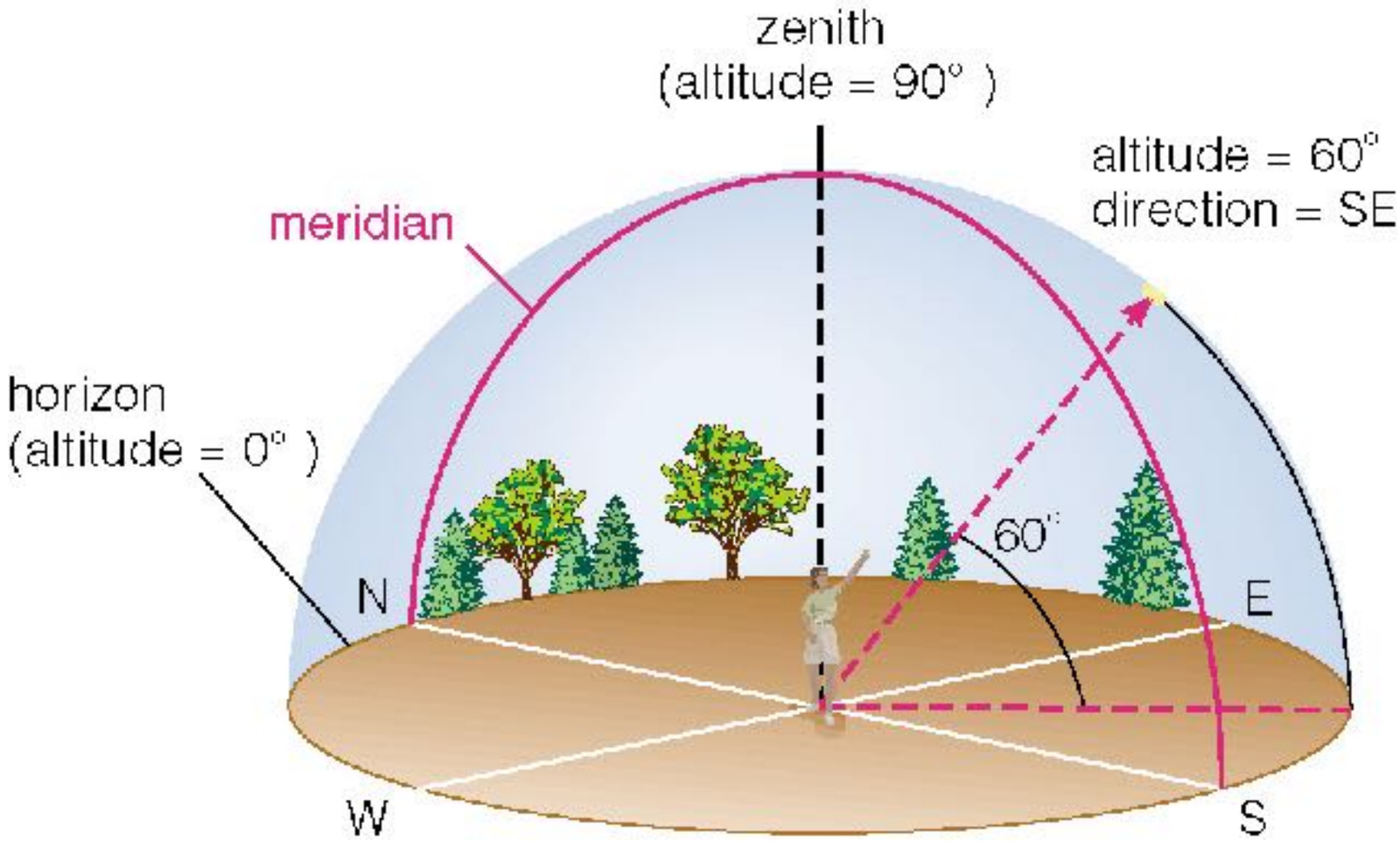
BUT we look up at it from the inside rather than down on it from above. East & West get flipped like left and right in a mirror.

The Milky Way

A band of light that makes a circle around the celestial sphere:
our view into the plane of our galaxy.

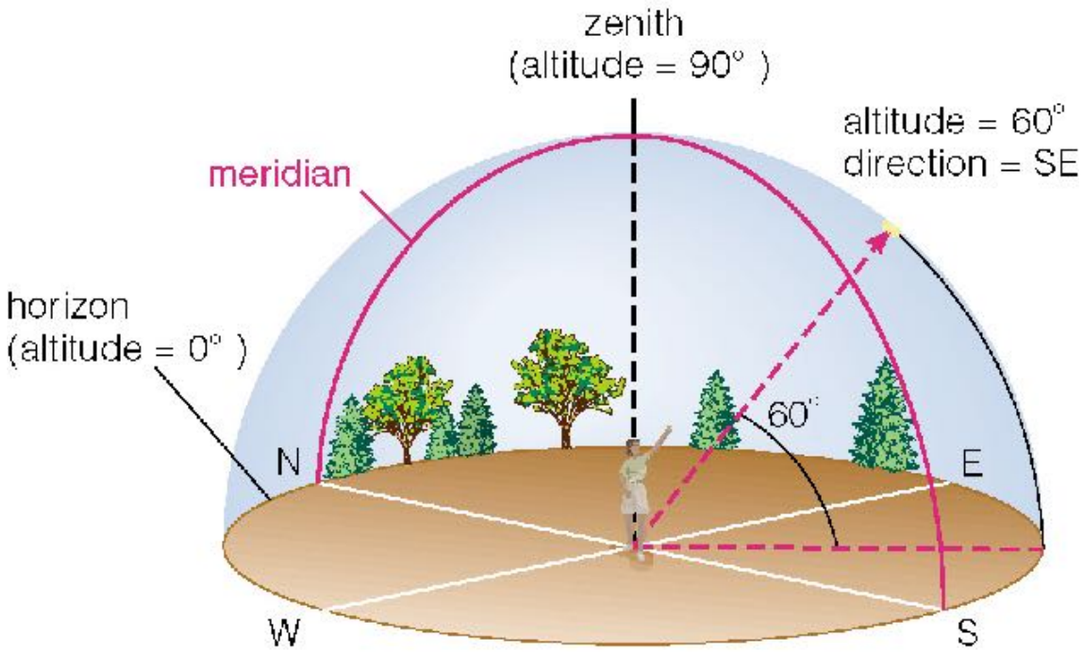
The Local Sky

An object's **altitude** (above horizon) and **direction** (along horizon) specify its location in your local sky.



Everything is measured in angles!

The Local Sky

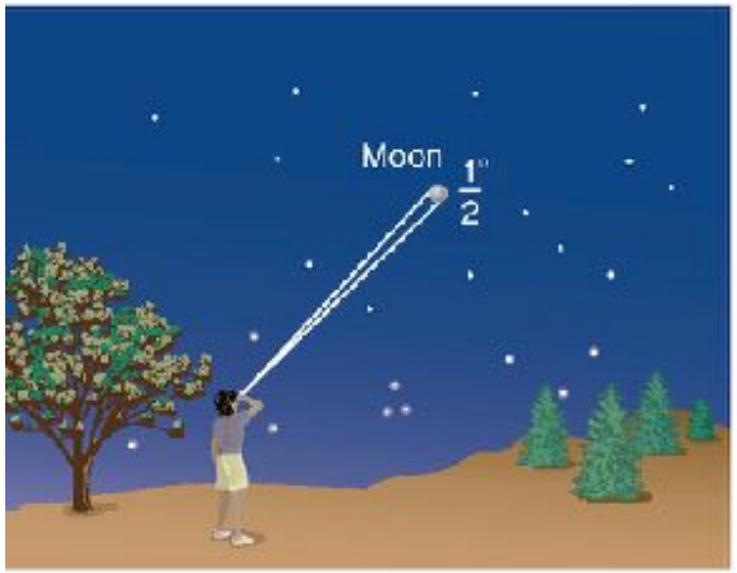


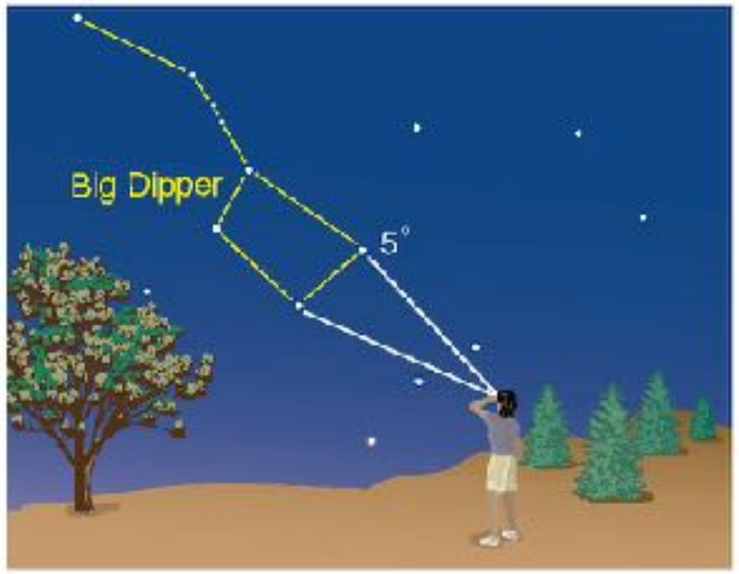
Zenith: The point directly overhead

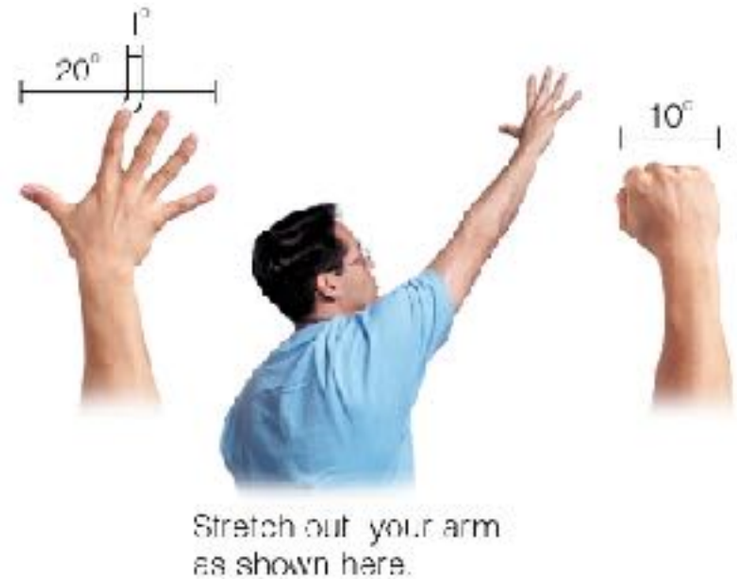
Horizon: All points 90° away from zenith

Meridian: Line passing through zenith and connecting N and S points on the horizon

We measure the sky using *angles*

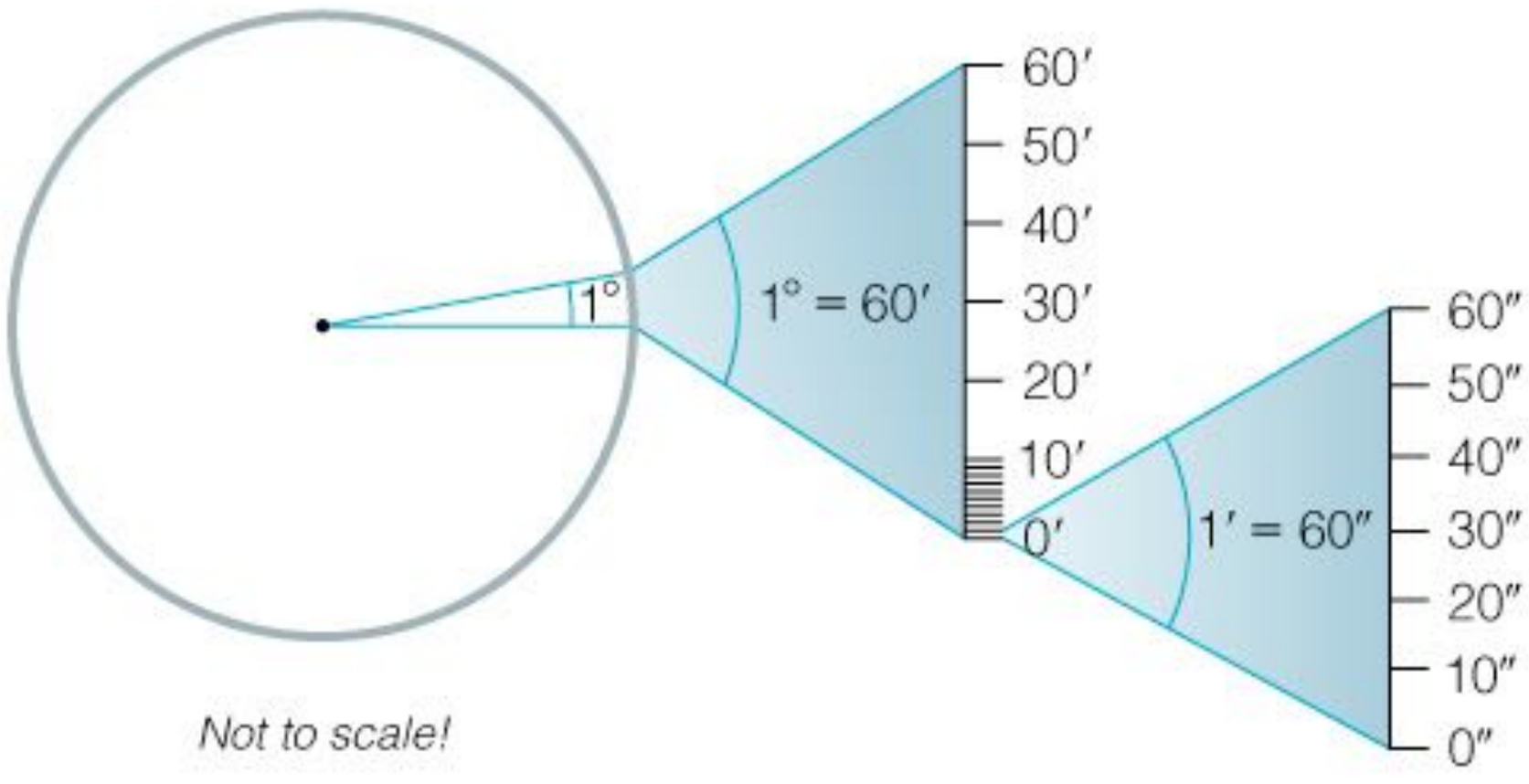






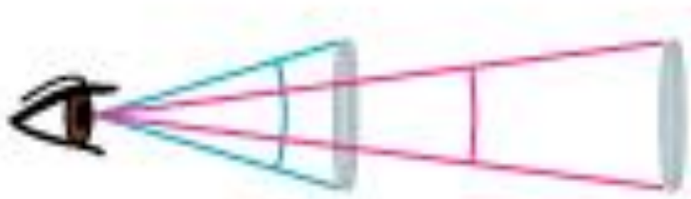
Angular Measurements

- Full circle = 360°
- 1° = 60′ (arcminutes)
- 1′ = 60″ (arcseconds)

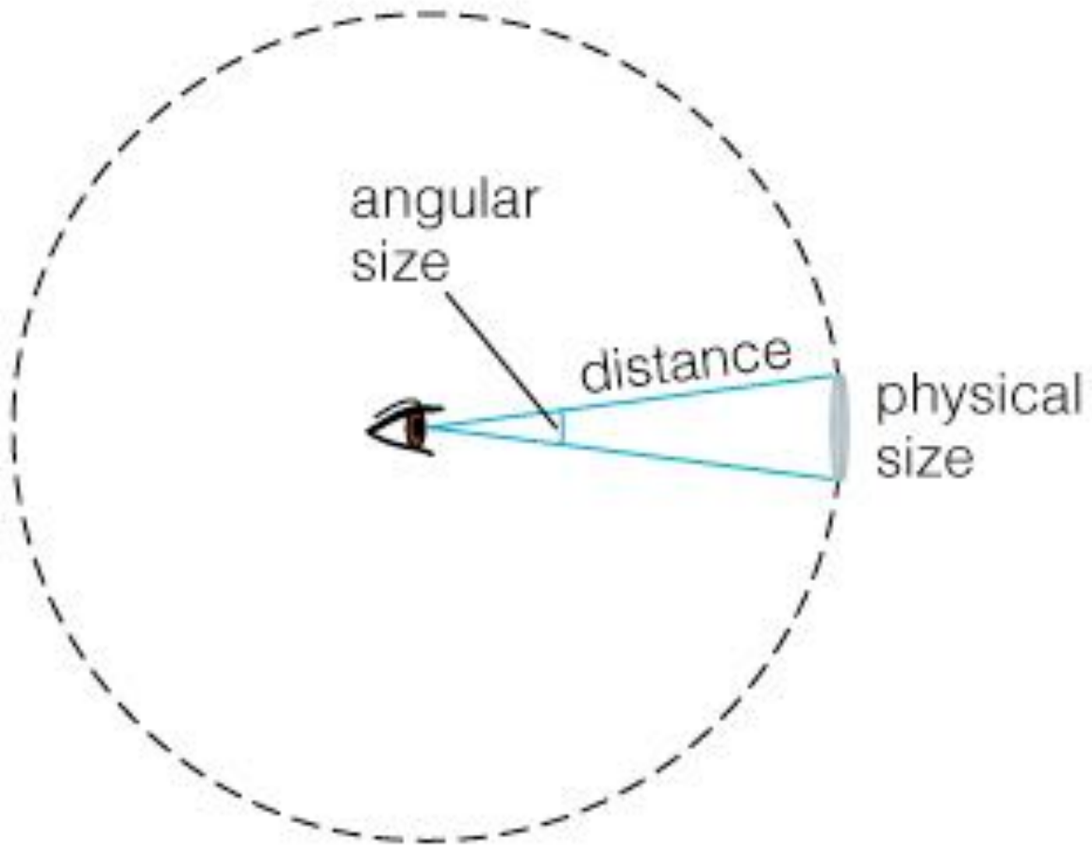


Angular Size

$$\text{angular size} = \text{physical size} \times \frac{360 \text{ degrees}}{2\pi \times \text{distance}}$$



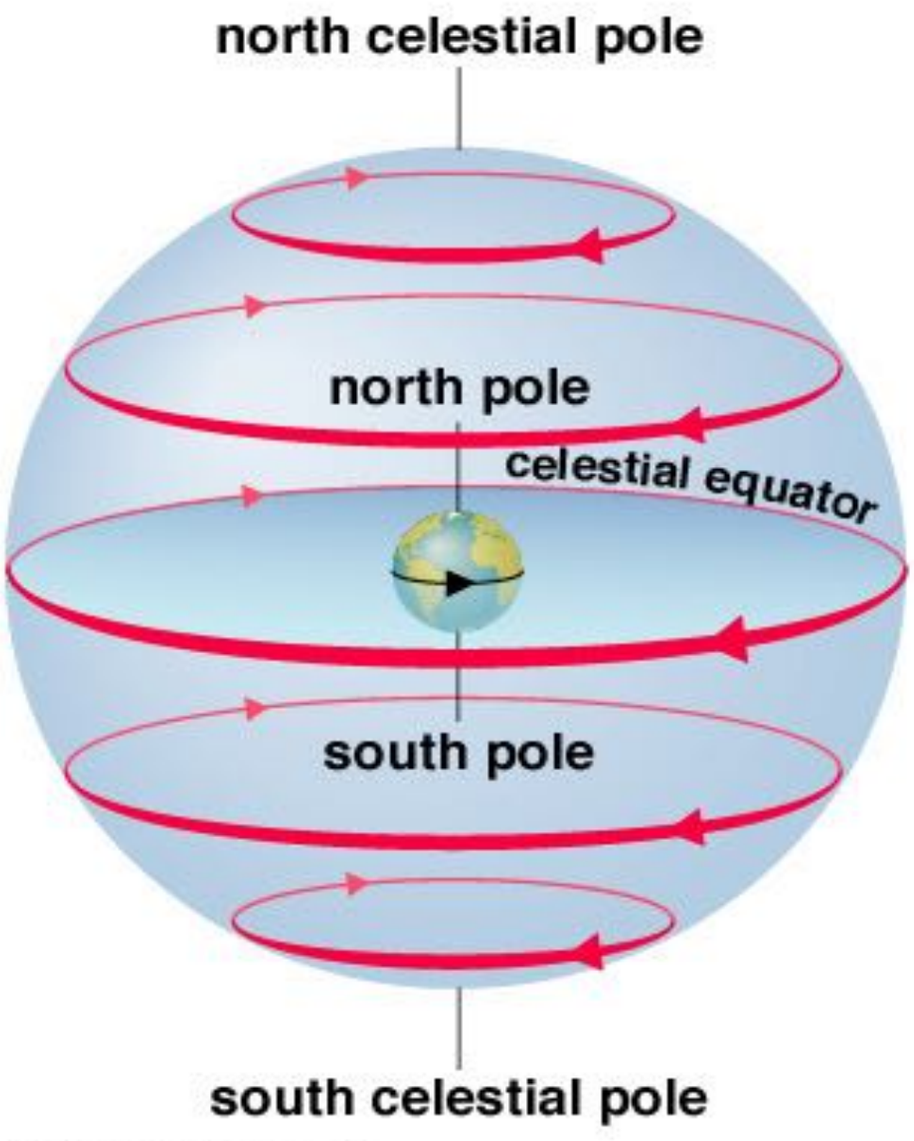
An object's angular size appears smaller if it is farther away.



$$\theta = \frac{L}{D}$$

$$\text{angular size (in radians)} = \frac{\text{physical size}}{\text{distance}}$$

Why do stars rise and set?

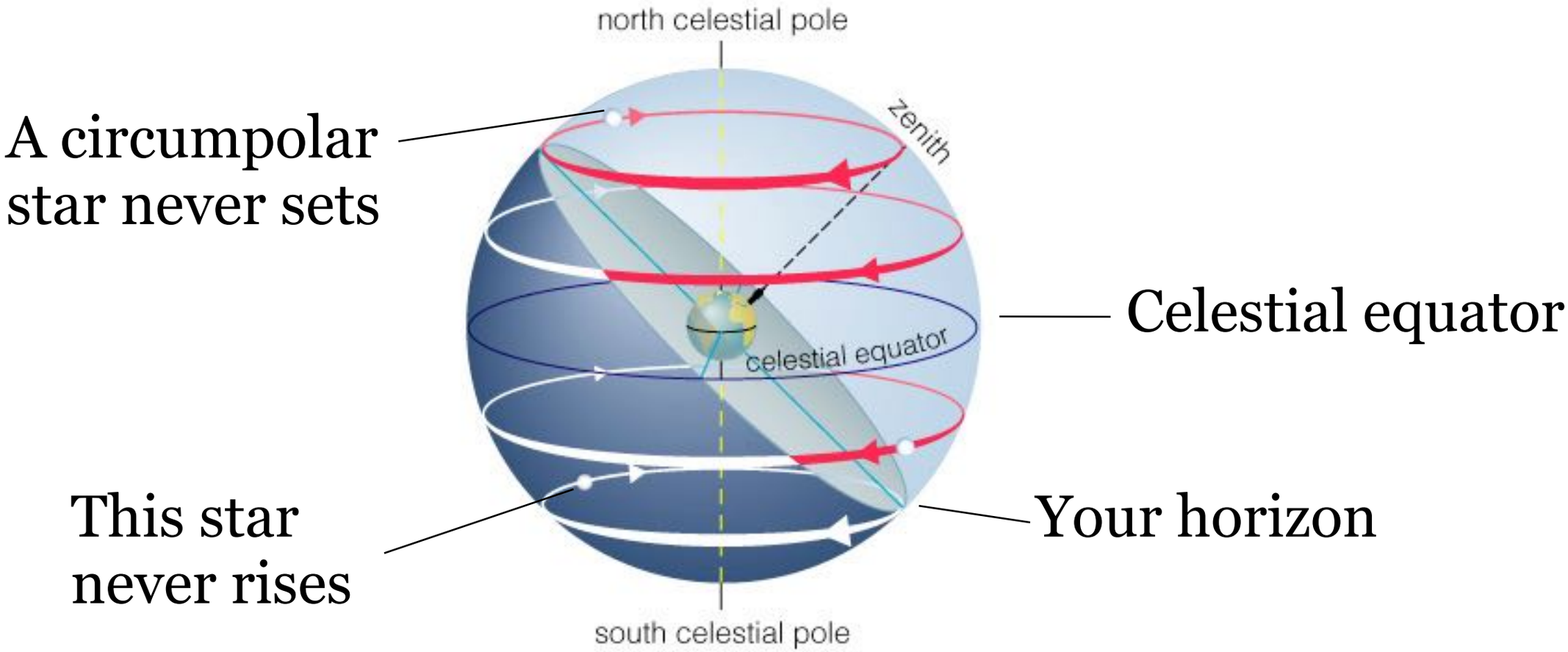


Earth rotates west to east, so stars appear to circle from east to west.

PLAY *Stellarium*

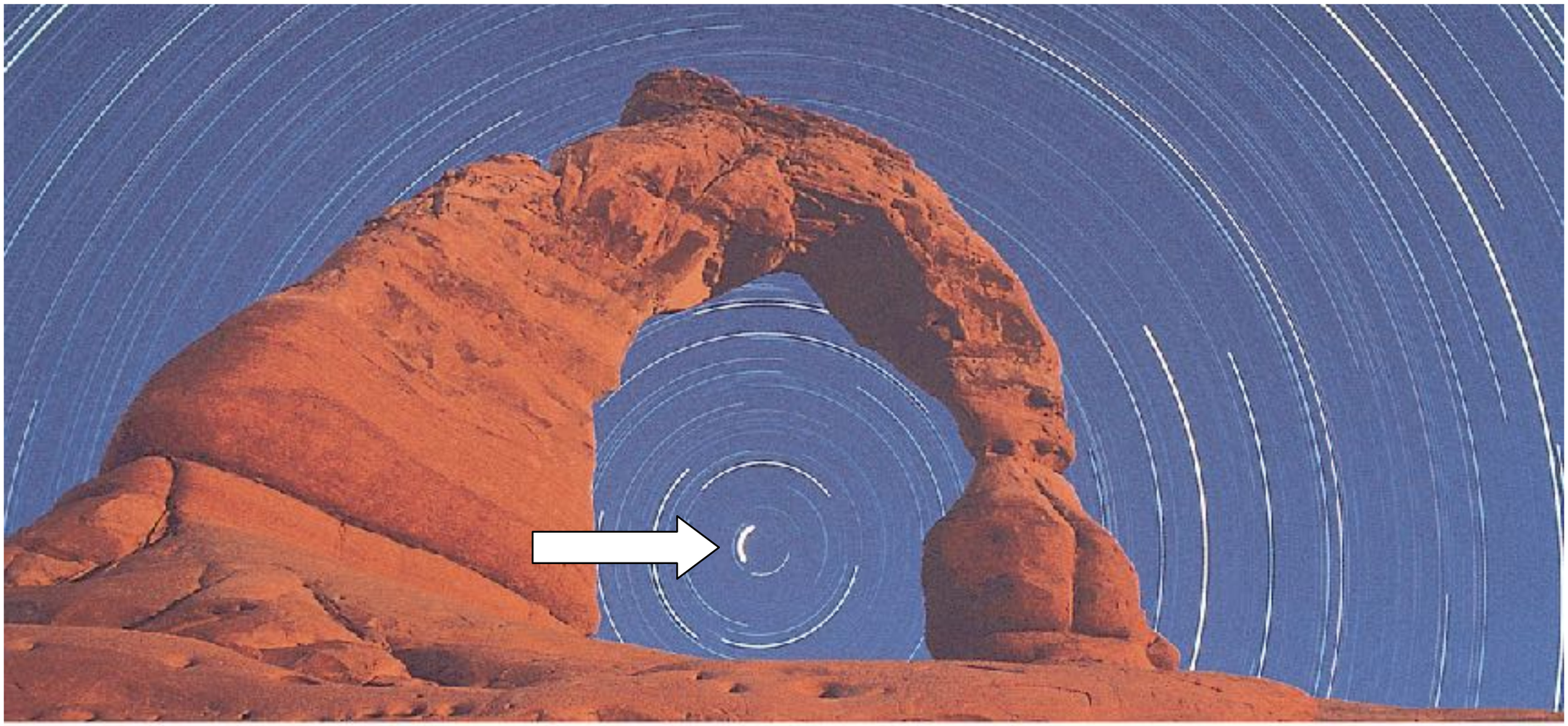
Our view from Earth:

- Stars near the north celestial pole are circumpolar and never set.
- We cannot see stars near the south celestial pole.
- All other stars (and Sun, Moon, planets) rise in east and set in west.



Thought Question

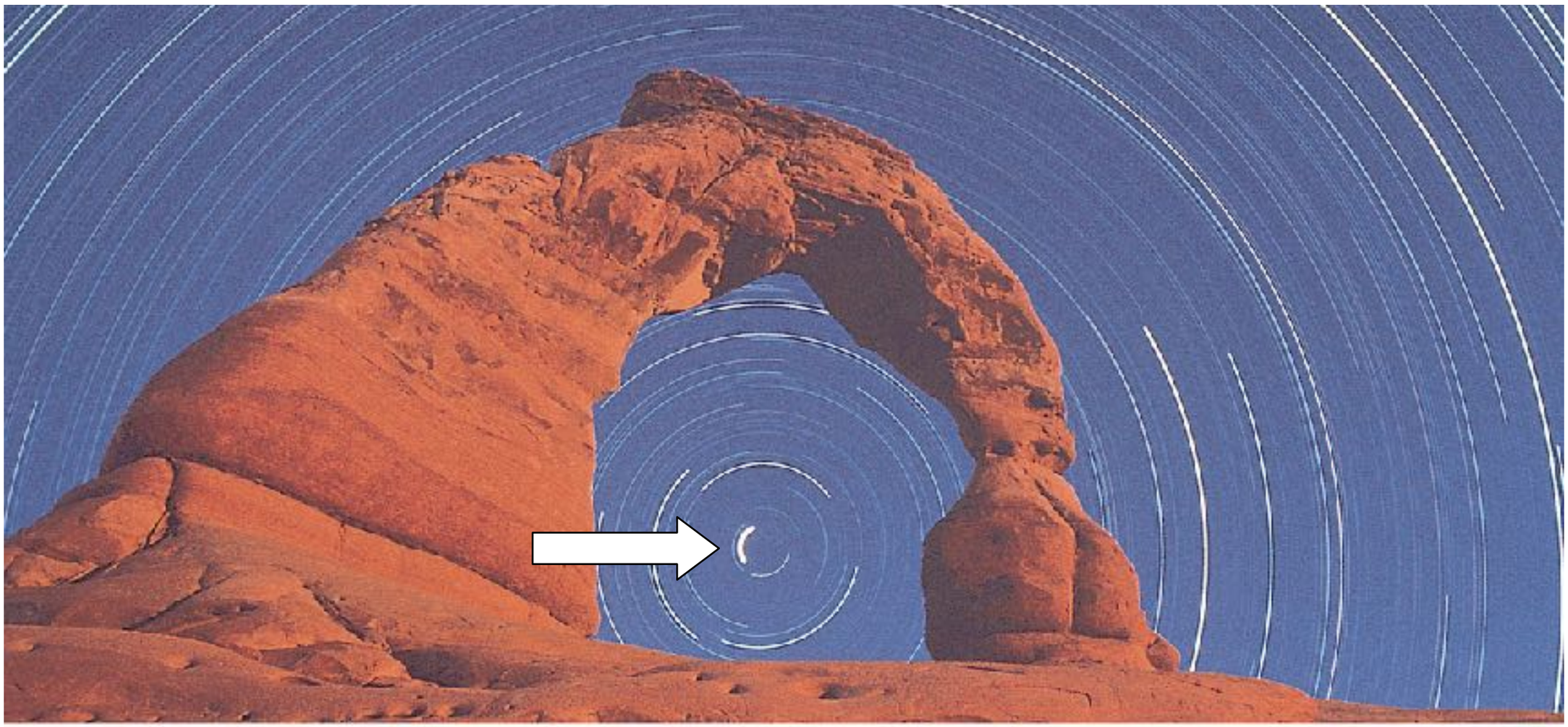
What is the arrow pointing to?



Thought Question

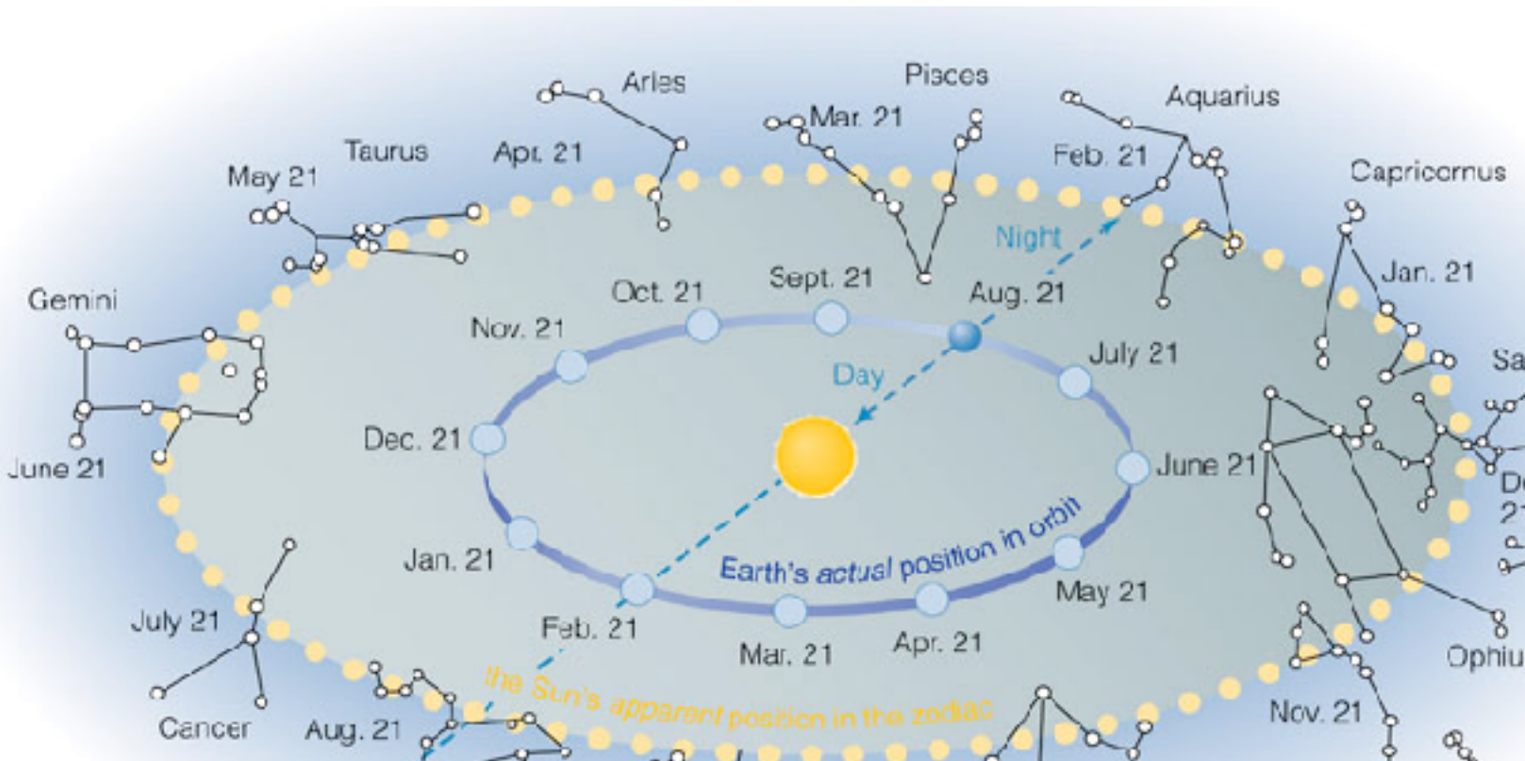
What is the arrow pointing to?

The North Star



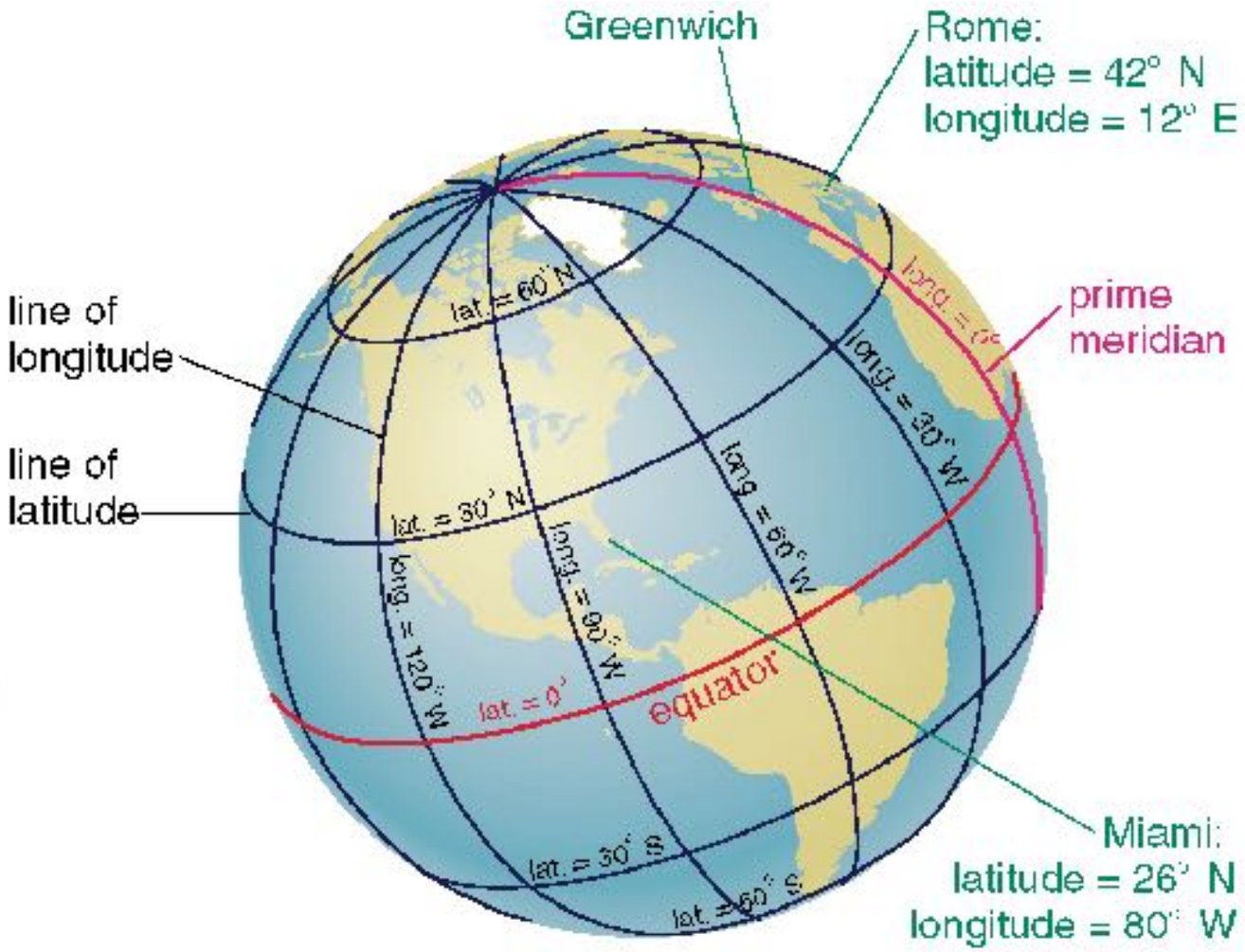
Why do the constellations we see depend on latitude and time of year?

- They depend on latitude because your position on Earth determines which constellations remain below the horizon.
- They depend on time of year because Earth's orbit changes the apparent location of the Sun among the stars.

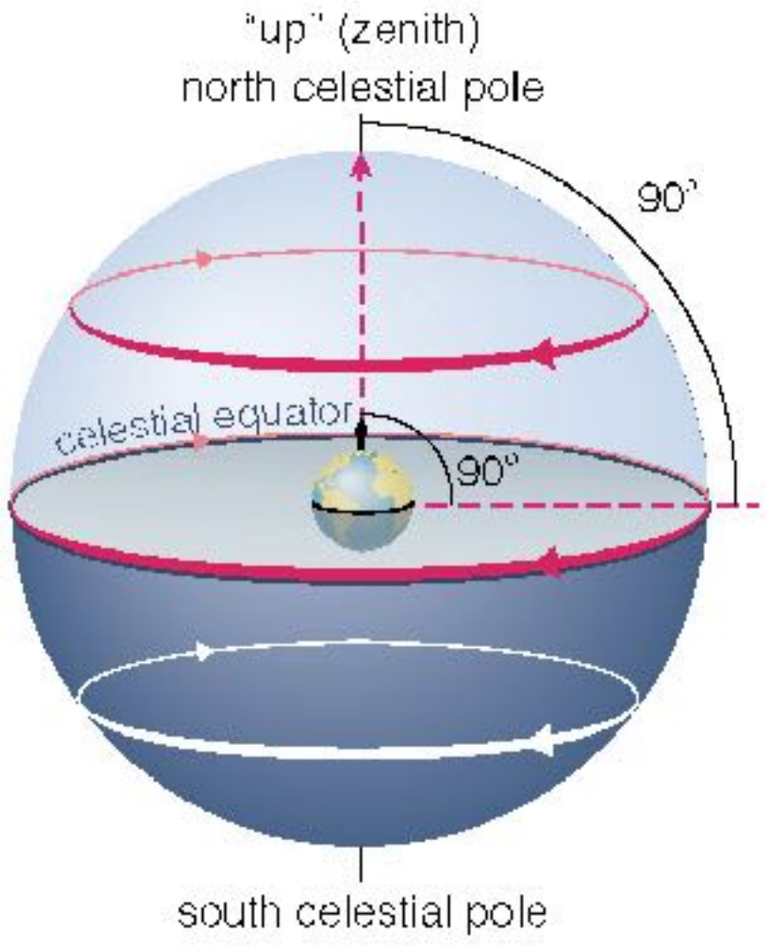


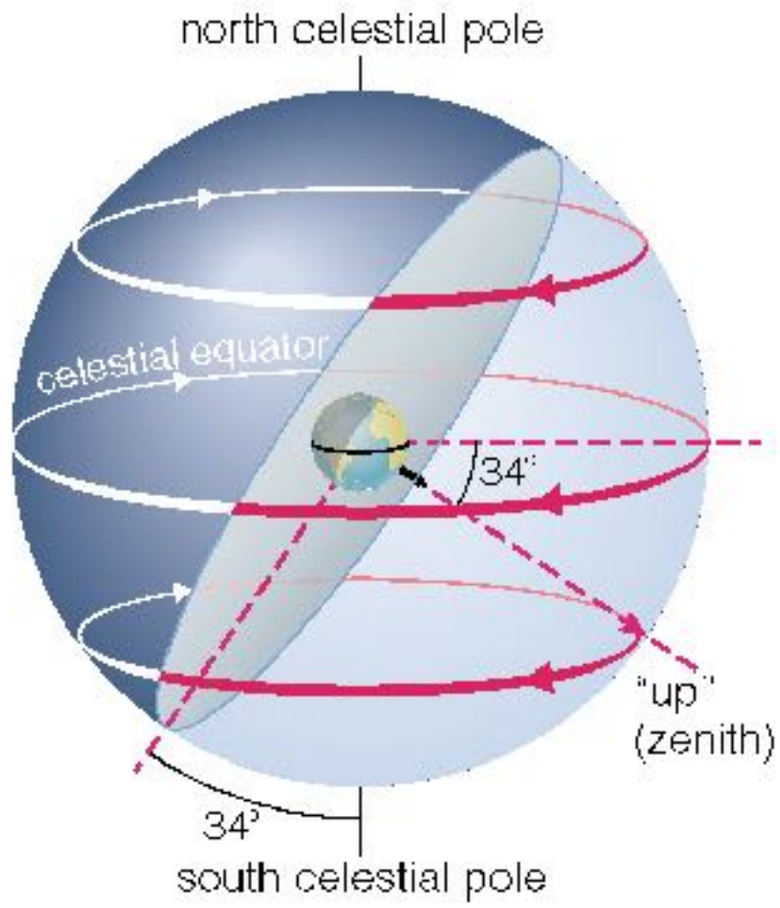
Review: Coordinates on the Earth

- Latitude: position north or south of equator
- Longitude: position east or west of prime meridian (runs through Greenwich, England)

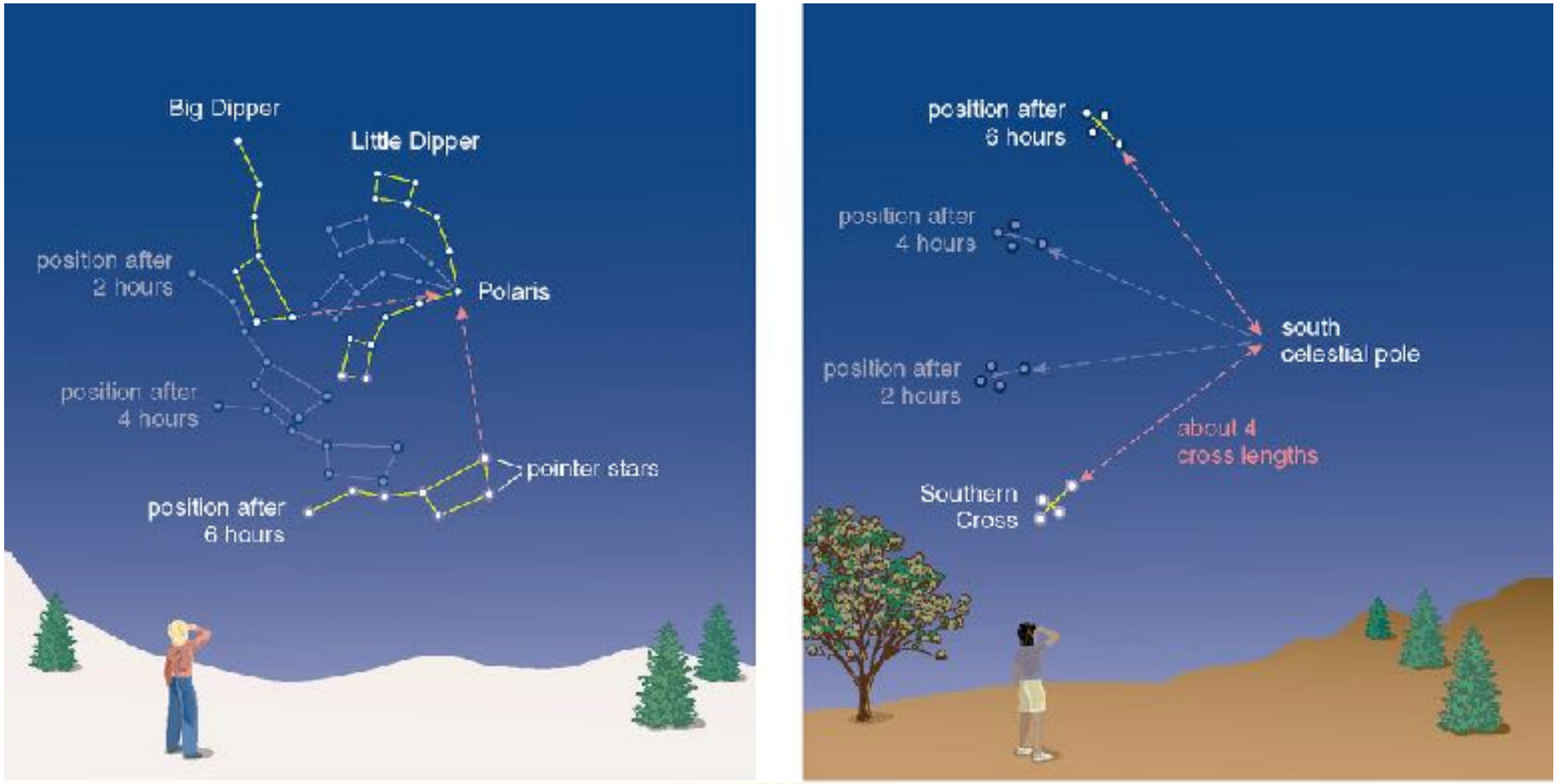


The sky varies with latitude but not longitude.





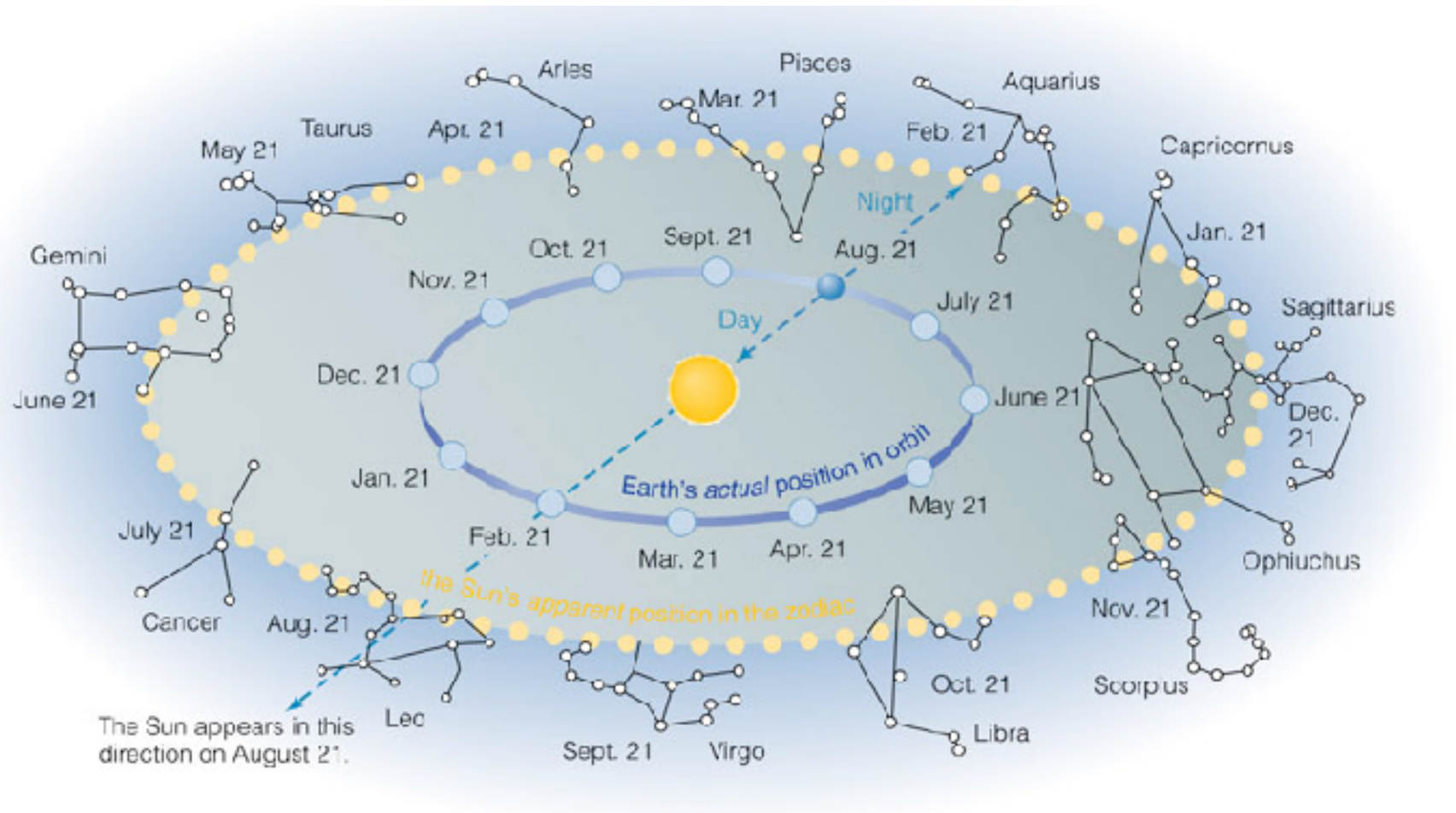
Altitude of the celestial pole = your latitude



Interactive Figure

The sky varies as Earth orbits the Sun

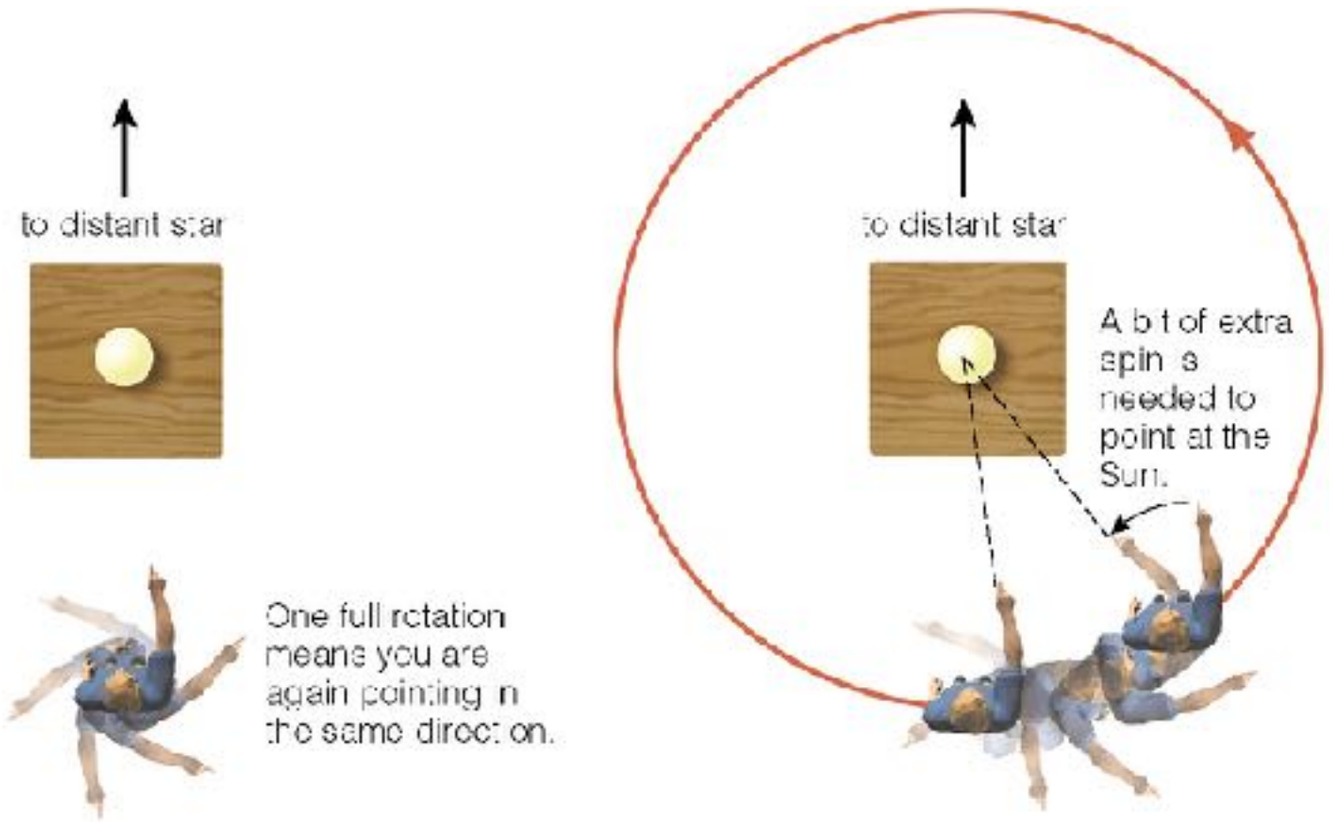
- As the Earth orbits the Sun, the Sun appears to move eastward along the ecliptic.
- At midnight, the stars on our meridian are opposite the Sun in the sky.

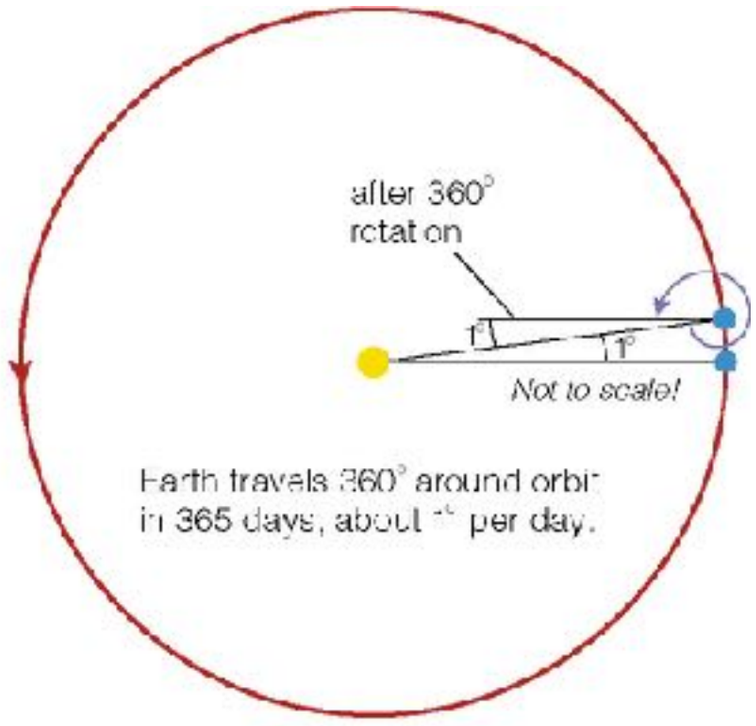


https://www.youtube.com/watch?v=x1DqwC7lRpk

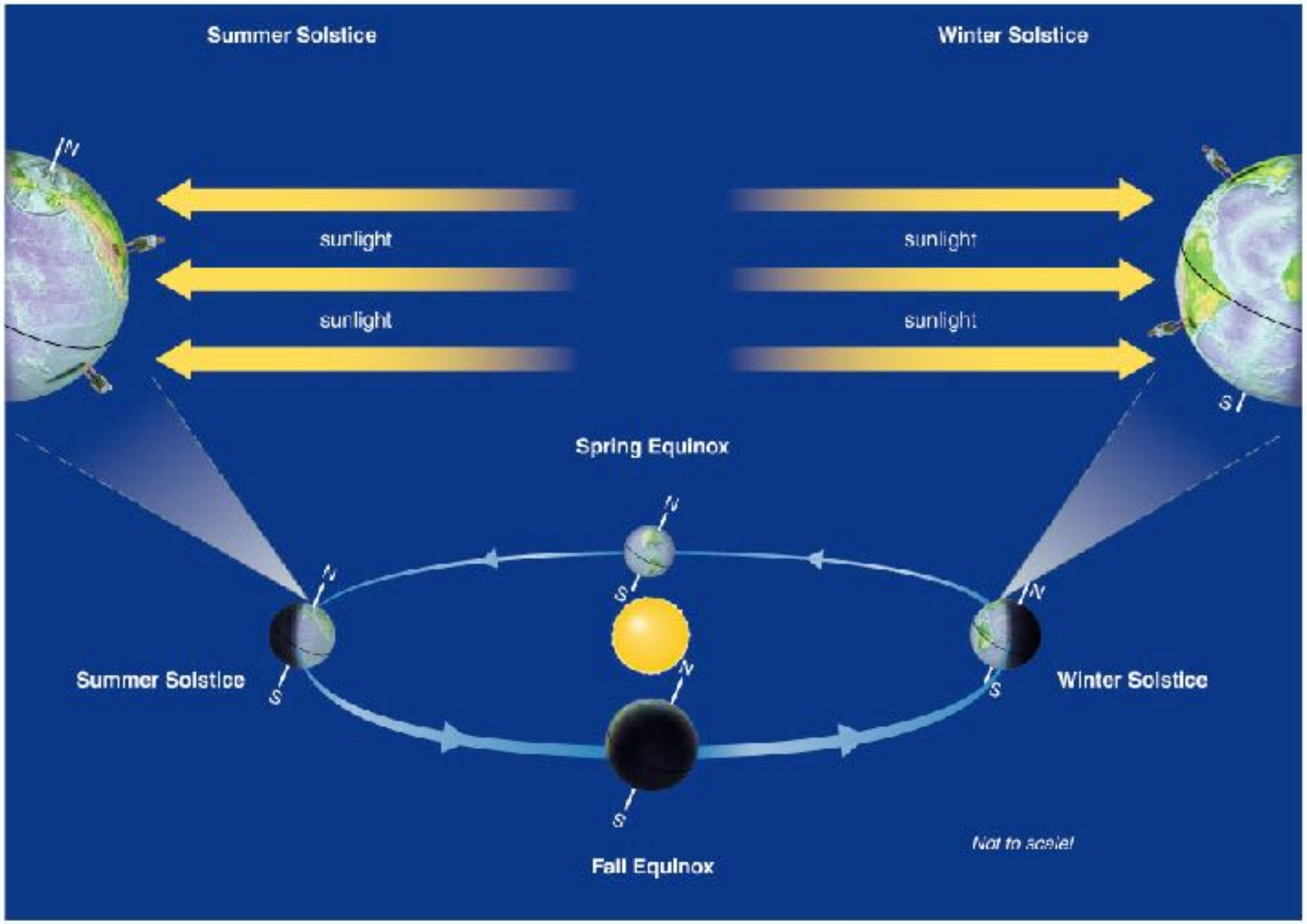
Solar & Sidereal Day

- **Solar** day = 24:00 hours (noon to noon)
  - combination of Earth's spin
  - plus Earth's orbital motion
- **Sidereal** day (Earth's spin period) = 23:56
  - time between meridian crossings of one star



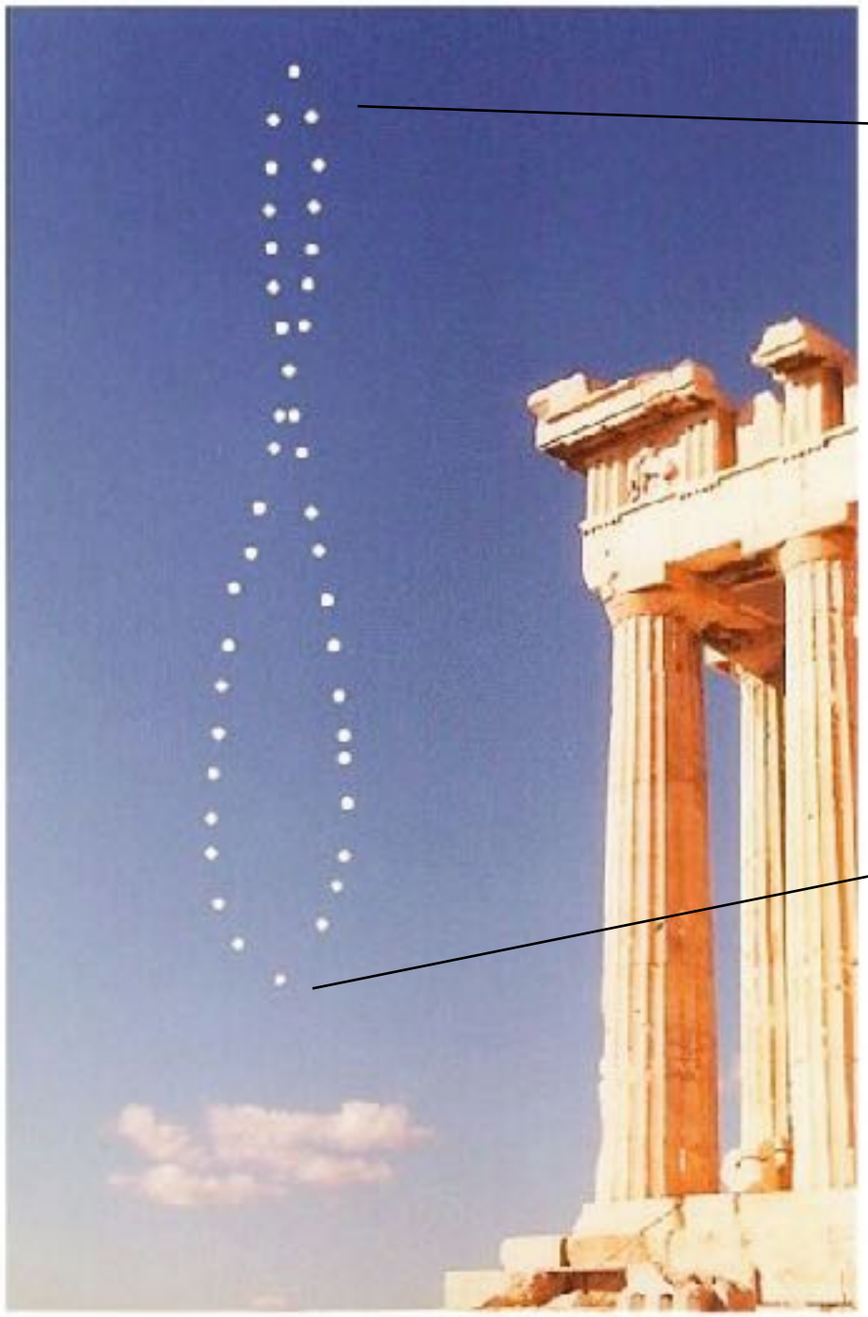


What causes the seasons?



Seasons depend on how Earth's axis affects the directness of sunlight.

Sun's altitude also changes with seasons



Sun's position at noon in summer: higher altitude means more direct sunlight.

Sun's position at noon in winter: lower altitude means less direct sunlight.

Summary: The Reason for Seasons

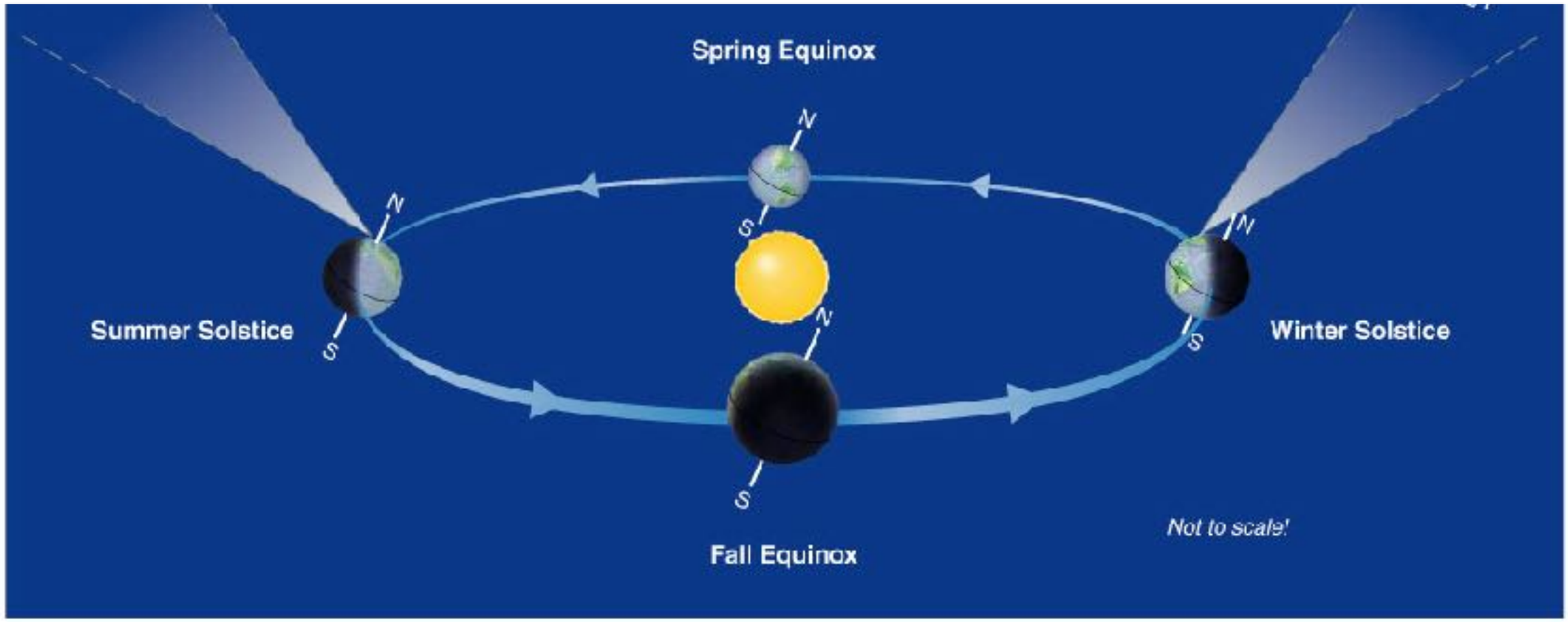
- Earth's axis points in the same direction (to Polaris) all year round, so its orientation *relative to the Sun* changes as Earth orbits the Sun.
- Summer occurs in your hemisphere when sunlight hits it more directly; winter occurs when the sunlight is less direct.
- **AXIS TILT** is the key to the seasons; without it, we would not have seasons on Earth.
- DISTANCE from the sun matters relatively little because the Earth's orbit is *nearly* circular. The variation of the Earth-Sun distance is only about 3%.

Distance variation could matter (e.g., for comets); it just isn't an important factor for the Earth.

Hypothesis check: how would seasons in the northern and southern hemisphere relate if distance from the sun caused the seasons?

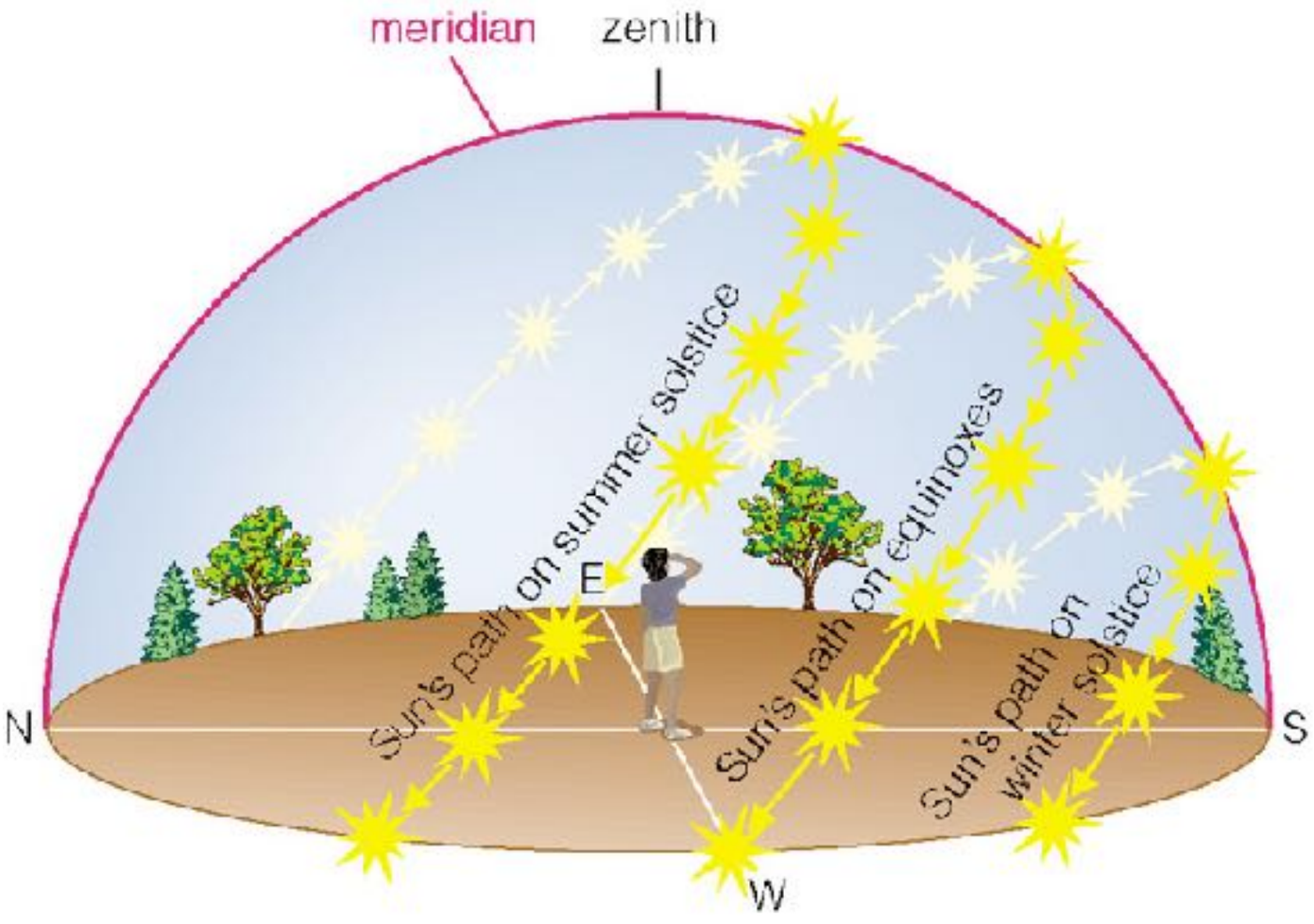
How do we mark the progression of the seasons?

- We define four special points:
  - summer solstice
  - winter solstice
  - spring (vernal) equinox
  - fall (autumnal) equinox



Fall equinox 2 weeks from Friday

We can recognize solstices and equinoxes by Sun's path across the sky.

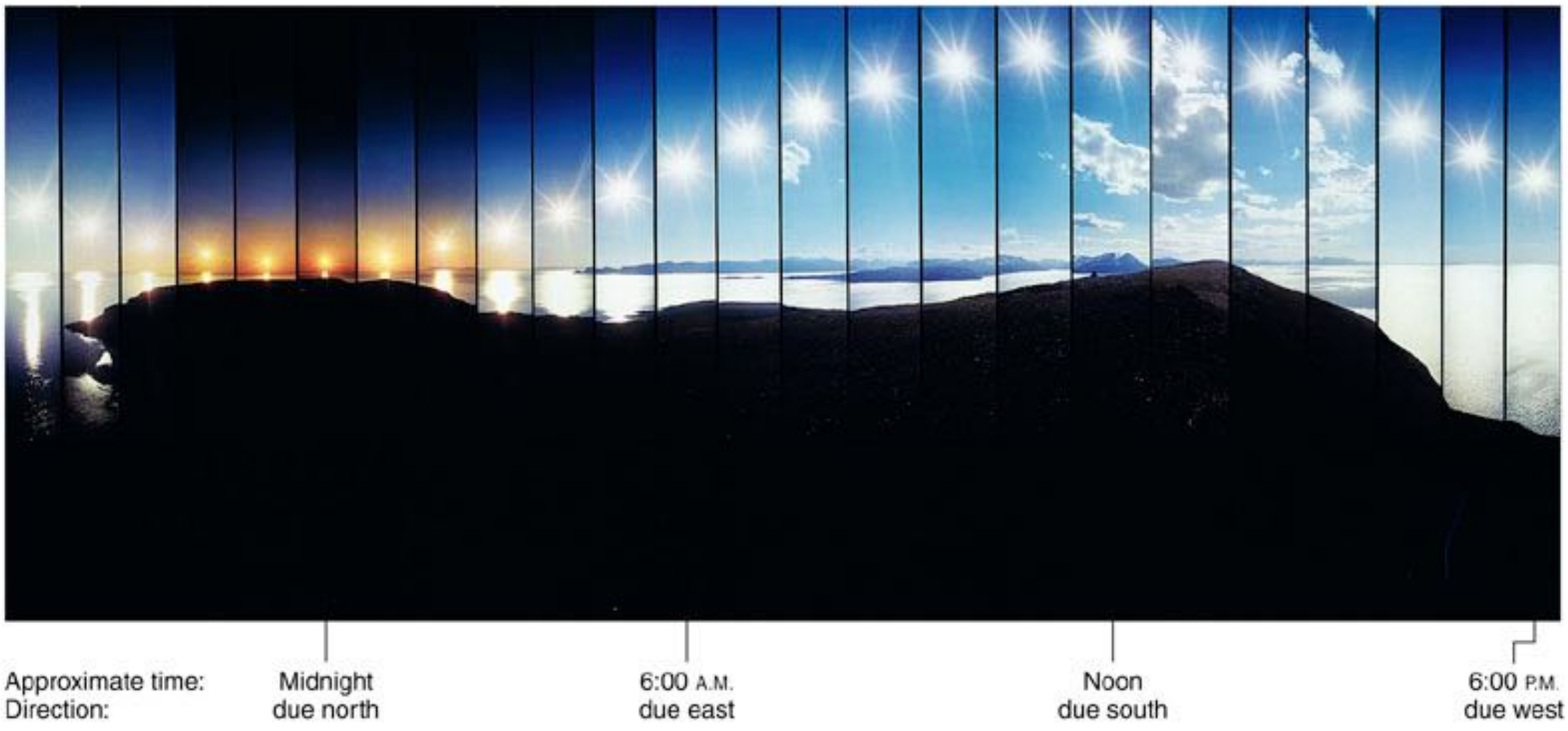


Summer solstice: Highest path, rise and set at most extreme north of due east

Winter solstice: Lowest path, rise and set at most extreme south of due east

Equinoxes: Sun rises precisely due east and sets precisely due west.

Seasonal changes are more extreme at high latitudes.

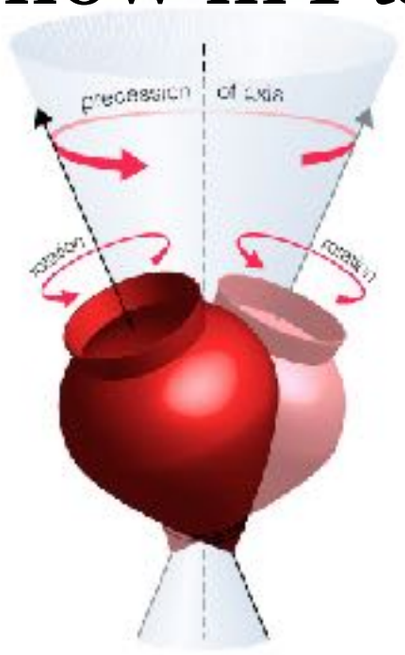


Path of the Sun on the summer solstice at the Arctic Circle

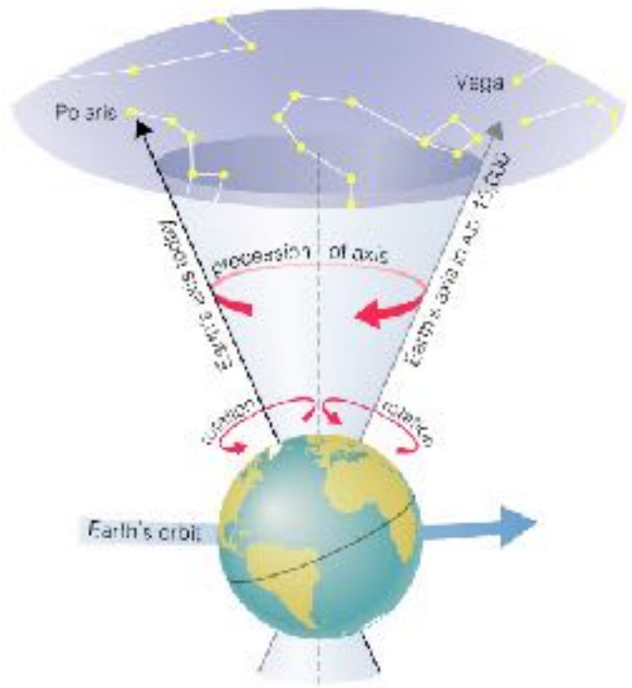
How does the orientation of Earth's axis change with time?

Precession:

- Although the axis seems fixed on human time scales, it actually precesses over about 26,000 years.
  - — Polaris won't always be the North Star.
  - — Positions of equinoxes shift around orbit; for example, the spring equinox, once in *Aries*, is now in *Pisces*!



Earth's axis precesses like the axis of a spinning top.



https://www.youtube.com/watch?v=Dw4Xhw4q4ec

What have we learned?

- How do we mark the progression of the seasons?
  - The **summer and winter solstices** are when the Northern Hemisphere gets its most and least direct sunlight, respectively. The **spring and fall equinoxes** are when both hemispheres get equally direct sunlight.
- How does the orientation of Earth's axis change with time?
  - The tilt remains about 23.5 degrees (so the season pattern is not affected), but Earth has a 26,000 year **precession** cycle that slowly and subtly changes the orientation of the Earth's axis.