Today

- Appearance of the Sky
  - Orientation
  - Motion of sky
  - Seasons
  - Precession

Course News

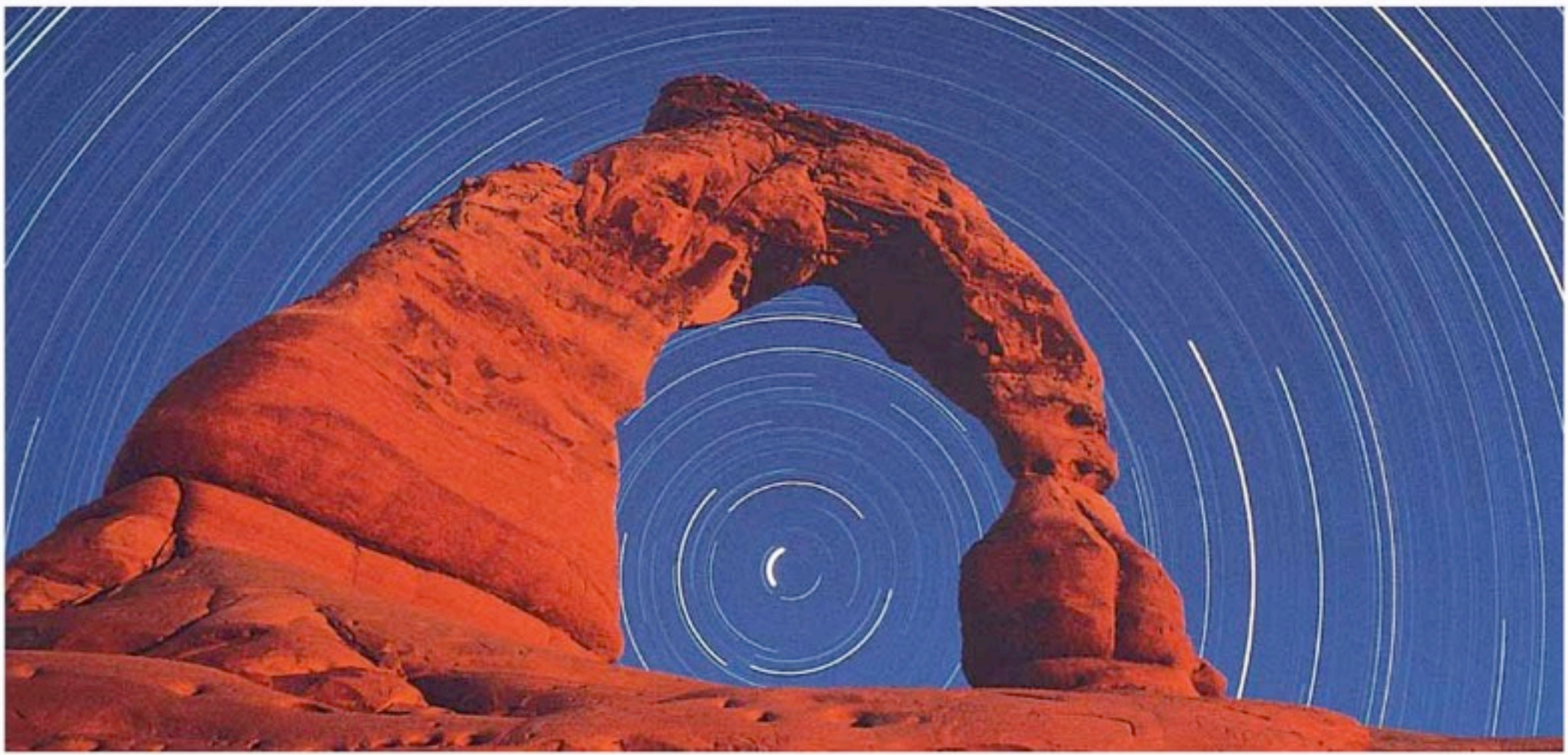
An interesting question was posed in class: How fast would the Earth have to spin to notice it? It turns out that it would take a rather modest (by astronomical standards) increase in the spin rate to have noticable effects. The acceleration we feel towards the center of the earth is 9.8 m/s/s. The acceleration due to the centrifugal force *at the equator* is the radius of the earth times the square of the frequency with which it turns. Equating this to 9.8 m/s/s and looking up that the radius of the earth is 6378 km leads to a spin period of 1.4 hours (instead of the usual 24). That's a "mere" 17 times faster - to completely counterbalance gravity!

It gets weirder. This means you'd sorta float on an earth moving this fast - at the equator. Off the equator the vector direction of the centrifugal and gravitational forces are different, so they wouldn't exactly cancel. So you'd still fall to the ground, but you'd also feel a tug at an angle that depends on your latitude, fading as you got closer to the poles (the central axis of this giant merry-go-round).

As we'll learn, the Earth did spin somewhat faster in the past, amounting to a day that is shorter by a few hours at the time of the dinosaurs. While they were in no danger of being flung off the face of the earth, some of them had big enough strides that maybe that could feel a little coriolis tug as they plodded around. This would feel like trying to walk on a merry-go-round; their foot would feel a little tug to the side of where they meant to put it down.

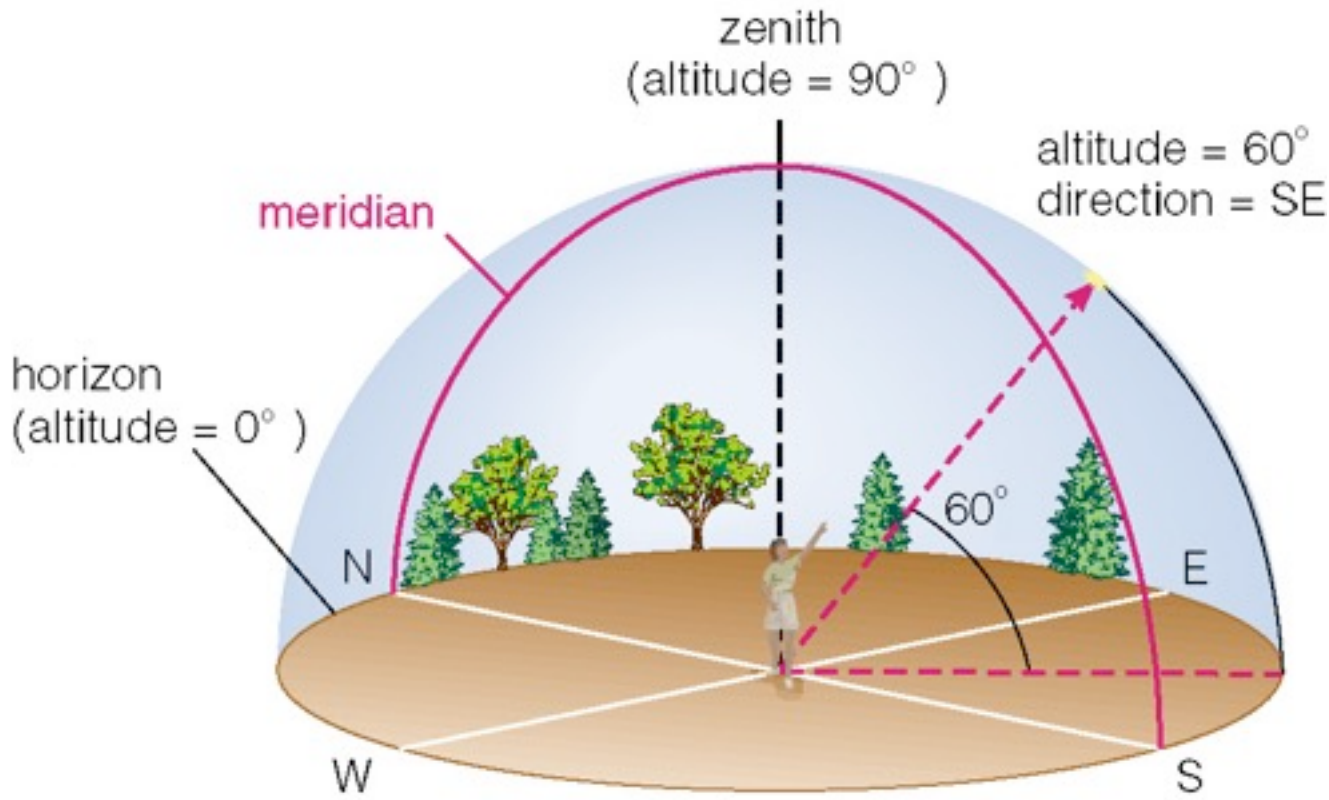
A modern demonstration of this can be seen at the Natural History Museum, where hangs a Foucault Pendulum. The fictitious force we're talking about happens because the Earth moves a little underneath the pendulum (or the dinosur's leg) with every swing.

The Appearance of the Sky

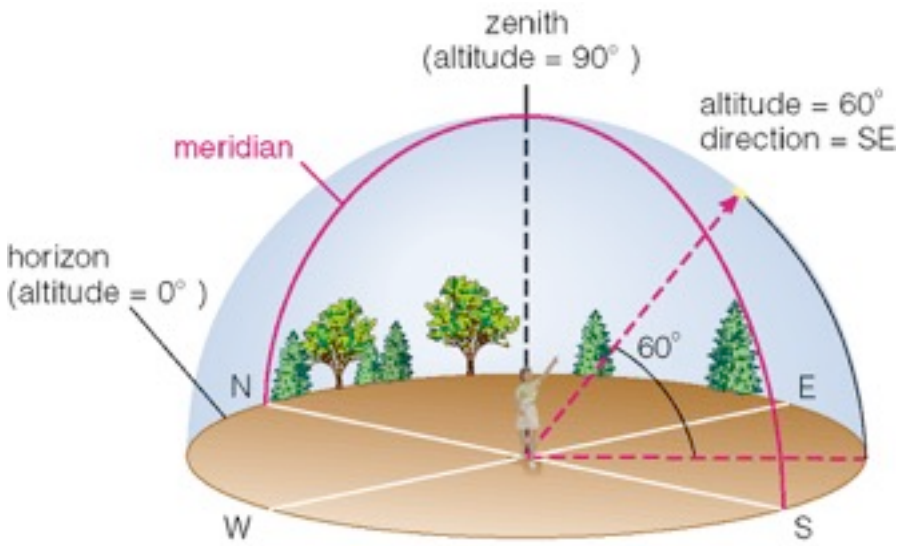


The Local Sky

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



The Local Sky

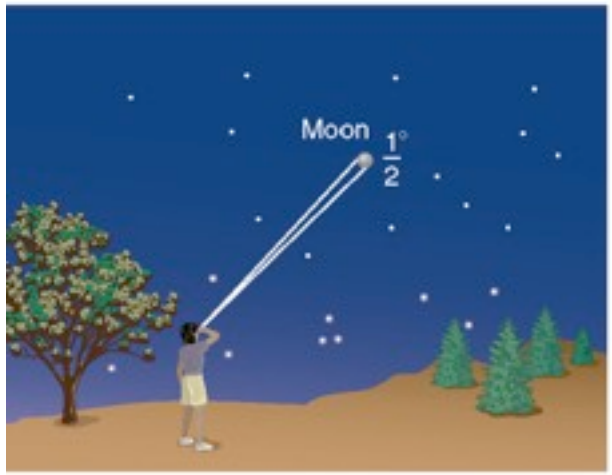


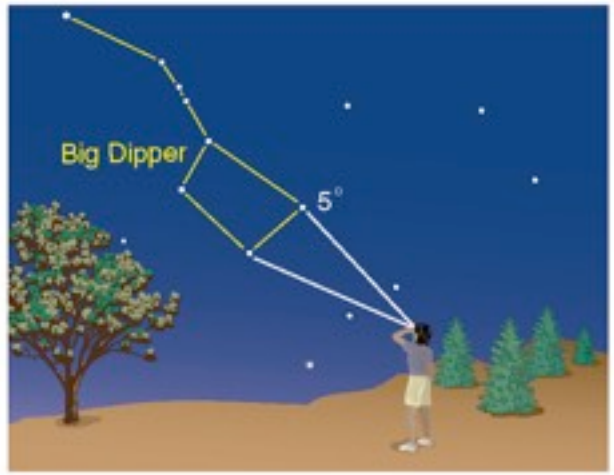
Zenith: The point directly overhead

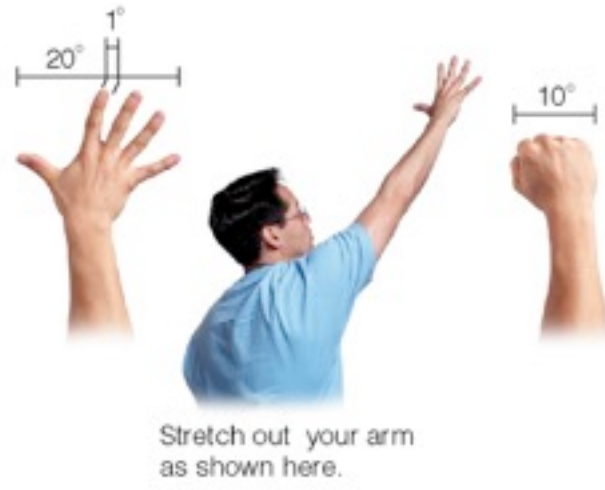
Horizon: All points 90° away from zenith

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

We measure the sky using *angles*

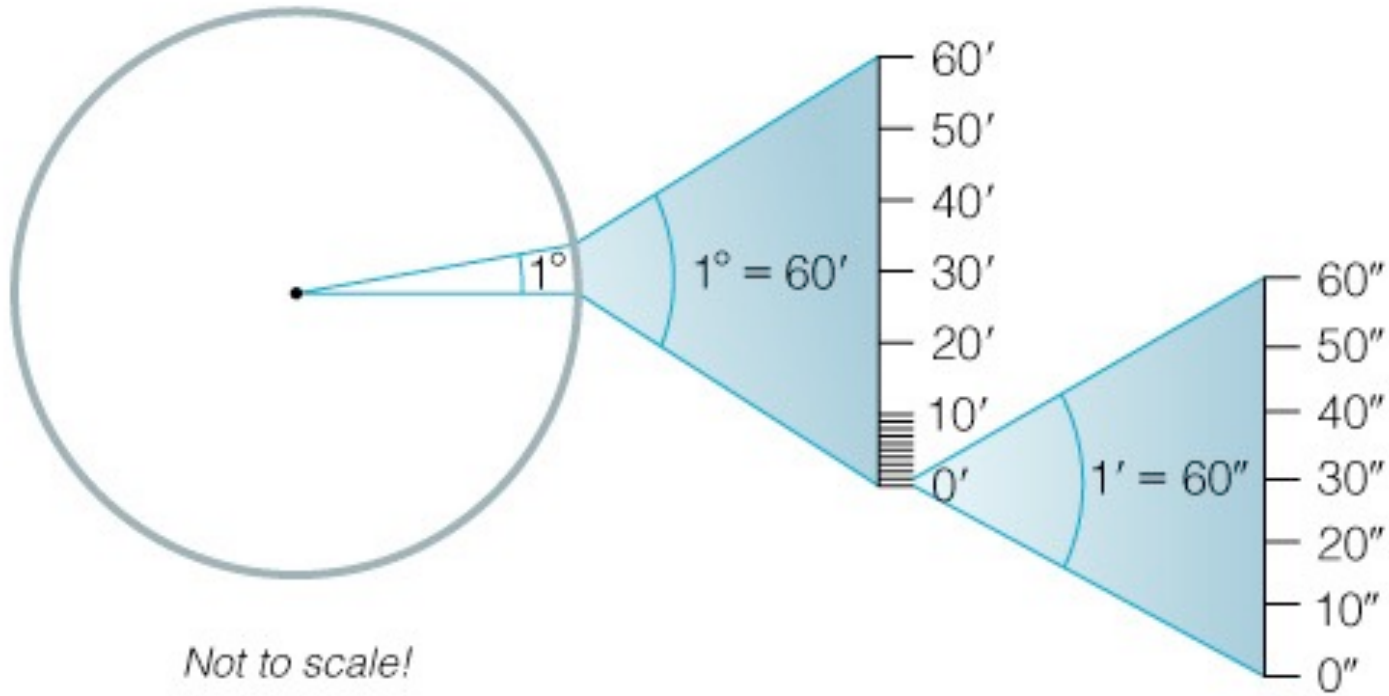






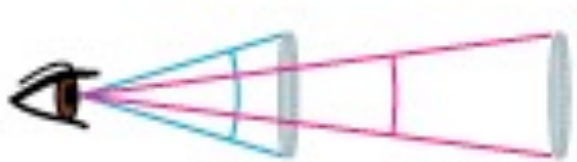
Angular Measurements

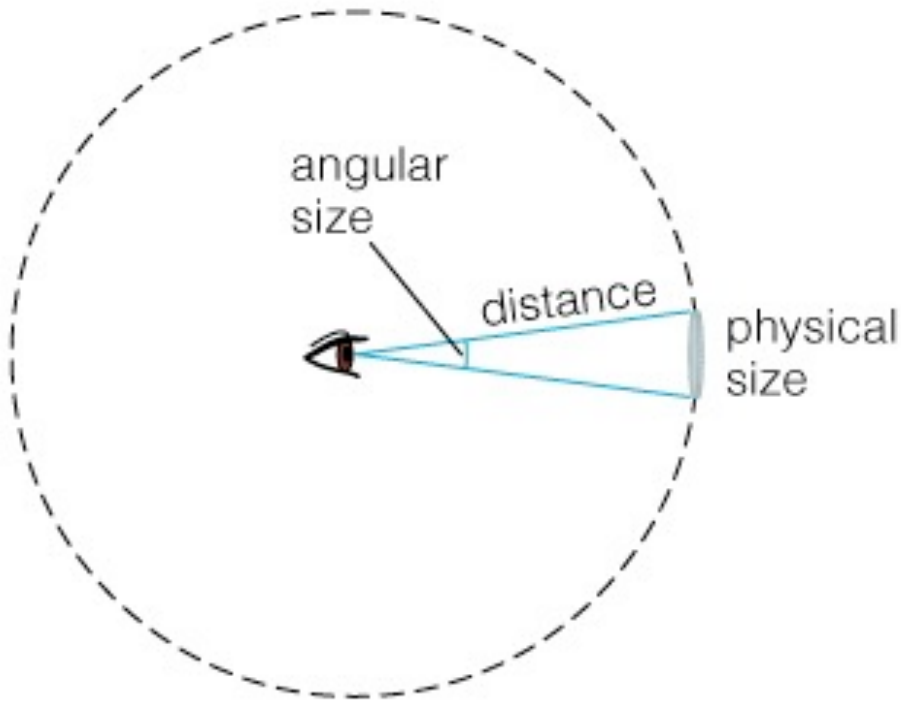
- Full circle = 360º
- 1º = 60′ (arcminutes)
- 1′ = 60″ (arcseconds)



Angular Size

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



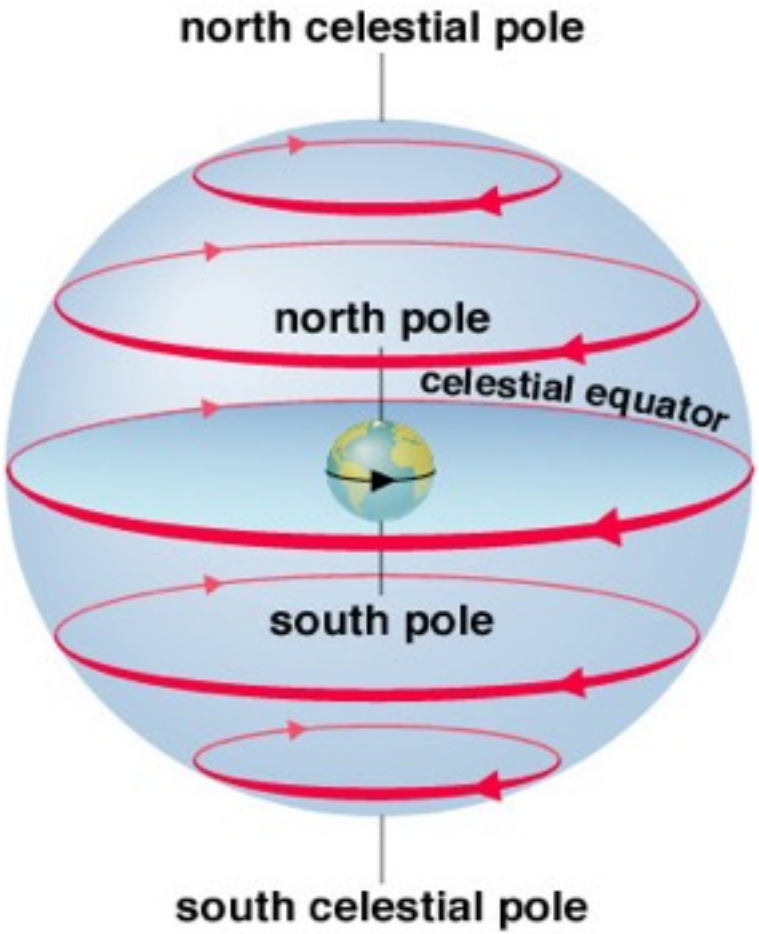


An object's angular size appears smaller if it is farther away.

$$\theta = L/D$$

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

Why do stars rise and set?

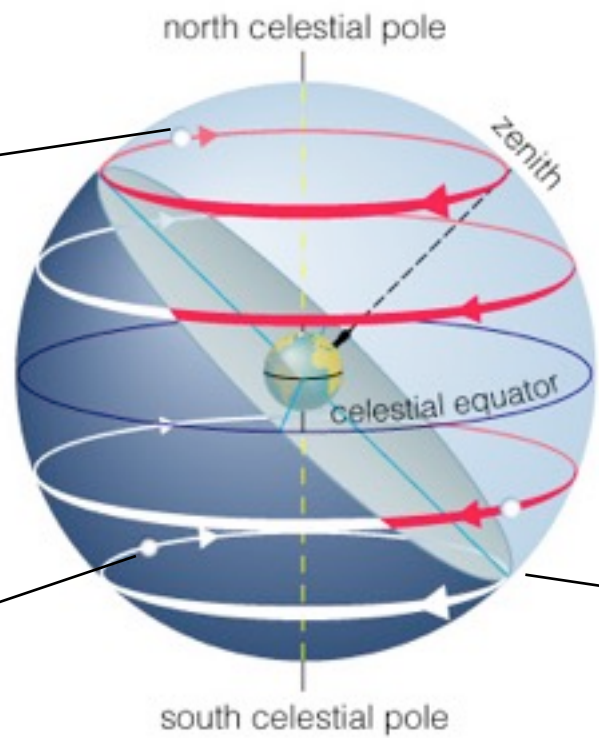


Earth rotates west to east, so stars appear to circle from east to west.

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.



A circumpolar star never sets

Celestial equator

This star never rises

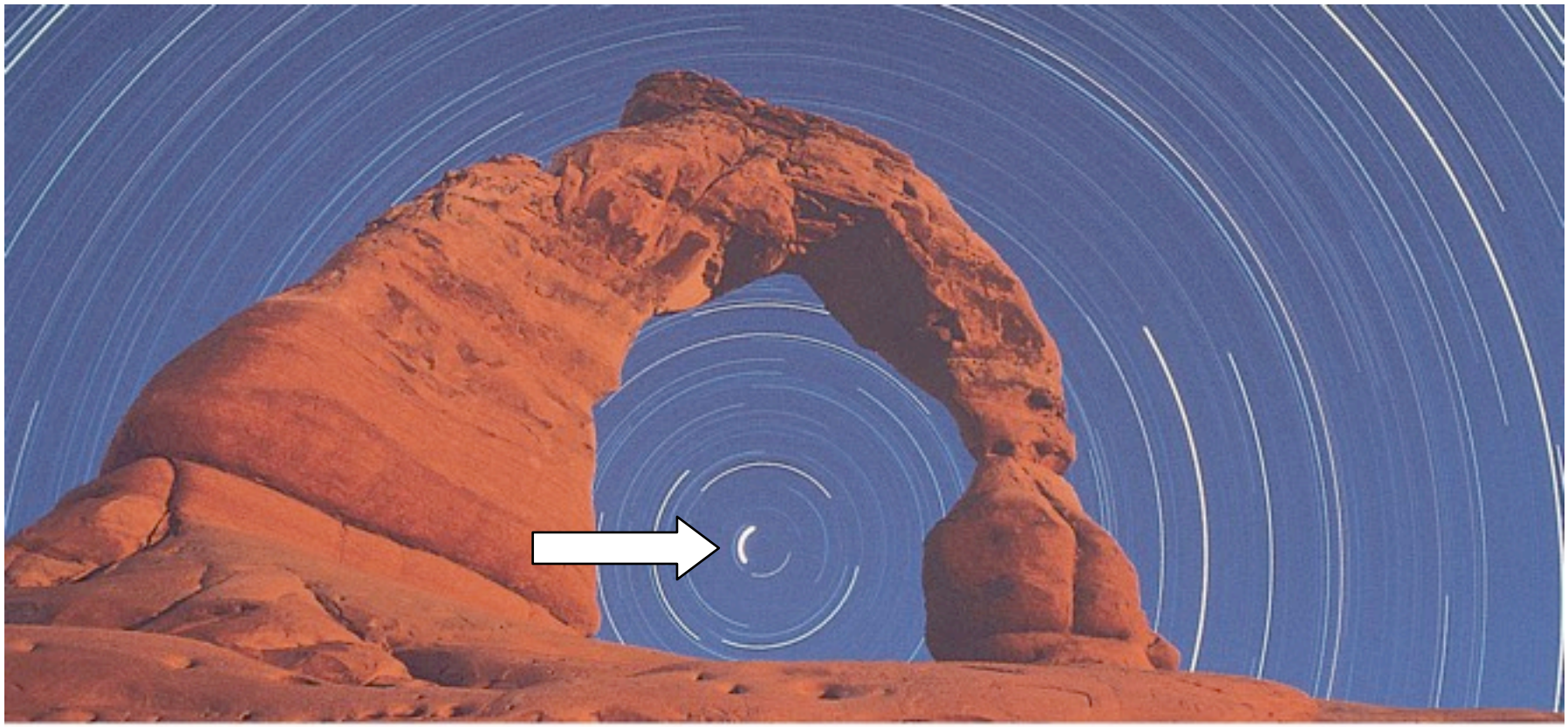
Your horizon

PLAY 02_01

Thought Question

What is the arrow pointing to?

The North Star

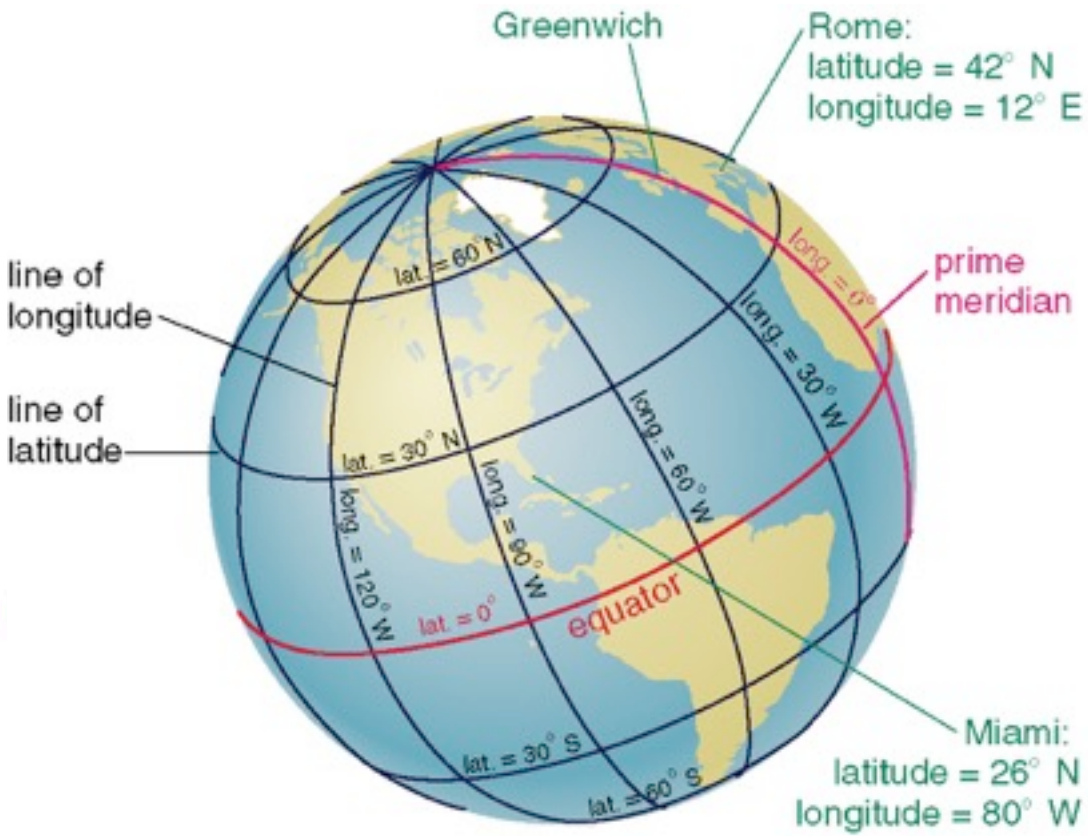


Why do the constellations we see depend on latitude and time of year?

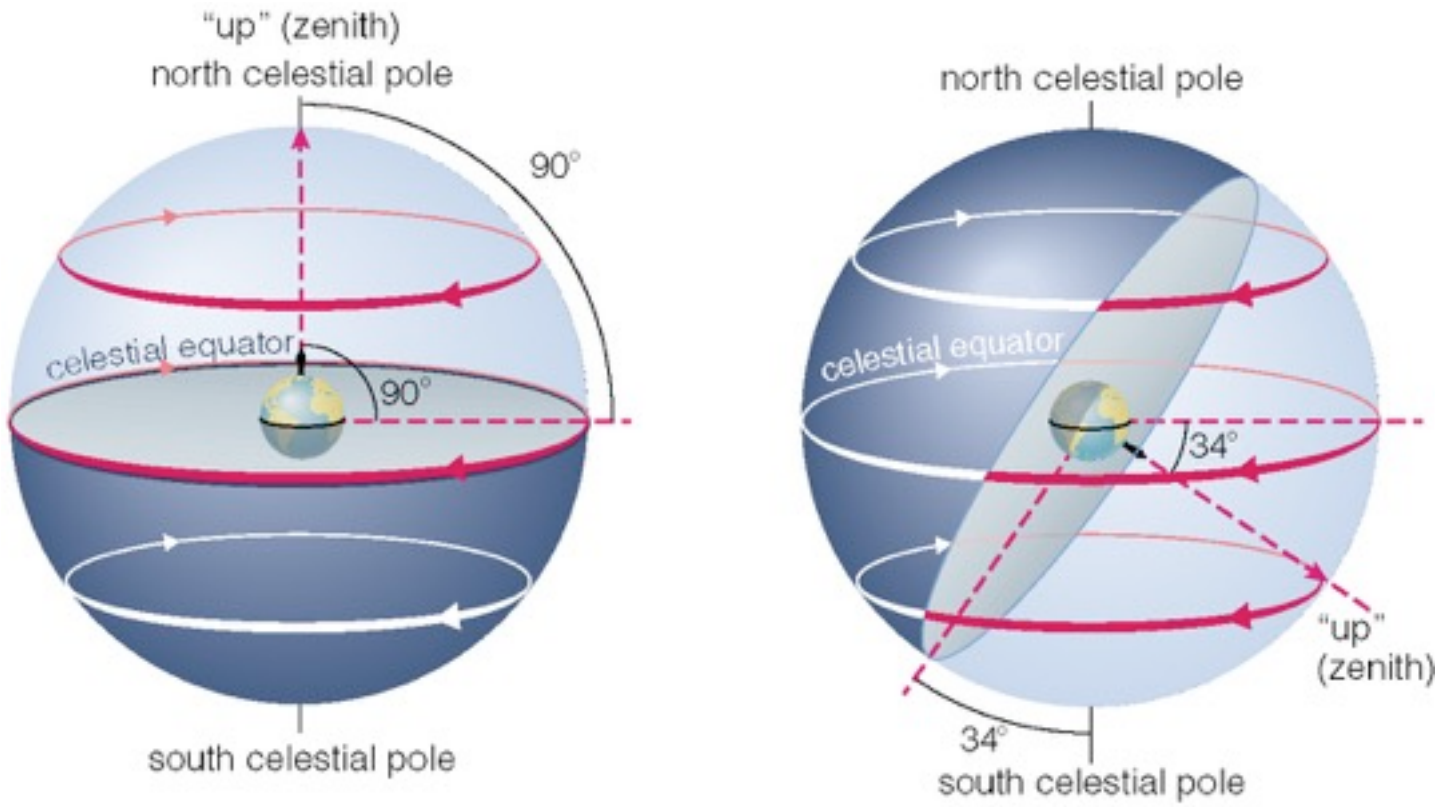
- They depend on latitude because your position on Earth determines which constellations remain below the horizon.
- They depend on time of year because Earth's orbit changes the apparent location of the Sun among the stars.

Review: Coordinates on the Earth

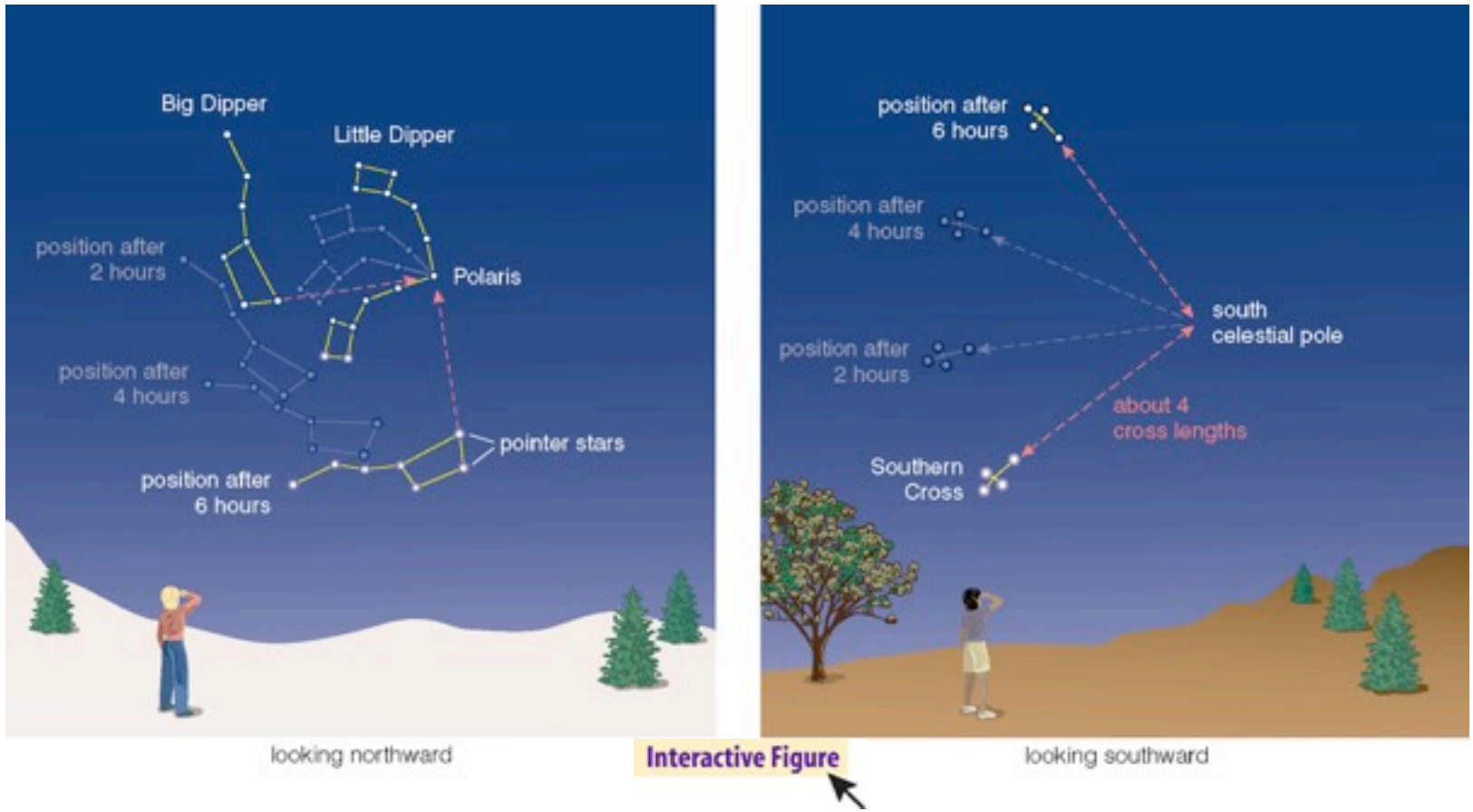
- Latitude: position north or south of equator
- Longitude: position east or west of prime meridian (runs through Greenwich, England)



The sky varies with latitude but not longitude.



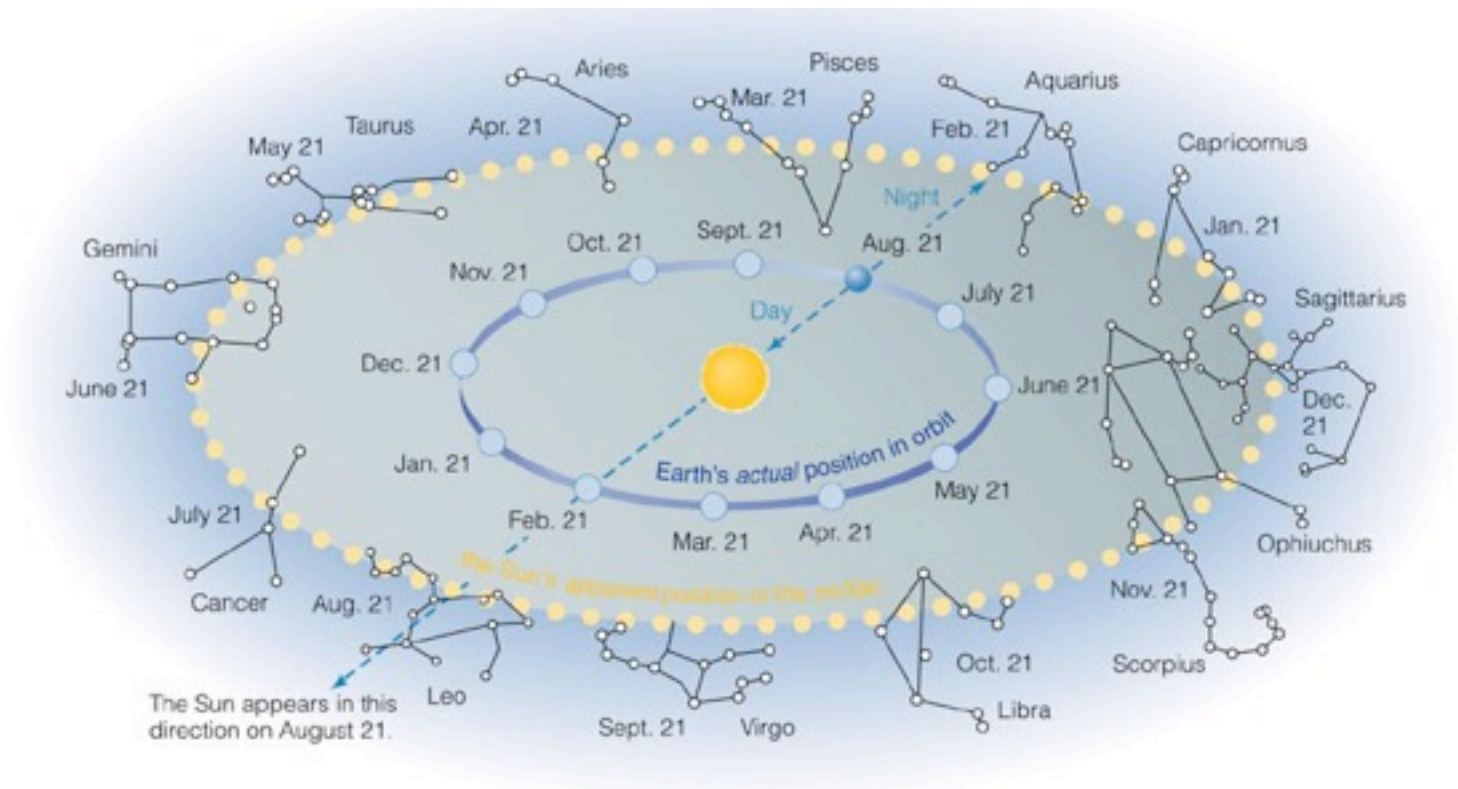
Altitude of the celestial pole = your latitude



PLAY 02_02

The sky varies as Earth orbits the Sun

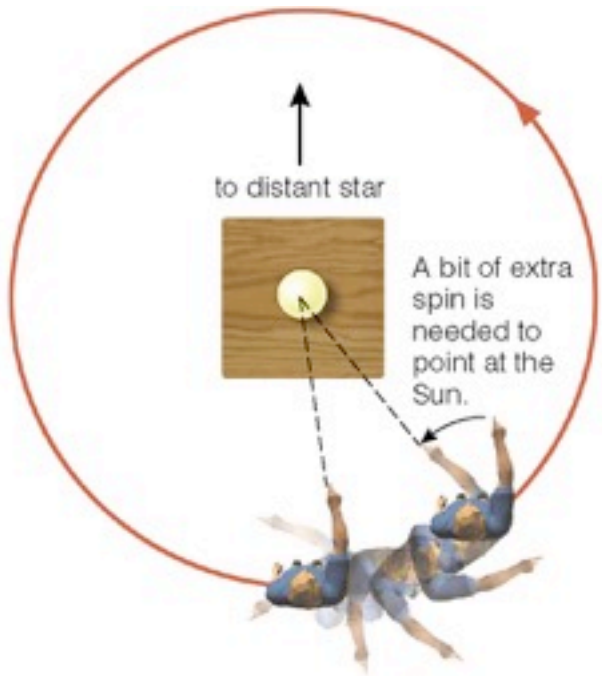
- As the Earth orbits the Sun, the Sun appears to move eastward along the ecliptic.
- At midnight, the stars on our meridian are opposite the Sun in the sky.

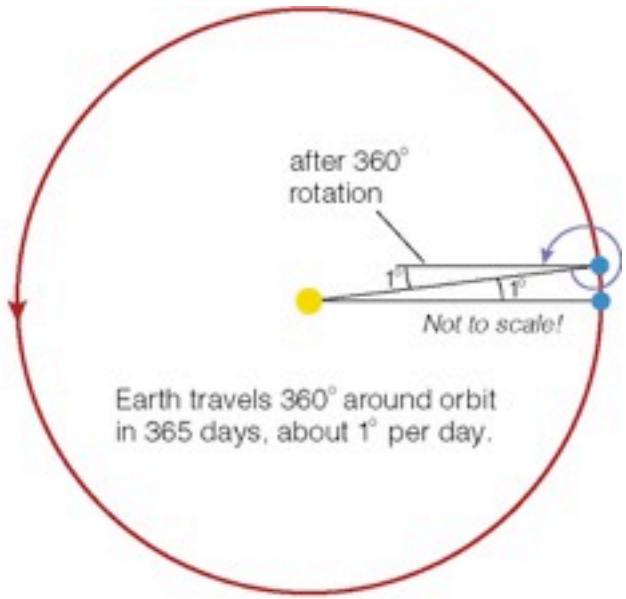


PLAY 02_03 Sun's Apparent Path through the Zodiac

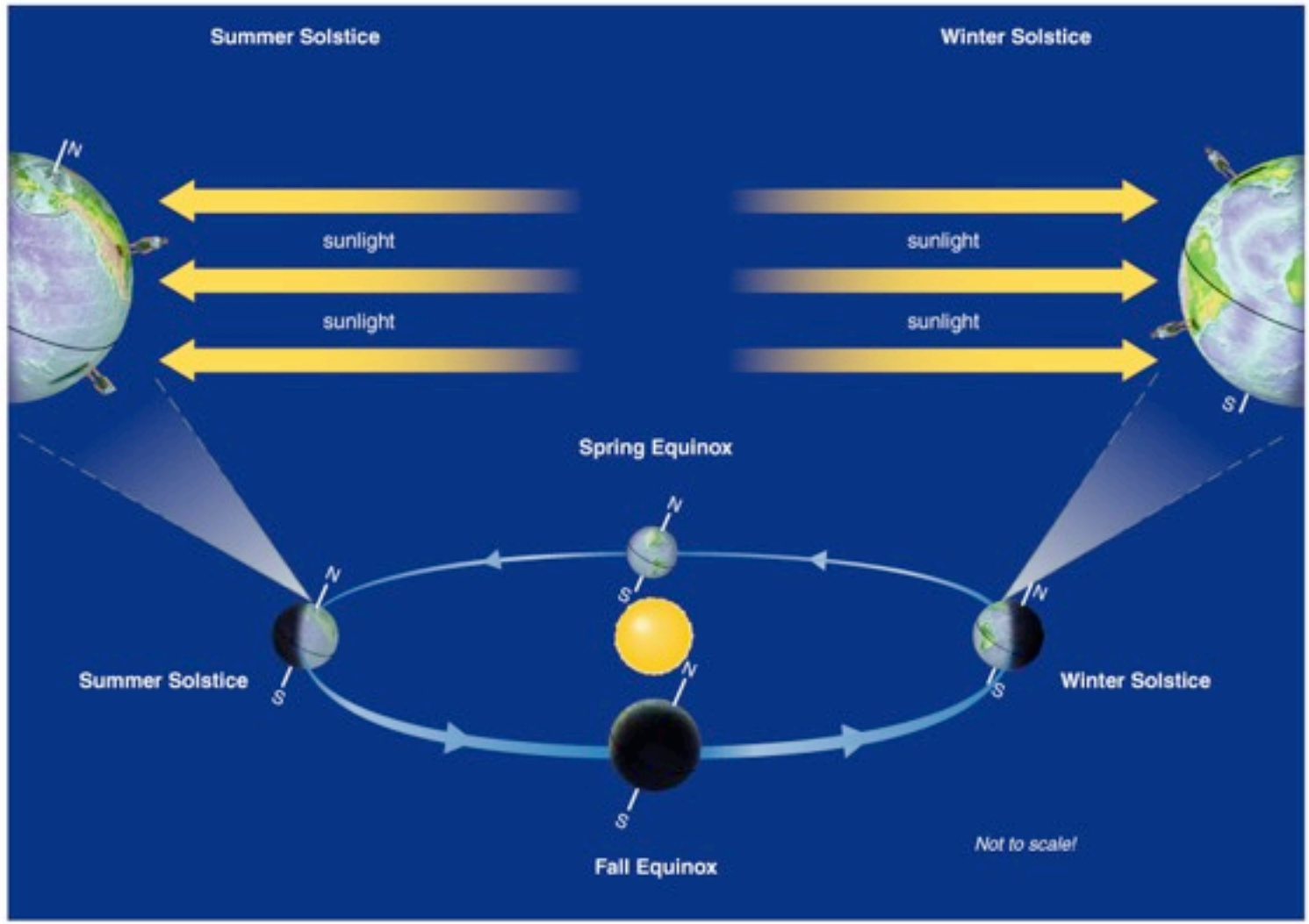
Solar & Sidereal Day

- **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



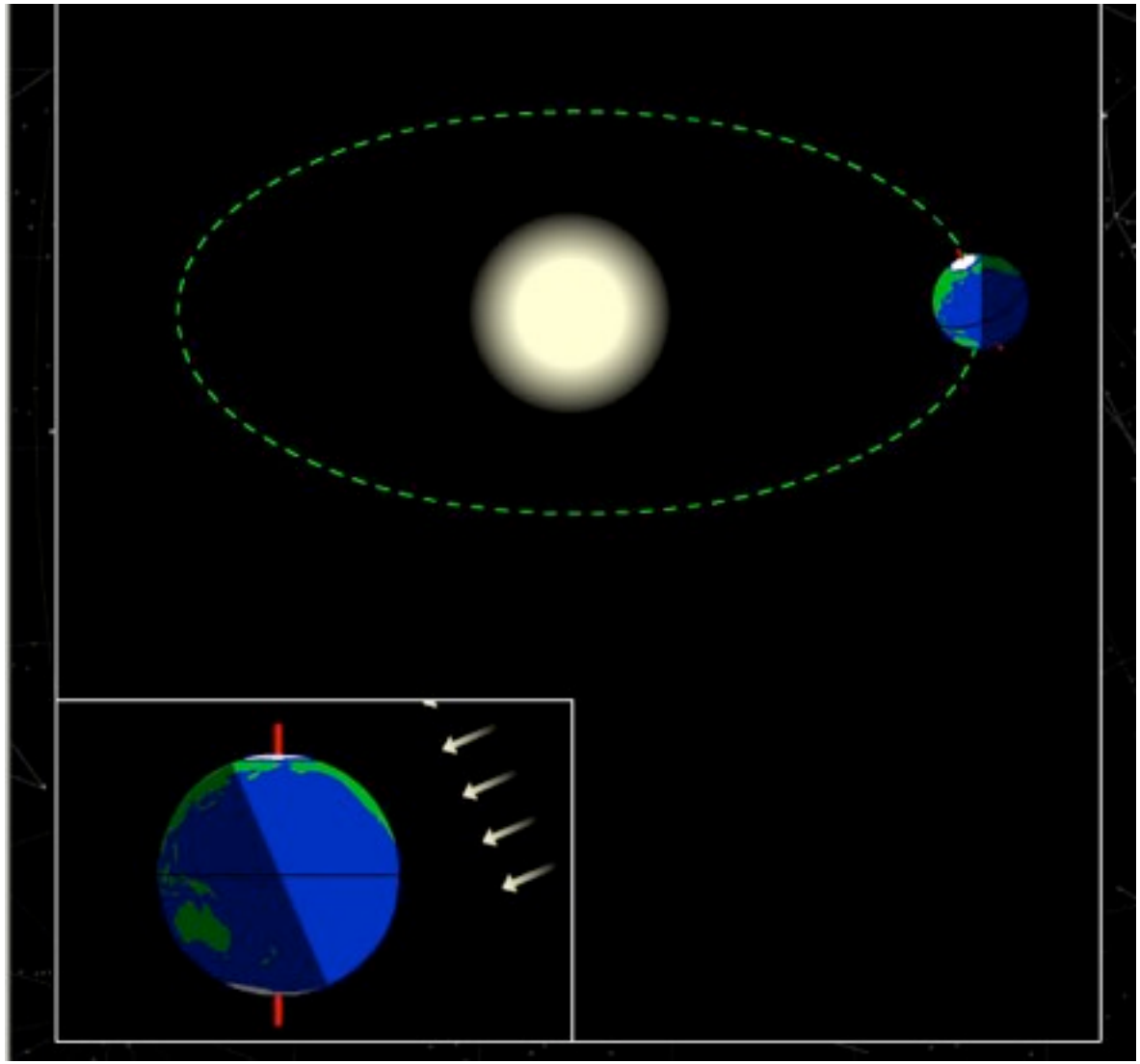


What causes the seasons?



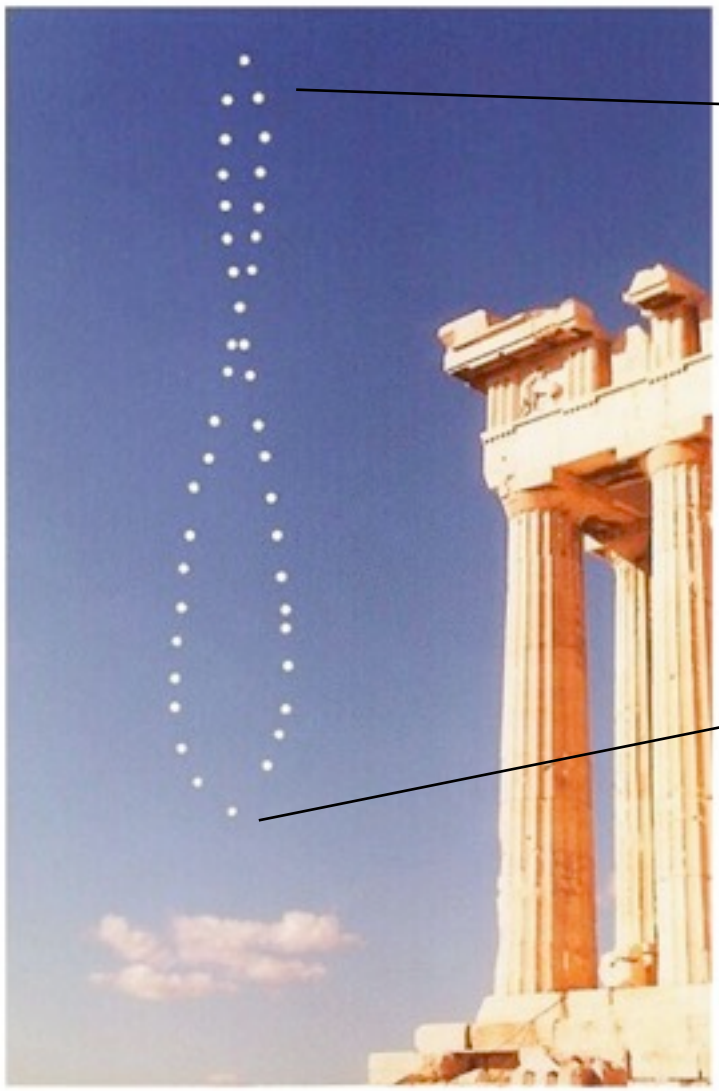
Seasons depend on how Earth's axis affects the directness of sunlight.

Axis tilt changes directness of sunlight during the year.



PLAY 02_04

Sun's altitude also changes with seasons



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

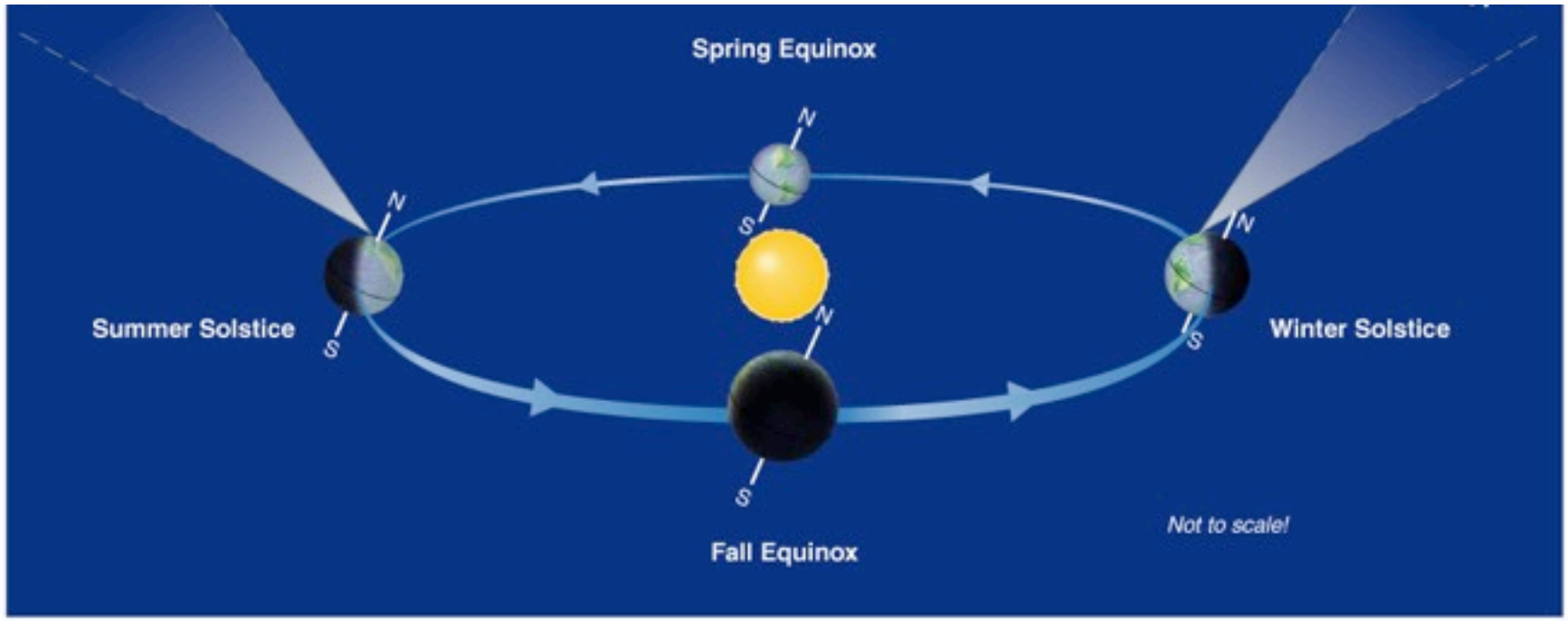
Sun's position at noon in winter: lower altitude means less direct sunlight.

Summary: The Reason for Seasons

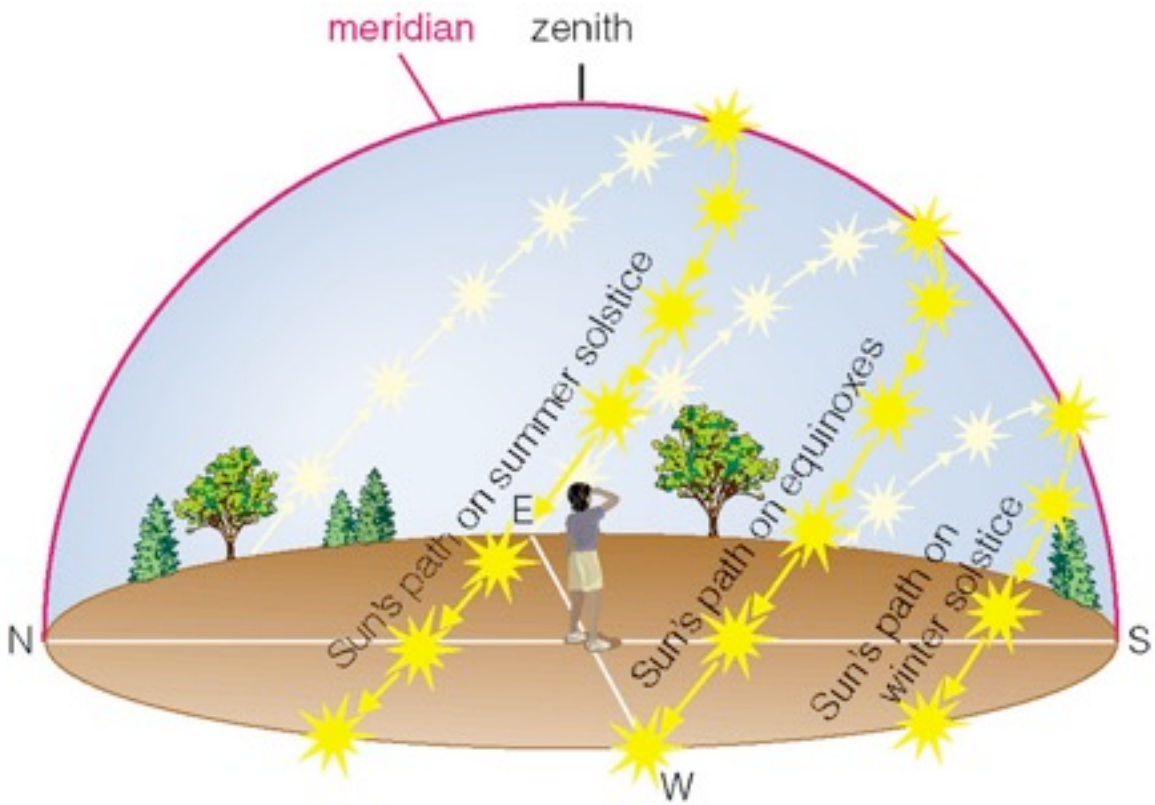
- Earth's axis points in the same direction (to Polaris) all year round, so its orientation *relative to the Sun* changes as Earth orbits the Sun.
- Summer occurs in your hemisphere when sunlight hits it more directly; winter occurs when the sunlight is less direct.
- **AXIS TILT** is the key to the 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%.

How do we mark the progression of the seasons?

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



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

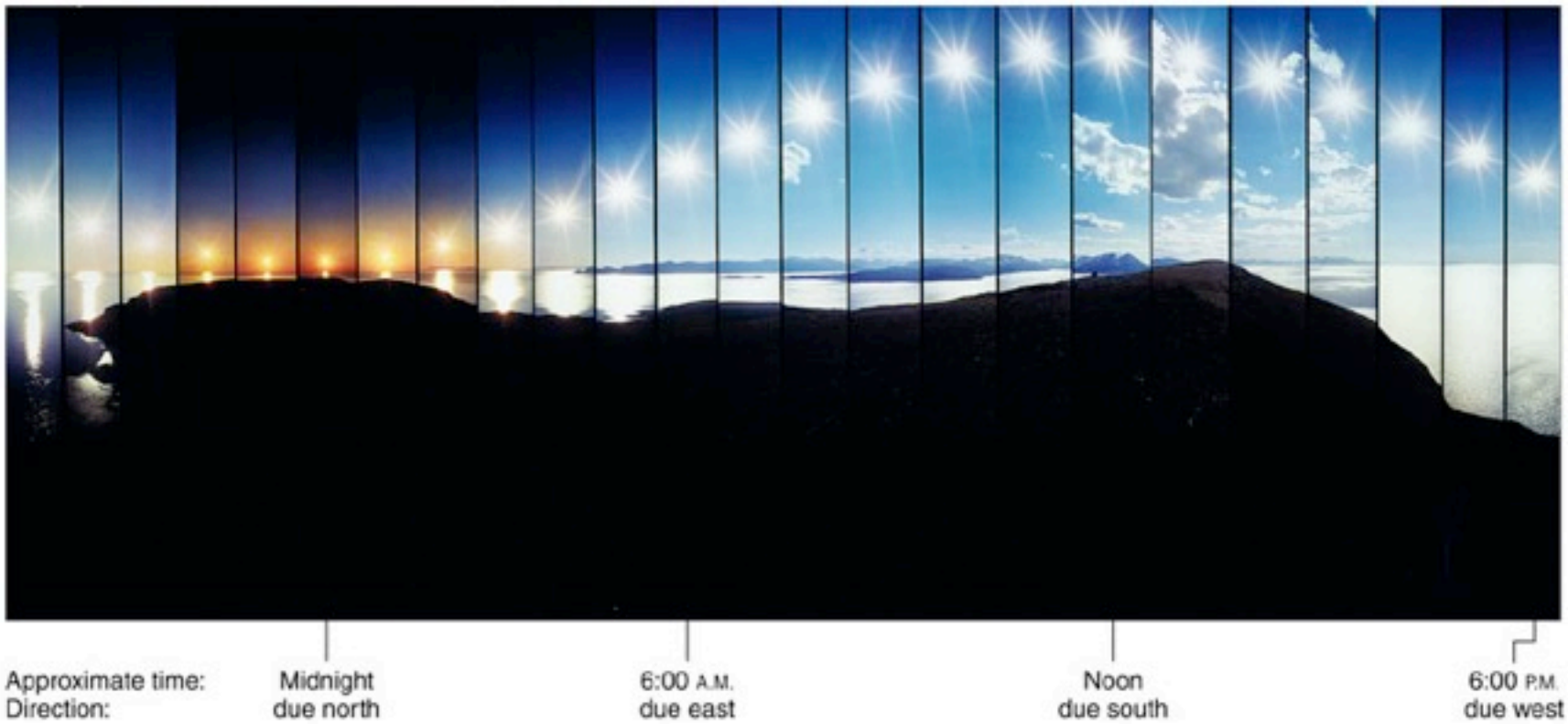


Summer solstice: Highest path, rise and set at most extreme north of due east

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.

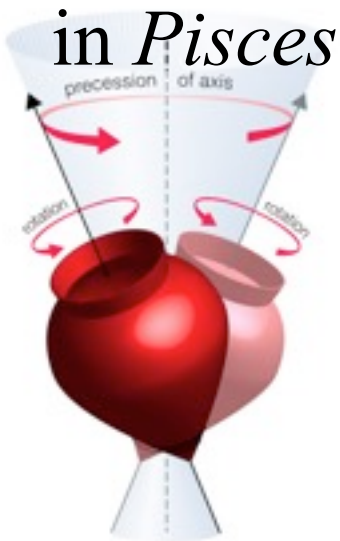


Path of the Sun on the summer solstice at the Arctic Circle

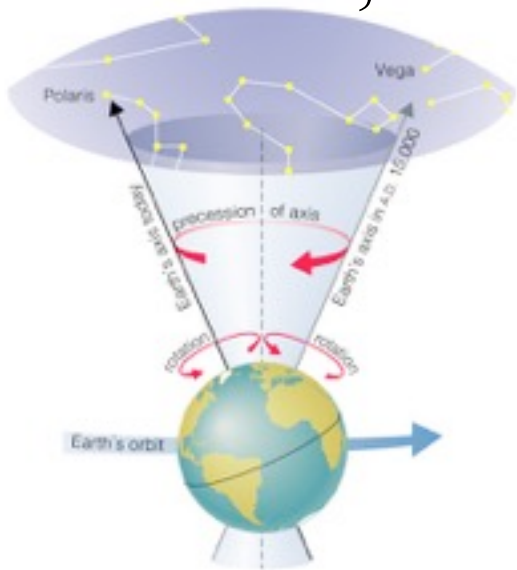
How does the orientation of Earth's axis change with time?

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.



PLAY 02_05 Precession

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.