Chapter 2
Discovering the Universe for Yourself

We had the sky, up there, all speckled with stars, and we used to lay on our backs and look up at them, and discuss about whether they was made, or only just happened.

Mark Twain (1835 – 1910)
American author, from Huckleberry Finn

2.1 Patterns in the Night Sky

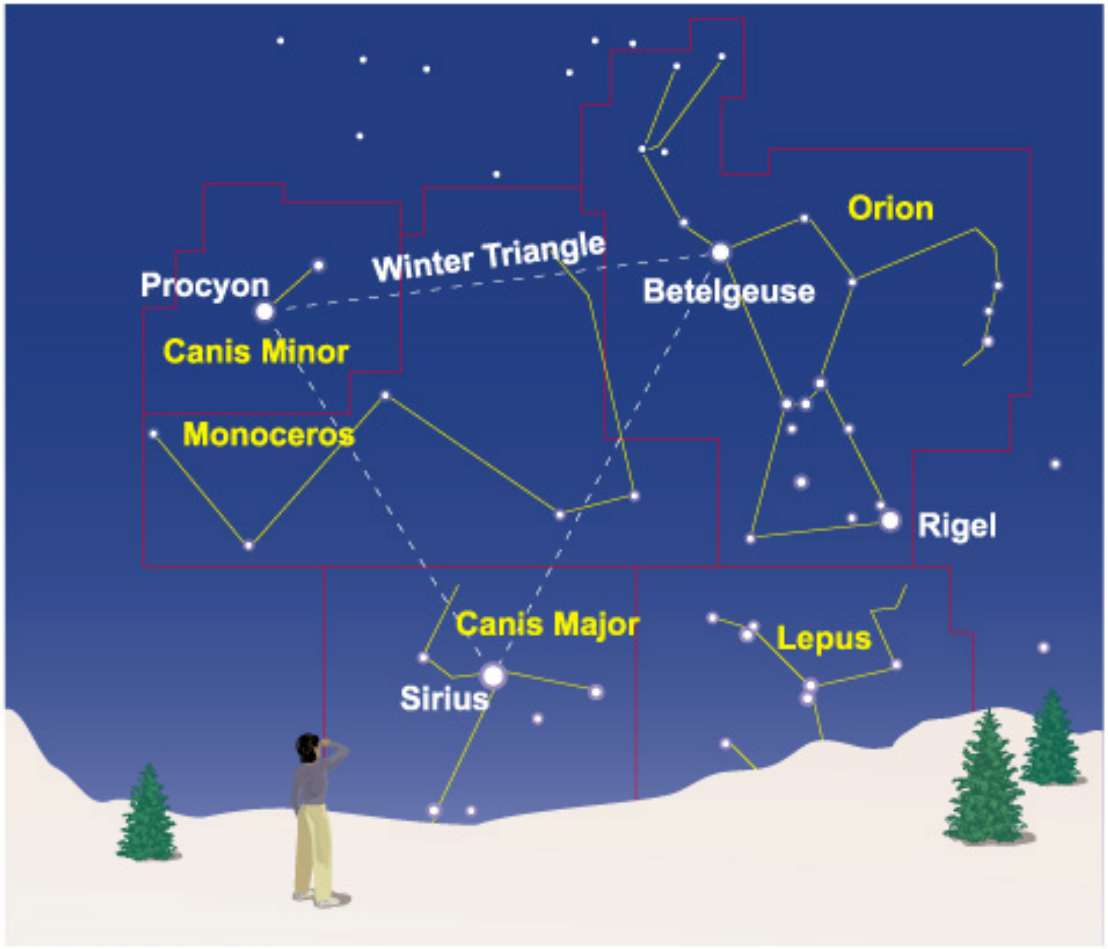
Our goals for learning:

- What are constellations?
- How do we locate objects in the sky?
- Why do stars rise and set?
- Why don't we see the same constellations throughout the year?

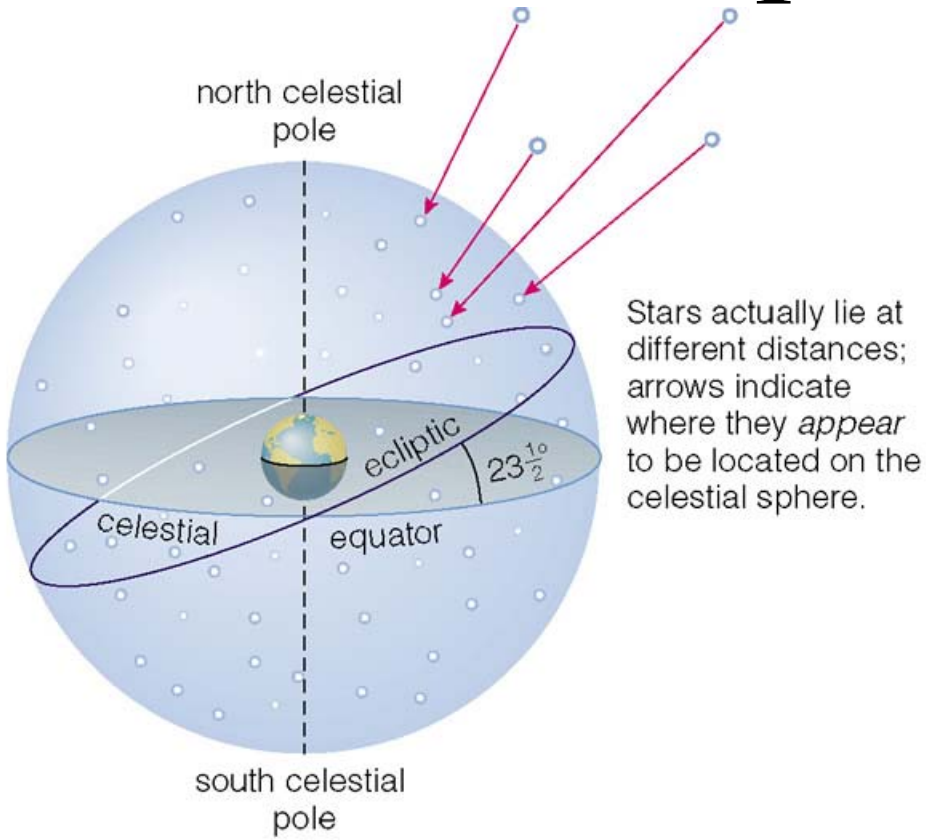
What are constellations?

A constellation is a *region* of the sky.

88 constellations fill the entire sky.



The Celestial Sphere



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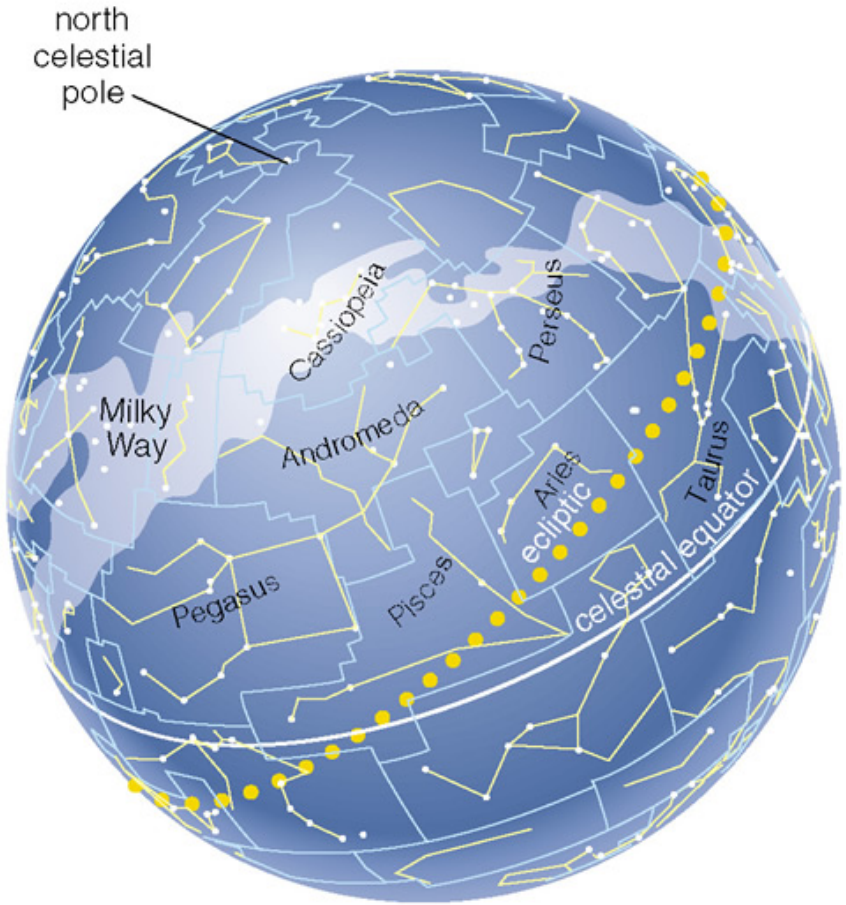


The Milky Way

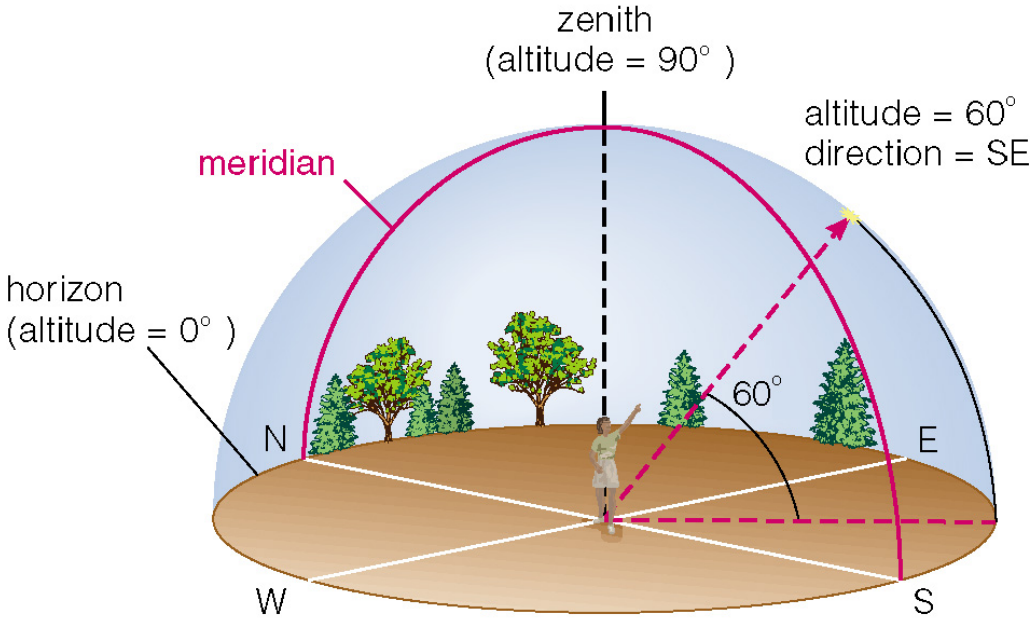
A band of light making a circle around the celestial sphere.

What is it?

Our view into the plane of our galaxy.

How do we locate objects in the sky?

(1) Know your reference points.
(2) Locate an object by its **altitude** (above horizon) and **direction** (along horizon)



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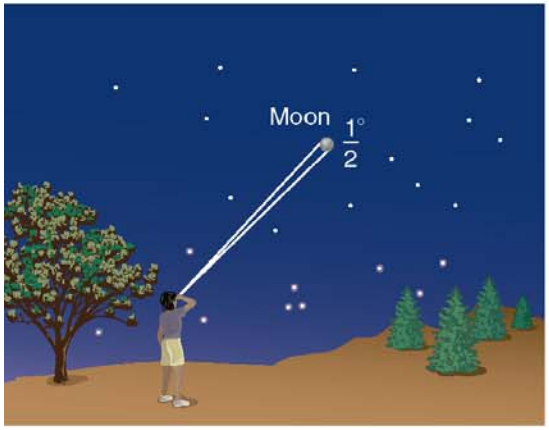
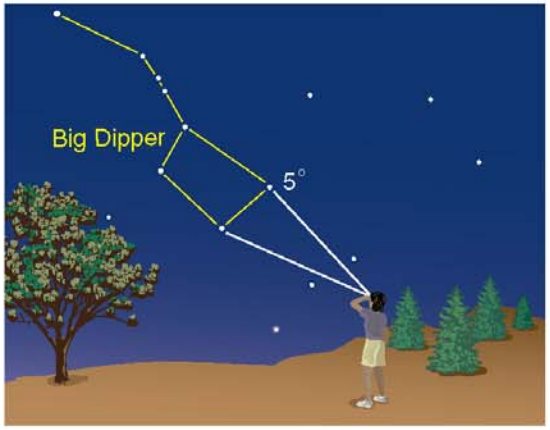
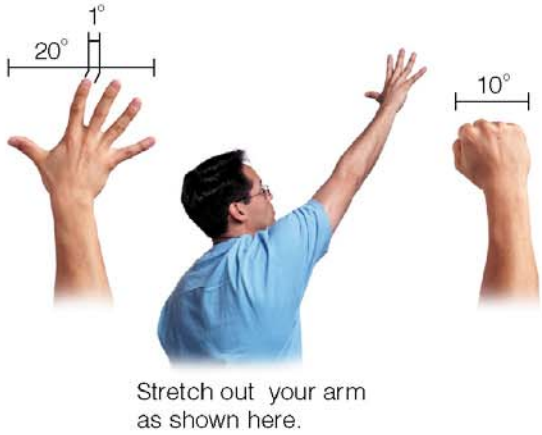
We measure the sky in *angles*...

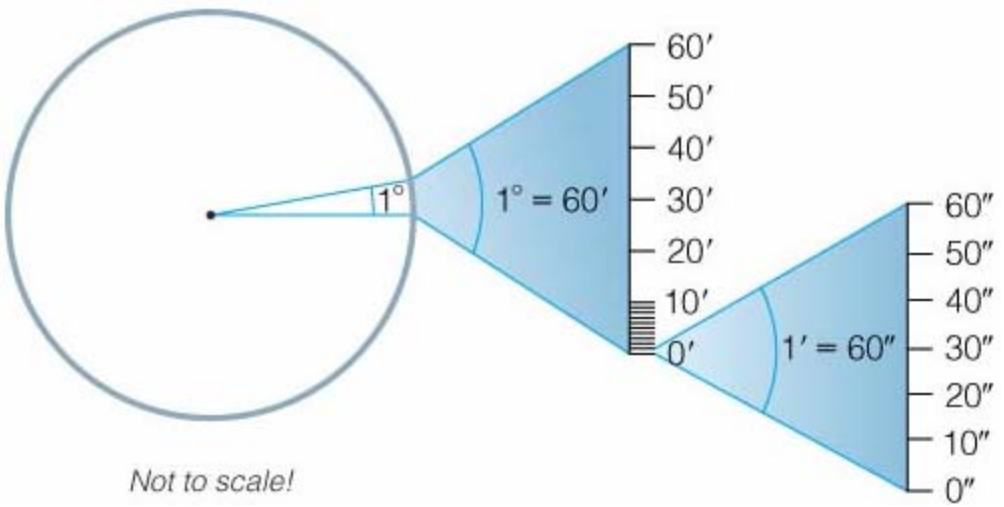




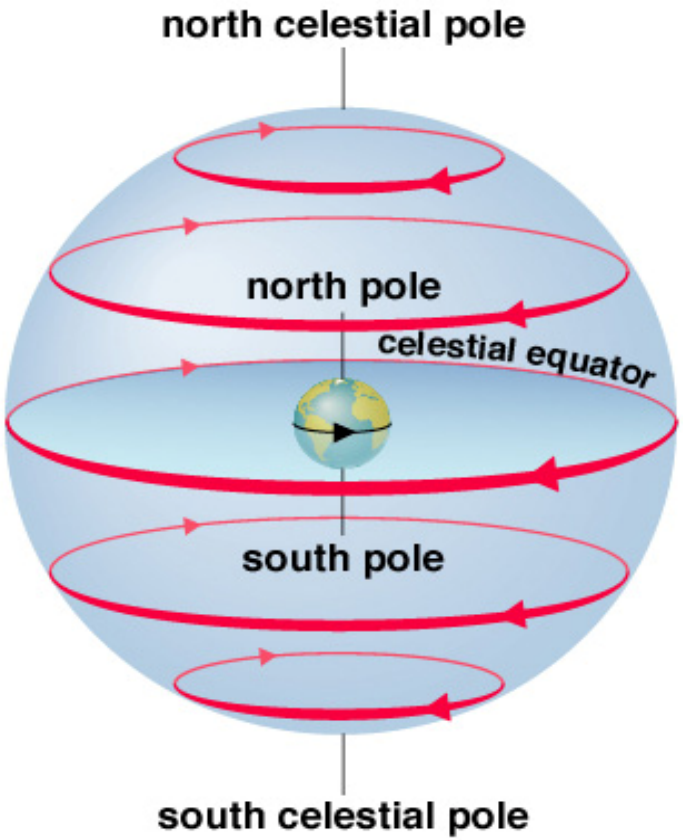


Angle measurements:

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



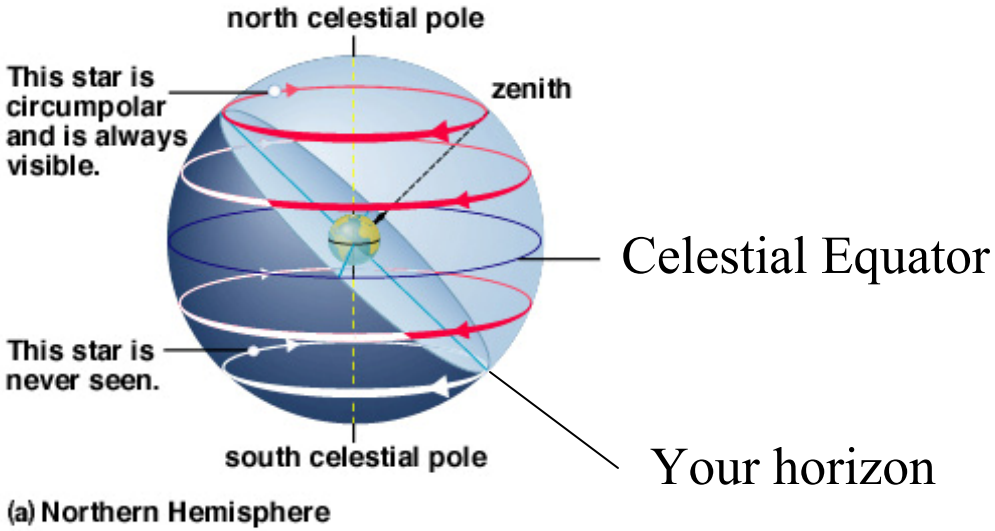
Why do stars rise and set?



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

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.



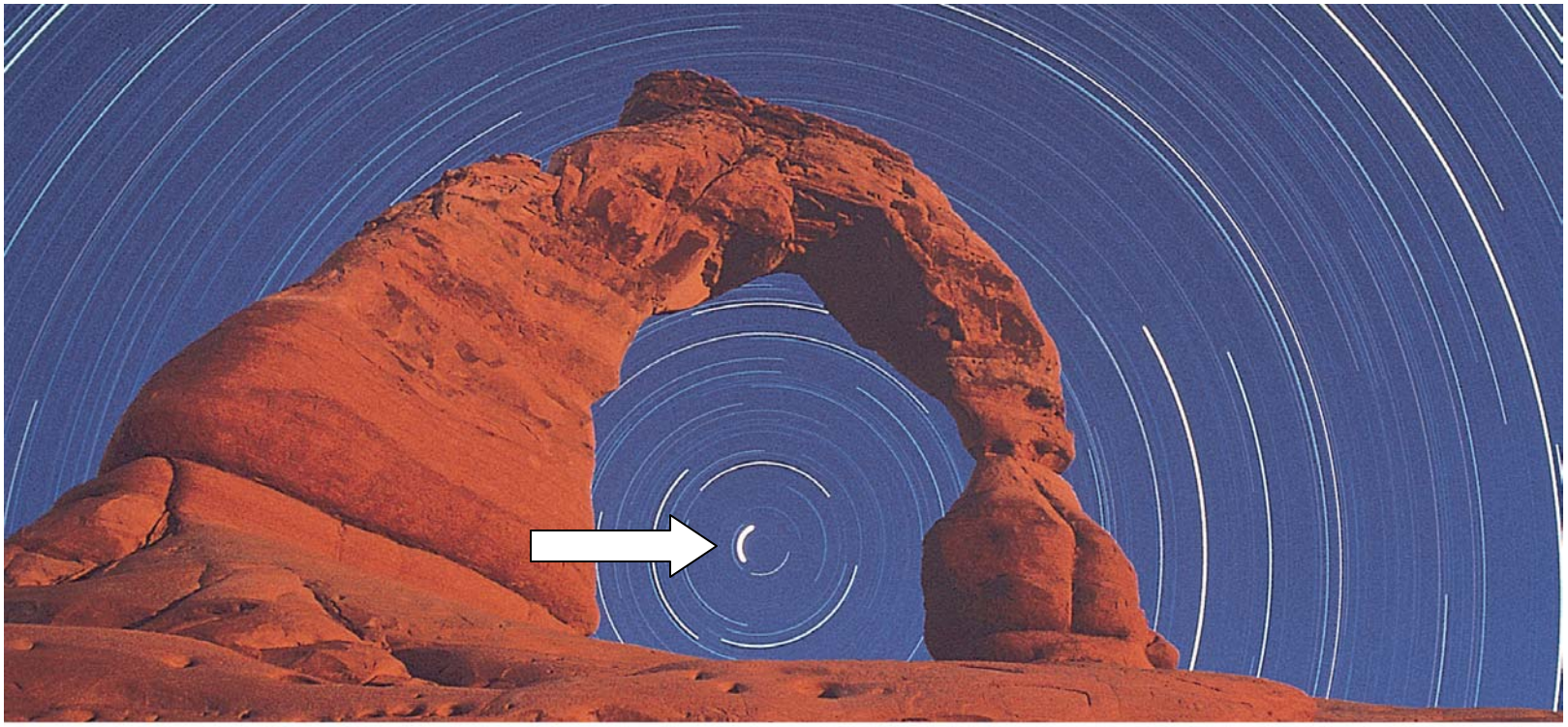
Thought Question

What is the arrow pointing to?

A. the zenith

B. the north celestial pole

C. the celestial equator



What is the arrow pointing to?

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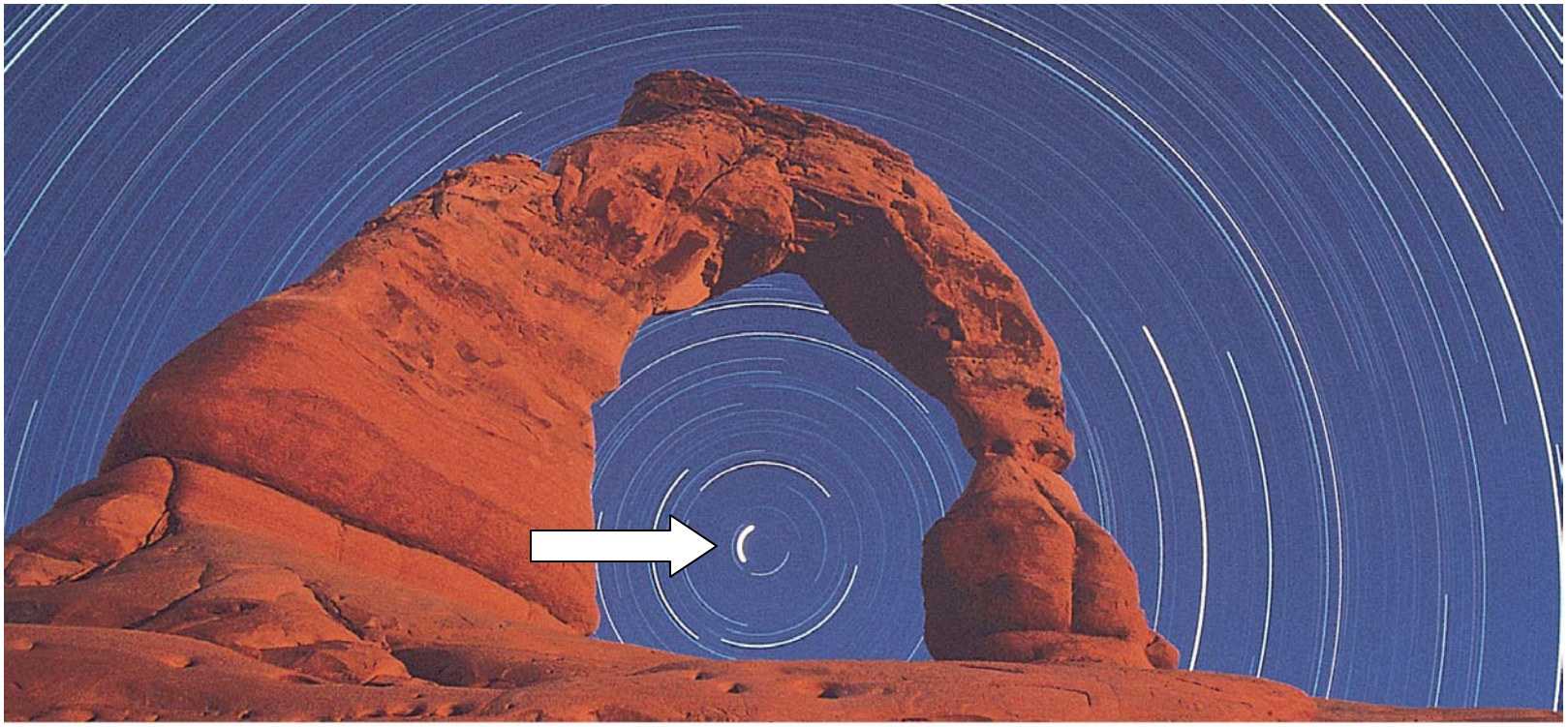
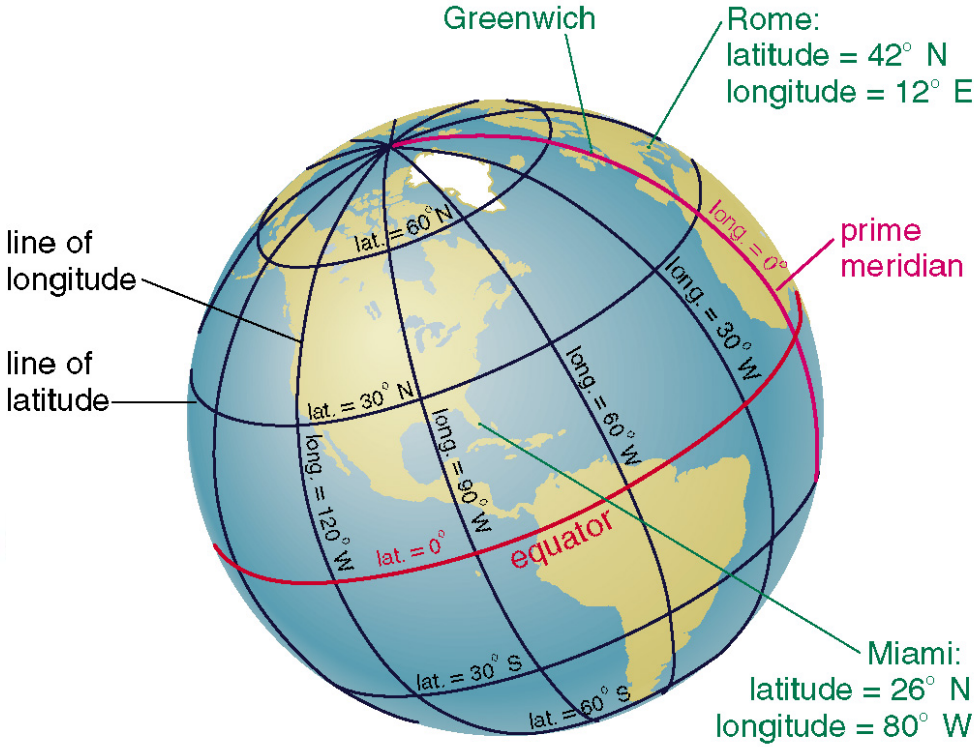


Why don't we see the same constellations throughout the year?

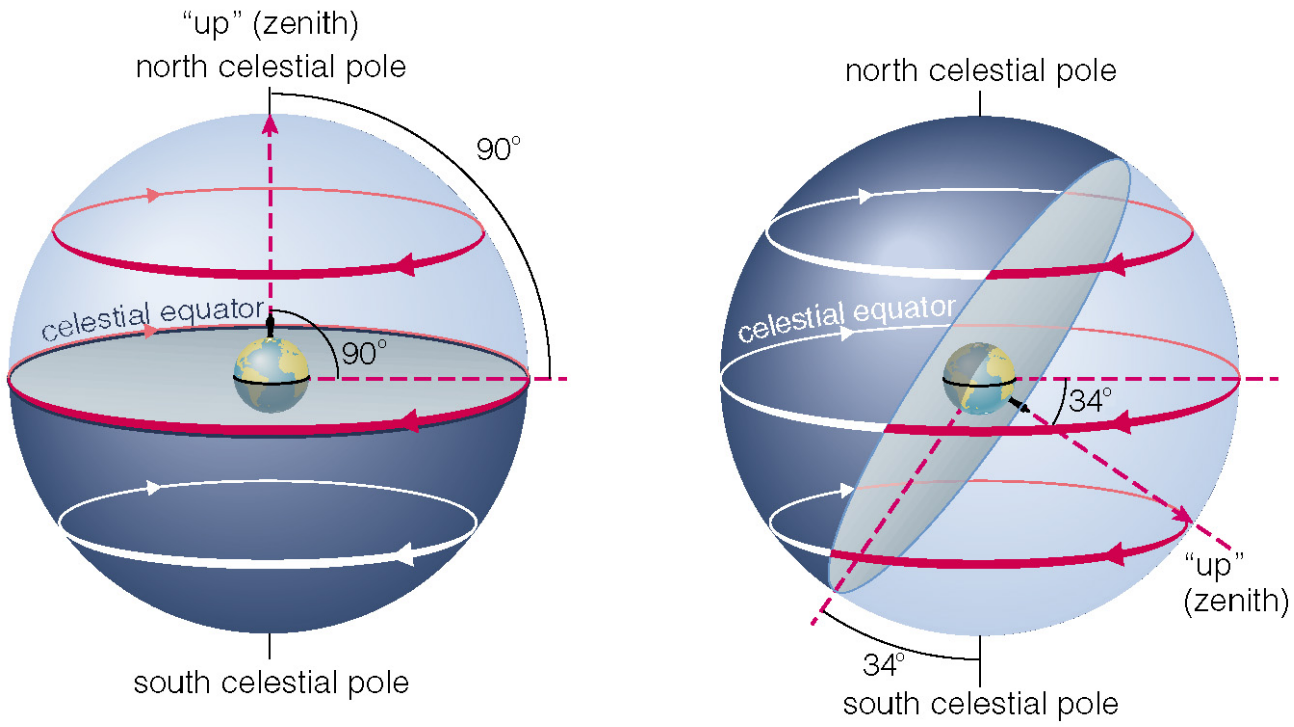
1. Depends on whether you stay home: Constellations vary with latitude.
2. Depends on time of year: Constellations vary as Earth orbits the Sun.

Review: Coordinates on the Earth

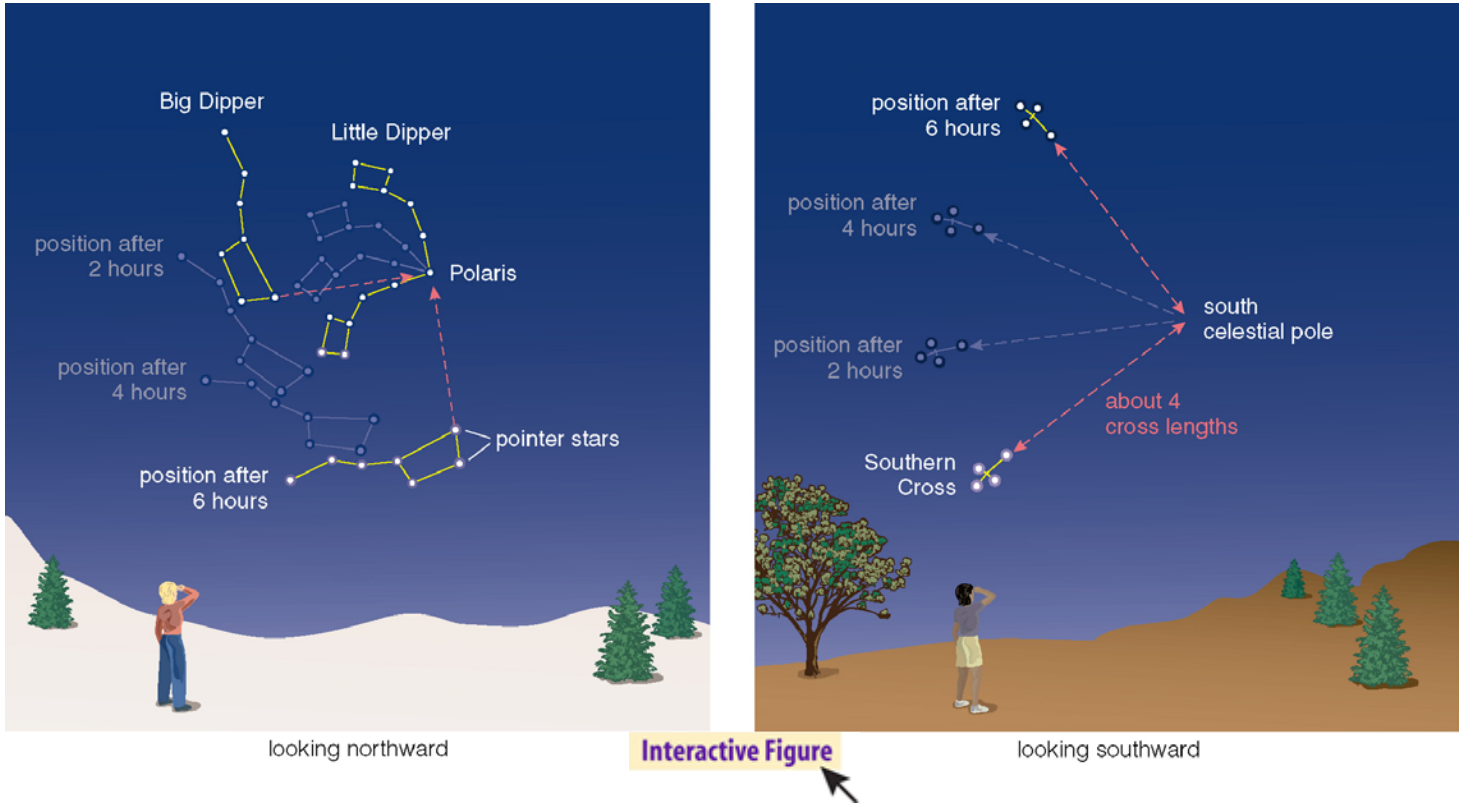
- Latitude: position north or south of equator
- Longitude: position east or west of prime meridian (runs through Greenwich, England)



The sky varies with latitude but not longitude.

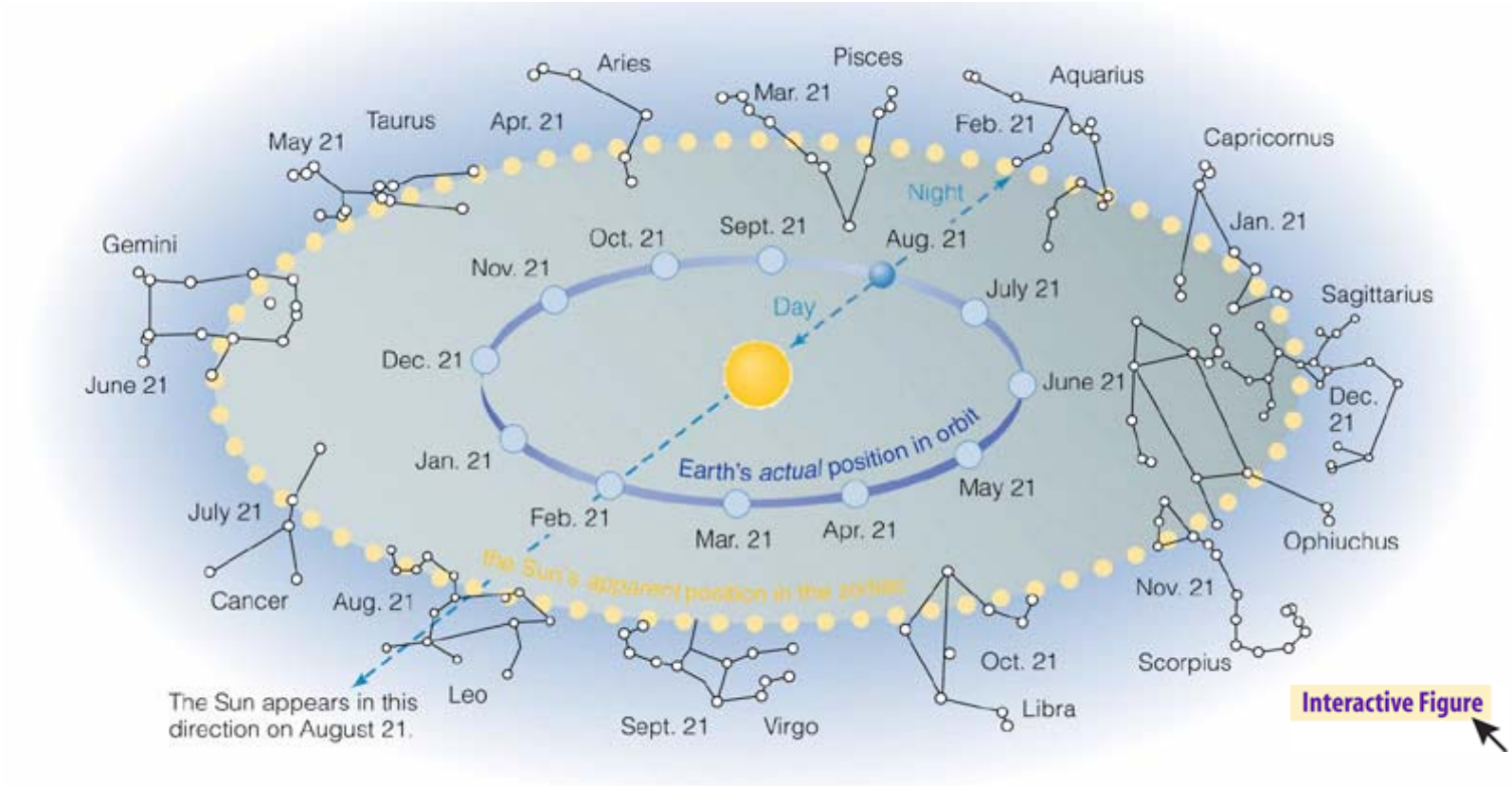


altitude of the celestial pole = your latitude



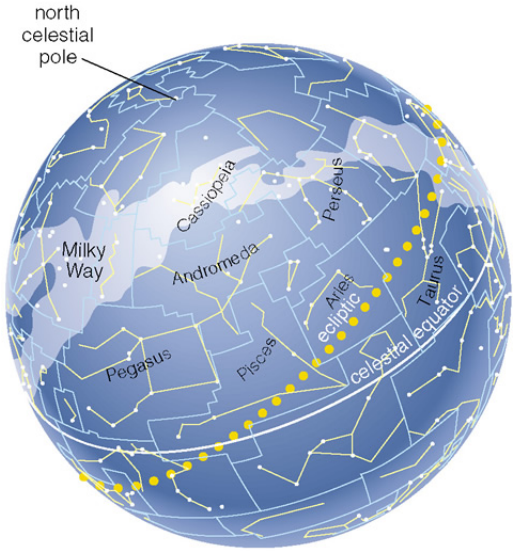
The sky varies as Earth orbits the Sun

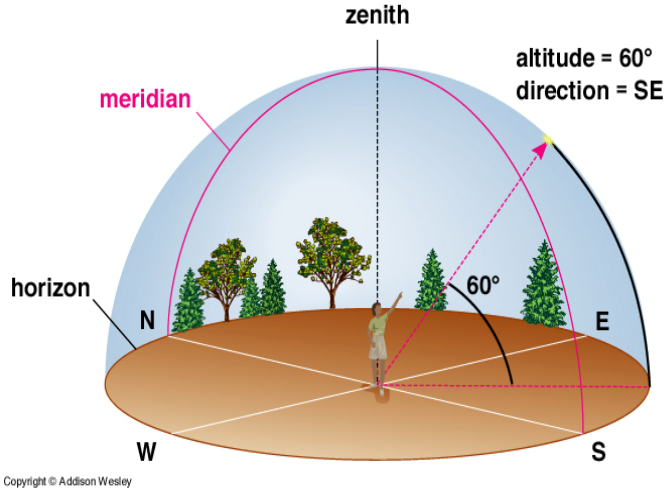
- As the Earth orbits the Sun, the Sun appears to move eastward along the ecliptic.
- At midnight, the stars on our meridian are opposite the Sun the



What have we learned?

- What are constellations?
  - A region of the sky; every position on the sky belongs to one of 88 constellations.
- How do we locate objects in the sky?
  - By its **altitude** above the **horizon** and its **direction** along the horizon.





What have we learned?

- Why do stars rise and set?
  - Because of Earth's rotation.
- Why don't we see the same constellations throughout the year?
  - The sky varies with latitude.
  - The night sky changes as Earth orbits the Sun.

2.2 The Reason for Seasons

Our goals for learning:

- What causes the seasons?
- How do we mark the progression of the seasons?
- Does the orientation of Earth's axis change with time?

Thought Question

TRUE OR FALSE? Earth is closer to the Sun in summer and farther from the Sun in winter.

TRUE OR FALSE? Earth is closer to the Sun in summer and farther from the Sun in winter.

Hint: When it is summer in the U.S., it is winter in Australia.

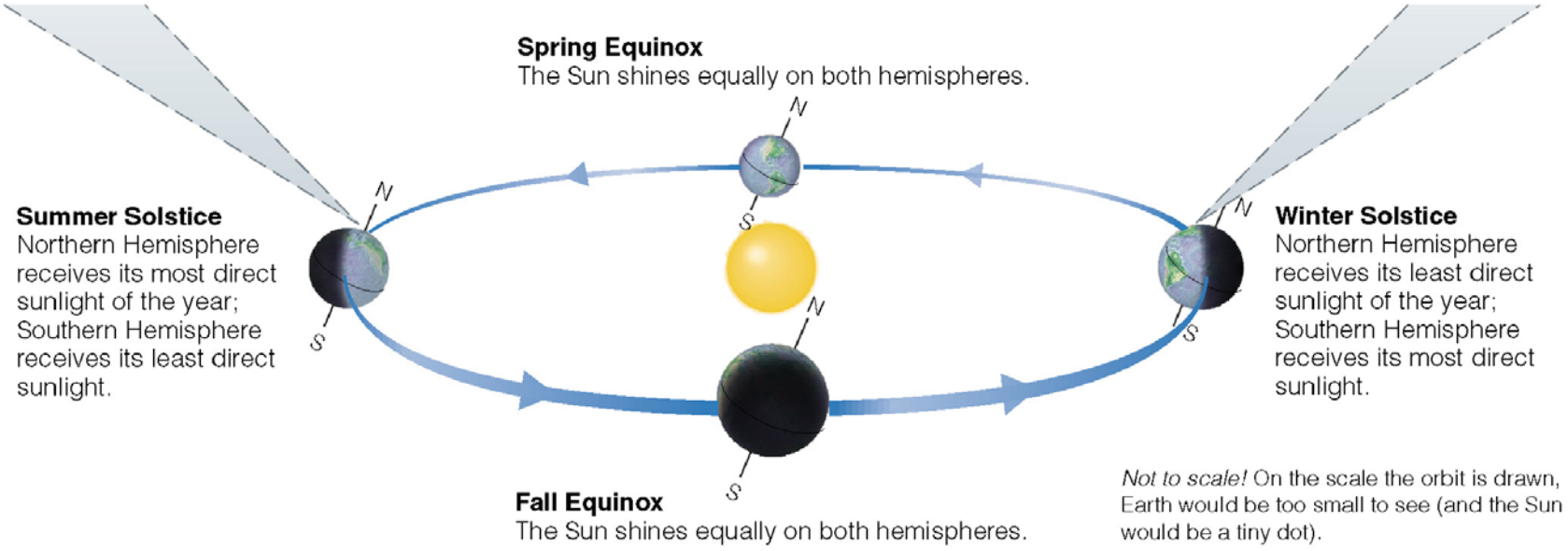
TRUE OR **FALSE!** Earth is closer to the Sun in summer and farther from the Sun in winter.

- Seasons are opposite in the N and S hemispheres, so distance cannot be the reason.
- The real reason for seasons involves Earth's axis tilt.

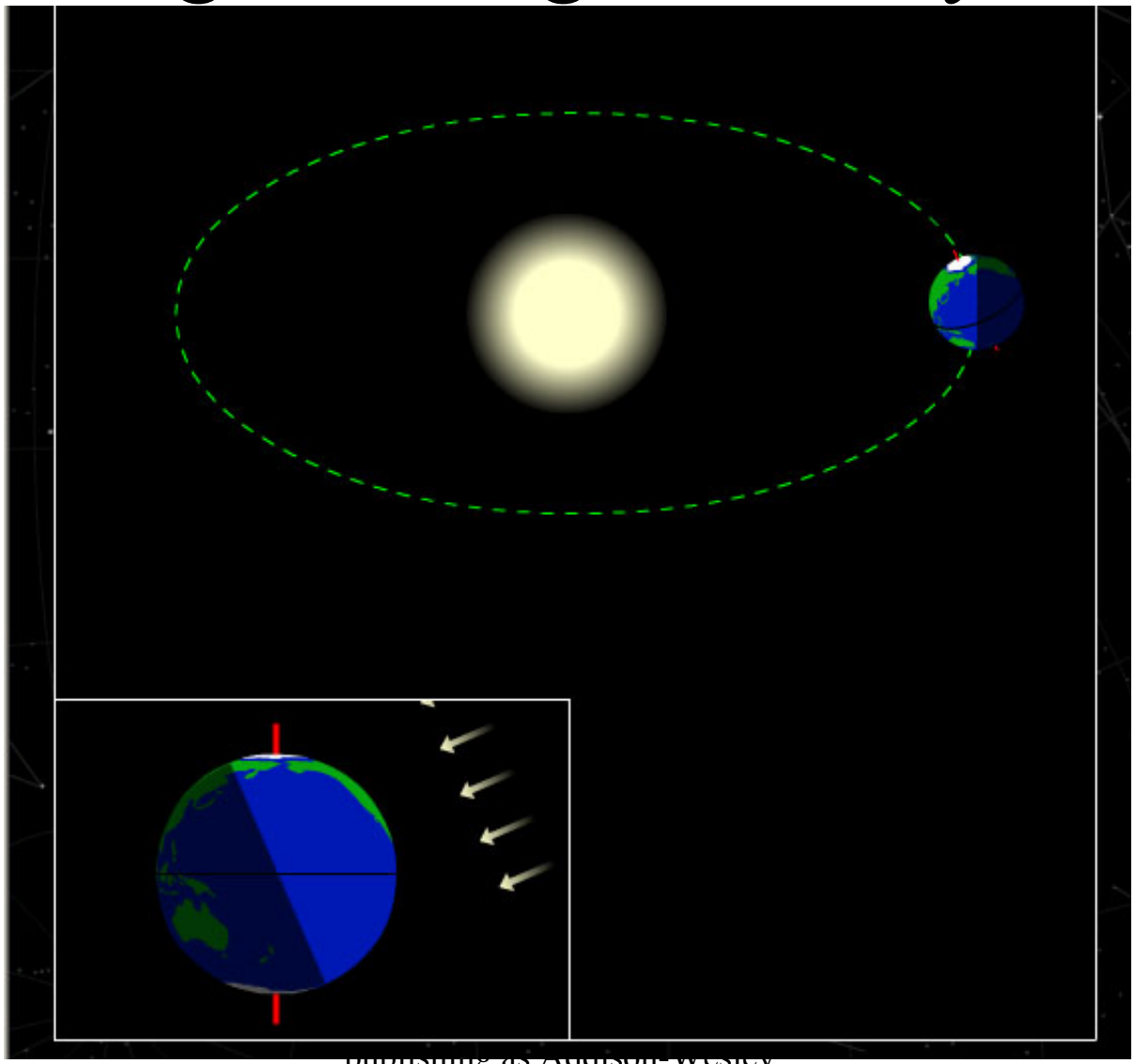
What causes the seasons?

Summer Solstice: Sunlight falls more directly on the Northern Hemisphere, making solar energy more concentrated (notice the smaller shadows) and making the Sun's path longer and higher through the sky.

Winter Solstice: The situation is reversed from the summer solstice, with sunlight falling more directly on the Southern Hemisphere than the Northern Hemisphere.



Axis tilt causes uneven heating by sunlight throughout the year.

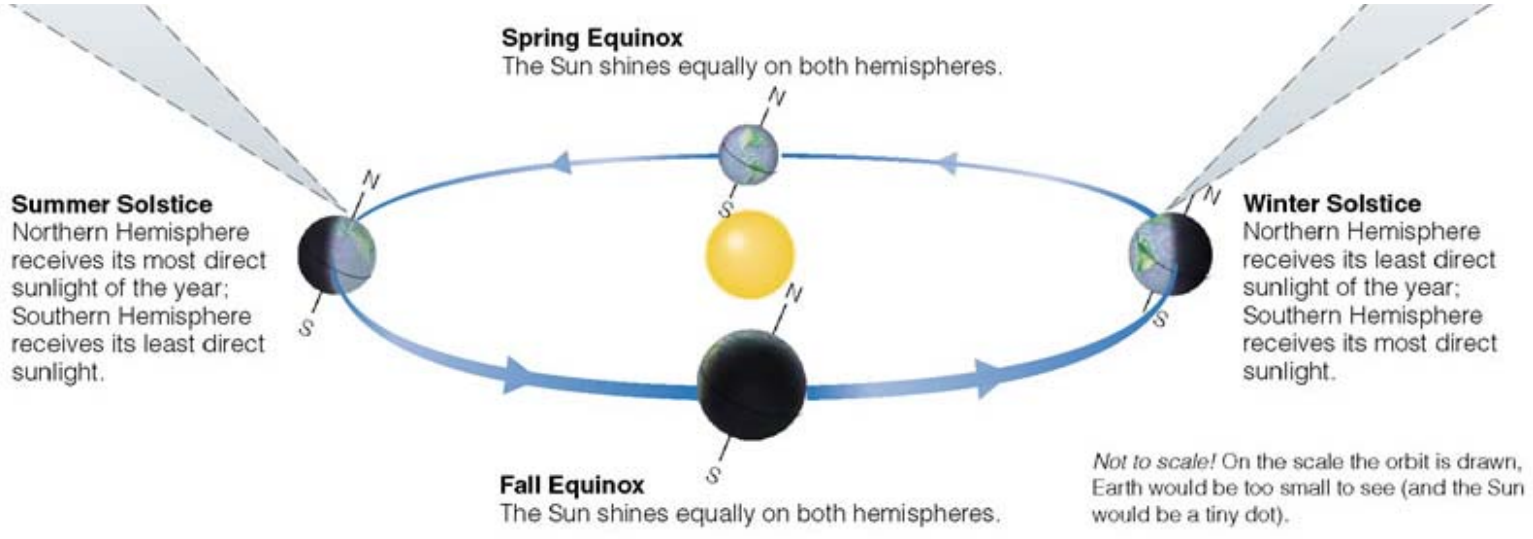


Summary: The Real Reason for Seasons

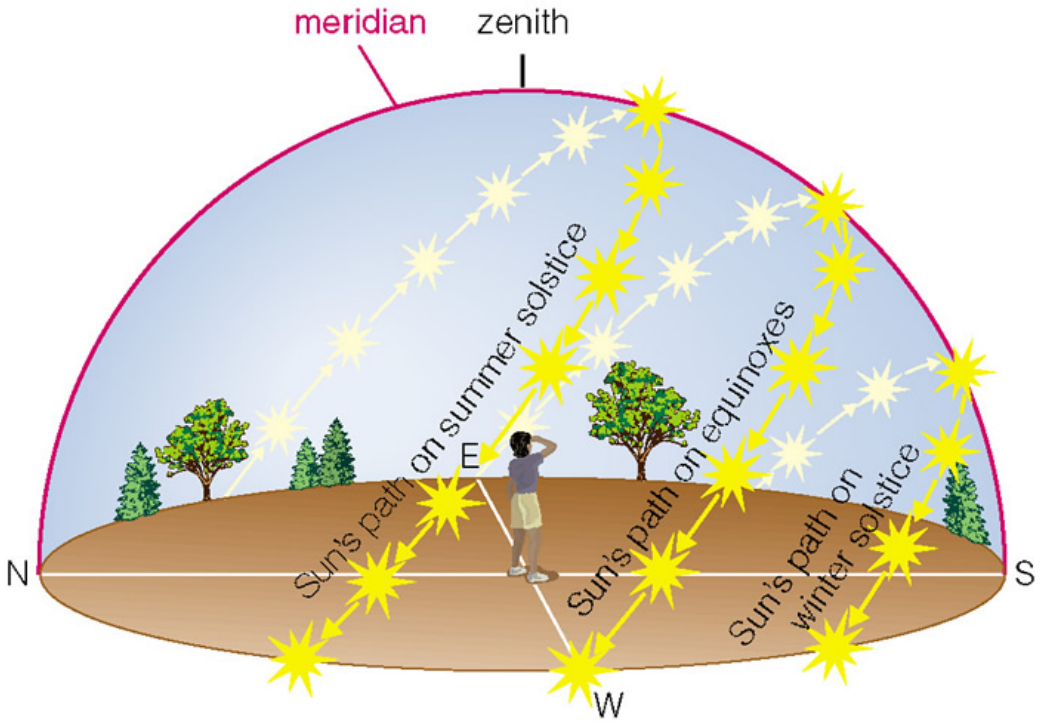
- Earth's axis points in the same direction (to Polaris) all year round, so its orientation *relative to the Sun* changes as Earth orbits the Sun.
- Summer occurs in your hemisphere when sunlight hits it more directly; winter occurs when the sunlight is less direct.
- **AXIS TILT** is the key to the seasons; without it, we would not have seasons on Earth.

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 sky:

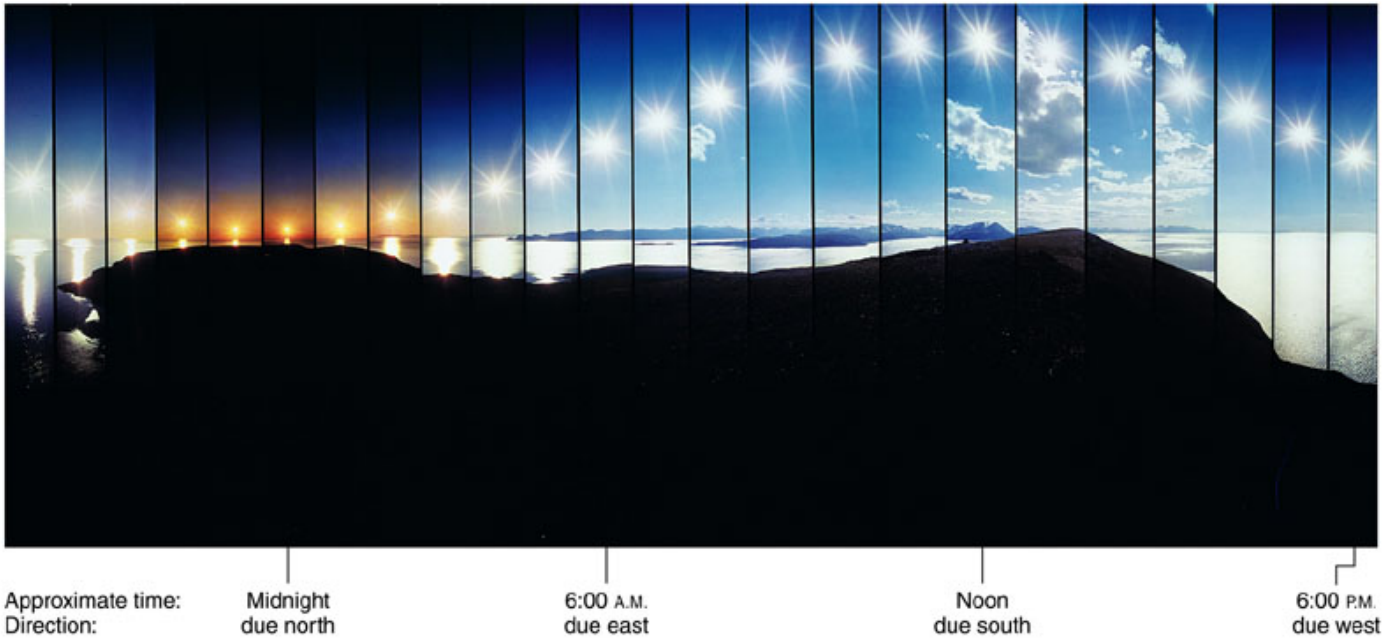


Summer solstice: highest path, rise and set at most extreme north of due east.

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

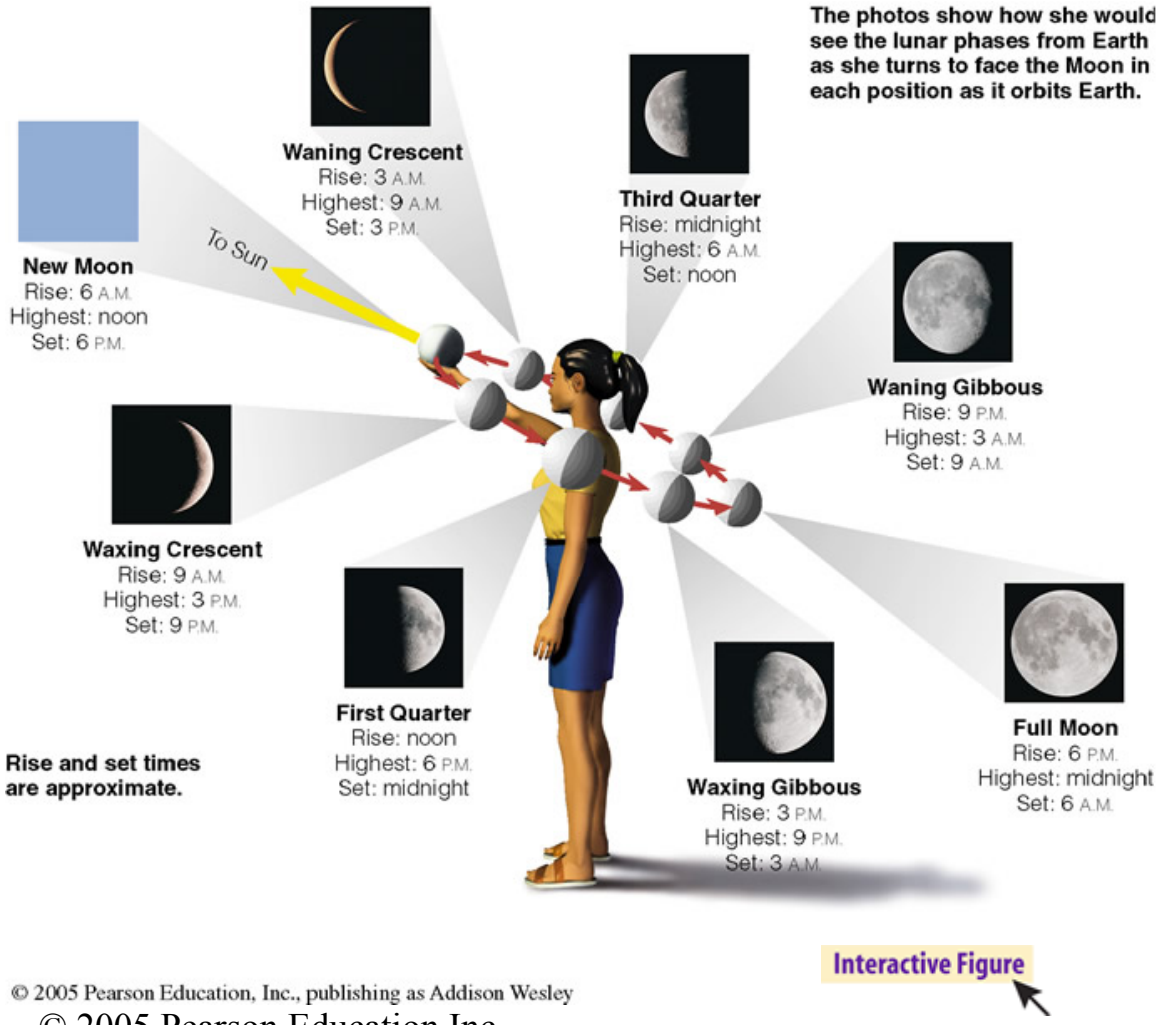
2.3 The Moon, Our Constant Companion

Our goals for learning:

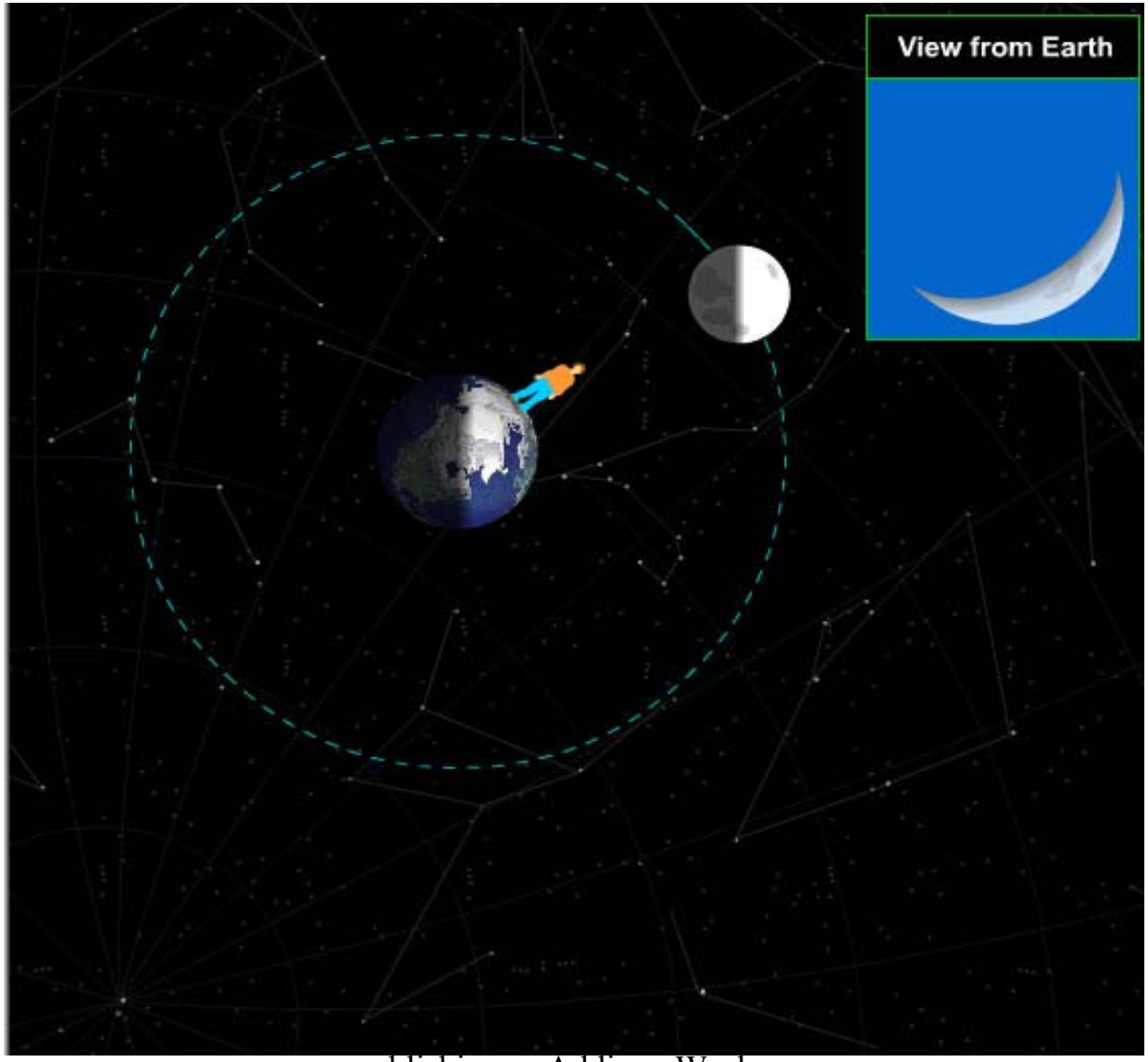
- Why do we see phases of the Moon?
- What causes eclipses?

Why do we see phases of the Moon?

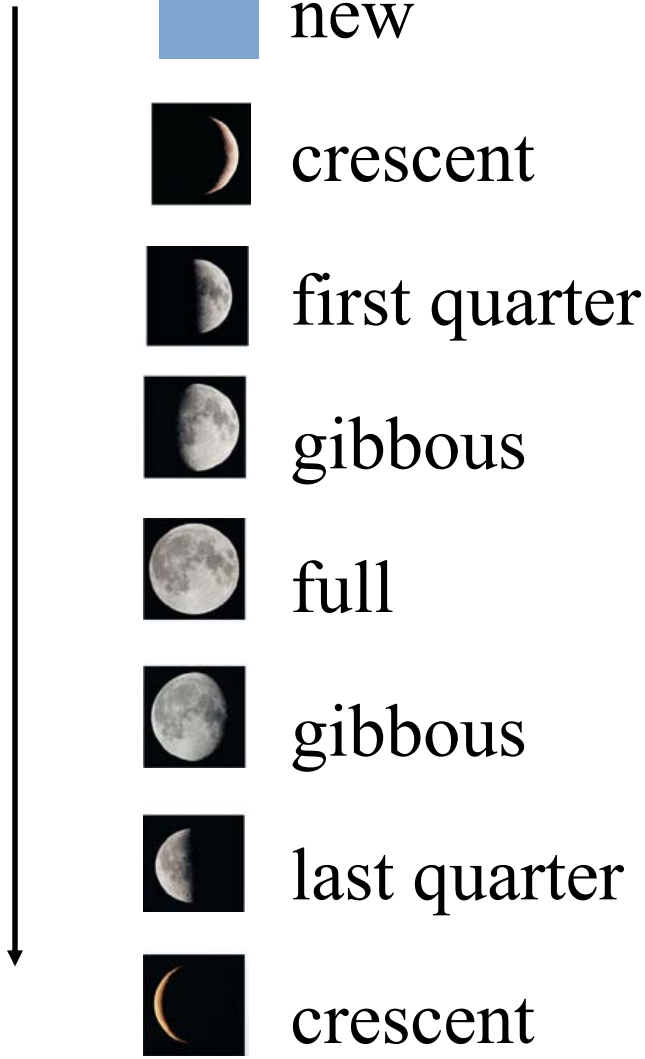
- Half the Moon illuminated by Sun and half dark
- We see some combination of the bright and dark faces



Phases of the Moon



Phases of the Moon: 29.5-day cycle



waxing

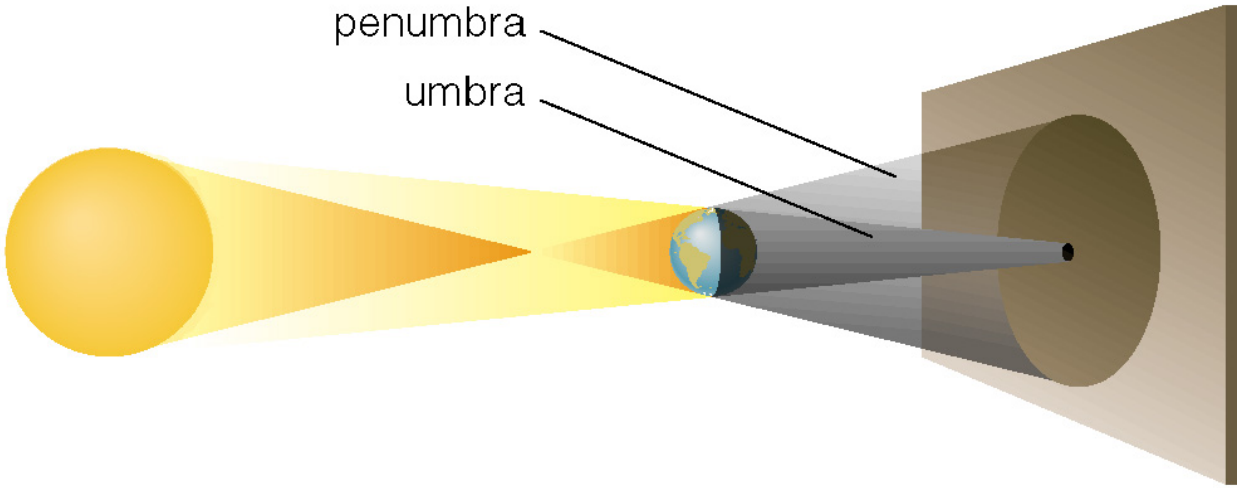
- Moon visible in afternoon/evening.
- Gets "fuller" and rises later each day.

waning

- Moon visible in late night/morning.
- Gets "less" and sets later each day.

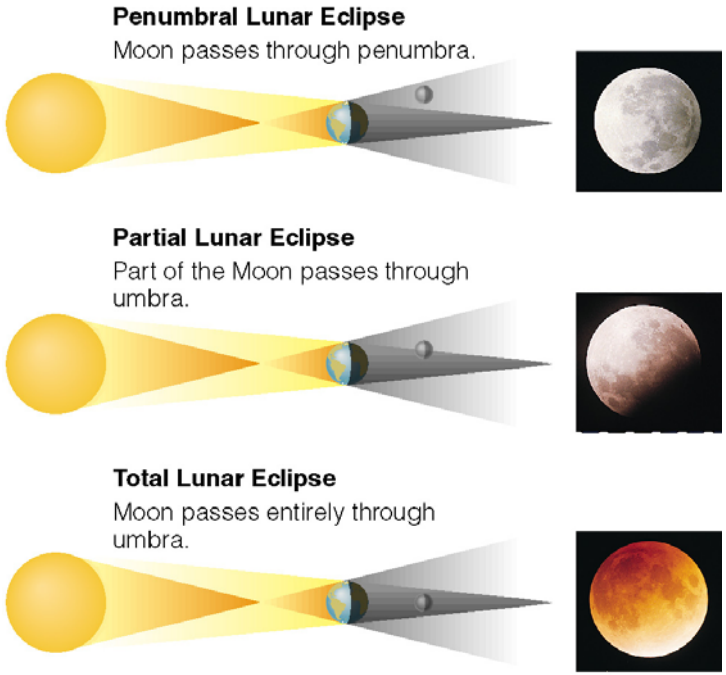
What causes eclipses?

- The Earth and Moon cast shadows.
- When either passes through the other's shadow, we have an **eclipse**.



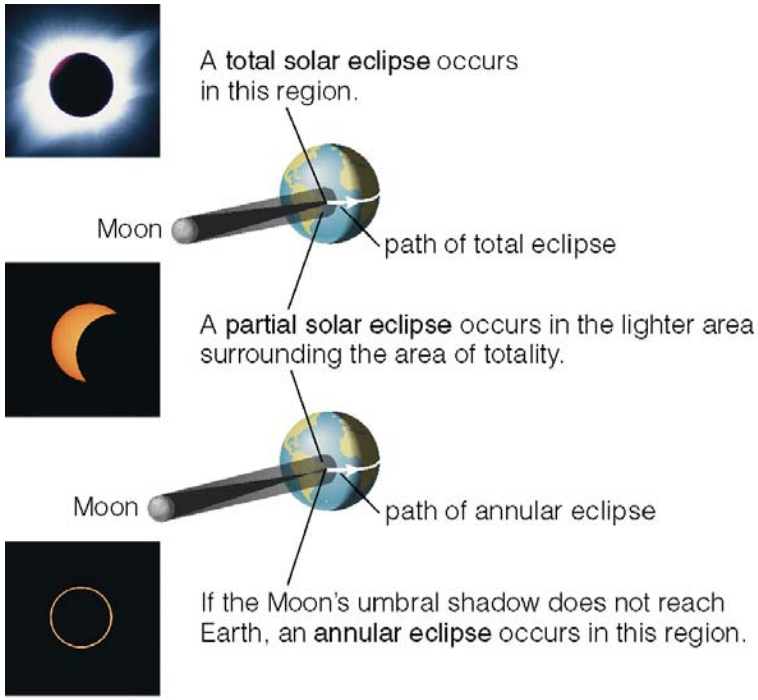
When can eclipses occur?

- **Lunar eclipses** can occur only at *full moon*.
- Lunar eclipses can be **penumbral**, **partial**, or **total**.



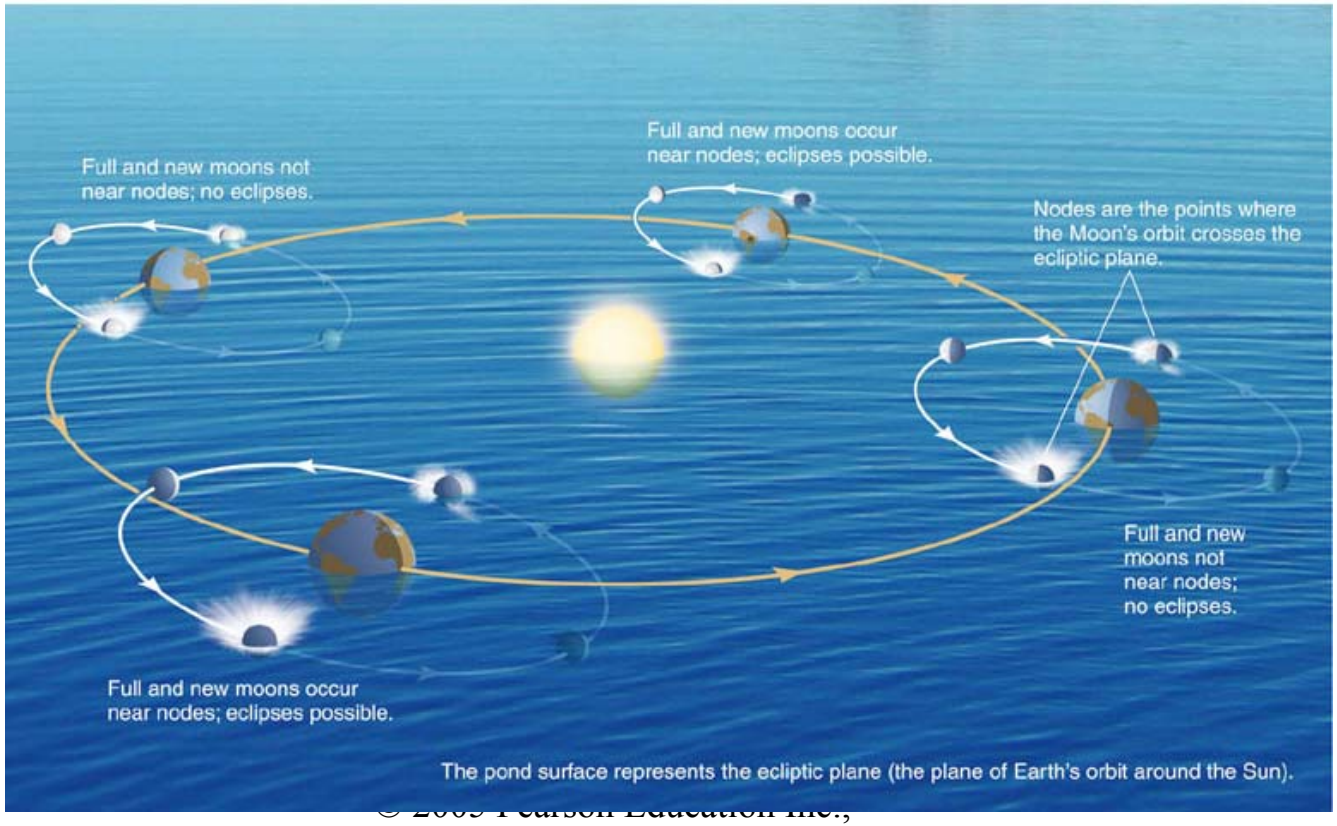
When can eclipses occur?

- **Solar eclipses** can occur only at *new moon*.
- Solar eclipses can be **partial**, **total,** or **annular**.



Why don't we have an eclipse at every new and full moon?

- The Moon's orbit is tilted 5° to ecliptic plane…
- So we have about two **eclipse seasons** each year, with a lunar eclipse at new moon and solar eclipse at full moon.



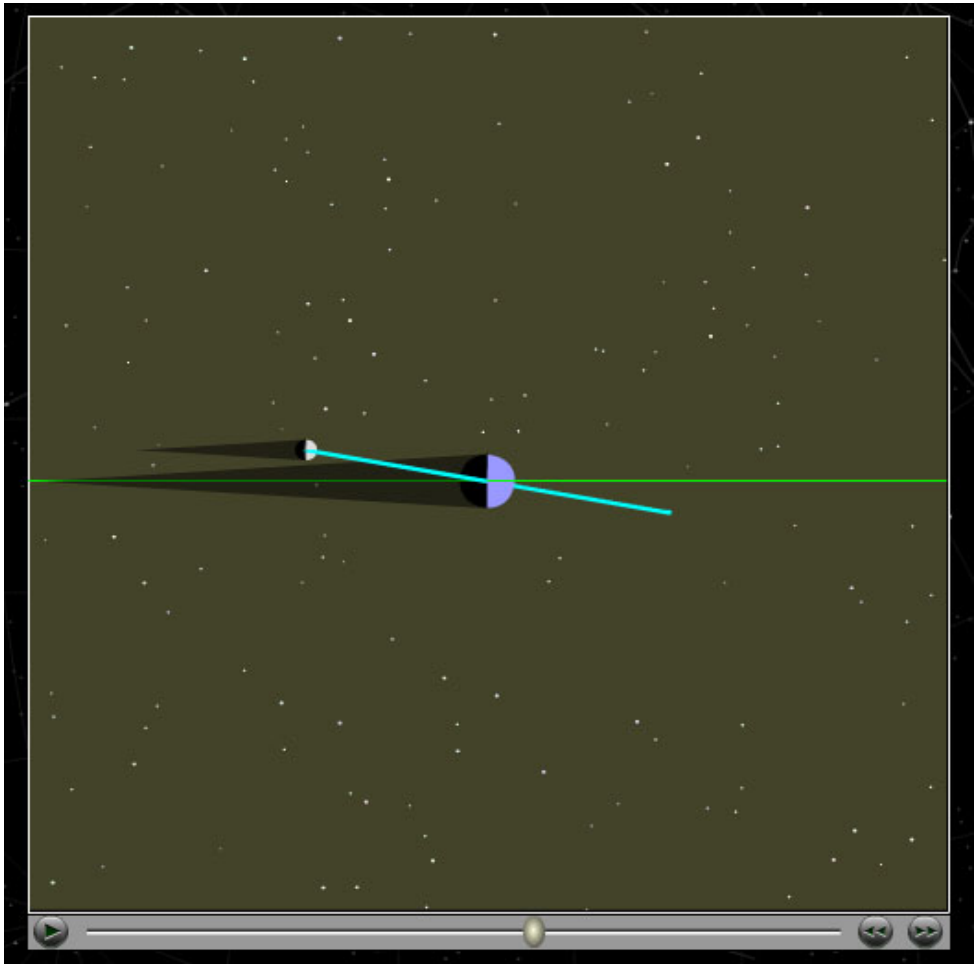
Summary: Two conditions must be met to have an eclipse:

1. It must be full moon (for a lunar eclipse) or new moon (for a solar eclipse).

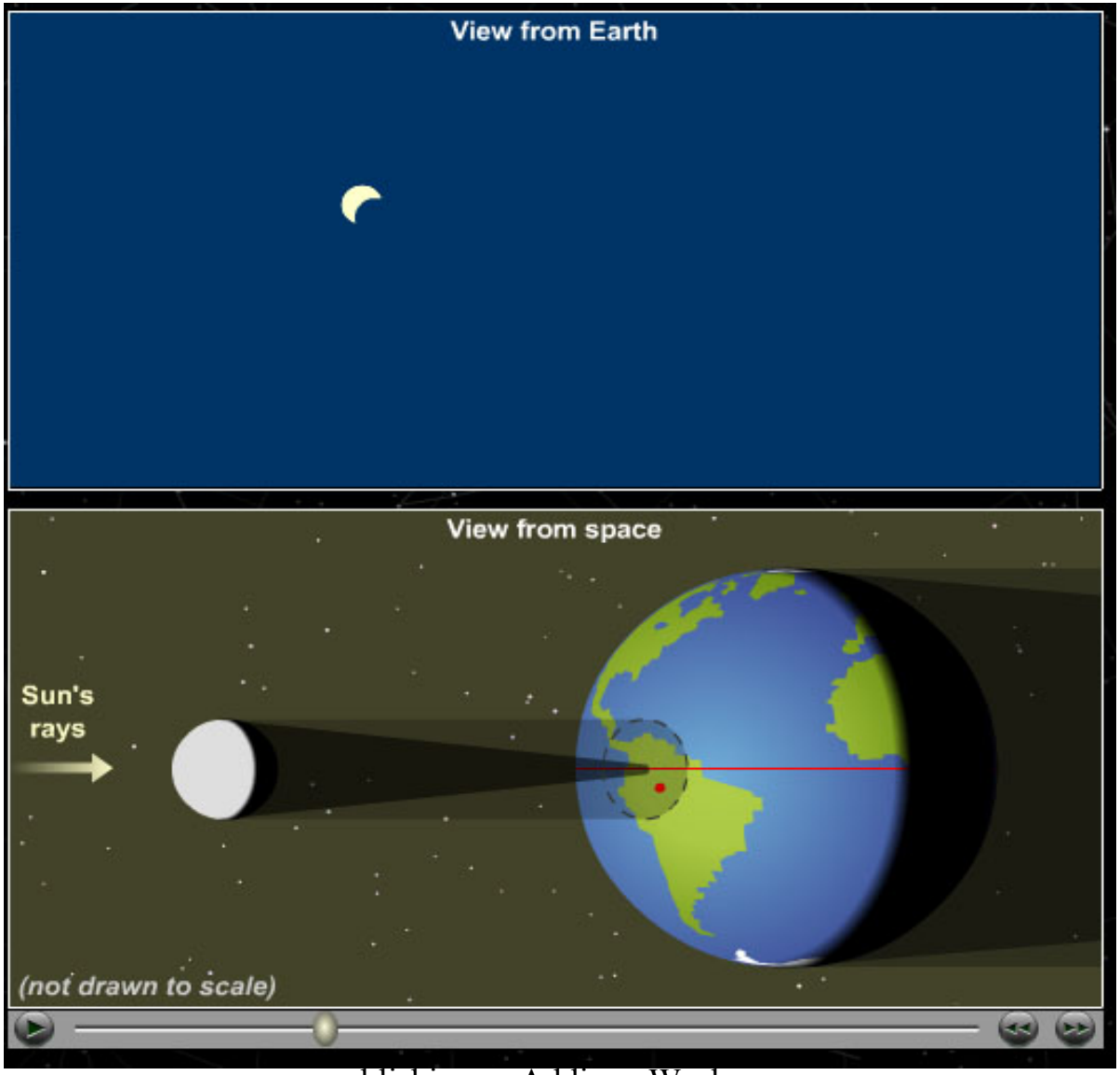
AND

2. The Moon must be at or near one of the two points in its orbit where it crosses the ecliptic plane (its nodes).

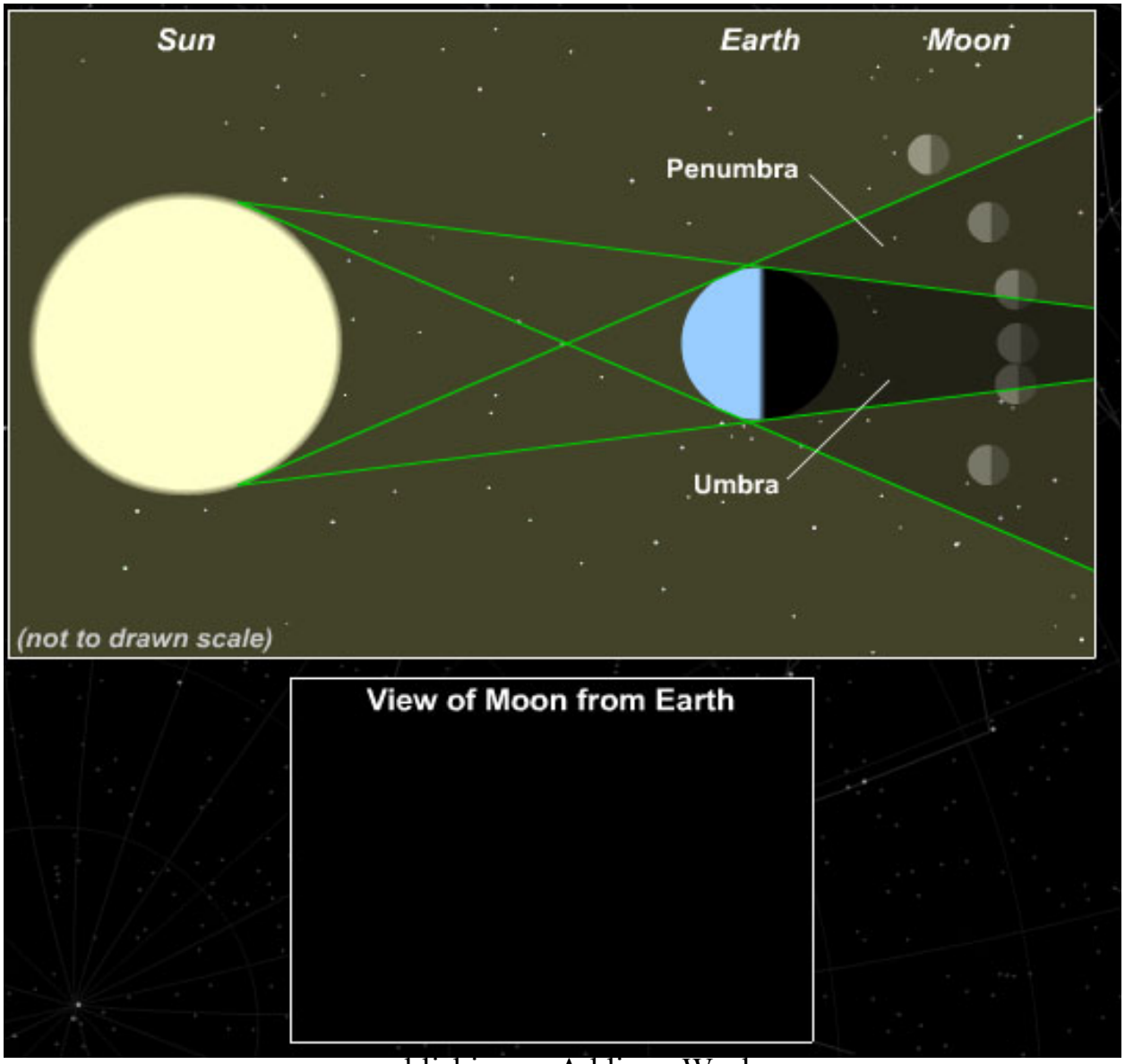
What causes eclipses?



Solar Eclipse

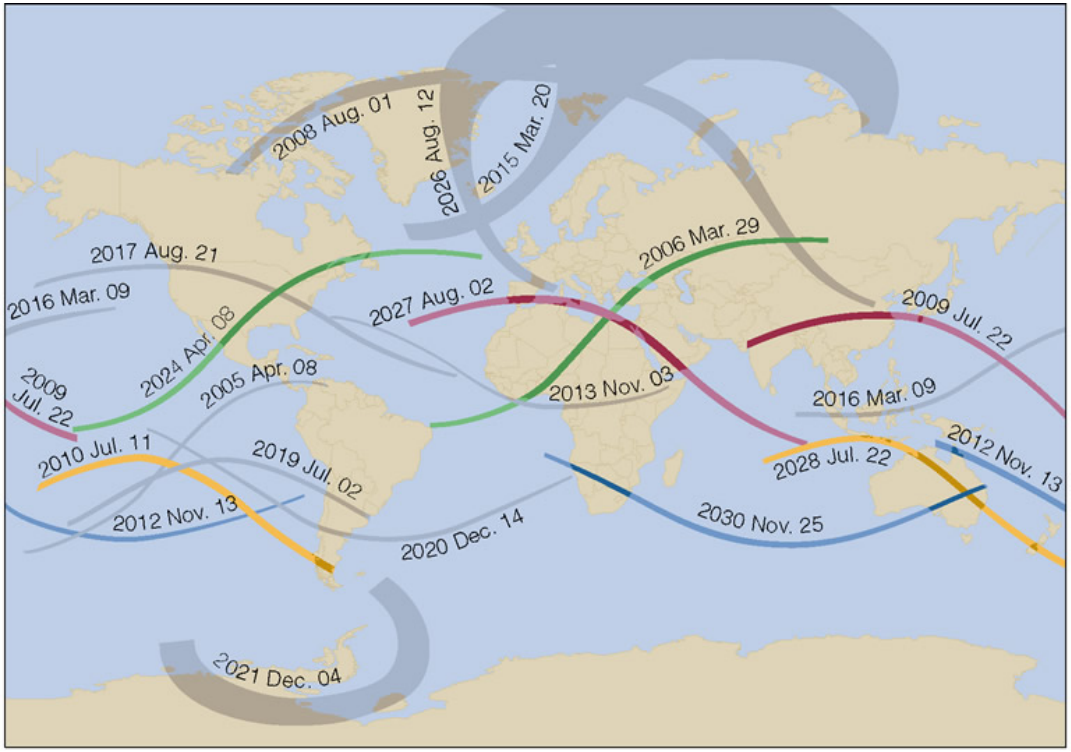


Lunar Eclipse



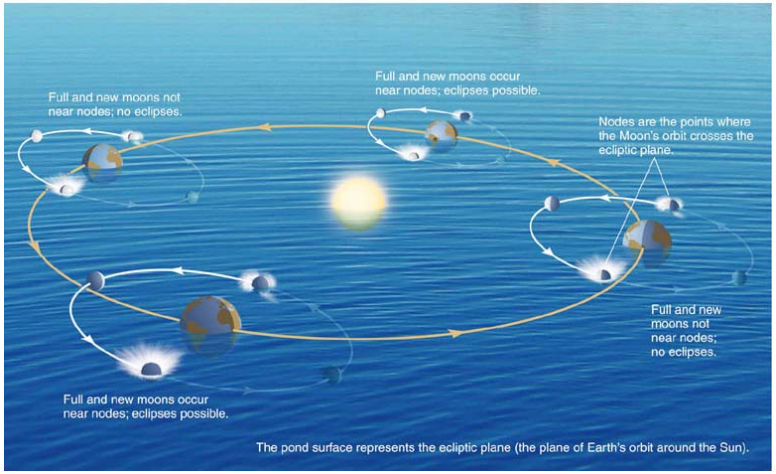
Predicting Eclipses

- Eclipses recur with the 18 yr, 11 1/3 day **saros cycle**, but type (e.g., partial, total) and location may vary.



What have we learned?

- Why do we see phases of the Moon?
  - Half the Moon is lit by the Sun; half is in shadow.
  - The appearance of the Moon to us is determined by the Sun, Earth, and Moon positions.
- What causes eclipses?
  - Lunar eclipse: Earth's shadow on the Moon. Can be penumbral, partial, or total.
  - Solar eclipse: the Moon's shadow on Earth. Can be partial, total, or annular.
  - Tilt of Moon's orbit means eclipses occur during two periods each year.
  - Eclipses recur with the 18 yr, 11 1/3 day saros cycle



2.4 The Ancient Mystery of the Planets

Our goals for learning:

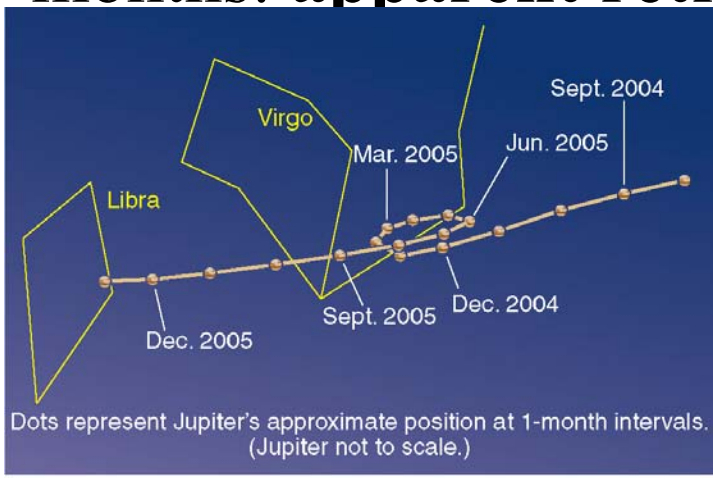
- What was once so mysterious about the movement of planets in our sky?
- Why did the ancient Greeks reject the real explanation for planetary motion?

Planets Known in Ancient Times

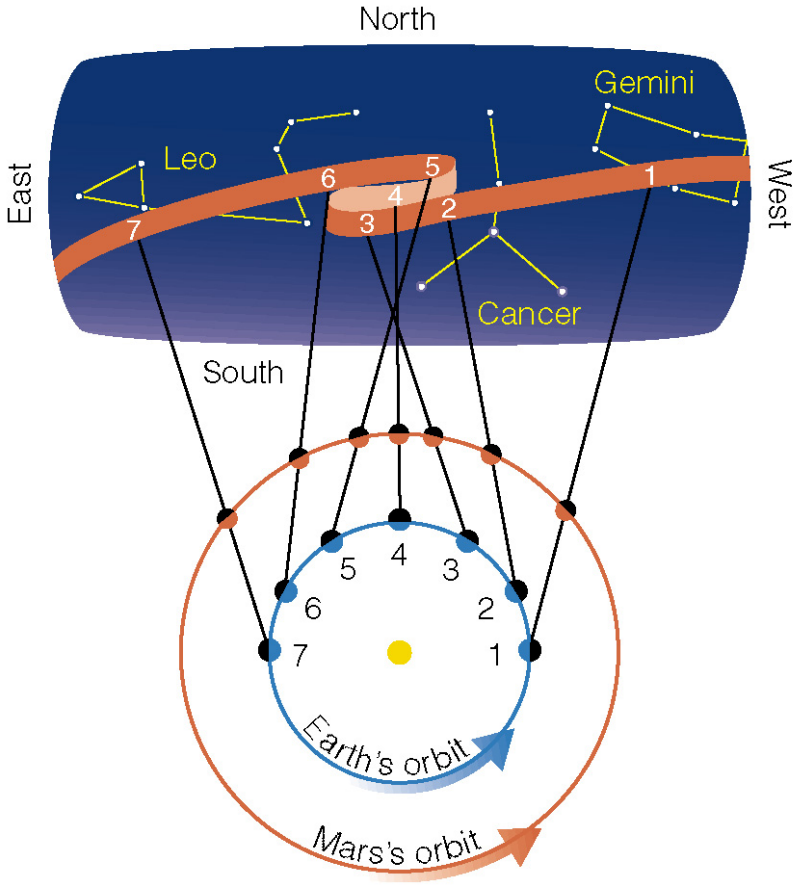
- Mercury
  - difficult to see; always close to Sun in sky
- Venus
  - very bright when visible — morning or evening "star"
- Mars
  - noticeably red
- Jupiter
  - very bright
- Saturn
  - moderately bright

What was once so mysterious about planetary motion in our sky?

- Planets usually move *eastward* from night to night relative to the stars.
  - You cannot see this motion on a single night; rather, planets rise in the east and set in the west.
- But sometimes they go *westward* for a few weeks or months: **apparent retrograde motion**



We see apparent retrograde motion when we pass by a planet in its orbit.

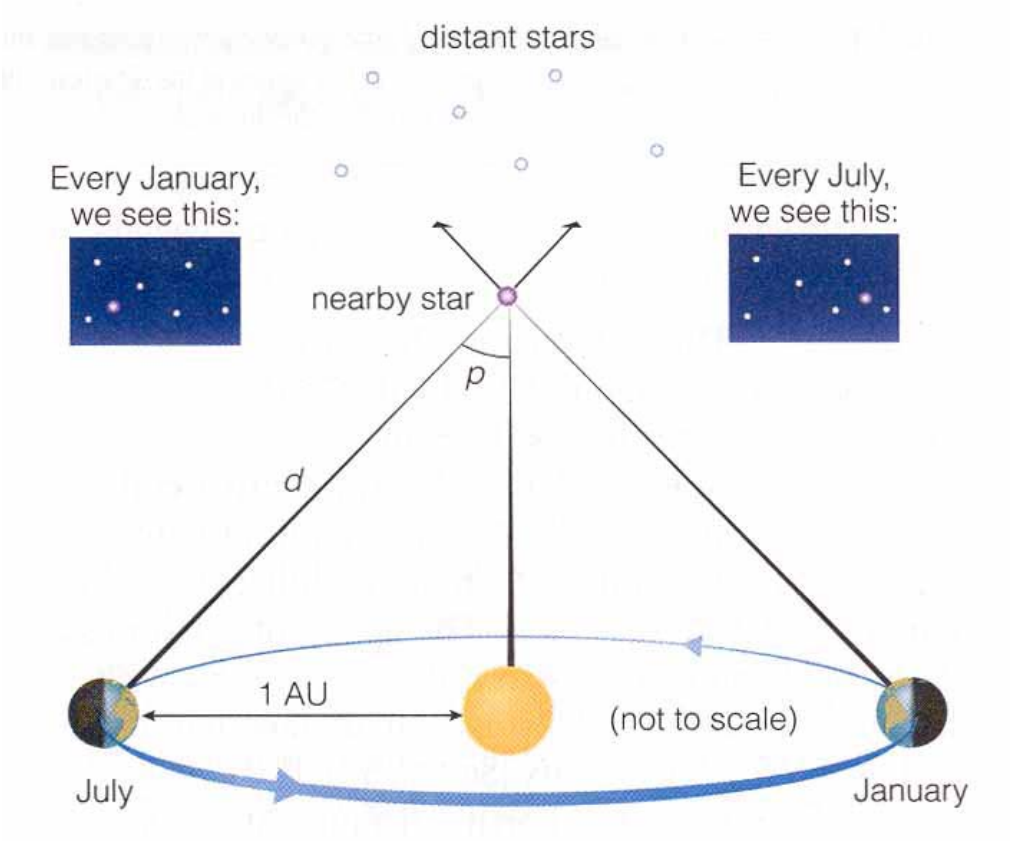


Explaining Apparent Retrograde Motion

- Easy *for us* to explain: occurs when we "lap" another planet (or when Mercury or Venus lap us)
- But very difficult to explain if you think that Earth is the center of the universe!
- *In fact, ancients considered but rejected the correct explanation…*

Why did the ancient Greeks reject the real explanation for planetary motion?

- Their inability to observe **stellar parallax** was a major factor.



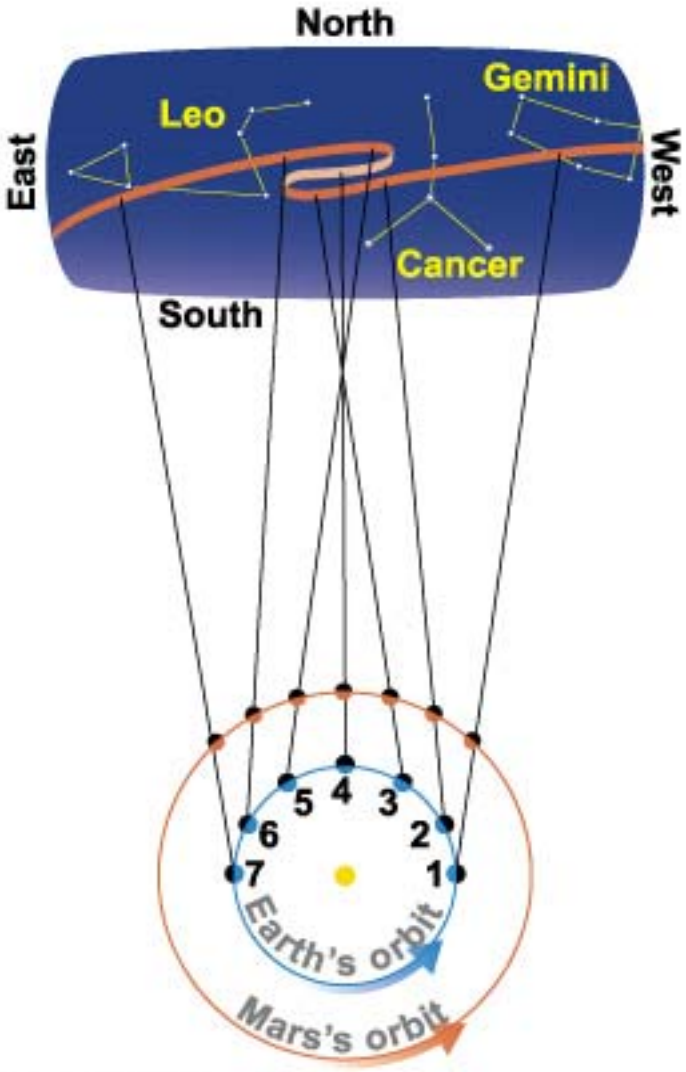
The Greeks knew that the lack of observable parallax could mean one of two things:

1. Stars are so far away that stellar parallax is too small to notice with the naked eye
2. Earth does not orbit Sun; it is the center of the universe

With rare exceptions such as Aristarchus, the Greeks rejected the correct explanation (1) because they did not think the stars could be *that* far away…

Thus setting the stage for the long, historical showdown between Earth-centered and Sun-centered systems.

What have we learned?



- What was so mysterious about planetary motion in our sky?
  - Like the Sun and Moon, planets usually drift eastward relative to the stars from night to night; but sometimes, for a few weeks or few months, a planet turns westward in its **apparent retrograde motion.**
  - Easy for us to explain: occurs when Earth passes a planet by ("laps it") in its orbit. But difficult to explain if you think Earth is the center of the universe.

What have we learned?

- Why did the ancient Greeks reject the real explanation for planetary motion?
  - They could not detect **stellar parallax**.
  - Most Greeks concluded that Earth must be stationary, because they thought the stars could not be so far away as to make parallax undetectable.