Chapter 2: Discovering the Universe for Yourself

2.2 The Reason for Seasons

- Our goals for learning:
  - **What causes the seasons?**
  - **How 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.

Thought Question

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

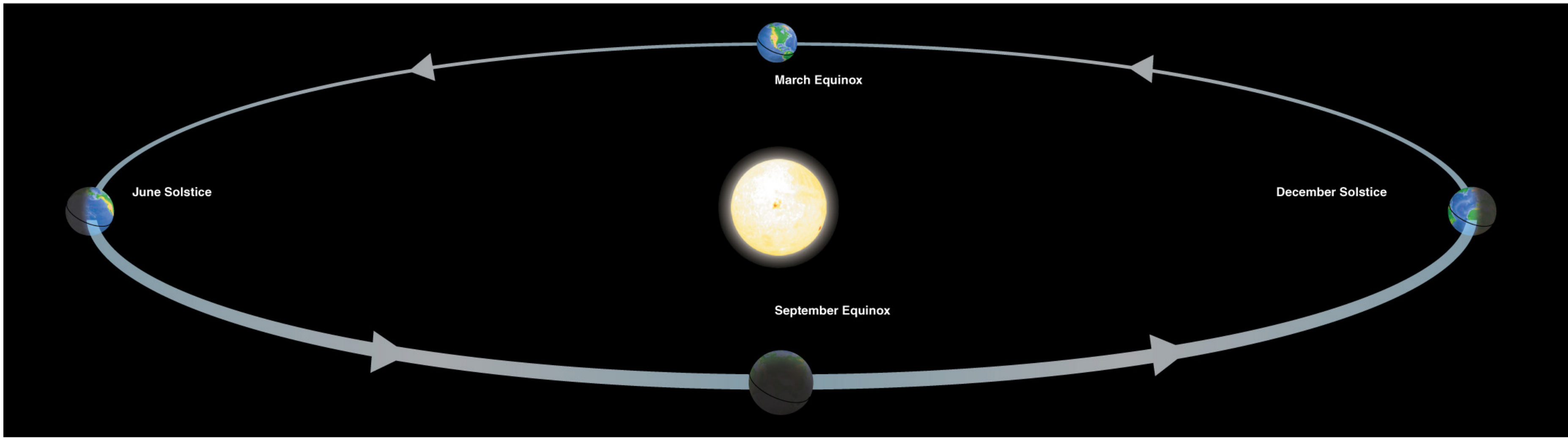
Hint: When it is summer in North America, it is winter in Australia.

Thought Question

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?



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

Sun's altitude also changes with seasons.

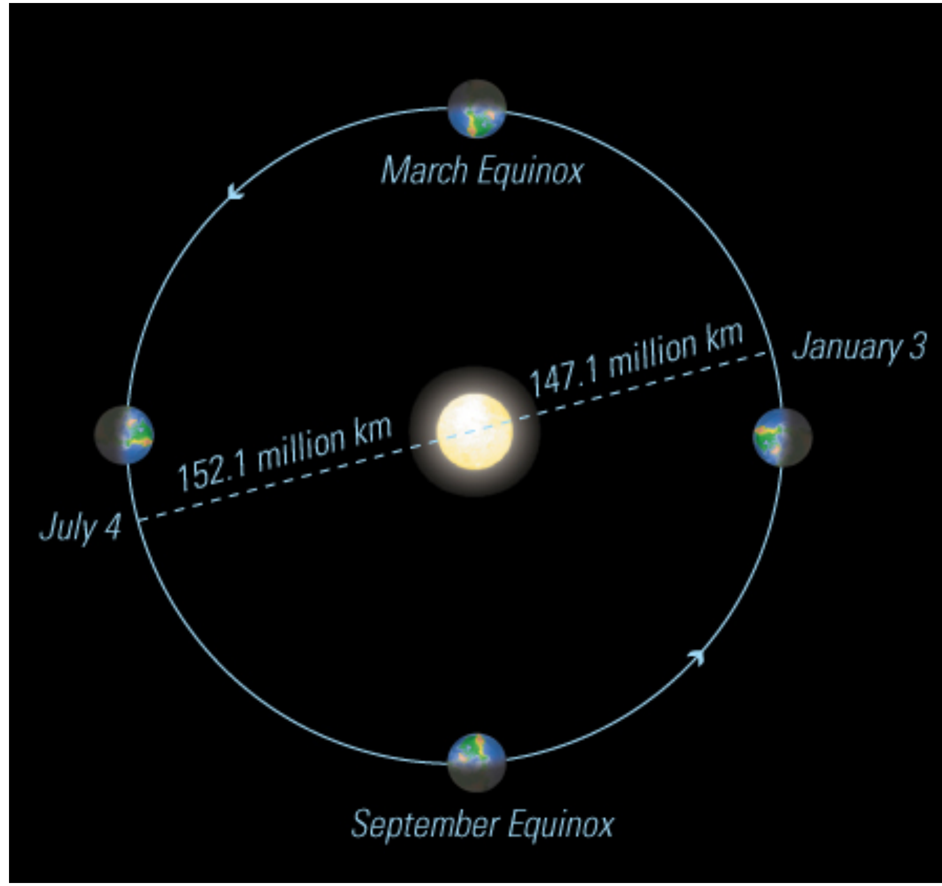
- Sun's position at noon in summer: Higher altitude means more direct sunlight.
- Sun's position at noon in winter: Lower altitude means less direct sunlight.

Summary: The 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.

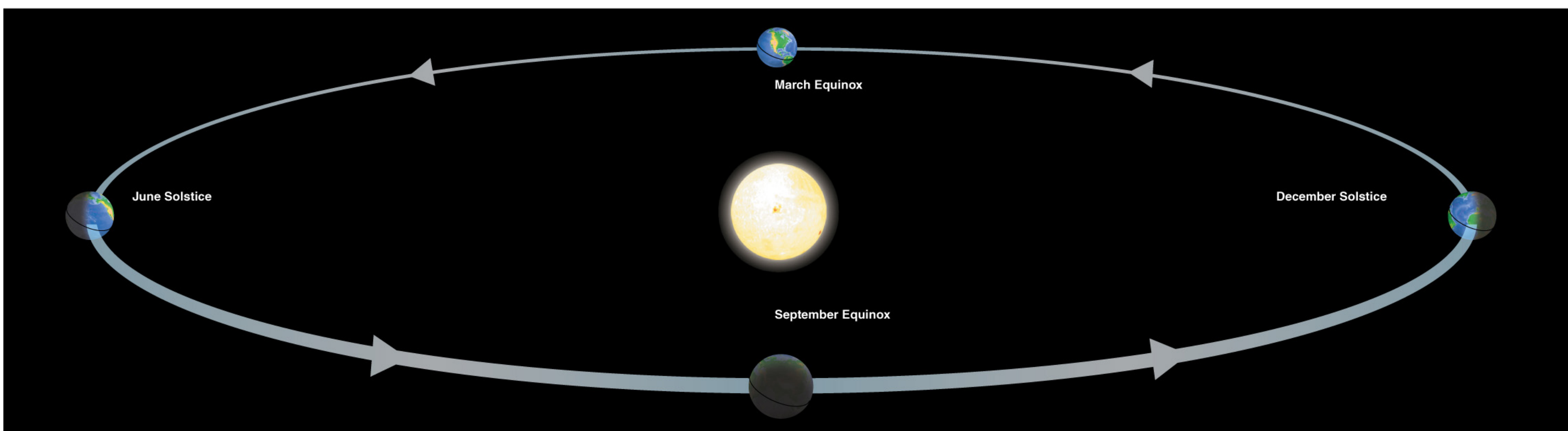
Why *doesn't* distance matter?

- Variation of Earth–Sun distance is small—about 3%; this small variation is overwhelmed by the effects of axis tilt.
- Variation in any season of each hemisphere—Sun distance is even smaller!



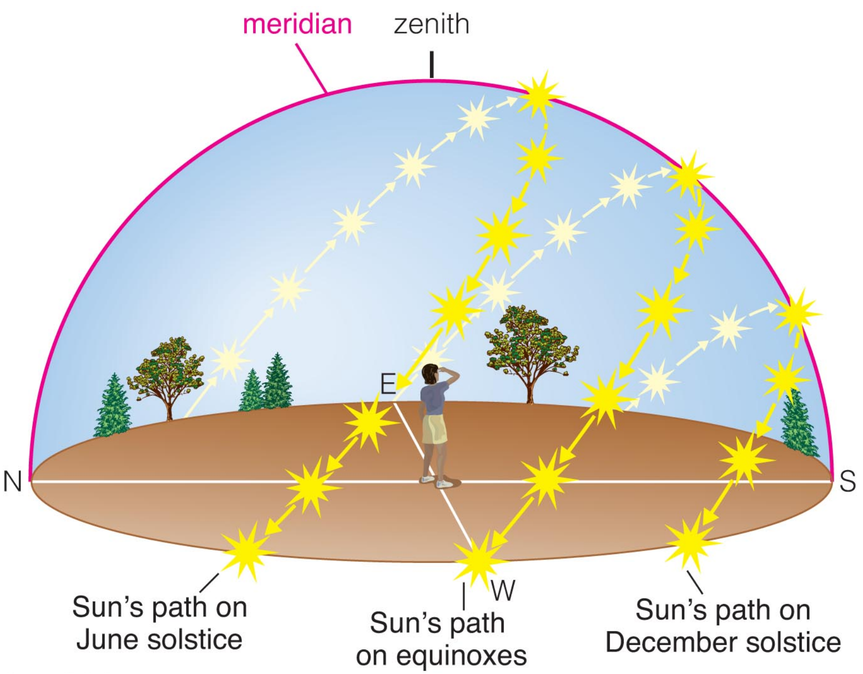
How do we mark the progression of the seasons?

- We define four special points:
  - summer (June) solstice
  - winter (December) solstice
  - spring (March) equinox
  - fall (September) equinox



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

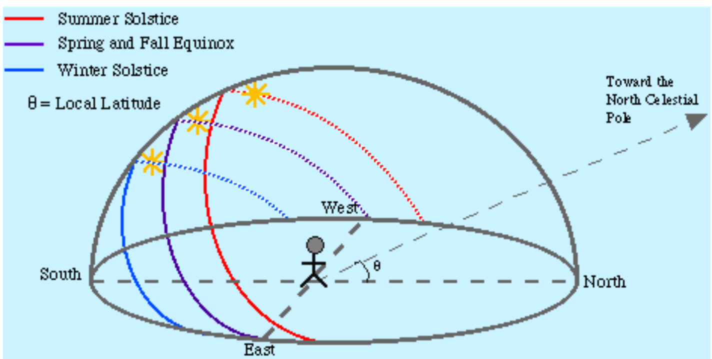
- Summer (June) solstice: highest path; rise and set at most extreme north of due east
- Winter (December) solstice: lowest path; rise and set at most extreme south of due east
- Equinoxes: Sun rises precisely due east and sets precisely due west.



How can E, W, N, and S be defined?

Two different ways:

I. By celestial north:



Facing celestial North, we can find

- S (on the back);
- E (right);
- W (left)

II. By finding equinoxes:

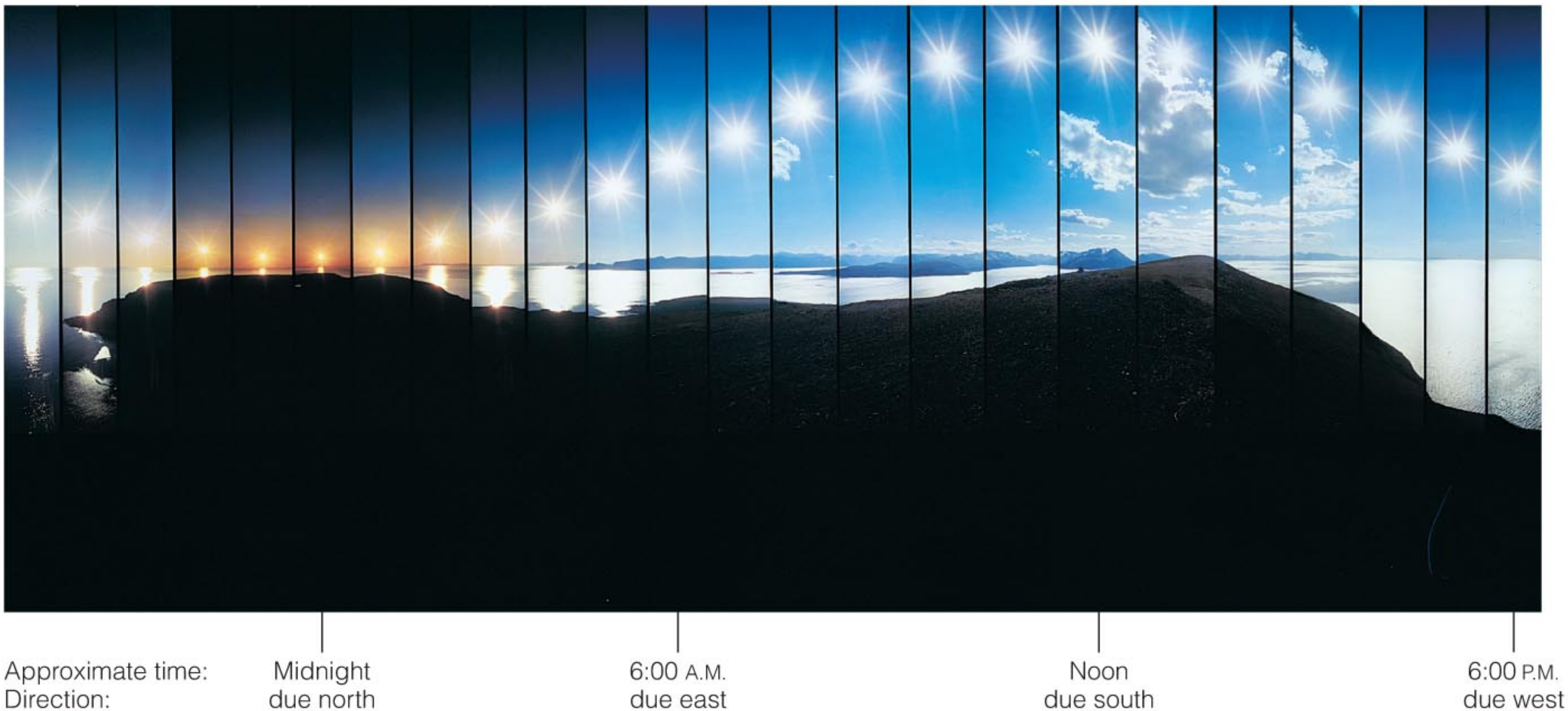
Facing East at sunrise we can find

- W (on the back)
- N (left)
- S (right)

How does it work when facing West at sunset?

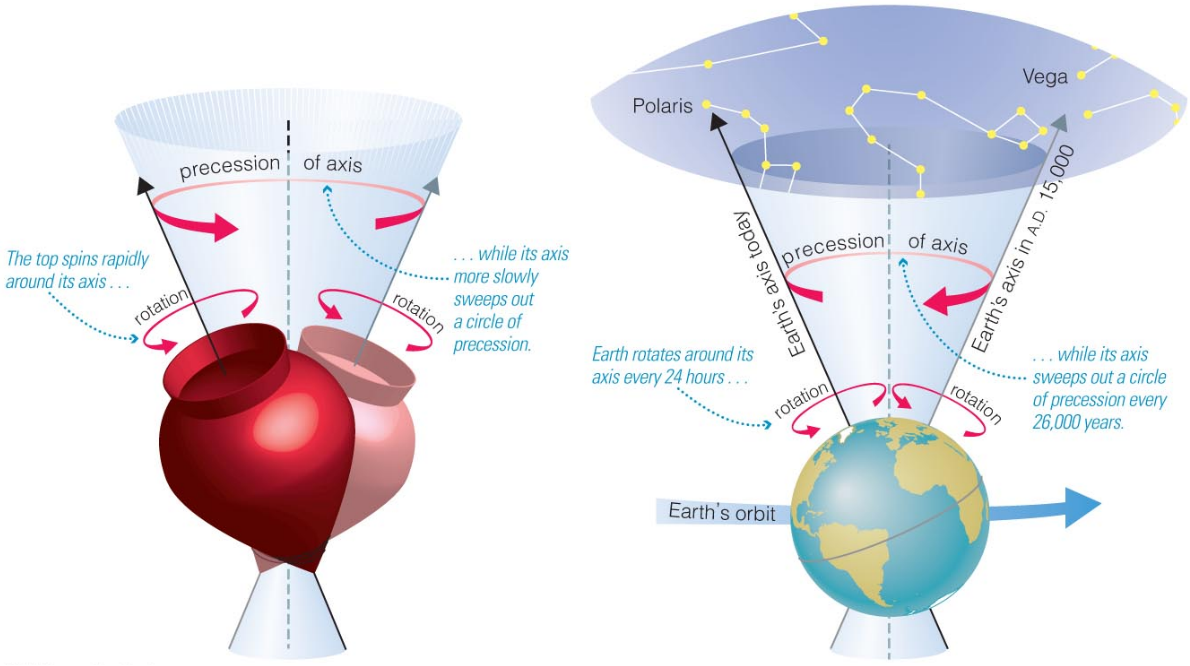
Seasonal changes are more extreme at high latitudes.

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



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

- 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; e.g., spring equinox, once in *Aries*, is now in *Pisces*!



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

What have we learned?

- **What causes the seasons?**
  - The tilt of the Earth's axis causes sunlight to hit different parts of the Earth more directly during the summer and less directly during the winter.
  - We can specify the position of an object in the local sky by its **altitude** above the horizon and its **direction** along the horizon.
  - 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.

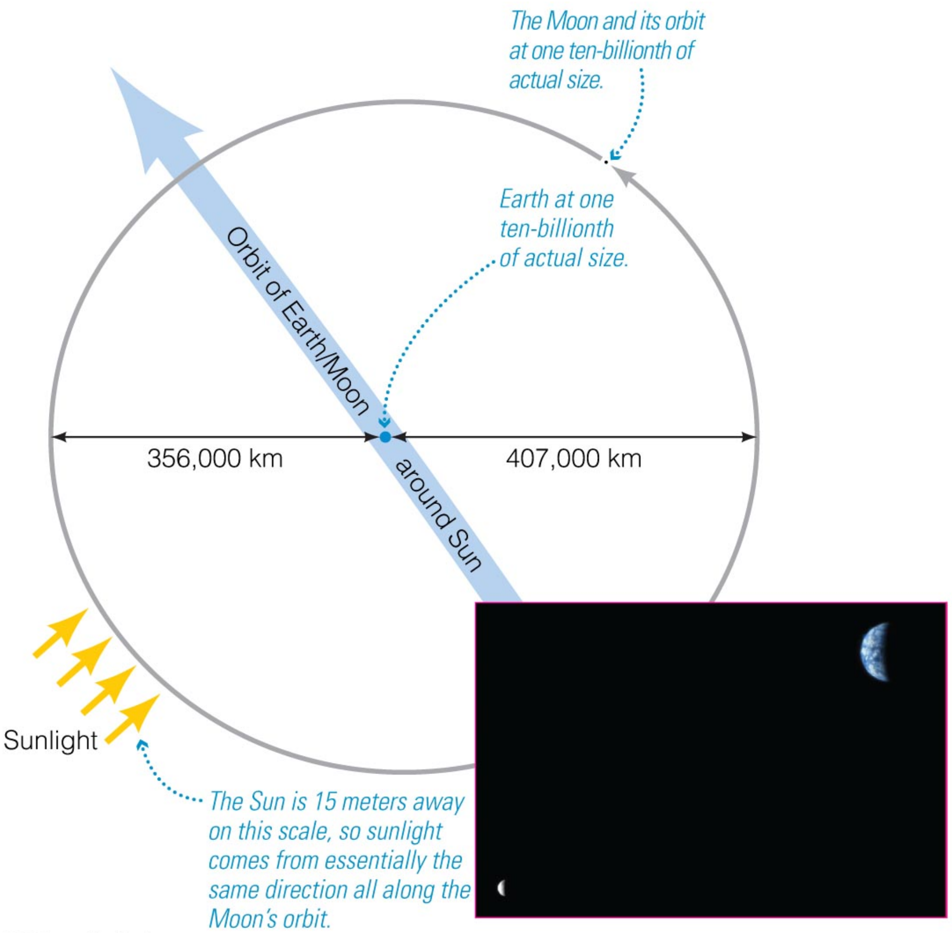
What have we learned?

- **How does the orientation of Earth's axis change with time?**
  - The tilt remains about 23.5º (so the season pattern is not affected), but Earth has a 26,000 year precession cycle that slowly and subtly changes the orientation of Earth's axis.

2.3 The Moon, Our Constant Companion

- Our goals for learning:
  - **Why do we see phases of the Moon?**
  - **What causes eclipses?**

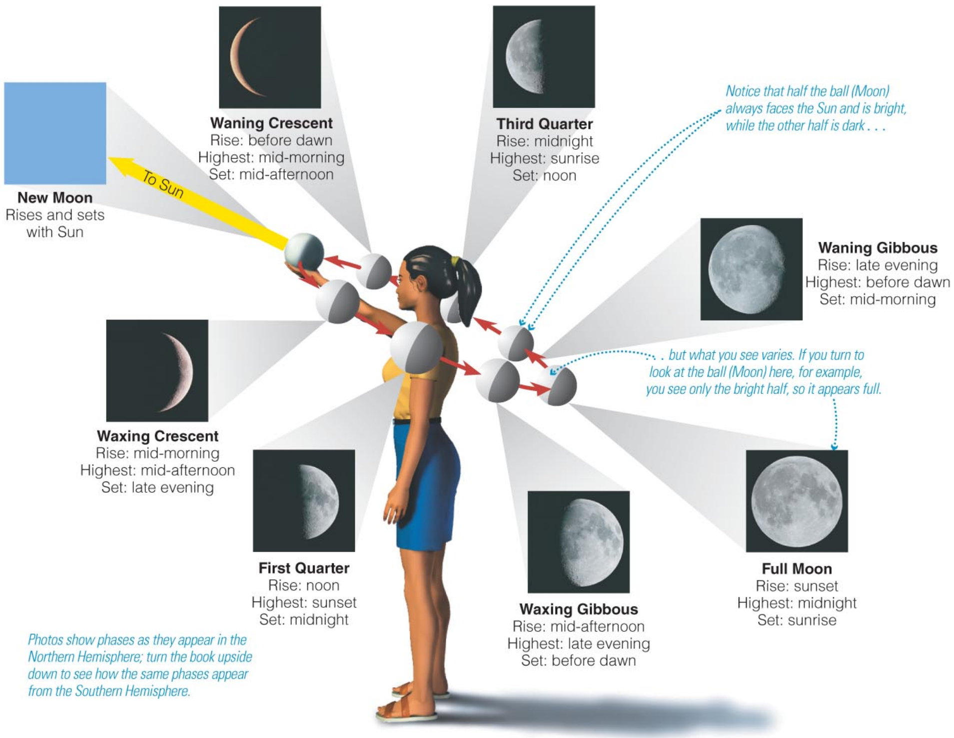
Why do we see phases of the Moon?



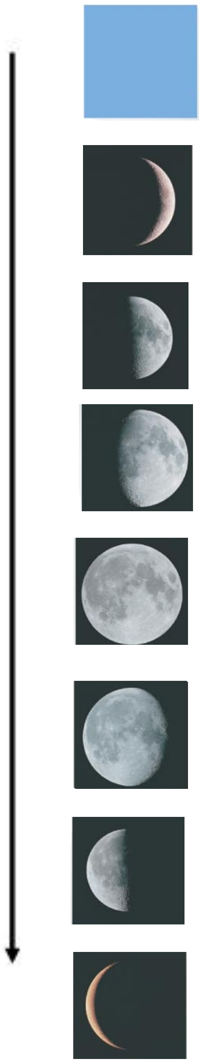
- Lunar phases are a consequence of the Moon's 27.3-day orbit around Earth.

Phases of the Moon

- Half of Moon is illuminated by Sun and half is dark.
- We see a changing combination of the bright and dark faces as Moon orbits.



Phases of the Moon: 29.5-day cycle



new

crescent

first quarter

gibbous

full

gibbous

last quarter

crescent

Waxing

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

Waning

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

Thought Question

It's 9 a.m. You look up in the sky and see a moon with half its face bright and half dark. What phase is it?

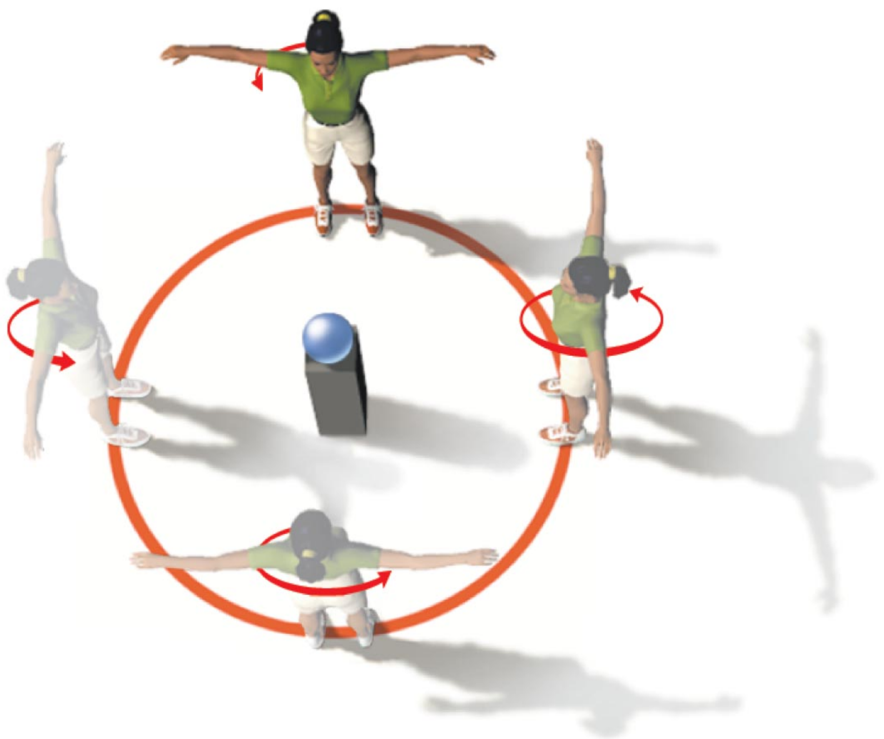
A. first quarter
B. waxing gibbous
C. third quarter
D. half moon

Thought Question

It's 9 a.m. You look up in the sky and see a moon with half its face bright and half dark. What phase is it?

A. first quarter
B. waxing gibbous
C. third quarter
D. half moon

We see only one side of Moon



b You will face the model at all times only if you rotate exactly once during each orbit.

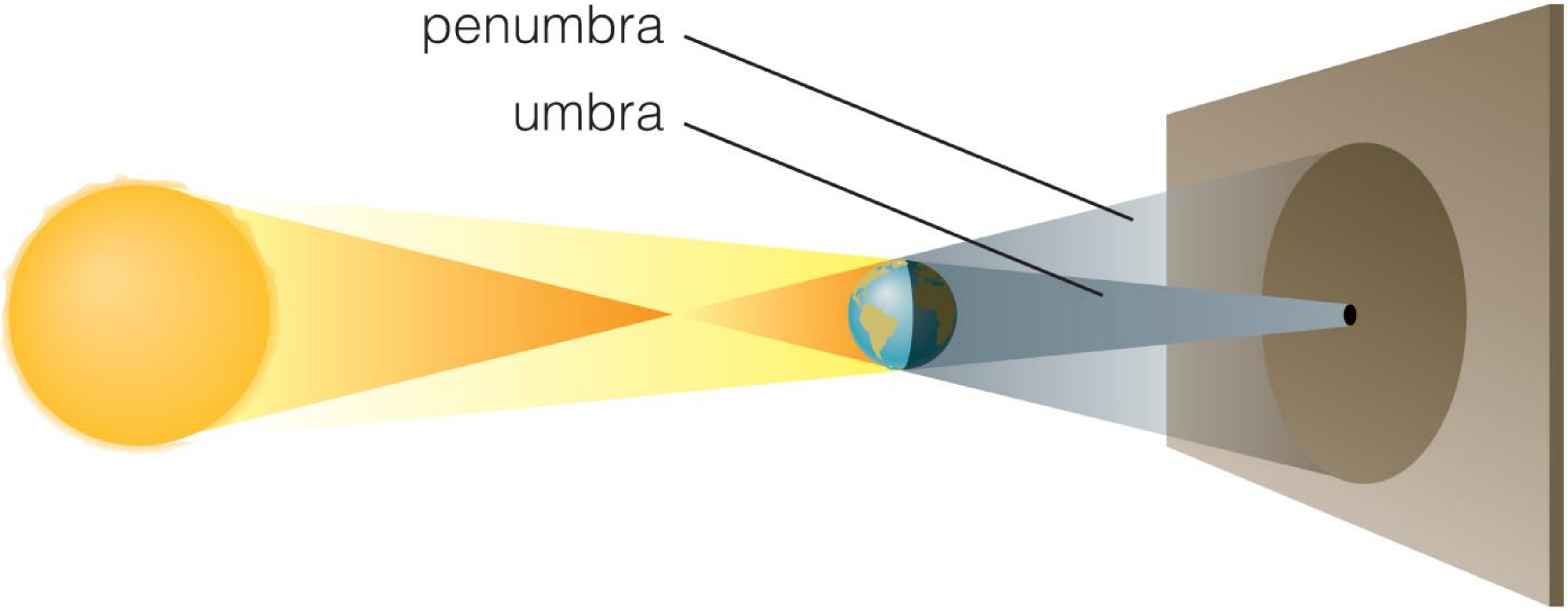
- Synchronous rotation: the Moon rotates exactly once with each orbit.
- That is why only one side is visible from Earth.

Tidal locking (synchronous rotation): see how

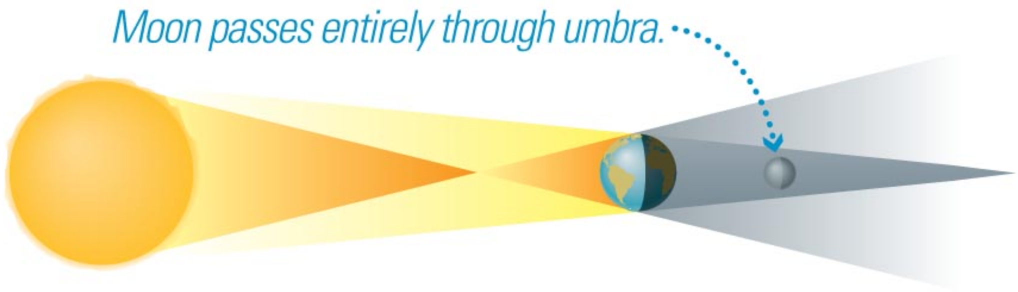
Source: Science Story (Youtube)

What causes eclipses?

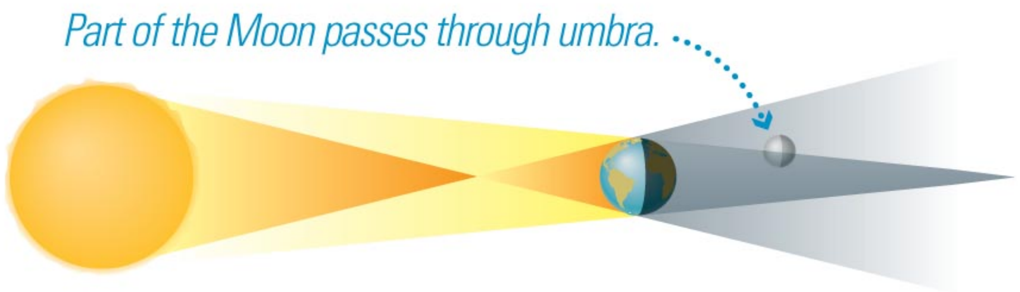
- The Earth and Moon cast shadows.
- When either passes through the other's shadow, we have an **eclipse**.



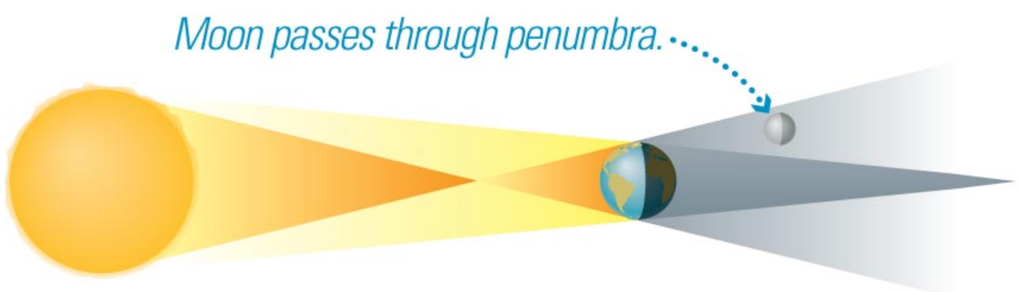
Lunar Eclipse



Total Lunar Eclipse



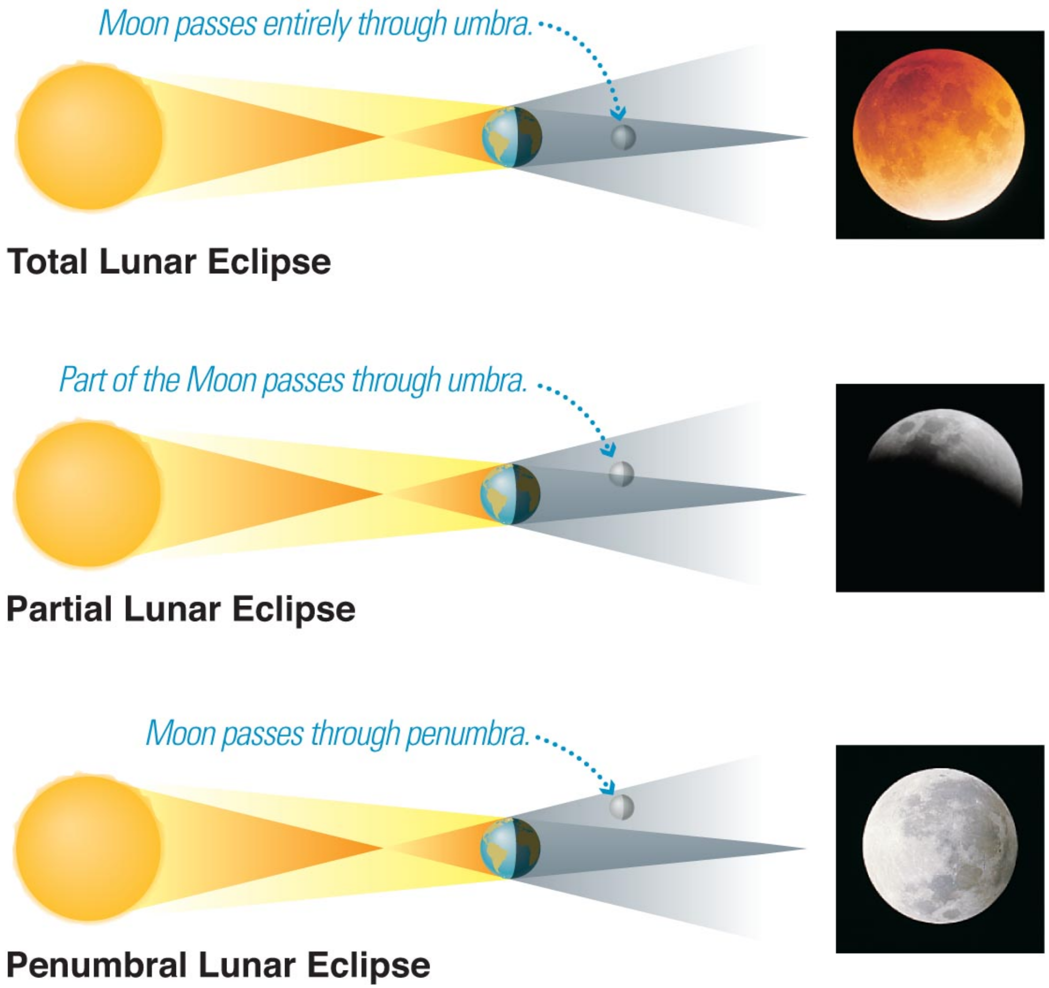
Partial Lunar Eclipse



Penumbral Lunar Eclipse

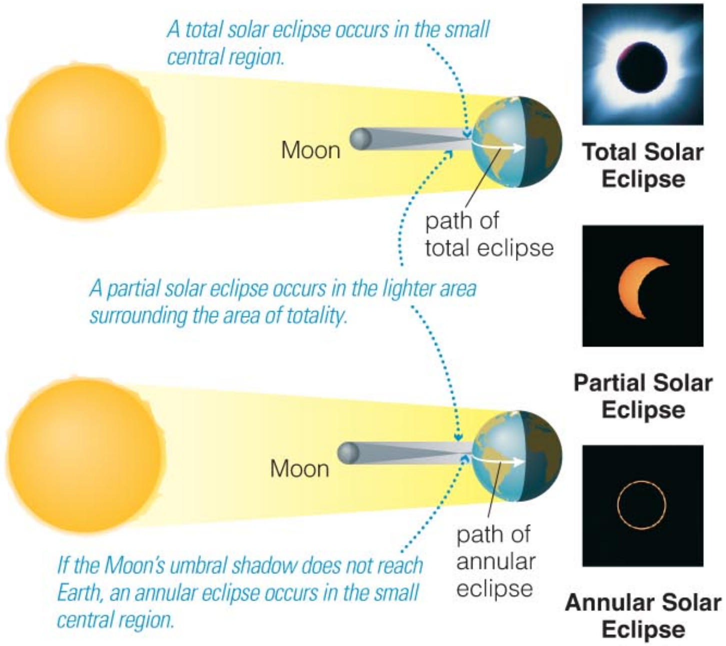
When can eclipses occur?

- **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**.

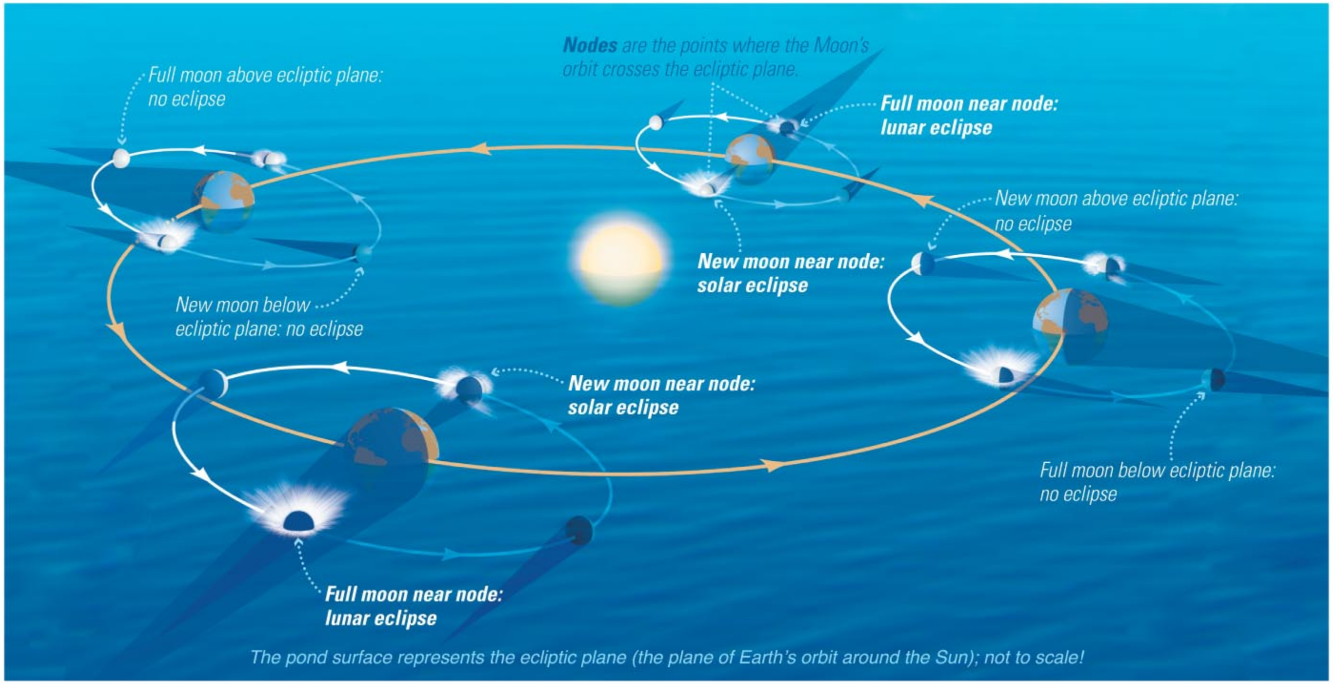


a The three types of solar eclipse. The diagrams show the Moon's shadow falling on Earth; note the dark central umbra surrounded by the much lighter penumbra.

b This photo from Earth orbit shows the Moon's shadow (umbra) on Earth during a total solar eclipse. Notice that only a small region of Earth experiences totality at any one time.

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

- The Moon's orbit is tilted 5º 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:

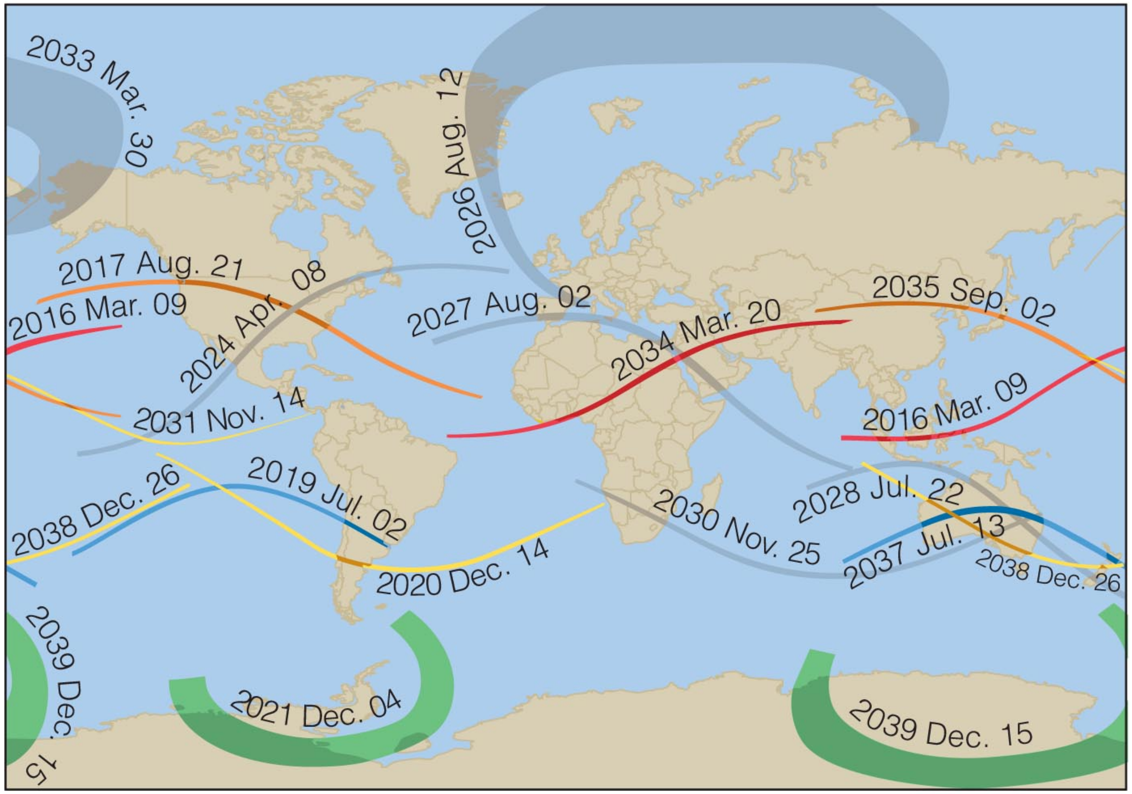
1. It must be full moon (for a lunar eclipse) or new moon (for a solar eclipse).

AND

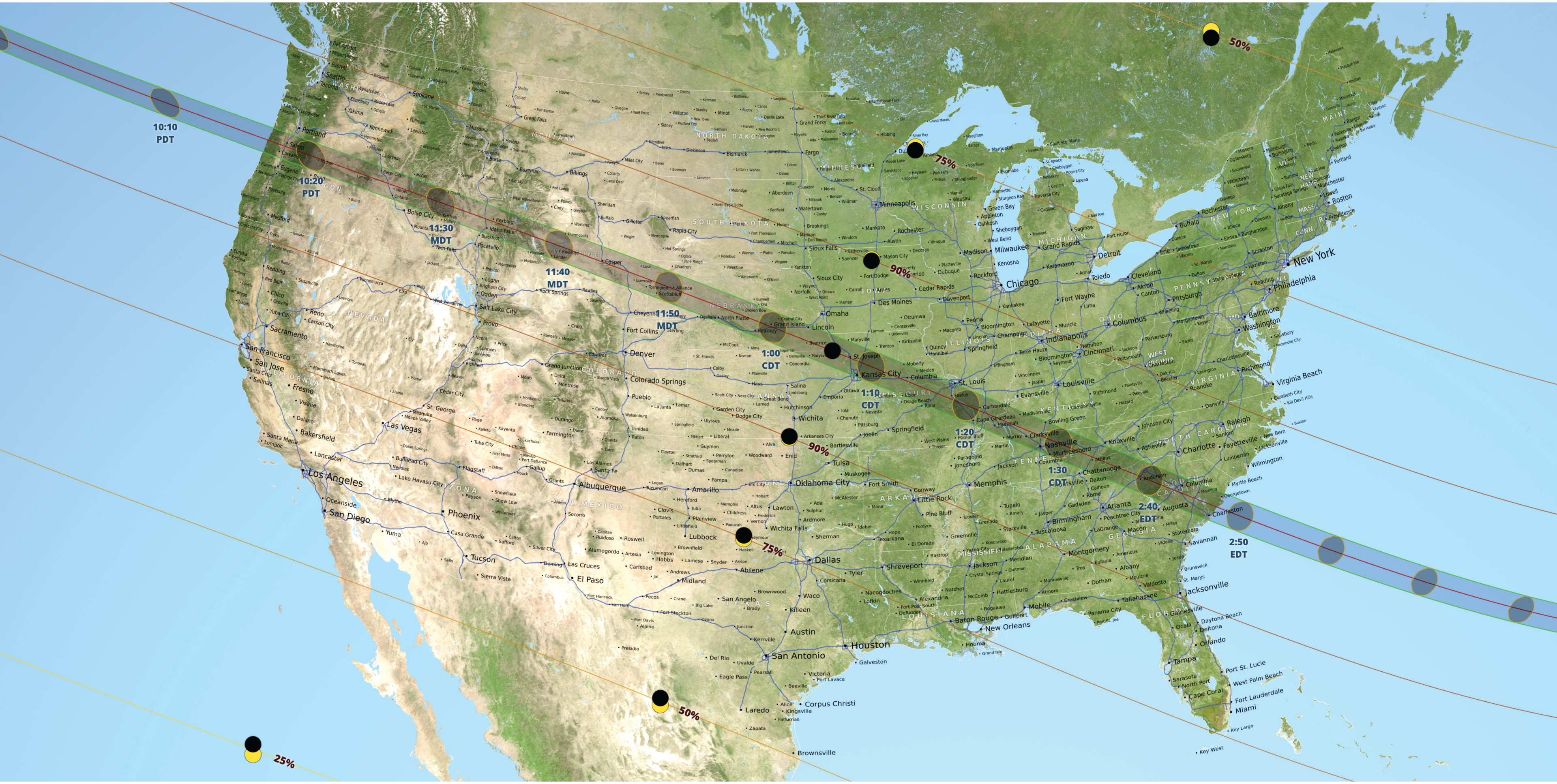
2. The Moon must be at or near one of the two points in its orbit where it crosses the ecliptic plane (its nodes).

Predicting Eclipses

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



The “Great American” eclipse (Aug 21, 2017)



Source: NASA

Latest Eclipse: 2 July 2019 (Chile, Argentina)

Location: San Juan, Argentina

What have we learned?

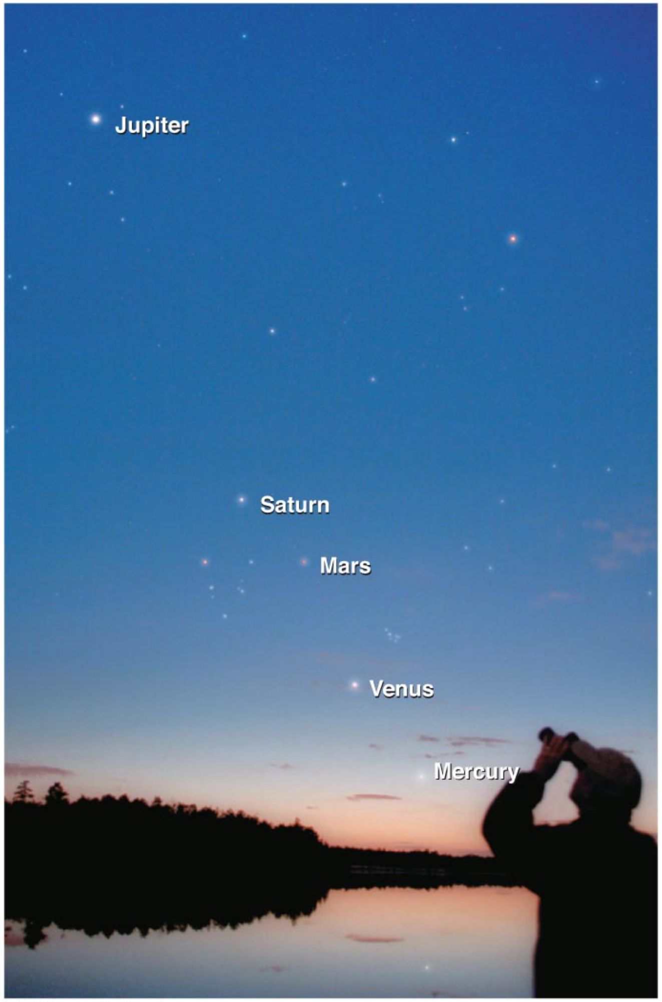
- **Why do we see phases of the Moon?**
  - Half the Moon is lit by the Sun; half is in shadow, and its appearance to us is determined by the relative positions of Sun, Moon, and Earth.
- **What causes eclipses?**
  - Lunar eclipse: Earth's shadow on the Moon
  - Solar eclipse: Moon's shadow on Earth
  - Tilt of Moon's orbit means eclipses occur during two periods each year.

2.4 The Ancient Mystery of the Planets

- Our goals for learning:
  - **What was once so mysterious about planetary motion in our sky?**
  - **Why did the ancient Greeks reject the real explanation for planetary motion?**

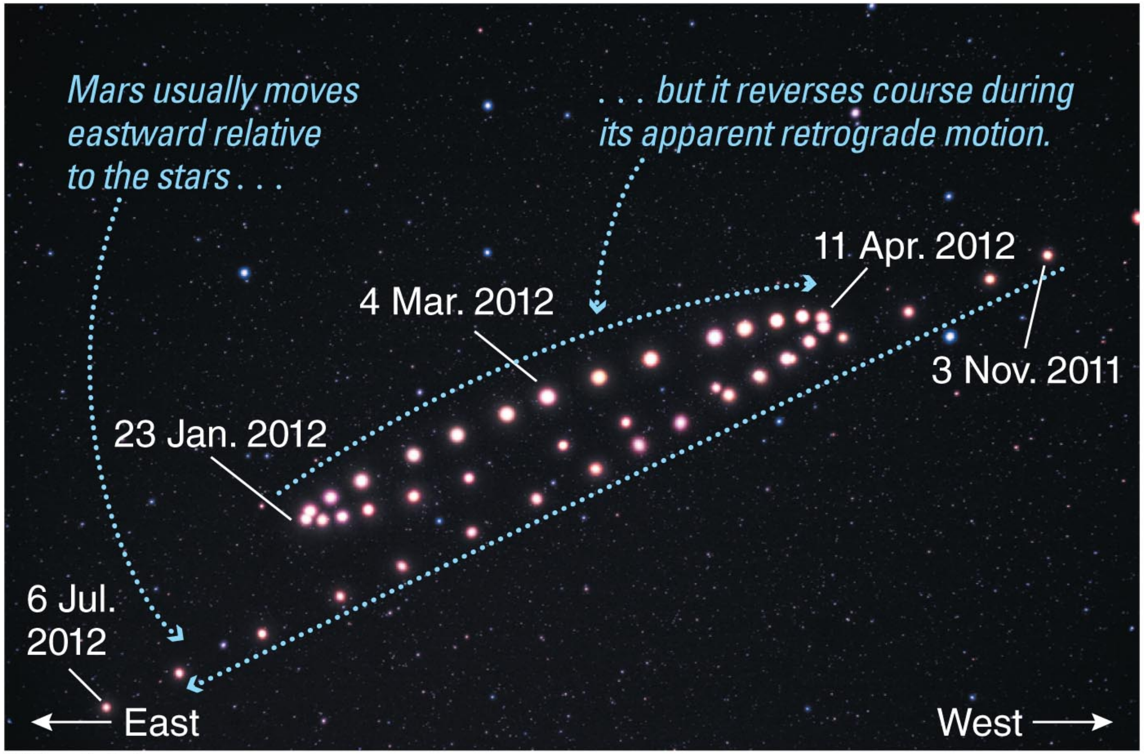
Planets Known in Ancient Times

- 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 slightly *eastward* from night to night relative to the stars.
- But sometimes they go *westward* relative to the stars for a few weeks: **apparent retrograde motion**.



Explaining Apparent Retrograde Motion

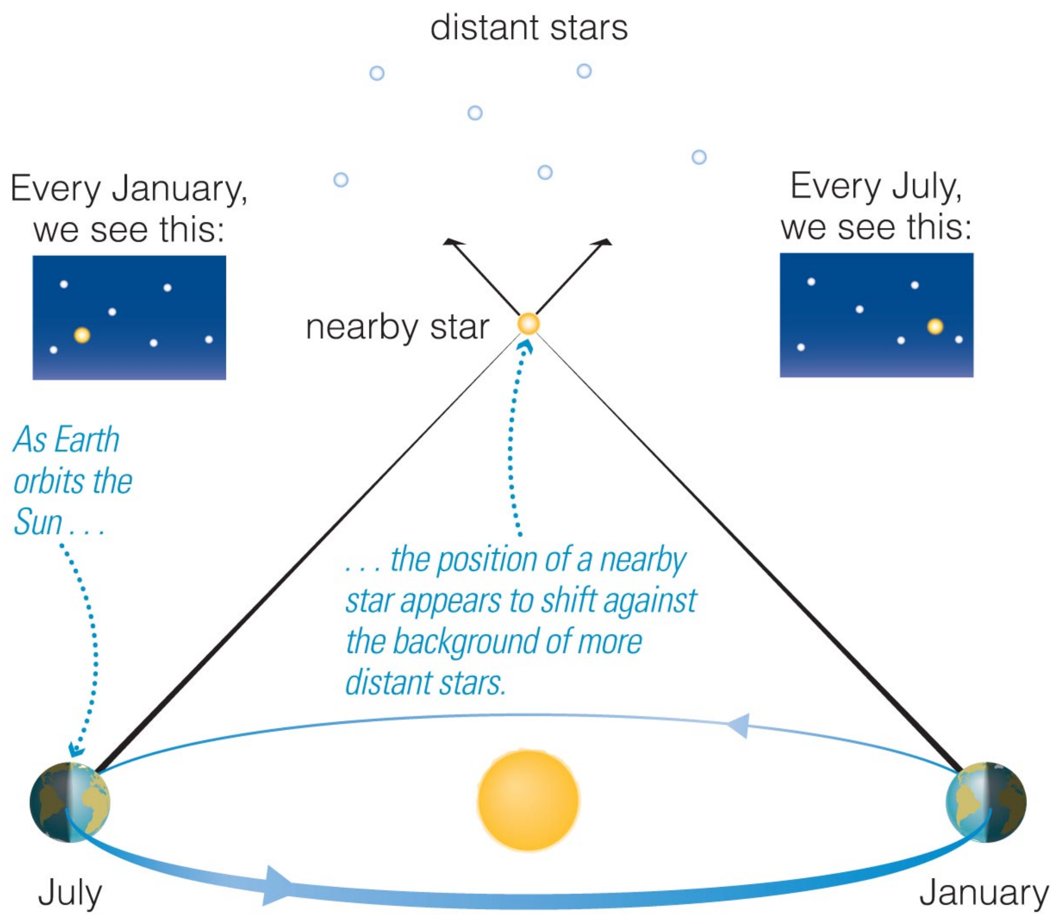
- Easy *for us* to explain: occurs when we "lap" another planet (or when Mercury or Venus laps us).
- But very difficult to explain if you think that Earth is the center of the universe!
- *In fact, ancients considered but rejected the correct explanation.*

Mars retrograde motion … in action

Source: astrogirlwest @ Youtube

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