For: As Soon As Possible:

Check the class web site: **http://www.ucolick.org/~jfortney/3.htm**

Register at www.masteringastronomy.com

- You will need to purchase access (7th edition) if you didn't buy the textbook package at the bookstore
- The class code is AY3FORTNEY

Register your iClicker:
www.iclicker.com/support/registeryourclicker/

Do the reading (check syllabus on web page)

HW 1 due Thursday at 2PM!

Go to section, meet your TA, get started on the homework

Review from last time:

- All atoms heavier than H & He in your body were made in the deep interiors of stars over 4.5 billion years (4.5 Gyr) ago
- Sitting atop the surface of the Earth, we are moving extremely fast
- Our standard units of length are the light-year and the astronomical unit (AU)
- Planet → star system → galaxy → galaxy clusters → Universe

Discovering the Universe for Yourself

2.1 Patterns in the Night Sky

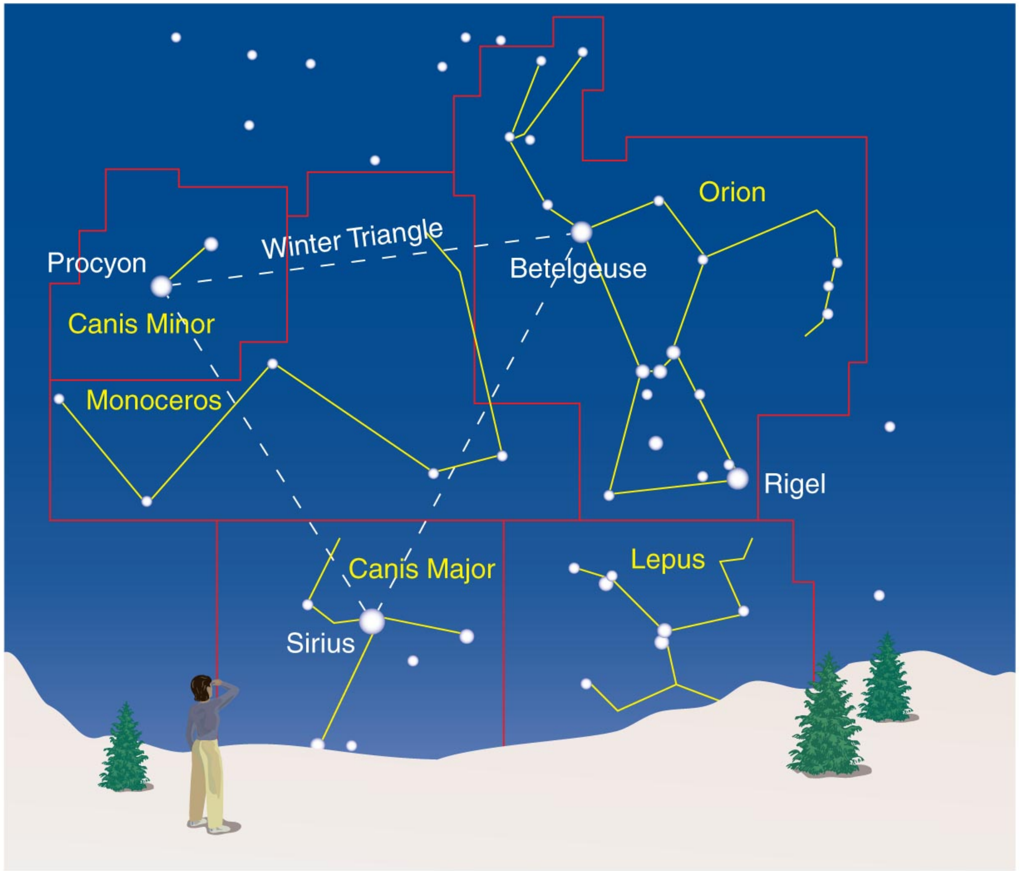
- Our goals for learning:
  - **What does the universe look like from Earth?**
  - **Why do stars rise and set?**

What does the universe look like from Earth?

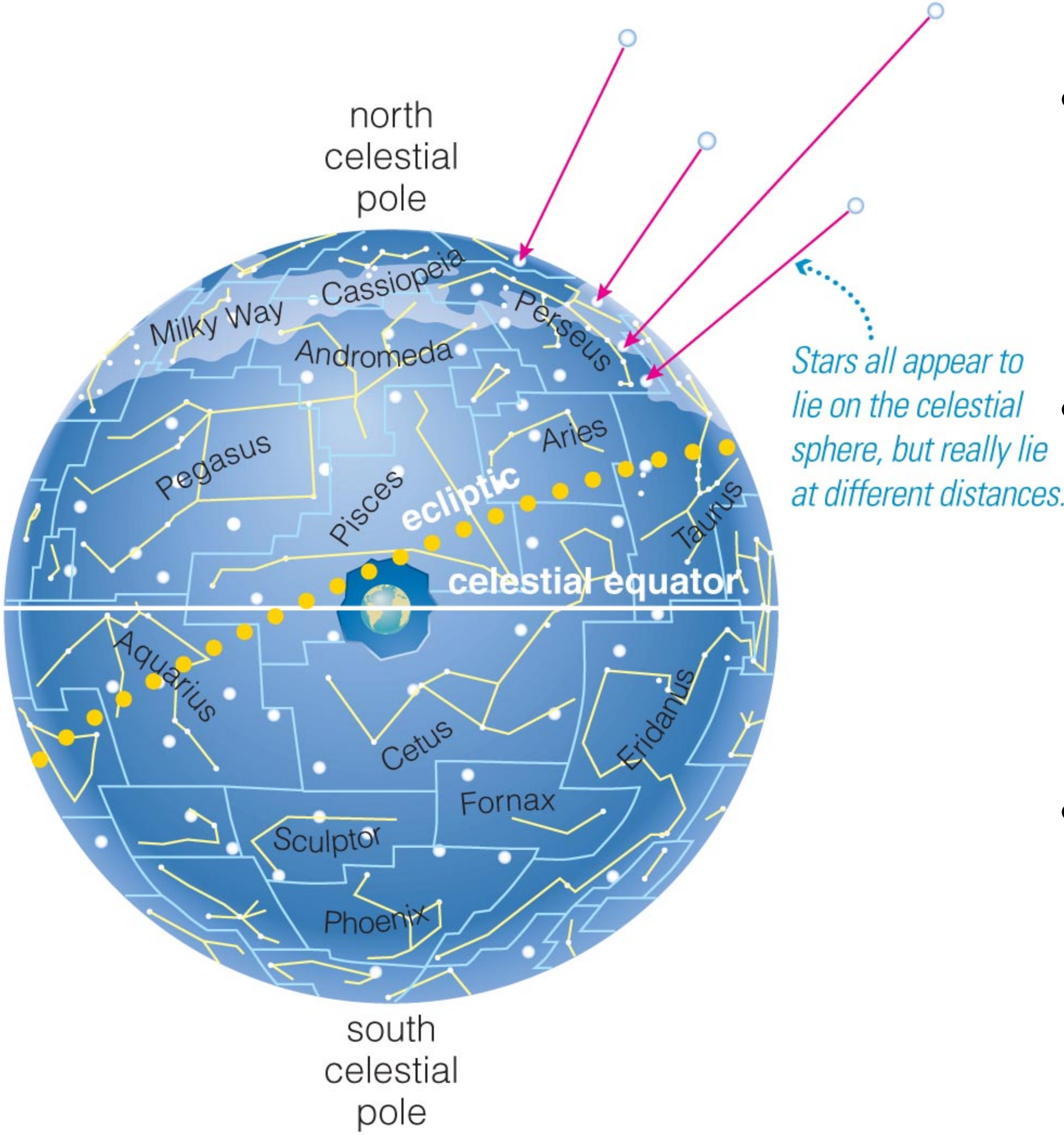
- With the naked eye, we can see more than 2000 stars as well as the Milky Way.

Constellations

- A constellation is a *region* of the sky.
- Eighty-eight constellations fill the entire sky.
- Some can only be seen from a particular hemisphere

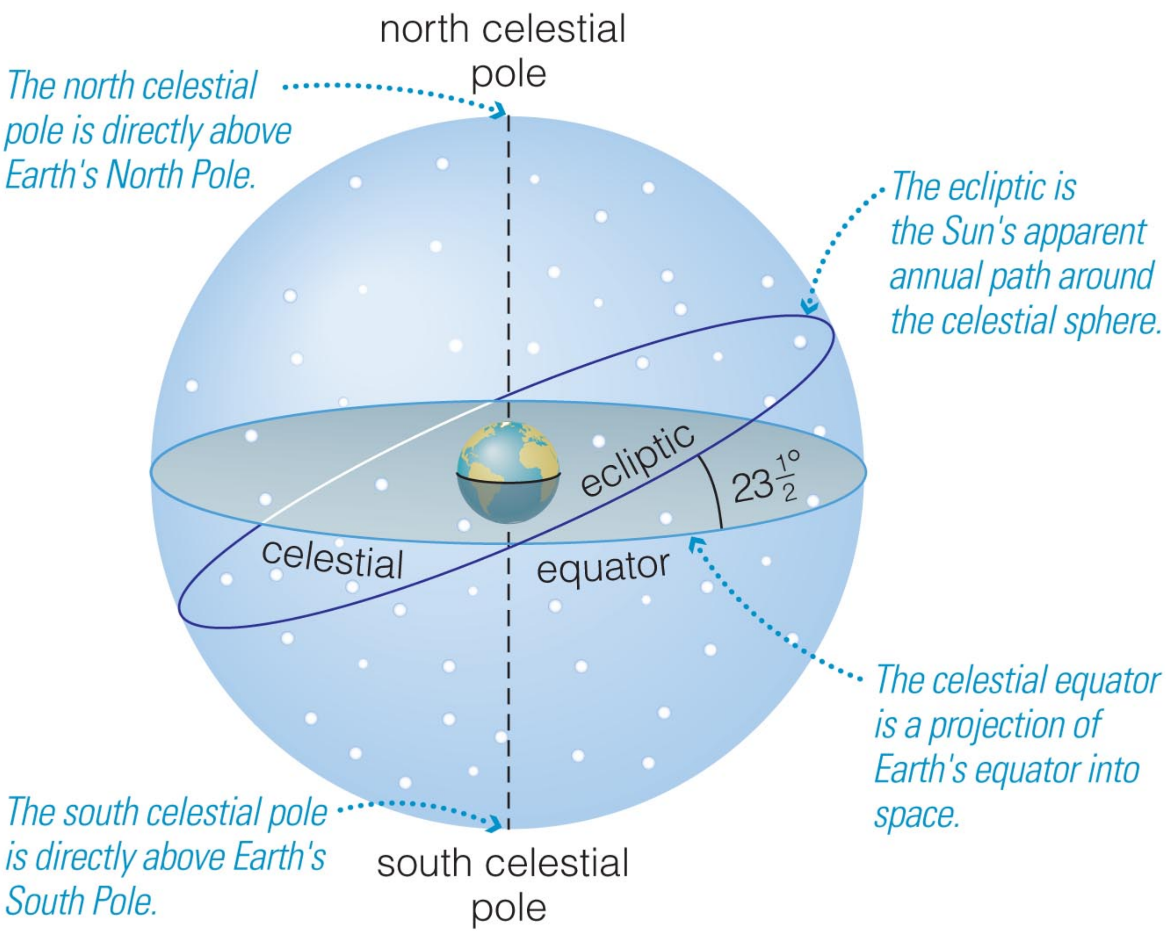


The Celestial Sphere



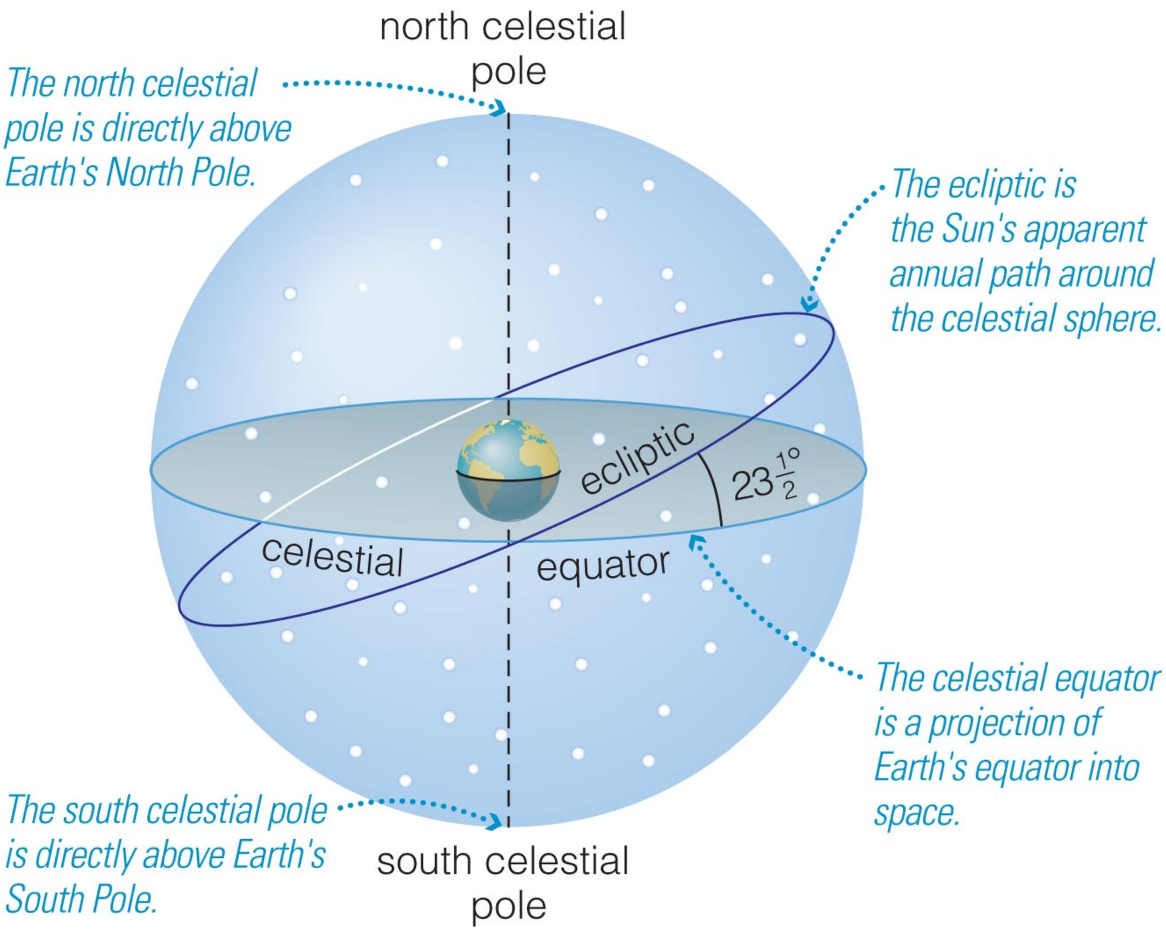
- Stars at different distances all appear to lie on the celestial sphere
- One can make a "globe" of the appearance of the night sky
- The 88 official constellations cover the celestial sphere

The Celestial Sphere



- The **Ecliptic** is the Sun's apparent path through the celestial sphere.
- This is 23.5 degrees inclined compared to projecting out the Earth's equator
- Earth's north celestial pole points at Polaris, the North Star

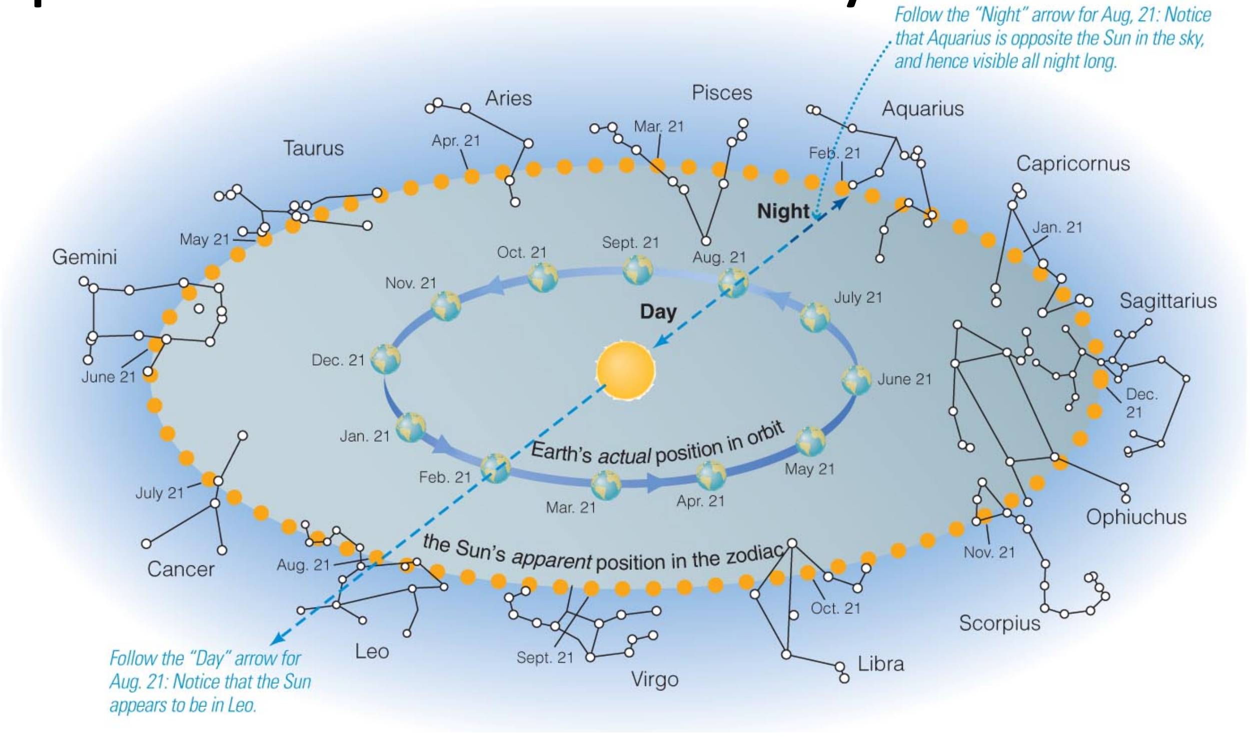
The Celestial Sphere

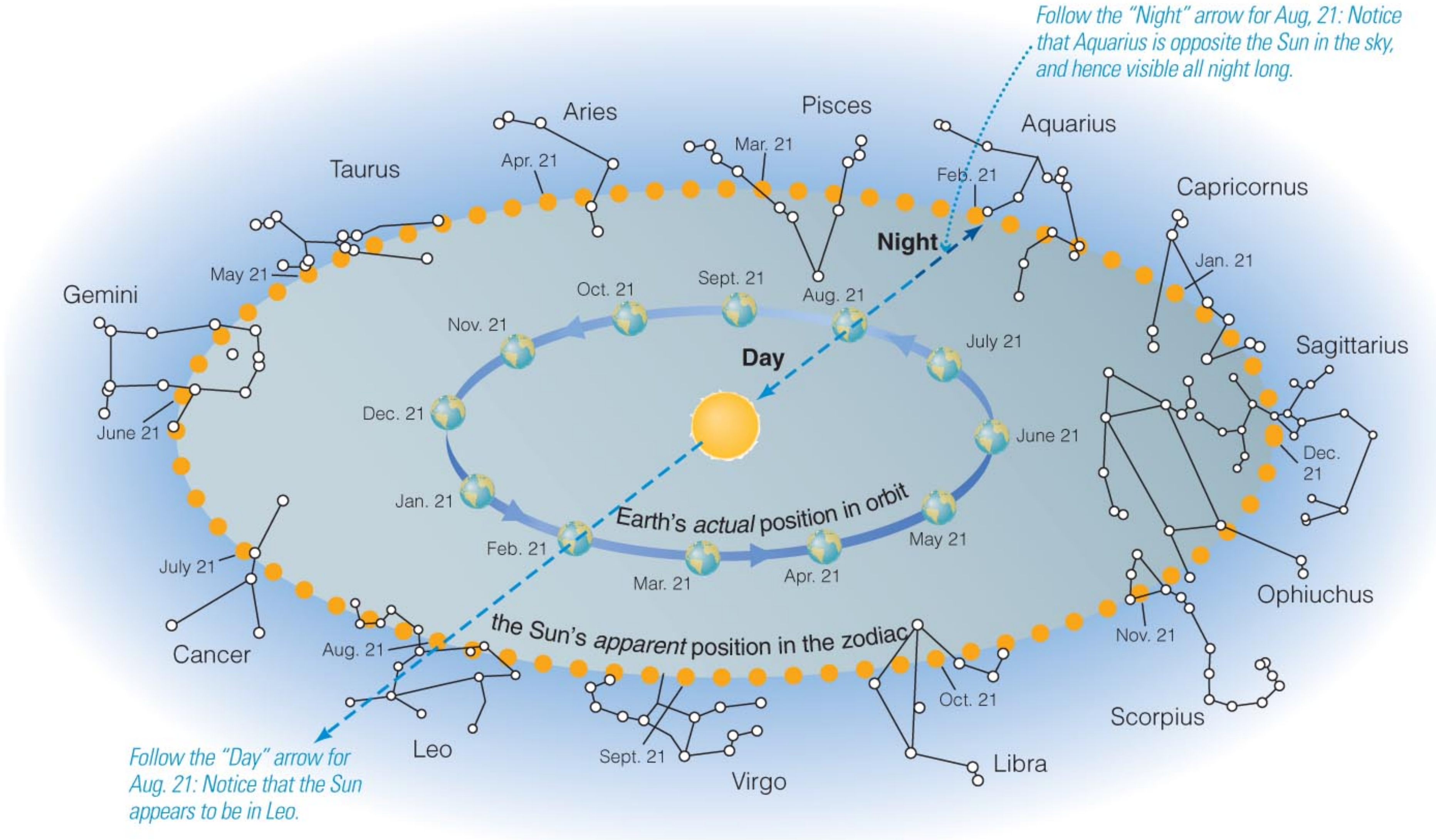


- **North celestial pole** is directly above Earth's North Pole.
- **South celestial pole** is directly above Earth's South Pole.
- **Celestial equator** is a projection of Earth's equator onto sky.

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.





Follow the "Night" arrow for Aug, 21: Notice that Aquarius is opposite the Sun in the sky, and hence visible all night long.
Aries
Pisces
Aquarius
Taurus
Apr. 21
Mar. 21
Feb. 21
Capricornus
Night
Jan. 21
May 21
Gemini
Oct. 21
Sept. 21
Aug. 21
Nov. 21
July 21
Sagittarius
Day
Dec. 21
June 21
June 21
Dec. 21
Jan. 21
Earth's actual position in orbit
May 21
Feb. 21
July 21
Mar. 21
Apr. 21
Ophiuchus
Nov. 21
the Sun's apparent position in the zodiac
Cancer
Aug. 21
Oct. 21
Scorpius
Leo
Sept. 21
Libra
Virgo
Follow the "Day" arrow for Aug. 21: Notice that the Sun appears to be in Leo.

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.

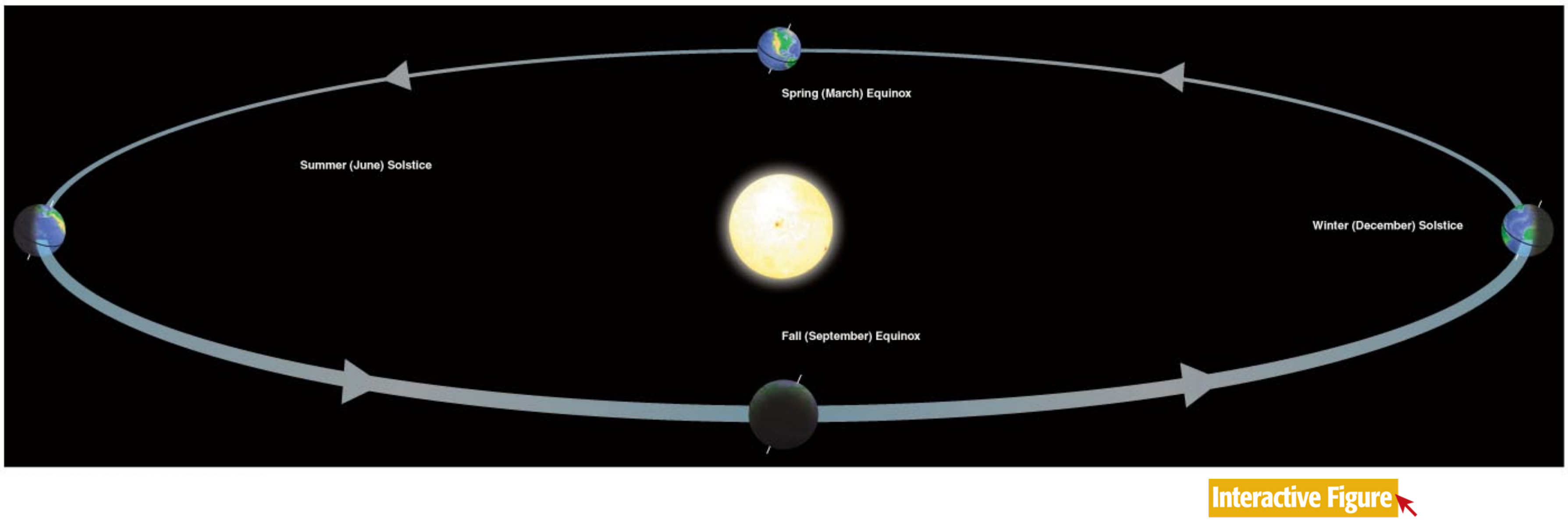
Hint: When it is summer in America, it is winter in Australia.

Thought Question

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

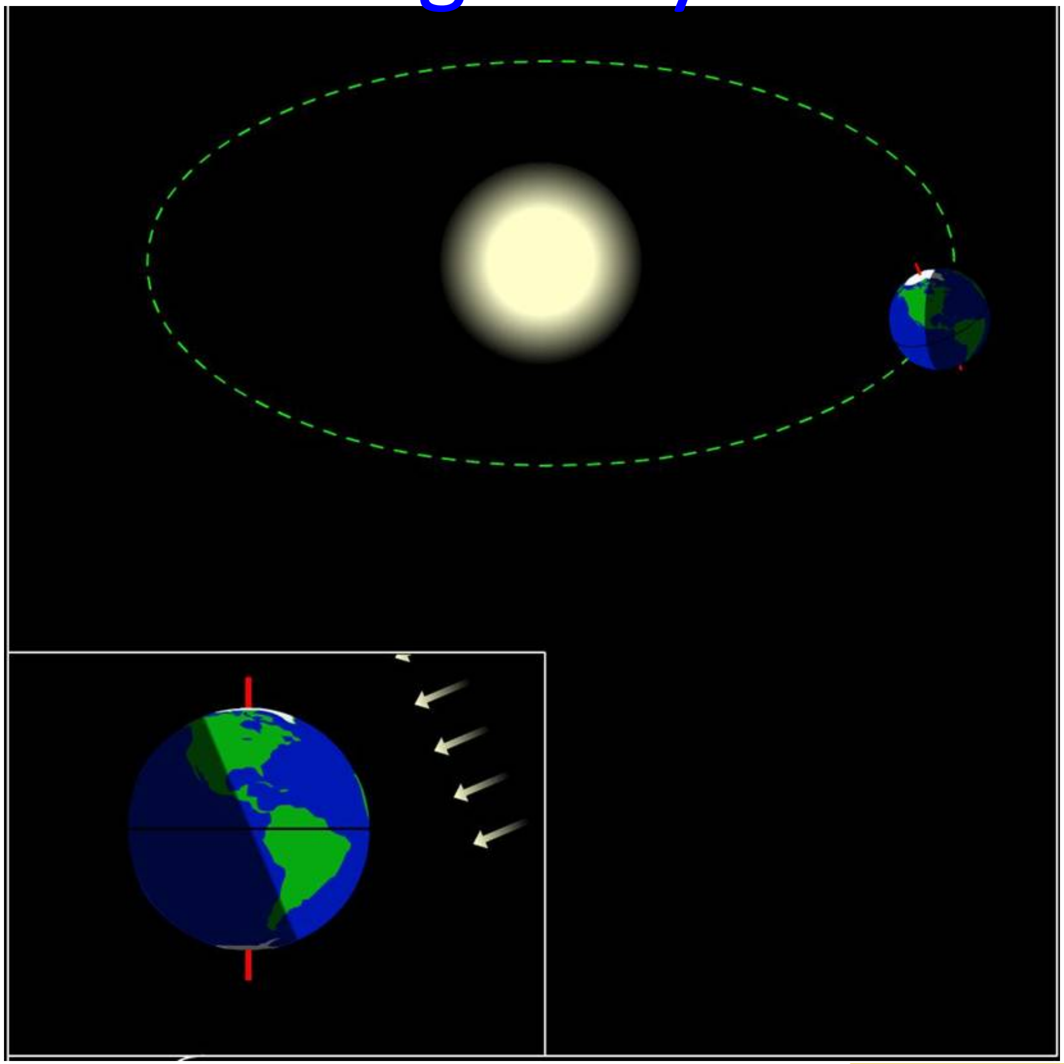
- Seasons are opposite in the N and S hemispheres, so distance cannot be the reason.
- The real reason for seasons involves Earth's axis tilt.

What causes the seasons?



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

Axis tilt changes directness of sunlight during the year.



Interactive Figure

Sun's altitude also changes with seasons.

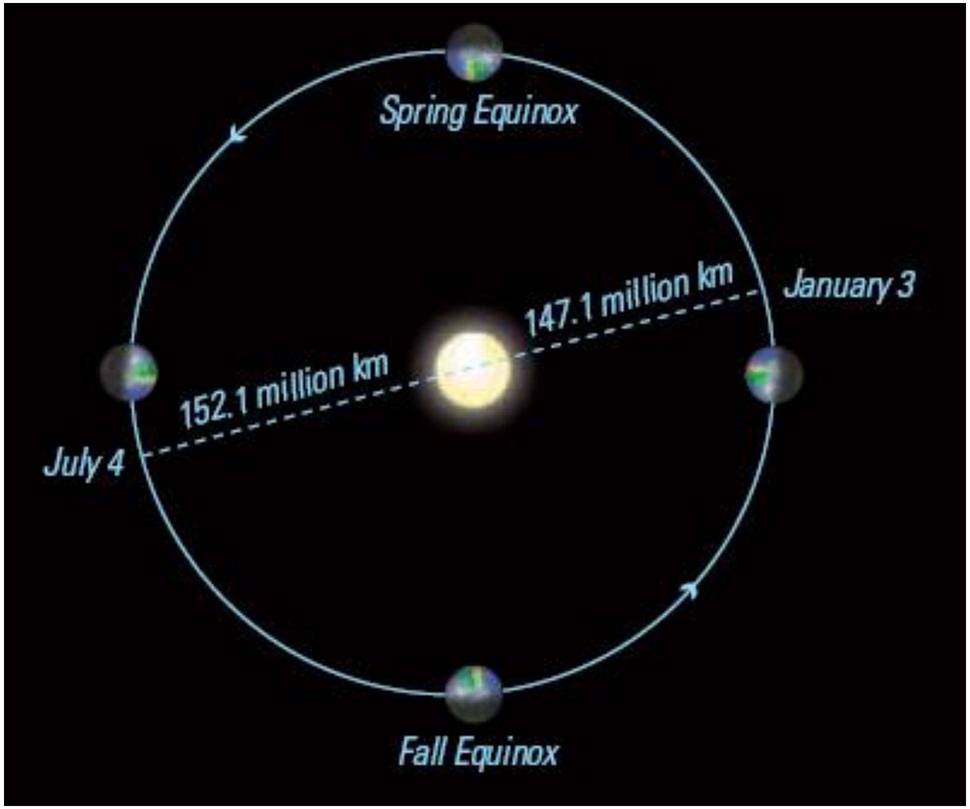
- Sun's position at noon in summer: Higher altitude means more direct sunlight.
- Sun's position at noon in winter: Lower altitude means less direct sunlight.

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.



Clicker Question

- Imagine planets with tilts that differed compared to the 23.5^o of Earth. Seasons would be the most extreme for tilts of:

- A) 0 degrees
- B) 45 degrees
- C) 90 degrees

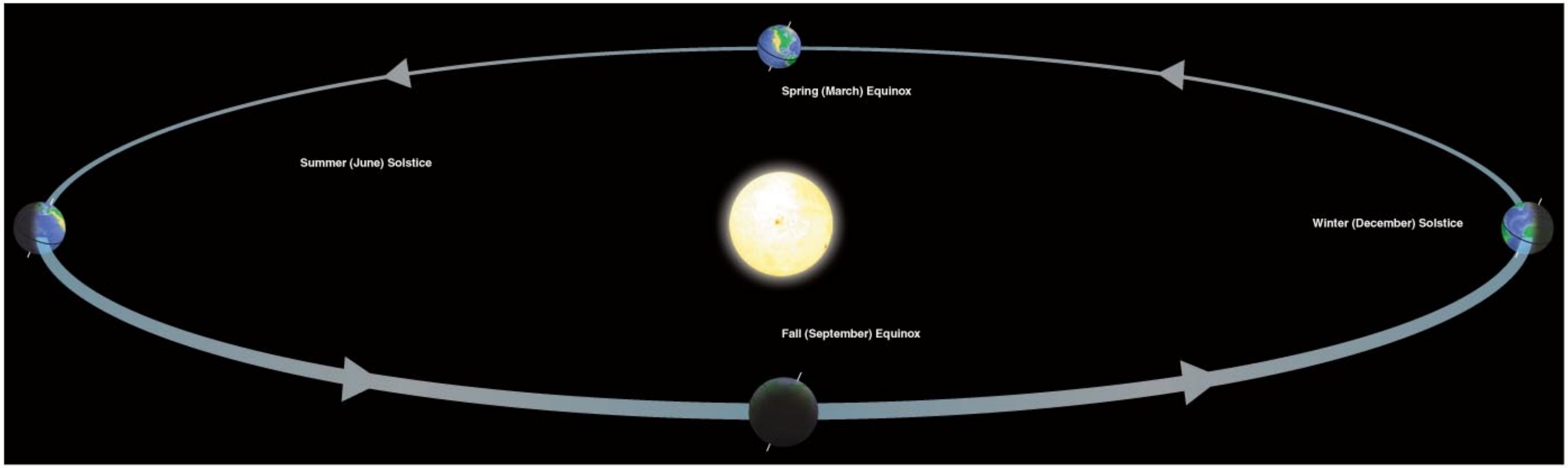
Clicker Question

- Imagine planets with tilts that differed compared to the 23.5^o of Earth. Seasons would be the most extreme for tilts of:

- A) 0 degrees
- B) 45 degrees
- **C) 90 degrees** (Uranus is close to this orientation)

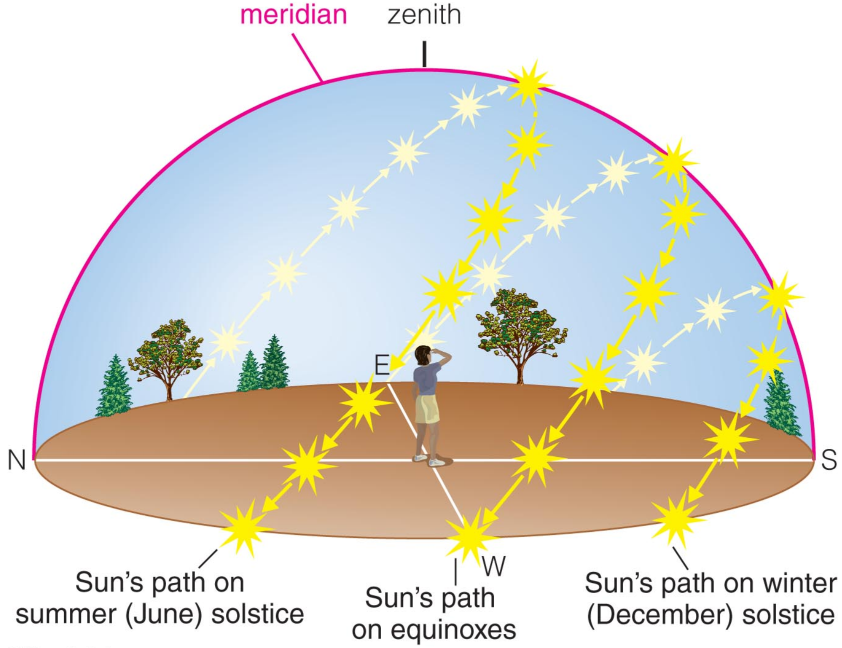
How do we mark the progression of the seasons?

- We define four special points:
  summer (June) solstice [longest day]
  winter (December) solstice [shortest day]
  spring (March) equinox [day=night]
  fall (September) equinox [day=night]



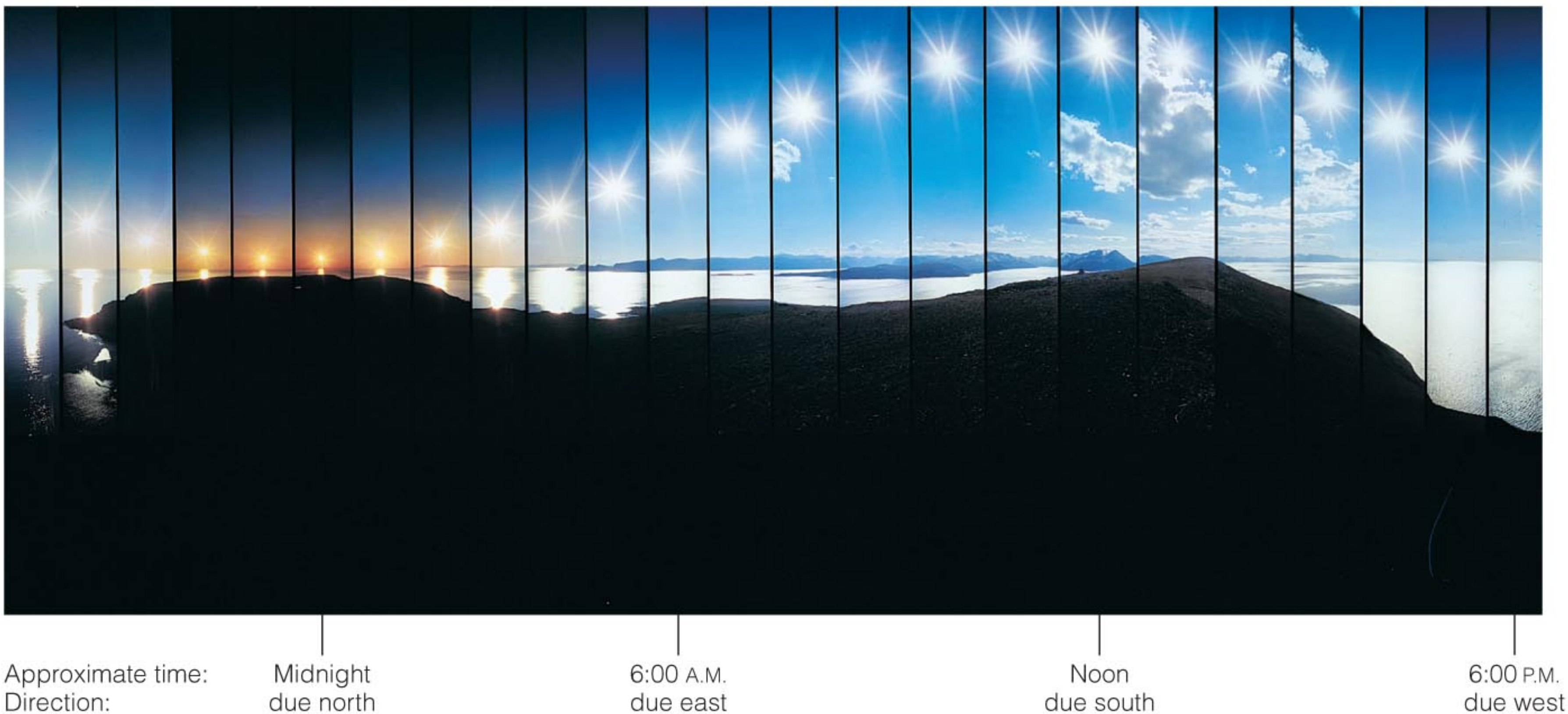
We can recognize solstices and equinoxes by Sun's path across sky:

- 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.



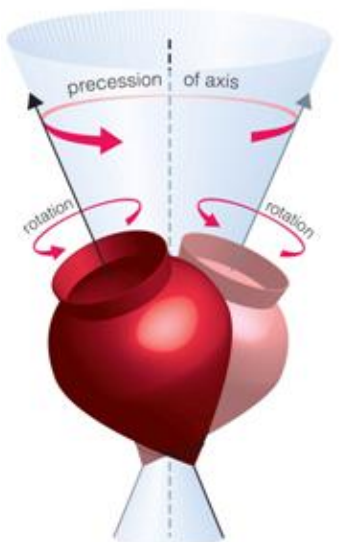
Seasonal changes are more extreme at high latitudes.

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

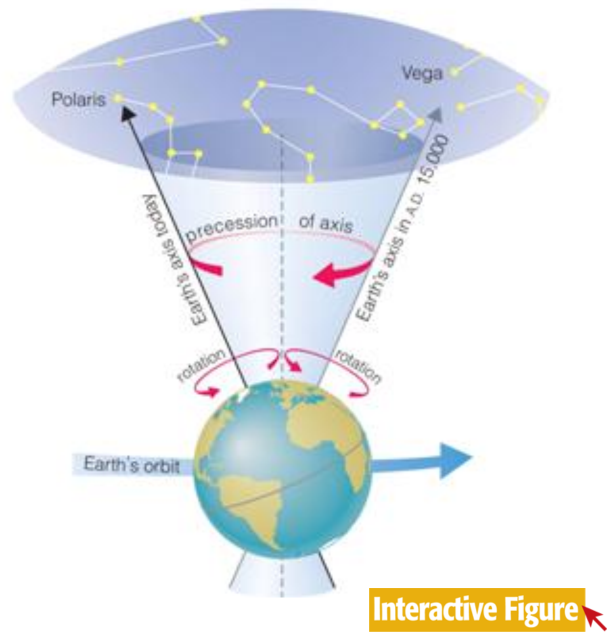


Related question: How does the orientation of Earth's axis change with time?

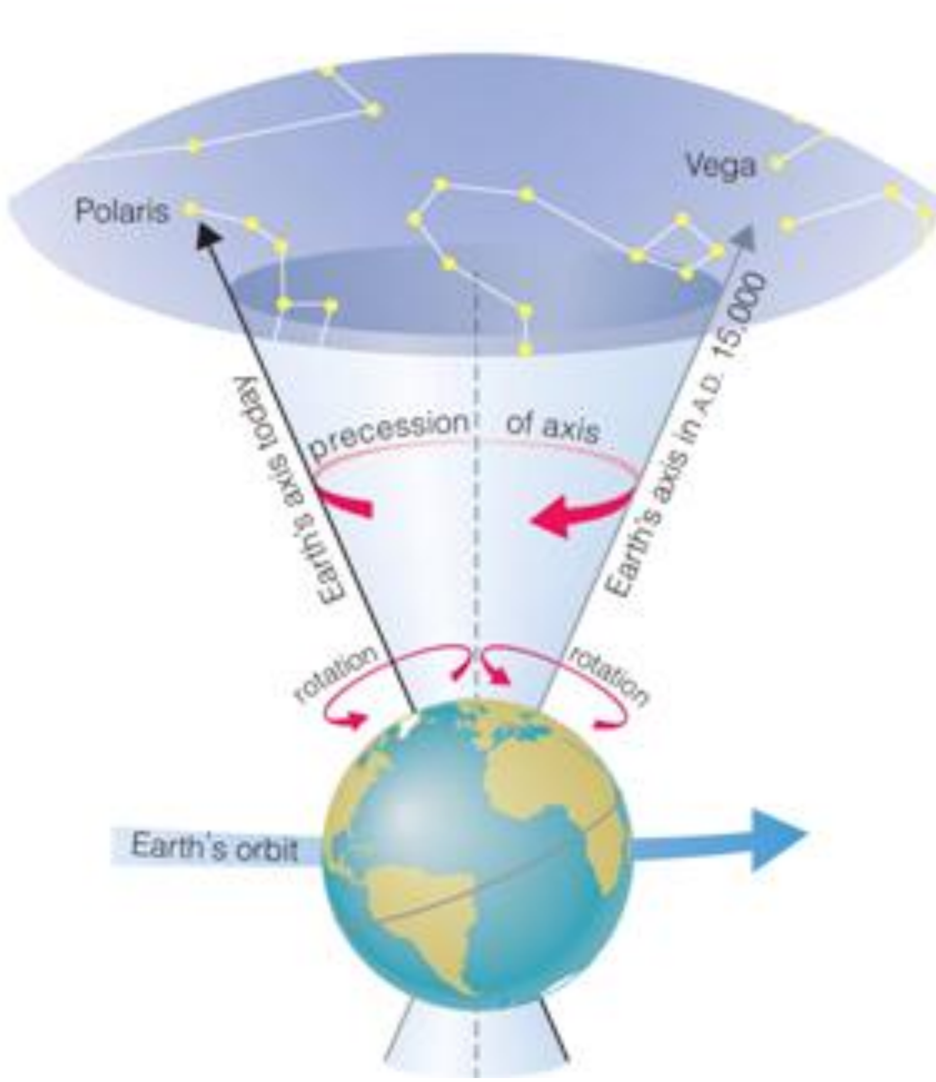
- Although the axis seems fixed on human time scales, it actually precesses over about 26,000 years.
  - ⇒ Polaris won't always be the North Star.
  - ⇒ Positions of equinoxes shift around orbit; e.g., spring equinox, once in *Aries*, is now in *Pisces*!



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



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



Interactive Figure

Icarus 217 (2012) 77–87

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Icarus

journal homepage: www.elsevier.com/locate/icarus

Obliquity variations of a moonless Earth

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[b] University of Idaho, Department of Physics, Campus Box 440903, Moscow, ID 83844-0903, United States
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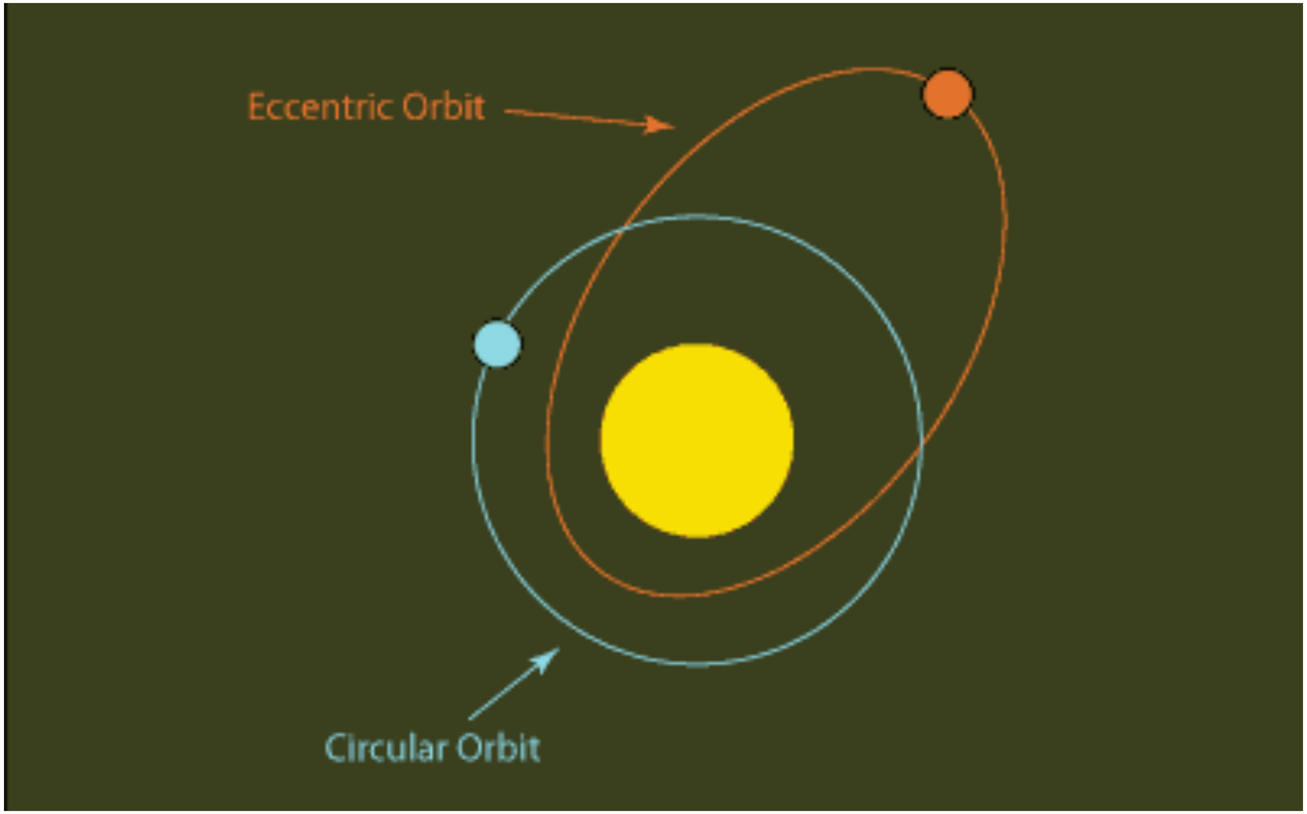
A B S T R A C T

We numerically explore the obliquity (axial tilt) variations of a hypothetical moonless Earth. Previous work has shown that the Earth's Moon stabilizes Earth's obliquity such that it remains within a narrow range, between 22.1° and 24.5°. Without lunar influence, a frequency map analysis by Laskar et al. (Laskar, J., Joutel, F., Robutel, P. [1993]. Nature 361, 615–617) showed that the obliquity could vary between 0° and 85°. This has left an impression in the astrobiology community that a big moon is necessary to maintain a habitable climate on an Earth-like planet. Using a modified version of the orbital integrator `mercury`, we calculate the obliquity evolution for moonless Earths with various initial conditions for up to 4 Gyr. We find that while obliquity varies significantly more than that of the actual Earth over 100,000 year timescales, the obliquity remains within a constrained range, typically 20–25° in extent, for timescales of hundreds of millions of years. None of our Solar System integrations in which planetary orbits behave in a typical manner show obliquity accessing more than 65% of the full range allowed by frequency-map analysis. The obliquities of moonless Earths that rotate in the retrograde direction are more stable than those of prograde rotators. The total obliquity range explored for moonless Earths with rotation periods less than 12 h is much less than that for slower-rotating moonless Earths. A large moon thus does not seem to be needed to stabilize the obliquity of an Earth-like planet on timescales relevant to the development of advanced life.

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.

- Without axial tilt, on a circular orbit, **there are no seasons**
- On a highly eccentric orbit, **planet-wide seasons** would occur as the entire planet heated up and cooled off in its orbit



The Lands of Always Winter
The Haunted Forest
The Frozen Shore
Shadow Tower
Castle Black
Eastwatch
Queenscrown
Bay of Ice
The Gift
Bay of Seals
Bear Island
Last Hearth
The Grey Cliffs
Karhold
Sea Dragon Point
WINTER IS COMING
The North
Stony Shore
The Rills
Ramsgate
Widow's Watch
White Harbor
Moat Cailin
Oldcastle
Blazewater Bay
The Neck
Flint's Finger
The Bite
Cape Kraken
The Three Sisters
The Fingers
The Twins
Iron Islands
Seagard
The Vale of Arryn

GEORGE DVORSKY – GAME OF THRONES – 4/30/12 3:46pm 134,854 1 318

5 Scientific Explanations for *Game of Thrones*' Messed-Up Seasons

We real-world Earthlings take for granted that the seasons will change on schedule. Our planet's clockwork-like seasonality allows us to predict the passage of time with complete precision, and we can always be sure that spring is right around the corner. The same cannot be said, however, for the unlucky inhabitants of George R. R. Martin's Westeros.

What have we learned?

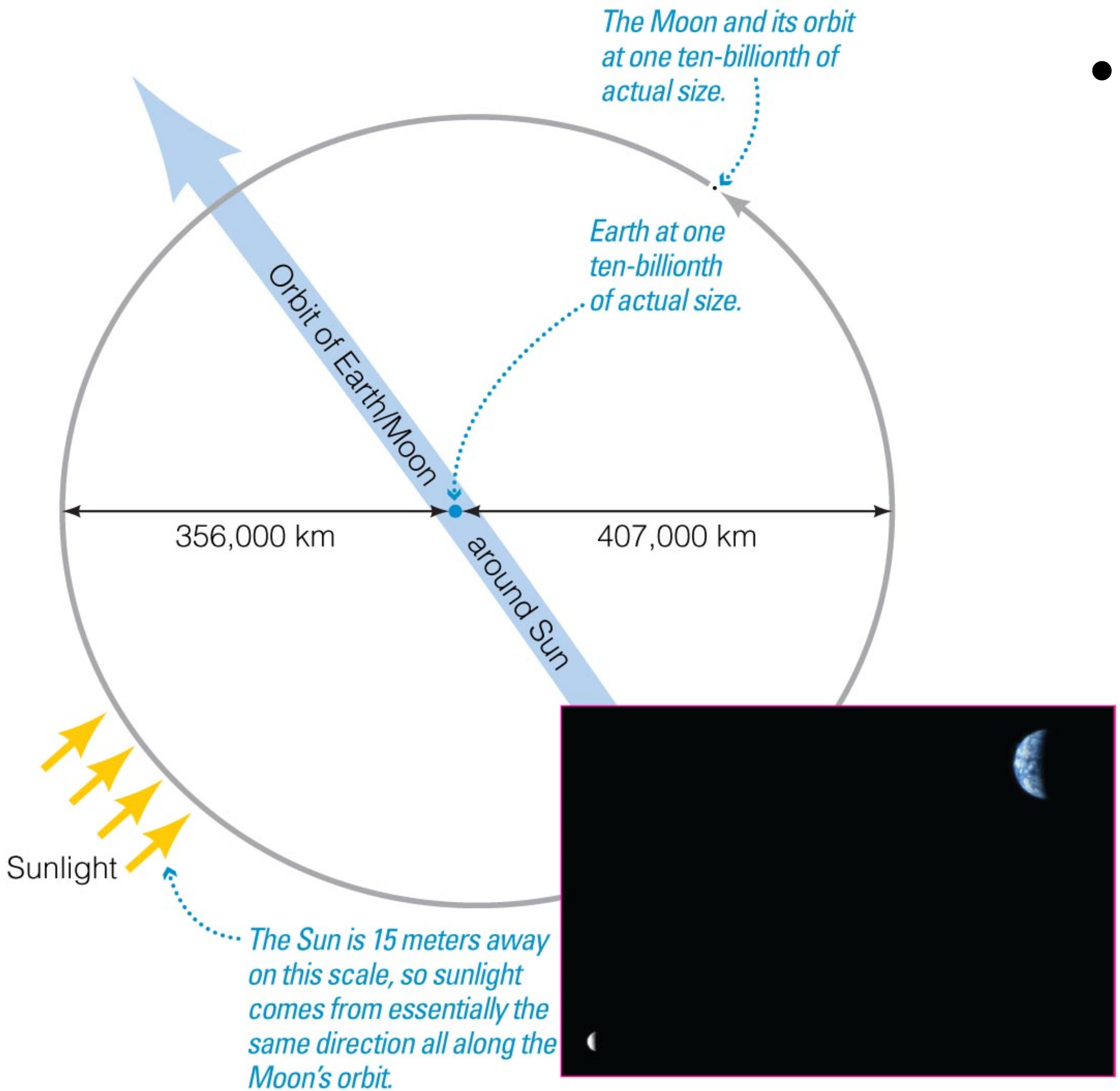
- **How does the orientation of Earth's axis change with time?**
  - The tilt remains about 23.5° (so the season pattern is not affected), but Earth has a 26,000 year precession cycle that slowly and subtly changes the orientation of Earth's axis.

Short Break

2.3 The Moon, Our Constant Companion

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

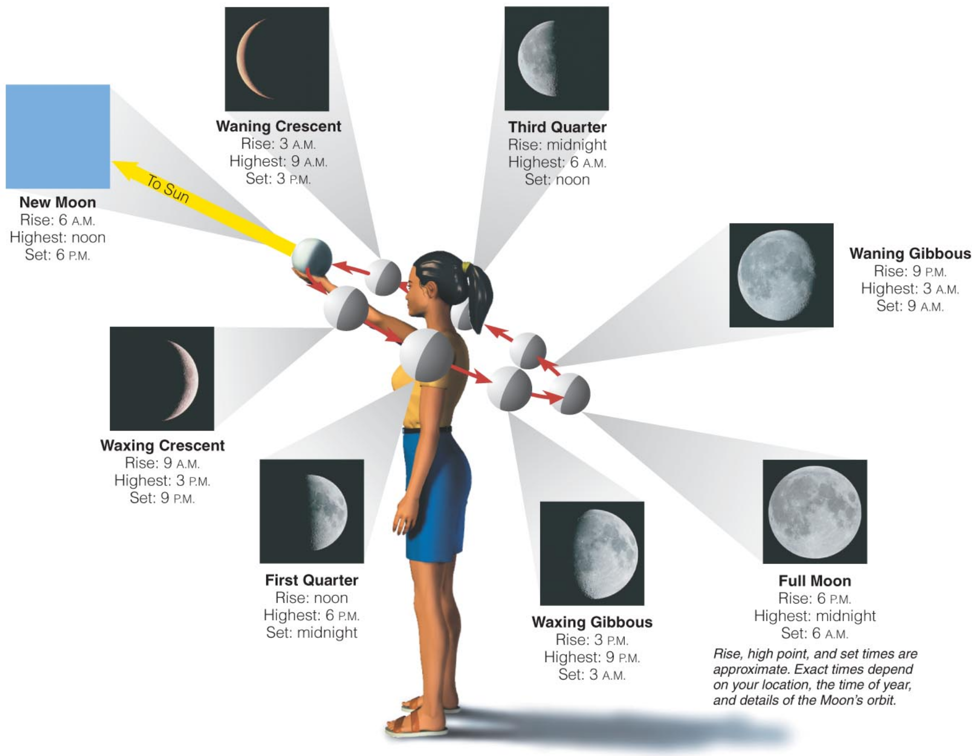
Why do we see phases of the Moon?

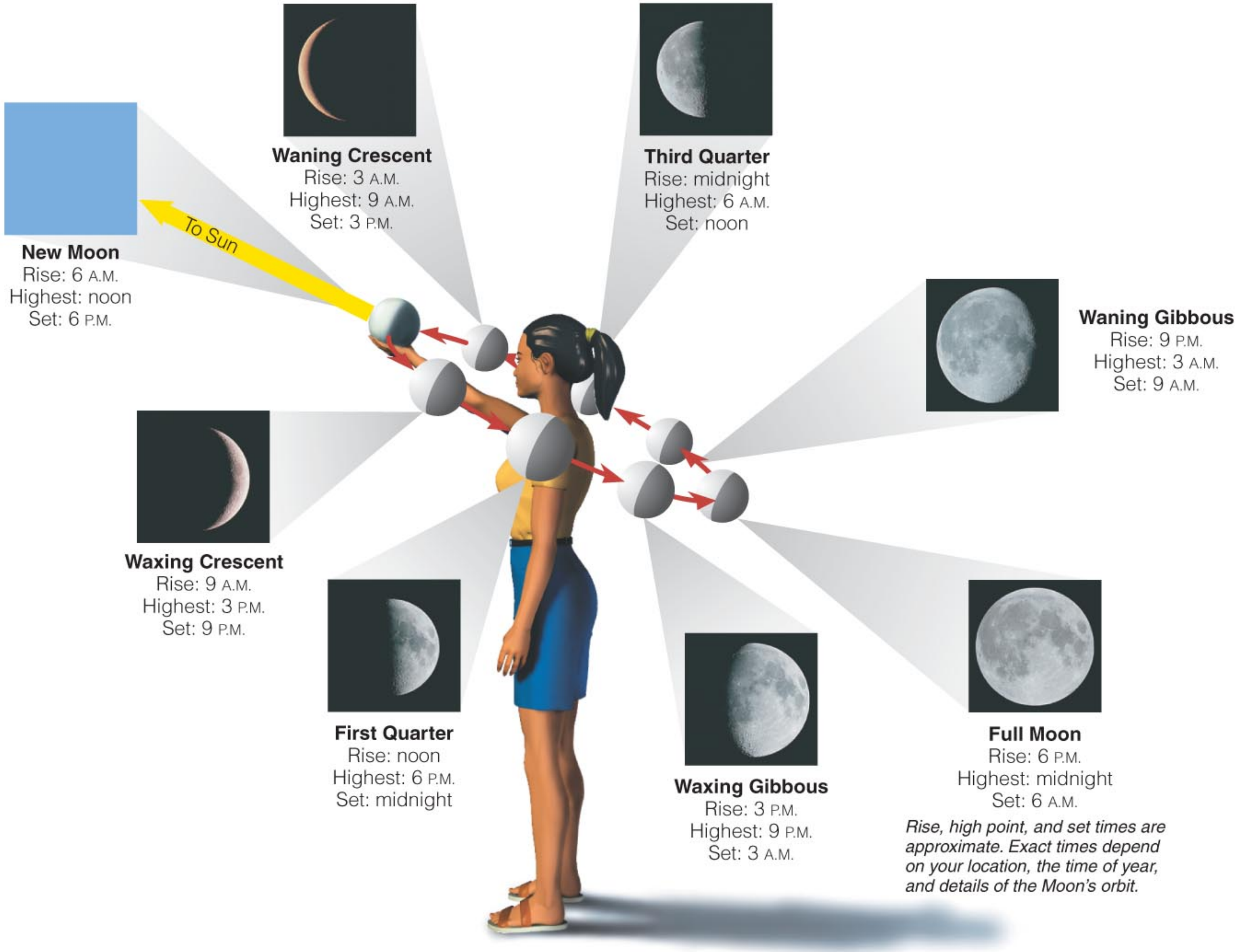


- Lunar phases are a consequence of the Moon's 27.3-day orbit around Earth.

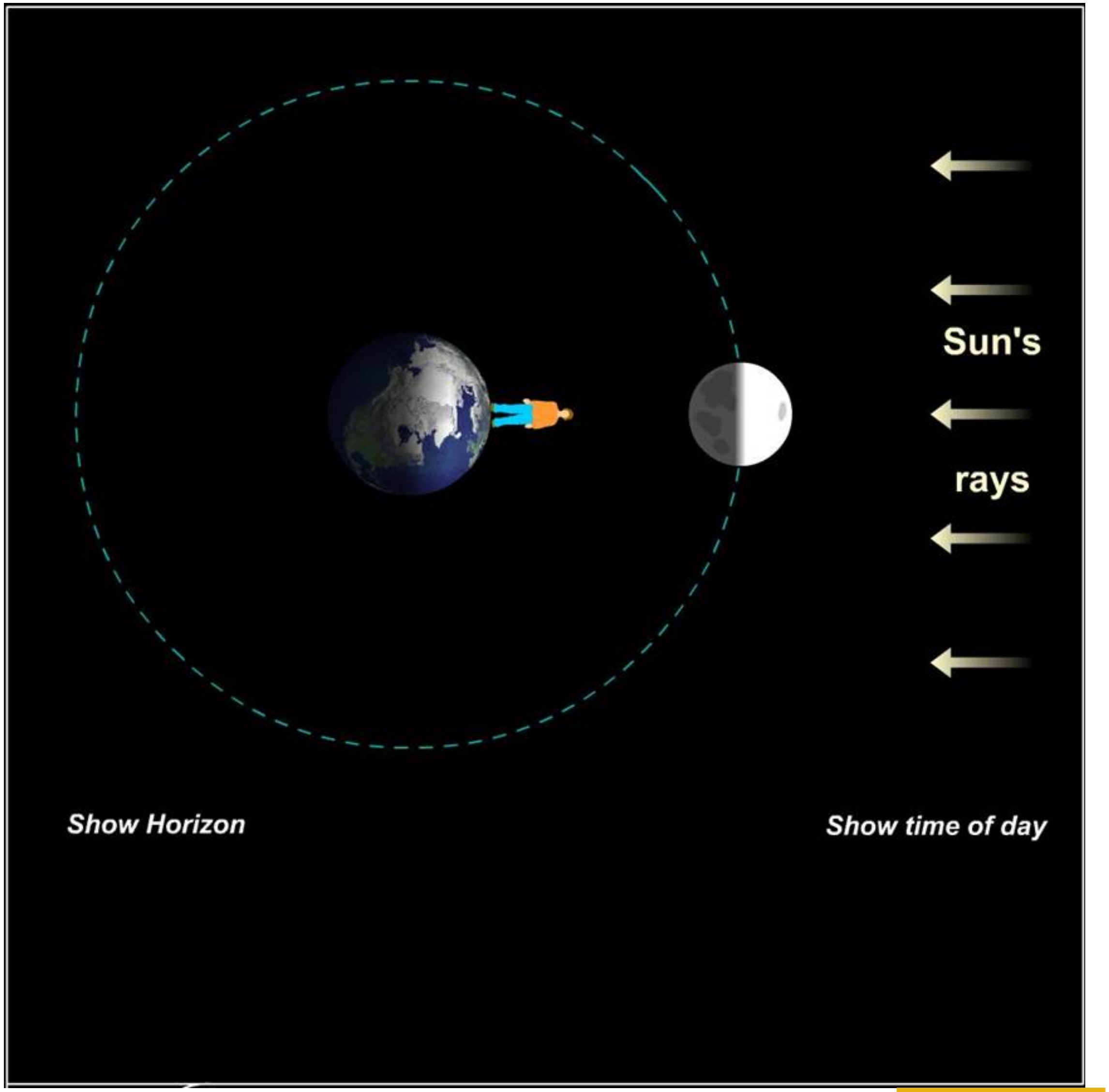
Phases of the Moon

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



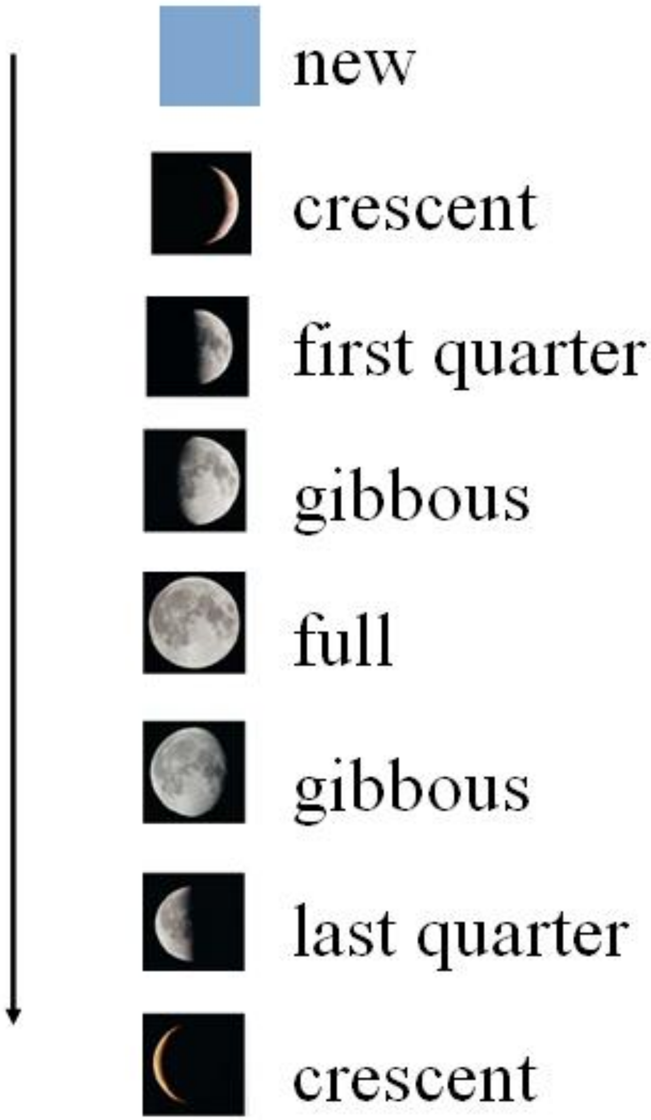

Waning Crescent
Rise: 3 A.M.
Highest: 9 A.M.
Set: 3 P.M.
Third Quarter
Rise: midnight
Highest: 6 A.M.
Set: noon
New Moon
Rise: 6 A.M.
Highest: noon
Set: 6 P.M.
To Sun
Waning Gibbous
Rise: 9 P.M.
Highest: 3 A.M.
Set: 9 A.M.
Waxing Crescent
Rise: 9 A.M.
Highest: 3 P.M.
Set: 9 P.M.
First Quarter
Rise: noon
Highest: 6 P.M.
Set: midnight
Waxing Gibbous
Rise: 3 P.M.
Highest: 9 P.M.
Set: 3 A.M.
Full Moon
Rise: 6 P.M.
Highest: midnight
Set: 6 A.M.
Rise, high point, and set times are approximate. Exact times depend on your location, the time of year, and details of the Moon's orbit.

Phases of the Moon



Interactive Figure

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 full" and sets later each day

Thought Question

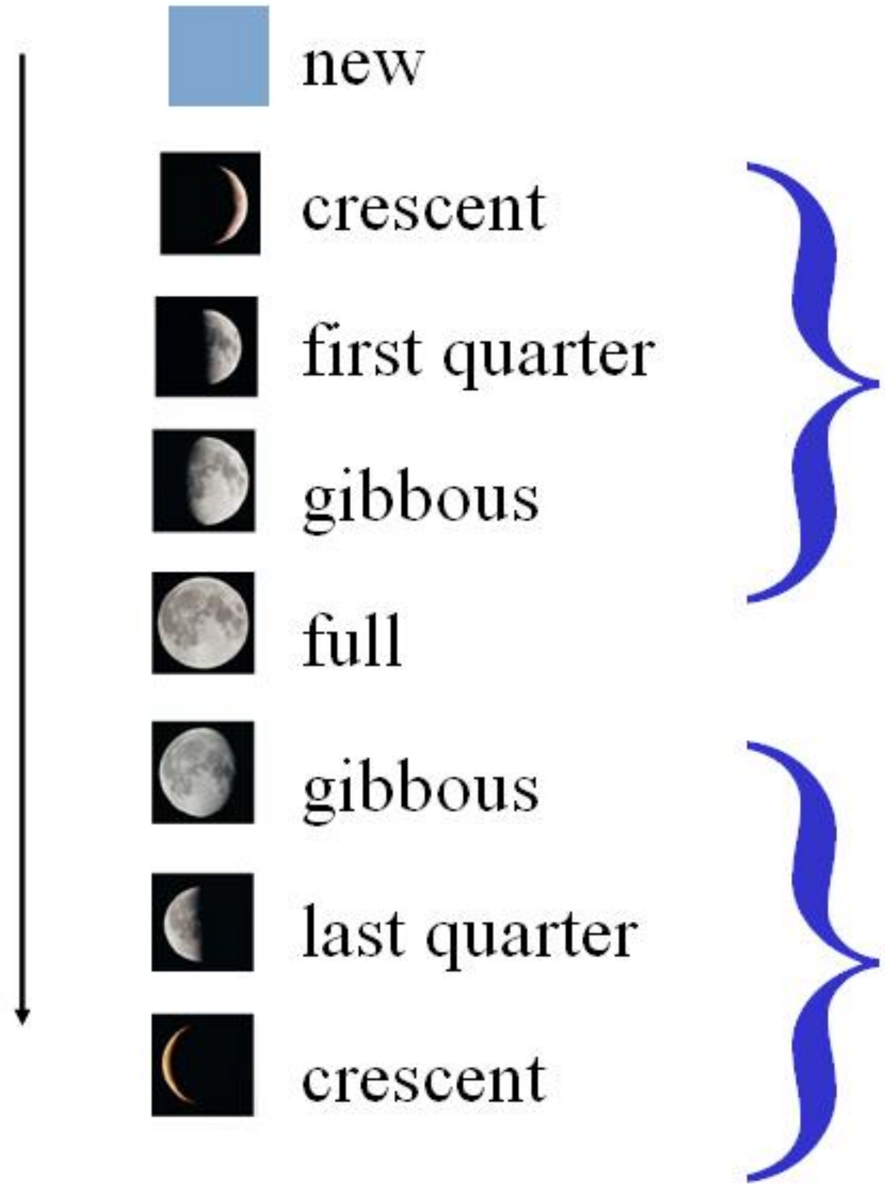
It's 9 a.m. You look up in the sky and see a moon with half its face bright and half dark. What phase is it?

A. first quarter

B. waxing gibbous

C. last (last) quarter

D. crescent



Clicker 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?

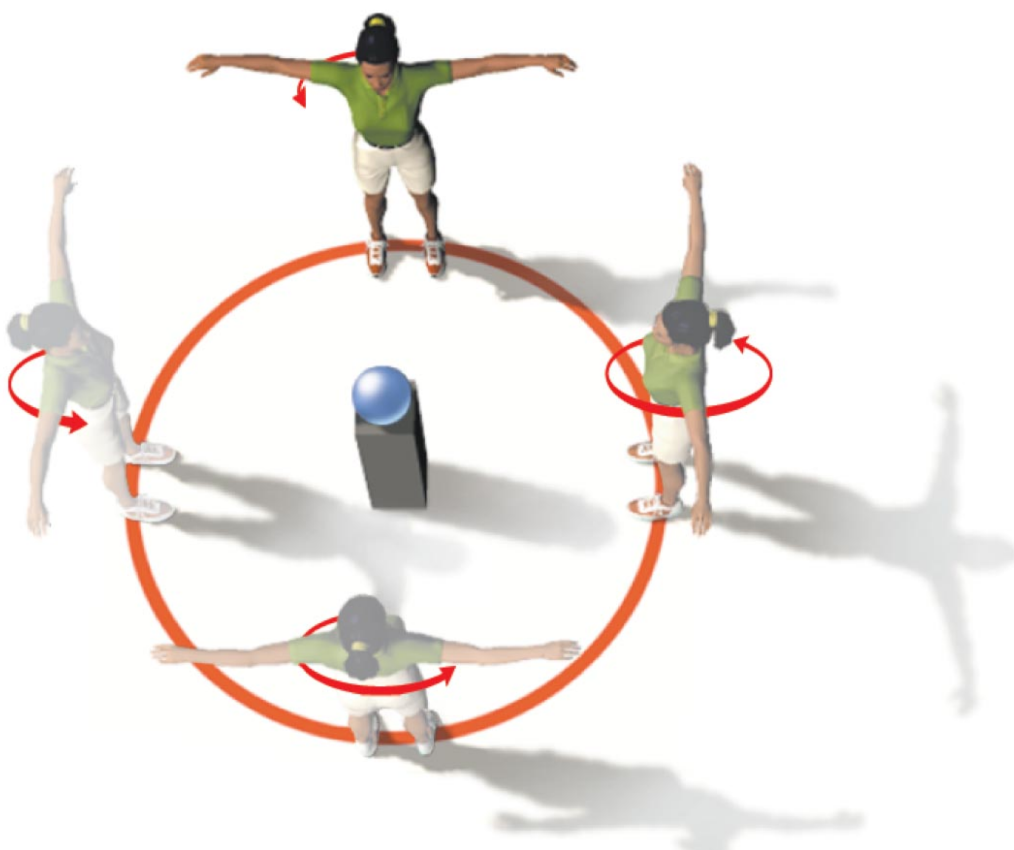
A. first quarter

B. waxing gibbous

C. third (last) quarter

D. crescent

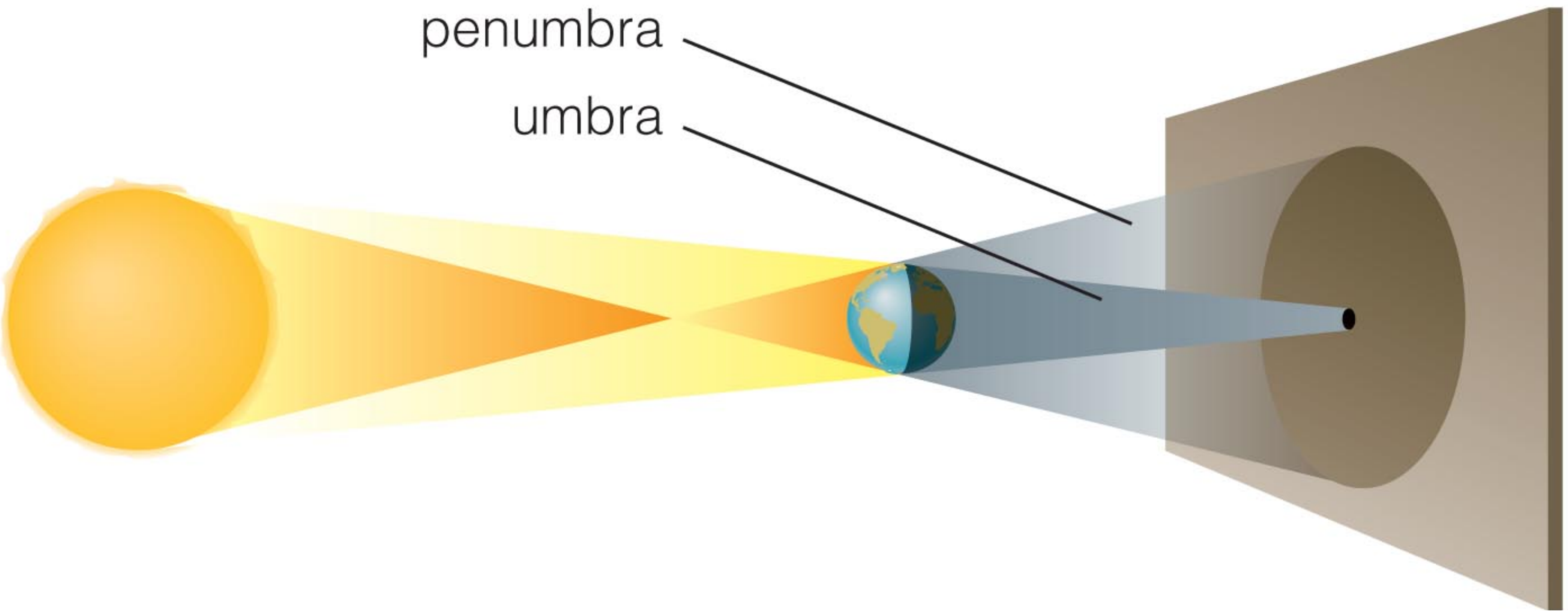
We see only one side of Moon



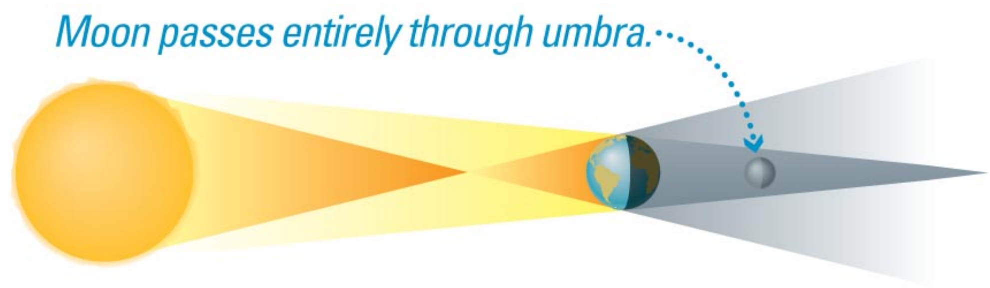
- Synchronous rotation: the Moon rotates exactly once with each orbit.
- That is why only one side is visible from Earth.
- The moon did not start out in this state when it formed, but tides changed its rotation rate over time. This is called “tidal locking.”

What causes eclipses?

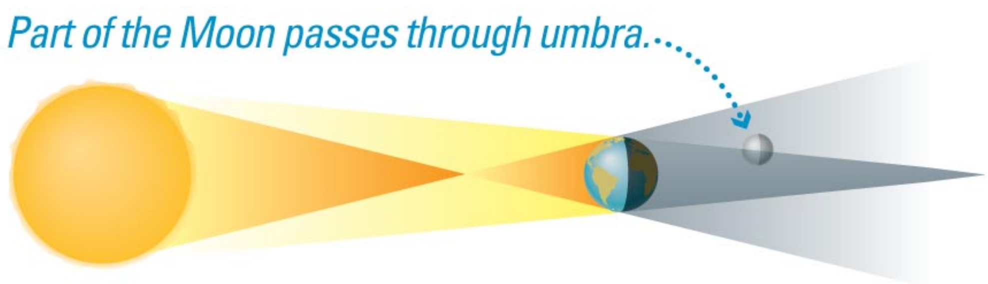
- The Earth and Moon cast shadows.
- When either passes through the other's shadow, we have an **eclipse.**



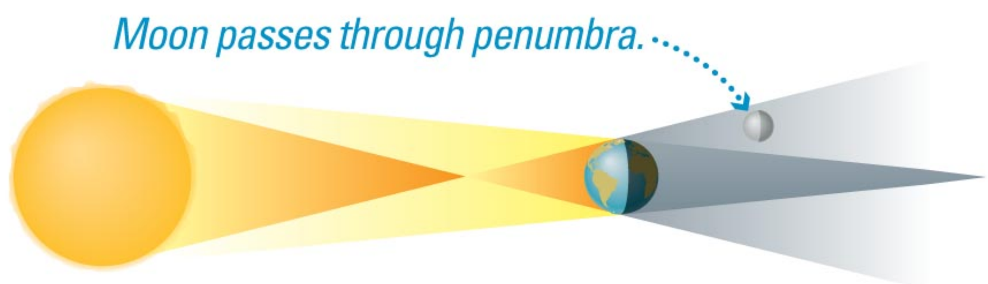
Lunar Eclipse



Total Lunar Eclipse



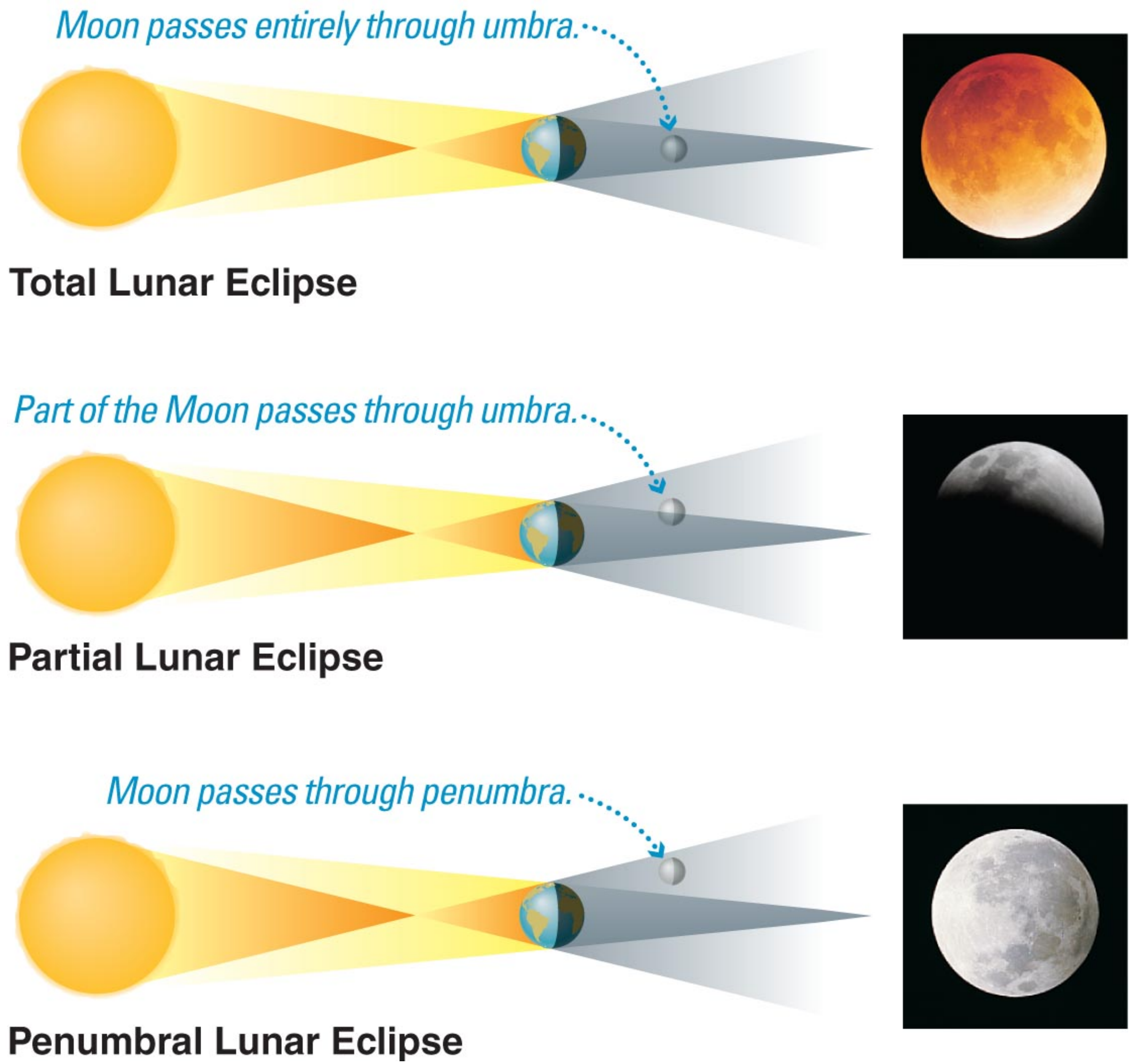
Partial Lunar Eclipse



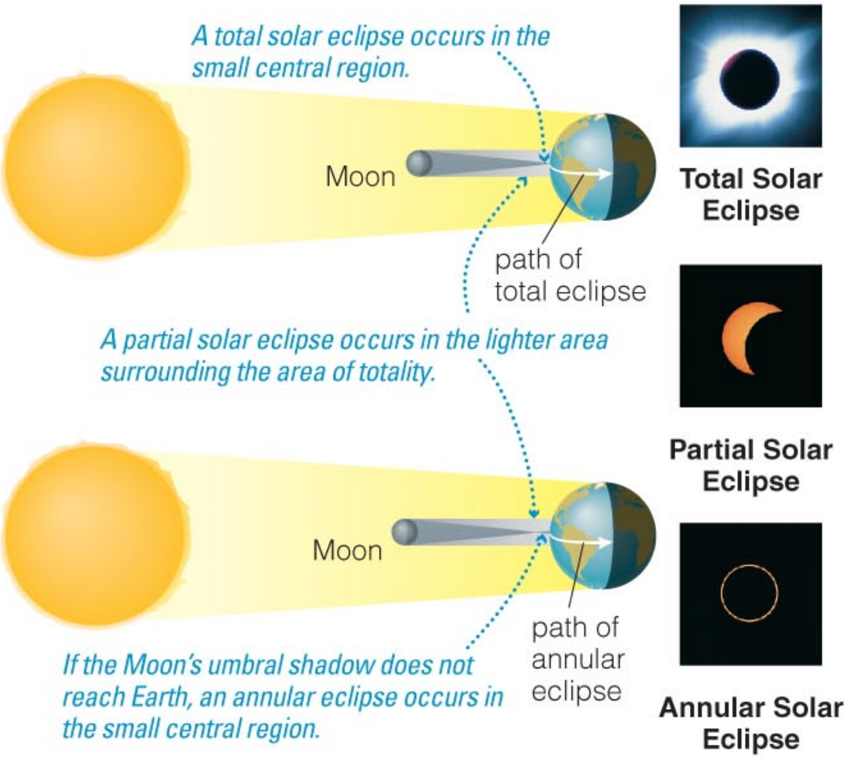
Penumbral Lunar Eclipse

When can eclipses occur?

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



Solar Eclipse



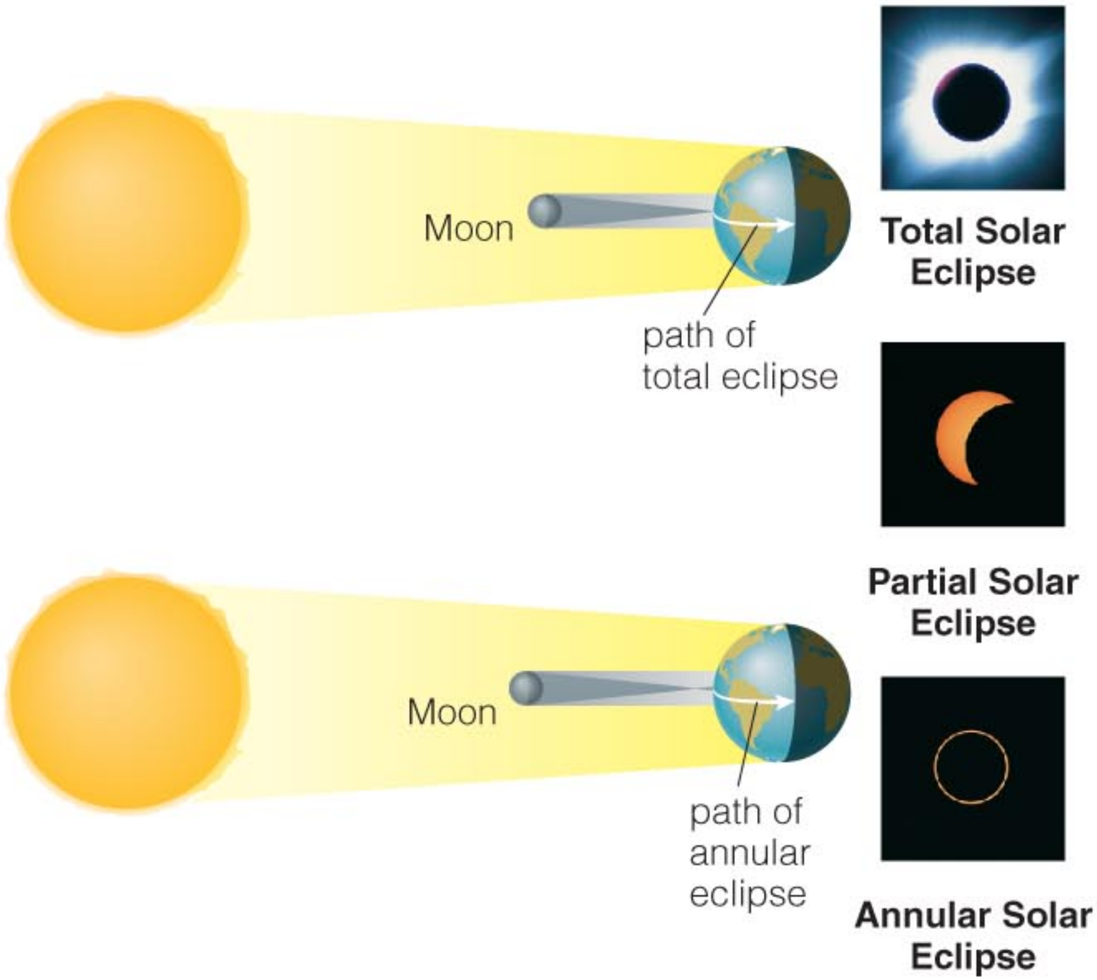
a The three types of solar eclipse. The diagrams show the Moon's shadow falling on Earth; note the dark central umbra surrounded by the much lighter penumbra.

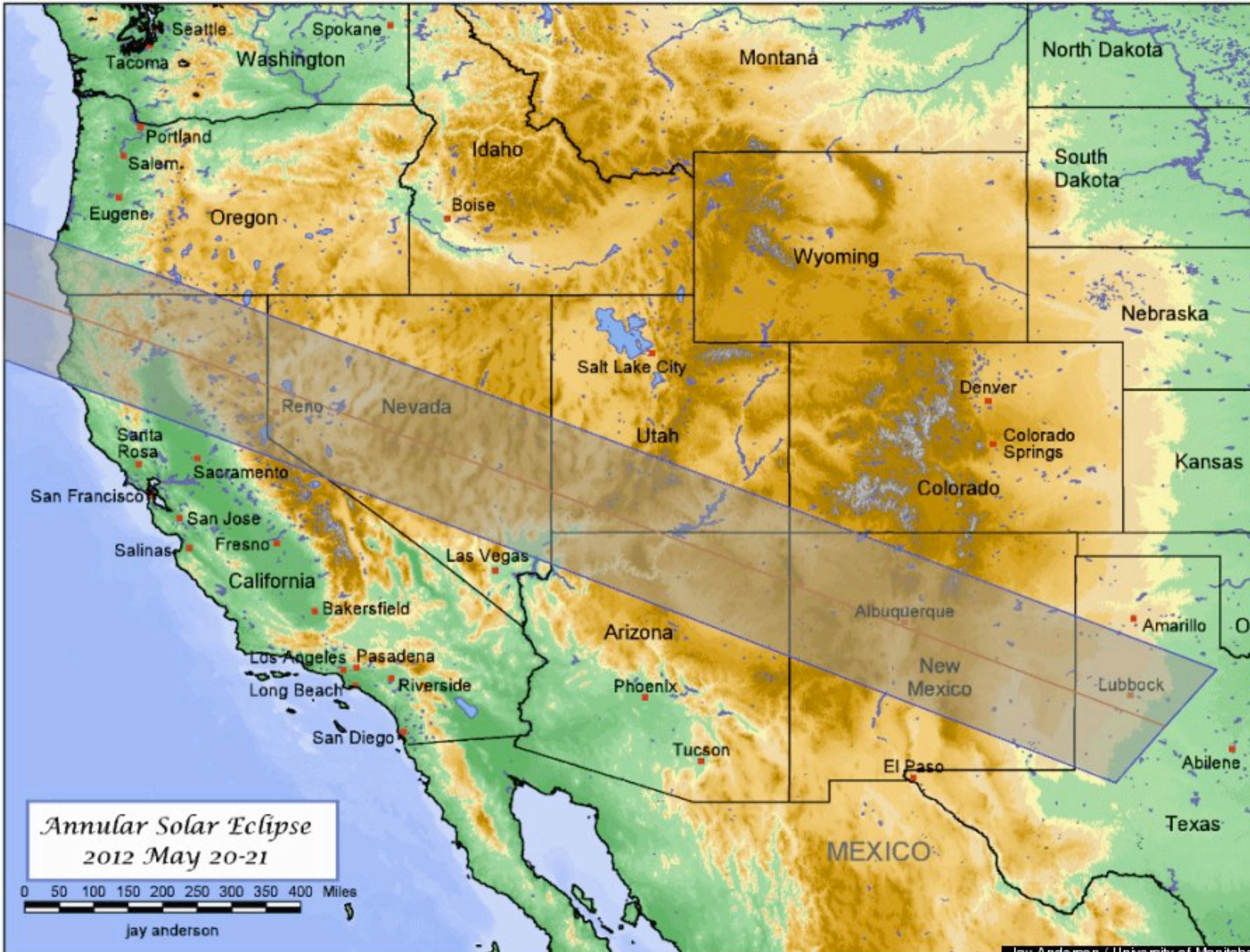
b This photo from Earth orbit shows the Moon's shadow (umbra) on Earth during a total solar elipse. Notice that only a small region of Earth experiences totality at any one time.

Interactive Figure

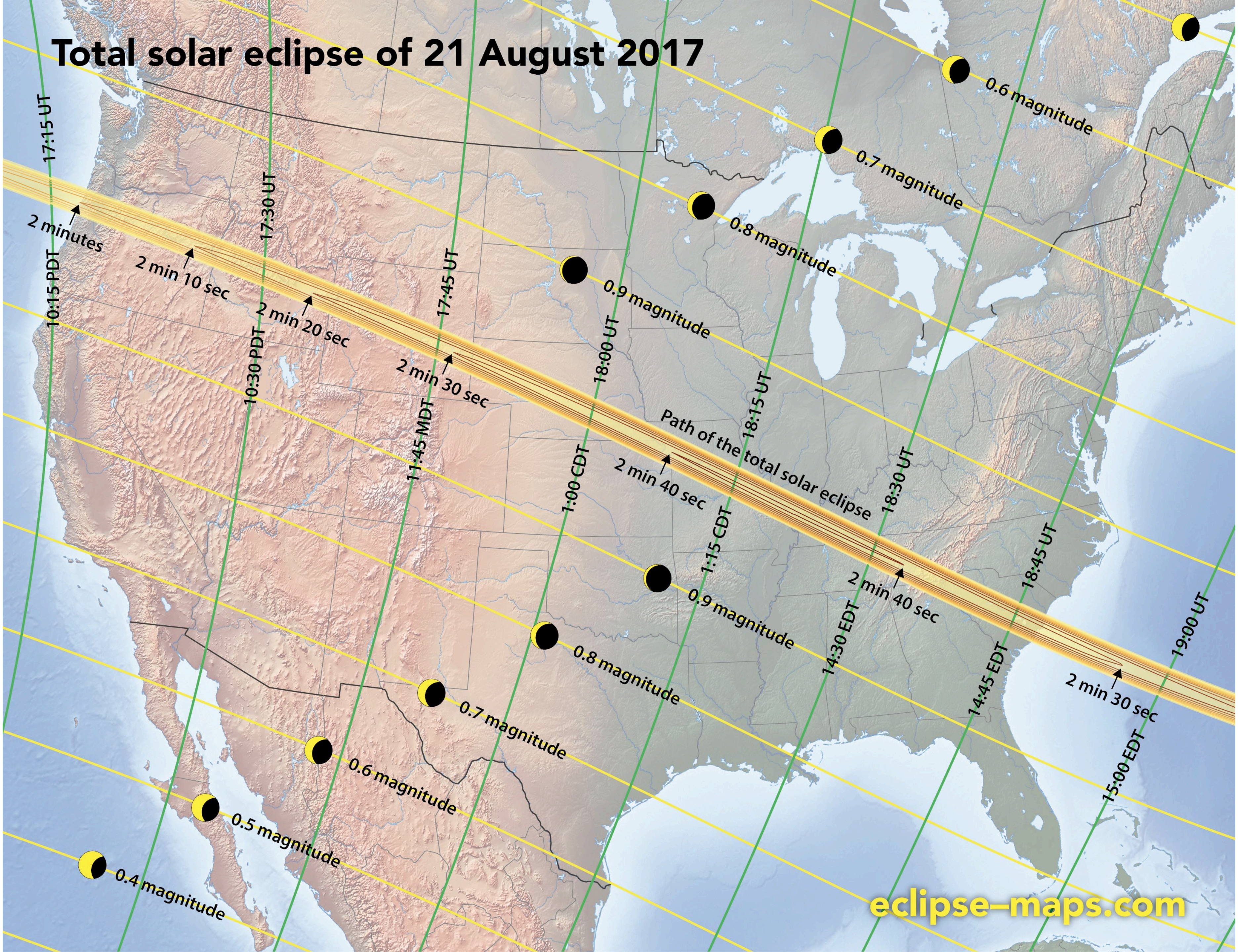
When can eclipses occur?

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



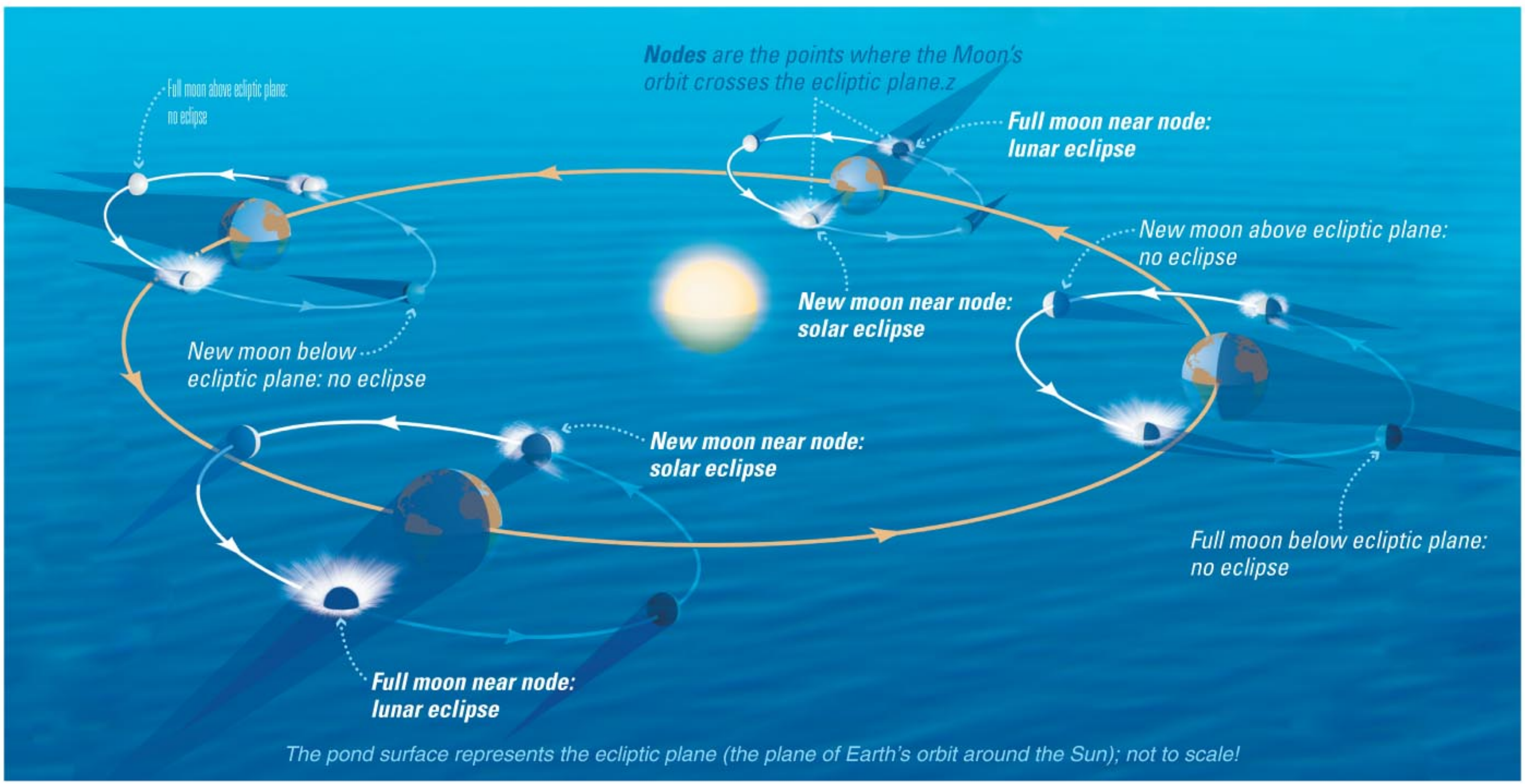

Seattle
Spokane
Tacoma
Washington
Montana
North Dakota
Portland
Idaho
Salem
South Dakota
Boise
Eugene
Oregon
Wyoming
Nebraska
Salt Lake City
Denver
Reno
Nevada
Utah
Colorado Springs
Santa Rosa
Kansas
Sacramento
Colorado
San Francisco
San Jose
Fresno
Salinas
Las Vegas
California
Bakersfield
Albuquerque
Amarillo
Ok
Arizona
Los Angeles
Pasadena
New Mexico
Long Beach
Riverside
Phoenix
Lubbock
San Diego
Tucson
El Paso
Abilene
Texas
MEXICO
Annular Solar Eclipse
2012 May 20-21
0 50 100 150 200 250 300 350 400 Miles
jay anderson
Jay Anderson / University of Manitoba

Redding, May 20, 2012


Total solar eclipse of 21 August 2017
17:15 UT
10:15 PDT
17:30 UT
10:30 PDT
17:45 UT
11:45 MDT
18:00 UT
1:00 CDT
18:15 UT
1:15 CDT
18:30 UT
14:30 EDT
18:45 UT
14:45 EDT
19:00 UT
15:00 EDT
2 minutes
2 min 10 sec
2 min 20 sec
2 min 30 sec
2 min 40 sec
Path of the total solar eclipse
2 min 40 sec
2 min 30 sec
0.6 magnitude
0.7 magnitude
0.8 magnitude
0.9 magnitude
0.9 magnitude
0.8 magnitude
0.7 magnitude
0.6 magnitude
0.5 magnitude
0.4 magnitude
eclipse–maps.com

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 full moon and solar eclipse at new moon.



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

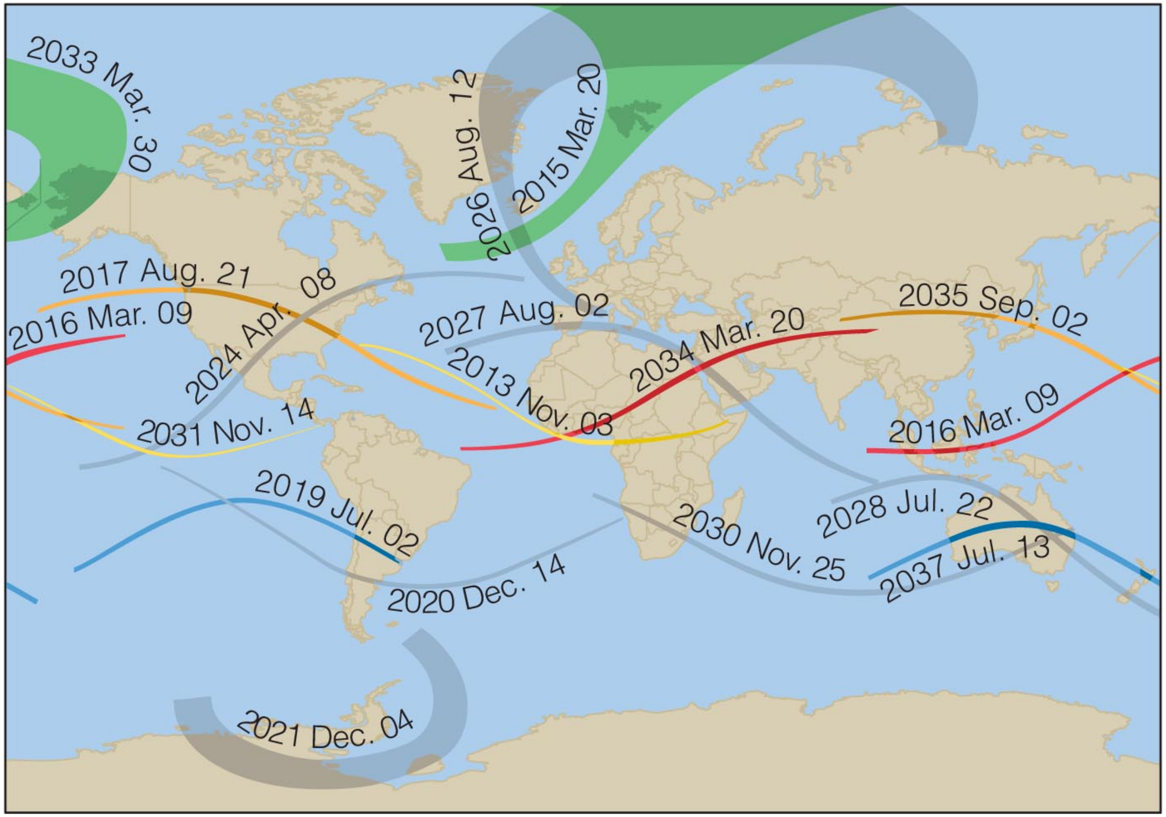
1. It must be full moon (for a lunar eclipse) or new moon (for a solar eclipse).

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.



What have we learned?

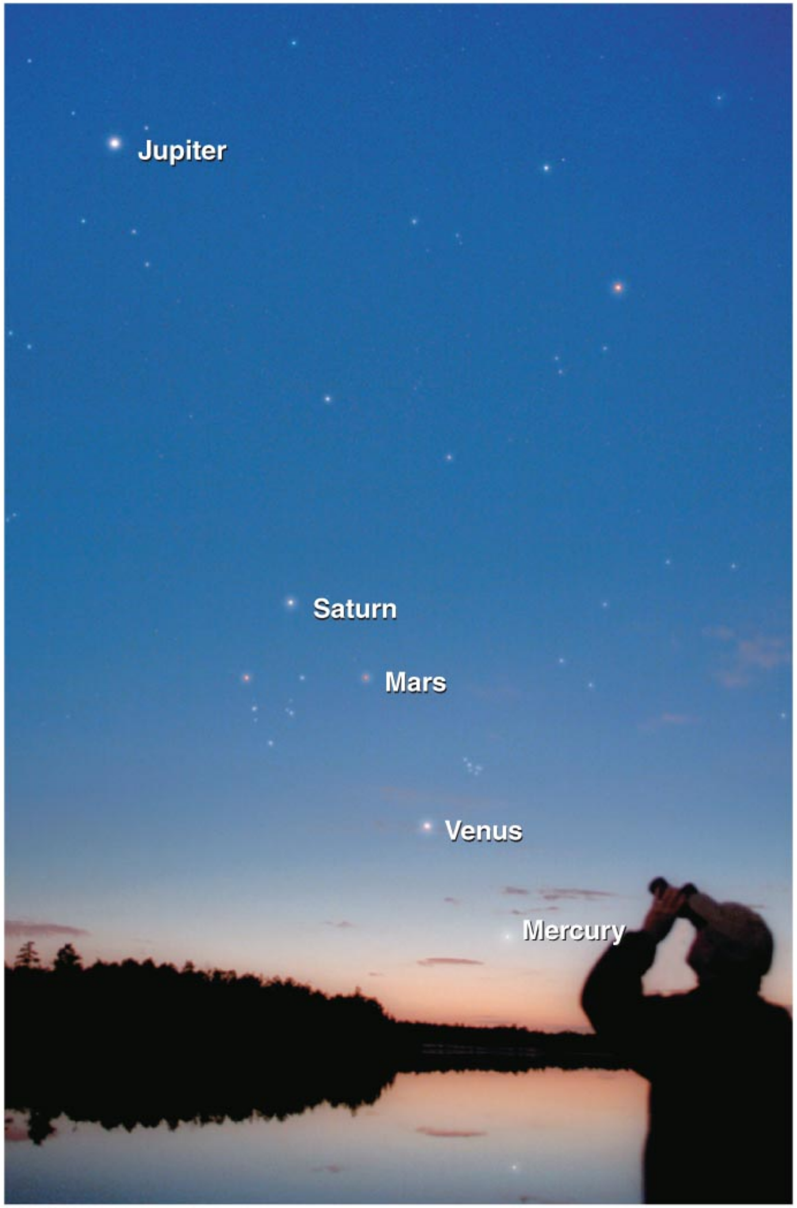
- **Why do we see phases of the Moon?**
  - Half the Moon is lit by the Sun; half is in shadow, and its appearance to us is determined by the relative positions of Sun, Moon, and Earth.
- **What causes eclipses?**
  - Lunar eclipse: Earth's shadow on the Moon
  - Solar eclipse: Moon's shadow on Earth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

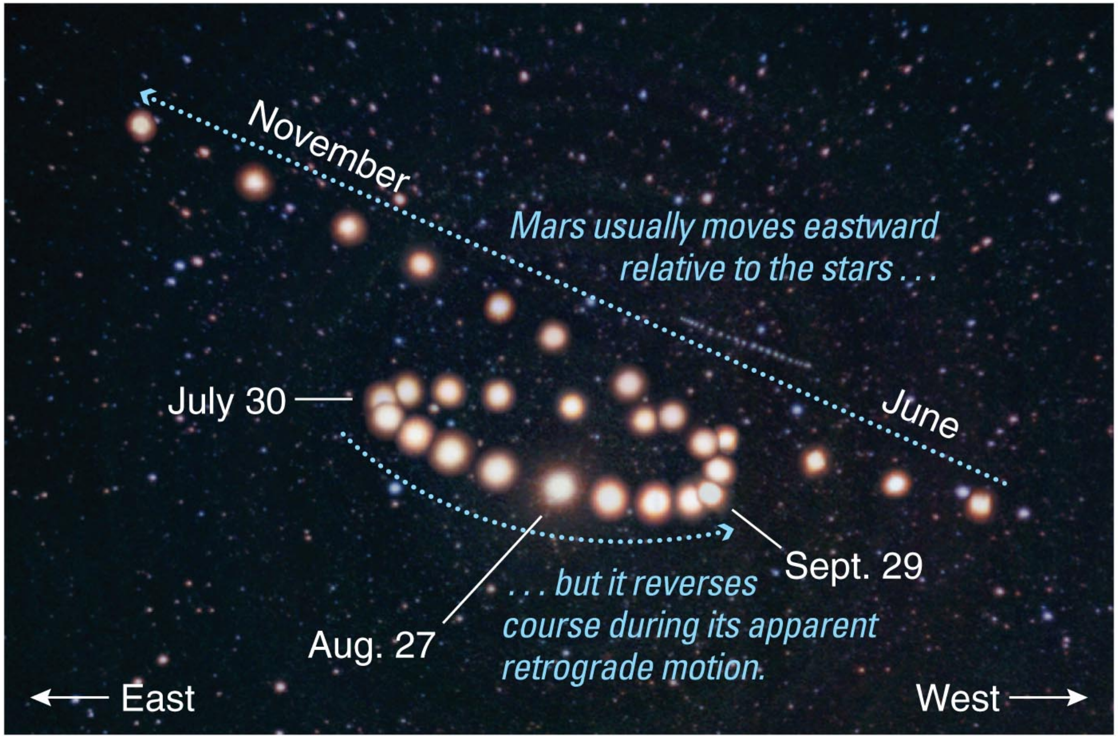
Planets Known in Ancient Times

- 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

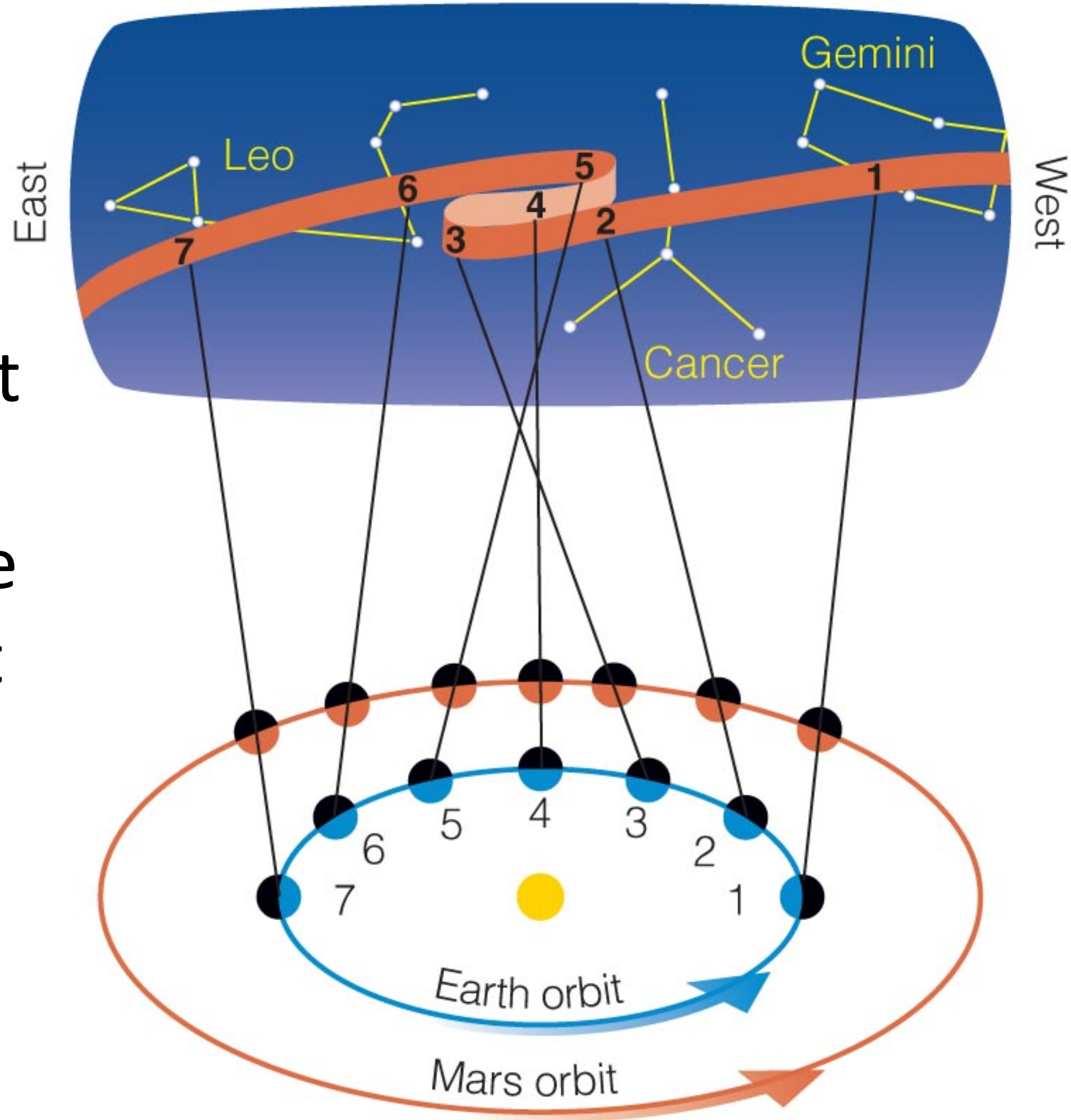


What was once so mysterious about planetary motion in our sky?

- 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.**



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



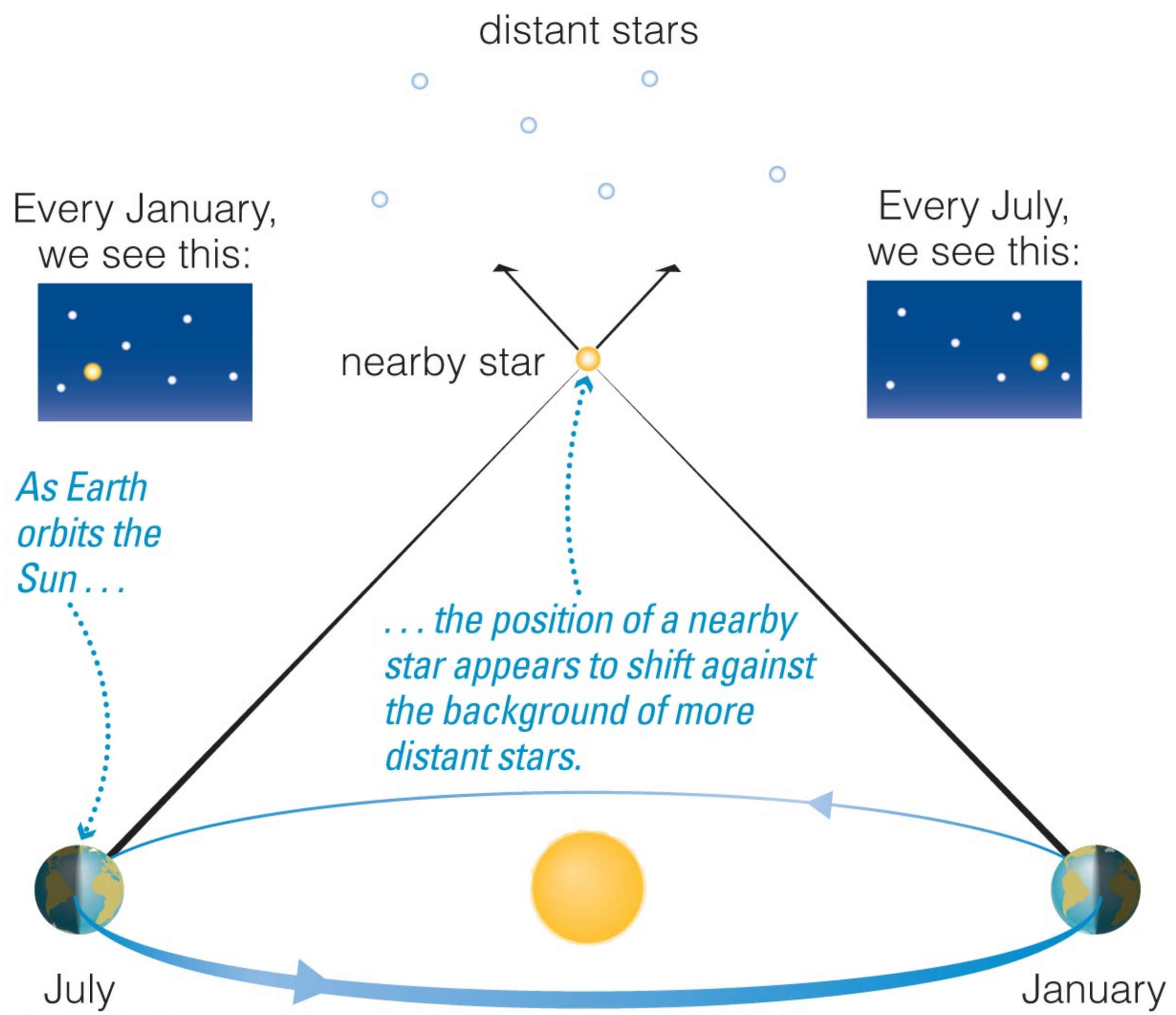
Interactive Figure

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*.

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.

For: As Soon As Possible:

Check the class web site: **http://www.ucolick.org/~jfortney/3.htm**

Register at www.masteringastronomy.com

- You will need to purchase access (7th edition) if you didn't buy the textbook package at the bookstore
- The class code is AY3FORTNEY
- **You CANNOT complete Homeworks without MasteringAstronomy**

Register your iClicker:
www.iclicker.com/support/registeryourclicker/

HW 1 due Thursday at 2PM!
Go to section, meet your TA, get started on the homework

Tuesday, 6:00-7:10 p.m., Phys Sciences 114 (Emily)
Wednesday, 8:00-9:10 a.m., Phys Sciences 114 (Emily)
Wednesday, 11:10 a.m.-12:10 p.m., Nat Sci Annex 101 (Chris)
Friday, 3:30-4:40 p.m., Nat Sci Annex 101 (Chris)

This Wednesday, my office hours: 9:00-10:30 a.m. instead of 1:30-3 p.m.