

[04] Seasons, Phases, and Eclipses (9/7/17)

Upcoming Items

- Homework #2 due next lecture.
- Read Ch. 3.3 and do the self-study quizzes for next lecture, and skim 2.4, 3.1, 3.2, & 3.4.

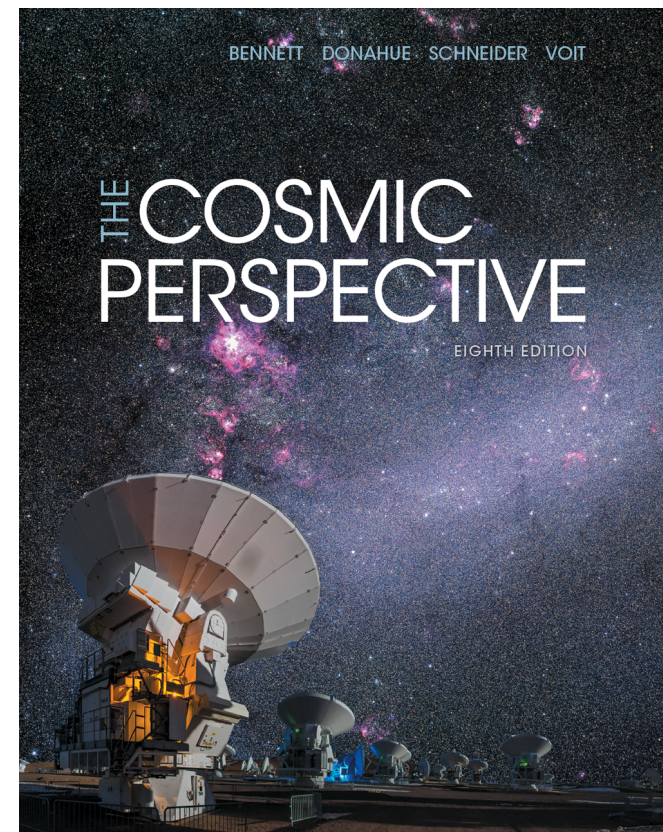


LEARNING GOALS

Chapters 2.2–2.3

For this class, you should be able to...

- ... predict seasonal changes based on a planet's tilt and orbit, and explain the contributing factors;*
- ... identify a planet or moon's phase, and/or when it will be visible from your location, given its position relative to you and the Sun, and vice versa;*
- ... describe the conditions needed for each type of eclipse to occur and explain why we do not see one involving the Moon each month.*



ClassAction: Coordinates & Motions

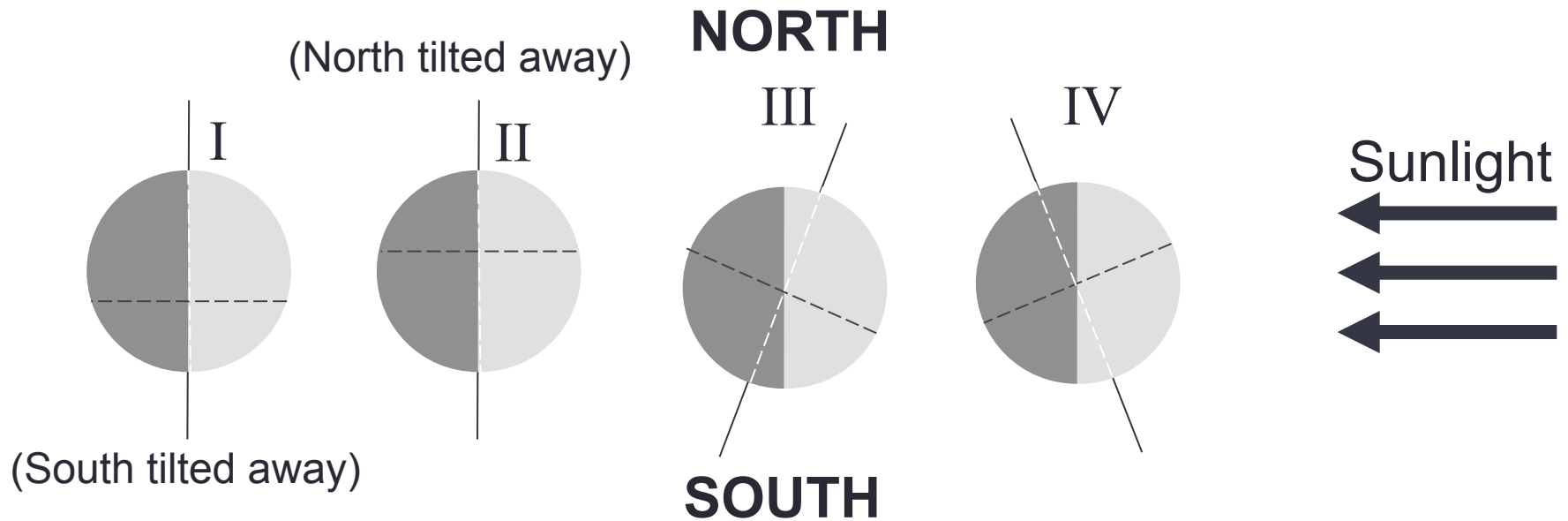
- **G2: Change to Earth Seasons**
- G3: Season Contributor(s)
- G4: No Orbital Tilt
- **G12: Sun's Rays**
- G13: Sun Movement
- G14: Sun at Zenith Frequency
- G15: Effects of Tilt
- G30: Sun Rise/Set After Equinox
- **C3: Sun Paths 1**
- C4: Sun Paths 2
- D2: Seasons on Uranus

Which of the following does not change over the course of the Earth's orbit?

- A. The number of daylight hours in College Park.
- B. The angle at which sunlight hits the Earth's surface.
- C. The amount of the northern hemisphere that is illuminated.
- D. The amount of the Earth that is illuminated.**

Which of the following changes the least over the course of a year?

- A. The number of daylight hours in College Park.
- B. The number of daylight hours in Equatorial Guinea.**
- C. The number of daylight hours in Iceland.
- D. They all change the same amount.
- E. It's impossible to tell.



Figures I–IV show the Earth at four points in its orbit, each representing a different season. Arrange them in order of the year, starting with winter in the Northern hemisphere.

- A. III, I, IV, II.
- B. III, II, IV, I.
- C. **IV, II, III, I.**
- D. IV, I, III, II.
- E. More than one arrangement is possible.

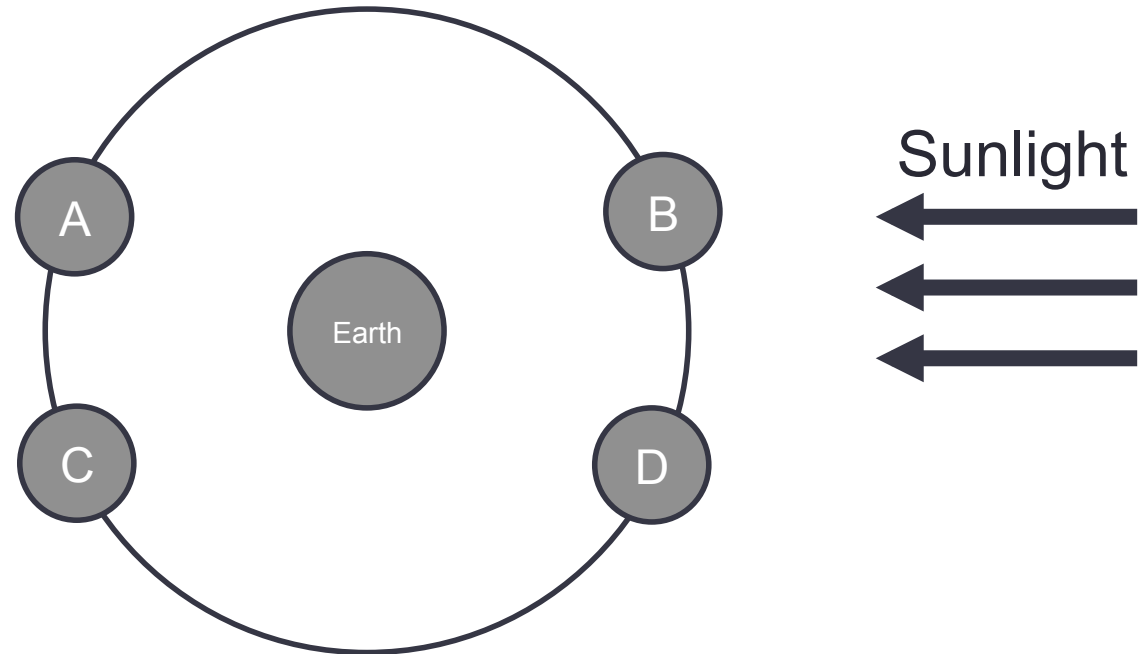
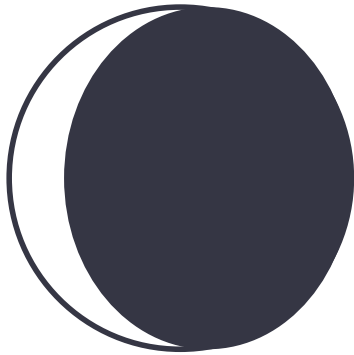
ClassAction: Lunar Cycles

- **G1: Identify Phase from Picture**
- G3: Identify Lunar Position from Phase
- G5: Phases, Eclipses and Tides
- G6: Phase Evolution
- **G8: Rising/Meridian/Setting Times**
- G10: Types of Lunar Eclipses
- G13: Horizon Diagram: Identify Phase
- G14: Horizon Diagram: Identify Time
- **C3: Earthrise on the Moon**
- C4: Location of the Crescent Moon
- C7: Phases Visible

During a new moon, how much of the Moon's surface is illuminated by the Sun?

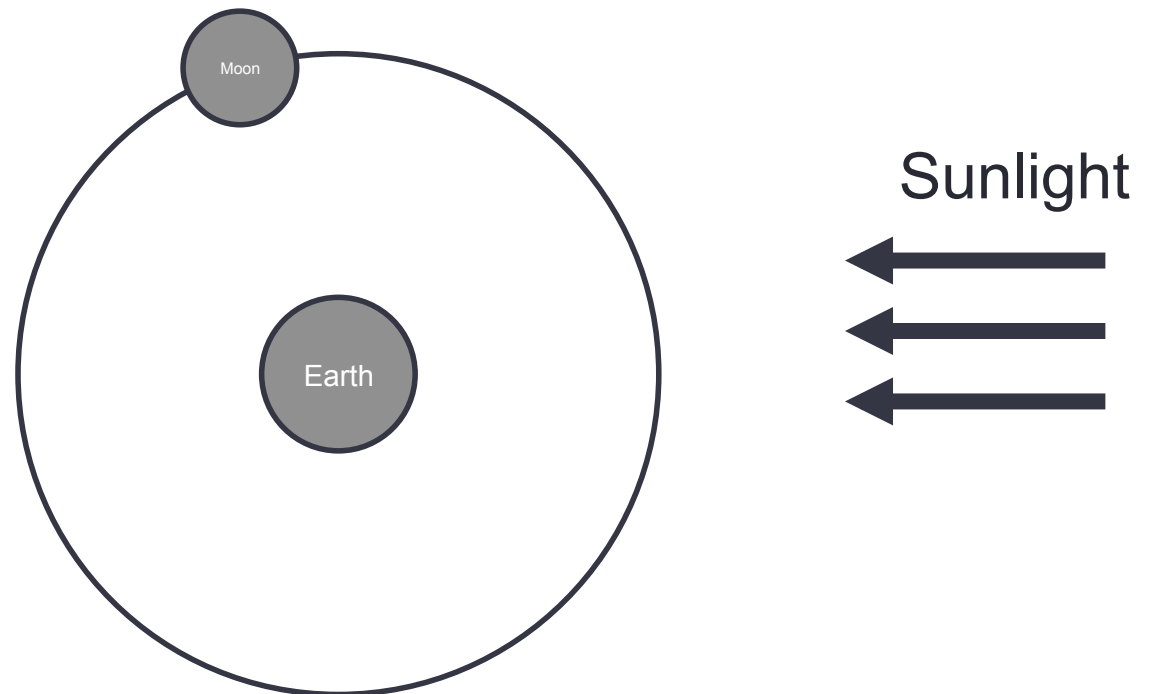
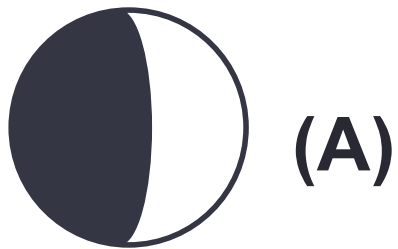
- A. None of it.
- B. A quarter of it.
- C. Half of it.**
- D. All of it.

View looking down on North Pole



You look at the sky one night and see the Moon as it is shown in the figure. Which letter corresponds to the Moon's position relative to Earth?

Answer: D



For the given position of the Moon relative to the Earth and Sun, what phase of the Moon would you see?

Answer: B

Imagine that the Sun increased in size, and we are somehow still alive to observe it. It is big enough that the Moon can no longer fully eclipse it. Which of the following would compensate for the Sun's growth, leaving us able to see a total solar eclipse?

- I. Decrease the size of the Earth.
- II. Increase the size of the Moon.
- III. Further increase the size of the Sun.
- IV. Increase the distance between the Earth and the Sun.
- V. Increase the distance between the Earth and the Moon.

- A. II only.
- B. II, IV.**
- C. II, III, IV.
- D. I, II, IV, V.
- E. III only.

The Seasons



Cause of Seasons

- Could changing distance of the Earth to the Sun explain the seasons *by itself*?
- That is, the Earth's orbit is not perfectly circular. When it is closer to the Sun, it gets a larger flux of radiation from the Sun; when it is farther away, it gets a smaller flux. Can that, by itself, produce the seasons?

Cause of Seasons

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- That is, the Earth's orbit is not perfectly circular. When it is closer to the Sun, it gets a larger flux of radiation from the Sun; when it is farther away, it gets a smaller flux. Can that, by itself, produce the seasons?
- **NO!**
- If distance were all that mattered, we'd have identical seasons to Australia, and we don't.
- Something else has to play a role; in this class we'll quantify what that is.

Tilt! The basic idea

- Earth's axis tilted wrt orbit
- Over a year, angle of Sun's rays changes
- Thus the flux of energy on the Earth's surface changes



http://www.bellevueamusements.com/wp-content/themes/bellevue/images/MAJOR_RIDES/LARGE/TILT_WHIRL_1024

- This can change the average temperature on Earth over the year, and we can do a demo to show that the maximum flux will be different for the northern and southern hemisphere, which is what we observe.
- But still, distance has to matter at least a little, right? So we need to quantify which effect is more important.

Getting Rid of a Misconception

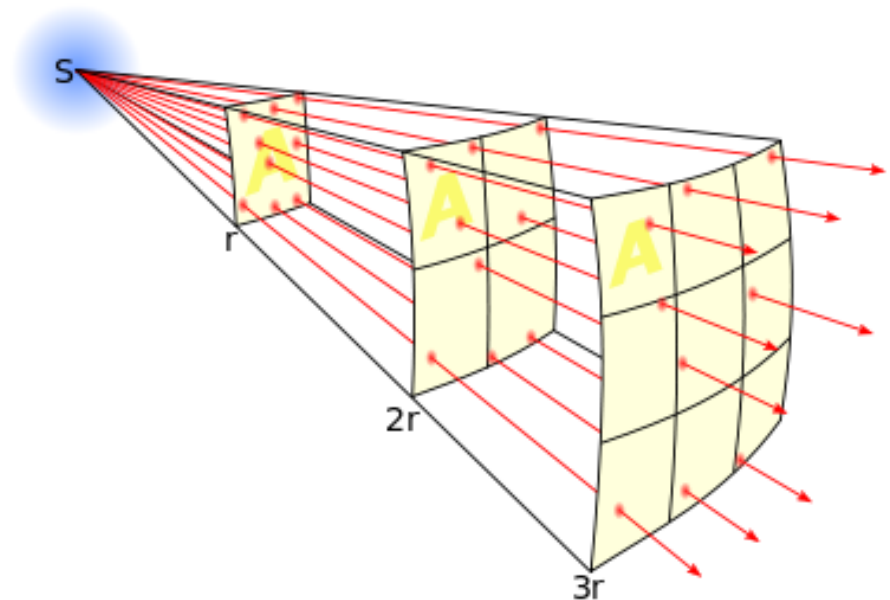
- General comment: we are not “blank slates”; instead, when we hear new information, we try to fit it into what we previously thought we knew.
If what we originally thought was wrong, this can cause problems!
- In this case: some people think distance is the key. When they hear about tilt, they try to fit this into their previous view by believing that the main effect of tilt is that the part of the Earth tilted toward the Sun is **closer** to the Sun.
- Technically, yes! But the Earth’s size is only about $1/20,000$ of the Earth-Sun distance, so the difference is completely negligible.

The Central Role of Flux

- Anticipating a bit a discussion we'll have later in the semester...
- Other things being equal (note the caveat!), the average amount of radiation, per time, per area on Earth's surface where you are, is the most important quantity. This is called the *flux*.
- Thus we need to figure out the effect on the flux of (1) the changing distance of the Earth from the Sun, and (2) the tilt of the Earth's axis to the Earth's orbit, and compare the two to determine which is more important.
- This will also allow us to judge whether distance or tilt is more important on other planets!

Inverse Square Law for Light

- Suppose you have light coming out from a source (for example, the Sun!)
- As you go farther, the *same* amount of light is distributed over a *larger* area.
- Area of a sphere is $4\pi r^2$
- Thus light per area scales as $1/r^2$
- In a circular orbit, there is a constant distance, so no change
- In a very elliptical orbit, the change can be large



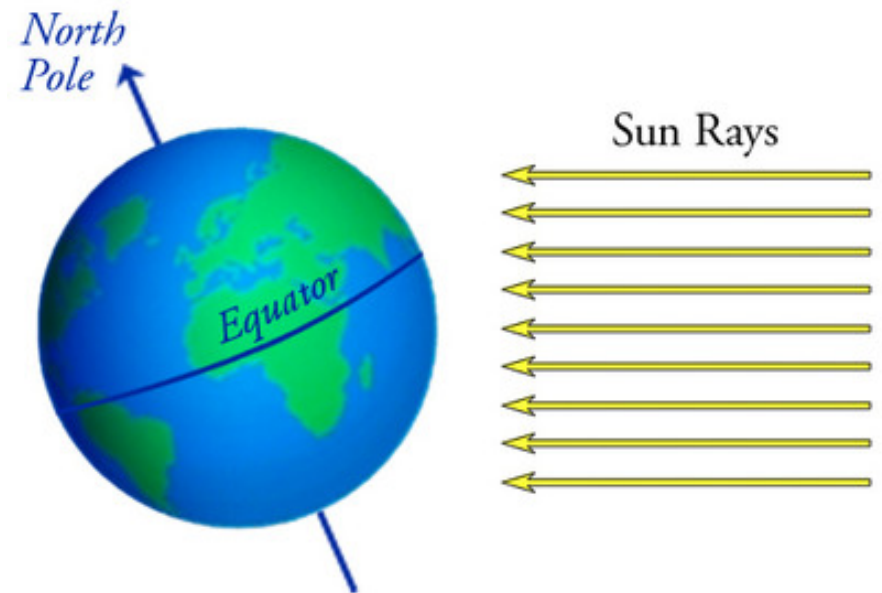
From Wikipedia

What Does Tilt Actually Do?

- Take a sphere and hold it up to a distant light source.
- Even though the rays are all parallel to each other, they are distributed over a much larger area near the pole than near the equator.
- If the rays are tangent to the surface, the flux goes to zero!

Can you see why?

- The Earth's rotation axis is tilted by 23.5 degrees relative to its orbit
- We'll work out what this means!



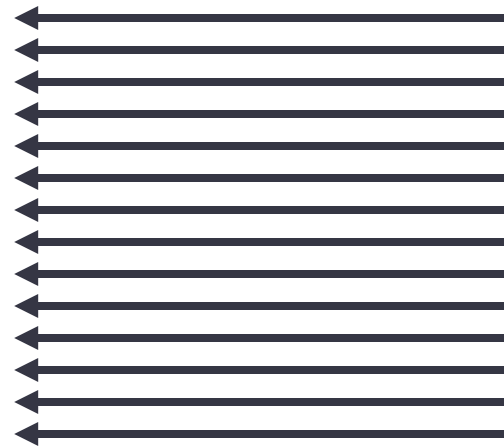
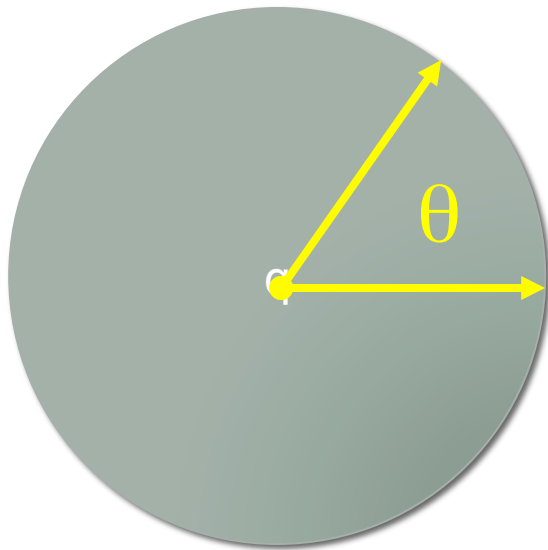
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Effect of Changing Distance

- We'll do some group questions to figure out the relative contribution of changing distance, versus Earth's tilt.
- We'll start with distance.
- At its farthest, Earth is 3.4% farther from the Sun than it is at its closest.
- **In your groups:** use the inverse square law to calculate how much the flux changes just due to the changing distance. Here “how much” would be in percent; that is, how many percent greater is the flux at the closest distance, compared with the flux at the farthest distance?

Effect of Tilt, Part 1

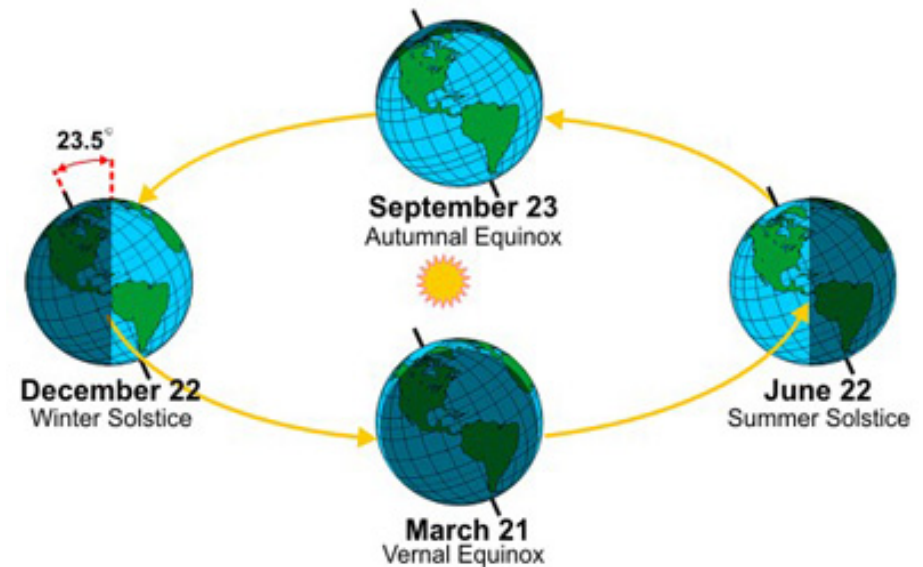
- Suppose we have parallel rays incident on a sphere:



- **Group question:** How does the area over which a bundle of rays is spread depend on θ ? **Note:** the area has to go up for θ farther away from the equator. What should be the answer in the limit that $\theta=90$ degrees?

Effect of Tilt, Part 2

- Earth's axis is tilted relative to its orbit by 23.5 degrees.
- Thus as the Earth moves around the Sun, a given point on the Earth's surface presents different angles to the Sun's rays.



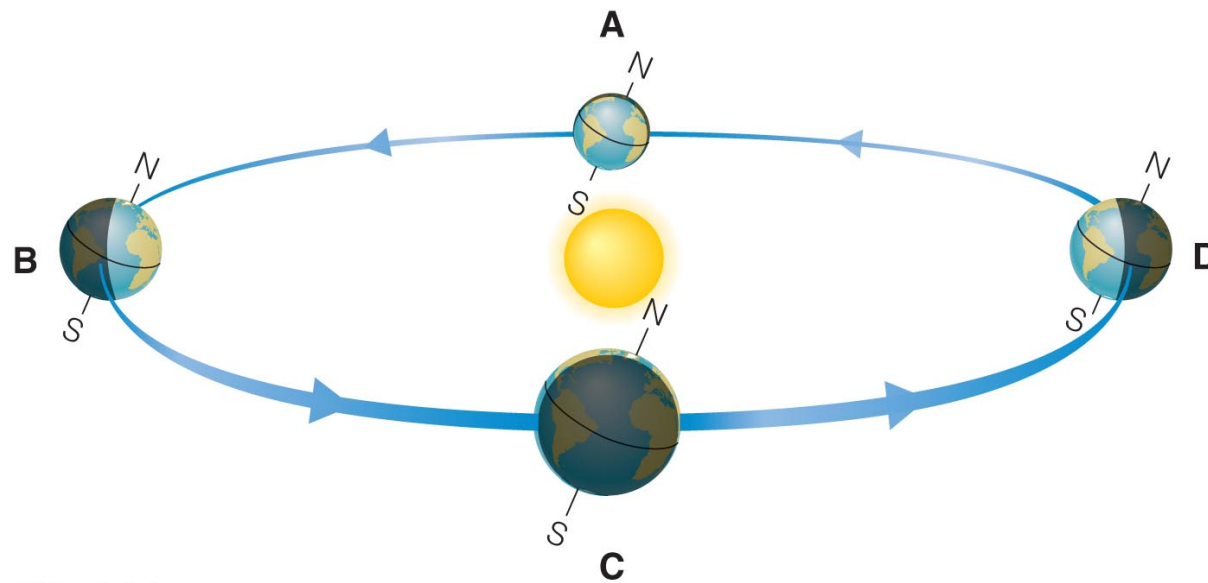
- Group Q: given that College Park is at 39 degrees latitude, what is the smallest angle it presents, at noon, to the Sun's rays? The largest?

<http://s.hswstatic.com/gif/earth-21.jpg>

- Finally: what does that imply about the flux variation due to tilt alone? Compare that with the distance effect.

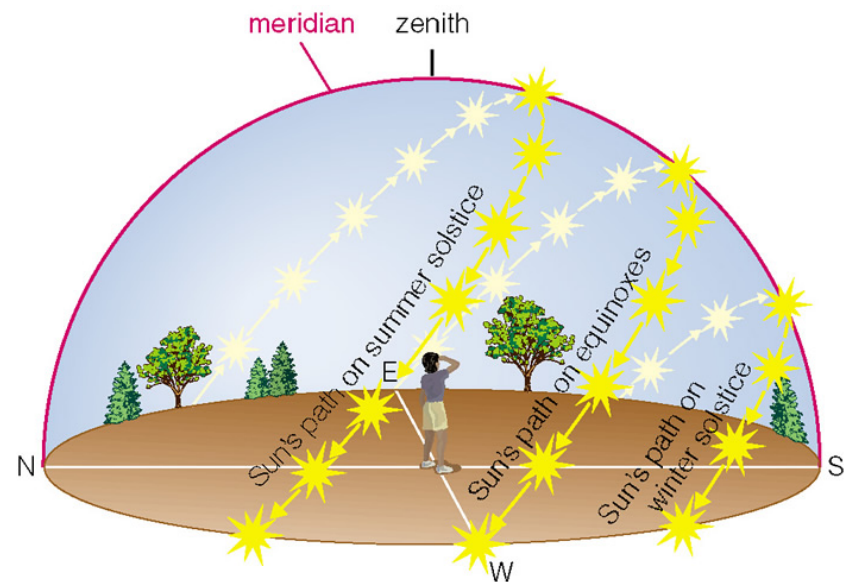
How do we mark the progression of the seasons?

- We define 4 special points:
 - Spring/vernal (March) equinox**
 - Summer (June) solstice**
 - Fall/autumnal (September) equinox**
 - Winter (December) solstice**

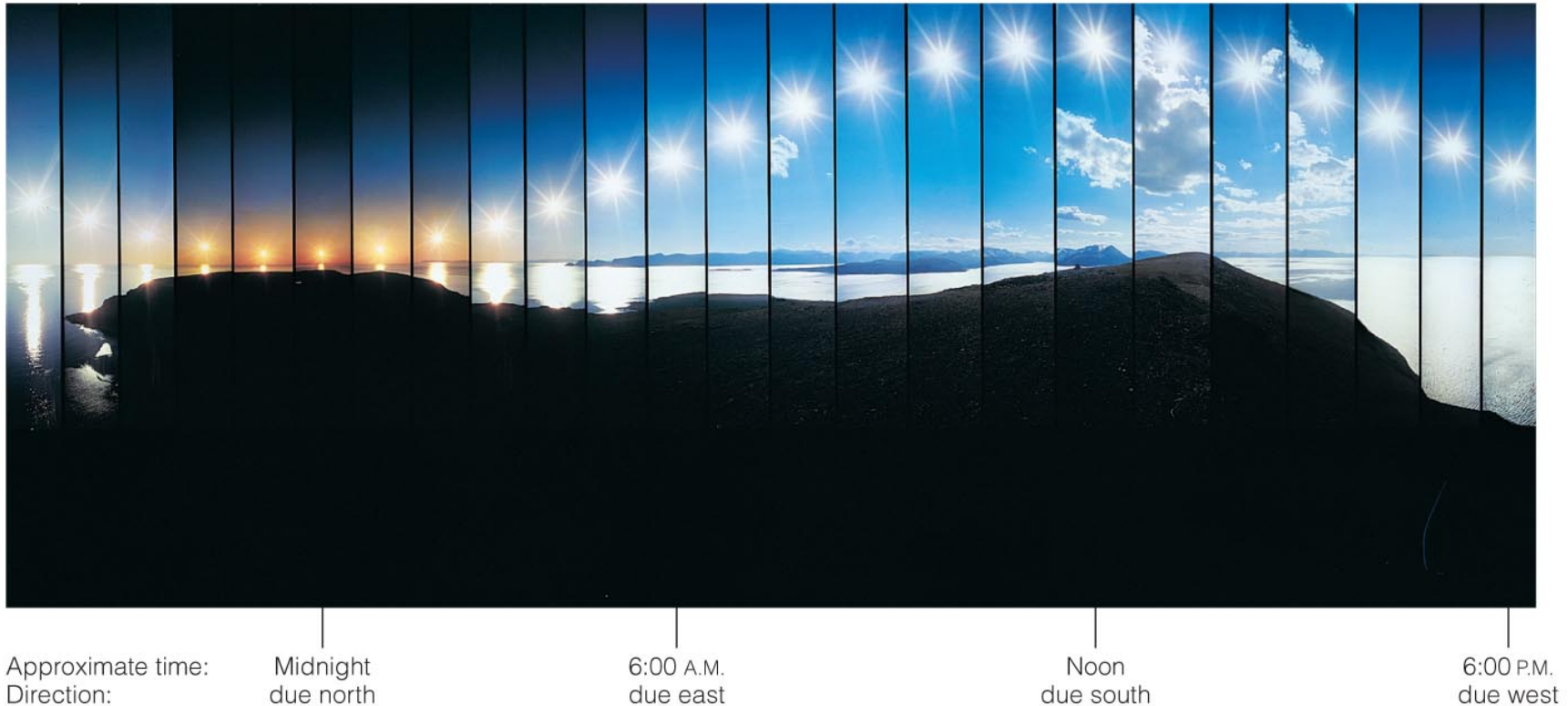


Solstices and equinoxes recognized by Sun's path:

- **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.



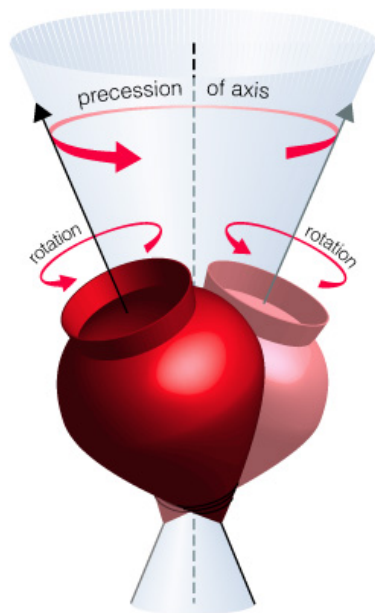
Seasonal changes are more extreme at high latitudes



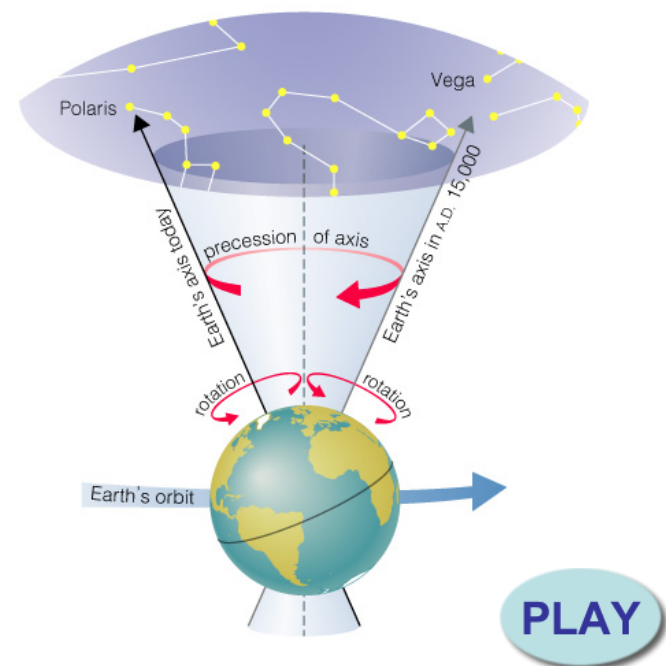
- Path of the Sun on the summer solstice at the Arctic Circle.
Group Q: do same calculation as for College Park, but at 61 degrees north latitude (latitude of Anchorage, Alaska)

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

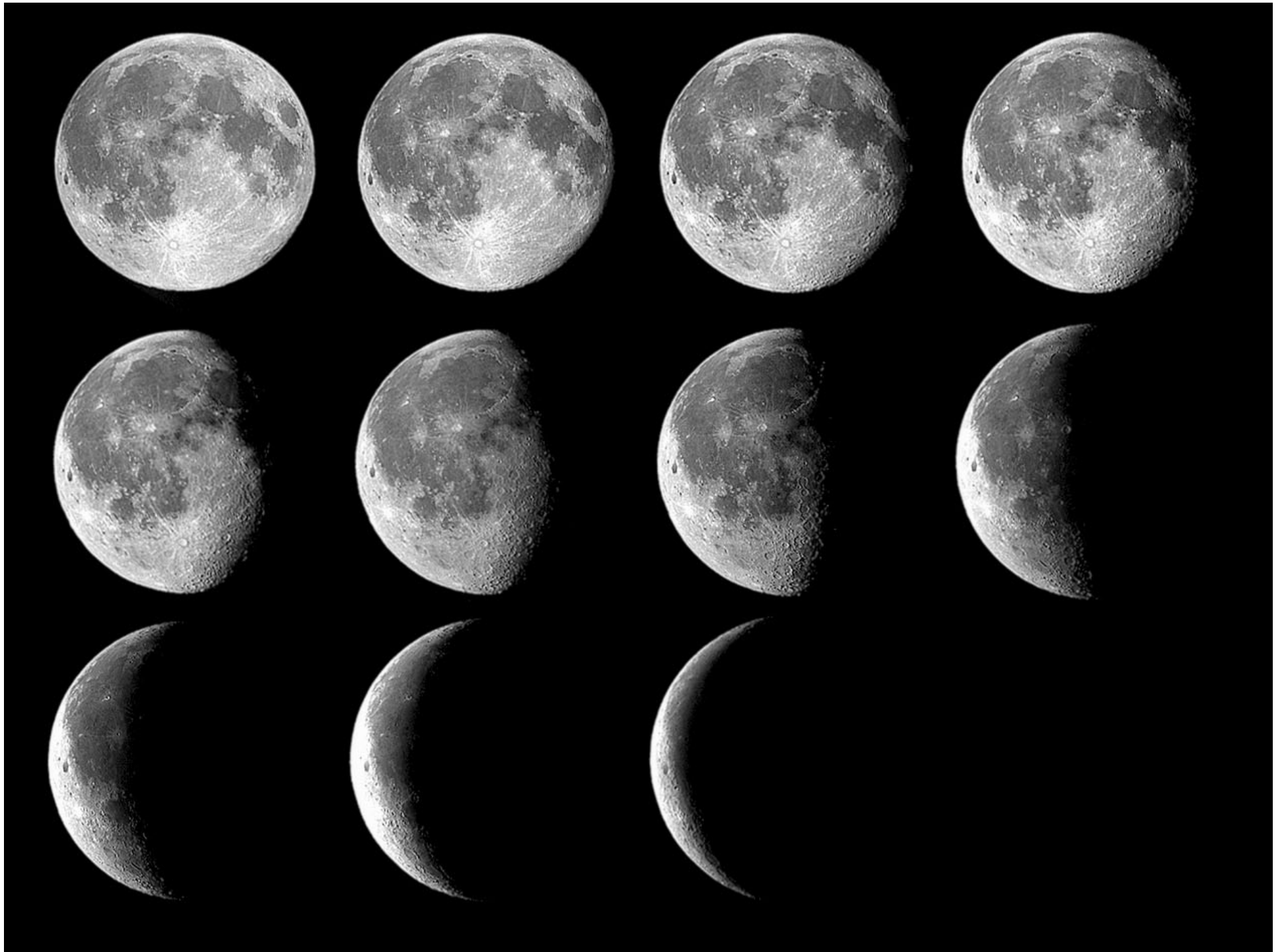
- Although the axis seems fixed on human time scales, it actually *precesses* over about 26,000 years.
 - Polaris won't always be the North Star!
 - Positions of equinoxes/solstices move.



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

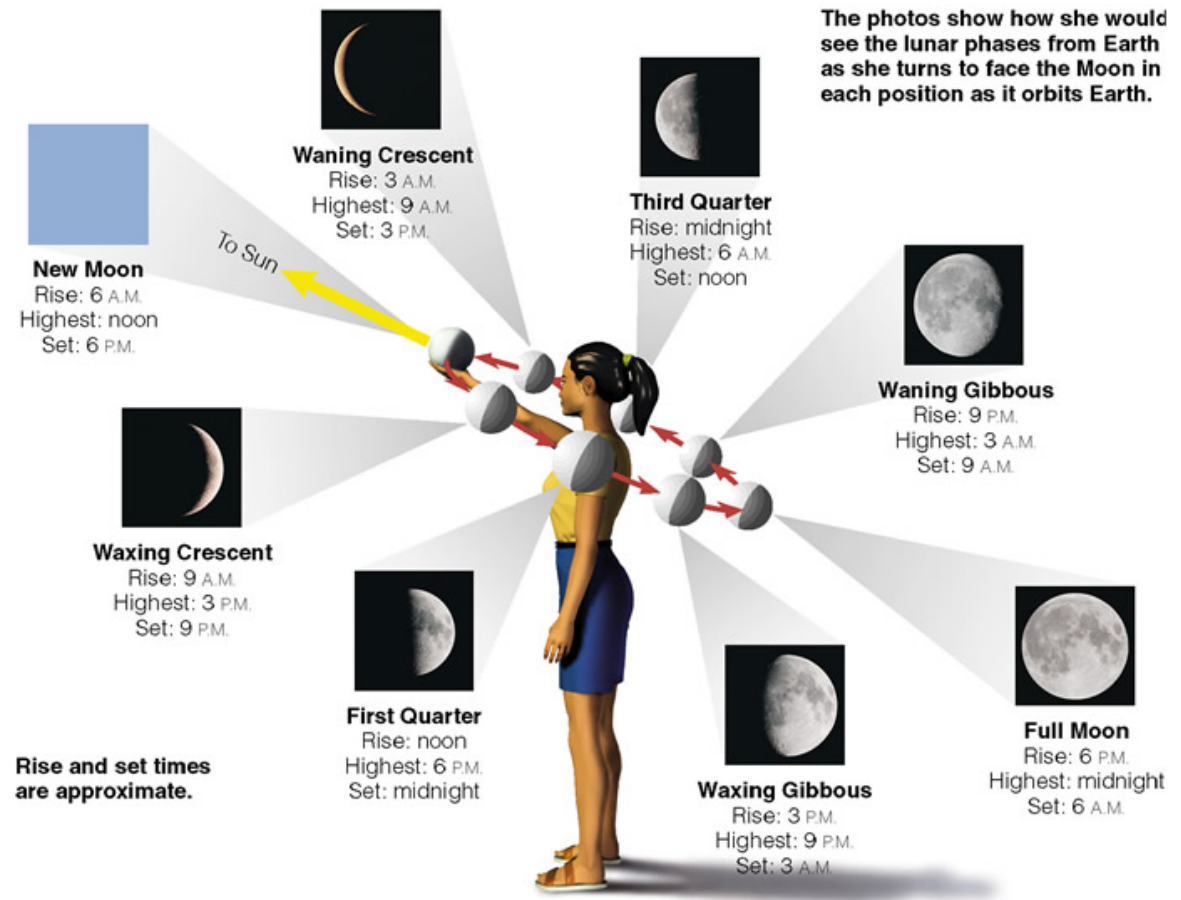




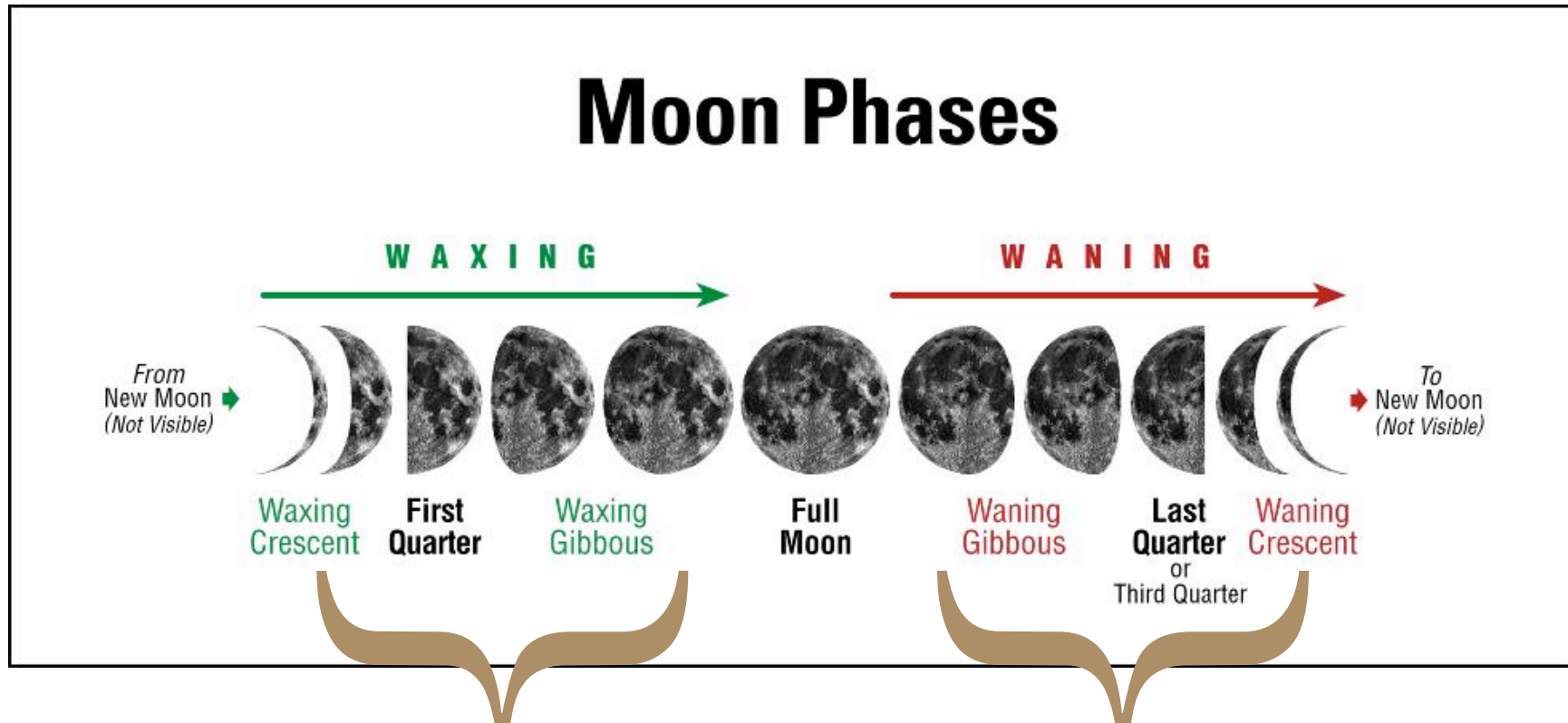


Why do we see phases of the Moon?

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



Moon Phases: 29½-day Cycle



- Moon visible in afternoon/evening.
- Gets “fuller” and rises later each day.
- Moon visible in late night/morning.
- Gets “less” and sets later each day.

Thought Question

It's 9 am. 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.

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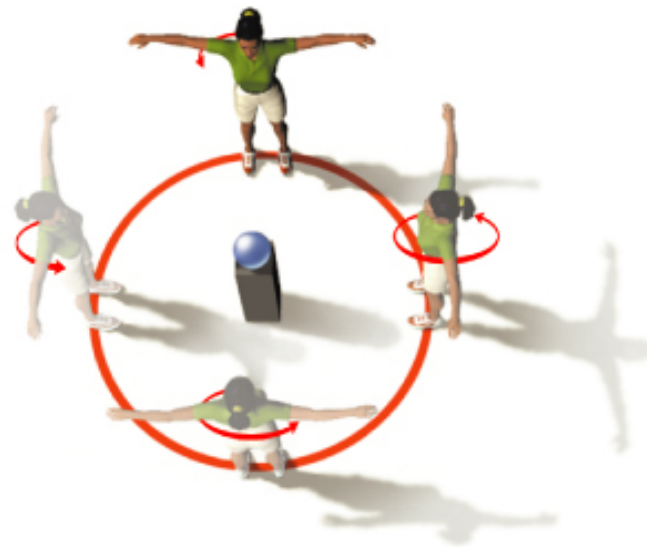
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Also called
"last quarter."



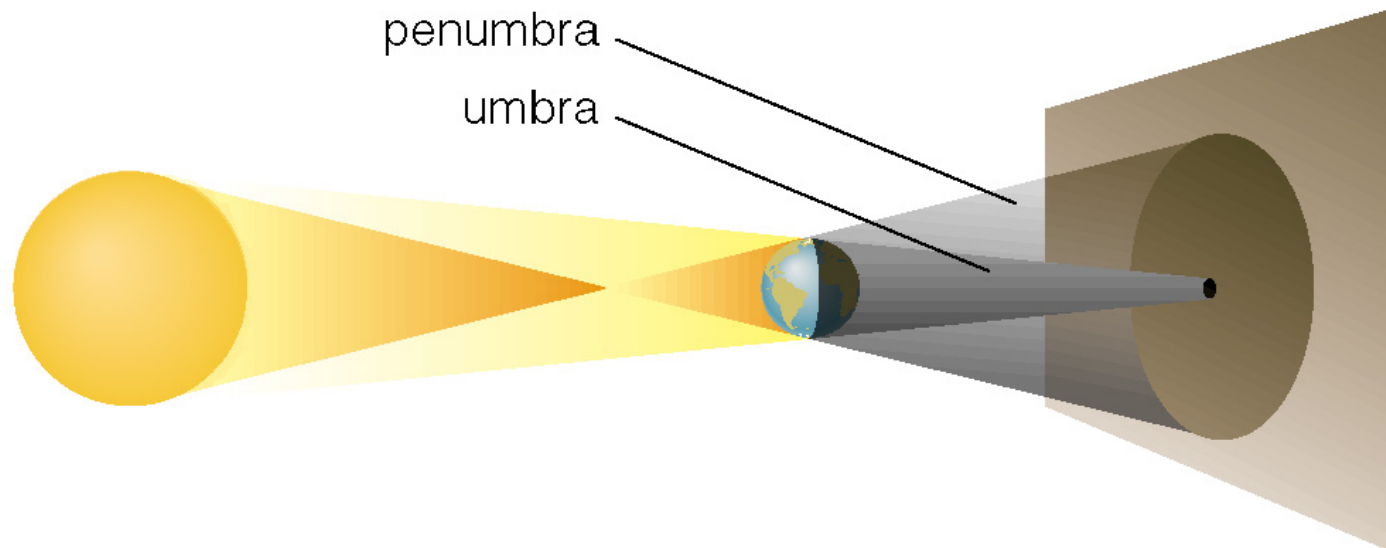
We see only one side of the Moon.

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



What causes eclipses?

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

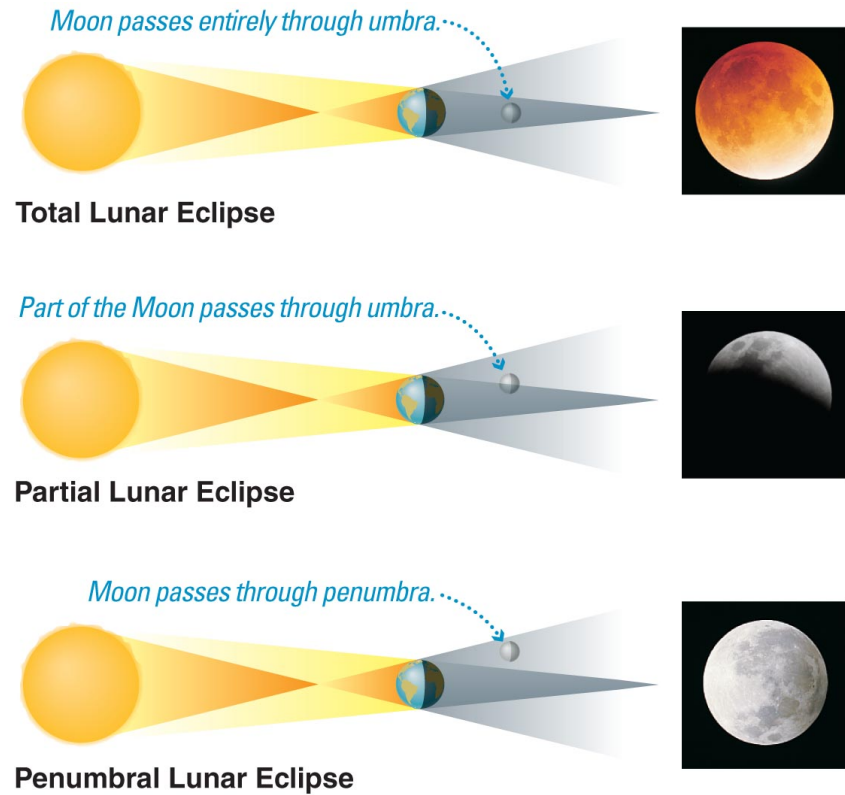


When can eclipses occur?

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

The next total lunar eclipse will occur Jan 20/21, 2019, and will be visible from College Park. 😊

<http://www.timeanddate.com/eclipse/>



Interactive Figure 

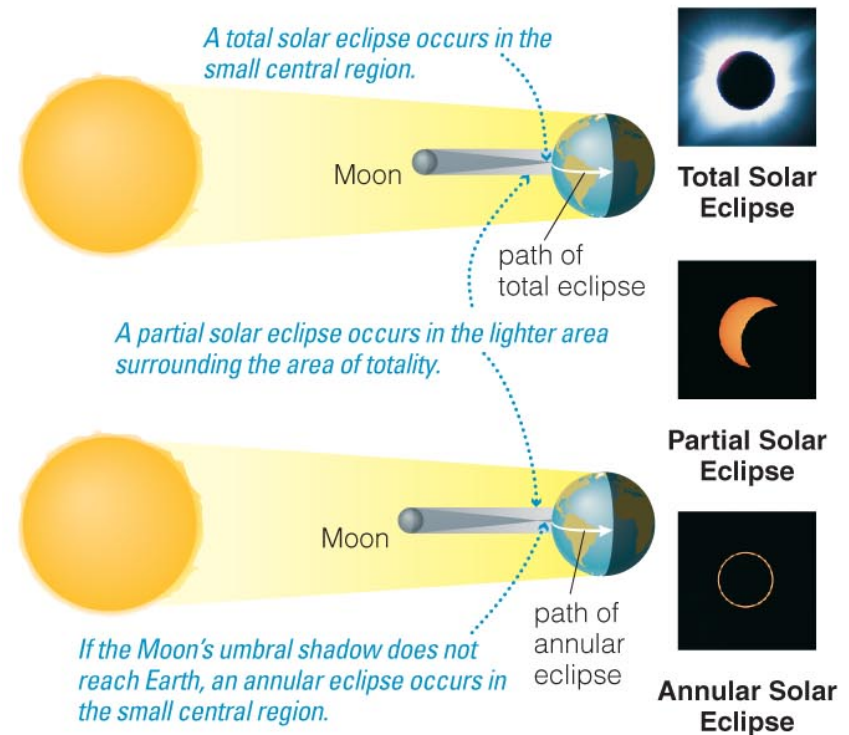


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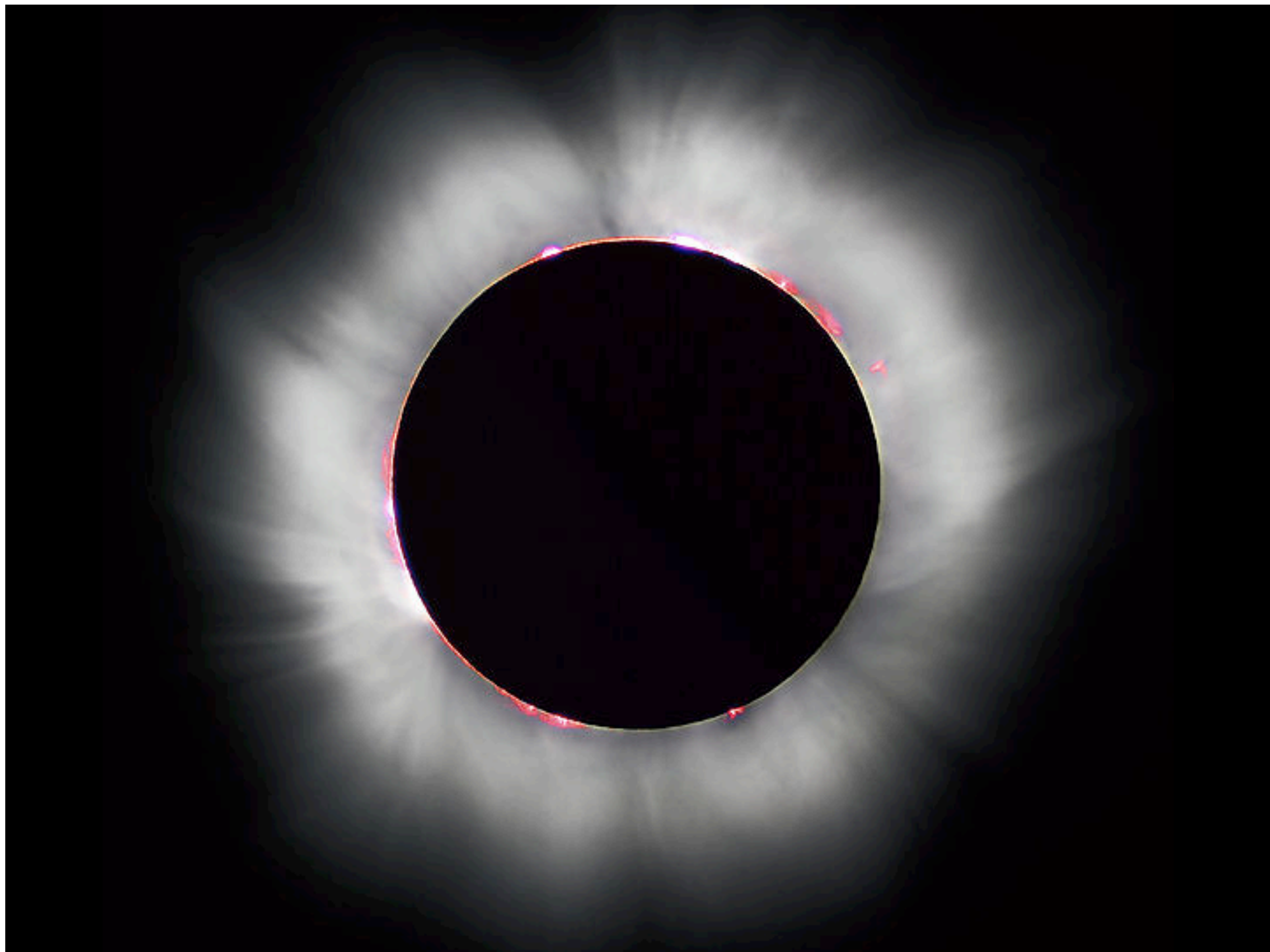
- **Solar eclipses** can occur only at *new moon*.
- Solar eclipses can be **partial, total, or annular**.

There was a total solar eclipse on Aug 21, 2017, visible across much of the United States!

<http://www.timeanddate.com/eclipse/>

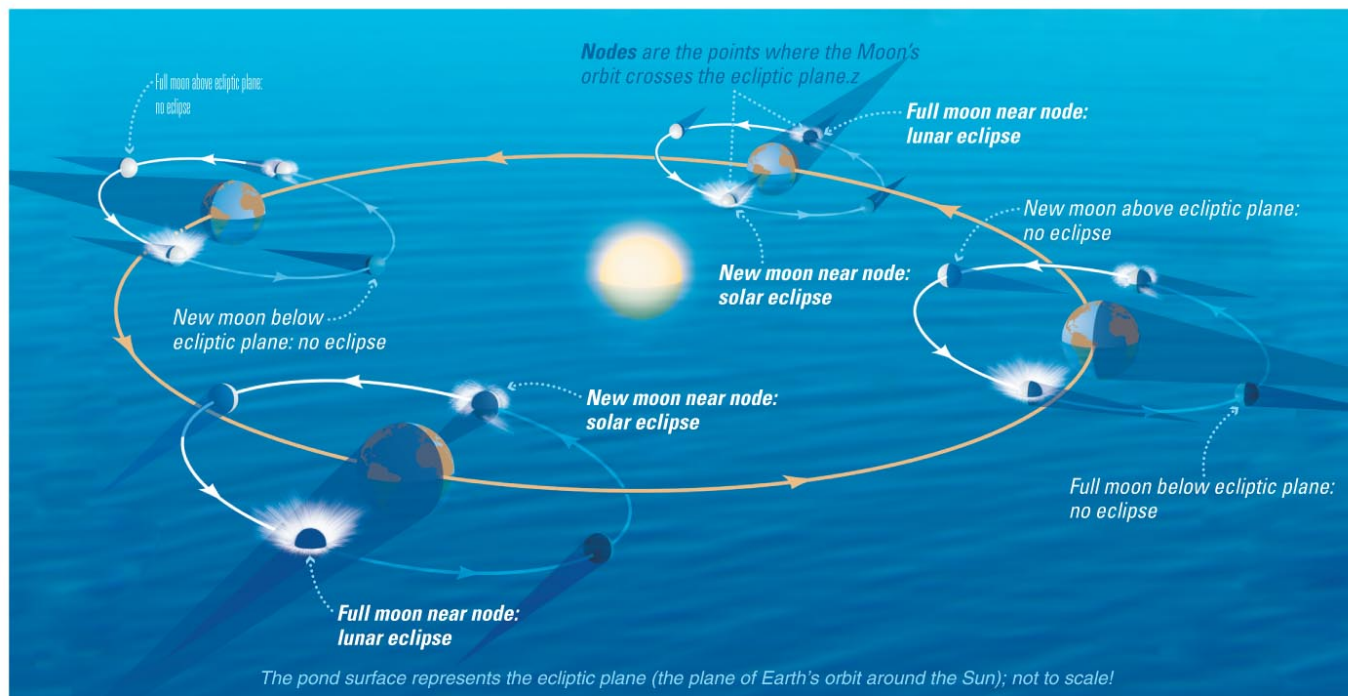


Interactive Figure 

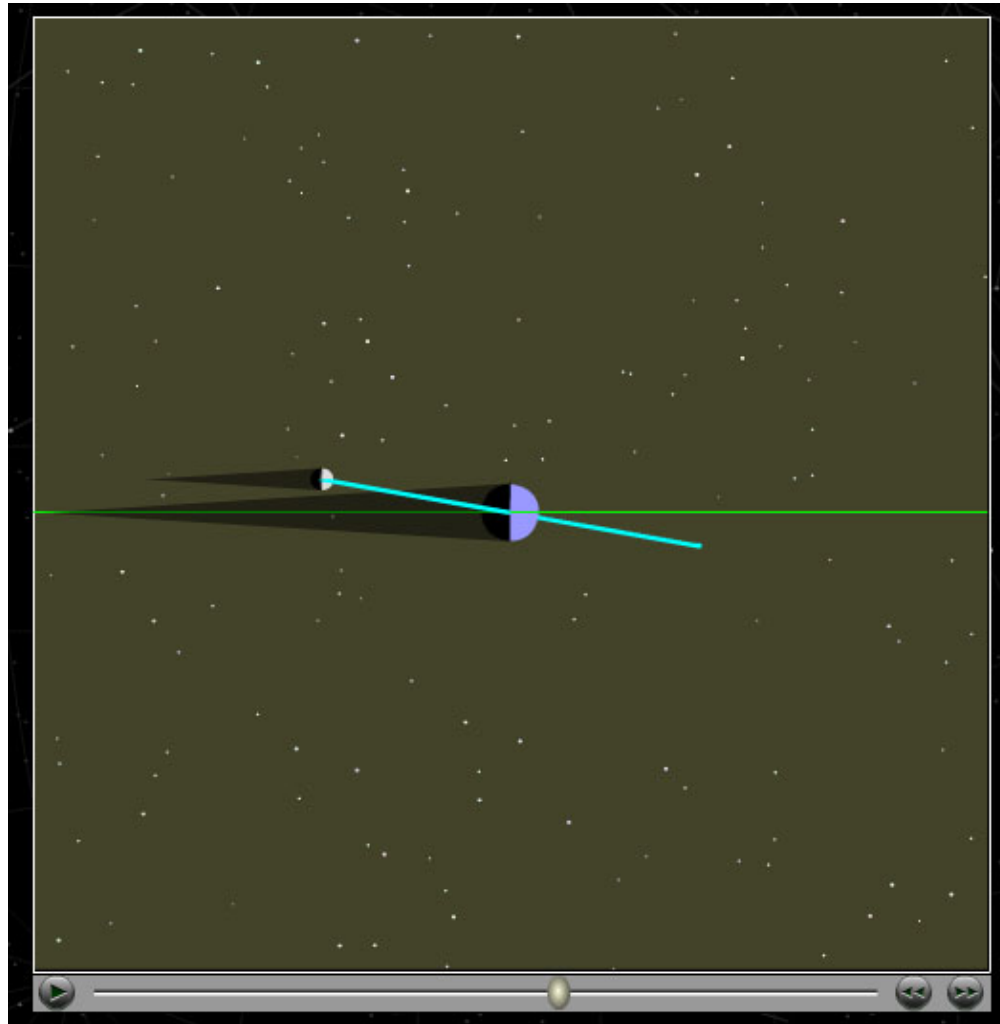


Why don't we have an eclipse at every new and full moon?

- 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.



Another look...



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).

Seasons, Phases, and Eclipses

- We have seasons because of Earth's tilt, which causes there to be more direct light for longer during summer.
- The phase of the Moon depends on the Moon-Earth-Sun angle, which also determines the rise/transit/set time.
- A lunar eclipse can occur when the Earth is between the Moon and the Sun.
- A solar eclipse can occur when the Moon is between the Earth and the Sun.
- Eclipses involving Earth's Moon occur only twice a year due to the Moon's orbital inclination to the ecliptic.
- Other bodies in the solar system can experience seasons, phases, and eclipses for the same reasons as us.

Next Time: The Great Debate!

- Will divide class into thirds: one third will argue for heliocentric model, one third for geocentric model, one third will judge.
- Will alternate brief points between sides until done.
- Ground rules are that no observations past the time of Copernicus can be used (thus, for example, no telescopic observations are allowed)
- Just for fun! Point will be to see that determination of better model is not easy.