In-Class Small Group Assignment

1. Form groups of 3-4 students
2. Create a shared "Google Doc" and share it with your professors too (LAndres@BU.edu and Henebry@BU.edu)
3. Include the names of all students on your small team in the body of the document.
4. Create a Mars Calendar. Be creative!!
   a. A day on Mars (called a "sol") is 24 hours and 40 minutes
   b. Mars goes around the sun in 668.6 days
   c. The moons (Phobos and Deimos) take eight hours and 30 hours to travel around Mars. Our moon takes 27.3 days to Travel around the Earth.

Attempt to Satisfy These Criteria

It would be convenient if the calendar met some criteria to match human comforts as well as possible. Your calendar will probably not satisfy all these conditions (neither does our own!).

1. **Each day of the year has a place in your calendar. There are no extra or bonus days tacked onto the end of the year (like in the Egyptian example)**
2. **The week has 7 days (like we are used to here on Earth)**
3. **The months match your lunar cycle (this doesn't happen with our calendar)**
4. **A whole number of weeks per month**
5. **A whole number of weeks per year**
6. **Number of months divides evenly into quarters (to mark the seasons)**

Image Link (and alternate link), Credit: NASA; “Earthrise” by William Anders, Apollo 8, 1968

Phases of the Moon: Initial Understanding

Pause-and-Think MC Question:

Based on your understanding before this class, what causes the moon to have different phases?

1) Obstruction by the Sun’s shadow
2) Obstruction by the Earth’s shadow
3) Clouds in the Earth’s atmosphere
4) Various alignments of the Sun-Earth-Moon system
5) None of the Above

Phases of the Moon: Goals

You will be able to answer the following questions when you see the actual Moon in the sky:

- What is the name of the current phase I am seeing?
- What will the Moon look like in a few days?
- Based on the Moon’s location in the sky, what time is it?

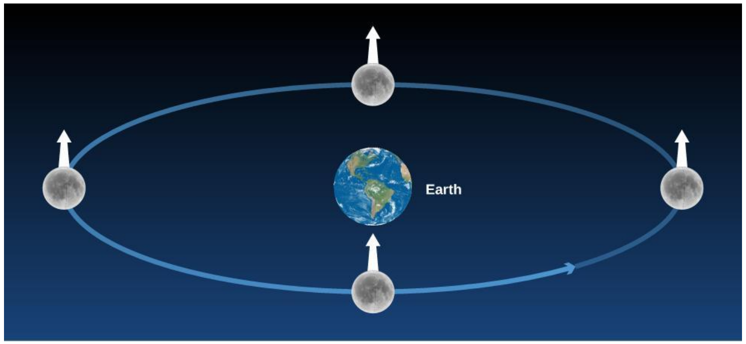
Phases of the Moon: The Dark Side?

Half of the Earth is always lit up (“day”) and half of it is dark (“night”). **This is true on the Moon, too.**

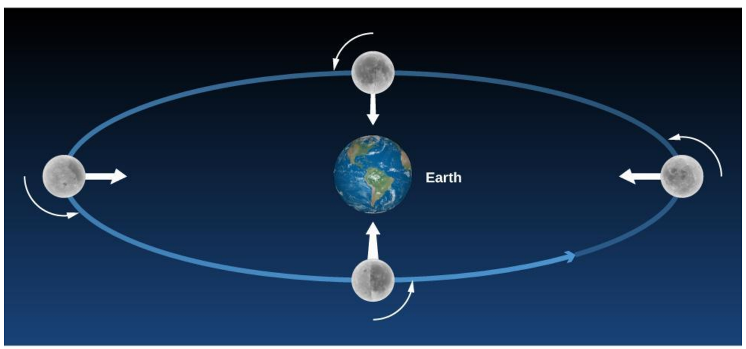
The dark side of the Earth change every 24 hours as it rotates on its axis. ***So, what about the Moon?***

Image Link (and alternate link), Credit: NASA; “Earthrise” by William Anders, Apollo 8, 1968

Phases of the Moon: The Dark Side?



(a)



(b)

Let's consider this big arrow to represent a visible pattern we can recognize on the Moon's surface.

We always see the same pattern on the Moon. Which situation fits that statement: (a) the Moon that doesn't rotate or (b) the Moon that rotates once each orbit of Earth?

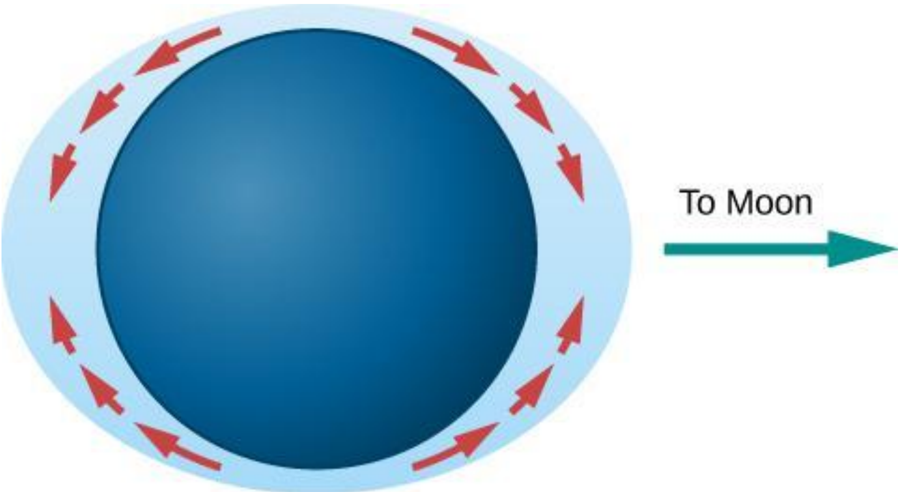
Phases of the Moon: A Brief Recap

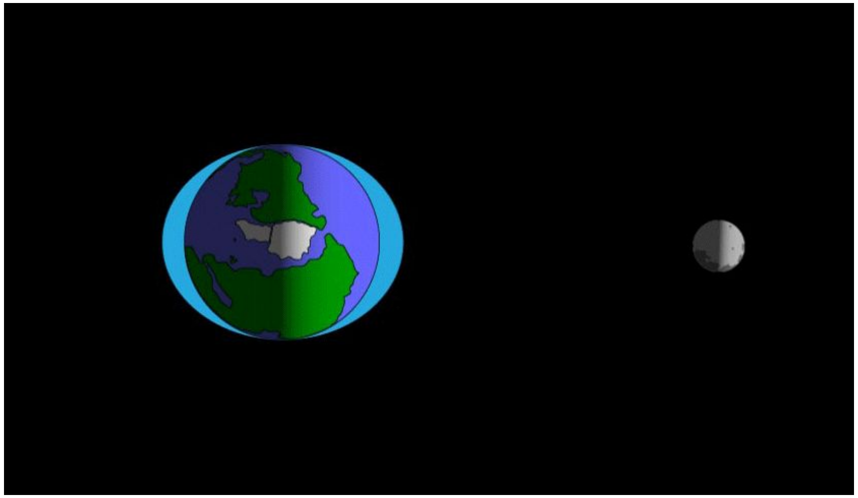
What we've determined so far:

- Moon is always half illuminated by **reflected sunlight**.
- The Moon half that is lit up changes over the course of the lunar cycle (i.e. there's **no single "dark side"**).
- The Moon spins on its own axis once for each orbit around Earth! This means there ***is* a single "far side"** of the Moon.

This last point is not a coincidence, it's due to **tidal locking**!

Tides: A Brief Discussion



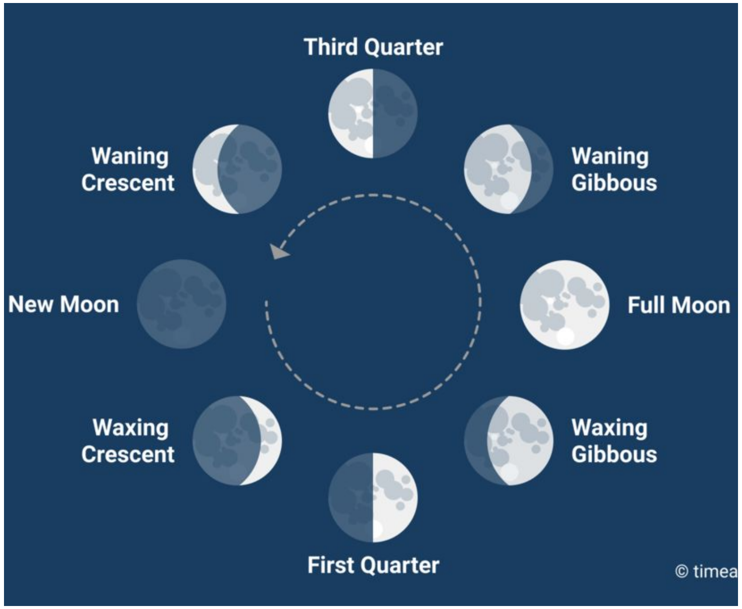


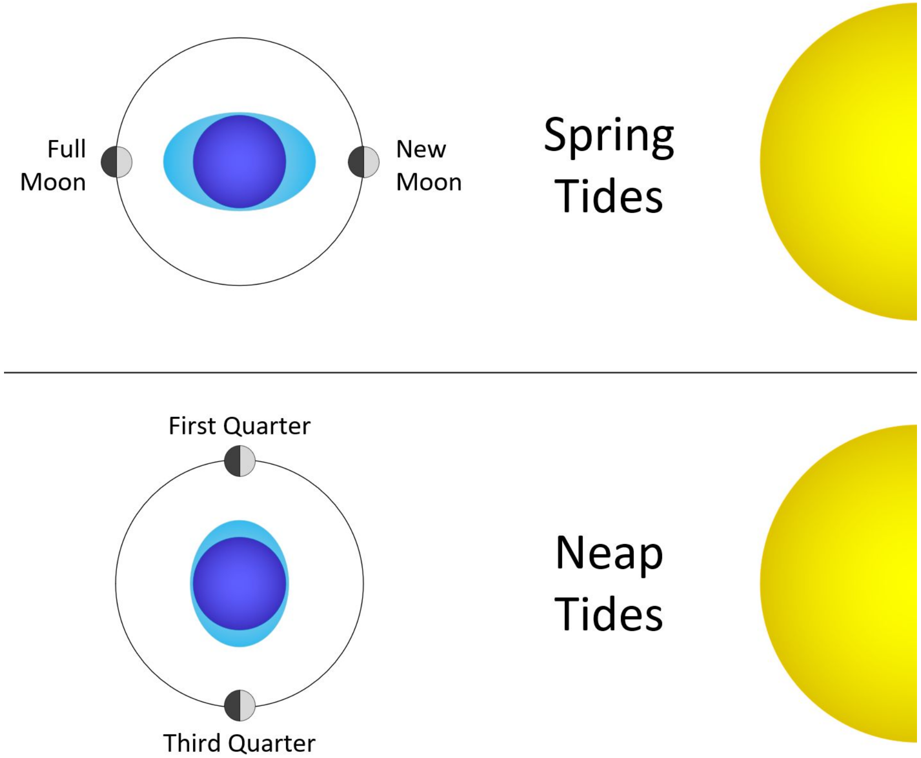
If you have a computer and web browser that can run flash, this ***Tidal Bulge Simulation*** *has a button to include Earth's rotation effects and shows the tides slightly ahead of the line connecting the Moon and the Earth.*

Tides: A Brief Discussion

Tides are strongest at **New Moon** and **Full moon.**

Tides are weakest (least extreme) at **Quarter Moons.**

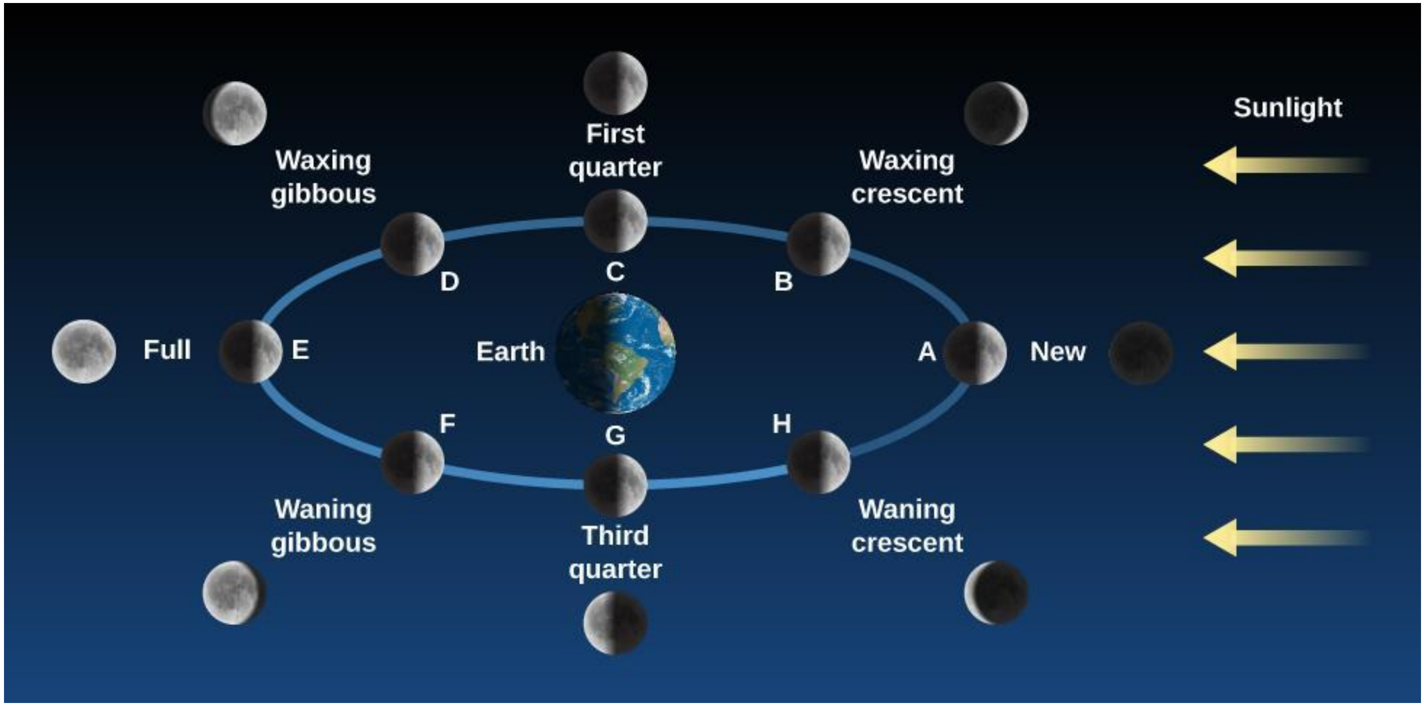




Phases of the Moon: New Terms

Here are all of the **terms** we need to learn for this topic:

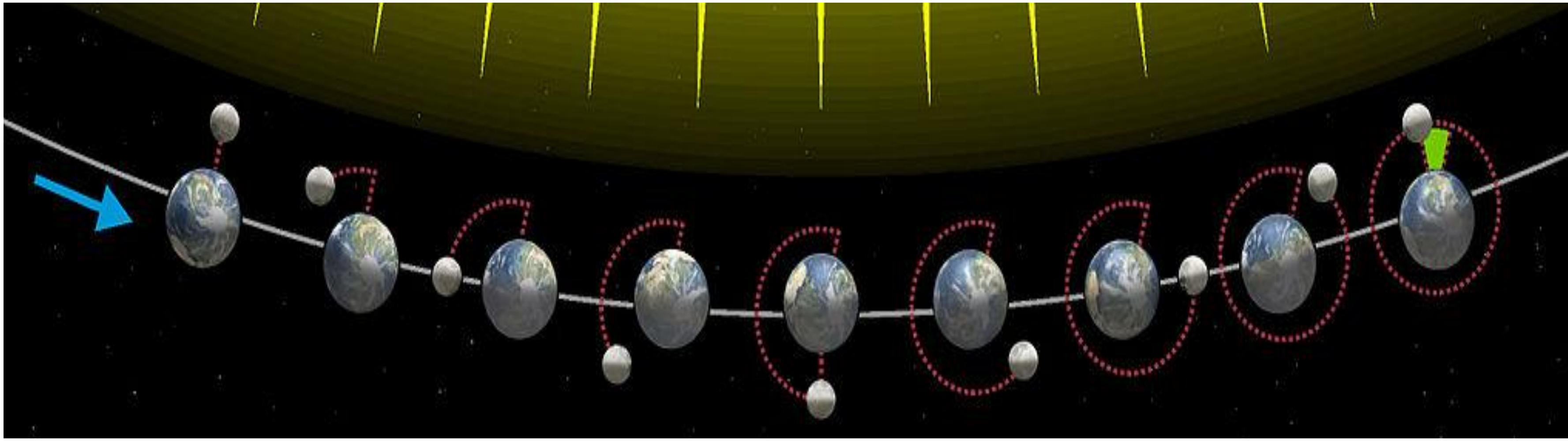
- Full
- New
- Quarter
- Crescent
- Gibbous
- Waxing
- Waning



Phases of the Moon: Predicting Time and Location

Moon Phase	Rise Time	Highest Point	Set Time
New Moon	Sunrise	Noon	Sunset
First Quarter	Noon	Sunset	Midnight
Full Moon	Sunset	Midnight	Sunrise
Third Quarter	Midnight	Sunrise	Noon
New Moon	Sunrise	Noon	Sunset

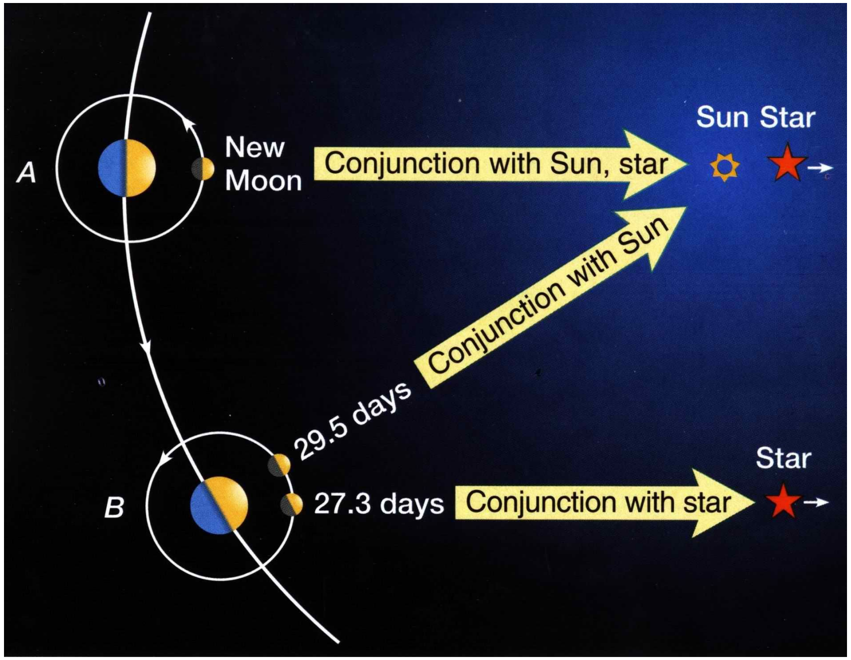
Phases of the Moon: Order and Length



Solar Month: 29.5 days (also called Synodic period) "New Moon to New Moon" period. This is 7.4 days for each quarter of the cycle, this is the length of time we care about.

Sidereal Month: 27.3 days (One orbit around the Earth)

Phases of the Moon: Order and Length



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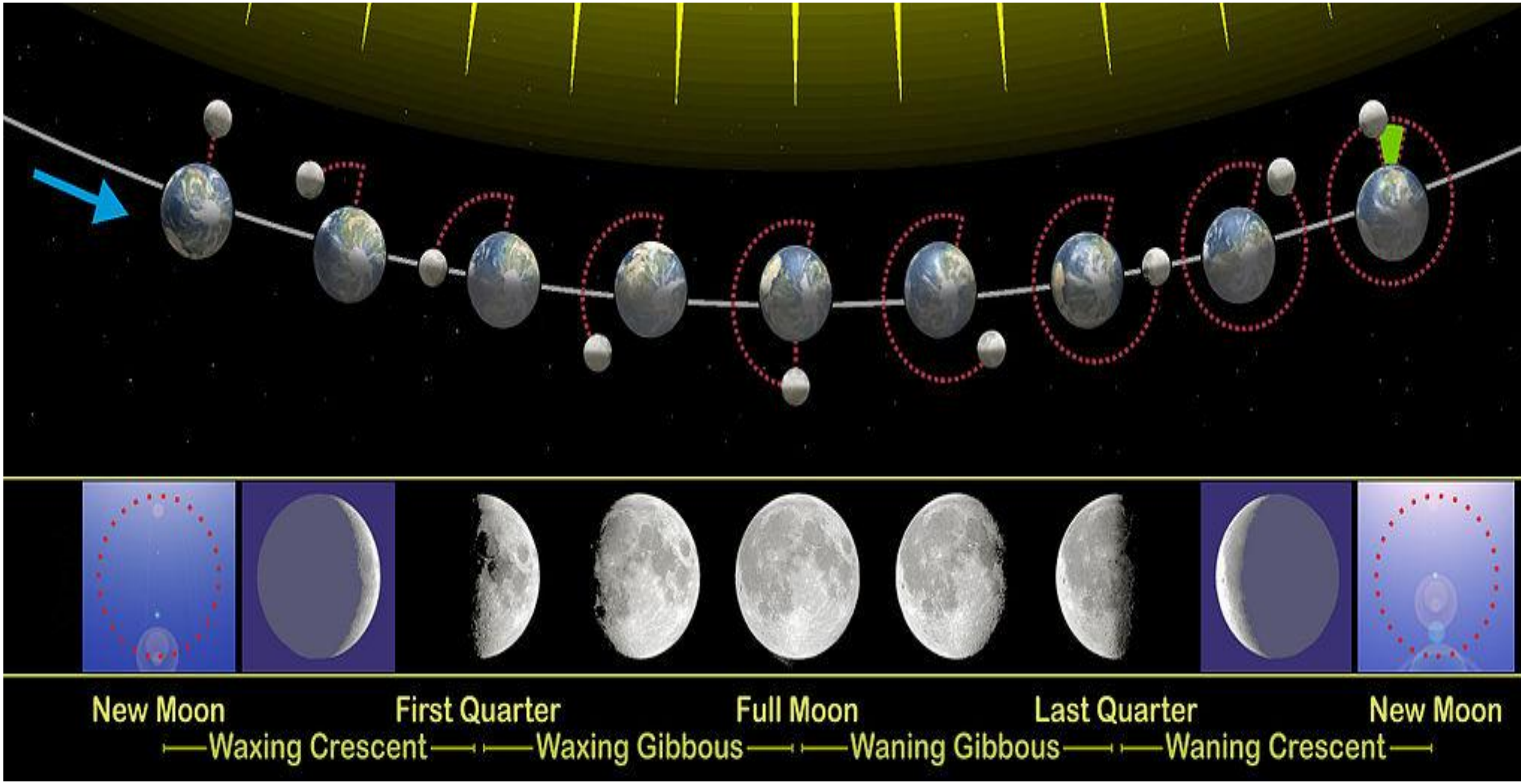
Phases of the Moon: Order and Length



The crescent and gibbous phases each last about a week.

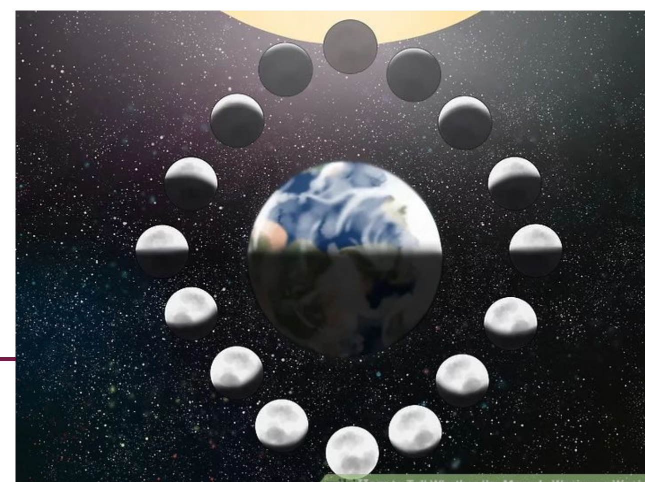
Phases of the Moon: Order and Length

We have talked about ***why*** the moon has phases, but now we need to think about the order and length of those phases.

Waxing: becoming progressively *more* visibly illuminated.
Waning: becoming progressively less visibly illuminated.

External Websites for Simulations:

- https://astro.unl.edu/classaction/animations/lunarcycles/moonphases.html
- https://www.khanacademy.org/partner-content/nasa/measuringuniverse/spacemath1/pi/animate-phases-of-the-moon



Phases of the Moon: Predicting Time and Location

Pause-and-Think MC Question(s):

Where would you look to see the full moon when it rises?

1) Directly overhead
2) On the eastern horizon
3) On the western horizon
4) In the southern sky

Where would you look to see the Sun at that time?

Phases Beyond the Moon!

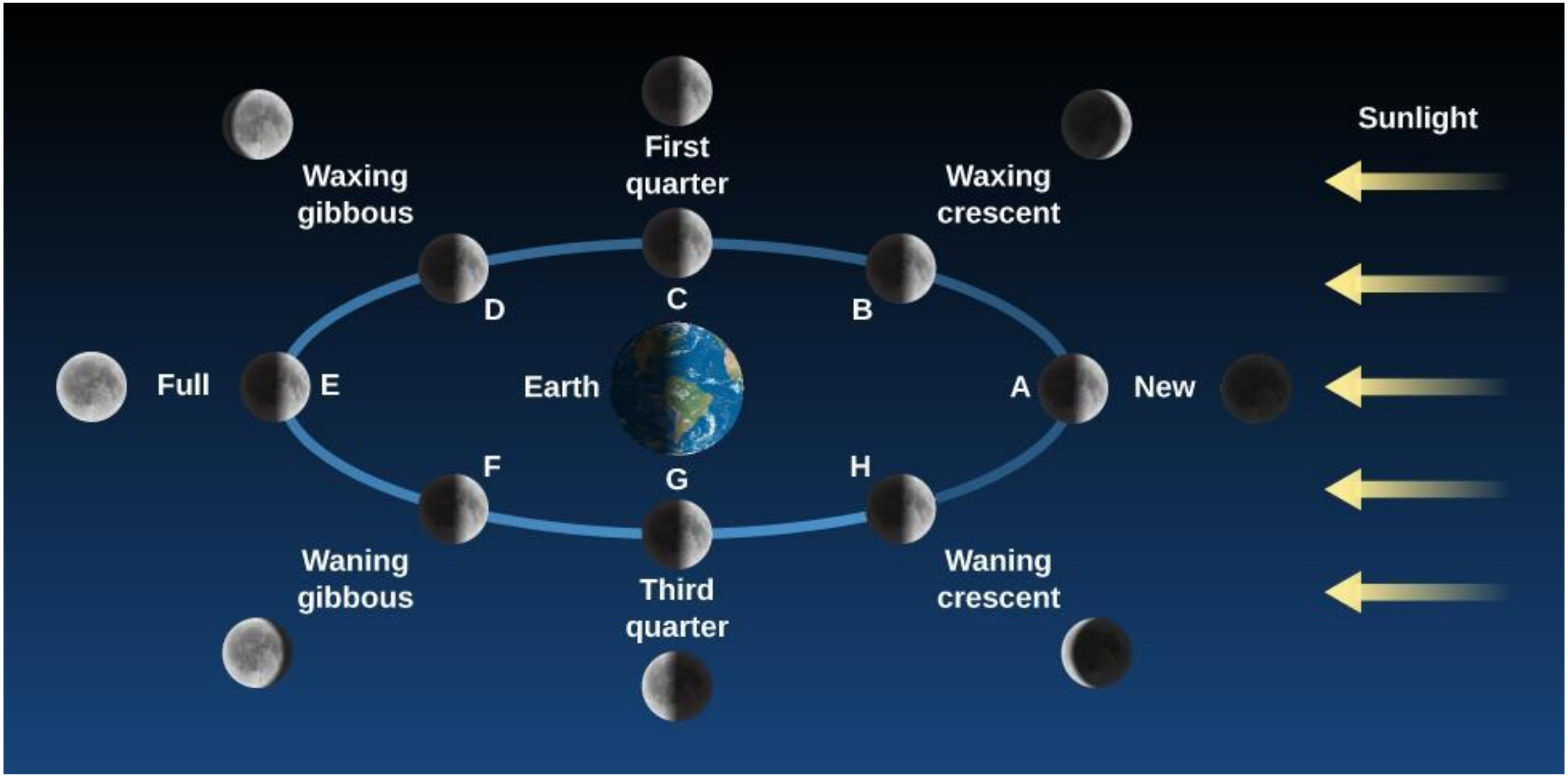
To wrap up, I have a few questions to consider about this photo we saw earlier.

What "Earth phase" is shown in this photo?

What Moon phase would people on Earth see?

Image Link (and alternate link), Credit: NASA; "Earthrise" by William Anders, Apollo 8, 1968

Phases of the Moon: Summary



Eclipses of the Sun and Moon

Remember that initial *pause-and-think* question from Section 4.5: What causes the moon to have different phases?

1) Obstruction by the Sun's shadow
2) Obstruction by the Earth's shadow
3) **Various alignments of the Sun-Earth-Moon system**
4) Clouds in the Earth's atmosphere

For those who voted (2) originally, there certainly **is** an astronomical event that is caused by the obstruction by the Earth's shadow. That's our next topic.

Eclipses of the Sun and Moon

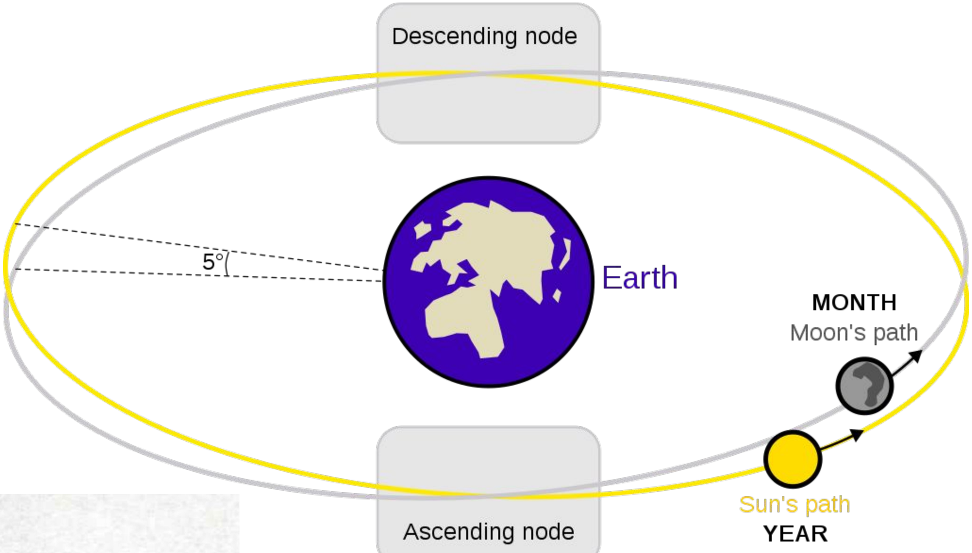
To understand eclipses, we need to start out with two points.

- **All the diagrams we've been seeing in the slides and textbooks are perfectly aligned, but that's not true.** We lose the third dimension in these diagrams.
- **All the diagrams we've been seeing in the slides and textbooks are not accurate to-scale models.** The Sun is about 400 times larger than the Moon. *By coincidence*, it is also about 400 times farther away.

Eclipse Requirements: Orbital Alignment

The Sun's apparent path through our sky is along the Ecliptic, and the Moon's path is ***almost*** along the ecliptic. Each month, there are two **nodes** where the Moon crosses the ecliptic plane. The nodes shift slowly over 18 years.

There are two types of eclipses, and both need the Moon to be at a **node** of its orbit. We call that time frame **eclipse season**.



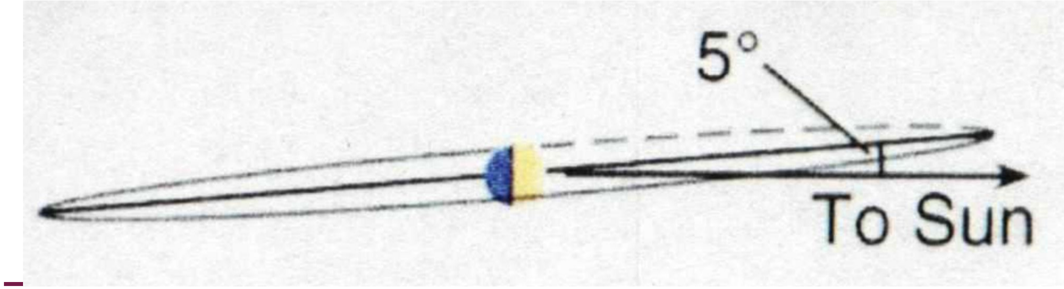
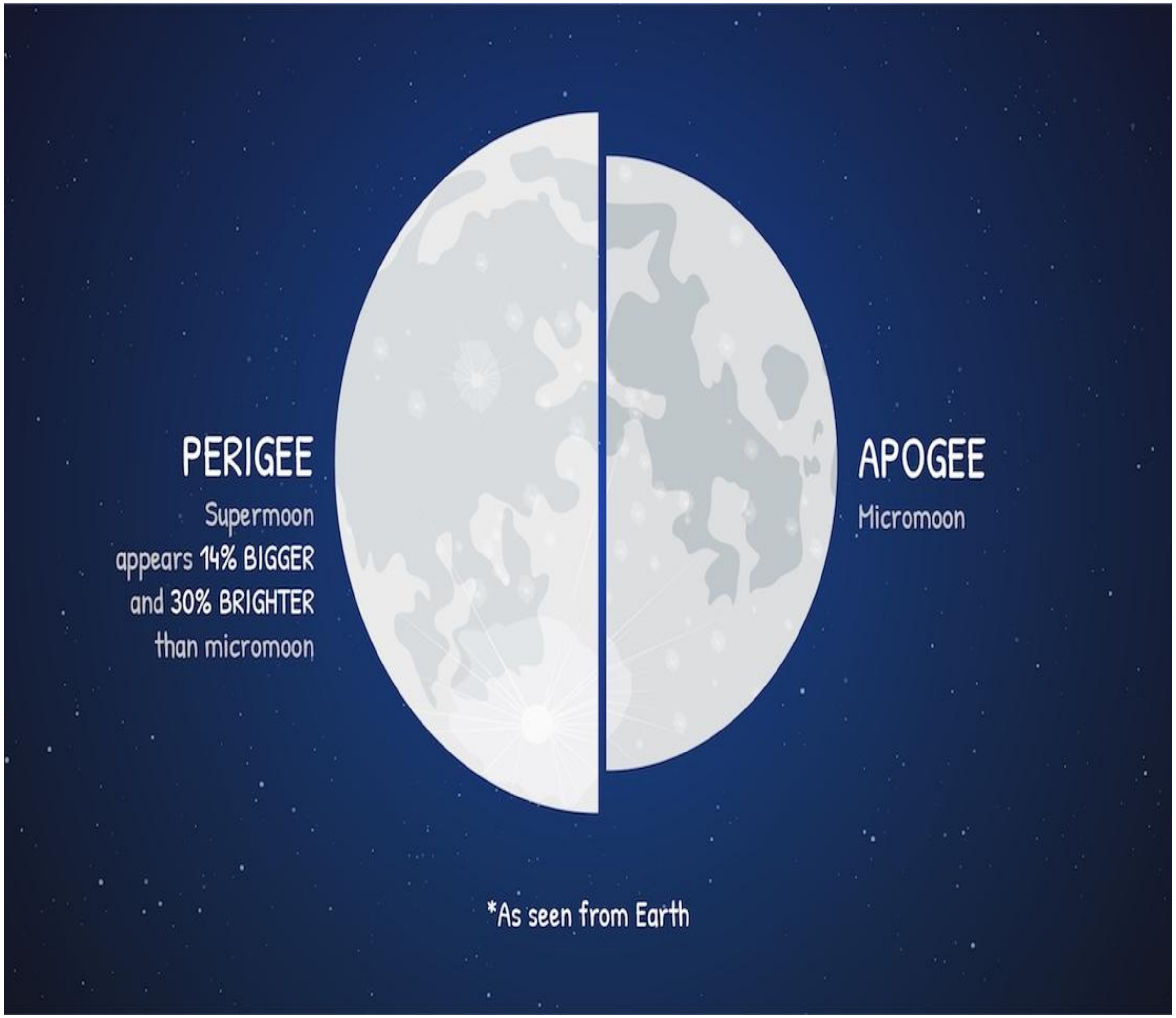


Image Link, Credit: SuperManu, following work by Tom Ruen, Public Domain

Eclipse Requirements: Angular Size

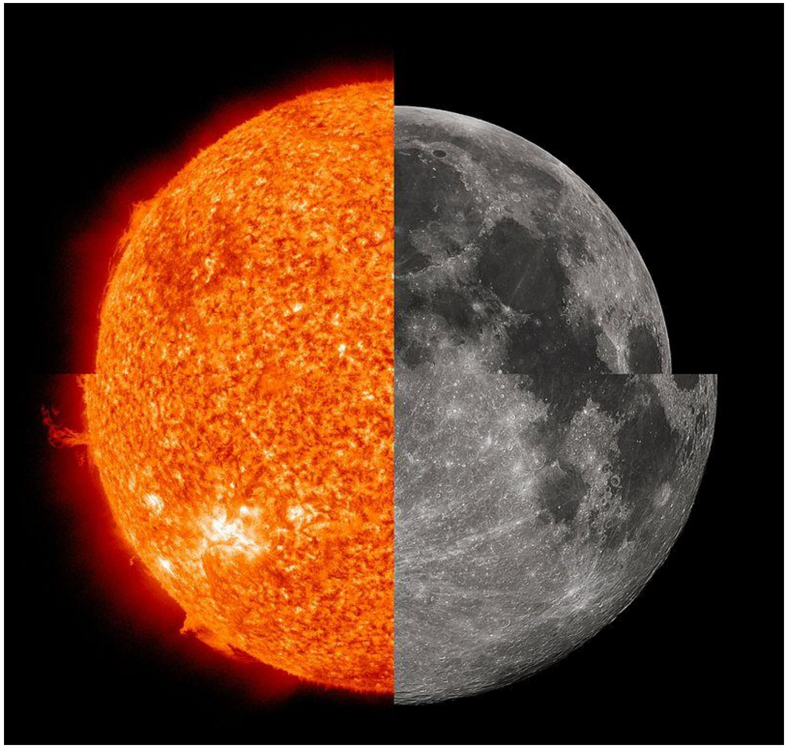


If you've ever heard the term "supermoon," you may be aware that the Moon's orbit is not circular. Sometimes it's closer (and bigger), sometimes it's farther (and smaller).

It isn't changing actual size, it is changing **angular size**.

Image Link, Credit: NASA/JPL-Caltech

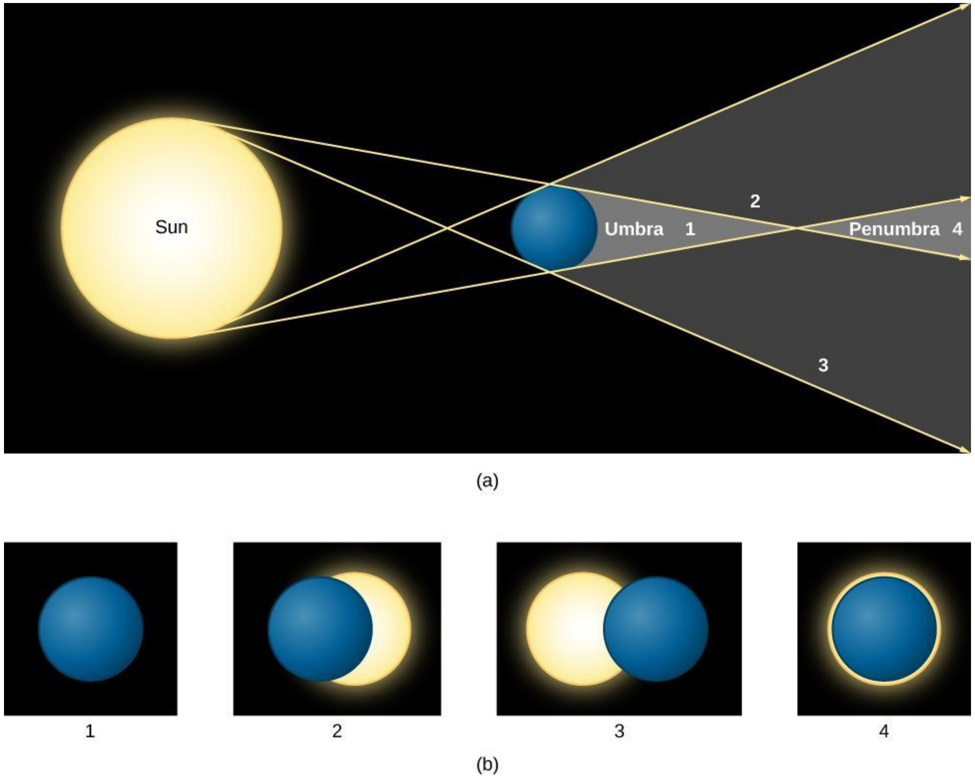
Eclipse Requirements: Angular Size



Because the ratio of physical sizes is similar to the ratio of their distances, the Moon and the Sun have a very similar **angular size** on our sky (0.5°).

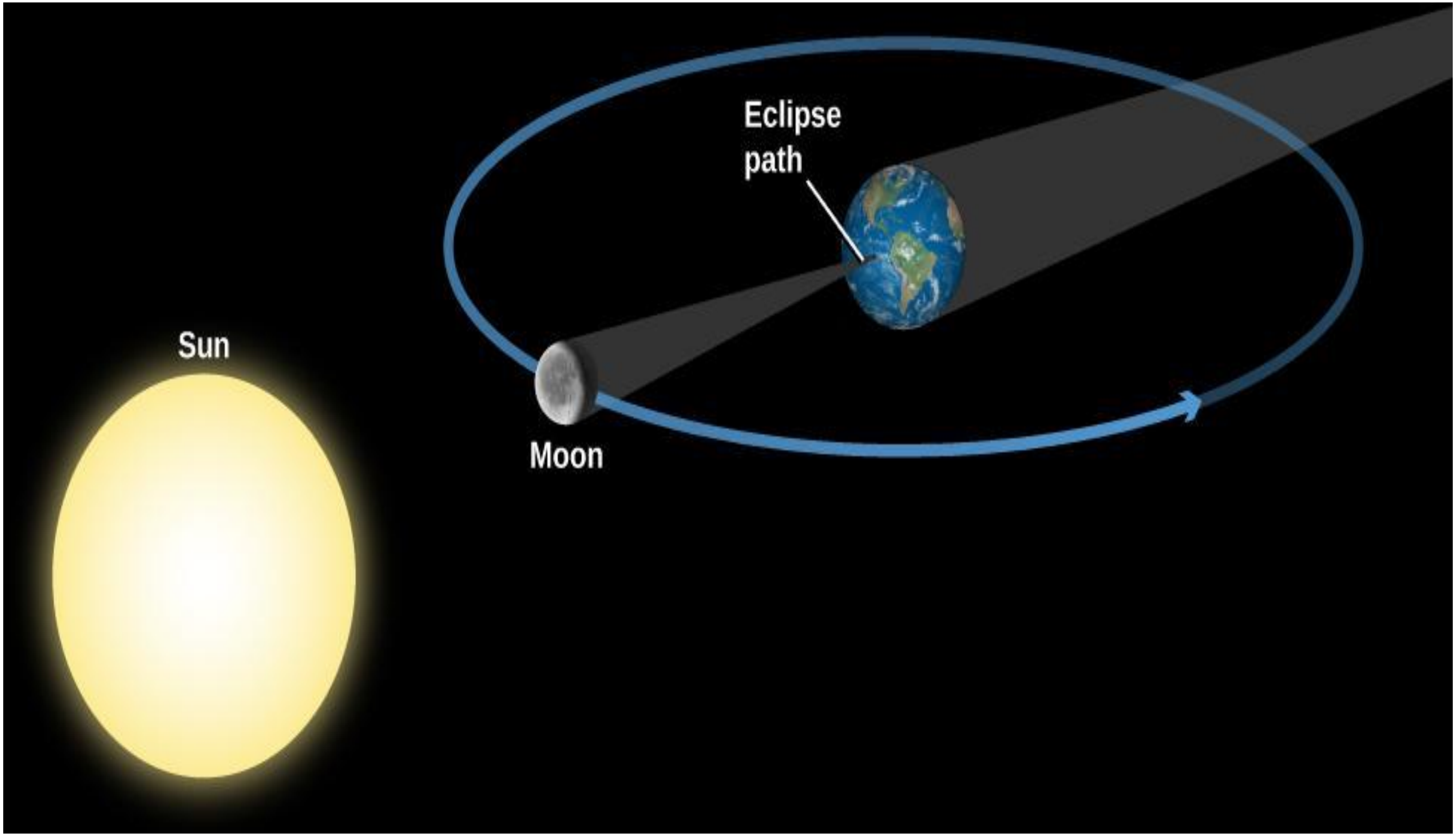
This is pure coincidence, and it means that the Moon is often able to completely cover the Sun!

Eclipse Requirements: Shadows

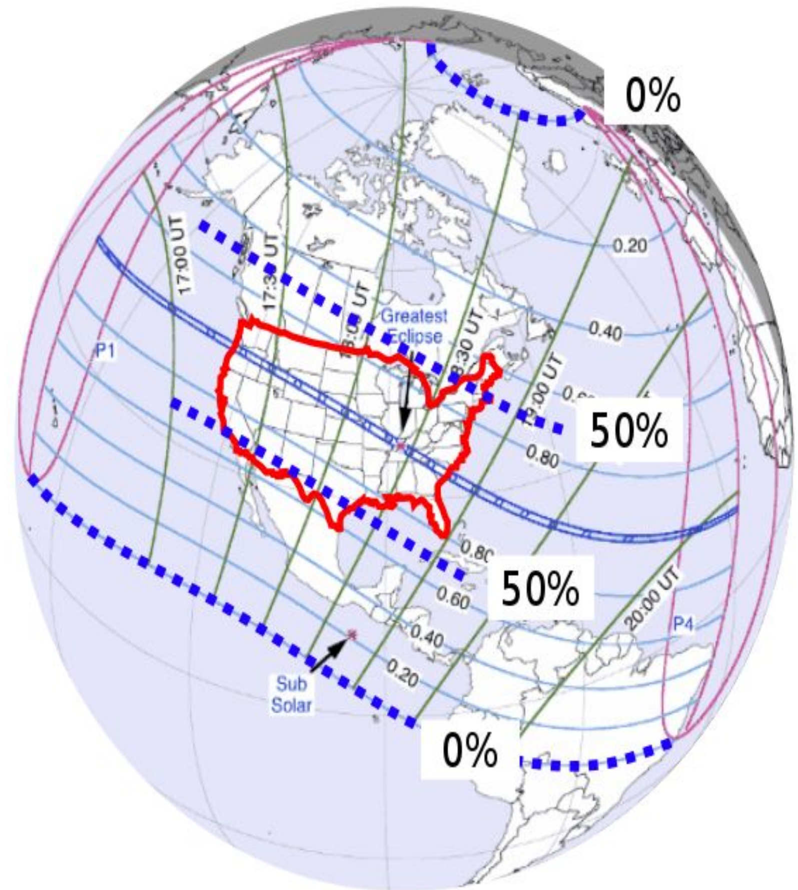


If illuminated by a light source, ***any object*** can cast a shadow. There will be a zone of partial shadow, the **Penumbra**, and a zone of full shadow, the **Umbra**. *Note: this diagram is not to scale.*

Solar Eclipses: Moon's Shadow



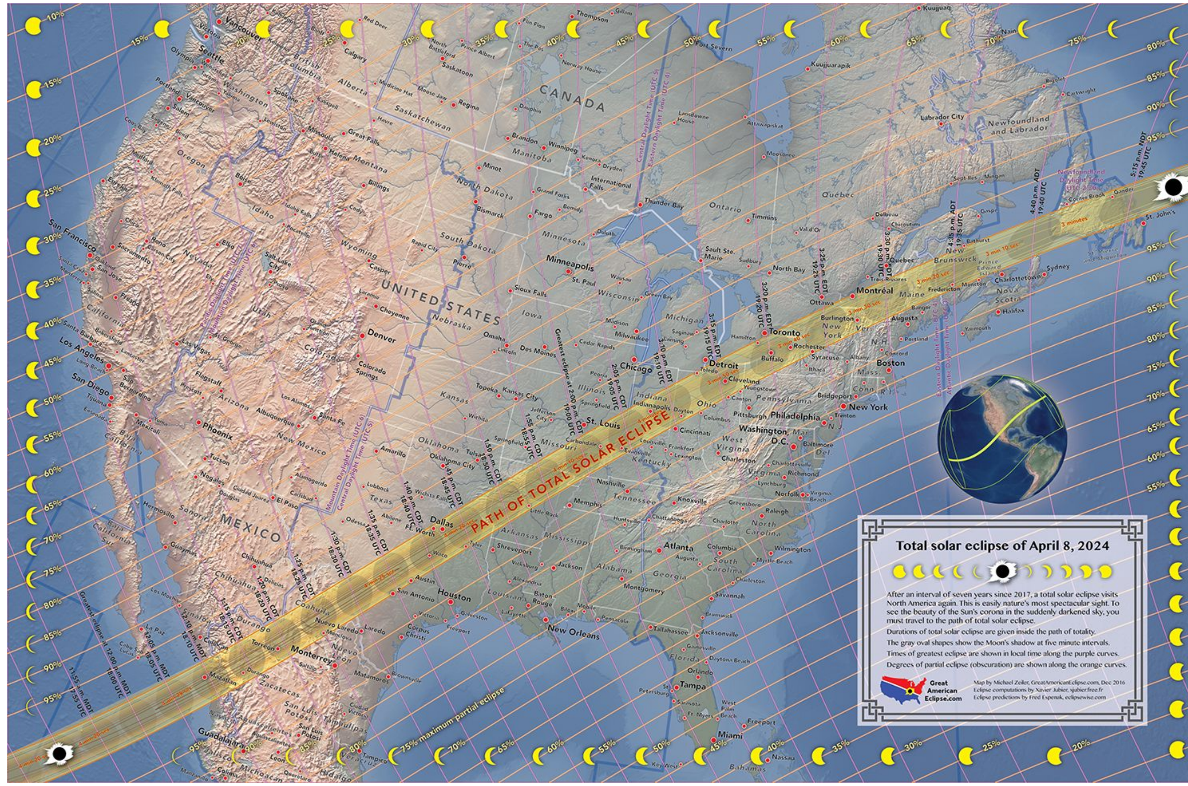
Solar Eclipses: Moon's Shadow



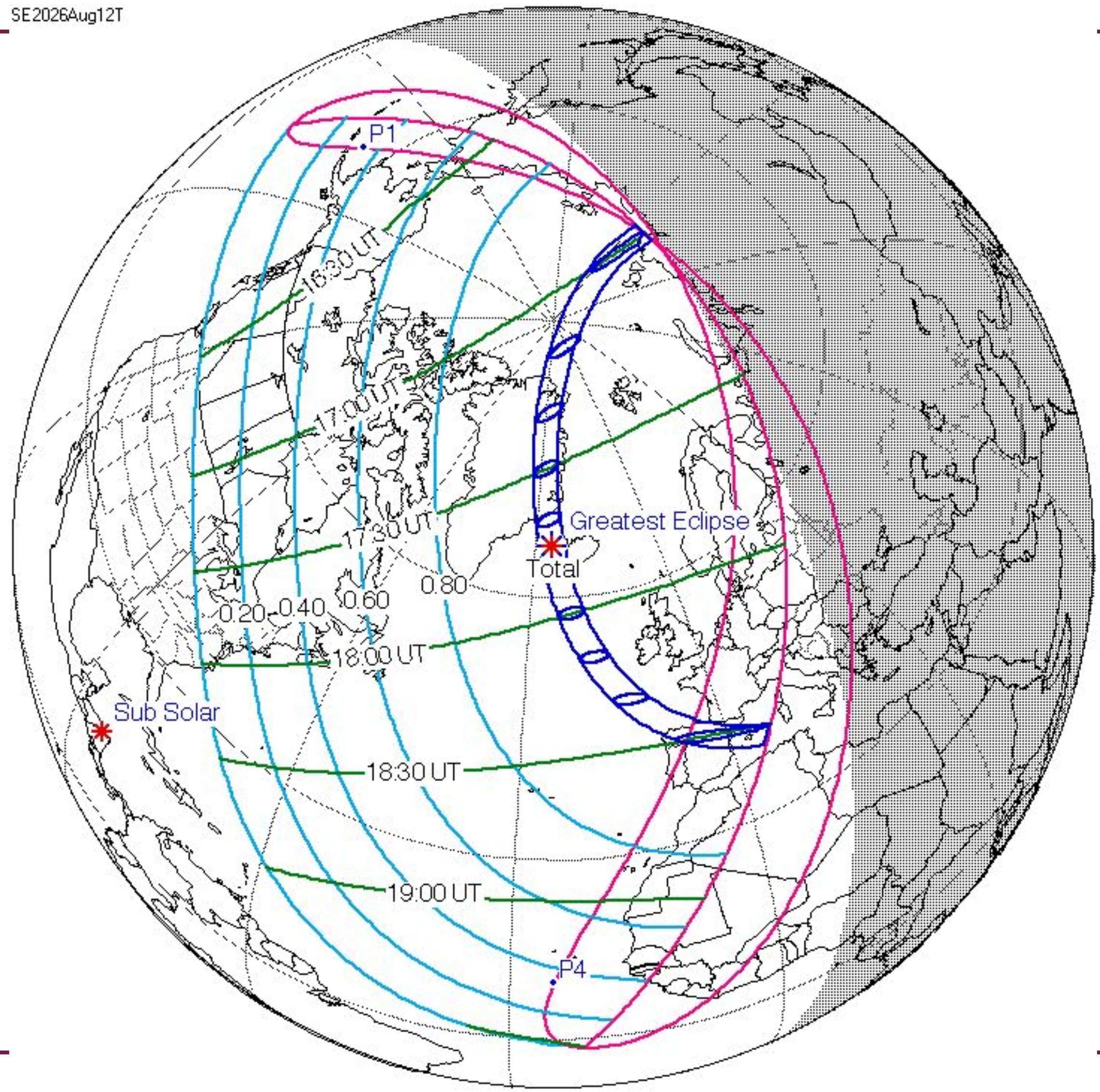
View from Space

Solar Eclipses: Total Eclipse

On April 8th, 2024 there was another "Great American" Total Solar Eclipse that doesn't require a flight around the world to watch!

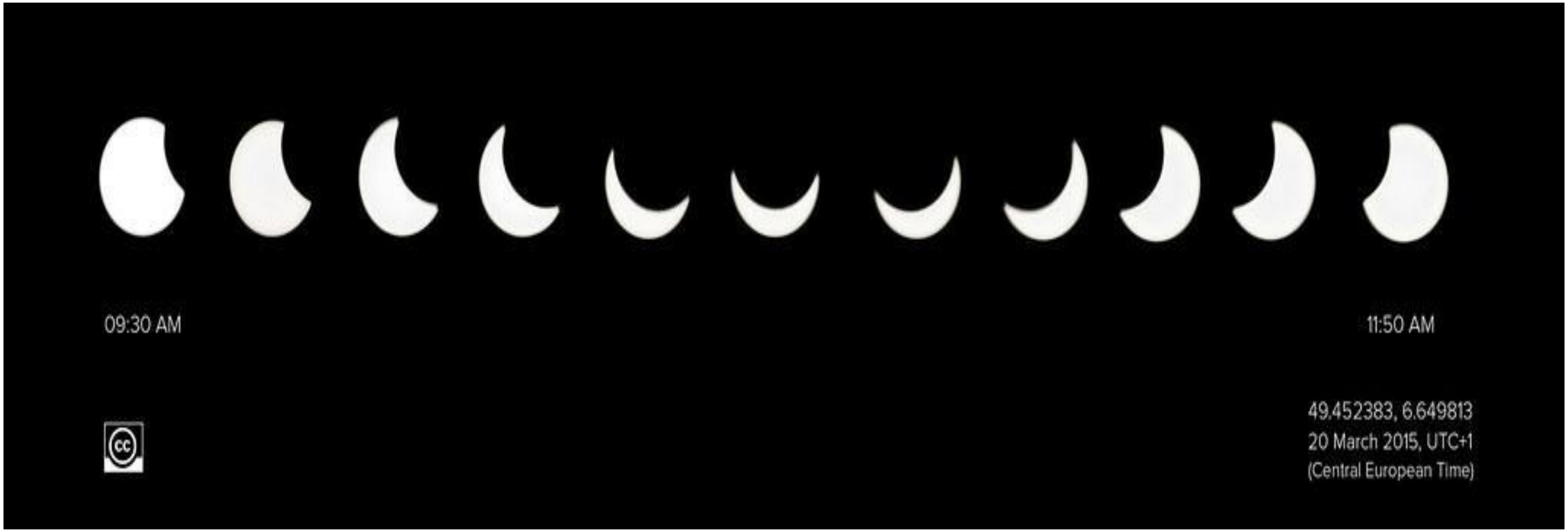


Solar Eclipses: Next Total Eclipse 12 August 26



Solar Eclipses: Partial Eclipse

If you are close to the path of a **total solar eclipse** but not quite lined up, just like Germany was in August 2017, then you might observe a **partial solar eclipse**.



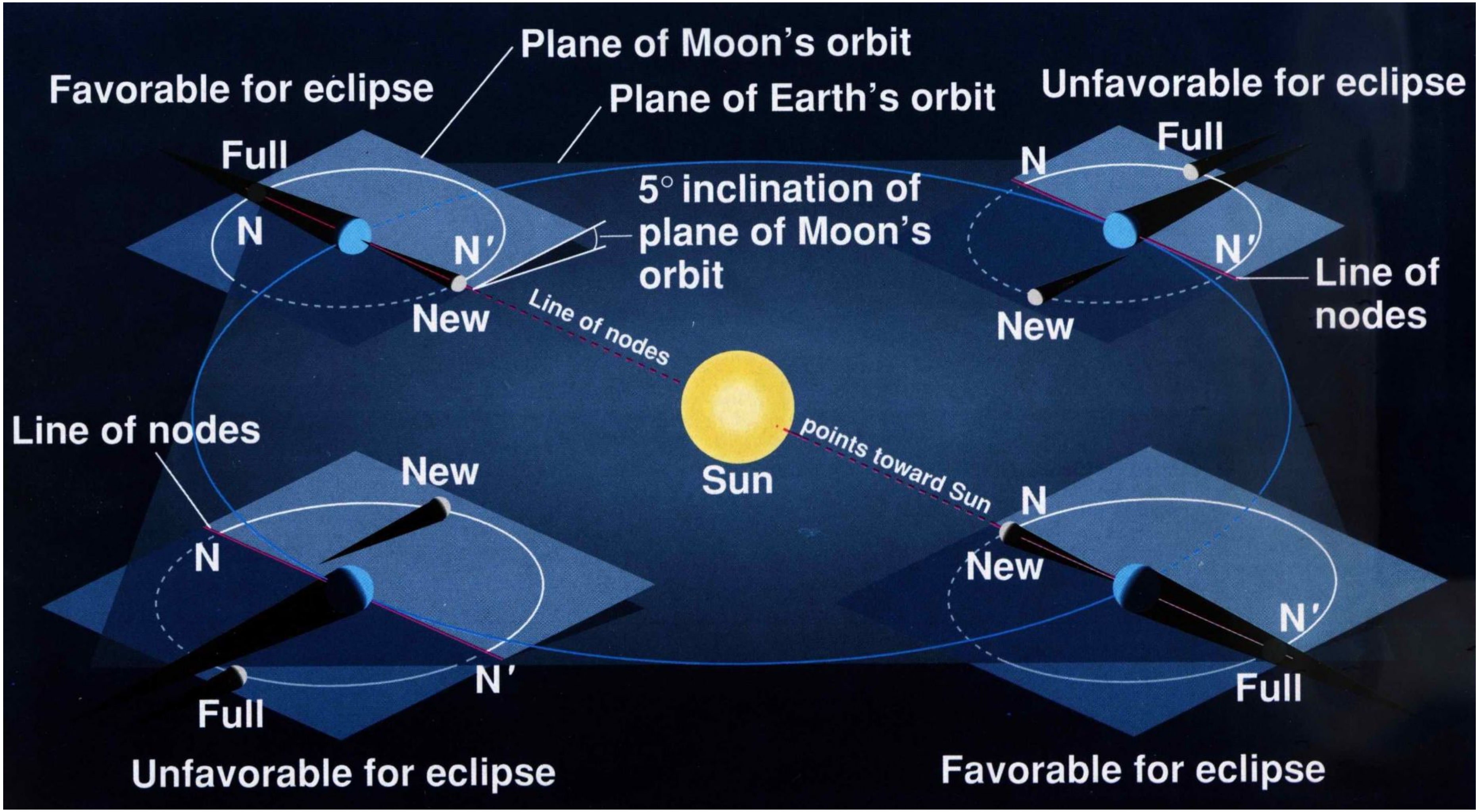
Solar Eclipses: Summary

There are **total, annular, and partial solar eclipses.**

Required Conditions:

- Must be an eclipse season. (*Nodes in right spot*)
- Observer must be in the narrow path of totality (or annularity), or near enough to see a partial eclipse.
- And the moon must be in the **New Moon** phase.

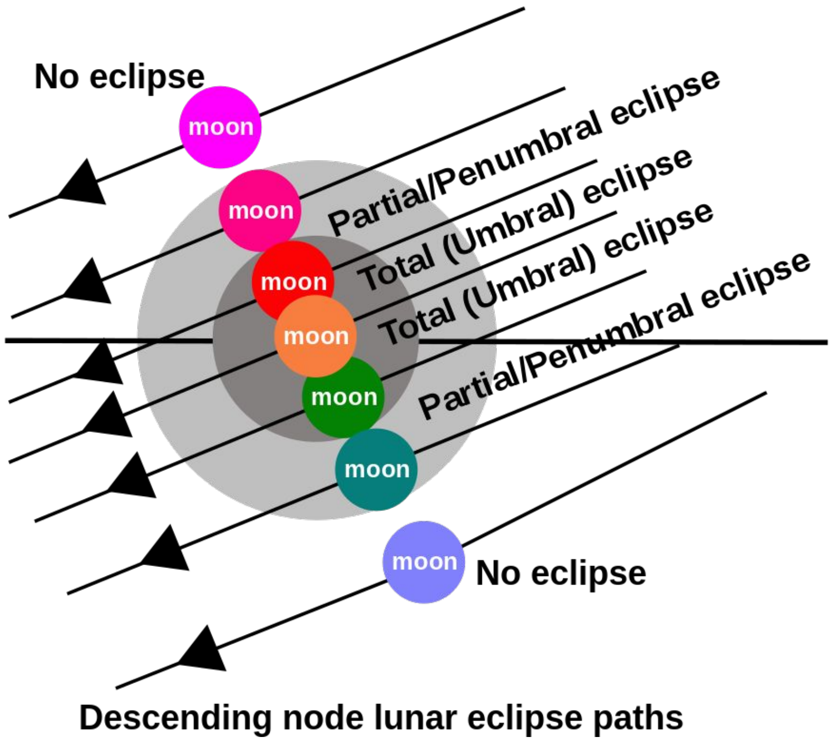
Solar and Lunar Eclipses: Nodes



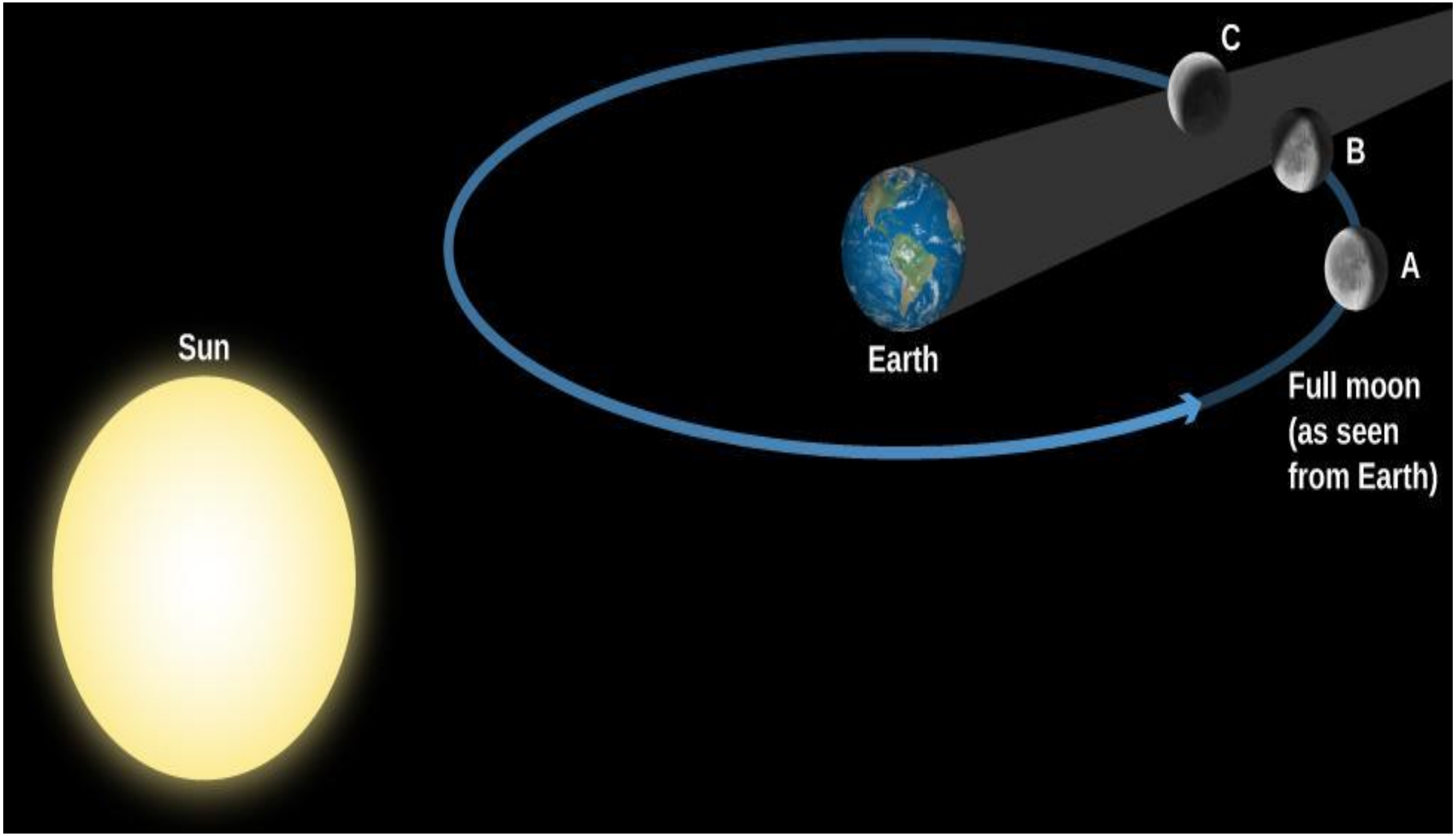
Lunar Eclipses: Earth's Shadow

There are three types of **lunar eclipses**.

1. **Penumbral** eclipses (we'll ignore these, not very exciting to non-astronomers)
2. **Partial** lunar eclipses
3. **Total** lunar eclipses



Lunar Eclipses: Earth's Shadow



Lunar Eclipses: Earth's Shadow

The shape of the Moon during the hours of a Lunar Eclipse **does not match** the phase shapes.

Lunar Eclipses: Summary

Because the Earth’s shadow provides a large target, **total lunar eclipses** are slightly more common than **total solar eclipses**, since there’s no chance the shadow is too small (as it is in annular solar eclipses).

Conditions for a **Lunar Eclipse**:

- Must be an eclipse season. (*Nodes*)
- Observer must be on night/evening side of Earth when the alignment occurs.
- And the moon **must be in the Full Moon phase**.

Eclipses of the Sun and Moon

Short (2-min) video from NASA that discusses eclipses and shows a nice animation of Moon's orbit and the shadows of the Moon and the Earth:

https://www.youtube.com/watch?v=lNi5UFpales

Archaeoastronomy

The founding of civilization may be the direct result of:

- cultivation of food plants
- domestication of animals
- **predicting seasons** by observing cycles of the heavens

First preserved writings are from ancient Egypt (hieroglyphics) and Babylon (cuneiform). First preserved written “paper” documents about ancient astronomy are from ancient Greek philosophy.

Archaeoastronomy

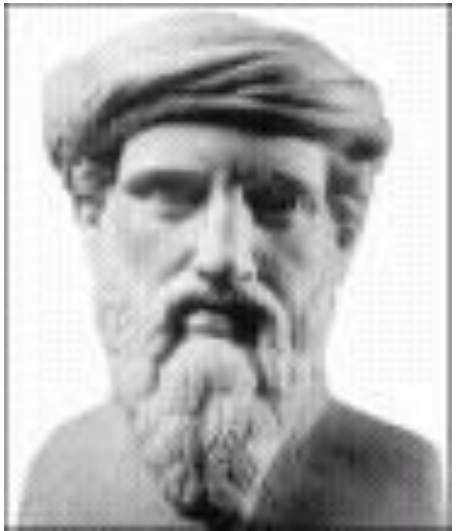
The Egyptians have the oldest recorded constellations. They were created to aid in measuring the passage of time. The appearance of the bright star Sirius in the night skies preceded the flooding of the Nile river. This helped identify the need for “leap years” (Calendar of Sothos, ~1500 BCE).

This was the beginning of **astronomy**, but also of **astrology**. The Babylonians expanded on the Egyptians’ work to create what we now call **astrology**. It was their religion.

Egyptian Astronomy 4236 BC (365 days a year: Dog Star)

Greek Astronomers

- **Pythagoras** (500 BC)
- Greek philosopher
- Believed that circles and spheres were "perfect" heavenly forms: thus the Earth must be a sphere (since the Earth was "obviously" at the center of the Universe).
-



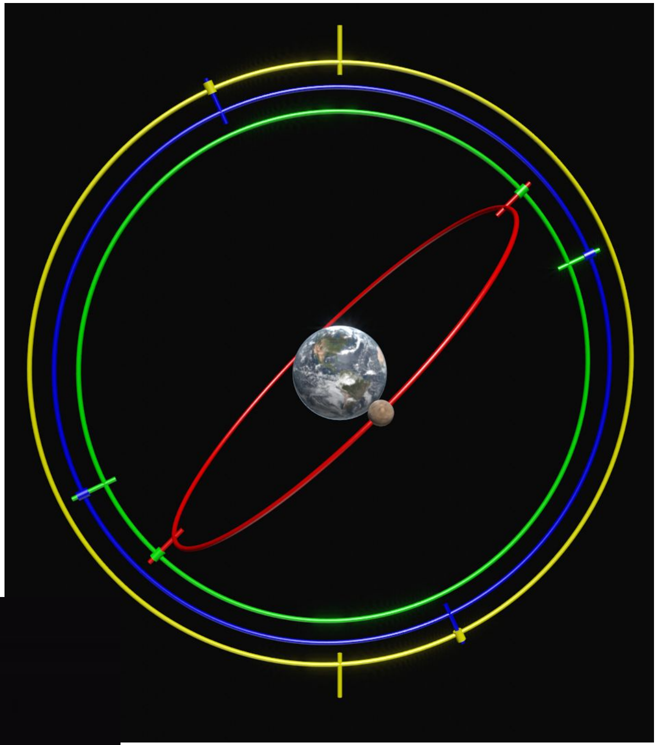
Greek Astronomers

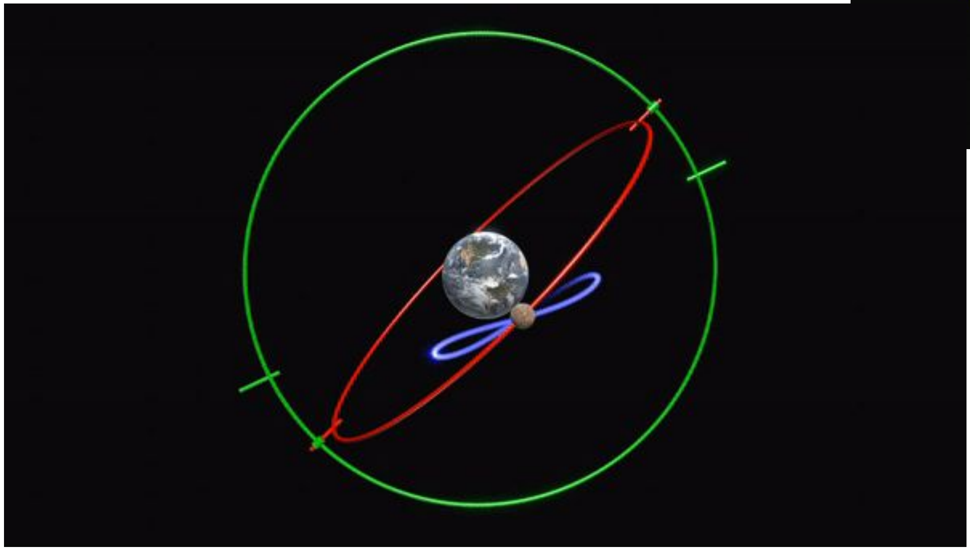
Eudoxus (390-340 BC)

Student of Plato

The Moon and Sun have three spheres

Five planets have four spheres





Early Greek and Roman Cosmology

Things changed with the rudimentary invention of the principles of “science” in Miletus, ~600 BCE. Our modern understanding of science requires having ***testable*** and ***verifiable*** ideas.

The Ancient Greek scholars (400s-100s BCE) knew more than we often give them credit for, and they did test their ideas against observations. Let’s make a list of the things they got right.

Aristotle

- Greek Philosopher (300 BC)
- Described evidence for spherical Earth:
  - Lunar eclipse always showed curved shadow of Earth
  - Altitude of North Star changes as we travel north, suggesting Earth's surface if curved
  - As a ship sails over the horizon, we lose sight of the hull before the sail.

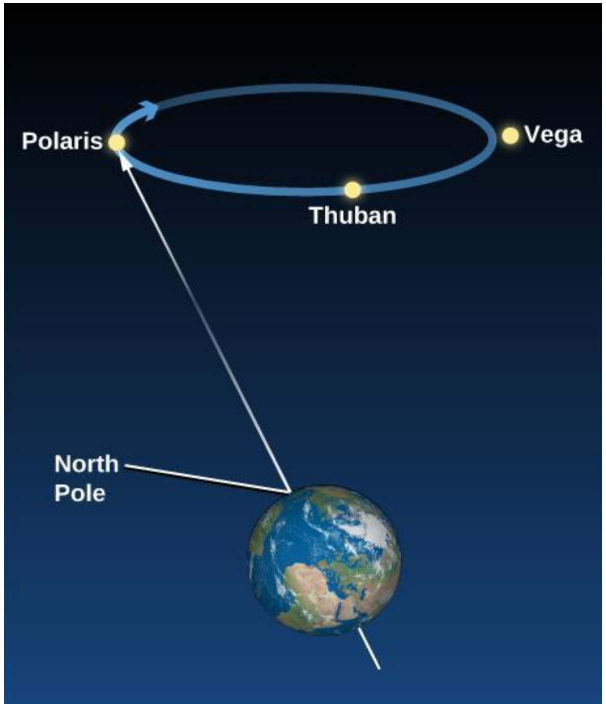
Early Greek and Roman Cosmology

1) Ancient Greek scholars knew the Earth was round.

Aristotle notes two main reasons:

The **circular** shadow of the Earth during a lunar eclipse.

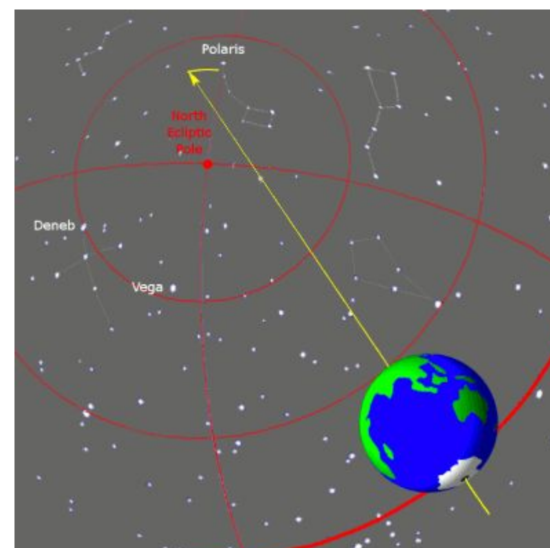
Early Greek and Roman Cosmology



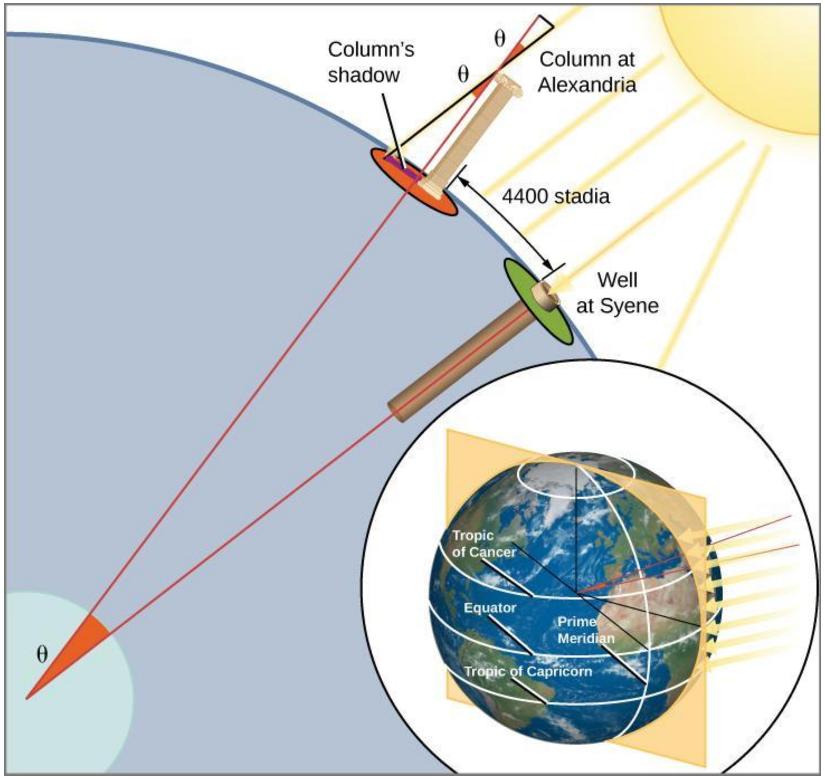
Ancient Greek astronomers knew that the Earth’s tilt “wobbled.”

Hipparchus (190-120 BC) cataloged stars and their brightnesses, and when he compared to earlier data he realized that Polaris has not always been the “North Star.”

The change was due to a 26,000 year cyclical motion called **precession**.



Early Greek and Roman Cosmology



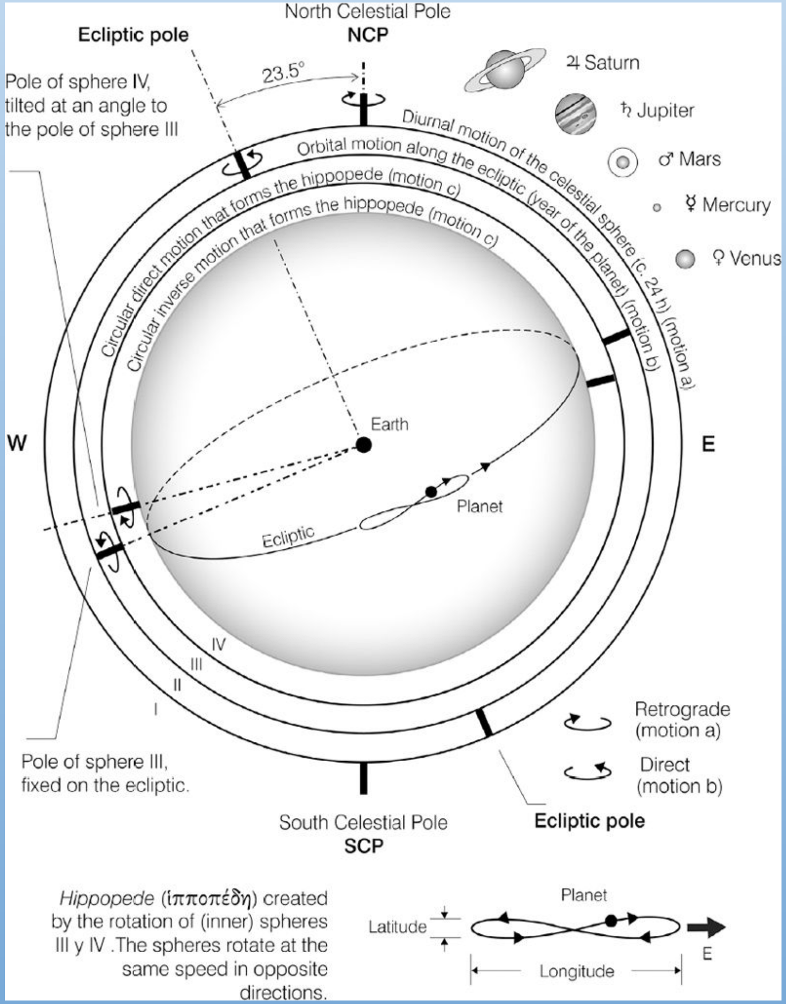
2) Ancient Greeks knew the approximate size of Earth.

Eratosthenes used geometry and trigonometry to determine the radius of the Earth.

The experiment required being close enough to the equator.

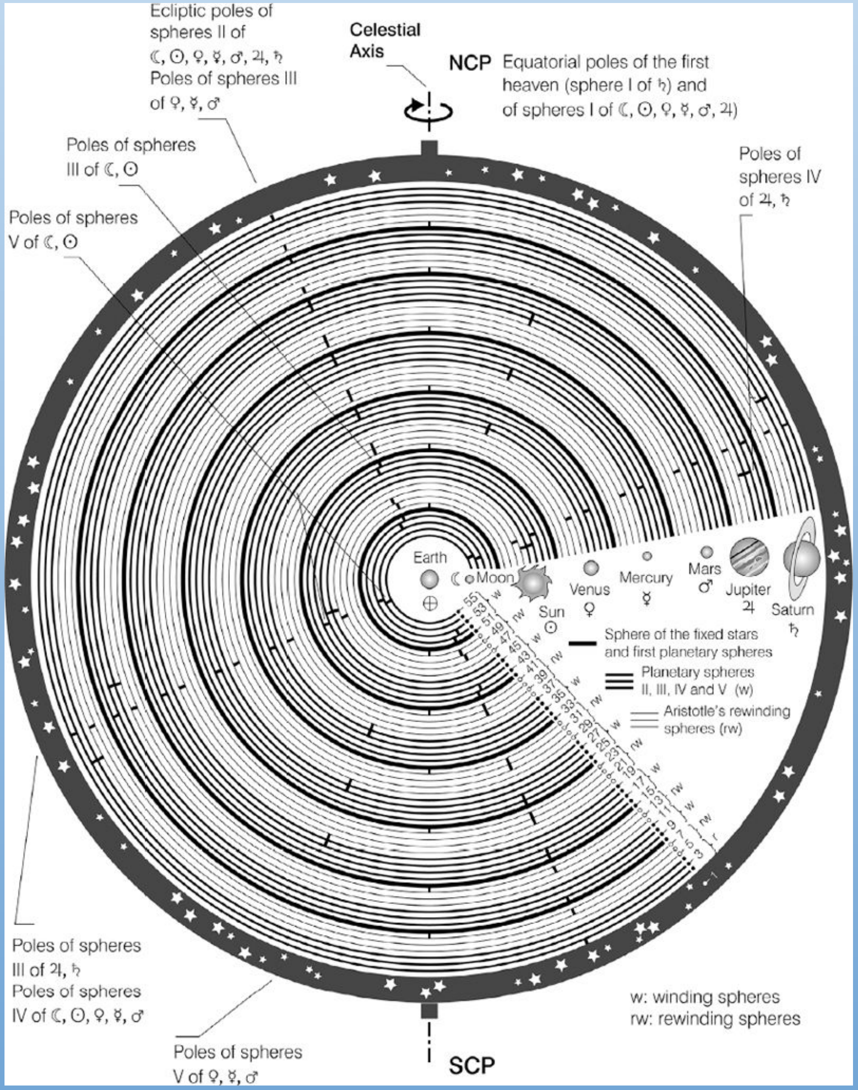
The Eudoxus-Aristotle system for the Planets

- In the system of Eudoxus, extended by Aristotle, the planets were the visible dots embedded on nested rotating spherical shells, centered on the Earth.



The Eudoxus-Aristotle system for the Planets

- The motions of the visible planet were the result of combinations of circular motions of the spherical shells.
  - For Eudoxus, these may have just been geometric, i.e. abstract, paths.
  - For Aristotle the spherical shells were real physical objects, made of the fifth element.



celum emireum habitaculum dei et omnium electrorum

The Empyrean (place of the highest heaven, filled with fire or ether) of God and the Elect (Christian Synthesis)

Aristotelian Cosmos

Ptolemy's Geography

- Like Eratosthenes, Ptolemy studied the Earth as well as the heavens.
- One of his major works was his *Geography,* one of the first realistic atlases of the known world.

The Almagest

- Ptolemy's major work was his *Mathematical Composition*.
- In later years it was referred as *The Greatest* (*Composition*), in Greek, *Megiste.*
- When translated into Arabic it was called *al Megiste.*
- When the work was translated into Latin and later English, it was called *The Almagest.*

The Almagest (cont.)

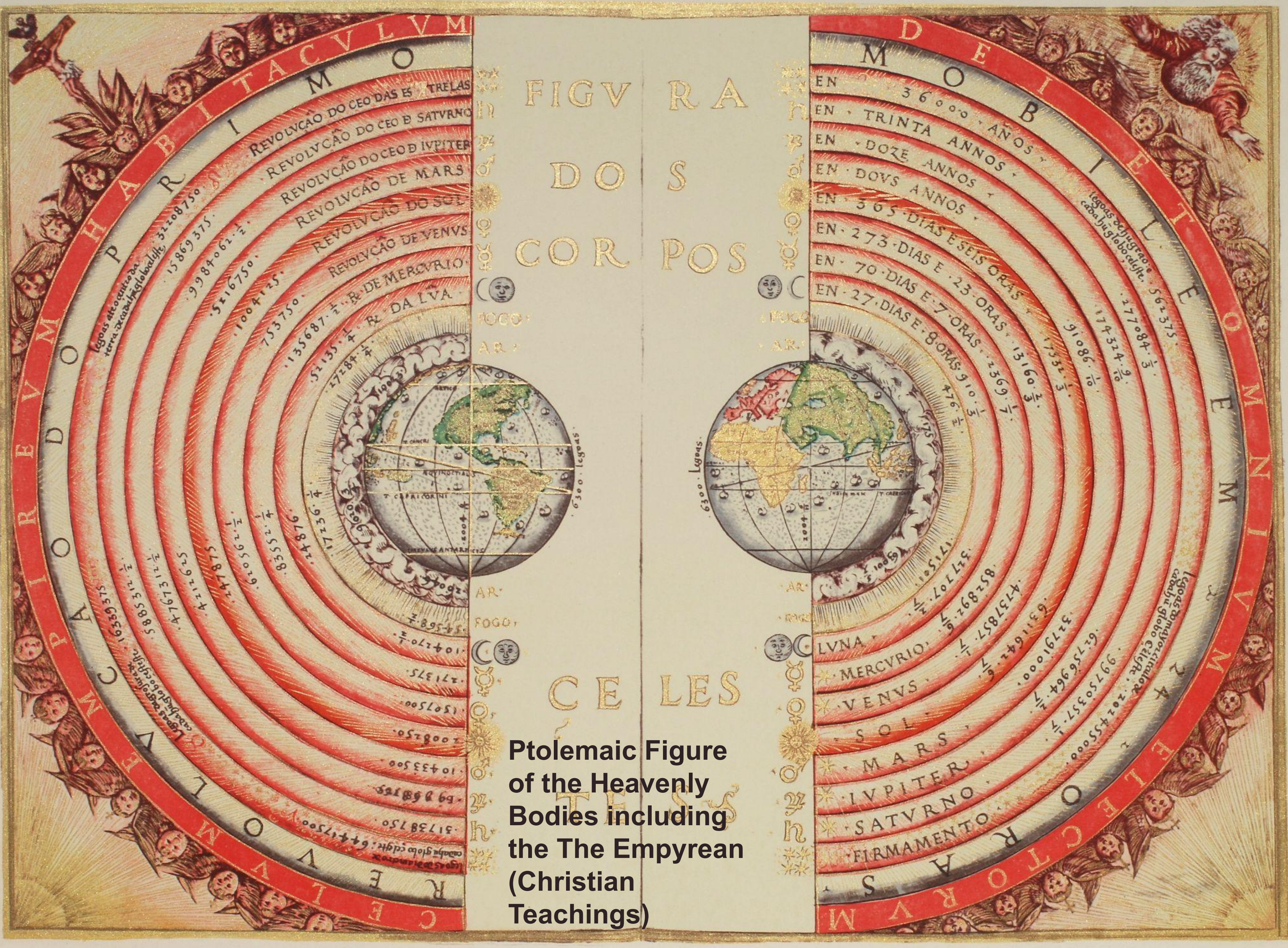
- *The Almagest* attempts to do for astronomy what Euclid did for mathematics:
  - Start with stated assumptions.
  - Use logic and established mathematical theorems to demonstrate further results.
  - Make one coherent system
- It even had 13 books, like Euclid.

Euclid-like assumptions

1. The heavens move spherically.
2. The Earth is spherical.
3. Earth is in the middle of the heavens.
4. The Earth has the ratio of a point to the heavens.
5. The Earth is immobile.

Ptolemy's Universe

- The basic framework of Ptolemy's view of the cosmos is the Empedocles' two-sphere model:
  - Earth in the center, with the four elements.
  - The celestial sphere at the outside, holding the fixed stars and making a complete revolution once a day.
- The seven wandering stars—planets—were deemed to be somewhere between the Earth and the celestial sphere.



Ptolemaic Figure of the Heavenly Bodies including the The Empyrean (Christian Teachings)

The Ptolemaic system

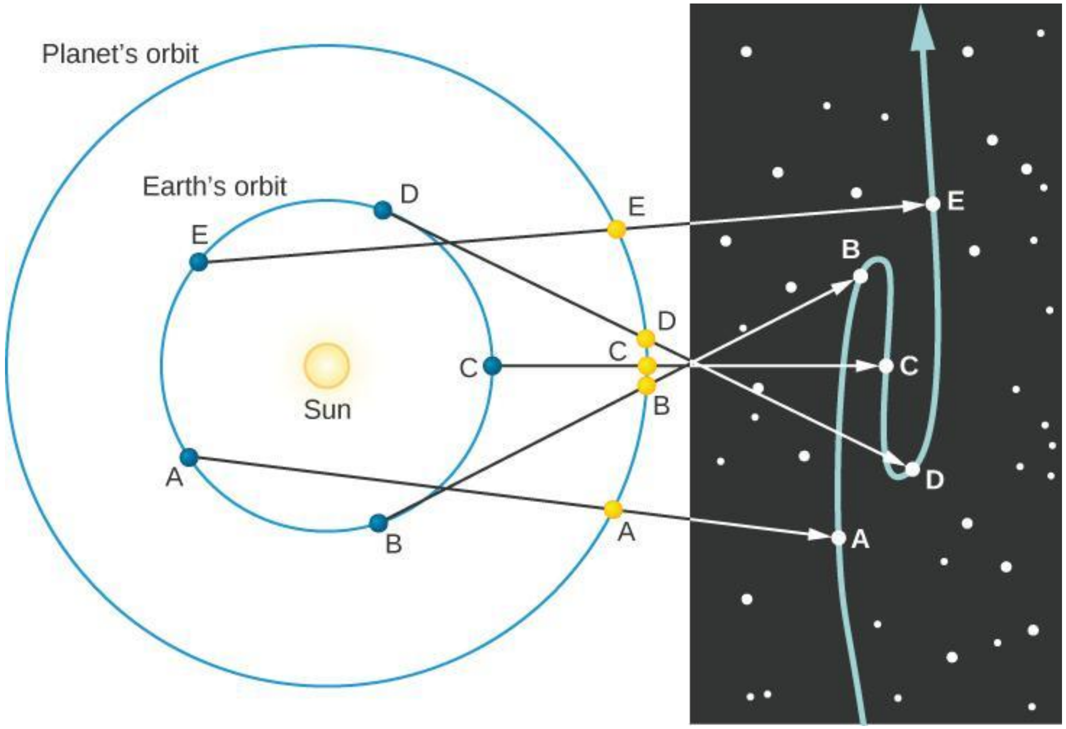
- Ptolemy's system was purely **geometric** with **combinations of circular motions**.
  - Modified Aristotle's spheres centered on the Earth.
  - Instead they used a device that had been invented by Hipparchus 300 years before: Epicycles and Deferents.

Ptolemy's Model

However, they didn't have everything figured out thousands of years ago. Early cosmology models, most famously that of Claudius **Ptolemy,** were based on ideas that were held to be obviously true (spoiler: they aren't true):

> "The Earth is most important, and is therefore at the center of everything", called a **geocentric** model
> "The **circle** is a perfect shape, and so everything moves in perfect **circles.**"

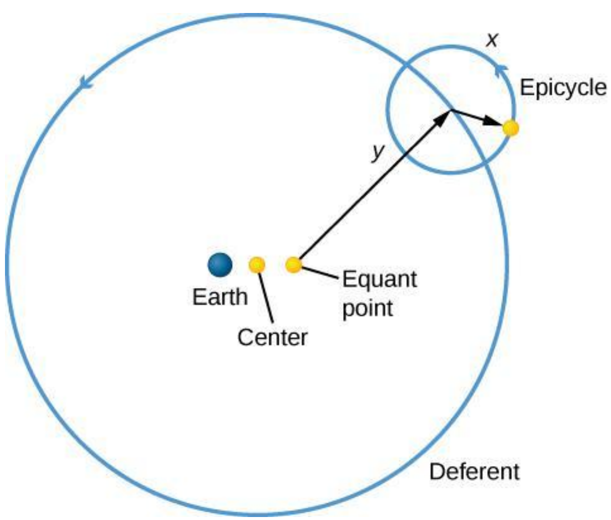
Ptolemy's Model



Some of the known planets seem to move **backwards** through the sky. This is called **<u>retrograde motion</u>**, and it occurs when we "catch up and pass" a slower planet.

Ptolemy's Model

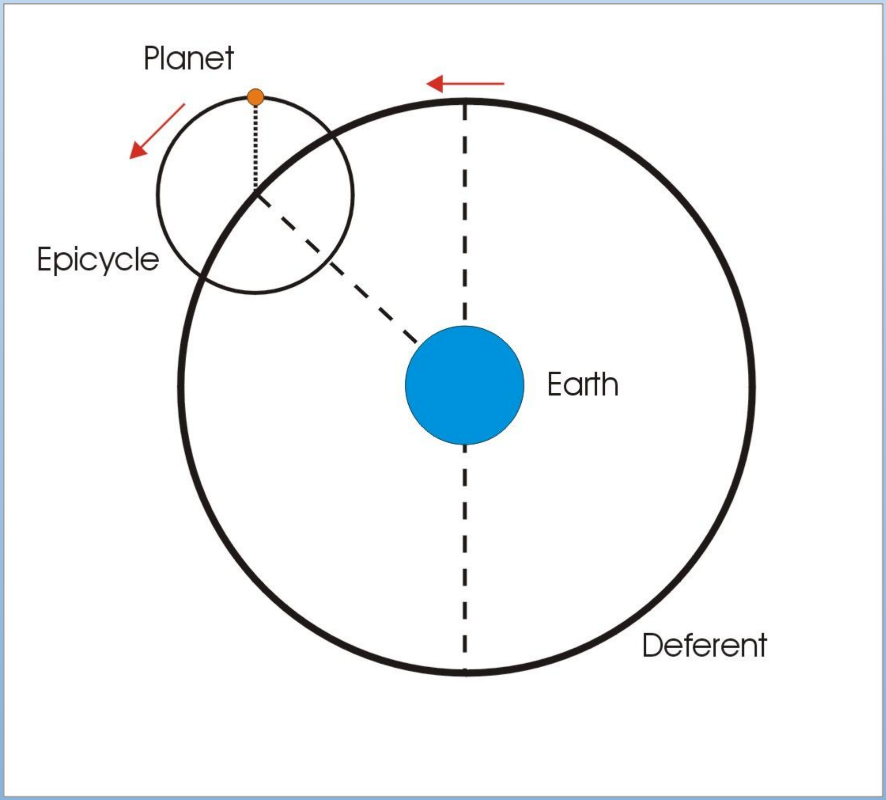
The way to deal with this motion in a geocentric idea was to create additional circles. **Ptolemy** added these circles, called **epicycles**.

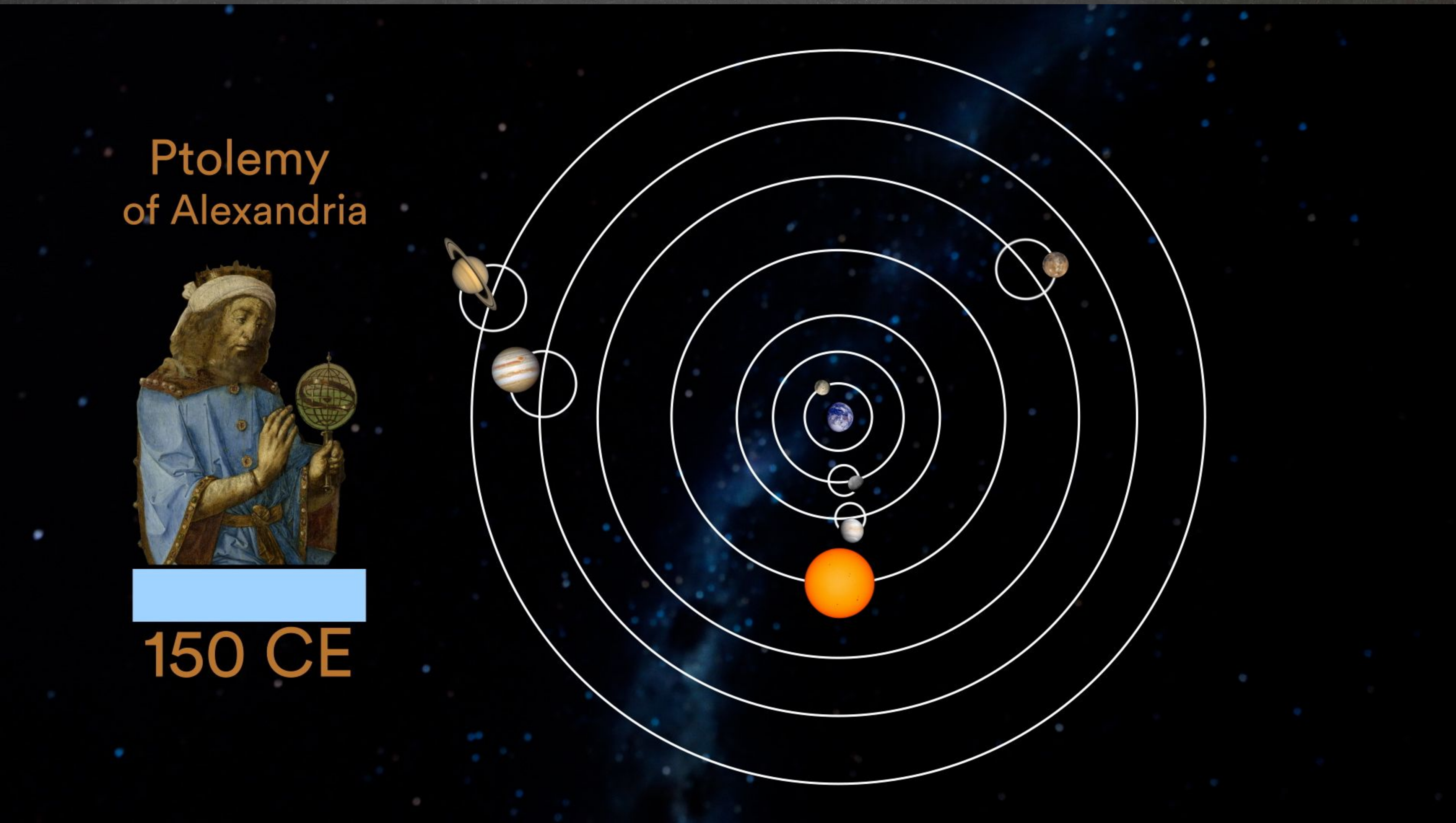


Ptolemy's epicycles were "circles on circles." This model lasted for 1000 years and was eventually accepted as authoritative (unquestionable truth) in Christian Europe.

Epicycles and Deferents

- Ptolemy's system for each planet involves a large (imaginary) circle around the Earth, called the ***deferent***, on which revolves a smaller circle, the ***epicycle****.*
- The visible planet sits on the edge of the epicycle.
- Both deferent and epicycle revolve in the same direction.





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