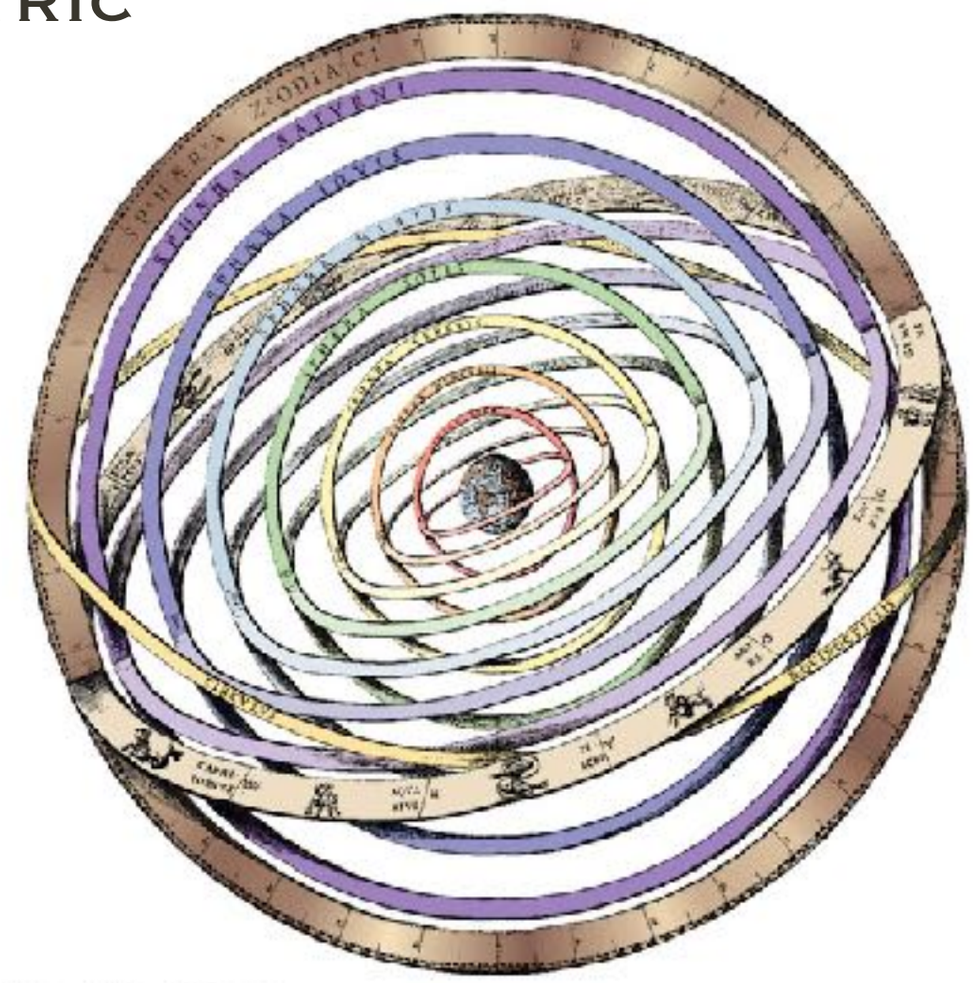
Today

first homework due

- Competing Cosmologies
  - Geocentric vs. Heliocentric
  - Ptolemy vs. copernicus
    - Retrograde Motion
    - Phases of Venus
  - Galileo



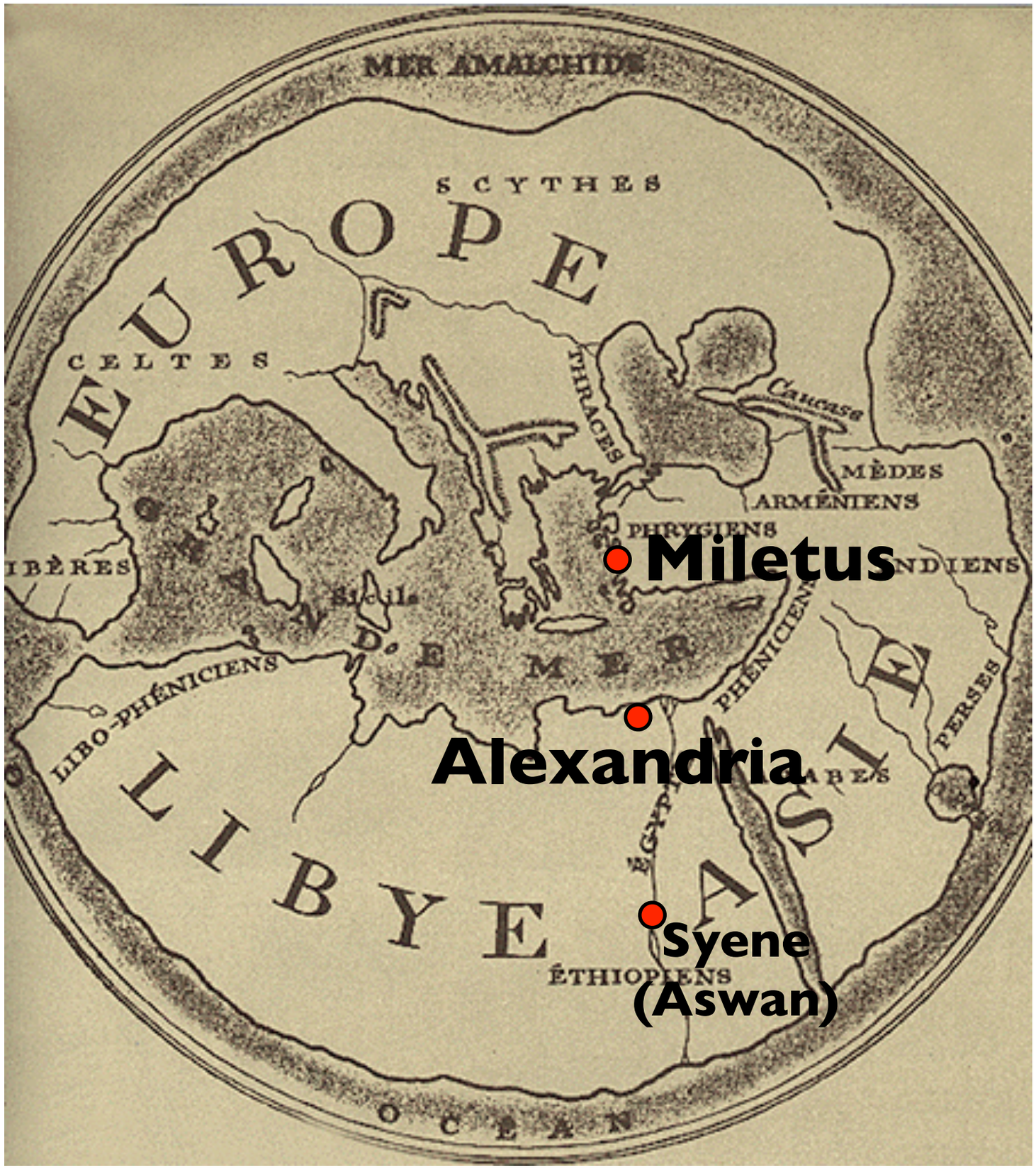
Ancient Cosmology: A Flat Earth

Here there be dragons!

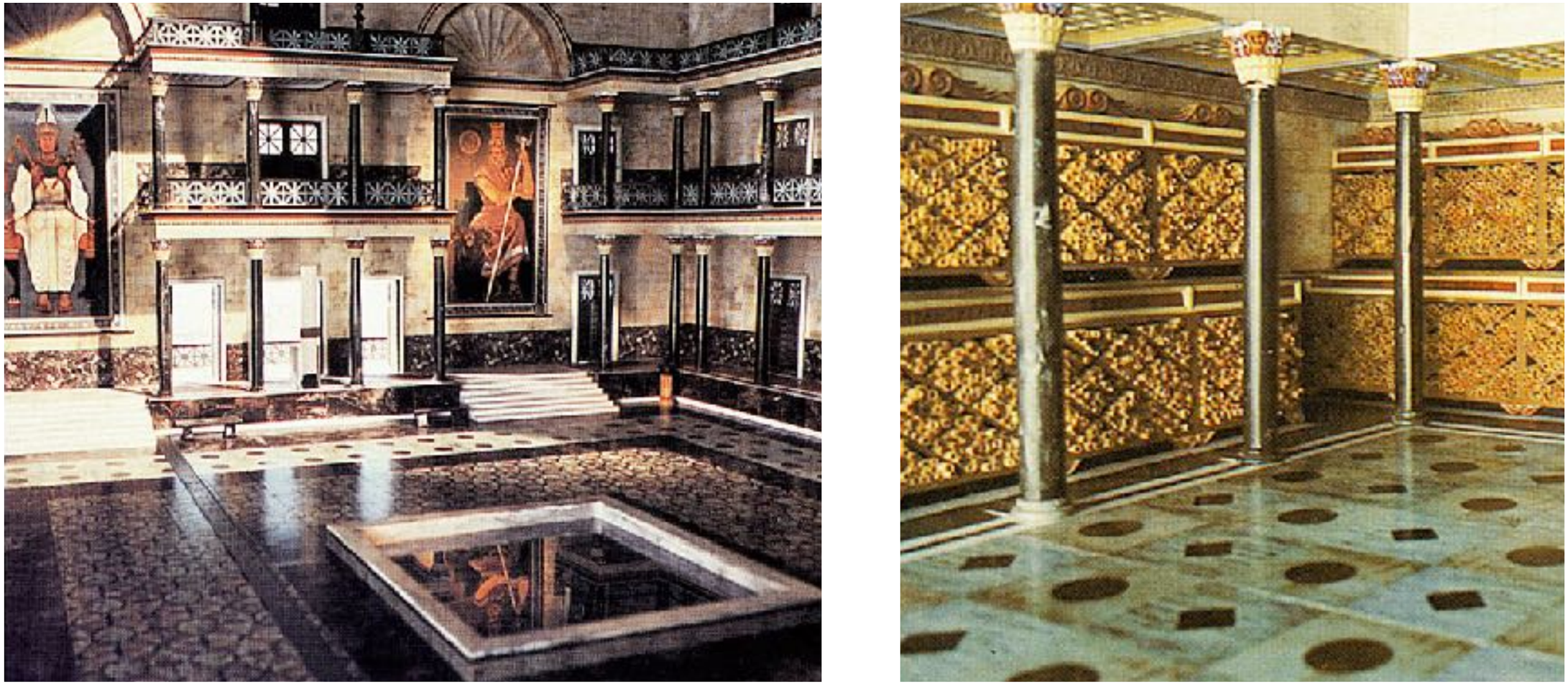
d Map of Hecataeus of Miletus (c. 500 BC)

Modern Map of the Mediterranean

Ancient Cosmology: A Flat Earth



World Map of Hecataeus of Miletus (c. 500 BC)



Artist's reconstruction of the Library of Alexandria

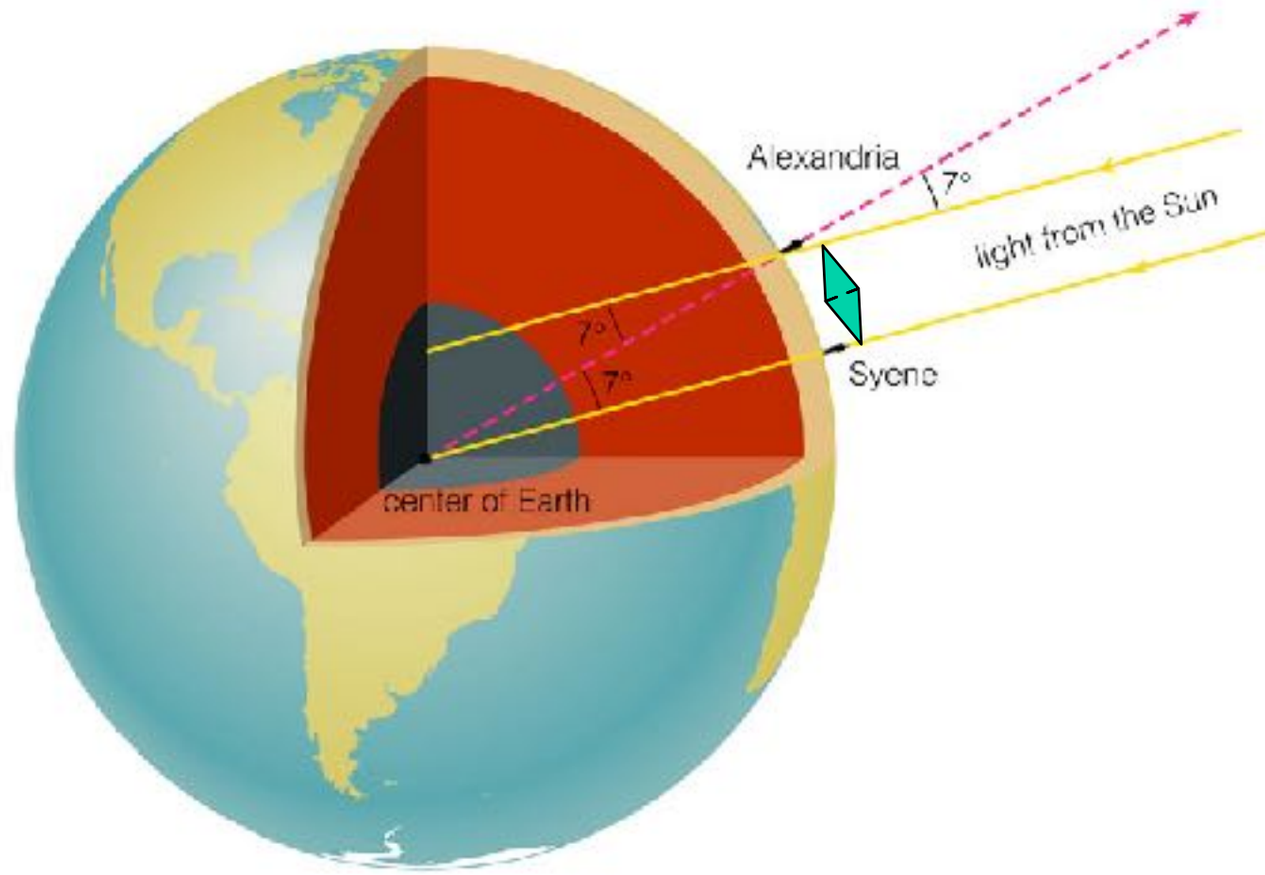
Eratosthenes became the third librarian at Alexandria under Ptolemy III in the Hellenistic period following the conquests of Alexander the Great. Ptolemy I had been one of Alexander's generals, and had taken Egypt as his own after Alexander's untimely death.

Eratosthenes measures the Earth (c. 240 B.C.)

<u>Measurements:</u>

Syene to Alexandria

- distance ≈ 5,000 stadia
- angle = 7°
- i.e, 7/360 of the circumference



<u>Calculate circumference of Earth:</u>

(7/360) × (circum. Earth) = 5,000 stadia

⇒ circum. Earth = 5,000 × 360/7 stadia ≈ 250,000 stadia

<u>Compare to modern value (≈ 40,100 km):</u>

Greek stadium ≈ 1/6 km ⇒ 250,000 stadia ≈ 42,000 km

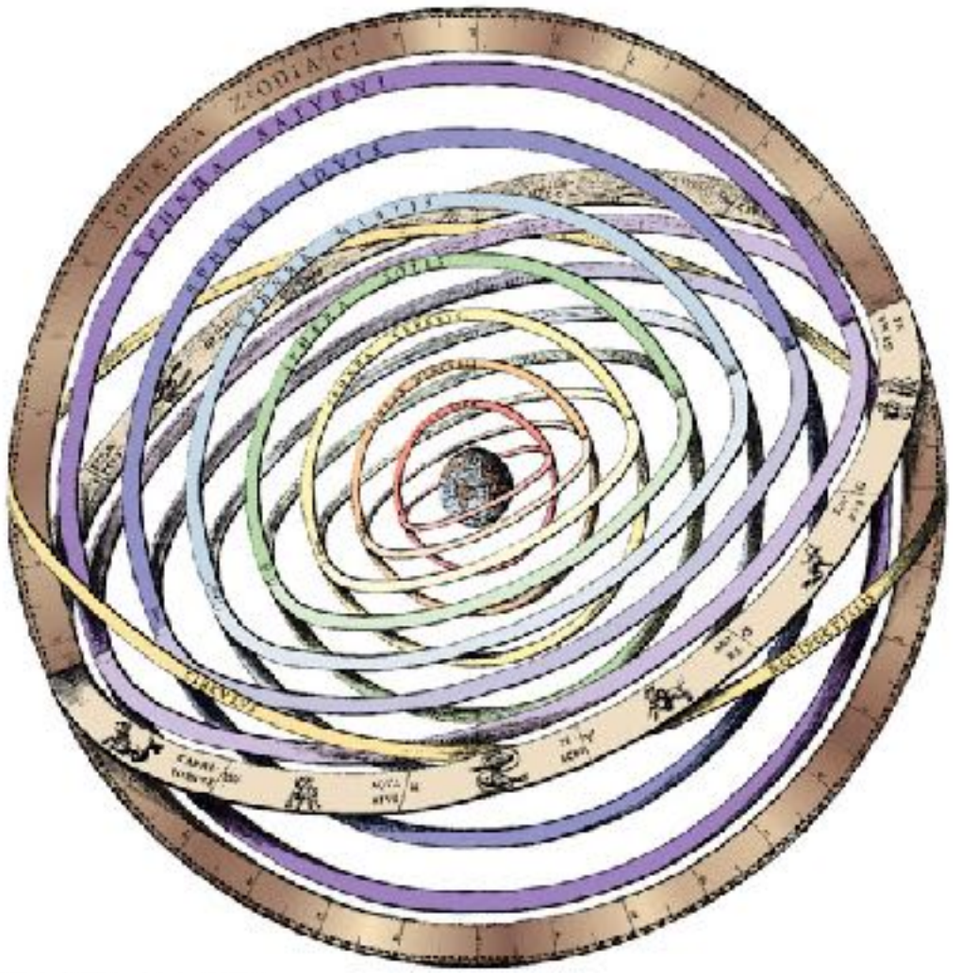
It was known long before Columbus that the Earth is not flat!

Competing Cosmologies

Geocentric

Ptolemaic

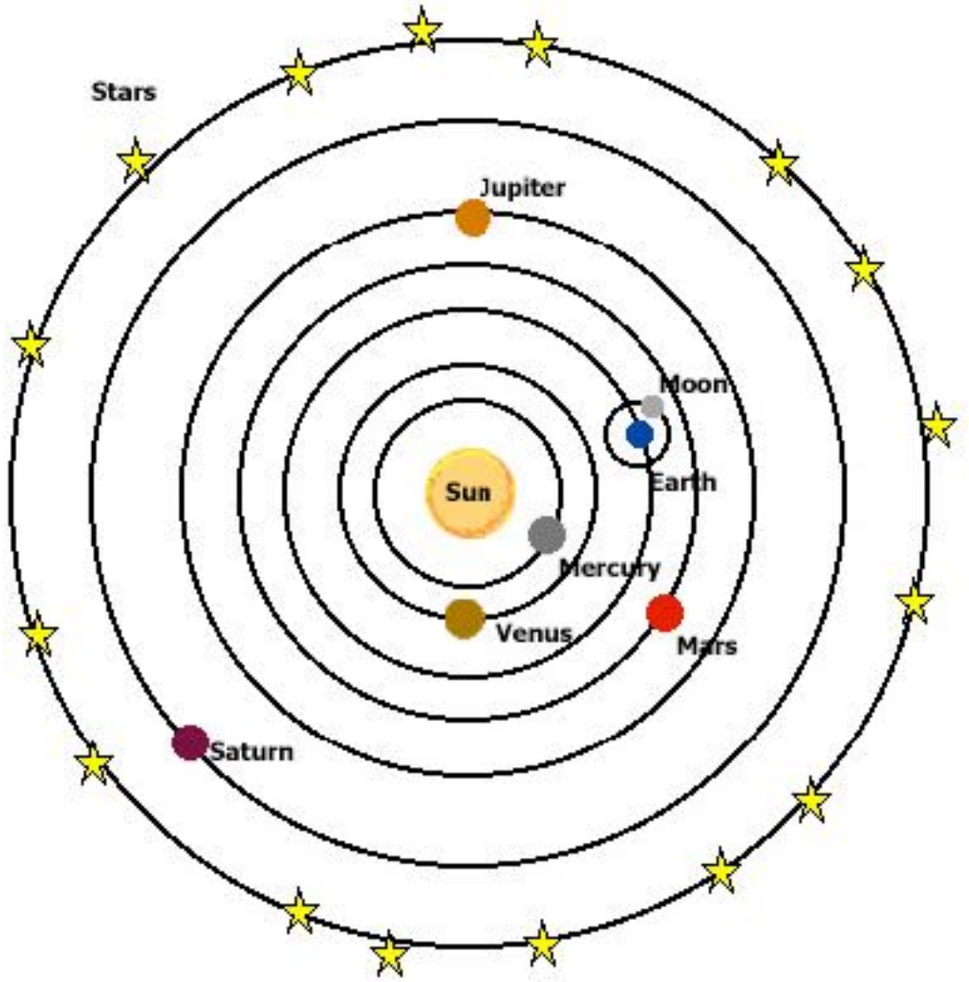
Earth at center



Heliocentric

Copernican

Sun at center



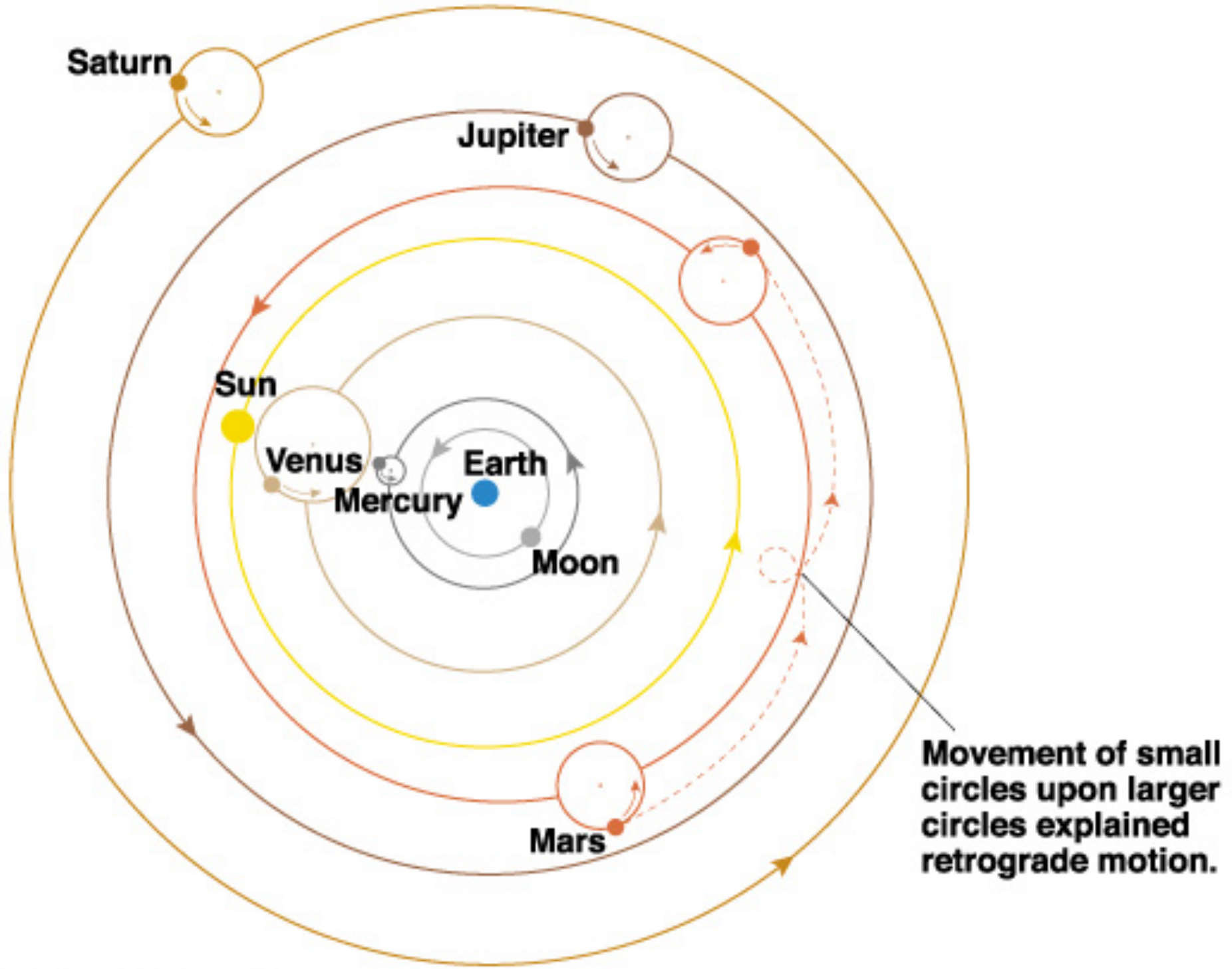
Geocentric

Ptolemy

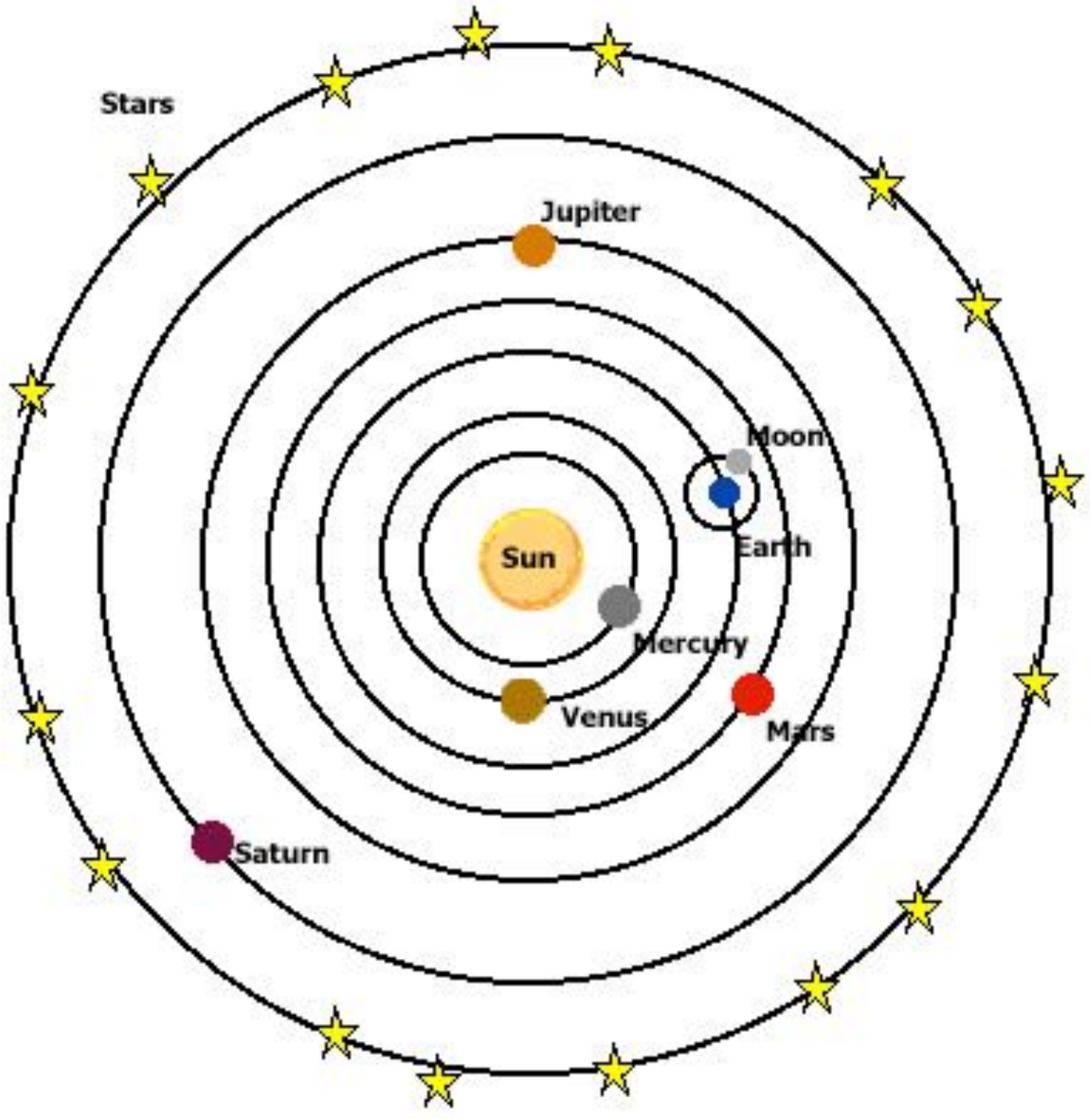
The most sophisticated geocentric model was that of Ptolemy (A.D. 100–170) — the **Ptolemaic model:**

- Sufficiently accurate to remain in use for 1,500 years
  - i.e., predicted correct positions of planets for many centuries
- Arabic translation of Ptolemy's work named *Almagest* ("the greatest compilation")

Geocentric Cosmology



Heliocentric Cosmology



Heliocentric

Copernicus (1473–1543):

- He proposed the Sun-centered model (published posthumously 1543).
- He used the model to determine the layout of the solar system (planetary distances in AU).

But . . .

- The model was no more accurate than Ptolemaic model in predicting planetary positions, because it still used perfect circles.

Heliocentric model first proposed by Aristarchus of Samos c. 280 BC. None of the original work of Aristarchus survives; it is only known through the many criticisms made of it by others.

Competing Cosmologies

Geocentric	**Heliocentric**
Ptolemaic	Copernican
Earth at center	Sun at center

The sun is the source of light in both models

Explains

- **Motion of Sun**
- **Motion of Moon**
- **Solar and Lunar Eclipses**
- **Phases of Moon**

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Hard to tell the difference!

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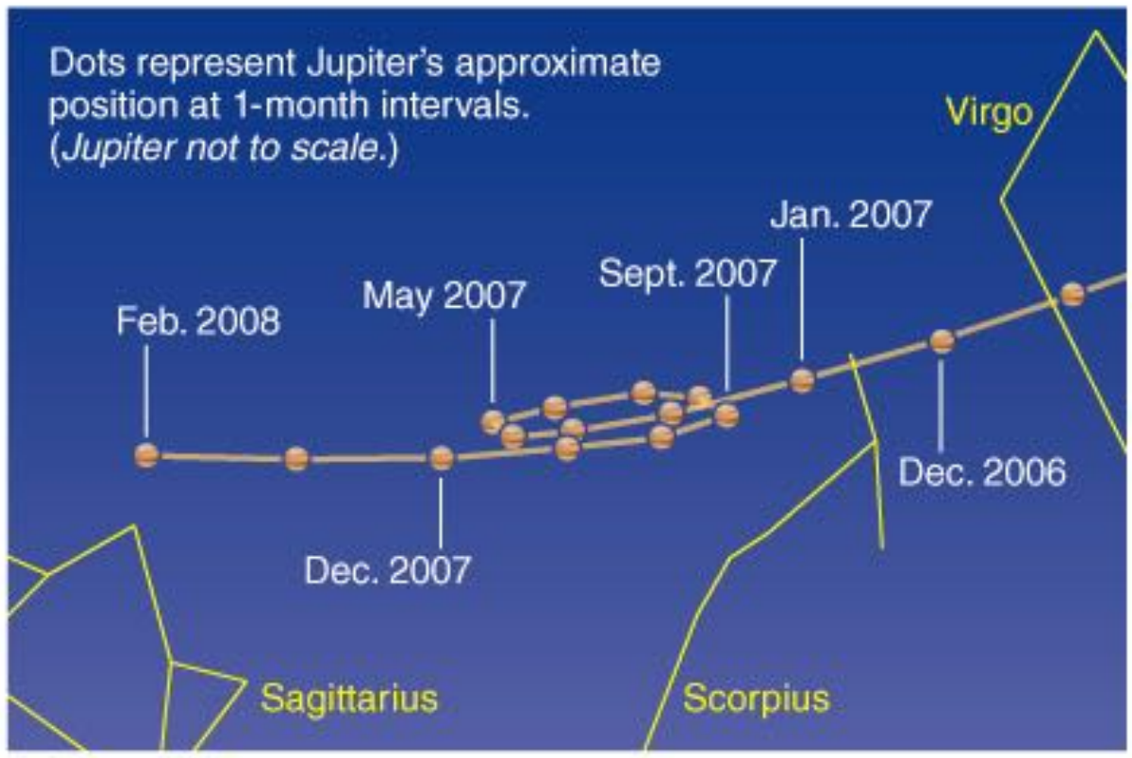
Retrograde Motion

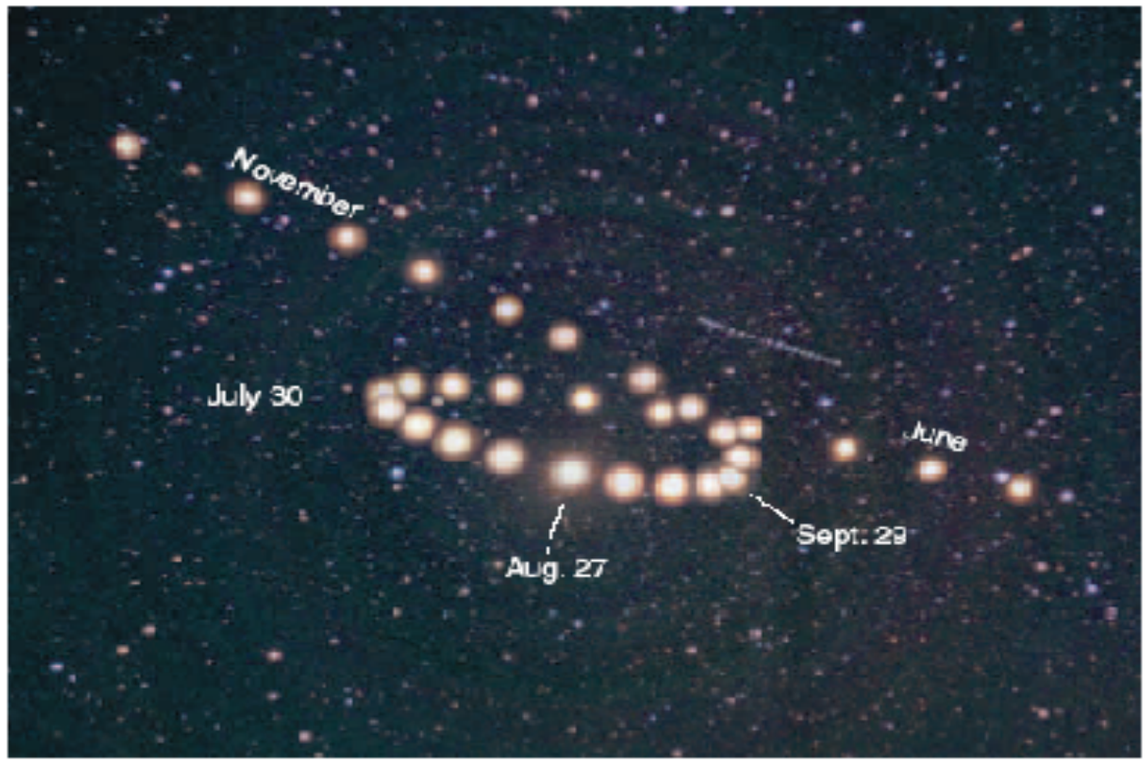
Needs epicycles

Consequence of Lapping

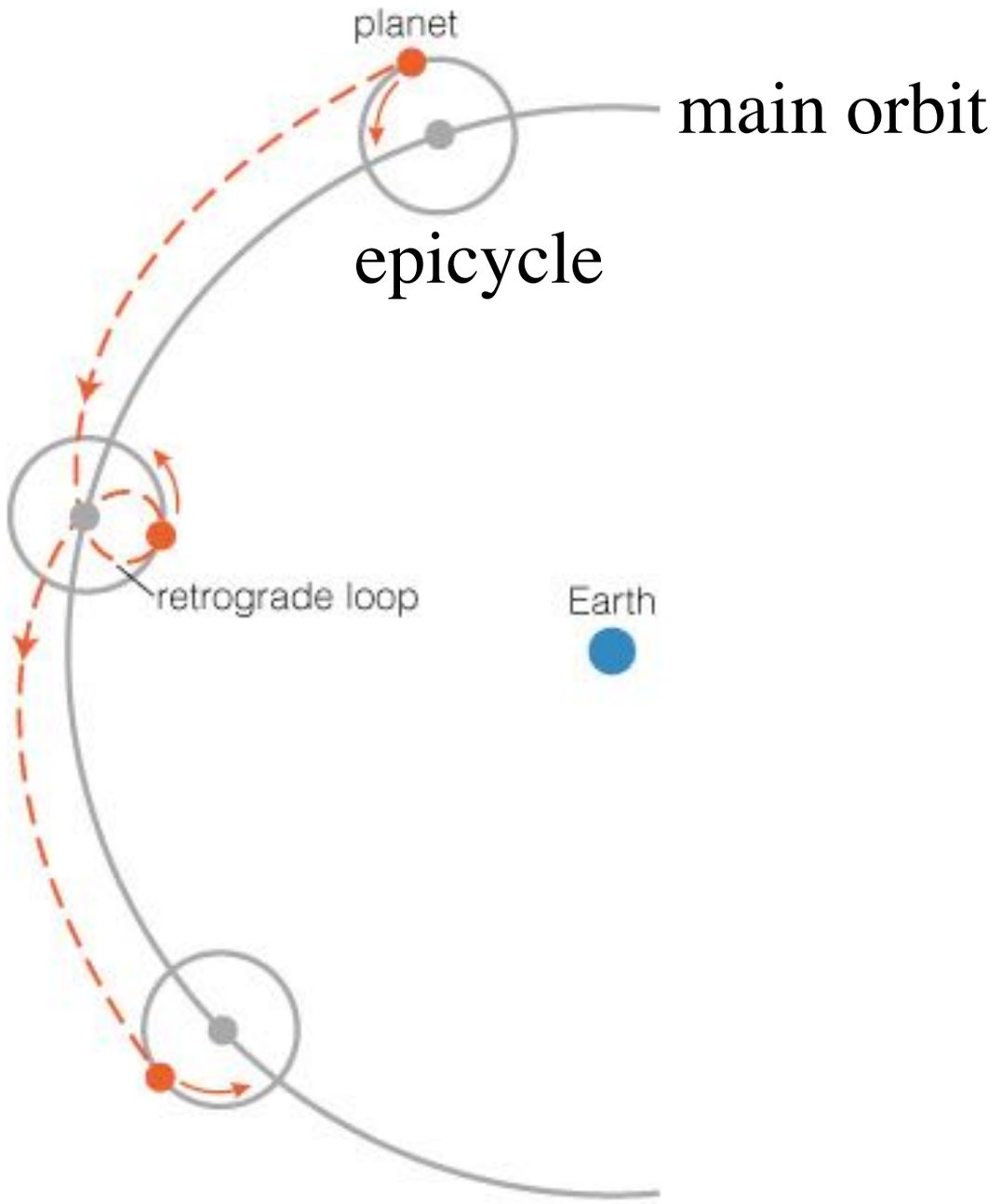
Retrograde motion

- 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.**

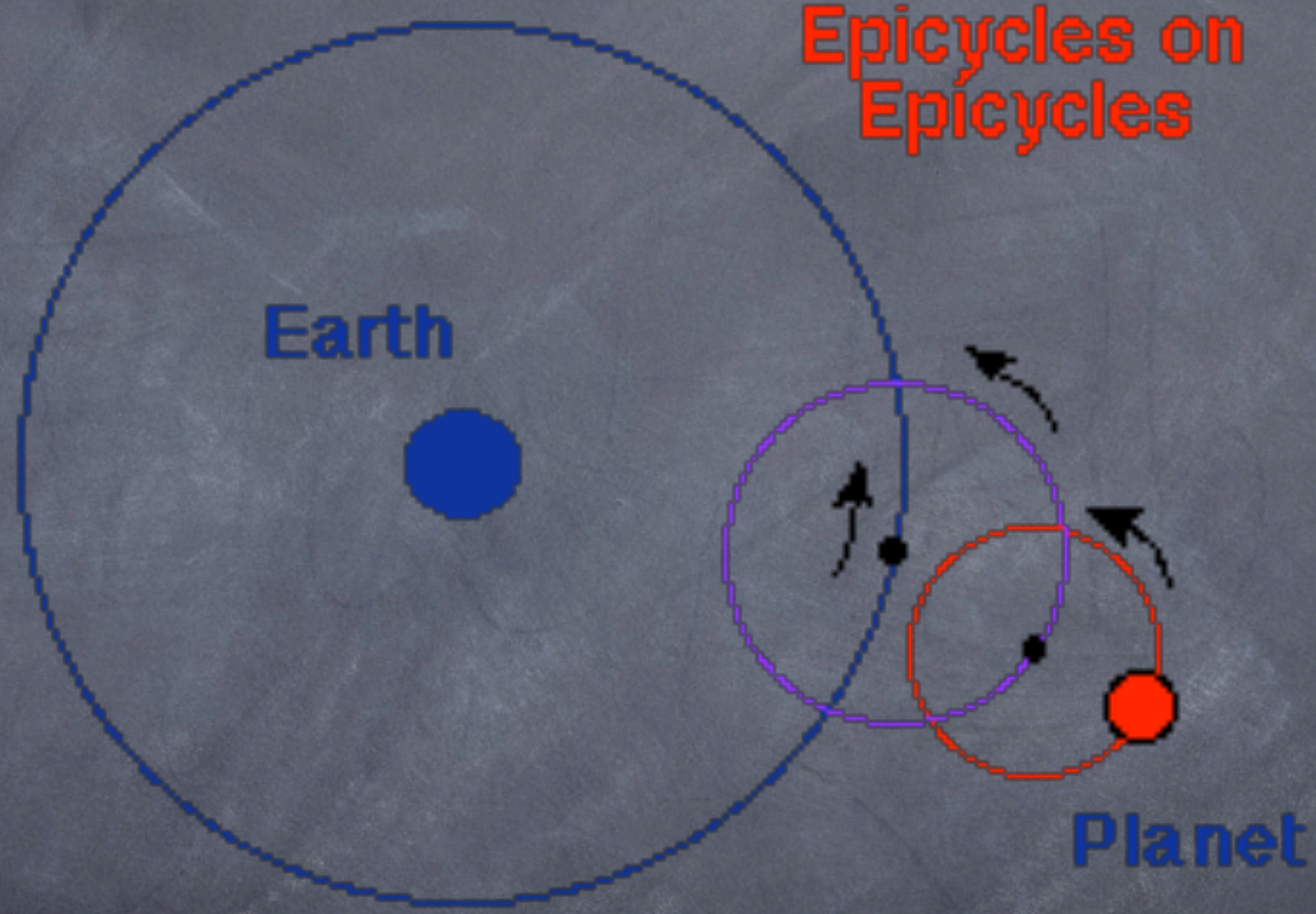




In the **Ptolemaic** model, planets *really do* go backwards.



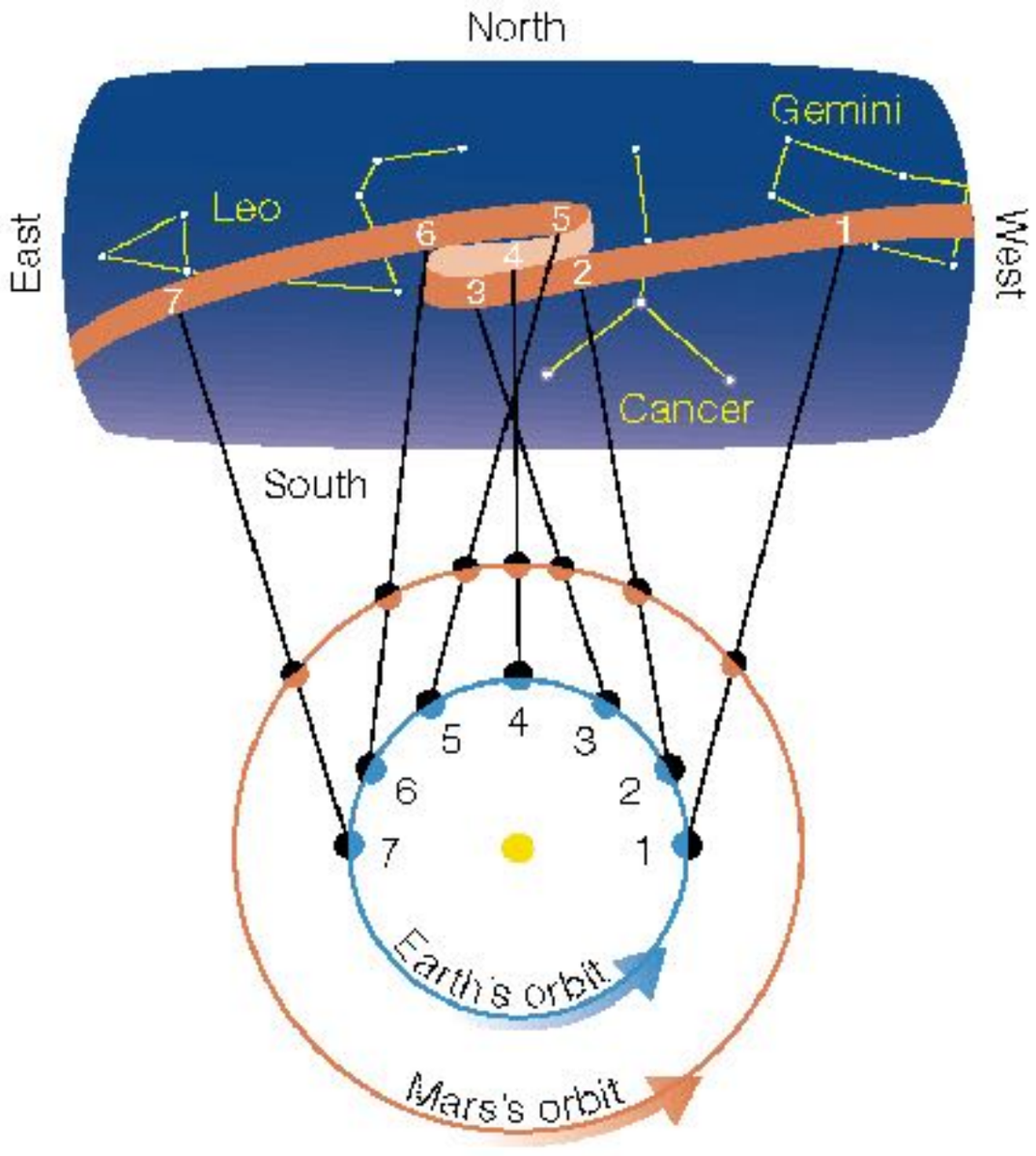
PLAY Ptolemaic Model



H.S. in epicycles

https://www.youtube.com/watch?v=QVuU2YCwHjw

In the **Copernican** model, retrograde motion is a consequence of one planet (Earth) "lapping" another in its orbit.



https://www.youtube.com/watch?v=7rJFHp47PtY

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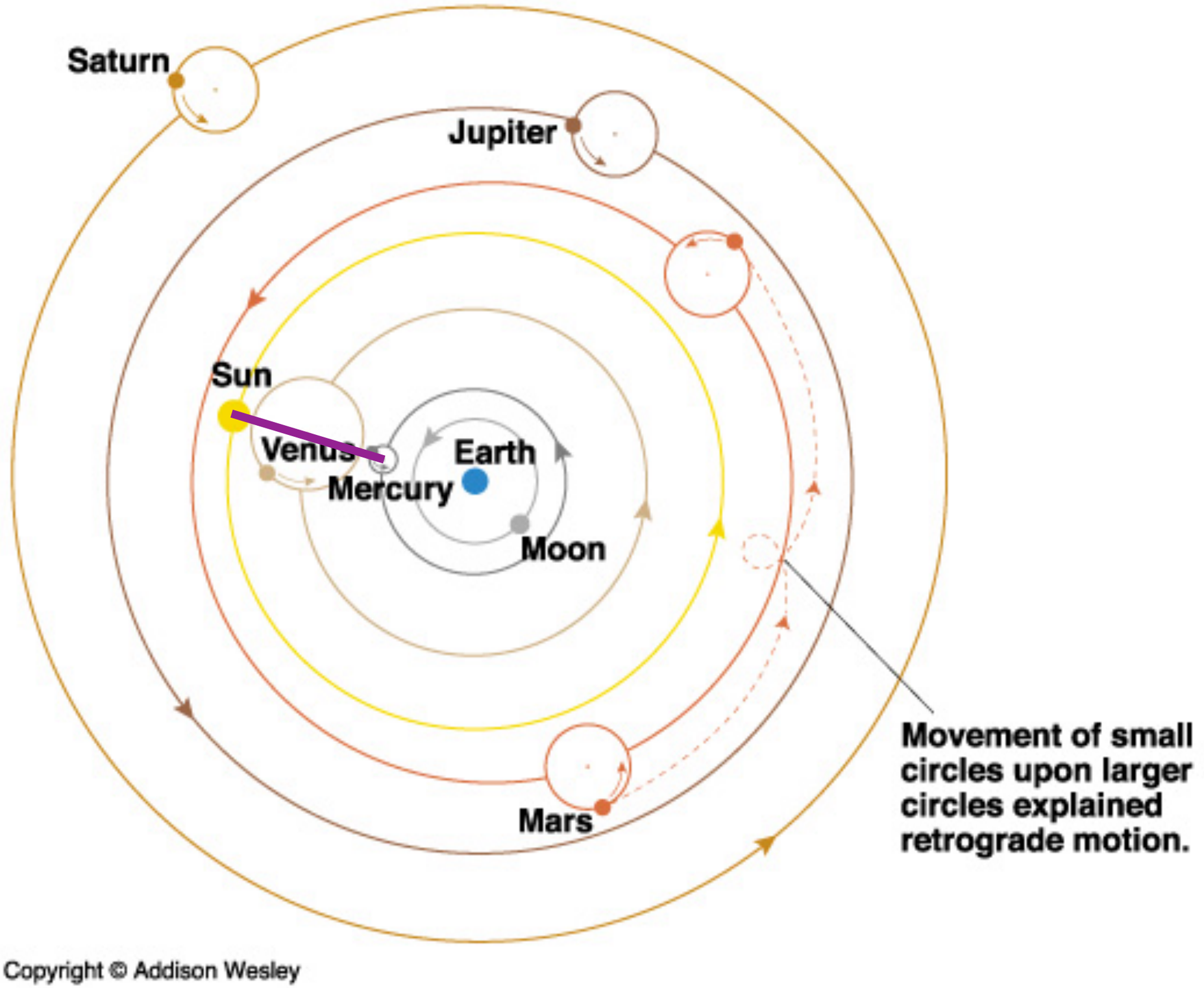
Retrograde Motion

Needs epicycles | Consequence of Lapping

Inferiority of Mercury & Venus

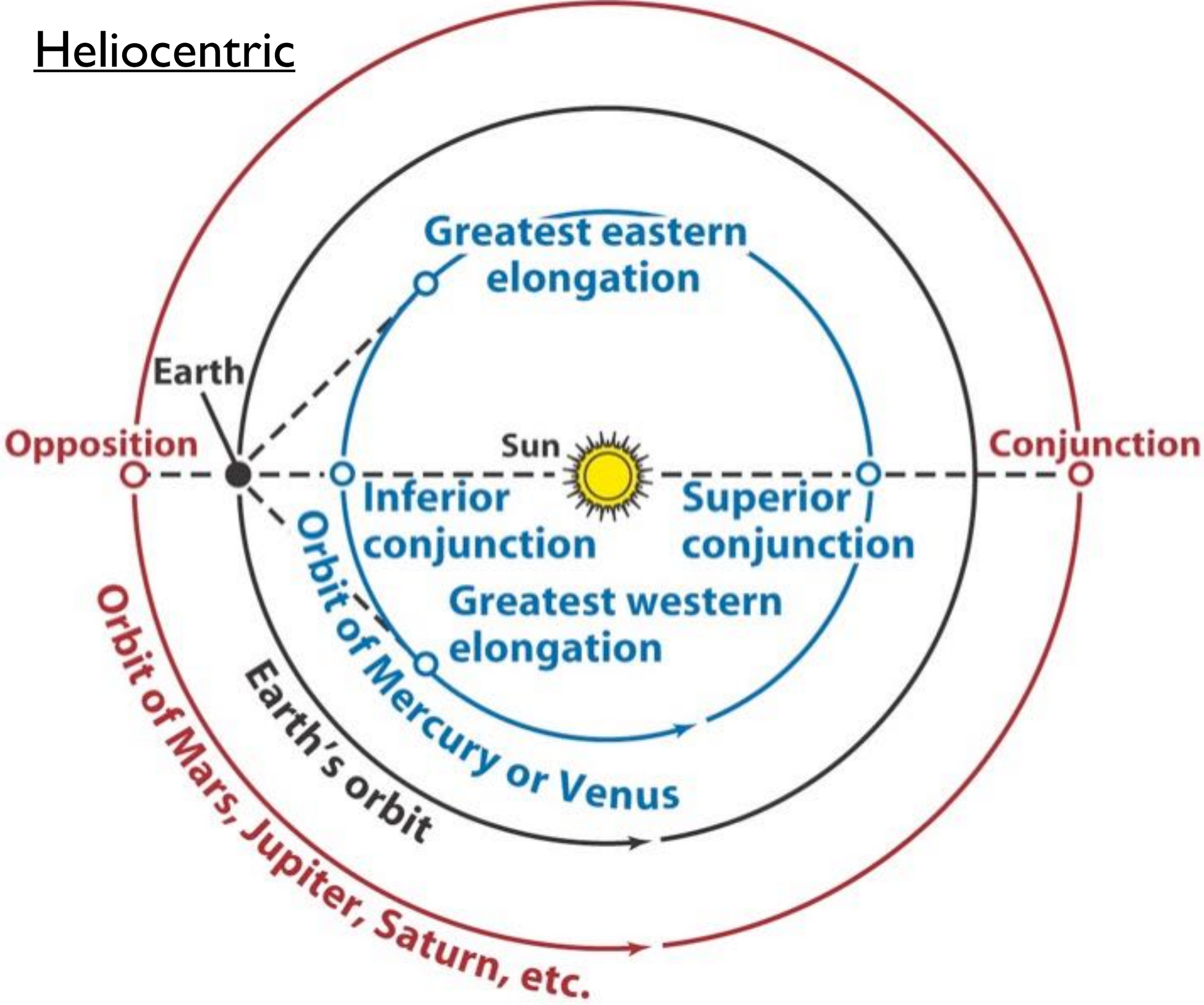
Must tie to sun | Interior to Earth's Orbit

Geocentric Cosmology



Mercury & Venus always close to sun on the sky

Heliocentric



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Retrograde Motion

Needs epicycles | Consequence of Lapping

Inferiority of Mercury & Venus — **more natural**

Must tie to sun | Interior to Earth's Orbit

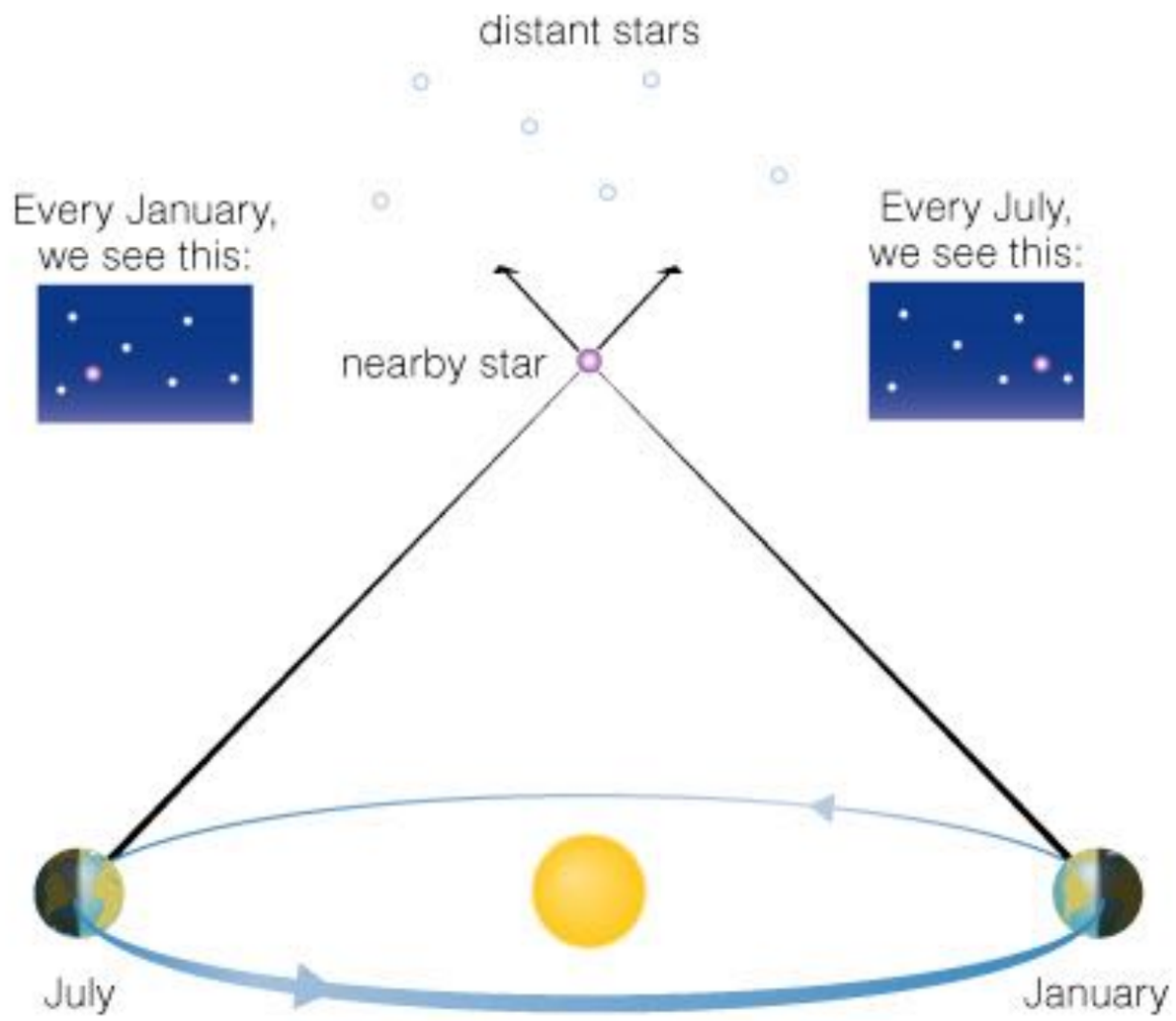
Predicts

- No parallax
- Venus: crescent phase only

- Parallax
- Venus: all phases

Parallax

If the Earth moves around the sun, the positions of stars should shift in reflex to that motion.



- The ancients could not detect **stellar parallax**.

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Retrograde Motion

Needs epicycles — Consequence of Lapping **nicer**

Inferiority of Mercury & Venus

Must tie to sun — Interior to Earth's Orbit **nicer**

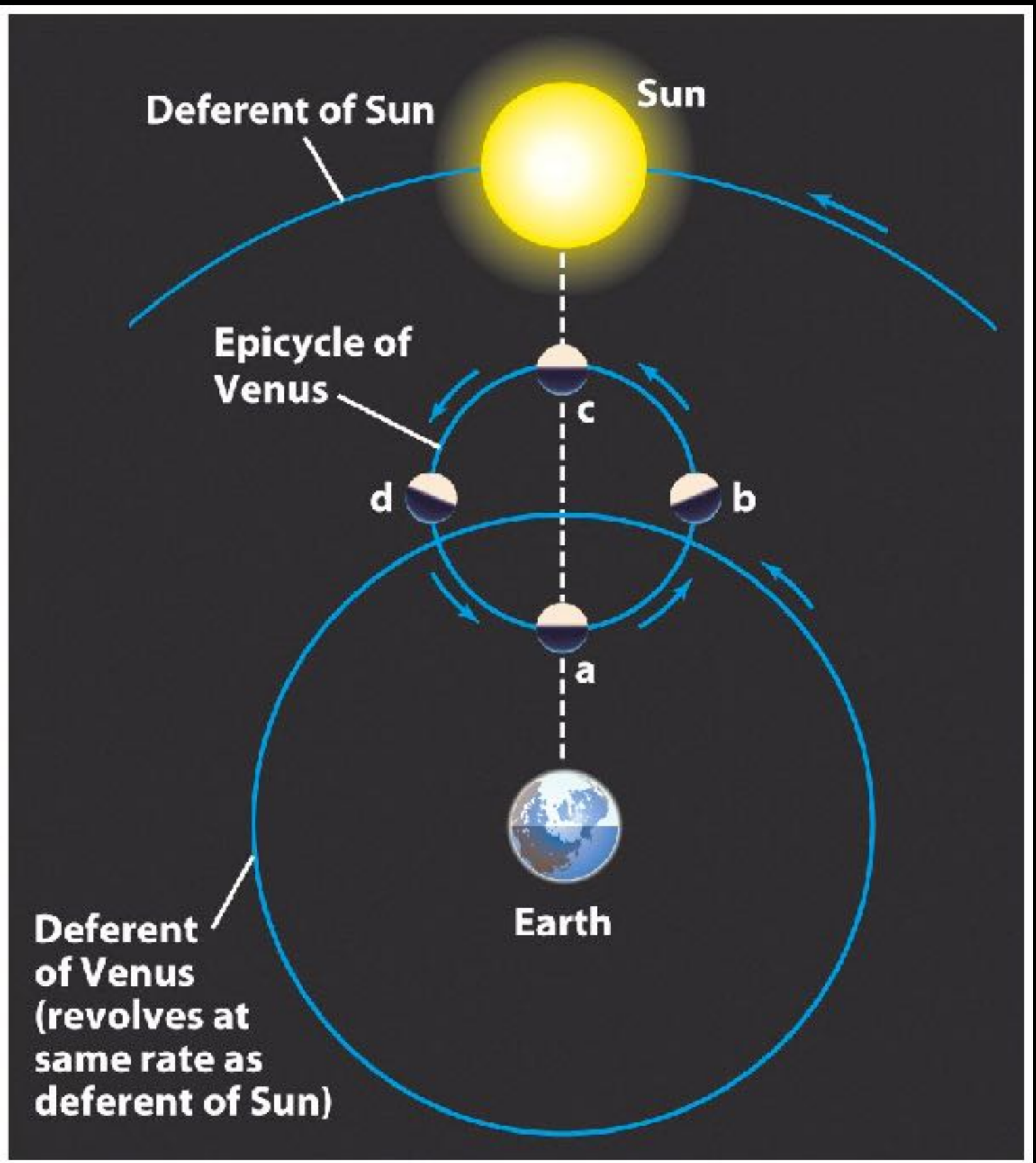
Predicts

- No parallax ✓
- Venus: crescent phase only

- Parallax X
- Venus: all phases

unkown to ancients

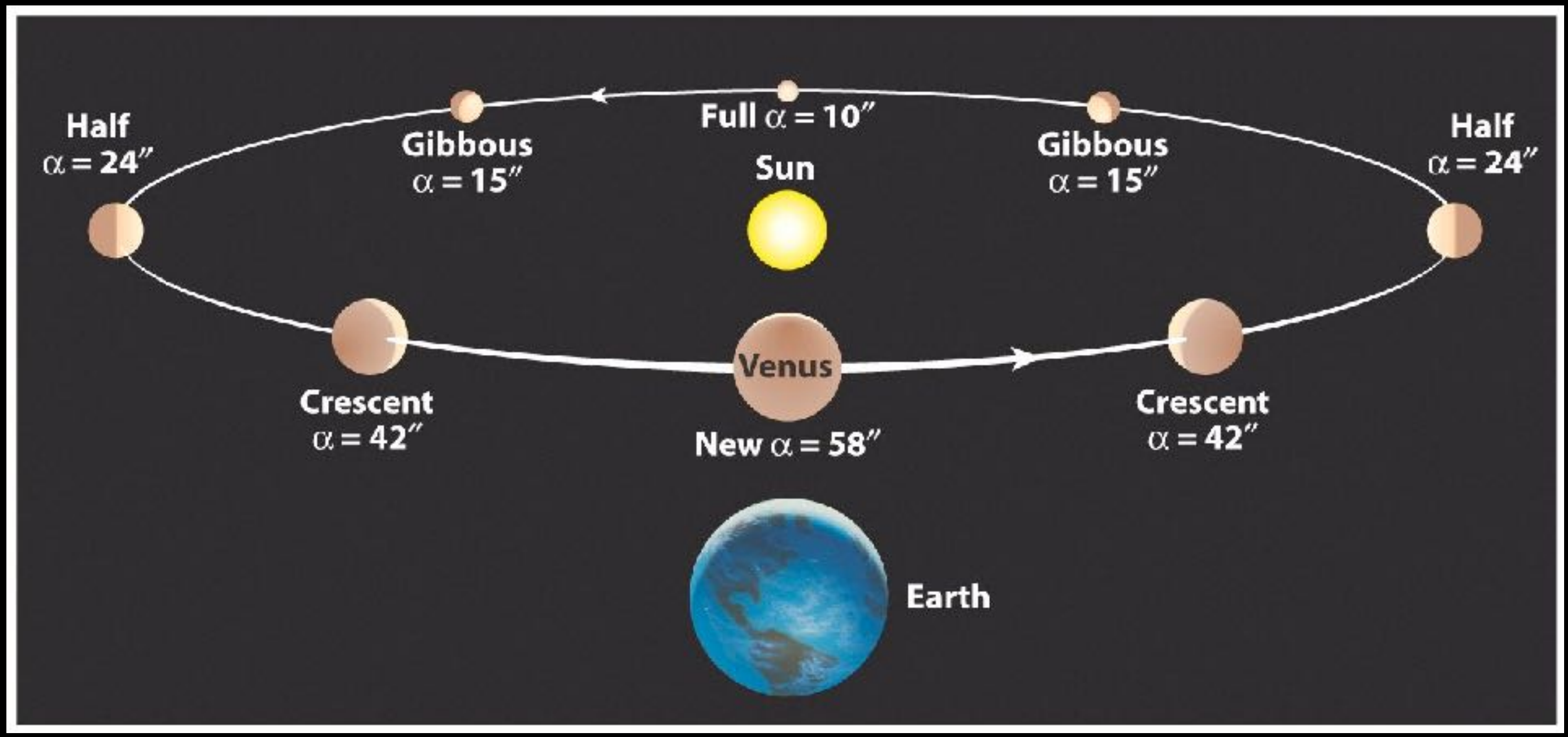
Geocentric



Only crescent phase can be observed - never full or even gibbous

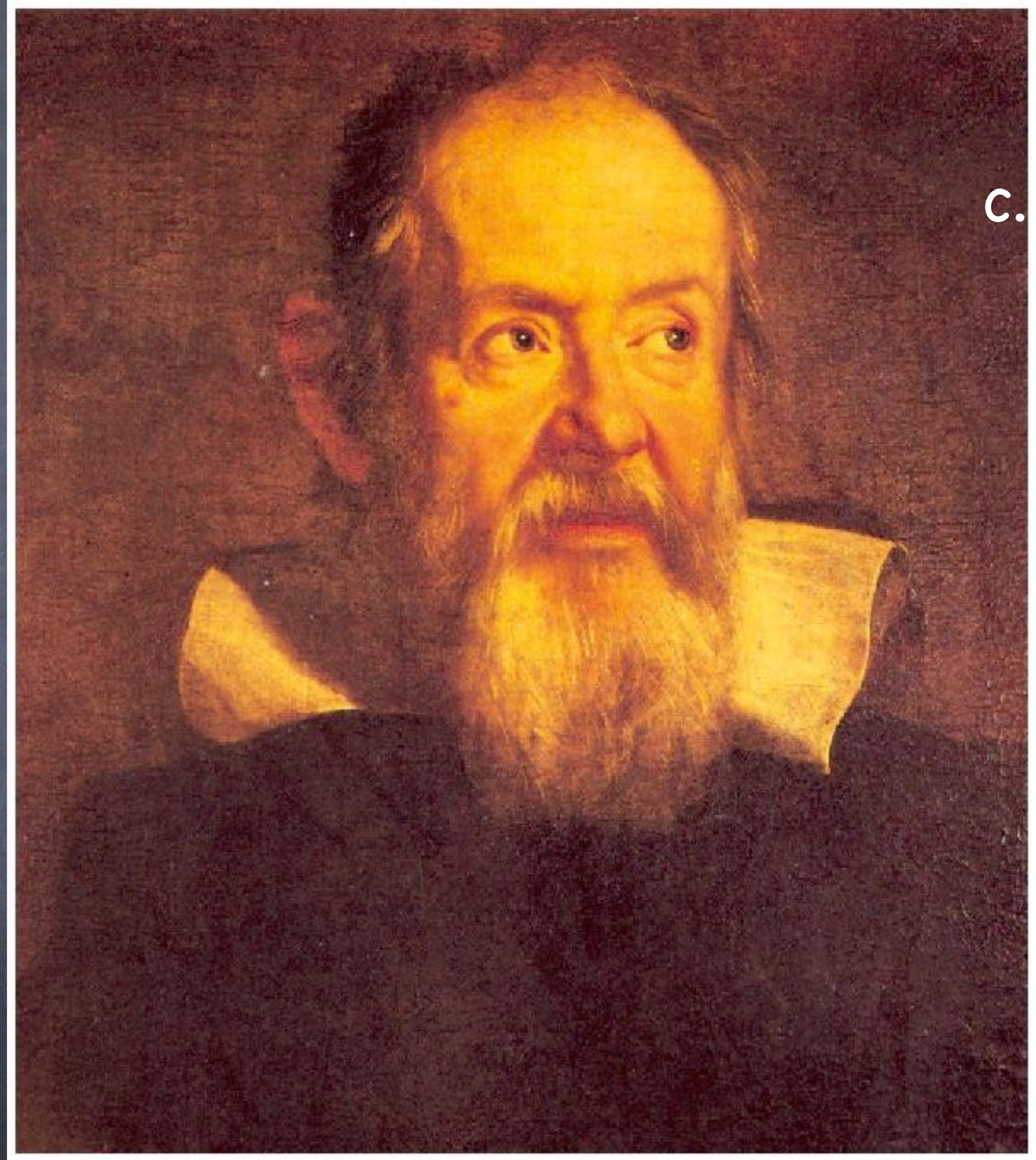
Heliocentric

The full range of phase can be observed - from crescent to full



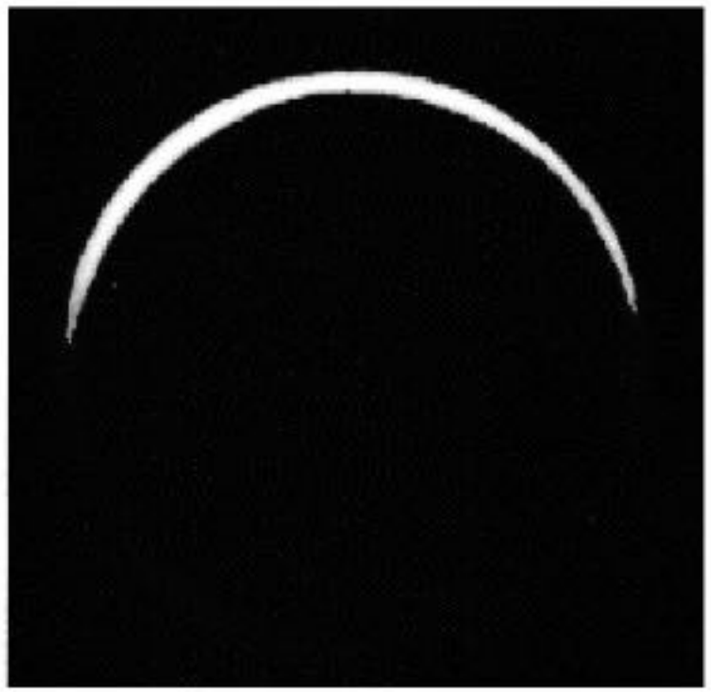
PLAY Phases of Venus

Galileo

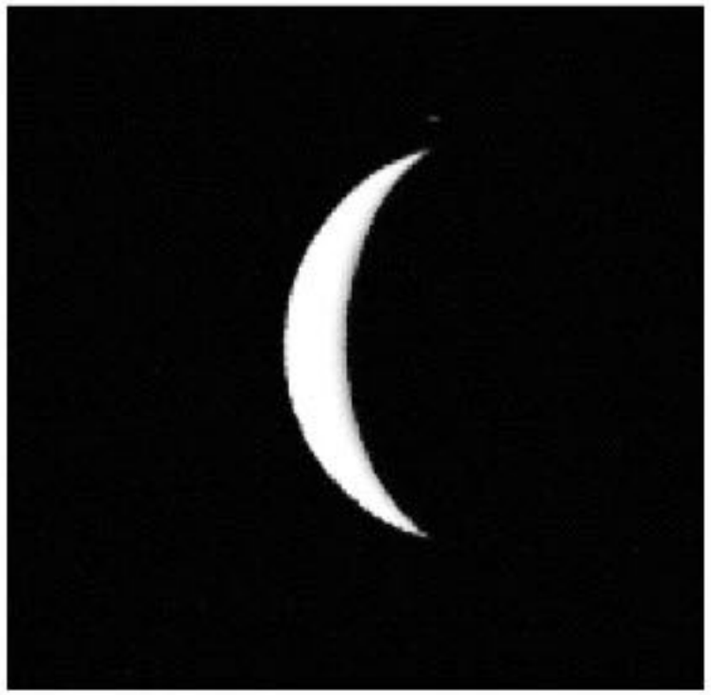


c. 1564–1640

First telescopic astronomical observations

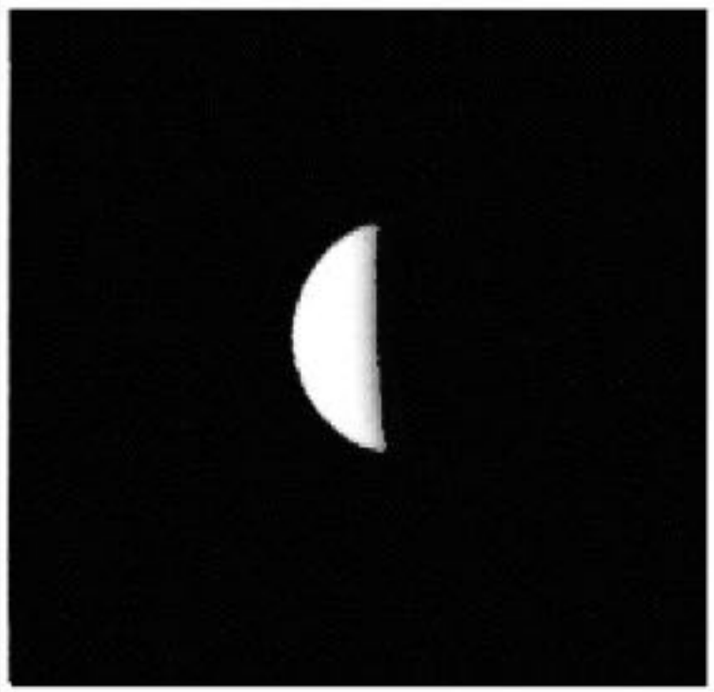


$\alpha = 58^\circ$

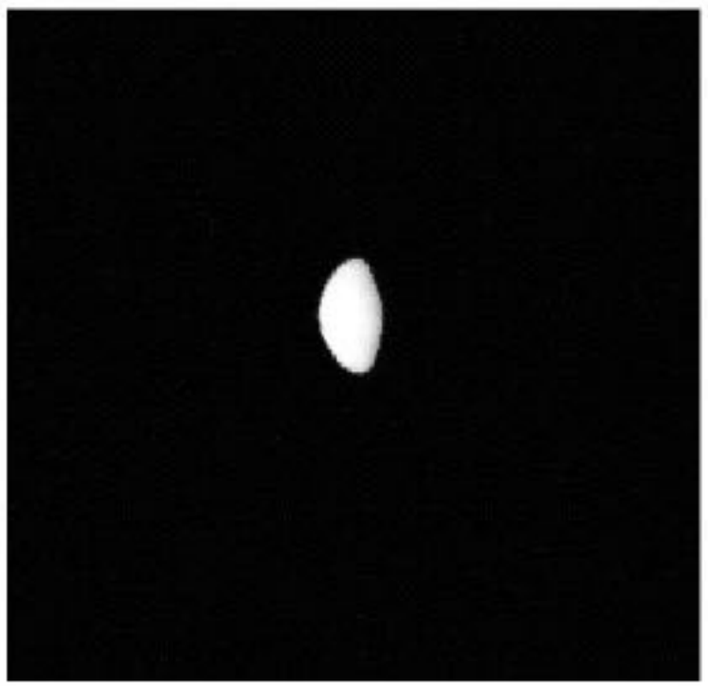


$\alpha = 42^\circ$

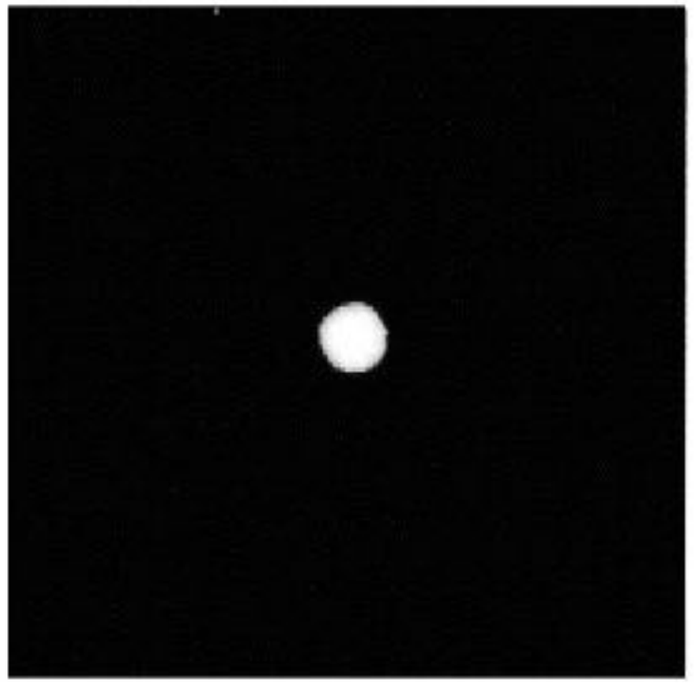
Phase and angular size of Venus depend on elongation (angle from sun)



$\alpha = 24^\circ$



$\alpha = 15^\circ$



$\alpha = 10^\circ$

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Retrograde Motion

Needs epicycles — Consequence of Lapping — **nicer**

Inferiority of Mercury & Venus

Must tie to sun — Interior to Earth's Orbit — **nicer**

Predicts

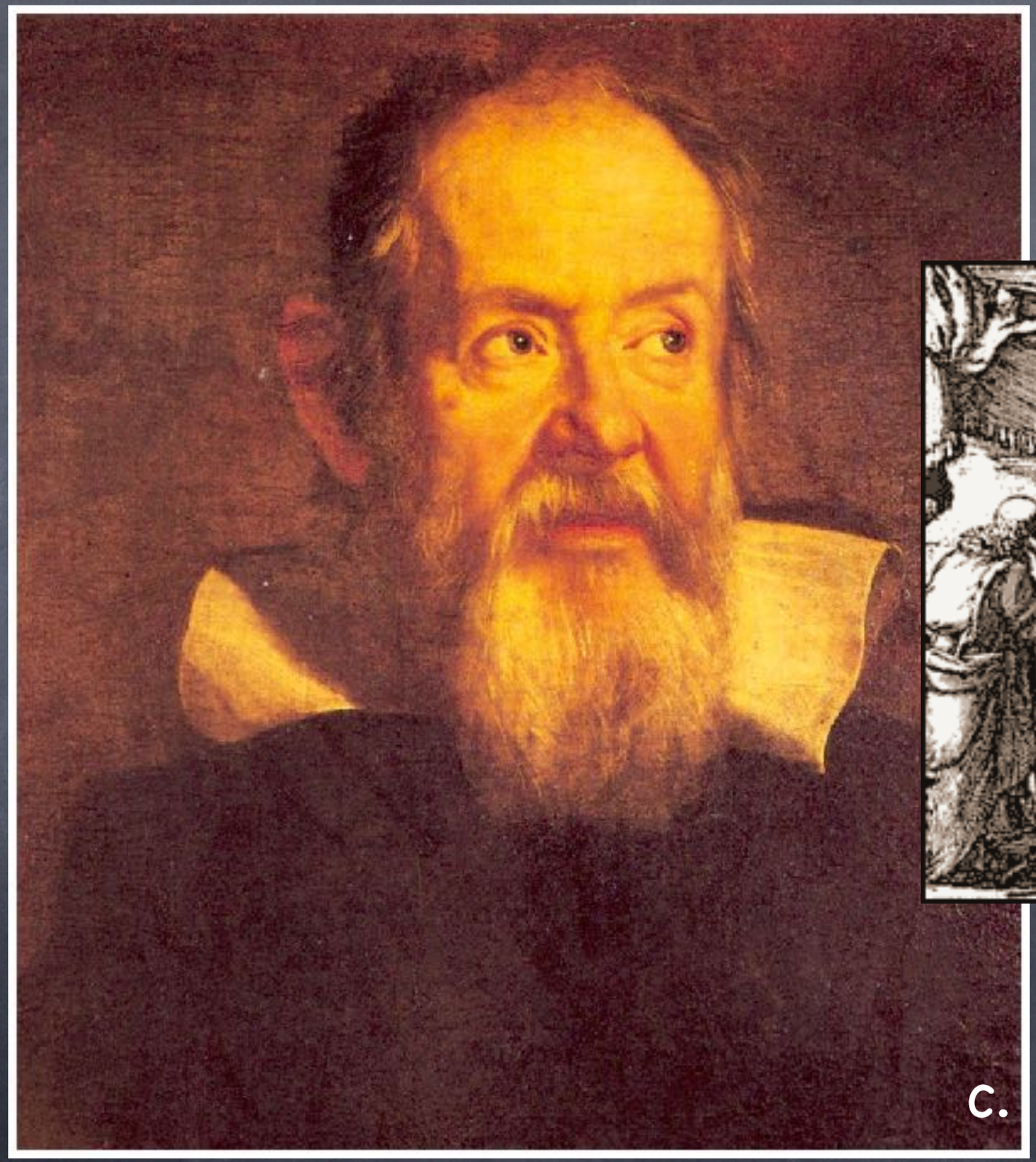
- No parallax ✓
- Venus: crescent phase only X

- Parallax X
- Venus: all phases ✓

Heliocentric Cosmology

- Provides better explanation for
  - Retrograde motion
  - proximity of Mercury and Venus to the Sun
- Provides only explanation for
  - Phases of Venus
  - Angular size variation of Venus
- What about parallax?
  - Hard to measure if stars VERY distant
    - Finally detected in 1839

Galileo



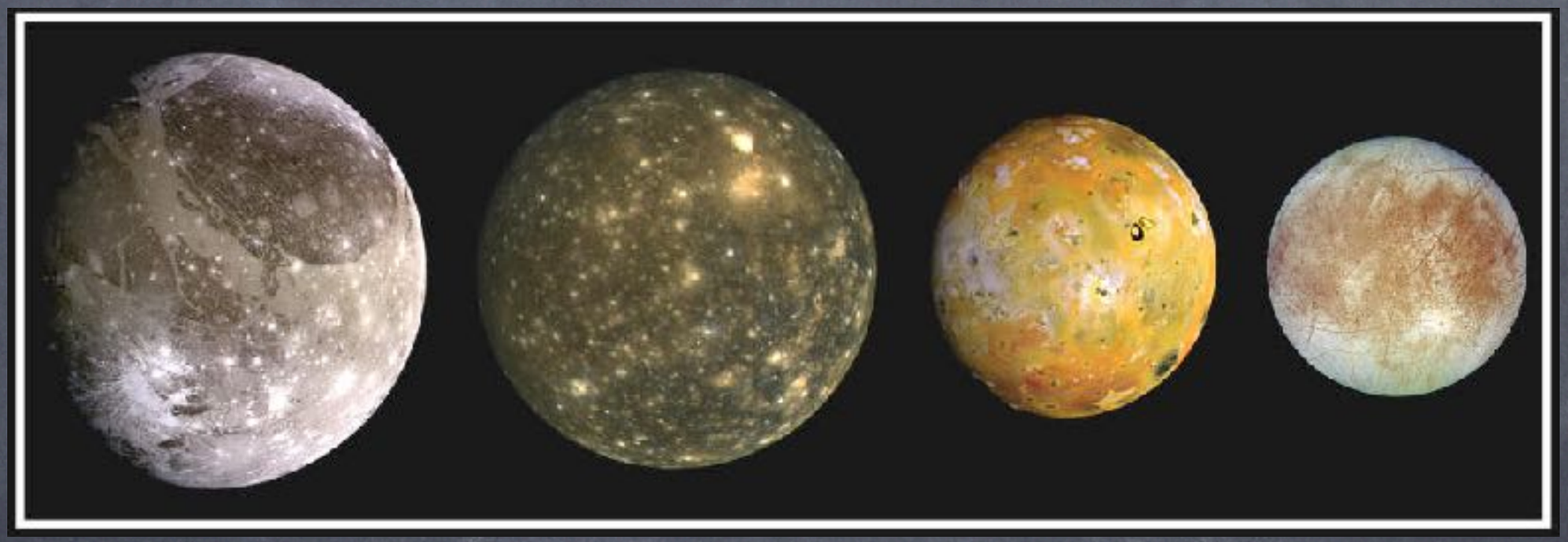
c. 1564–1640

Galileo's telescopic discoveries

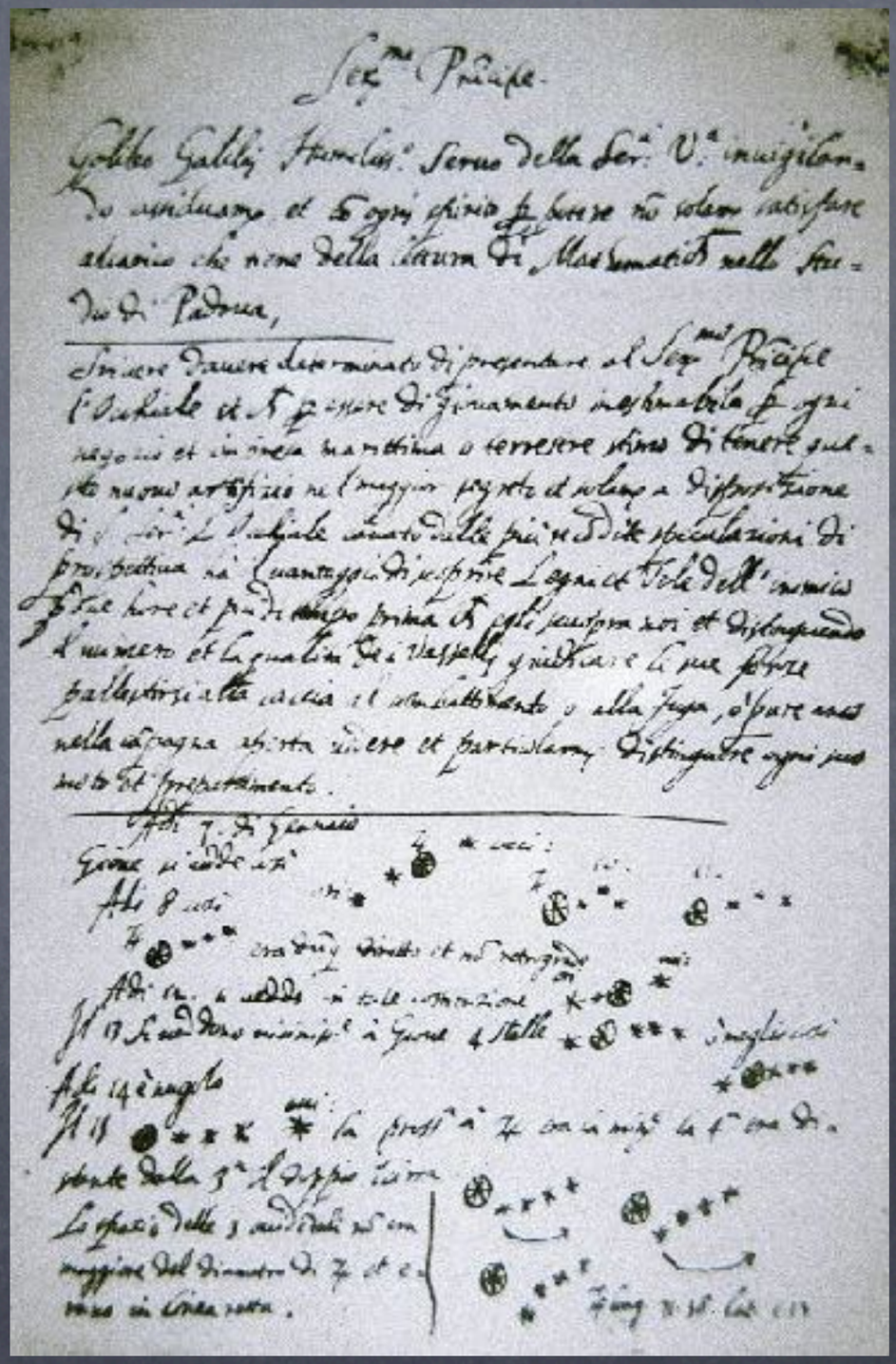
- Stars in the Milky Way
- Mountains on the Moon
- Sun spots (celestial spheres NOT perfect)
- Rings of Saturn (barely resolved)
- Moons of Jupiter ("Medicean stars")
  - Earth NOT center of all revolution
- Phases of Venus
  - Good test of geocentric hypothesis

Jupiter and moons

Galilean moons (from Galileo spacecraft!)



Letter from Galileo to Prince of Venice reporting the discovery of Jupiter's moons…



Observationes Joviales
1610

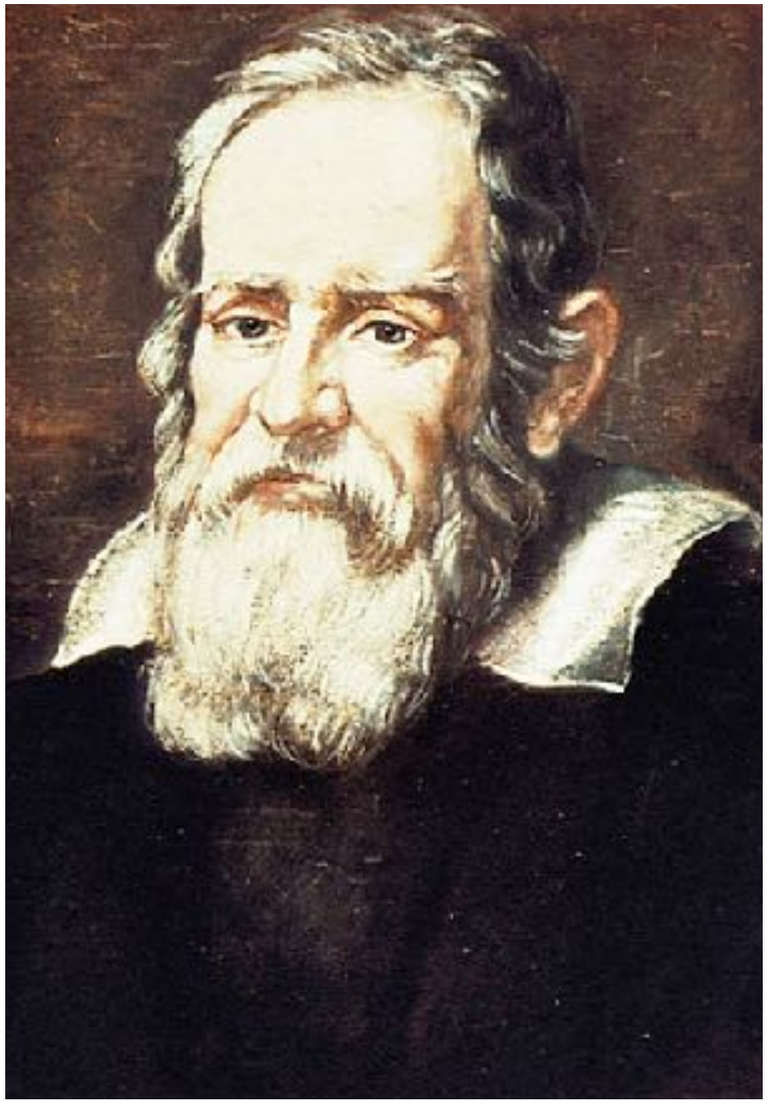
2. S. Jovis. mane H. 12	○	*	*	
30. mane	*	*	○	*
2. Jov.	○	*	*	*
3. mane	○	*	*	
3. Ho. 5.	*	○	*	
4. mane	*	○	*	
6. mane	*	*	○	*
8. mane H. 13.	*	*	*	○
10. mane	*	*	*	○ *
11.	*	*	○	*
12. H. 4 vesp.	*	○	*	
13. mane	*	*	*	○ *
14 Casu.	*	*	*	○ *

"Medician stars"

Heavenly spheres NOT perfect

Even the sun has spots!

How did Galileo solidify the Copernican revolution?



Galileo (1564–1642) overcame major objections to the Copernican view. Three key objections rooted in the Aristotelian view were:

1. Earth could not be moving because objects in air would be left behind.
2. The heavens are not "perfect" as they should be.
3. If Earth were really orbiting Sun, we'd detect stellar parallax.

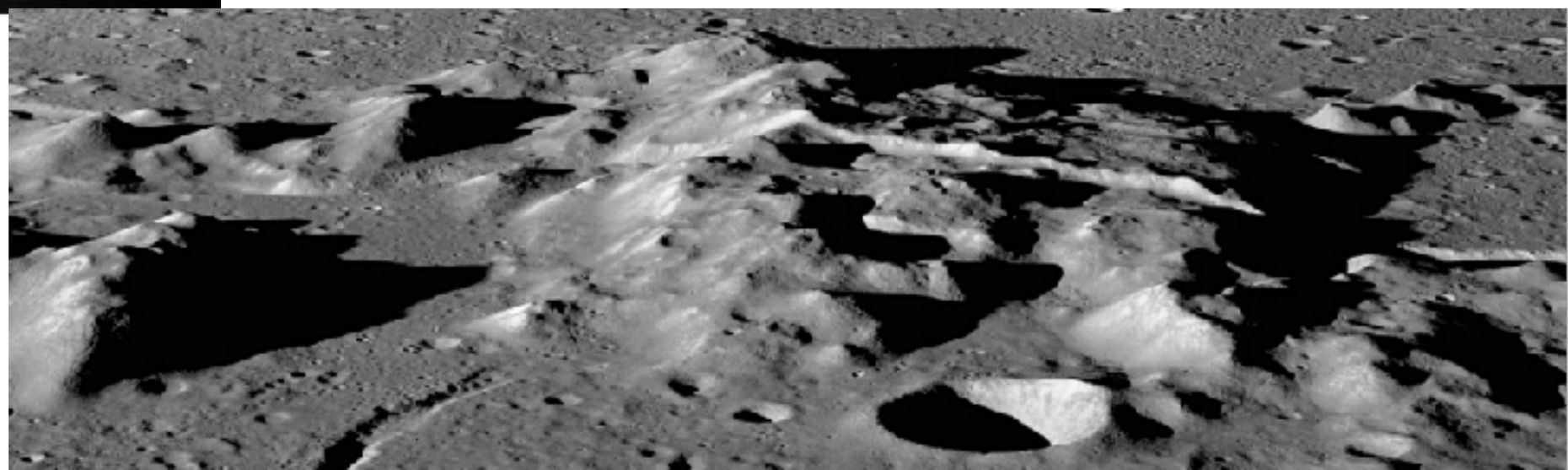
Overcoming the first objection (nature of motion):

Galileo's experiments showed that objects in air would stay with a moving Earth.

- Aristotle thought that all objects naturally come to rest.
- Galileo showed that objects will stay in motion unless a force acts to slow them down (Newton's first law of motion).

Overcoming the second objection (heavenly perfection):

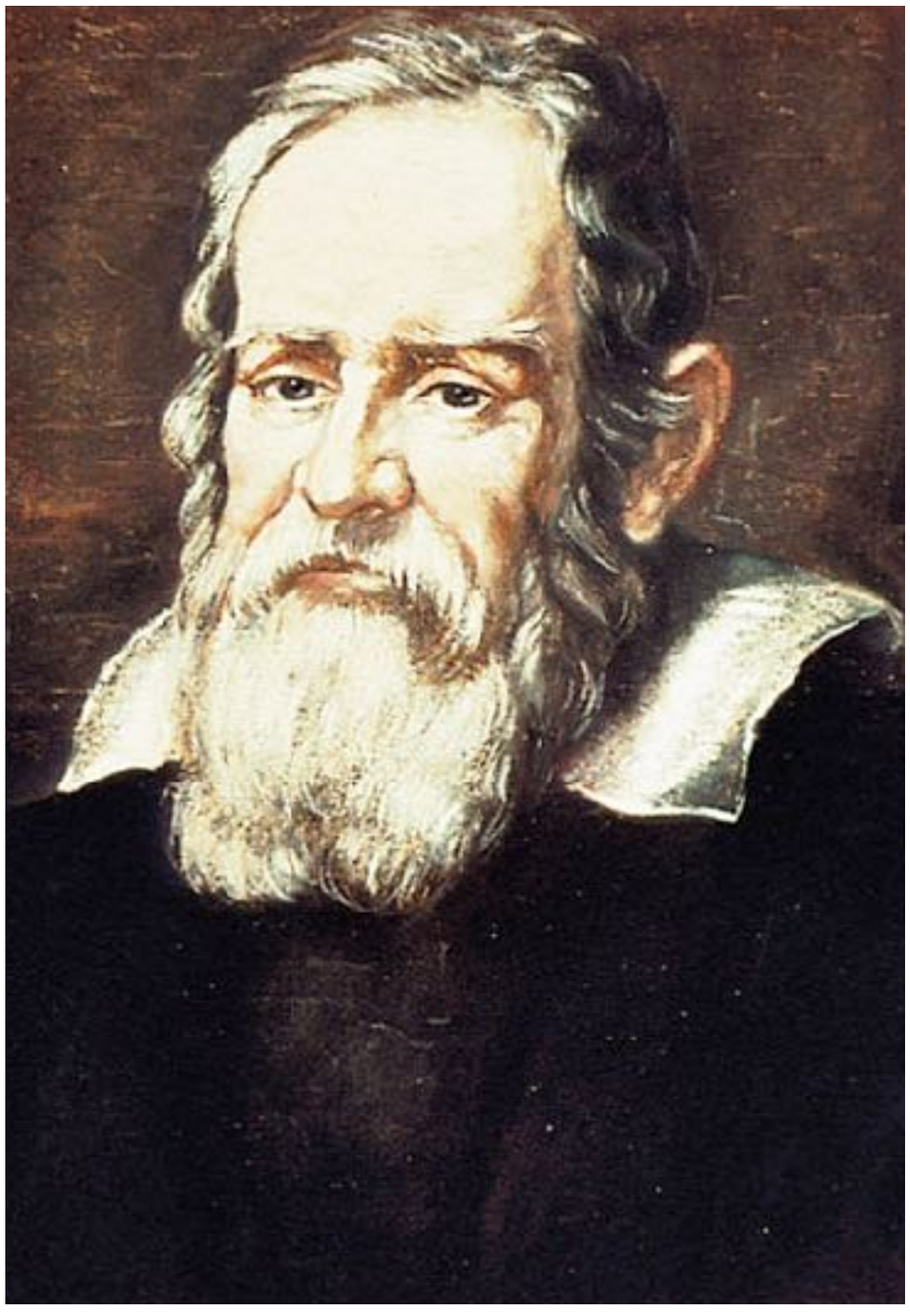
- Tycho's observations of comet and supernova already challenged this idea.
- Using his telescope, Galileo saw:
  - Sunspots on Sun ("imperfections")
  - Mountains and valleys on the Moon (proving it is not a perfect sphere)



Overcoming the third objection (parallax):

- Tycho *thought* he had measured stellar distances, so lack of parallax seemed to rule out an orbiting Earth.
- Galileo showed stars must be much farther than Tycho thought—in part by using his telescope to see that the Milky Way is countless individual stars.

If stars were much farther away, then the lack of detectable parallax was no longer so troubling.



Galileo Galilei

In 1633 the Catholic Church ordered Galileo to recant his claim that Earth orbits the Sun.

His book on the subject was removed from the Church's index of banned books in 1824.

Galileo was formally vindicated by the Church in 1992.

That the Earth may be a Planet.

Prop. I.

That the ſeeming Noveltie and Singularitie of this opinion, can be no ſufficient reaſon to prove it erronious.

IN the ſearch of Theologicall Truths, it is the ſafeſt method, firſt of all to looke unto Divine Authority; becauſe that carryes with it as cleer an evidence to our Faith, as any thing elſe can be to

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That the Earth may be a Planet

the seeming novelty and singularity of this opinion can be no sufficient reason to prove it erroneous