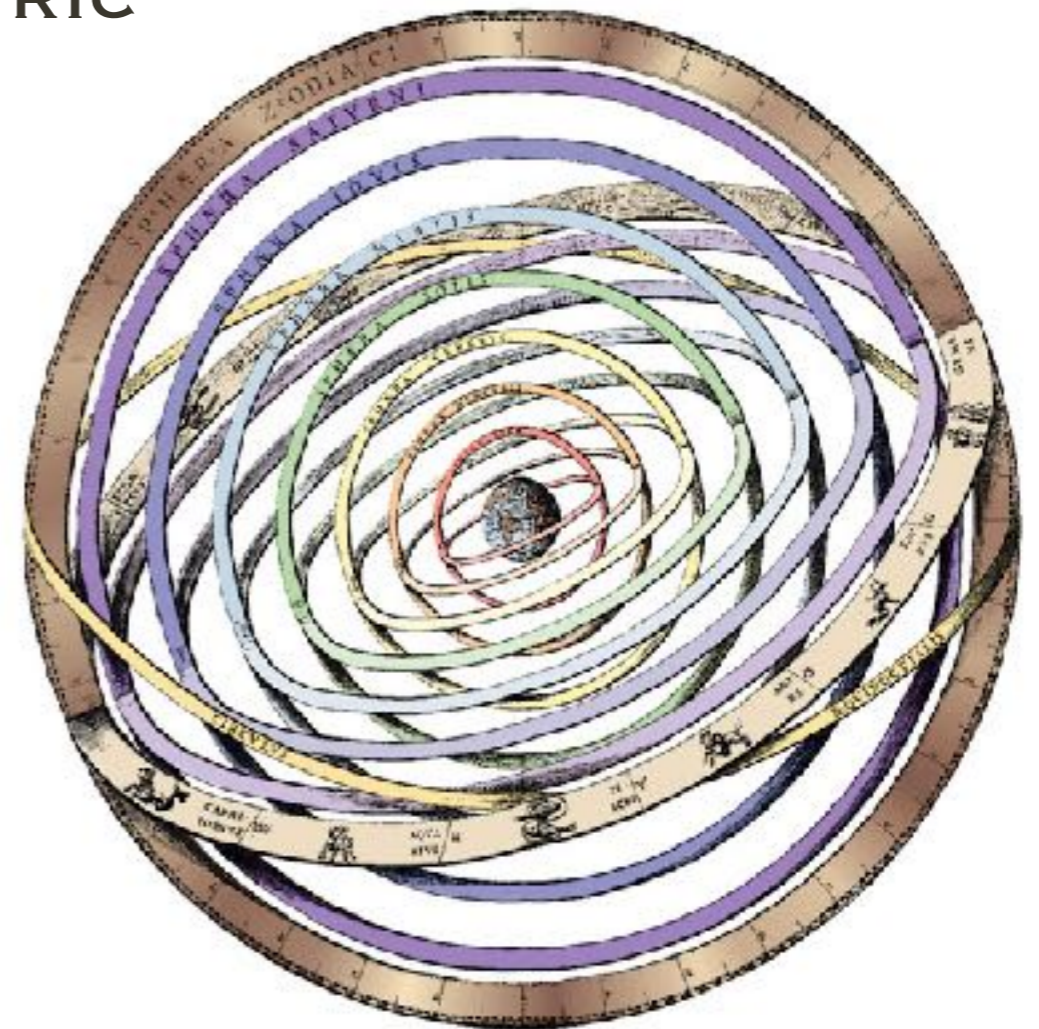


TODAY

FIRST HOMEWORK DUE

- **COMPETING COSMOLOGIES**
- **GEOCENTRIC VS. HELIOCENTRIC**
- **PTOLEMY VS. COPERNICUS**
- **RETROGRADE MOTION**
- **PHASES OF VENUS**
- **GALILEO**



Ancient Cosmology: A Flat Earth



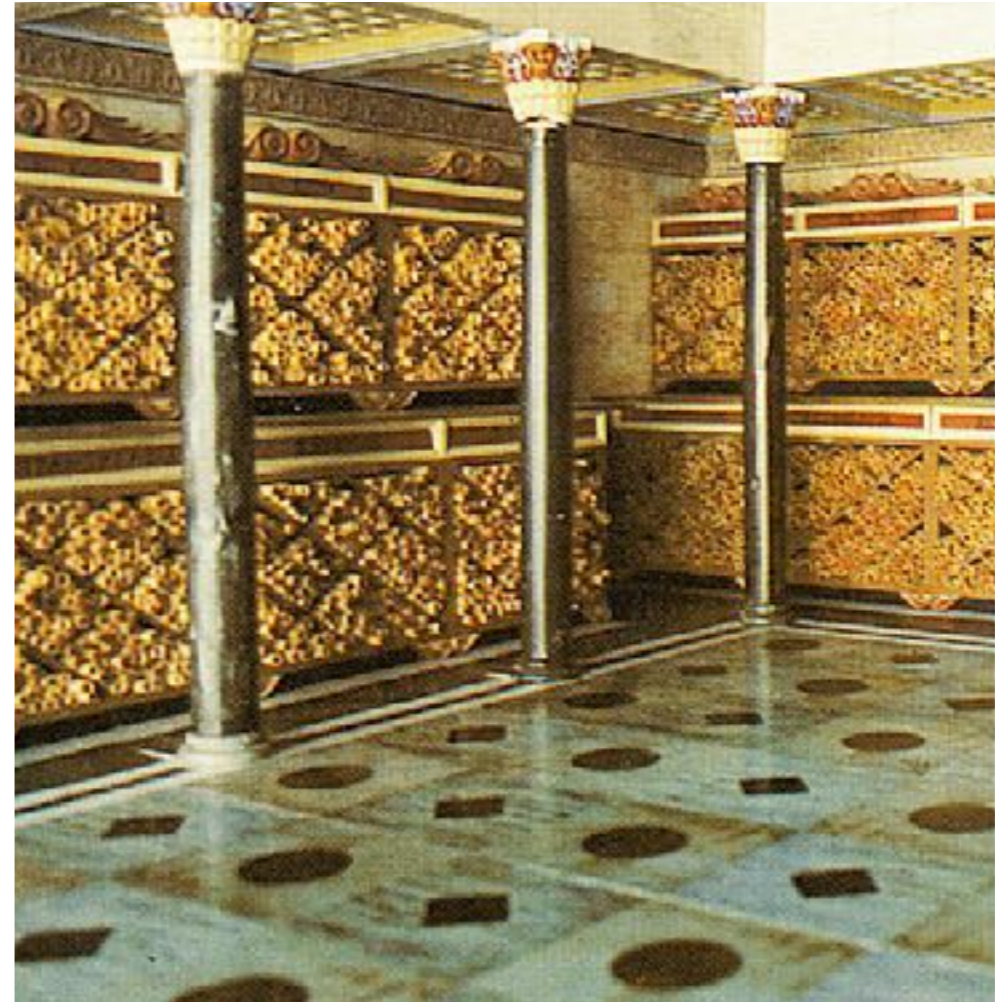
Here there
be dragons!



Map of Hecataeus of Miletus (c. 500 BC)



Modern Map of the Mediterranean



Artist's reconstruction of the Library of Alexandria

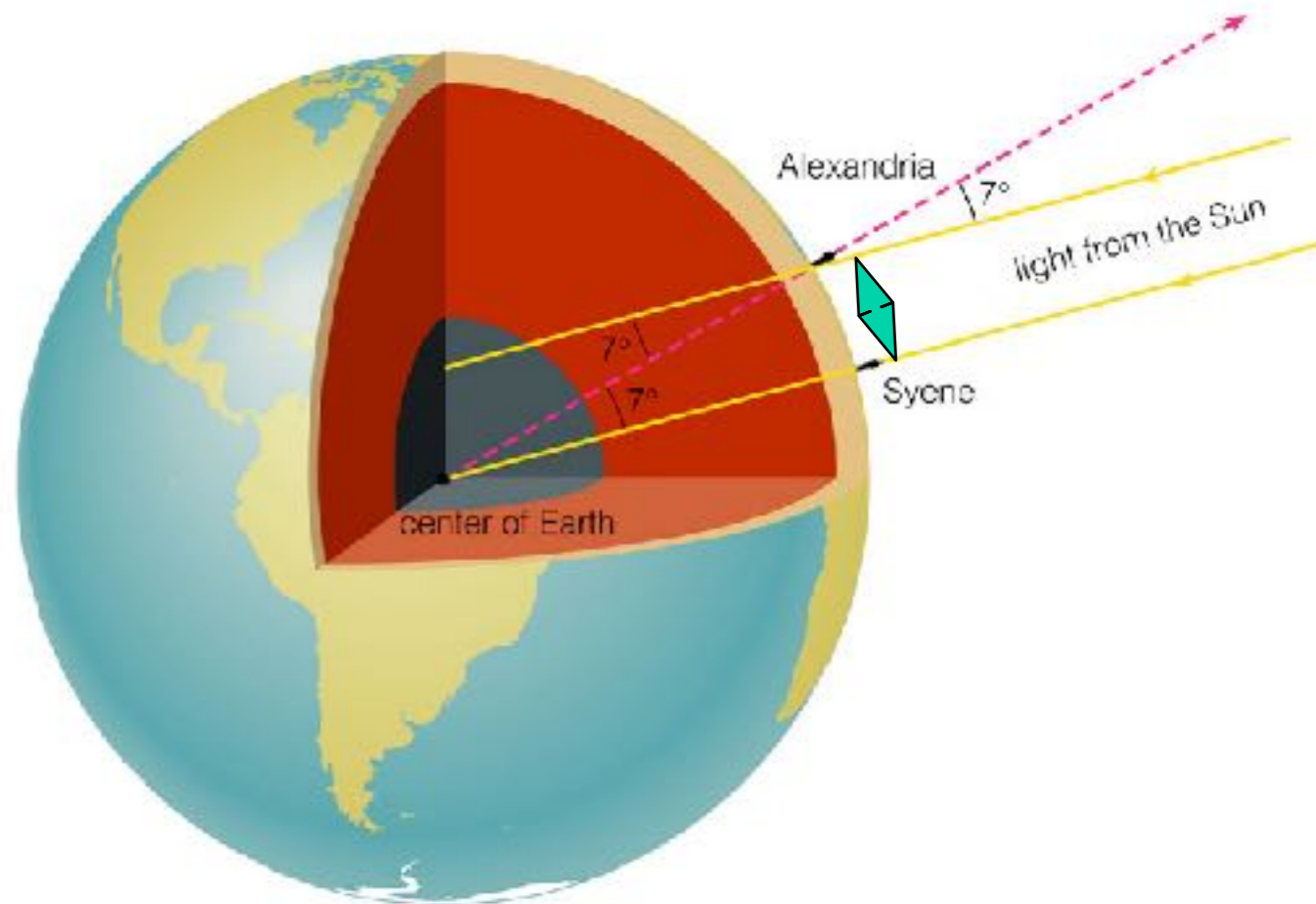
Eratosthenes became the third librarian at Alexandria under Ptolemy III in the Hellenistic period following the conquests of Alexander the Great. Ptolemy I had been one of Alexander's generals, and had taken Egypt as his own after Alexander's untimely death.

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

Measurements:

Syene to Alexandria

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



Calculate circumference of Earth:

$$(7/360) \times (\text{circum. Earth}) = 5,000 \text{ stadia}$$

$$\Rightarrow \text{circum. Earth} = 5,000 \times 360/7 \text{ stadia} \approx 250,000 \text{ stadia}$$

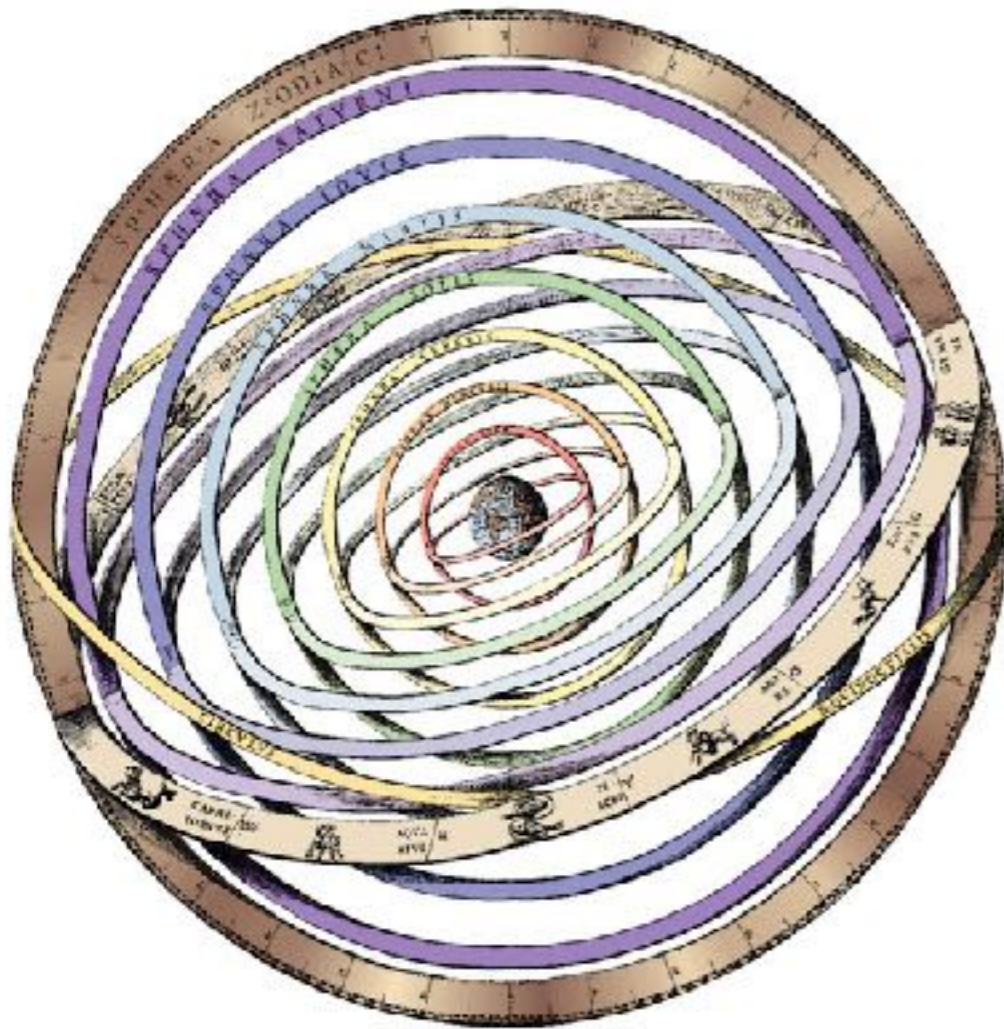
Compare to modern value ($\approx 40,100$ km):

$$\text{Greek stadium} \approx 1/6 \text{ km} \Rightarrow 250,000 \text{ stadia} \approx 42,000 \text{ km}$$

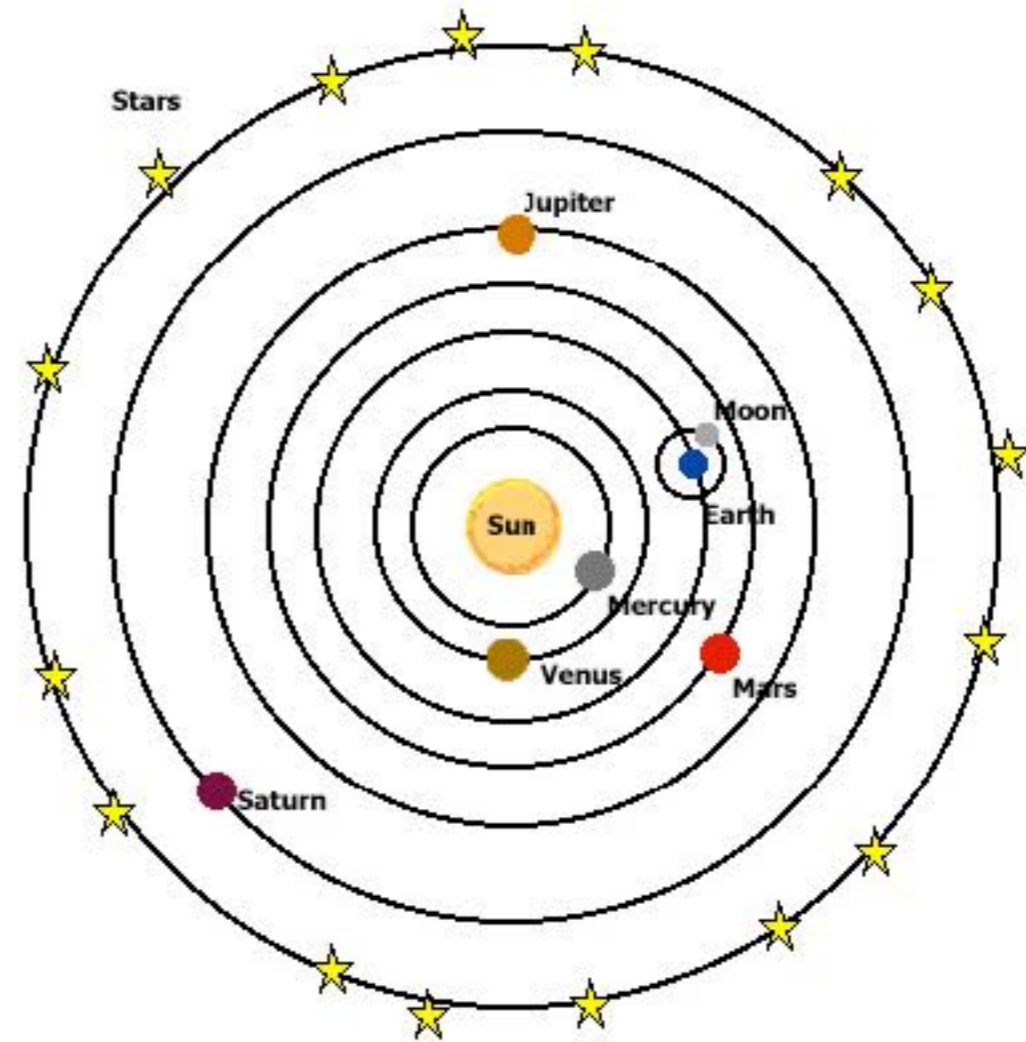
It was known long before Columbus that the Earth is not flat!

Competing Cosmologies

Geocentric
Ptolemaic
Earth at center



Heliocentric
Copernican
Sun at center



Geocentric

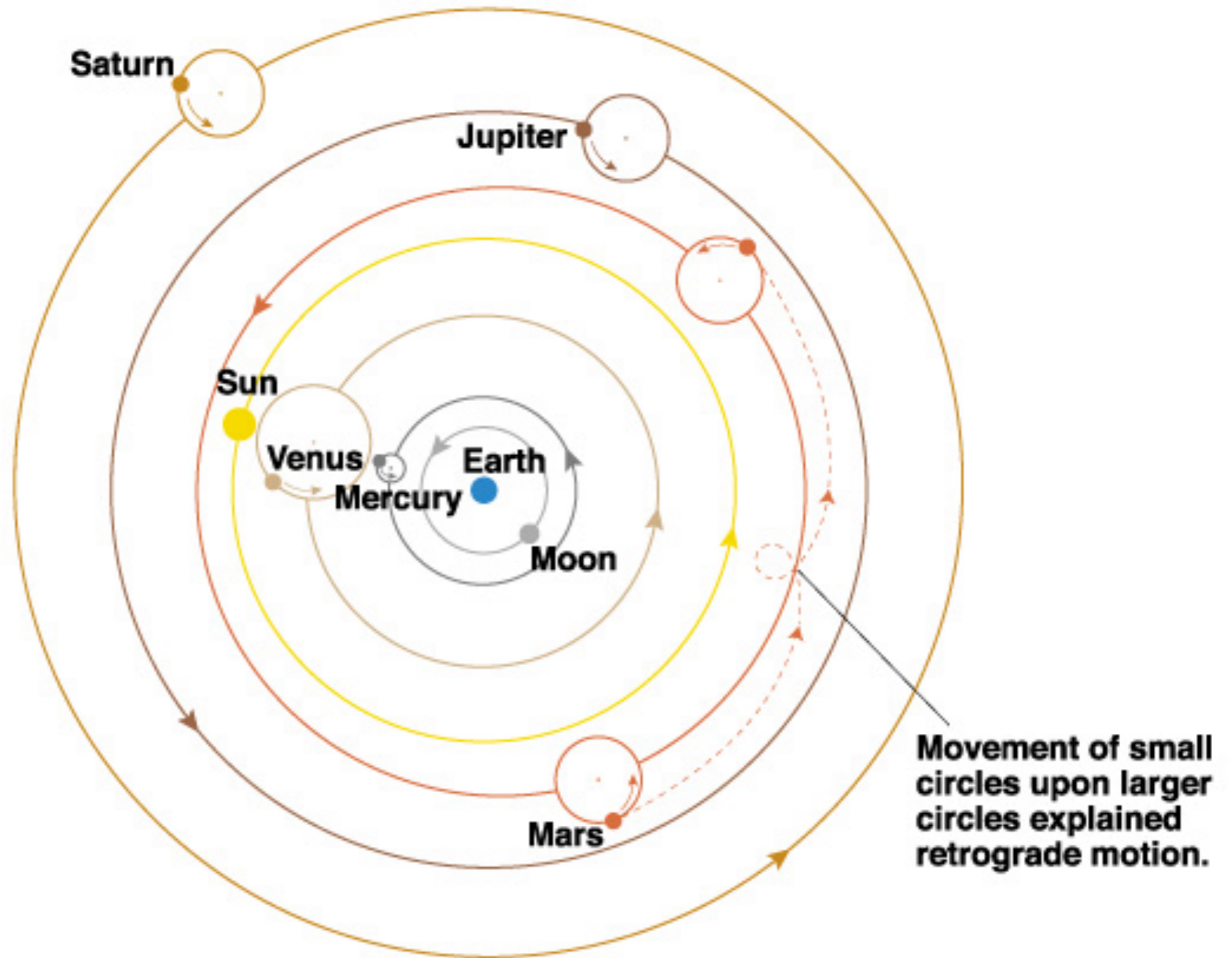


Ptolemy

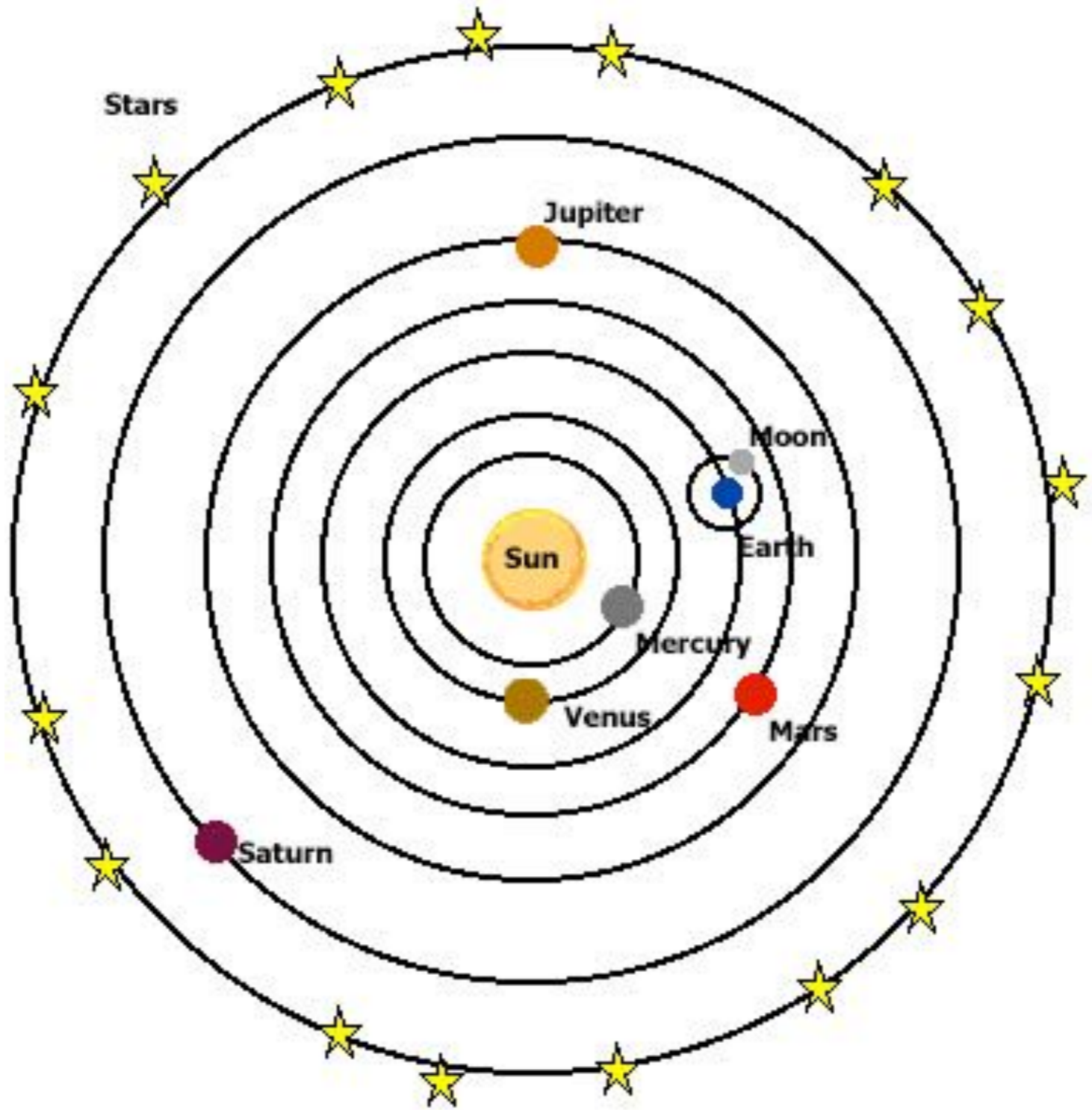
The most sophisticated geocentric model was that of Ptolemy (A.D. 100–170) — the **Ptolemaic model**:

- 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

Ptolemaic

Earth at center

Heliocentric

Copernican

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**

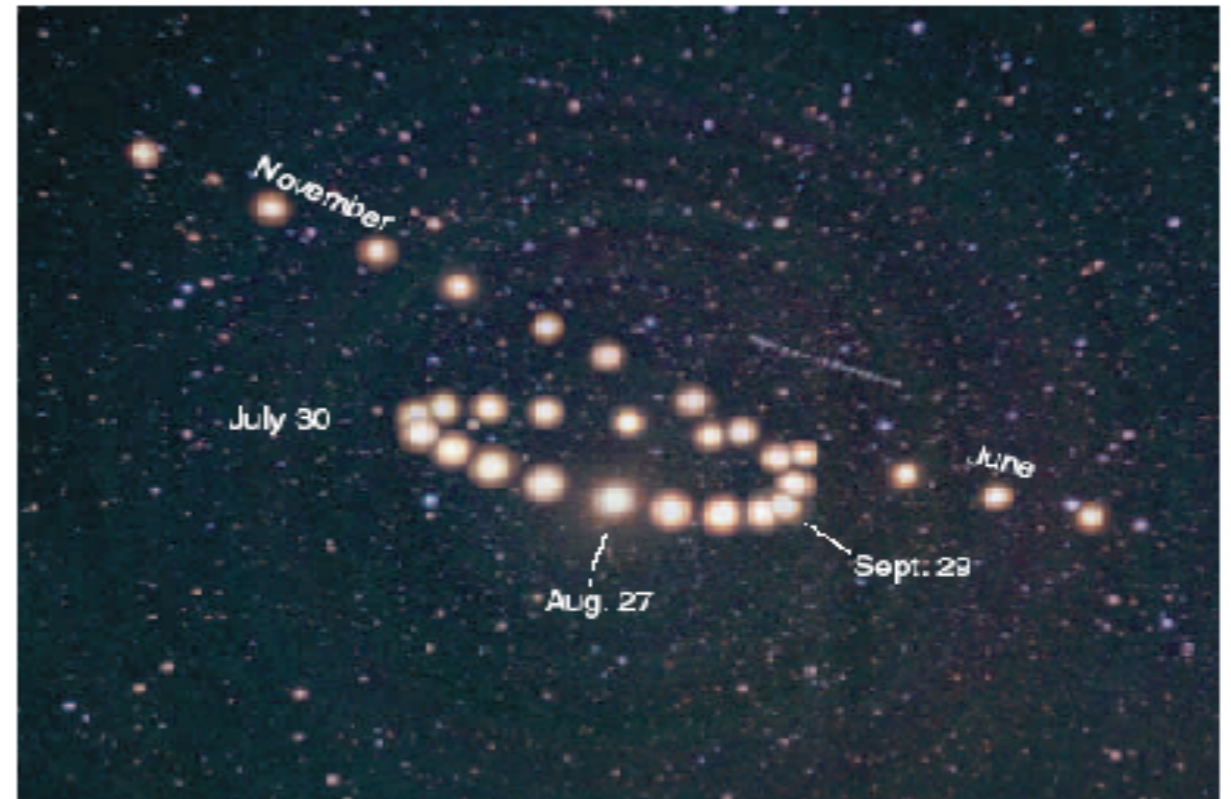
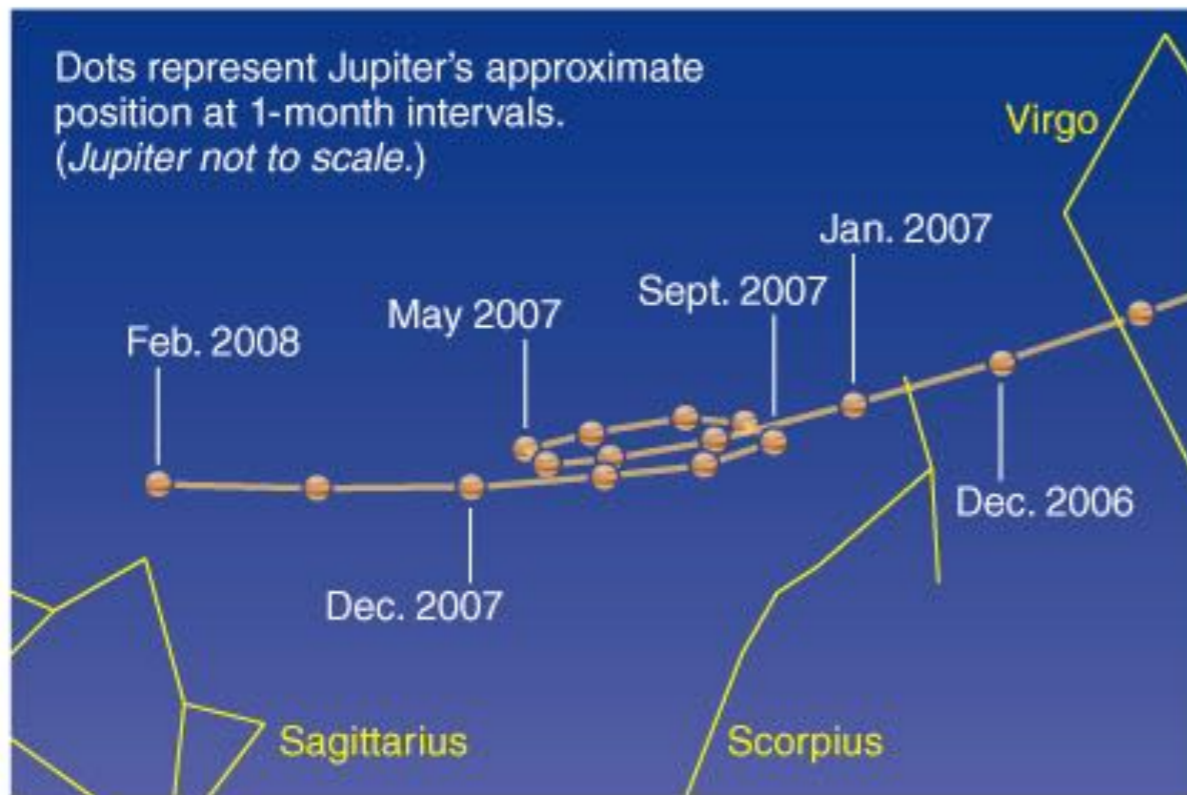
Explains

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

Hard to tell the difference!

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.**

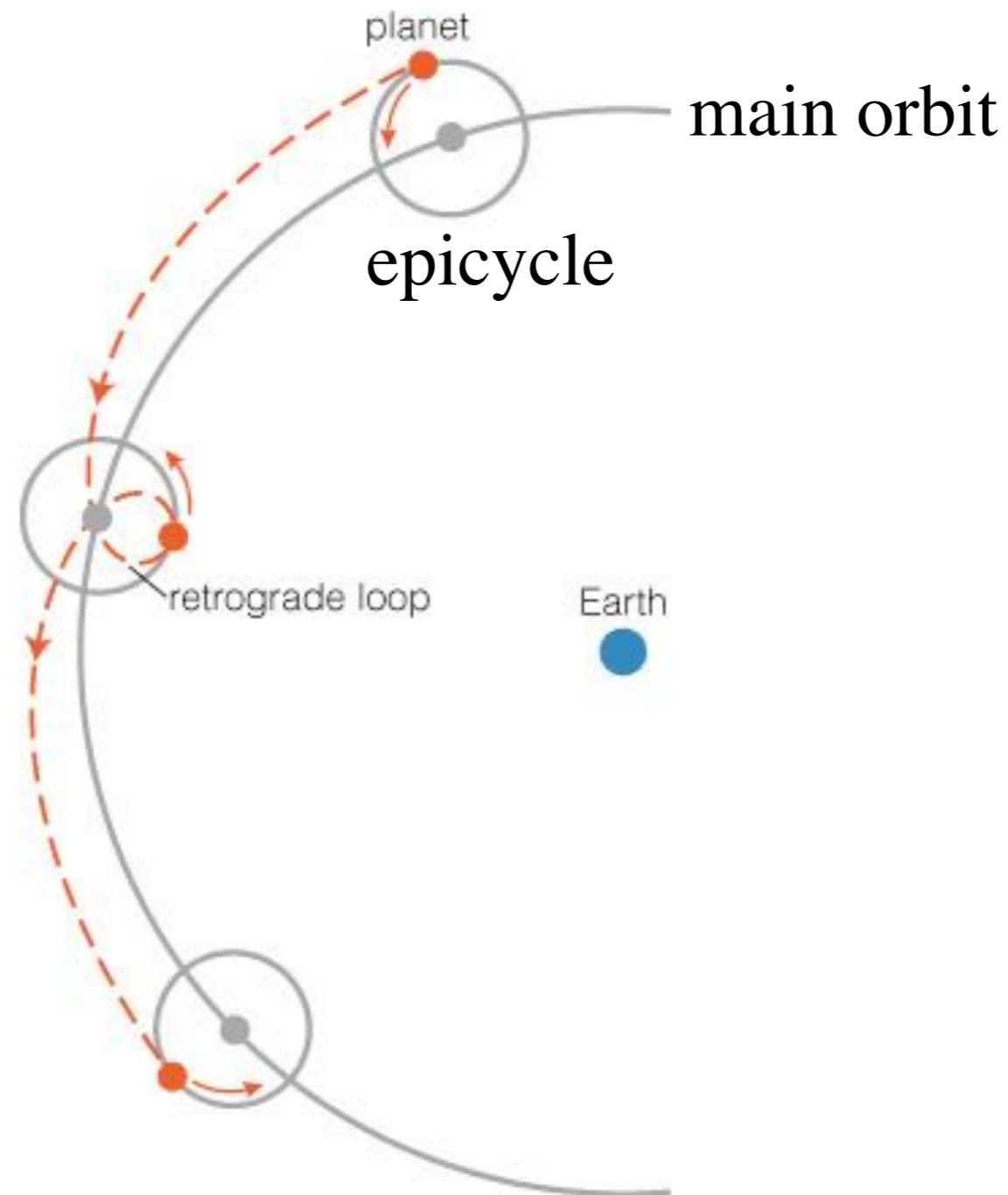


PLAY

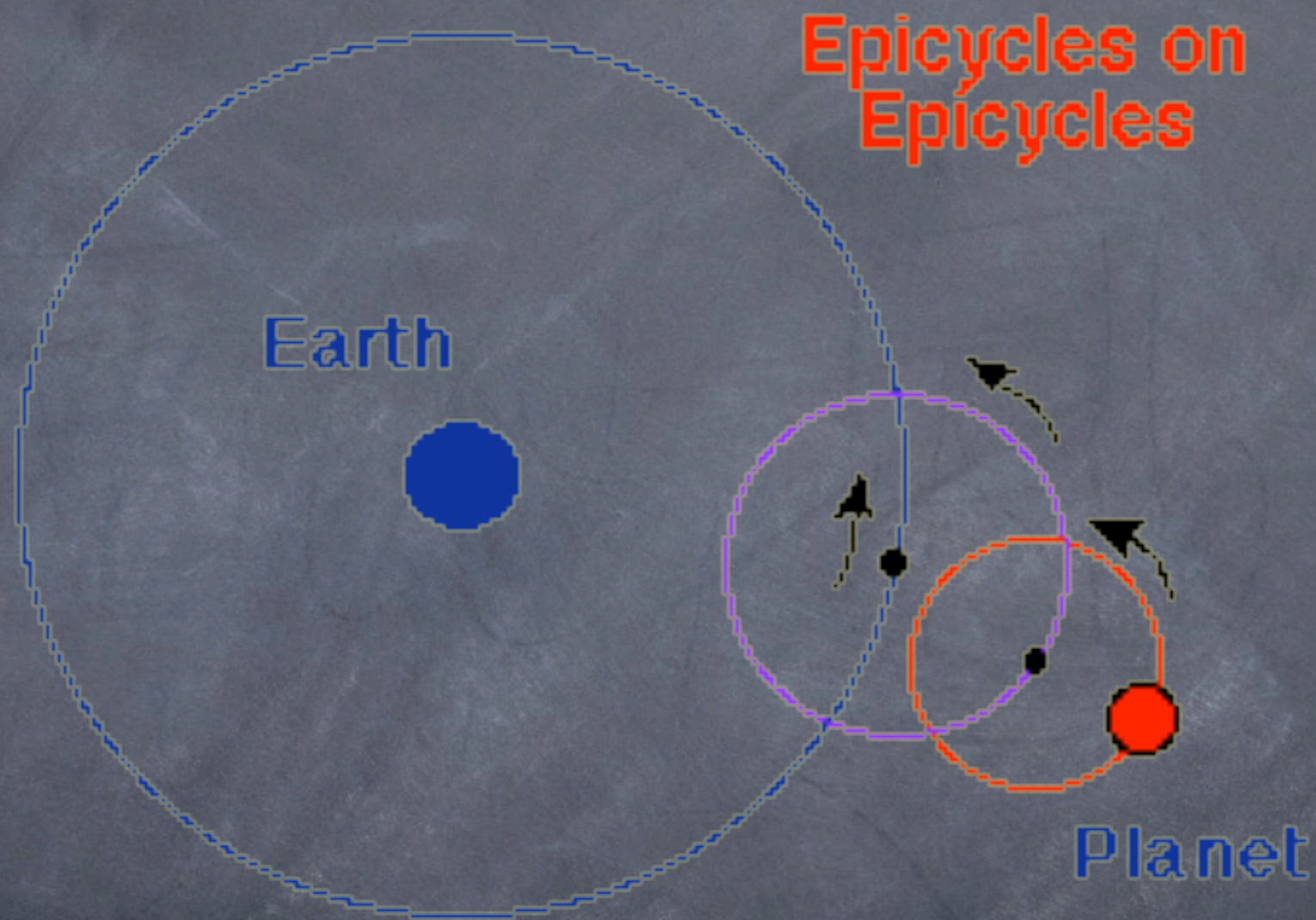
Retrograde motion

IF_03_33_MarRetgradeMotion.swf

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



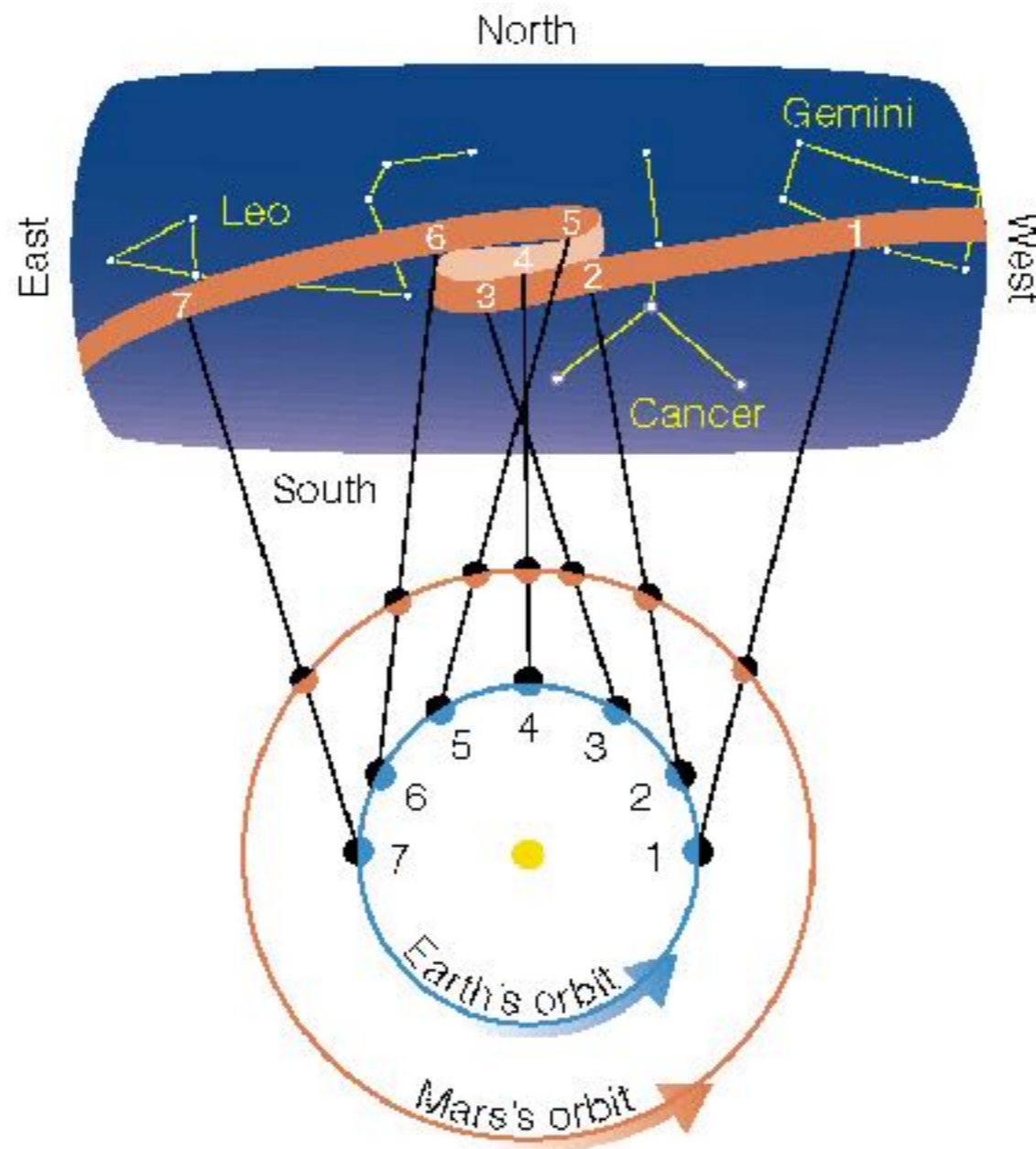
Ptolemaic Model



H.S. in epicycles

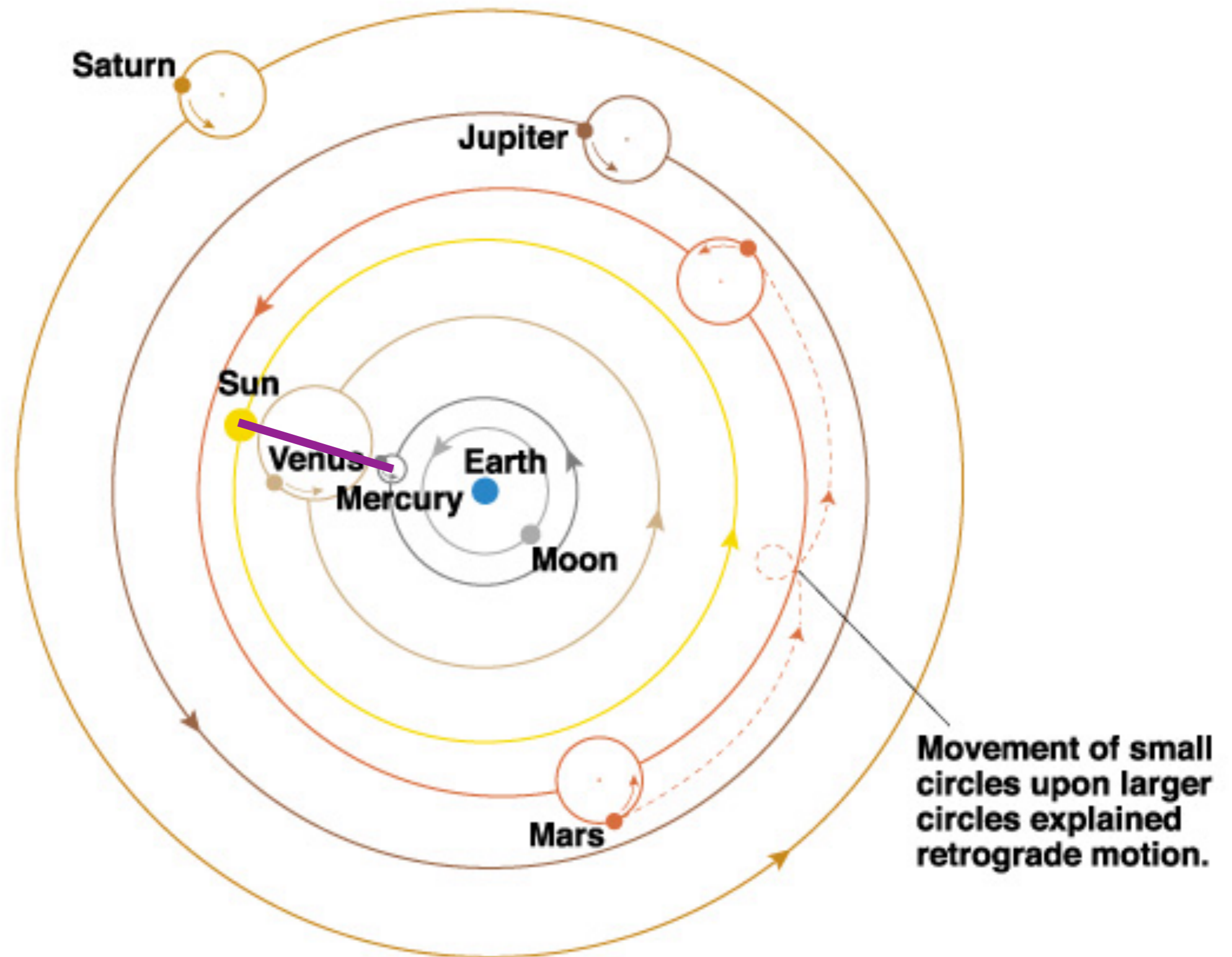
<https://www.youtube.com/watch?v=QVuU2YCwHjw>

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>

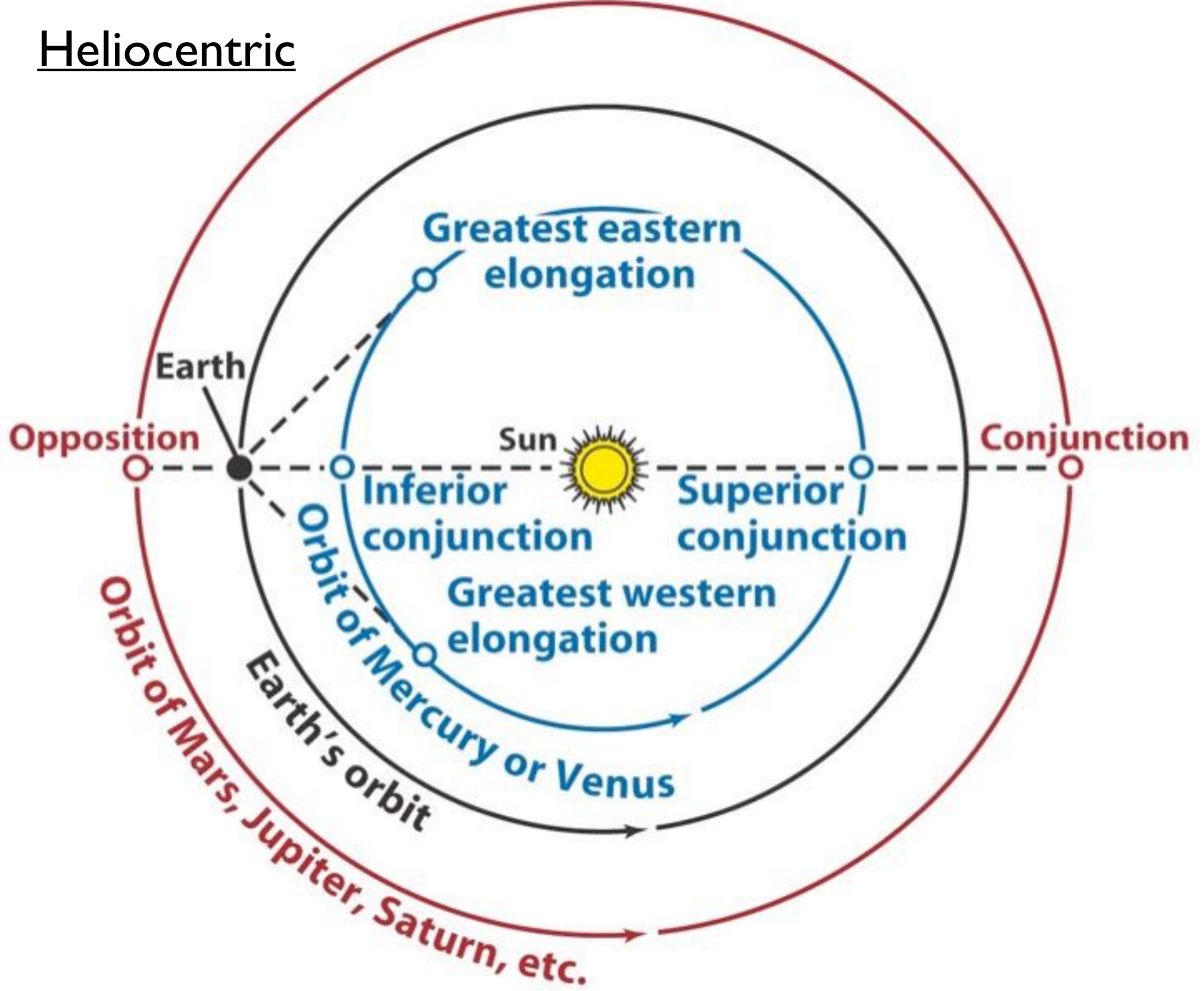
Geocentric Cosmology



Copyright © Addison Wesley

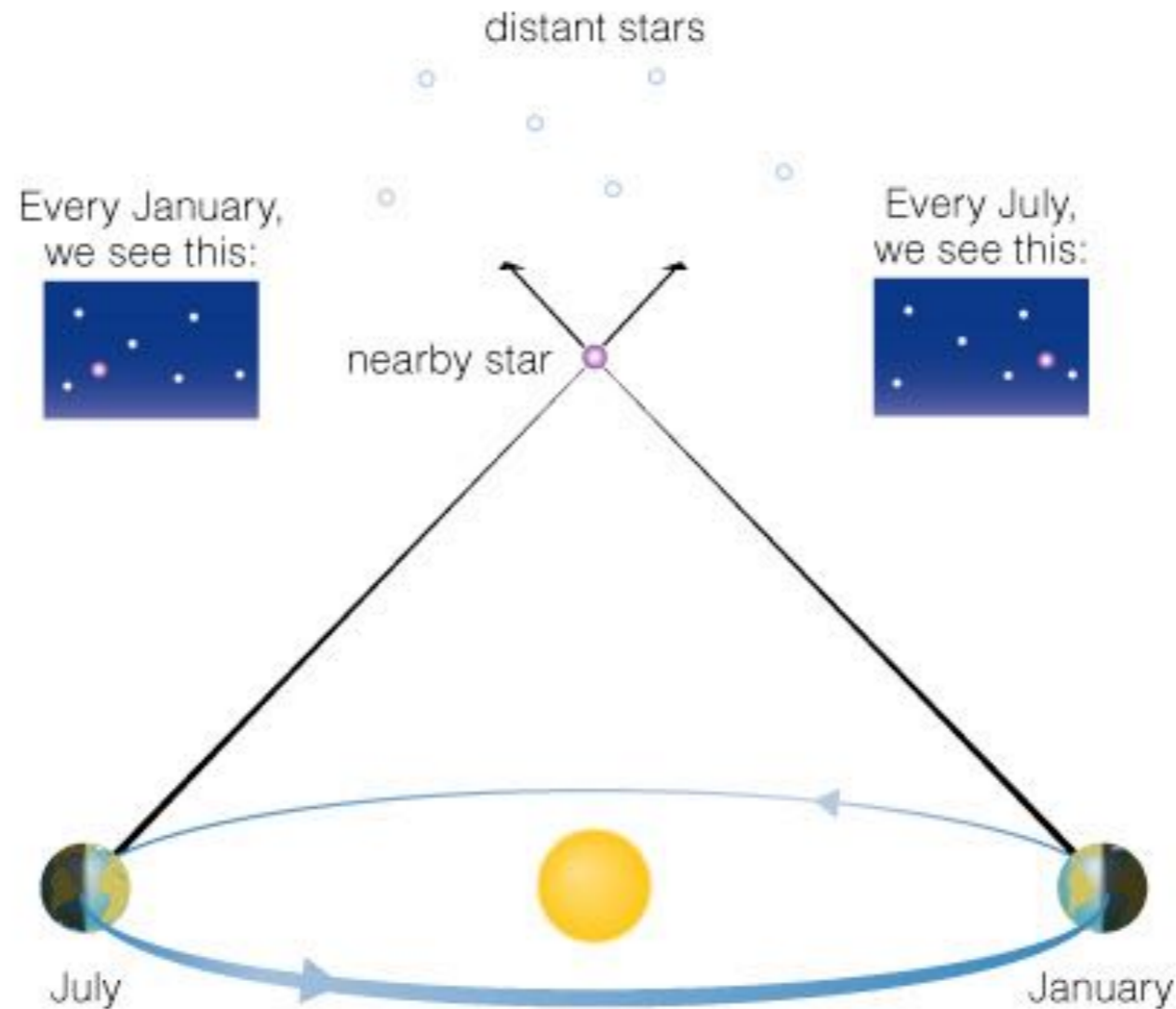
Mercury & Venus always close to sun on the sky

Heliocentric



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**.

Competing Cosmologies

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Ptolemaic

Earth at center

Heliocentric

Copernican

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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

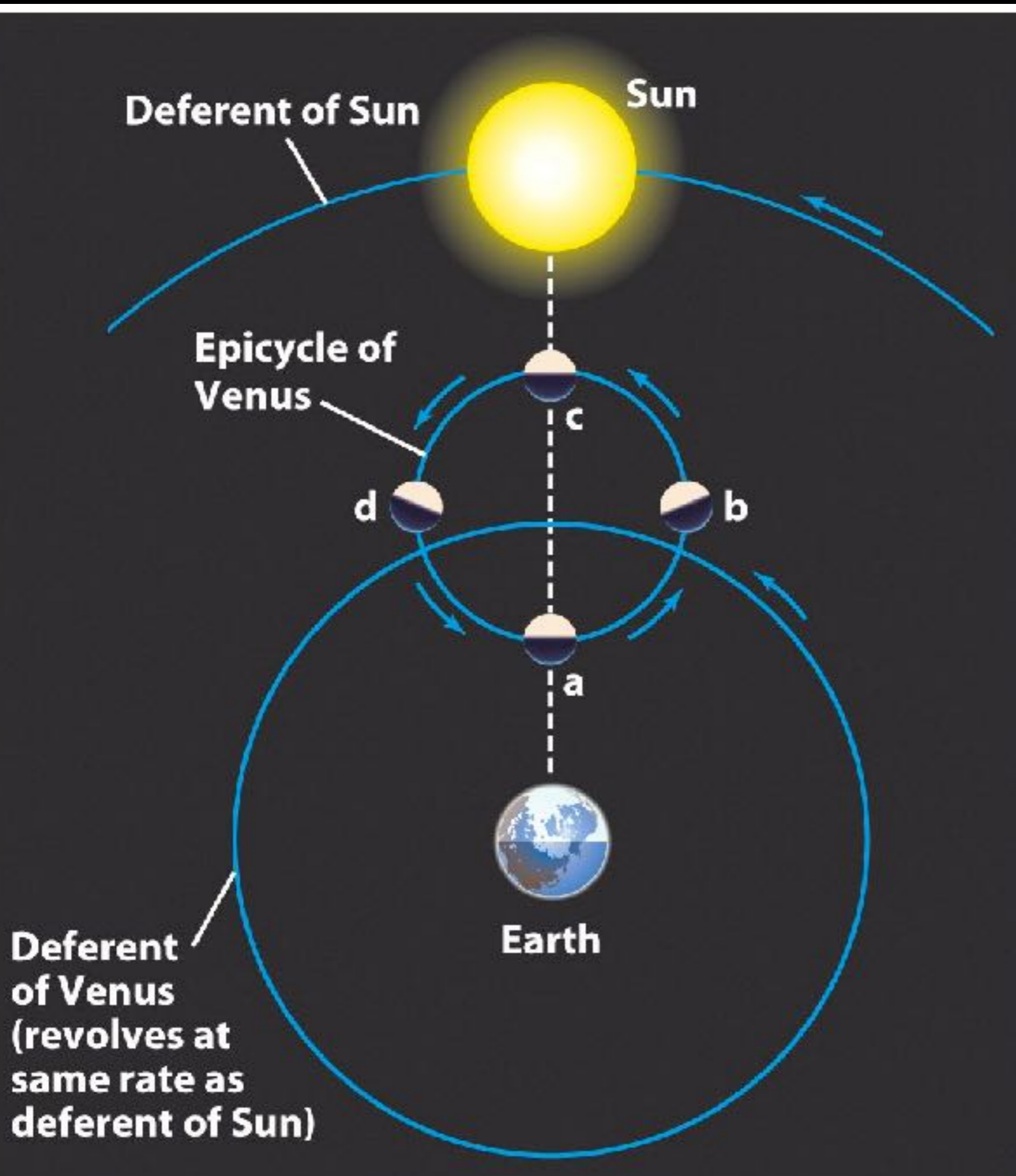
nicer

Predicts

- No parallax ✓
- Venus: crescent phase only

- Parallax X
- Venus: all phases
unknown to ancients

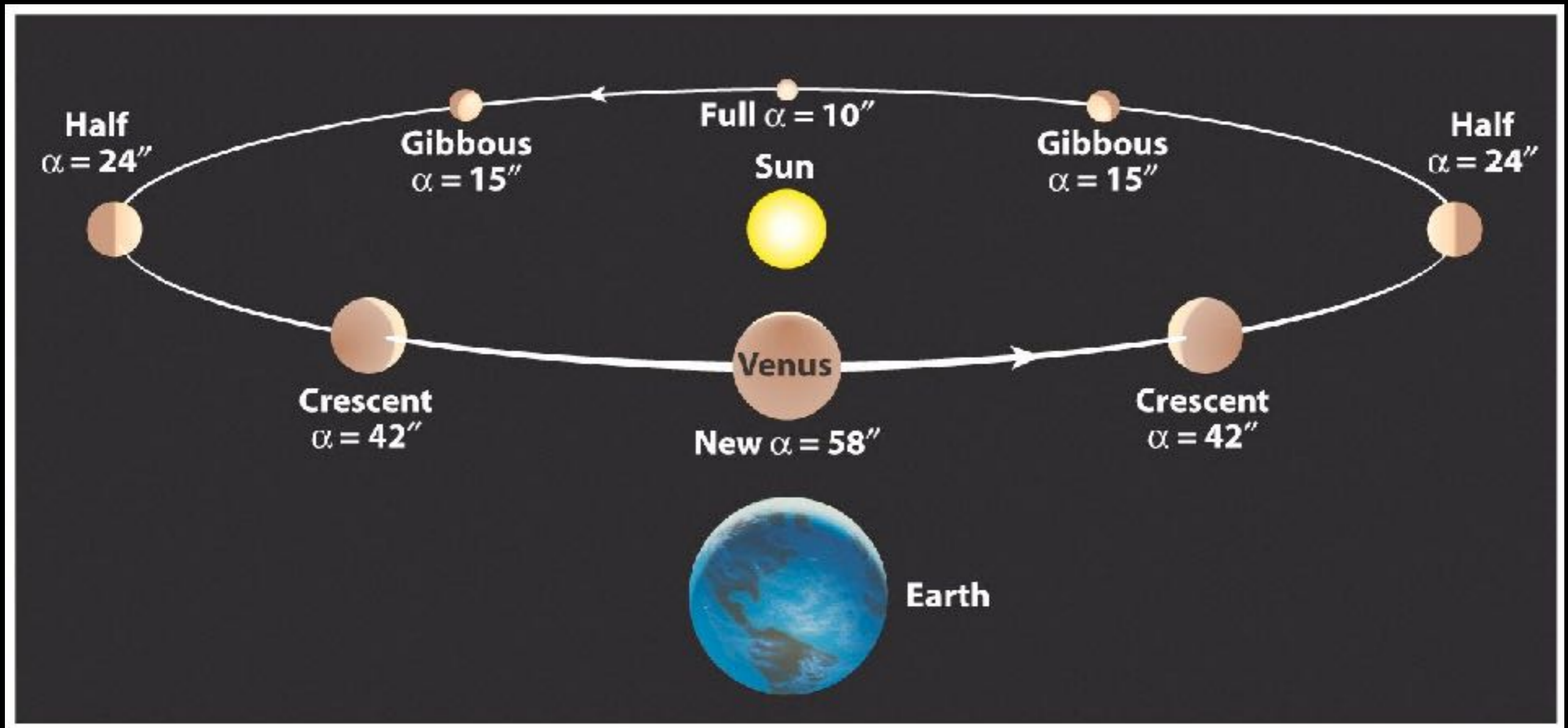
Geocentric



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

Heliocentric

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

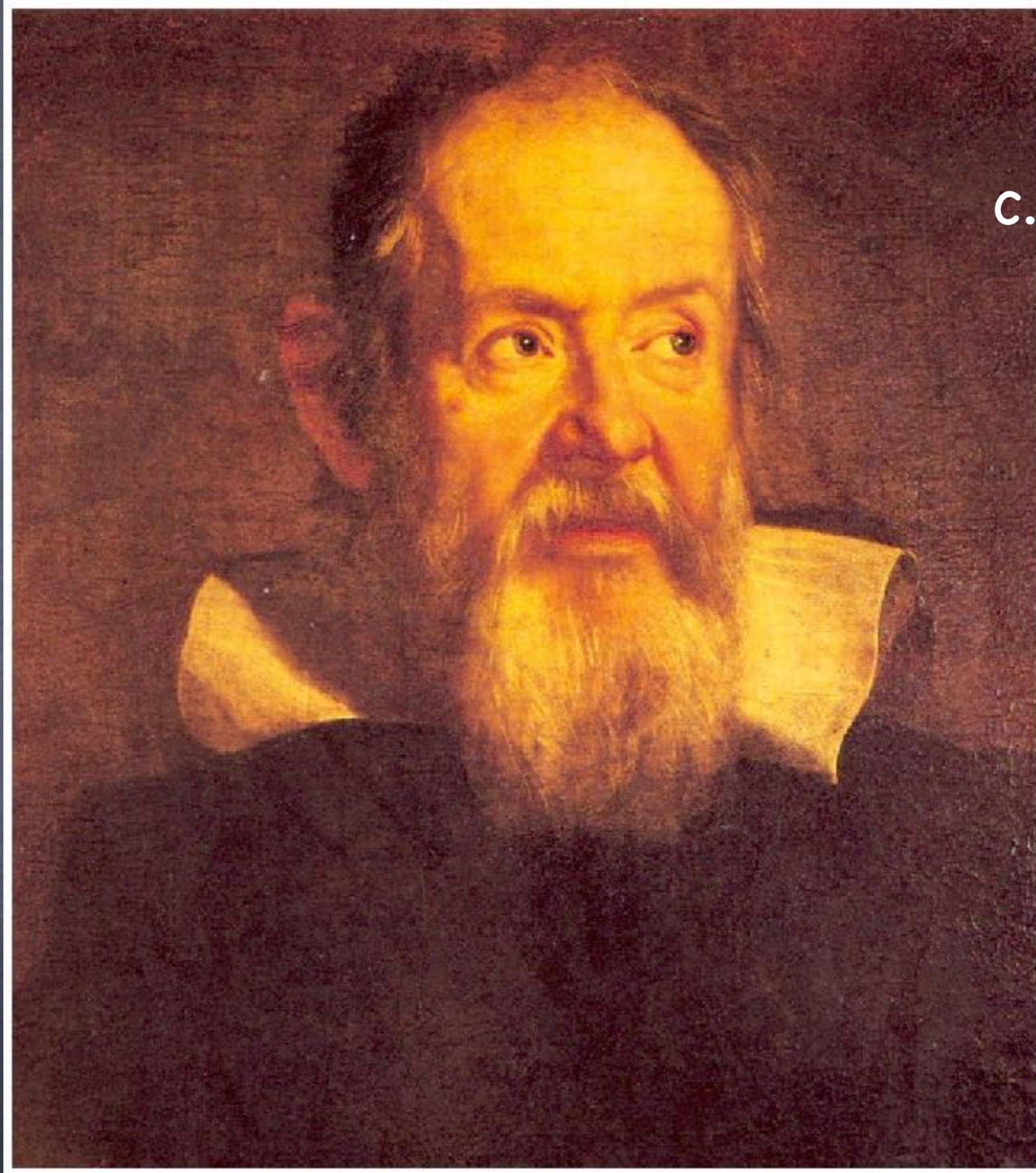


PLAY

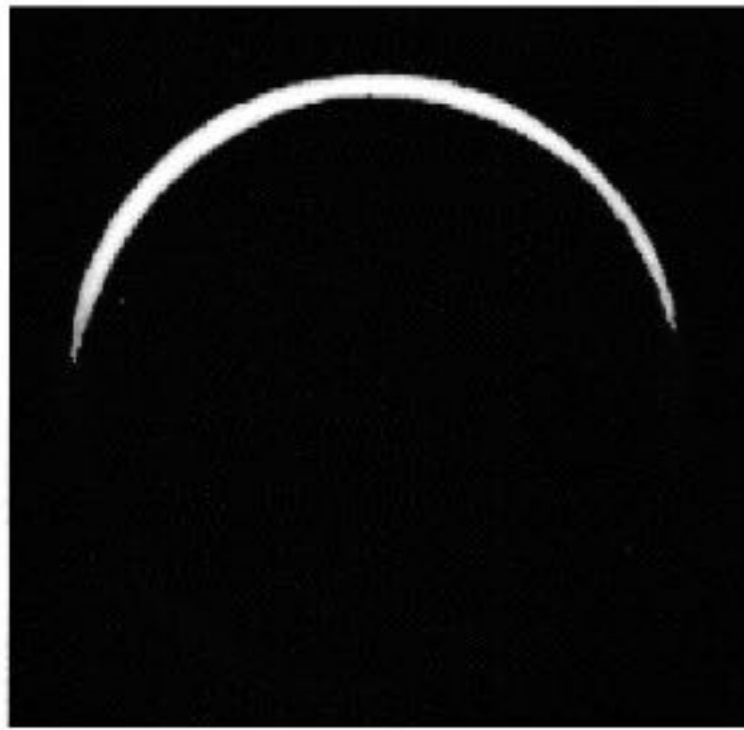
Phases of Venus

Galileo

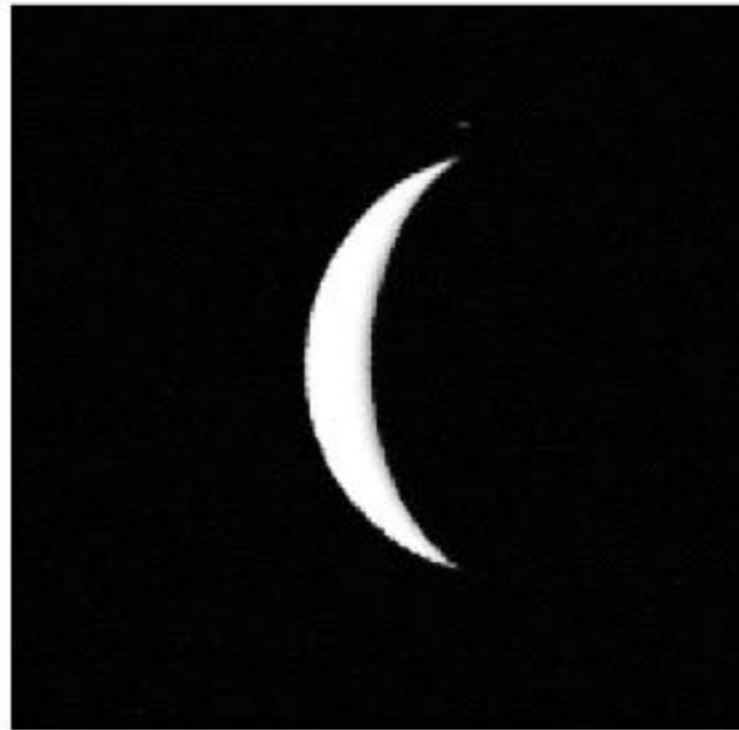
c. 1564–1640



First telescopic astronomical observations

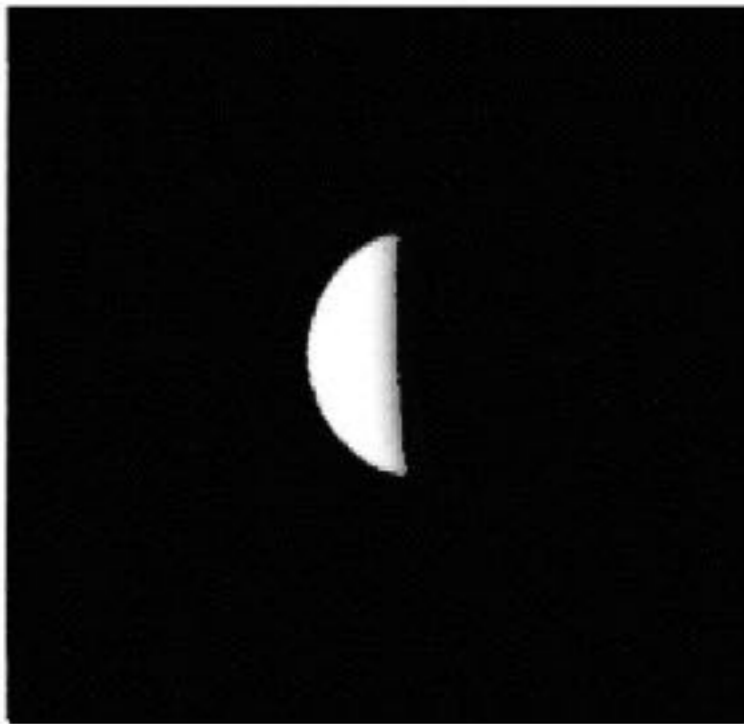


$\alpha = 58^\circ$

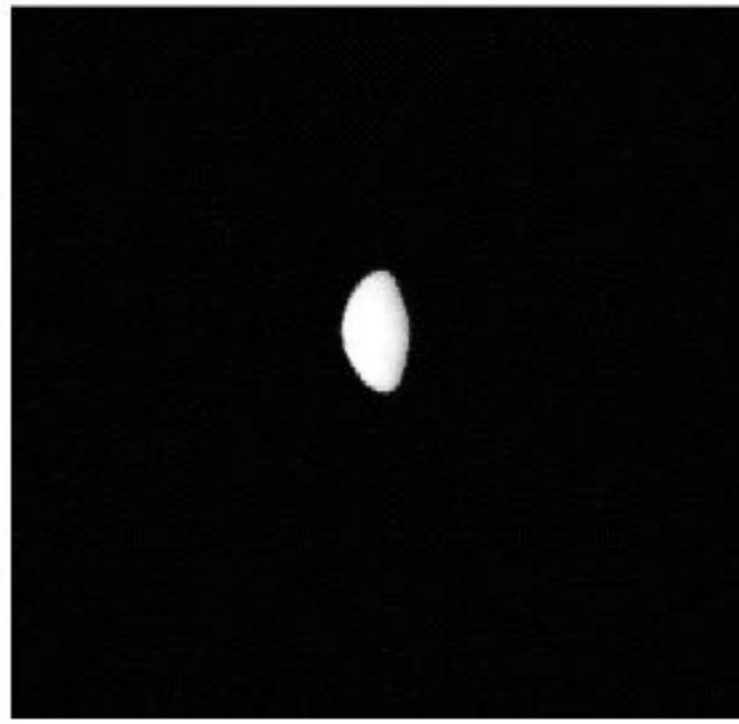


$\alpha = 42^\circ$

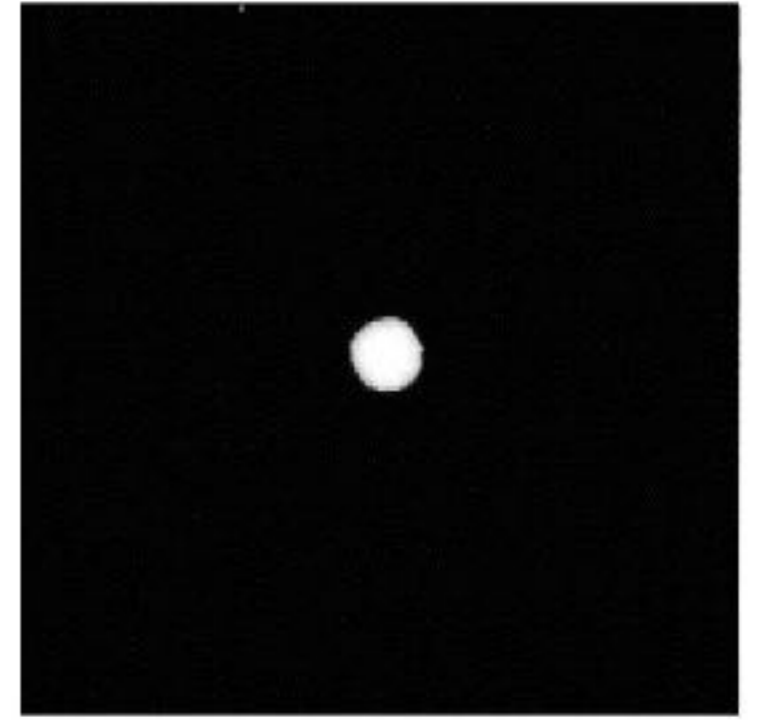
Phase and angular size of Venus depend on elongation (angle from sun)



$\alpha = 24^\circ$



$\alpha = 15^\circ$



$\alpha = 10^\circ$

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Ptolemaic

Earth at center

Heliocentric

Copernican

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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

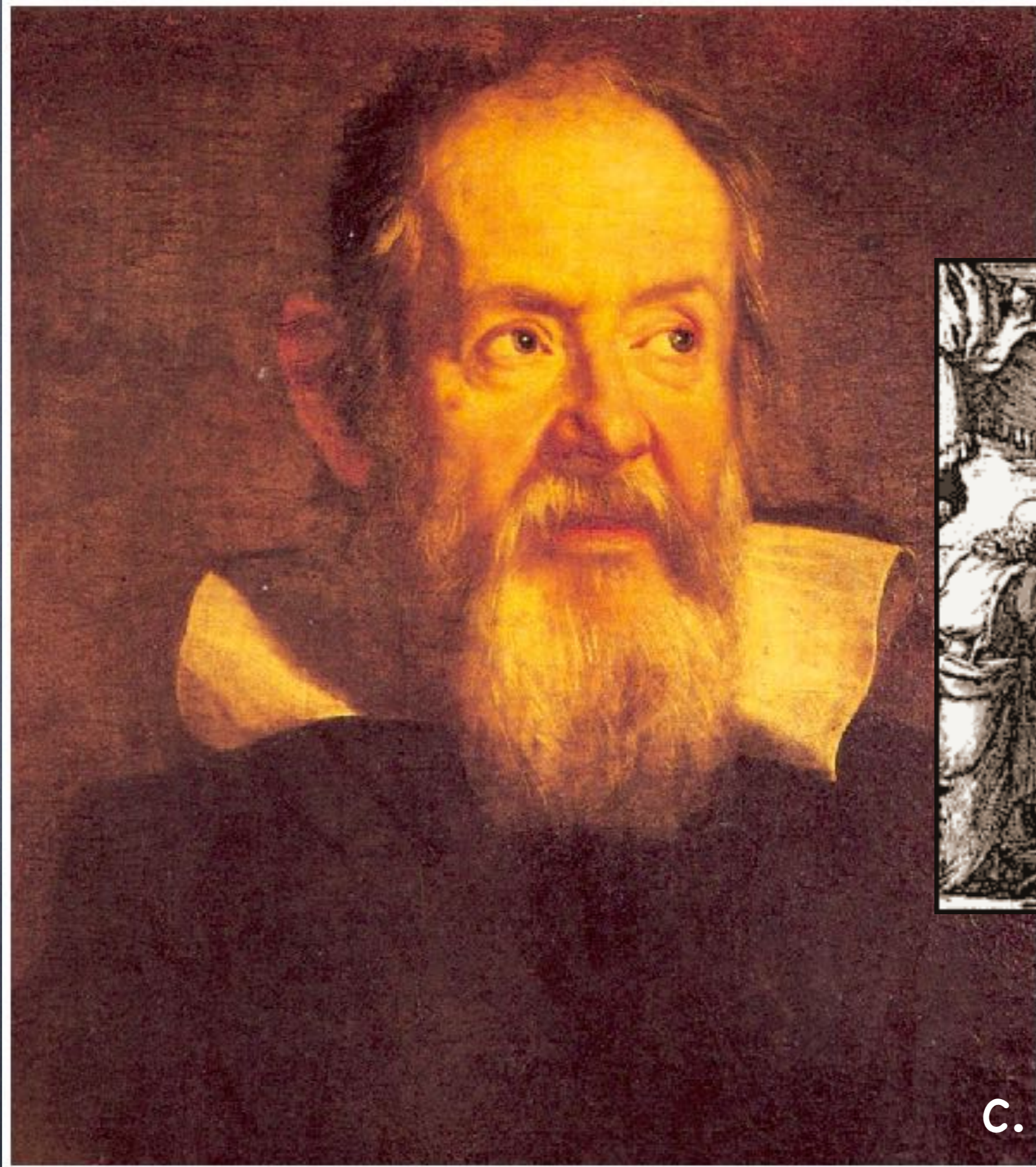
X

- 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

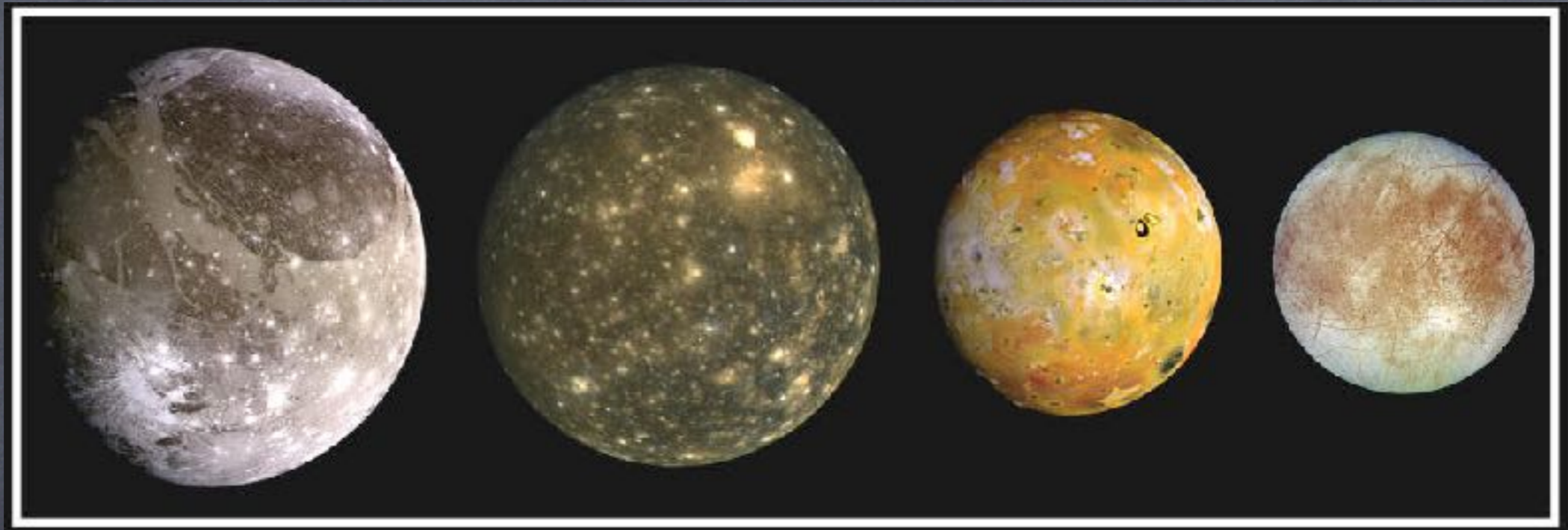
Galileo's telescopic discoveries

- 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

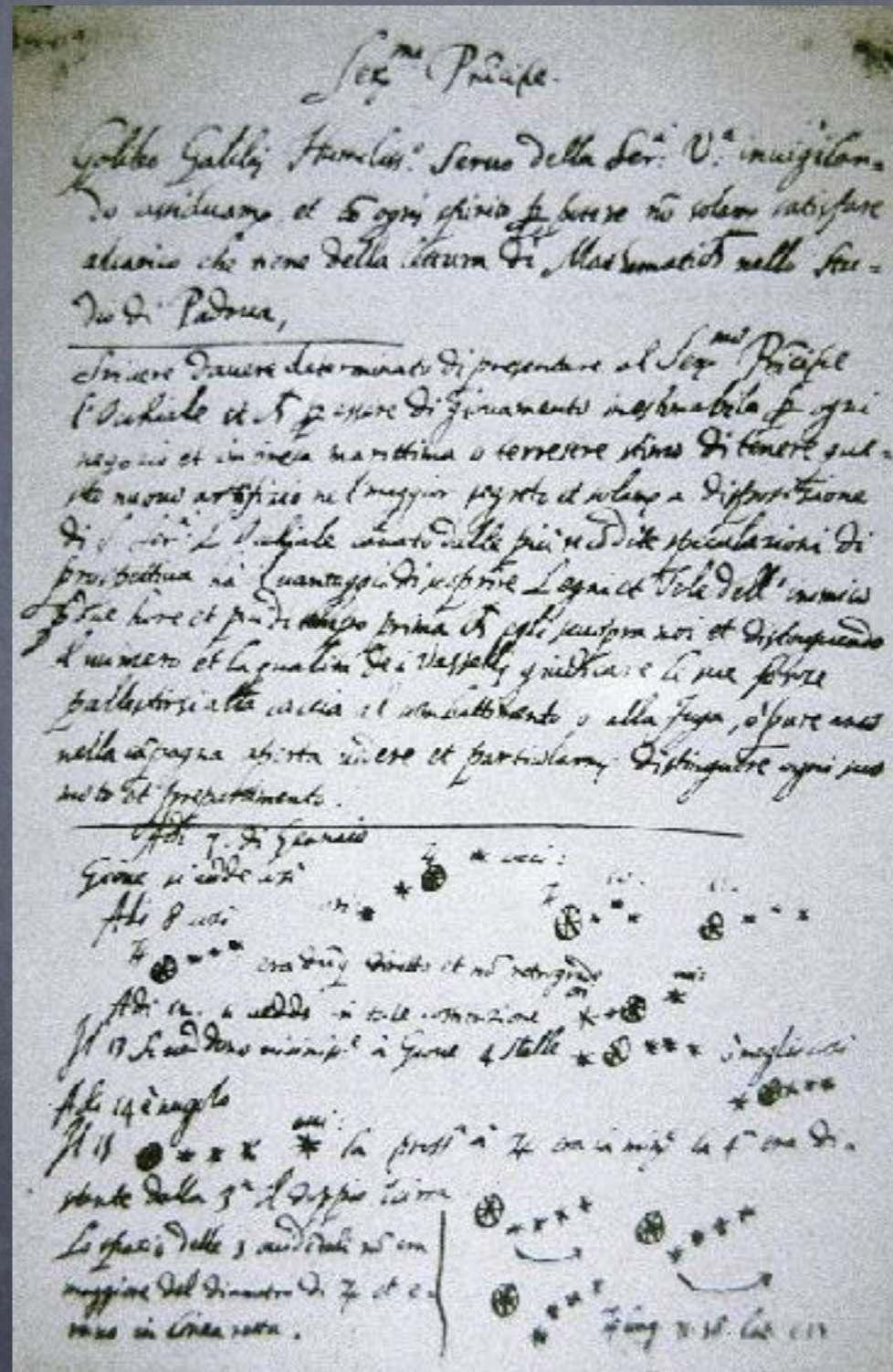
Jupiter and moons



Galilean moons (from Galileo spacecraft!)



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



Образовательный Деятель
1623

2. Д. Фриг.
марч H. 12

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10. марч

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13. марч

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14. марч

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"Medician
stars"

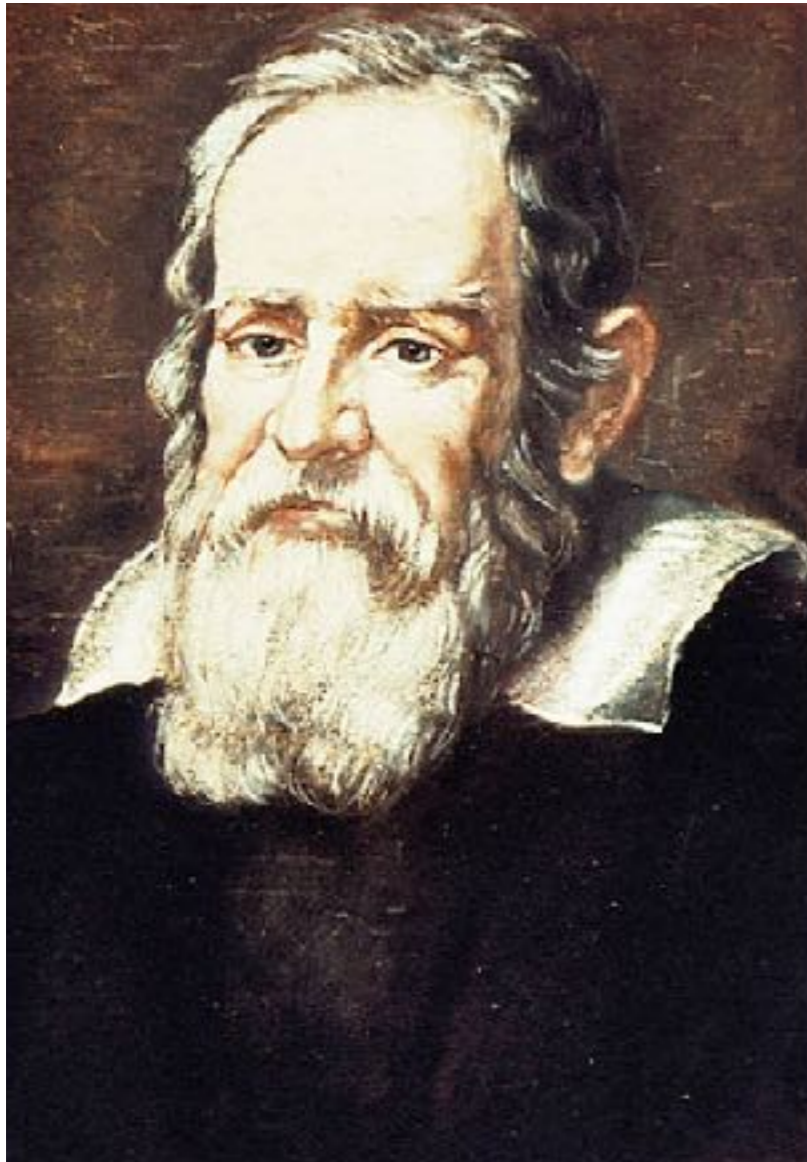
Heavenly
spheres
NOT
perfect



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):

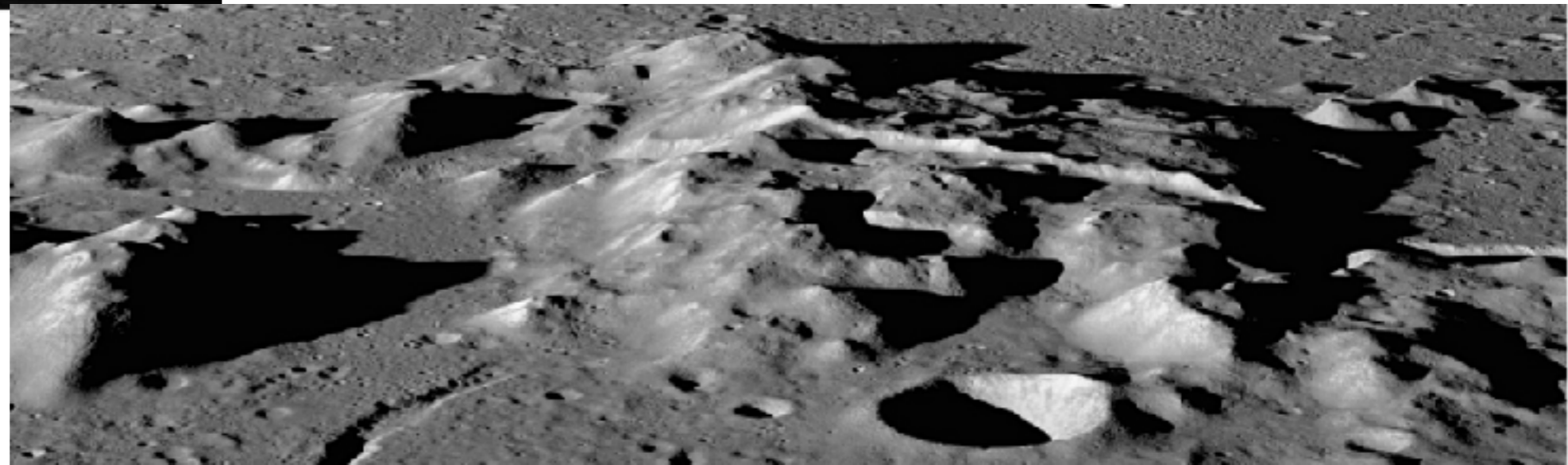
Galileo's experiments showed that objects in air would stay with a moving Earth.

- 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):



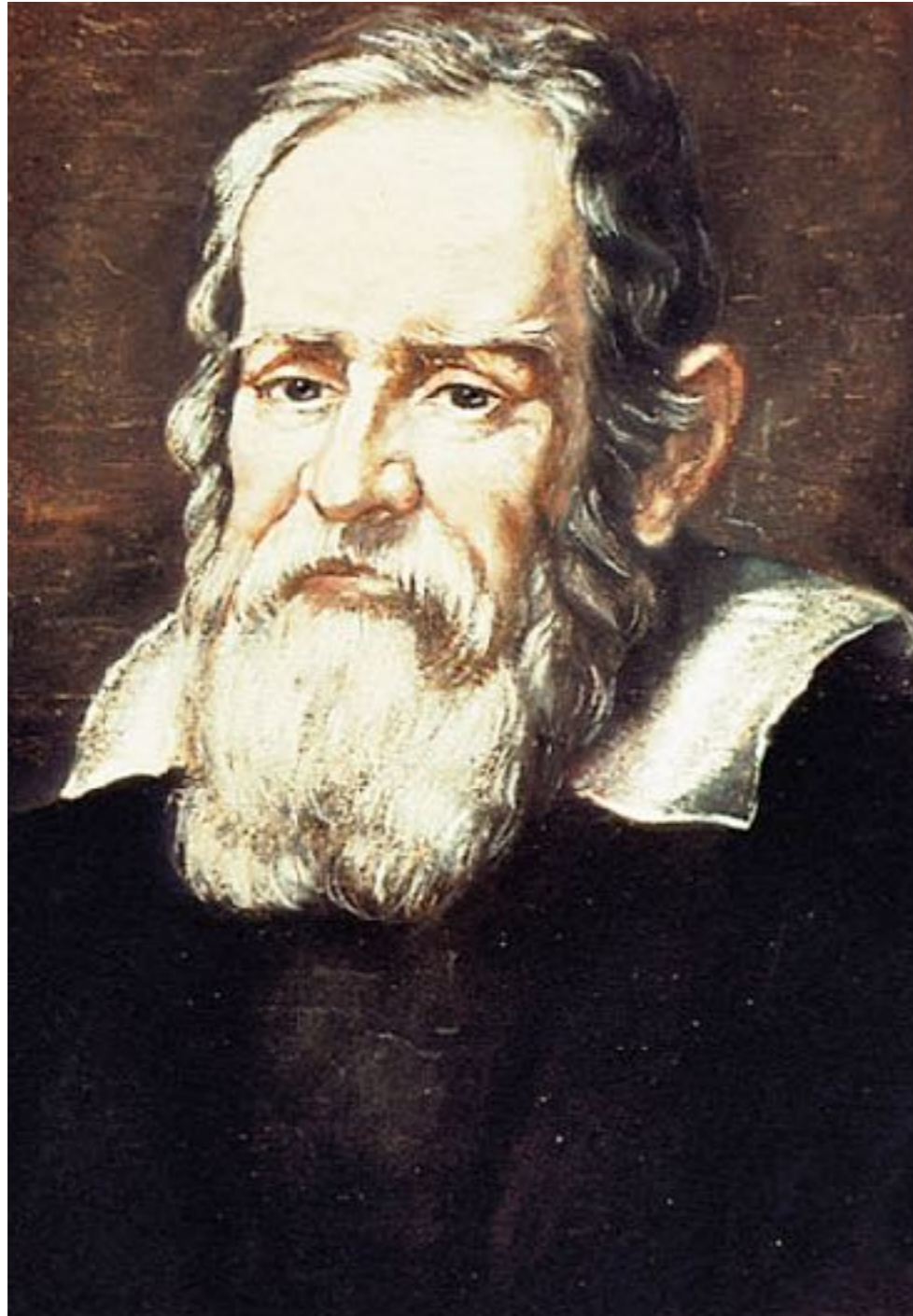
- Tycho's observations of comet and supernova already challenged this idea.
- Using his telescope, Galileo saw:
 - Sunspots on Sun (“imperfections”)
 - Mountains and valleys on the Moon (proving it is not a perfect sphere)



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 Novelty and Singularitie of this opinion, can be no sufficient reason to prove it erroneous.



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

That the Earth
may be a Planet

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