TODAY

FIRST HOMEWORK DUE

- ANCIENT ASTRONOMY

- COMPETING COSMOLOGIES

  - GEOCENTRIC VS. HELIOCENTRIC

  - PTOLEMY VS. COPERNICUS

    - RETROGRADE MOTION

    - PHASES OF VENUS

  - GALILEO

3.1 The Ancient Roots of Science

Our goals for learning:

- How did astronomical observations benefit ancient societies?
- What did ancient civilizations achieve in astronomy?

Astronomical observations were important to ancient societies

- In keeping track of time and seasons
  - — for practical purposes, including agriculture
  - — for religious and ceremonial purposes

- In aiding navigation
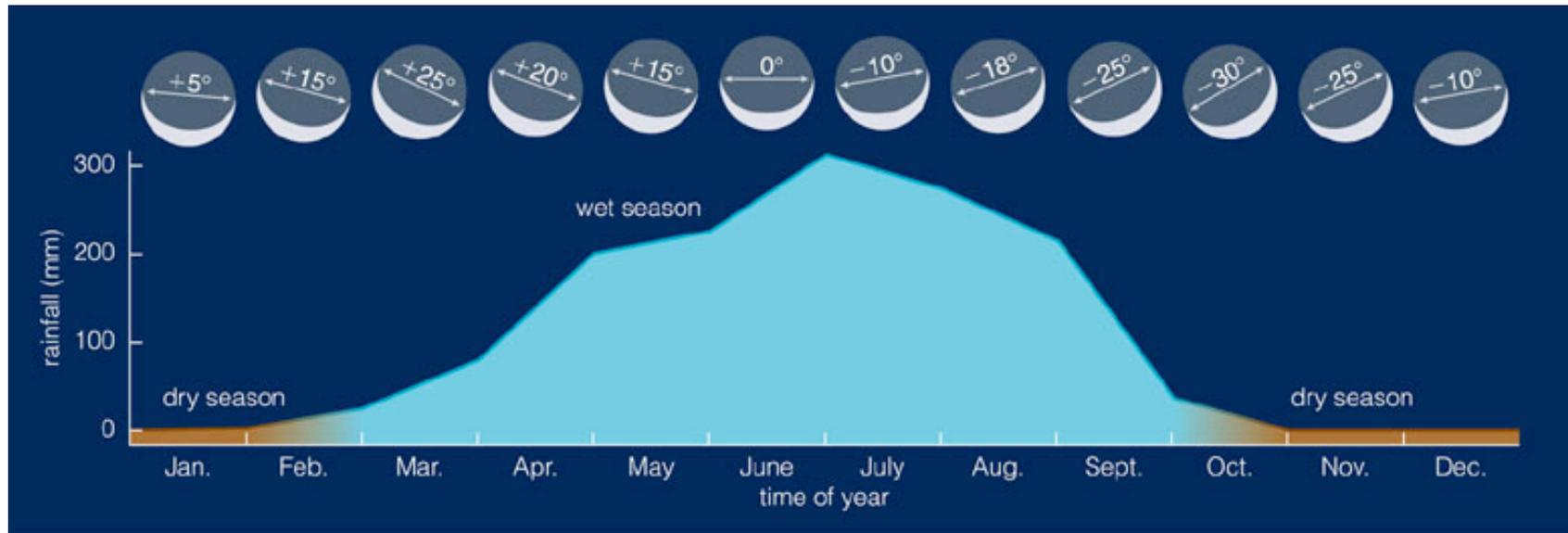
Ancient people of central Africa (6500 B.C.) could predict seasons from the orientation of the crescent moon.

Ancient achievements

- Daily timekeeping
- Tracking the seasons and calendar
- Monitoring lunar cycles
- Monitoring planets and stars
- Predicting eclipses
- Discovered precession
- And more…

Aztec calendar

5

- Egyptian obelisk:
  Shadows tell time of
  day.

England: Stonehenge (completed around 1550 B.C.)

Stonehenge

sunrise
(summer)

Heel Stone

sunset
(summer)

sunrise
(winter)

extreme
moonset

sunset
(winter)

extreme
moonrise

Aubrey holes

chalk banks

Copyright © Addison Wesley

8
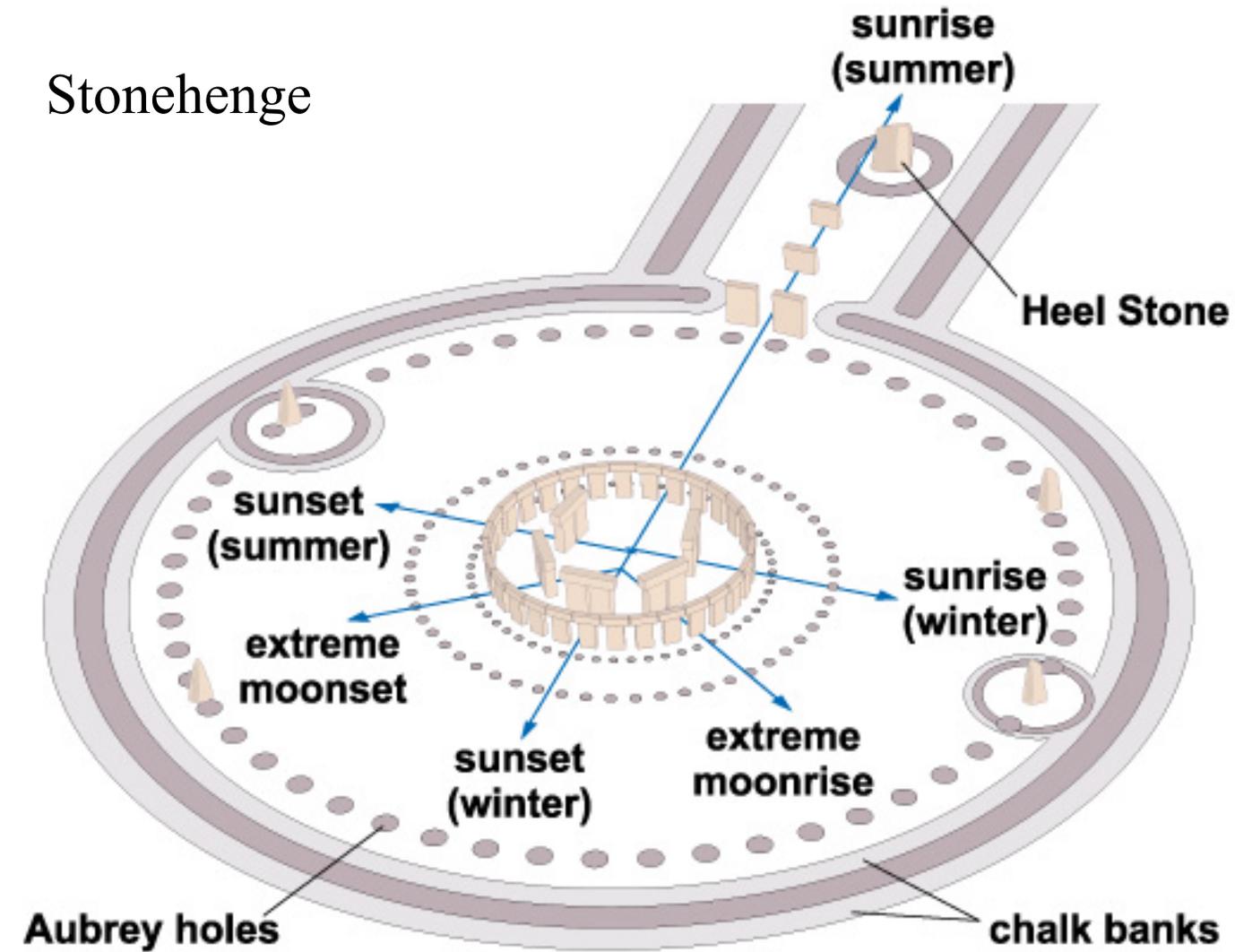
SW United States: "Sun Dagger" marks summer solstice

9

Scotland: 4,000-year-old stone circle; Moon rises as shown here every 18.6 years.

South Pacific: Polynesians were very skilled in the art of celestial navigation.
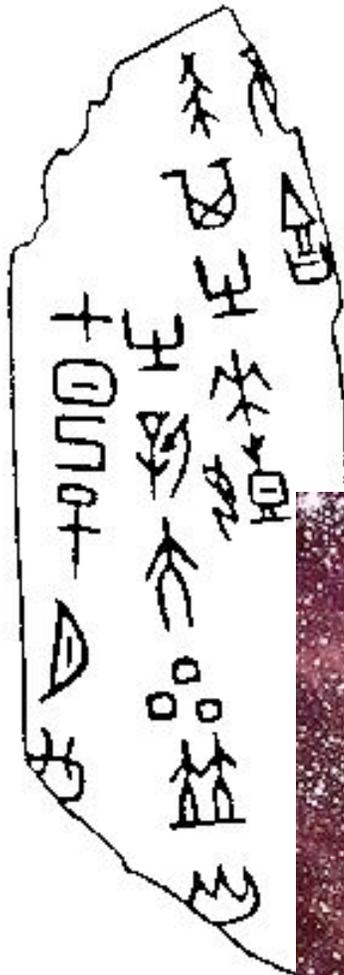
"On the Jisi day, the 7th day of the month, a big new star appeared in the company of the Ho star."

SN 1987A

...e new star dwindled."

© Anglo-Australian Observatory

China: earliest known records of supernova explosions (1400 B.C.)

12

Ancient Cosmology: A Flat Earth

Here there be dragons!

d 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.)

Measurements:
Syene to Alexandria
- distance ≈ 5,000 stadia
- angle = 7°
- i.e, 7/360 of the circumference

Alexandria
7°
light from the Sun
7°
7°
Syene
center of Earth
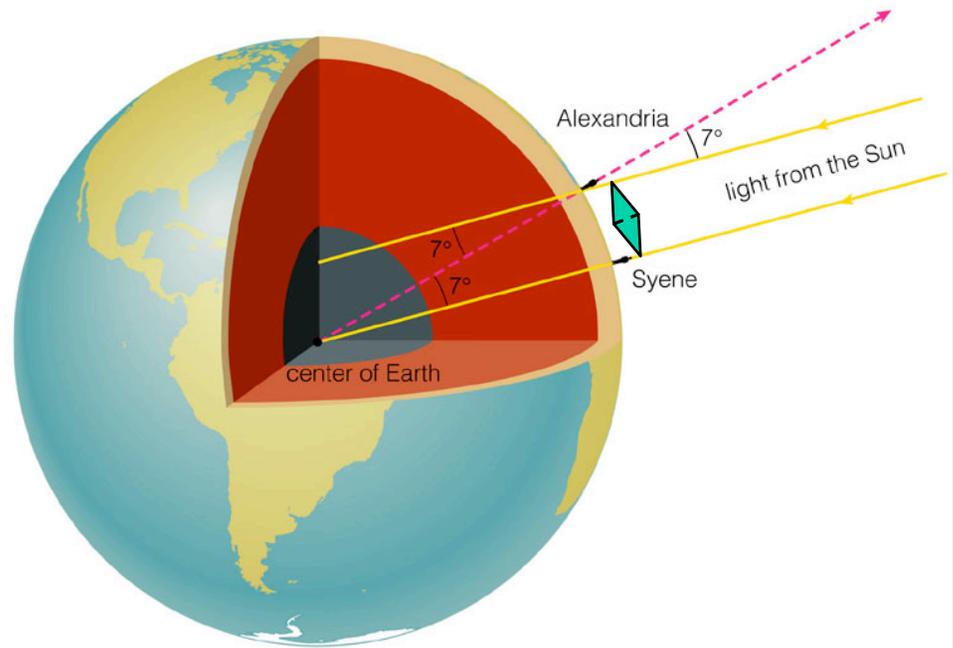
Calculate circumference of Earth:
(7/360) × (circum. Earth) = 5,000 stadia
⇒ circum. Earth = 5,000 × 360/7 stadia ≈ 250,000 stadia

Compare to modern value (≈ 40,100 km):
Greek stadium ≈ 1/6 km ⇒ 250,000 stadia ≈ 42,000 km

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

15

Competing Cosmologies

Geocentric
Ptolemaic
Earth at center

Heliocentric
Copernican
Sun at center

16
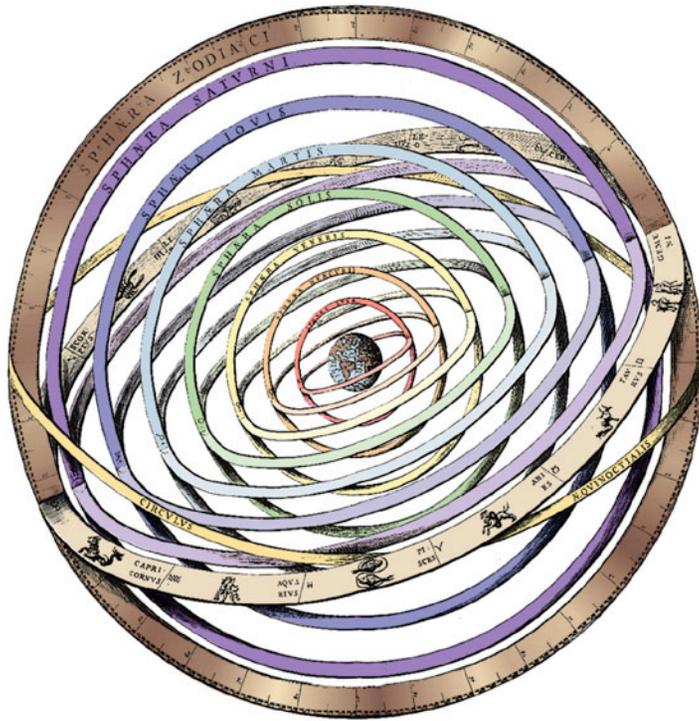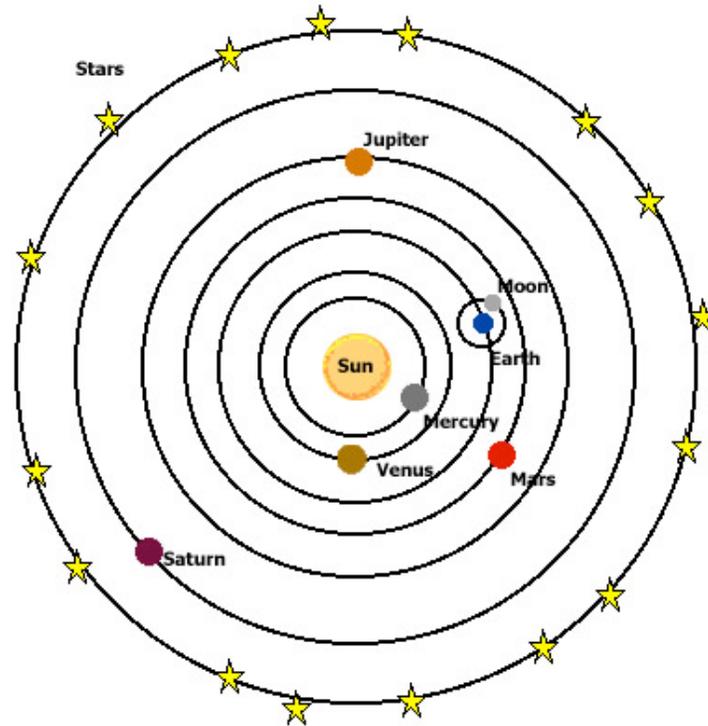
Earth- vs. Sun-Centered

To the ancients, which of the following would have been an argument in favor of a Sun-centered cosmology?

A. The Earth is clearly moving

B. The Sun is larger than the Earth, so it should be in the center

C. The Earth is corrupt, so it should move

D. None of the above

E. I don't know

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")

18

Geocentric Cosmology

Saturn

Jupiter

Sun

Venus

Mercury

Earth

Moon

Mars

Movement of small circles upon larger circles explained retrograde motion.
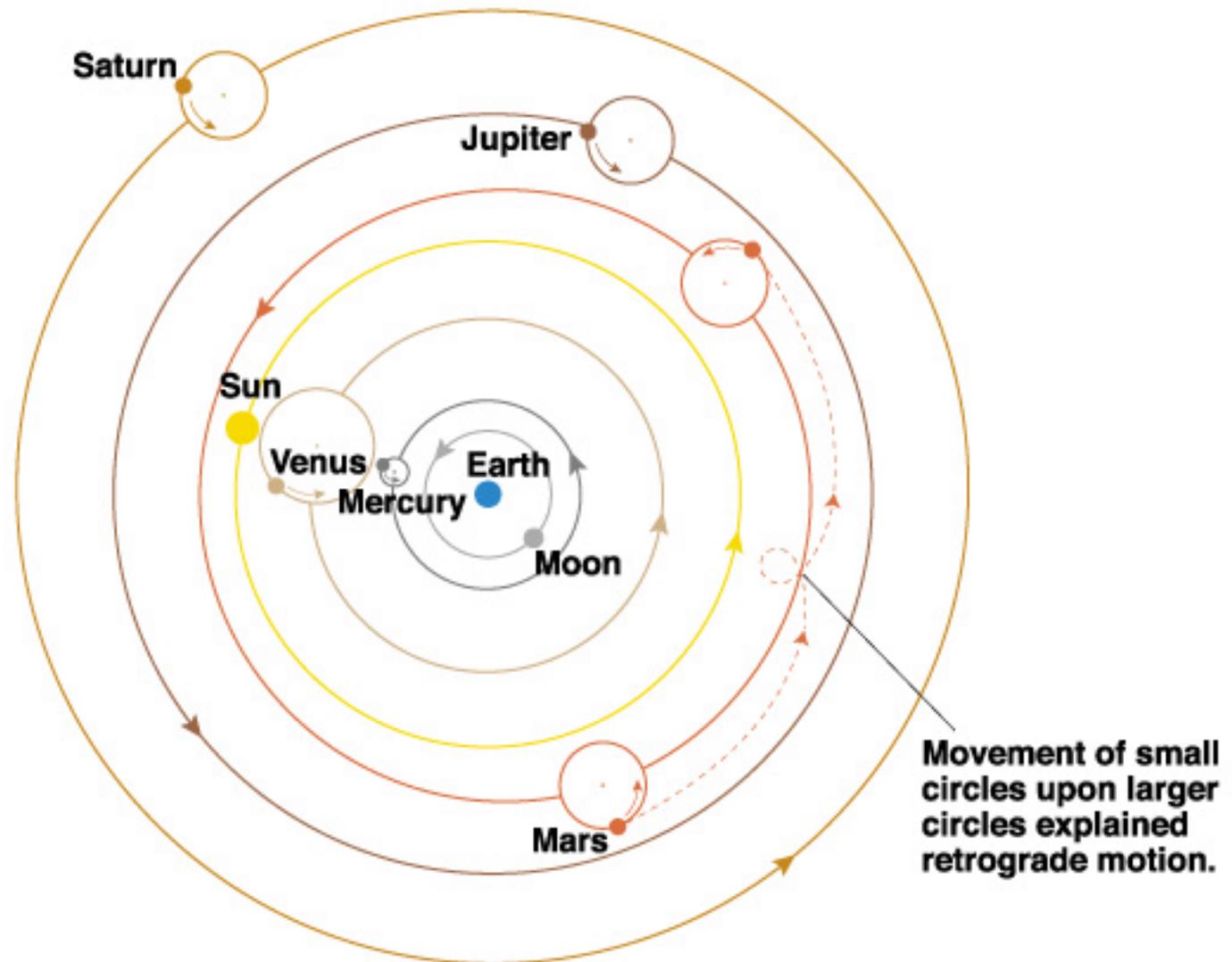
Heliocentric Cosmology
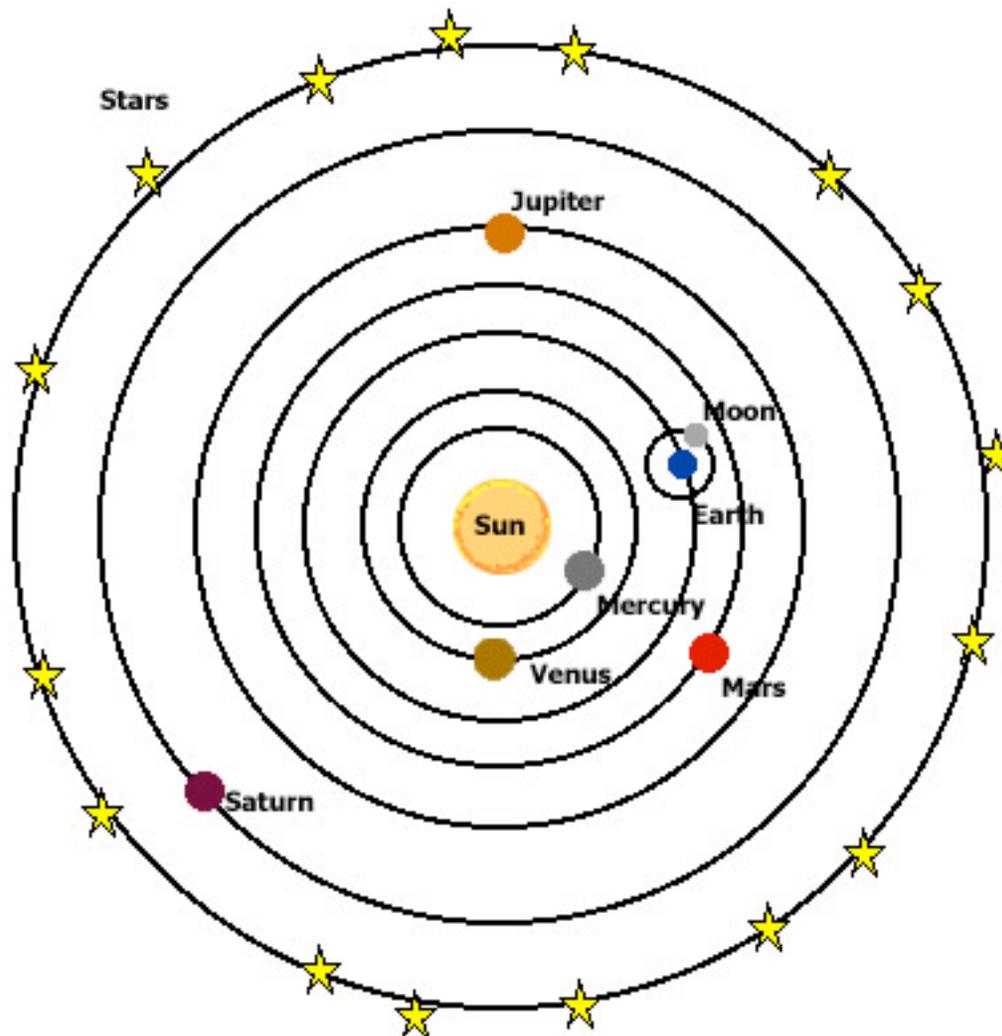
Heliocentric

Copernicus (1473–1543):

- He proposed the Sun-centered model (published 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.

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

Explains

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

Hard to tell the difference!

22

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

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.**

Dots represent Jupiter's approximate position at 1-month intervals. (*Jupiter not to scale.*)

Virgo

Jan. 2007

Sept. 2007

Feb. 2008

May 2007

Dec. 2006

Feb. 2008

Dec. 2007

Sagittarius

Scorpius

November

July 30

June

Sept. 29

Aug. 27
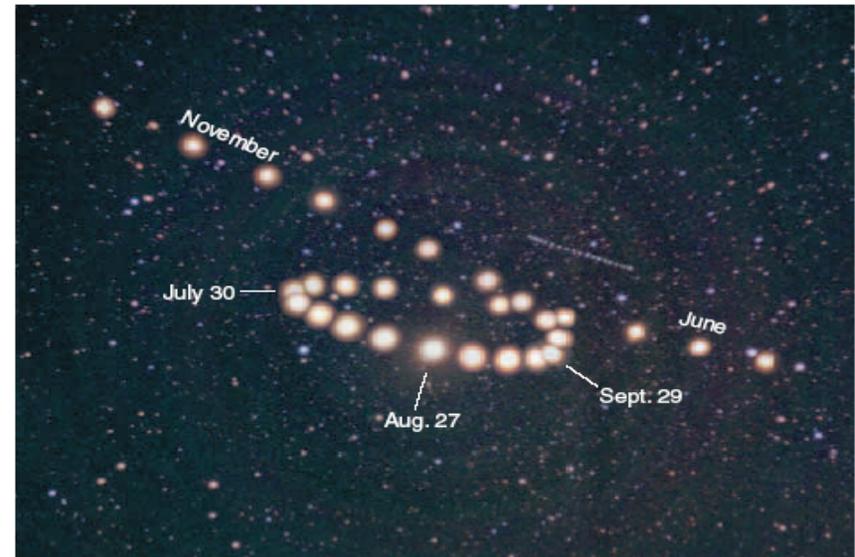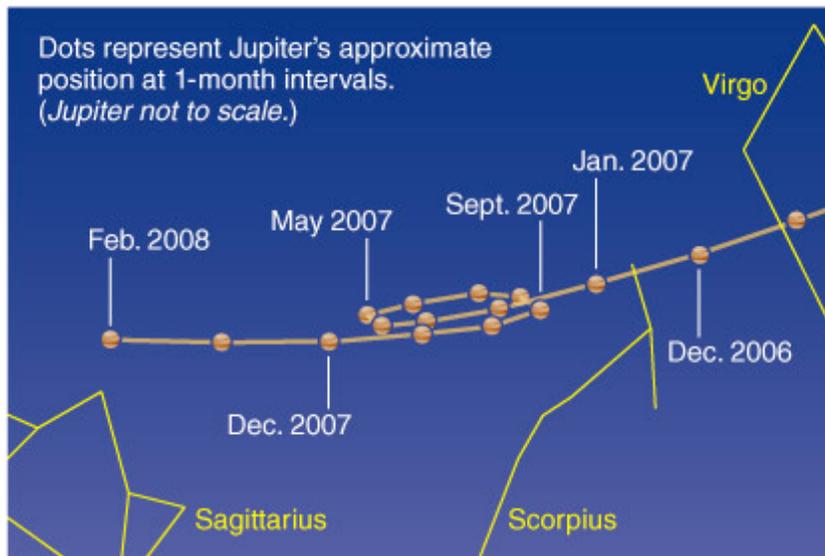
In the **Ptolemaic** model, planets *really do* go backwards.

planet

main orbit

epicycle

retrograde loop
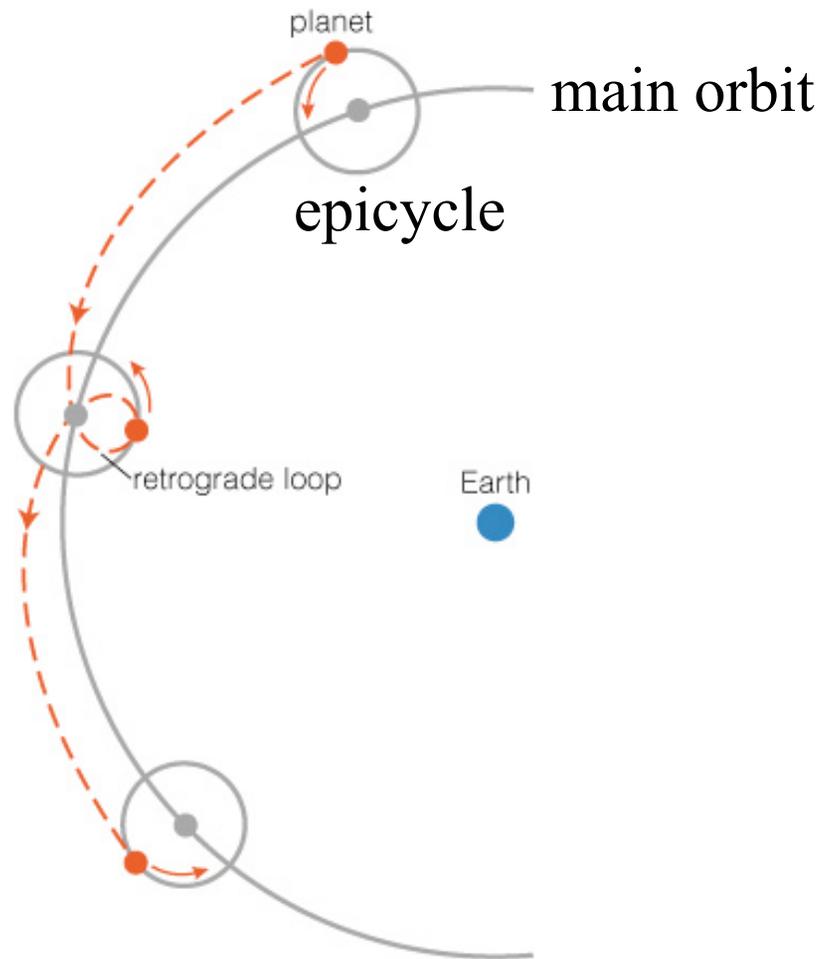
Earth

Epicycles on Epicycles
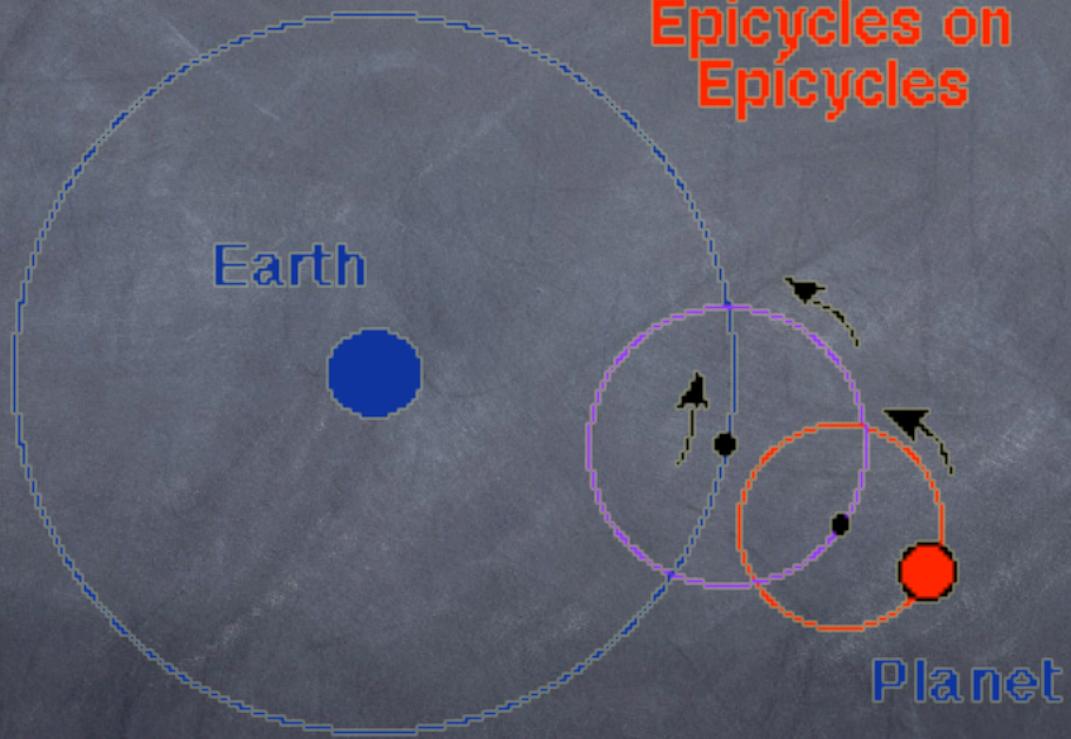
Earth

Planet

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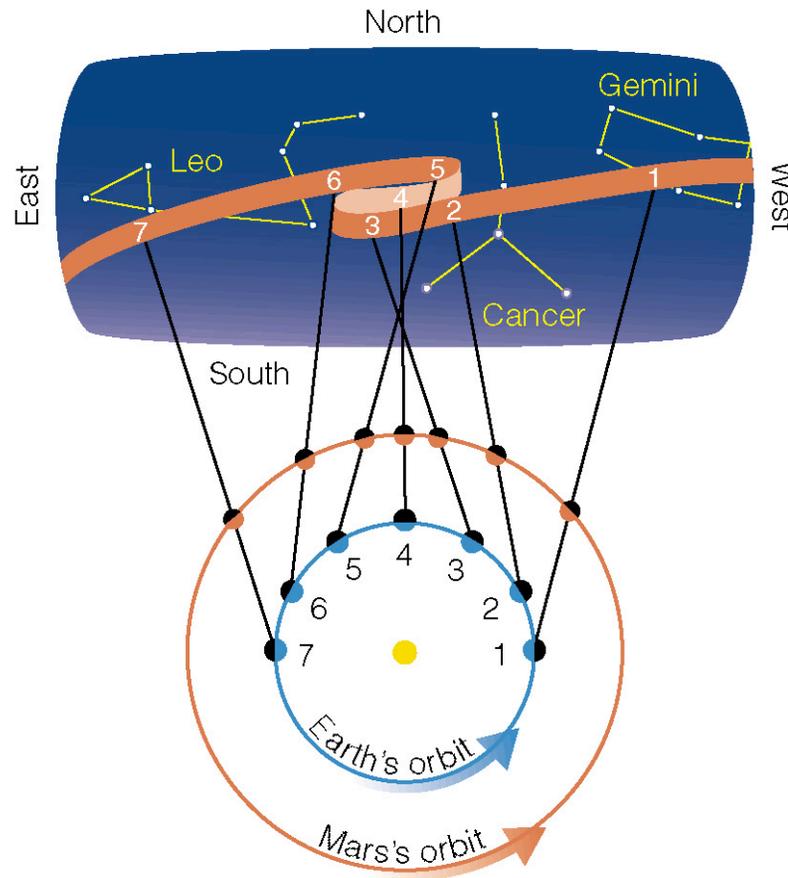
Competing Cosmologies

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

Retrograde Motion

Needs epicycles   Consequence of Lapping

Inferiority of Mercury & Venus

Must tie to sun   Interior to Earth's Orbit

Geocentric Cosmology

Saturn

Jupiter

Sun

Venus

Earth

Mercury

Moon

Mars

Movement of small circles upon larger circles explained retrograde motion.
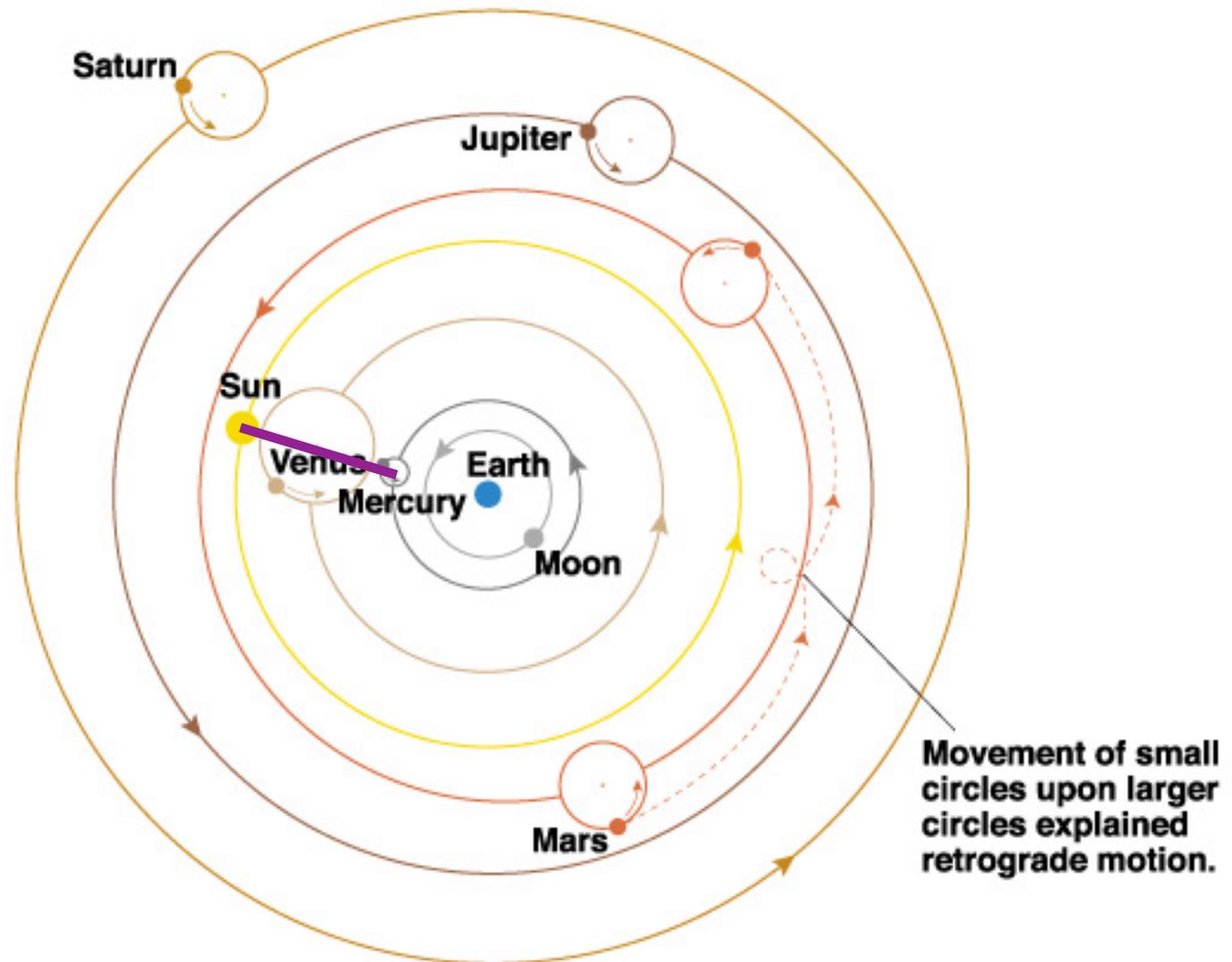
Copyright © Addison Wesley

Mercury & Venus always close to sun on the sky

Heliocentric
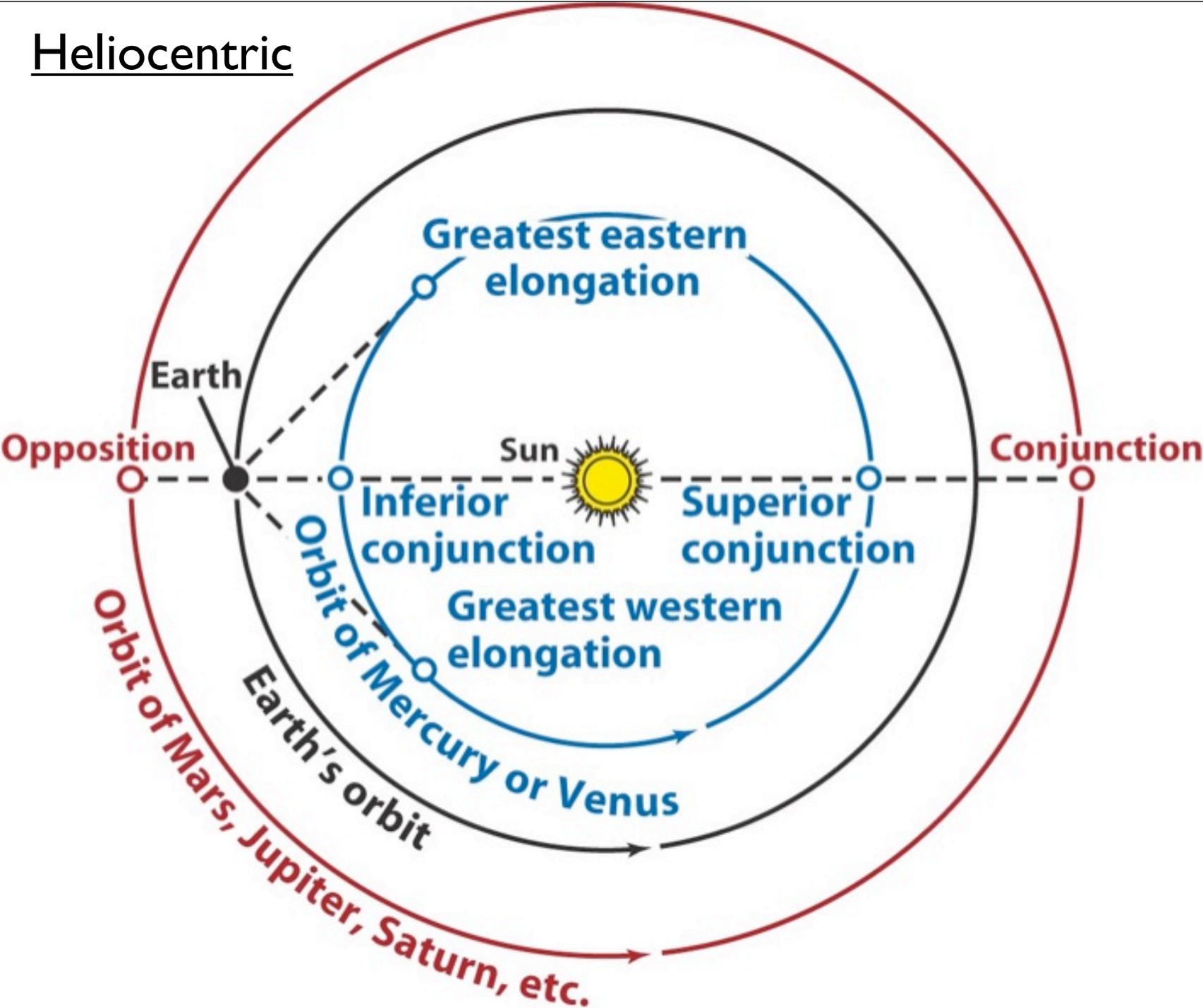
Competing Cosmologies

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**

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

31

Parallax

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

distant stars

Every January, we see this:

nearby star

Every July, we see this:

July

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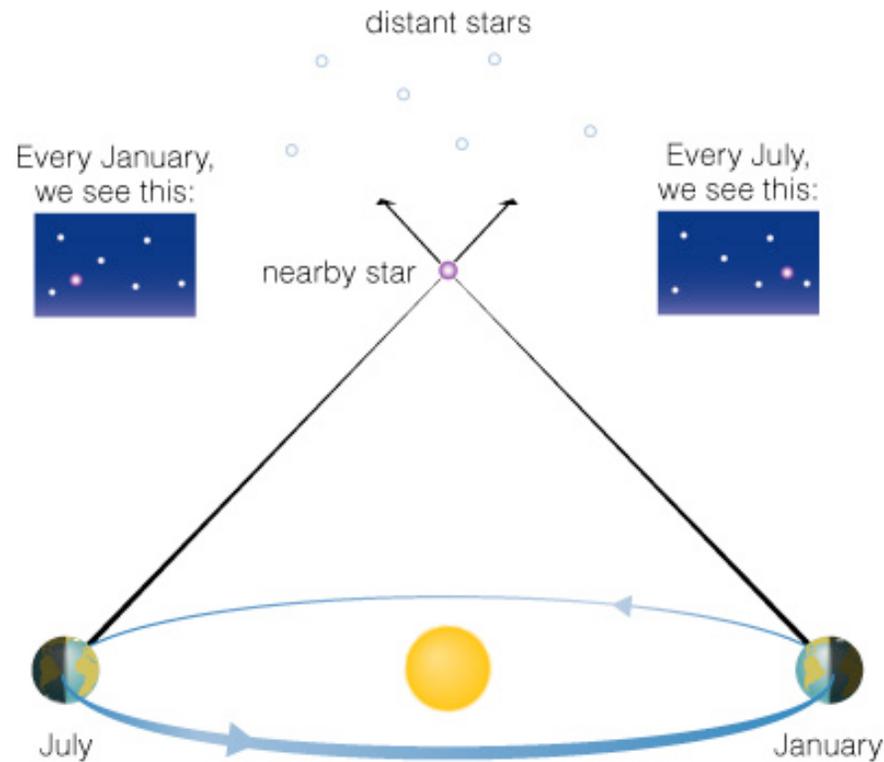
- The ancients could not detect **stellar parallax**.

32

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**

Explains

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

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 ✓   - Parallax **X**
- Venus: crescent phase only   - Venus: all phases

**unkown to ancients**

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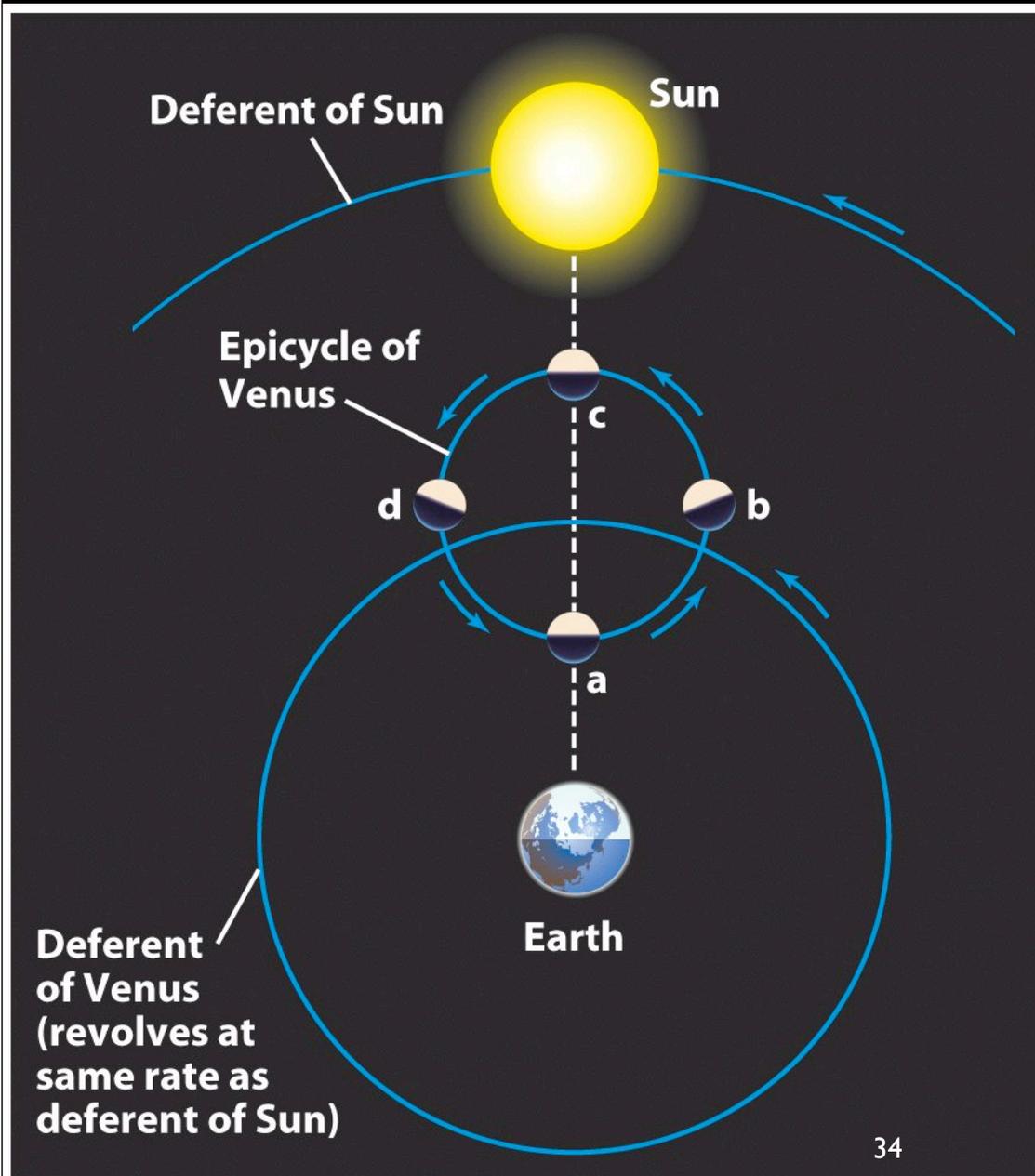
Only crescent phase can be observed - never full or even gibbous

Heliocentric

The full range of phase can be observed
- from crescent to full
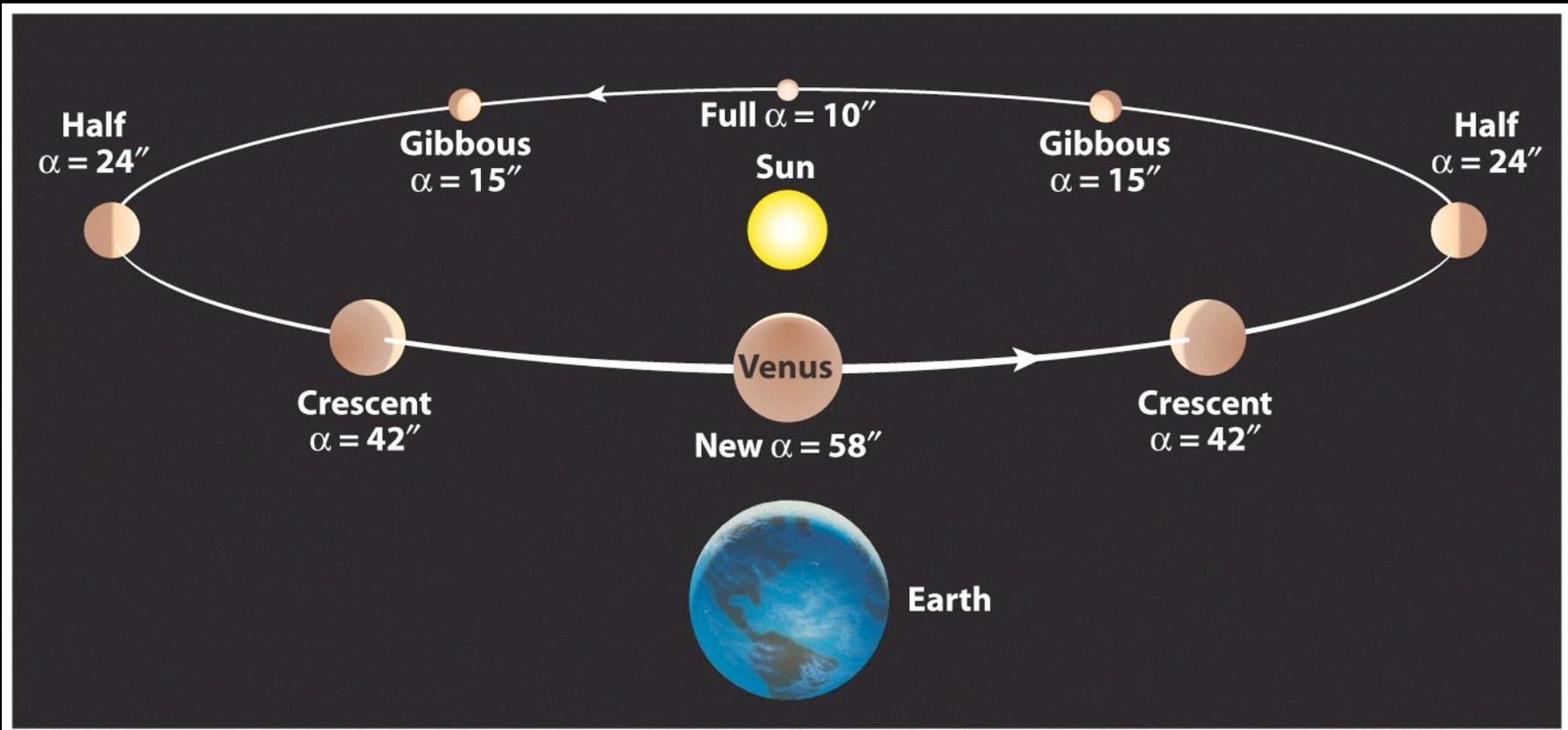
Phases of Venus
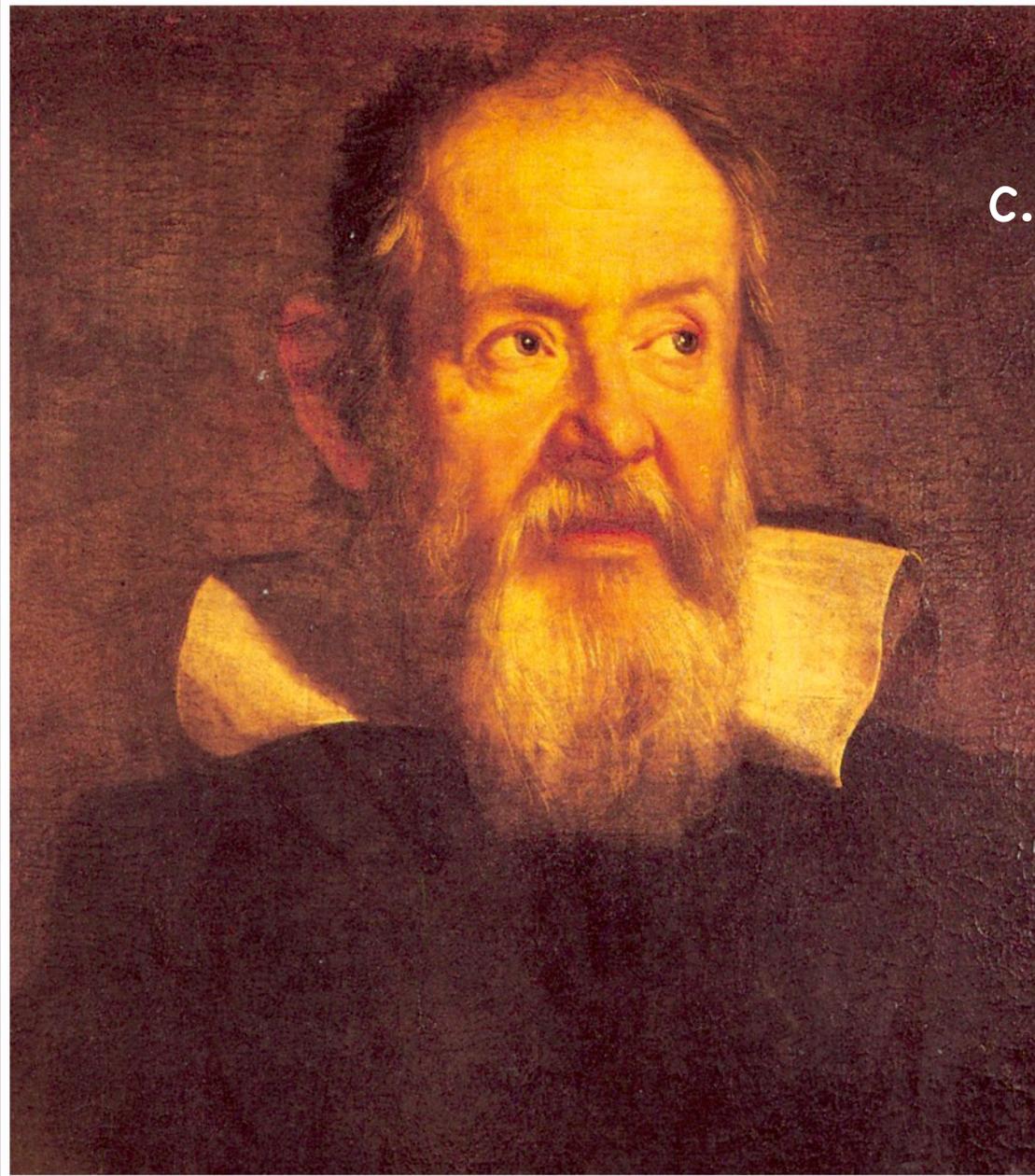
Galileo   c. 1564–1640

First telescopic astronomical observations

- First use of telescope for astronomy

- in 1609

- 400 years ago!

THE UNIVERSE
YOURS TO DISCOVER

INTERNATIONAL YEAR OF
ASTRONOMY
2009
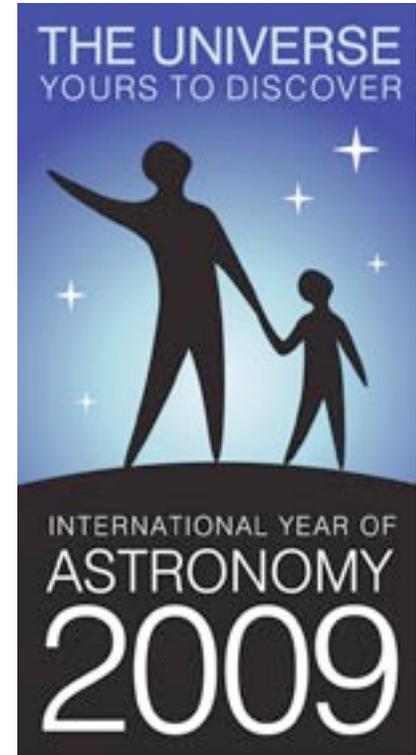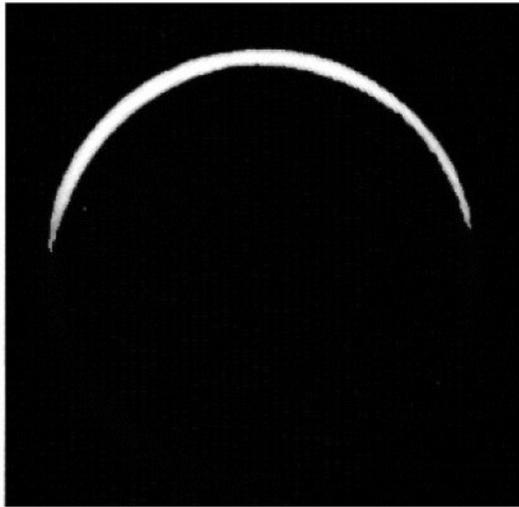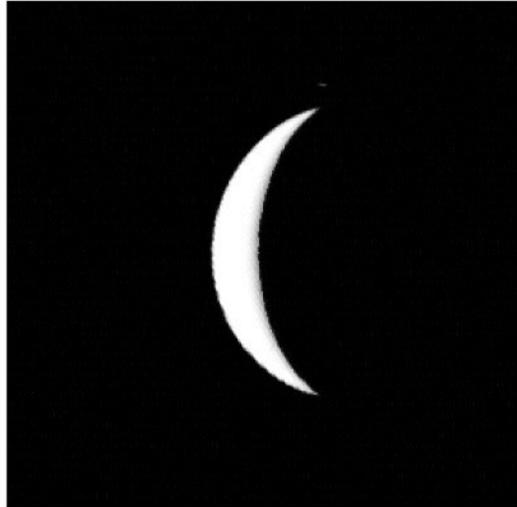
Phase and angular size of Venus depend on elongation

$\alpha = 58°$ $\alpha = 42°$

$\alpha = 24°$ $\alpha = 15°$ $\alpha = 10°$

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**

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 ✓