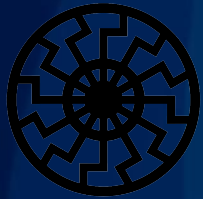


The Copernican Revolution - Separating Science and Superstition

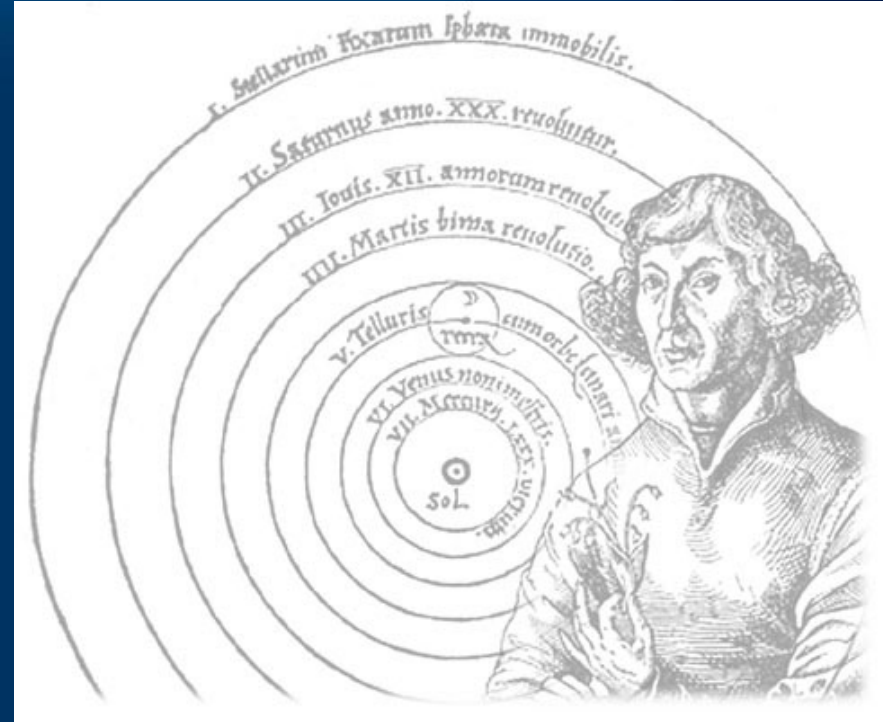


J. Pinkney
ONU 2011



Outline

- Our universe viewed by the ancients
- Greek cosmological models
- Copernican Revolution
 - Nicolaus Copernicus
 - Tycho Brahe
 - Johannes Kepler
 - Galileo Galilei
 - Isaac Newton
- Science vs Superstition: it never ends



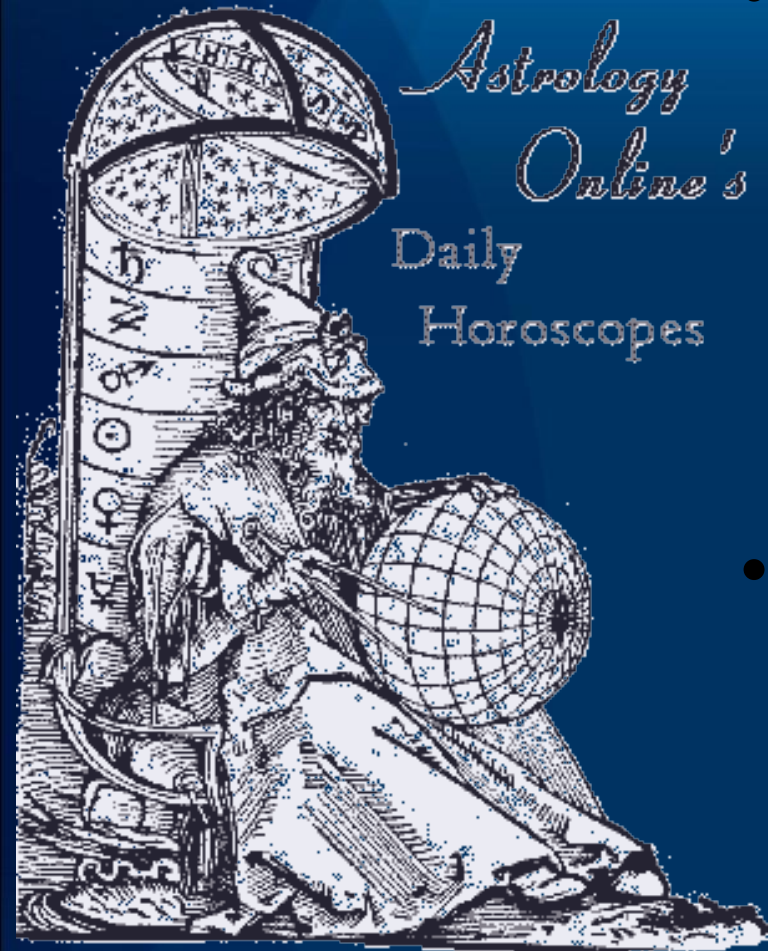
What the Ancients Knew

The Naked-Eye Universe

- The Sun (daily motion and annual motion)
- The Moon (phases, eclipses)
- 5 Planets (not including the Earth)
 - Mercury, Venus, Mars, Jupiter, Saturn
- 6500 Stars (contained within 88 constellations)
- 3 galaxies
- Occasional novae and supernovae
- Comets
- Aurora, meteors, and other atmospheric phenomena



What the Ancients Knew



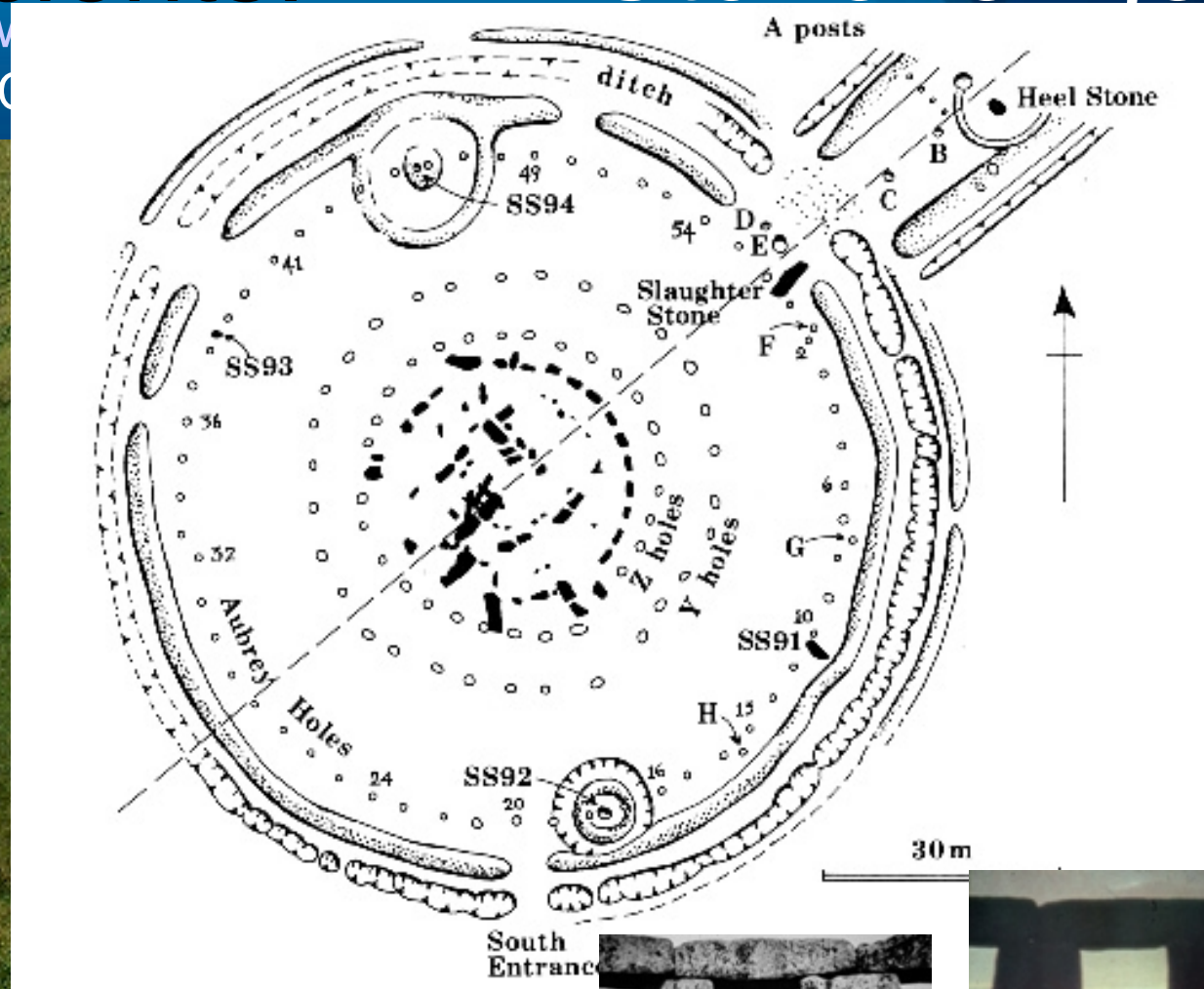
- Mysterious cultures
 - People of Stonehenge, Plains Indians, Anasazi, Mayans
 - ► left behind calendar-like constructions.
- Well documented cultures
 - Greek, but also Chinese, Babylonian, Egyptian, Arab
 - ► left records of lunar cycles, eclipses, comets, novae, star maps, models

Unknown nature → superstition → astrology.

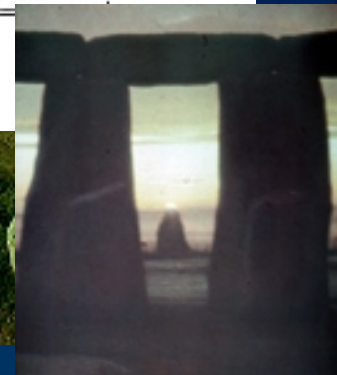
The Ancients:

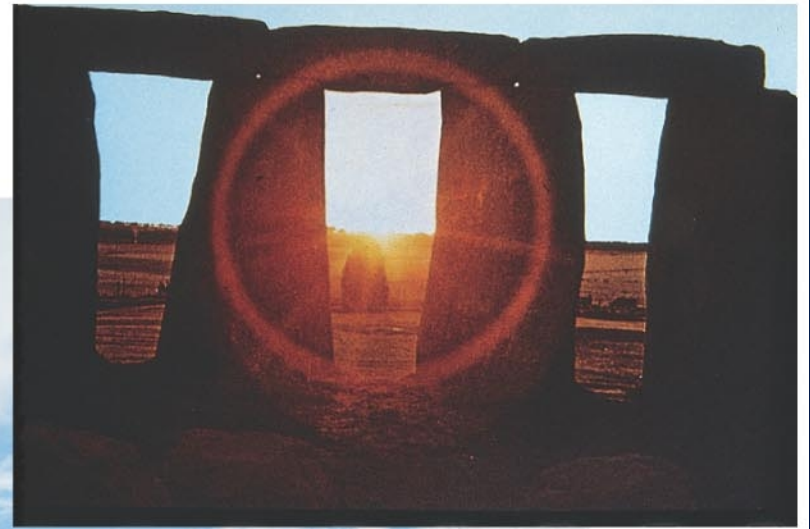
Stonehenge

- Check out: <http://www.stonehenge.com>
- 2950 BC – 1600 BC



- 30 Y-holes, 28 Z-holes, 56 Aubrey holes = 3 Saros cycles
- Heel stone marks sunrise on Summer Solstice







(b)

The Plains Indians – Big Horn
The Mayans – Caracol in Chichen Itza
The Anassazi/Pueblo – Chaco Canyon



(c)

What the Ancients Knew



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es
odiac, “year of the _____”
t alphabet, ziggurats,
planetary rise times,

nd Osiris, pyramids, Nile

during dark ages

inction between
1000 AD!

measurements
y

stitution → 2000 AD. **astronomy.**



Knowledge of the Ancient Greeks I.

- Ideas and philosophies were rich and varied, some correct and some **incorrect**.

- Thales of Miletus (624-547 BC):

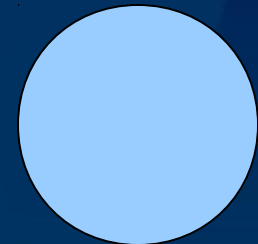
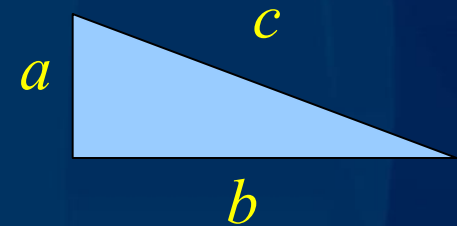
- universe is rational
- predicted eclipse ~585 BC

- Pythagoras (570-497 BC):

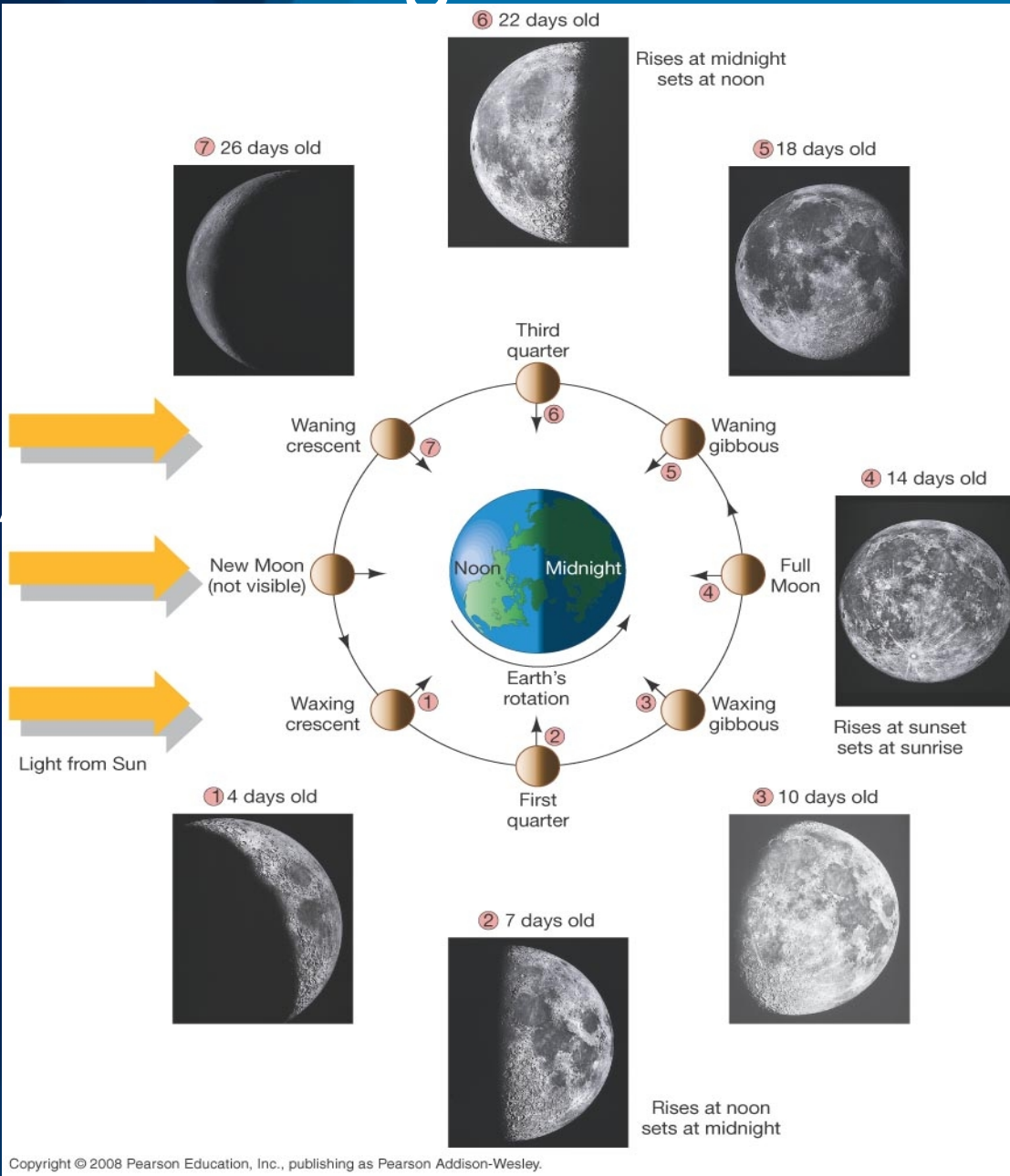
- math in nature, music of spheres
- Earth and planets are spherical

- Plato (428-347 BC):

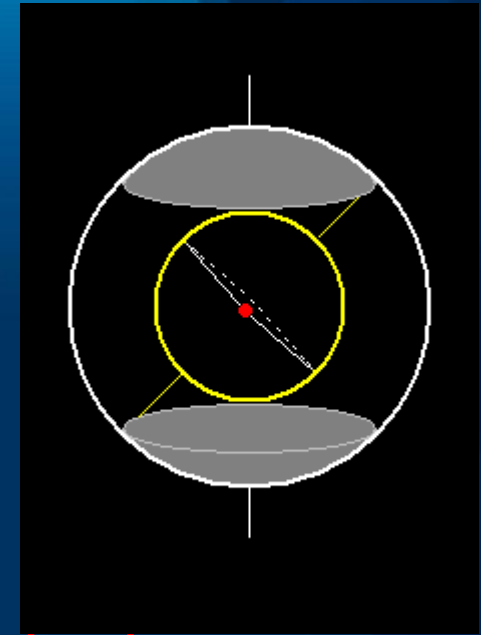
- **Truth through pure thought over observations**
- **Circle is most perfect form**



Knowledge of the Ancient Greeks II.



c):
del



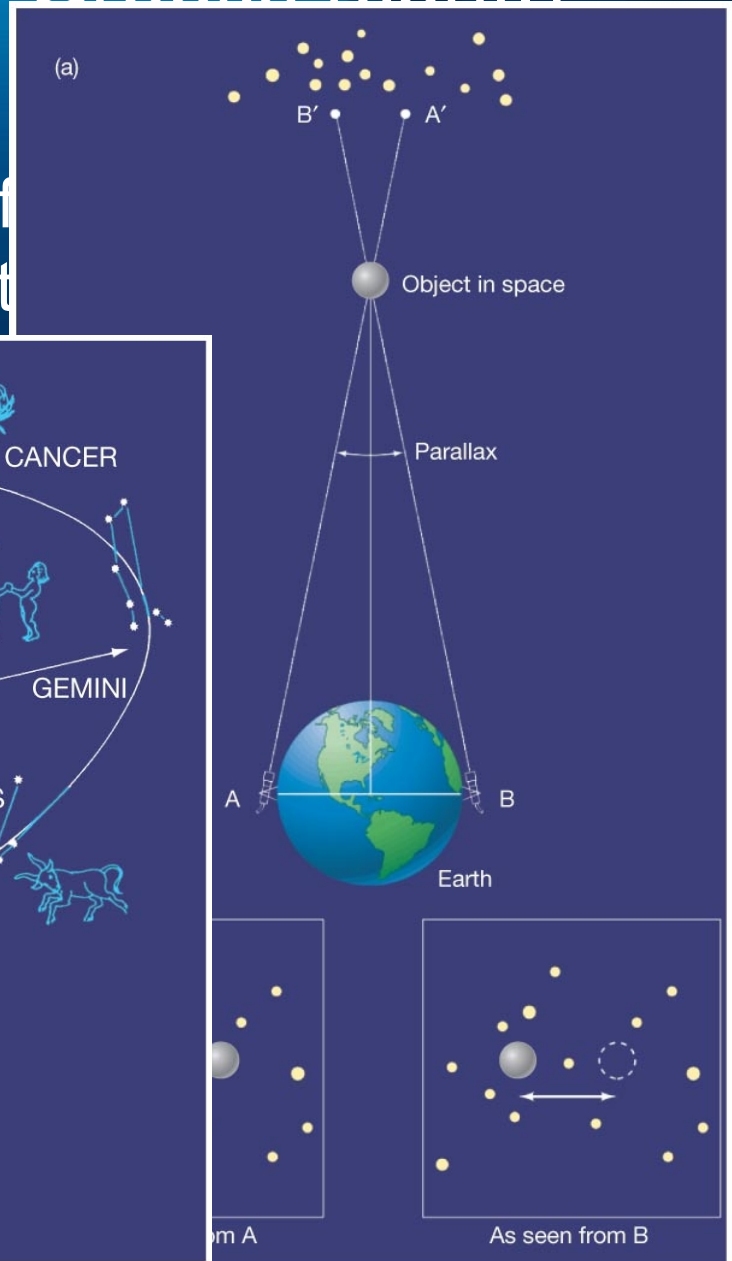
e perfect
: earth, water, wind,

d

uld exhibit parallax

Knowledge of the Ancient Greeks (cont.)

Parallax = the apparent motion or shift caused by the motion or shifting of t



Knowledge of the Ancient Greeks III

–Philolaus (480-385 BC)

- Earth in motion **around invisible “fire”**

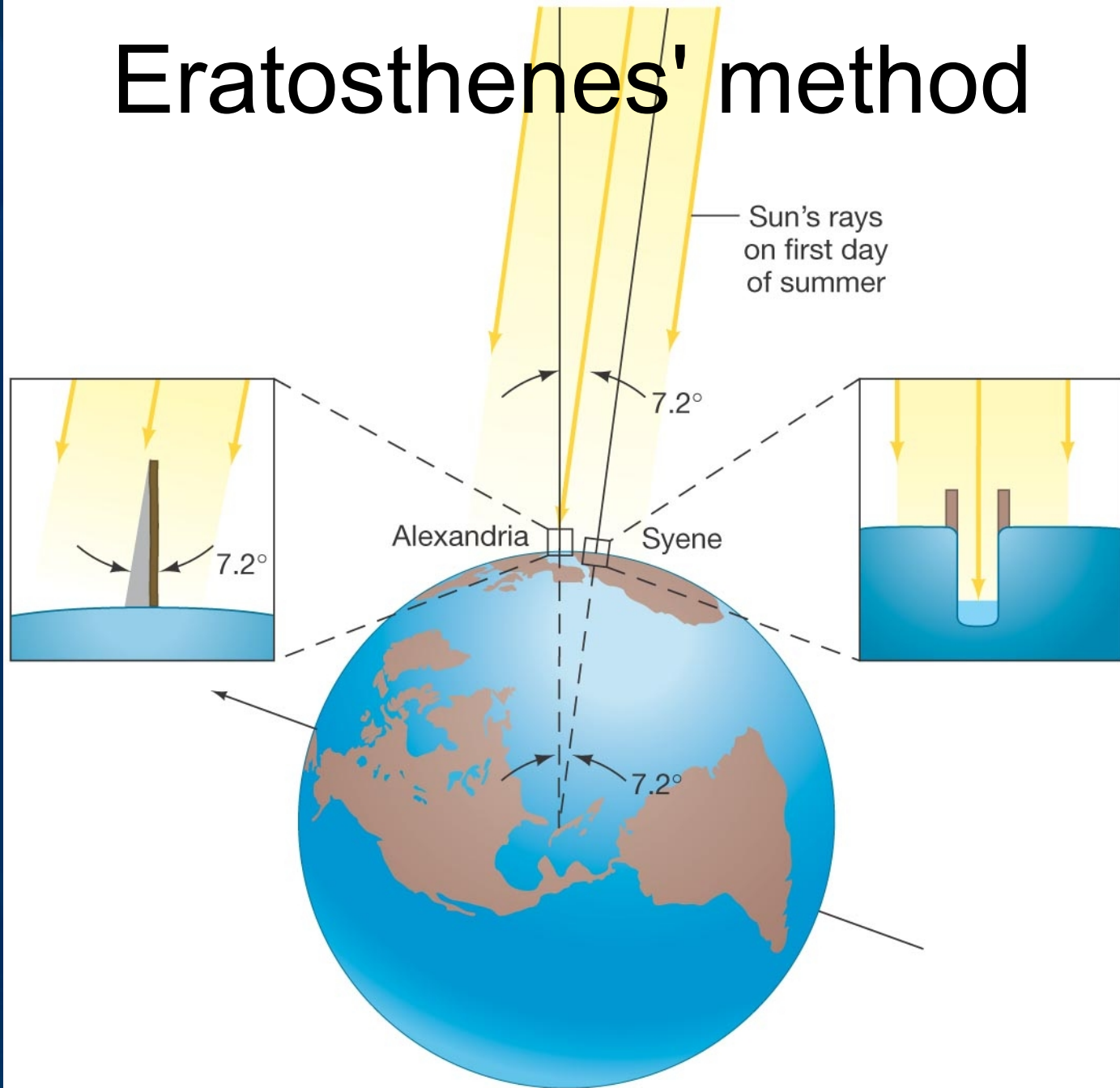
–Aristarchus (310-230 BC)

- The Earth orbits around the Sun (!)
- Size and distance to Moon
- Size and distance to Sun

–Eratosthenes (276-195 BC)

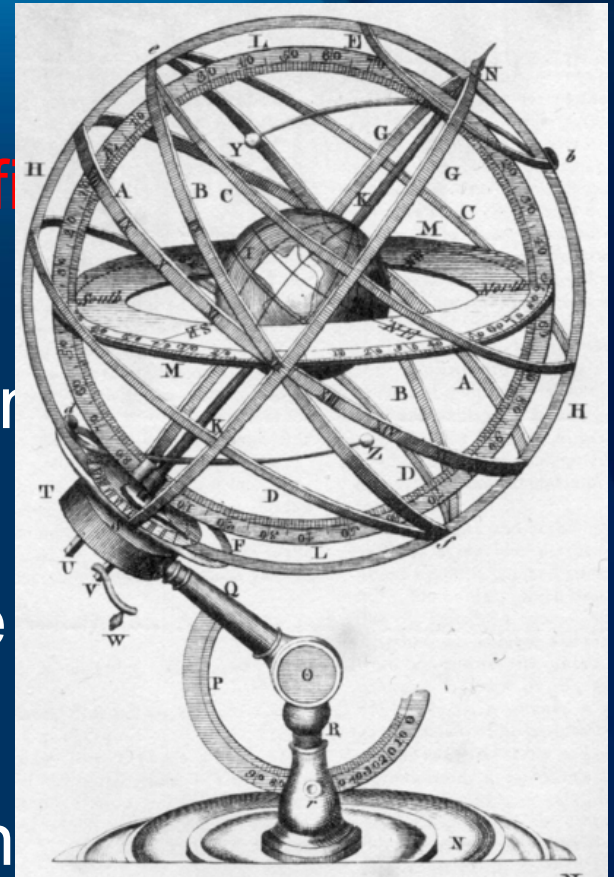
- Measured circumference of the Earth.

Erastosthenes' method



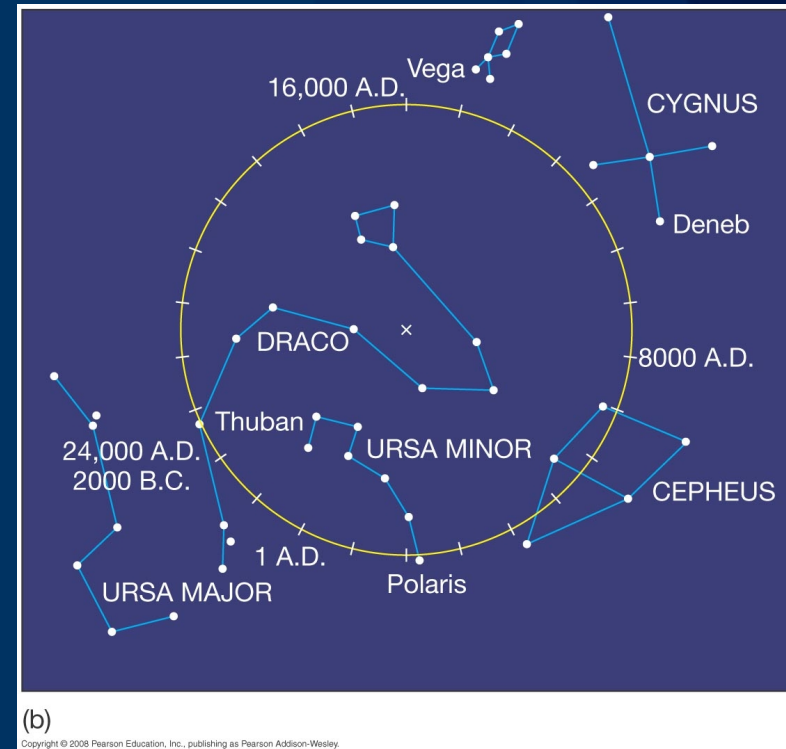
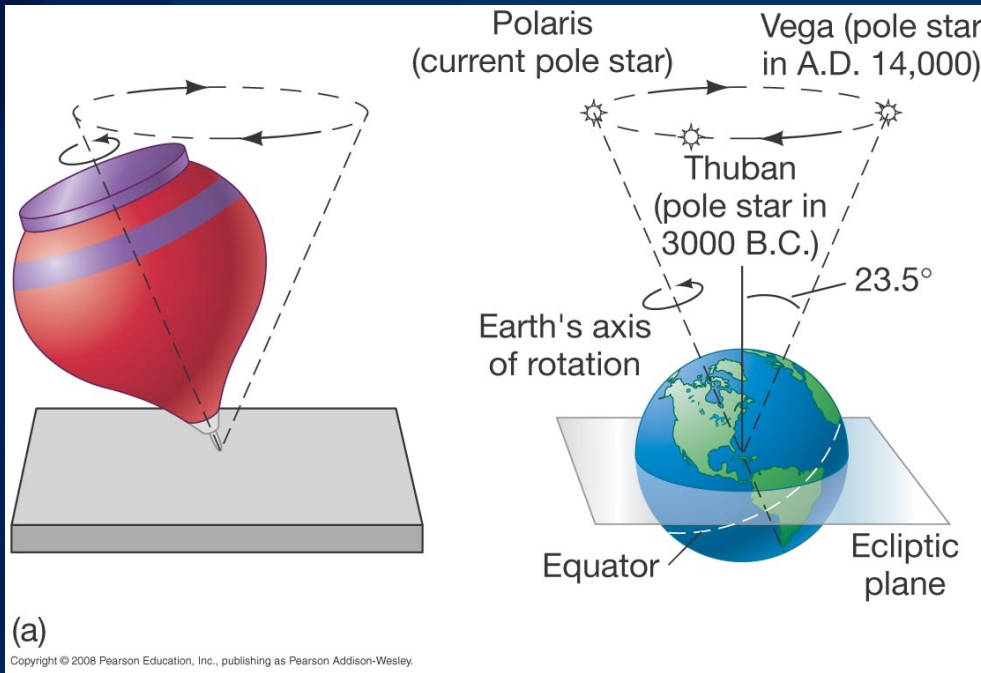
Knowledge of the Ancient Greeks III

- Philolaus (480-385 BC)
 - Earth in motion **around invisible “fire”**
- Aristarchus (310-230 BC)
 - The Earth orbits around the Sun
- Eratosthenes (276-195 BC)
 - Measured circumference of the Earth
- Hipparchus (190-120 BC)
 - Discovered precession of Earth
 - Uses epicycles, deferents and eccentrics in modelling motion of Sun and Moon.
 - Invents armillary sphere



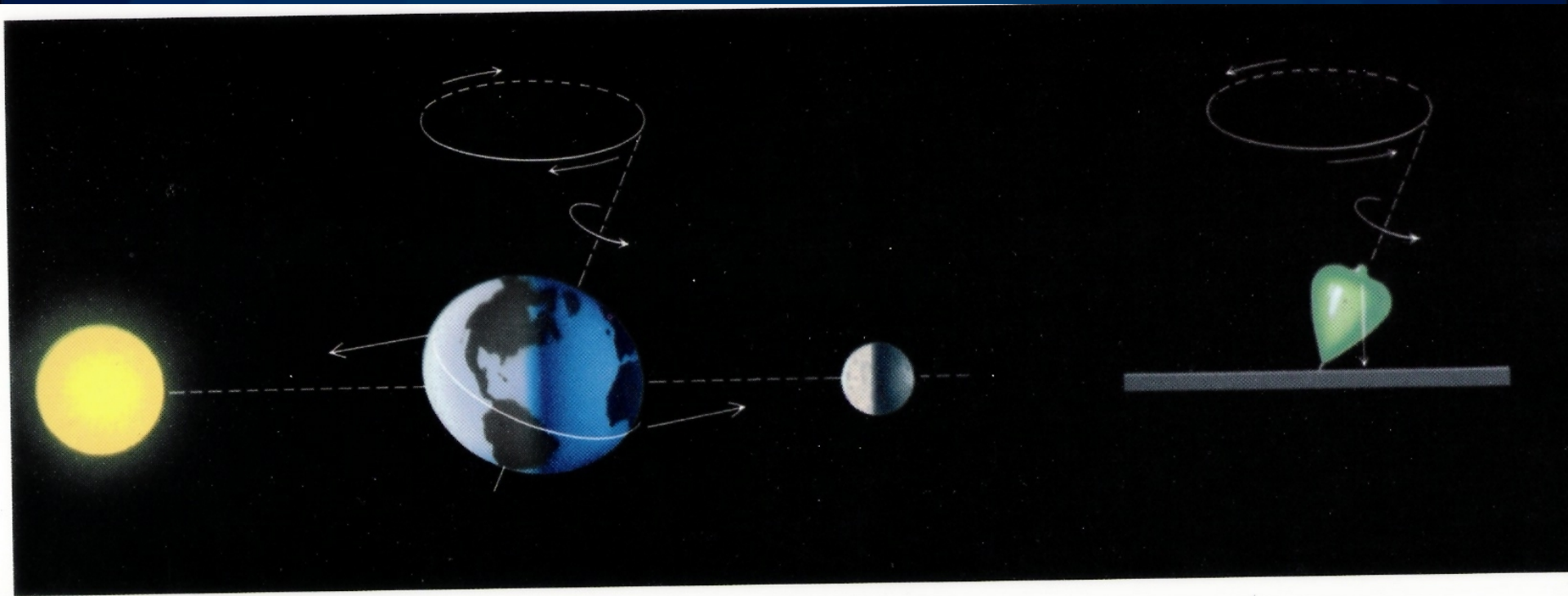
Knowledge of the Ancient Greeks (cont.)

Earth's spin axis precesses with 26,000 yr period (Hipparchus 160-127 BC)



Knowledge of the Ancient Greeks (cont.)

Cause of precession:



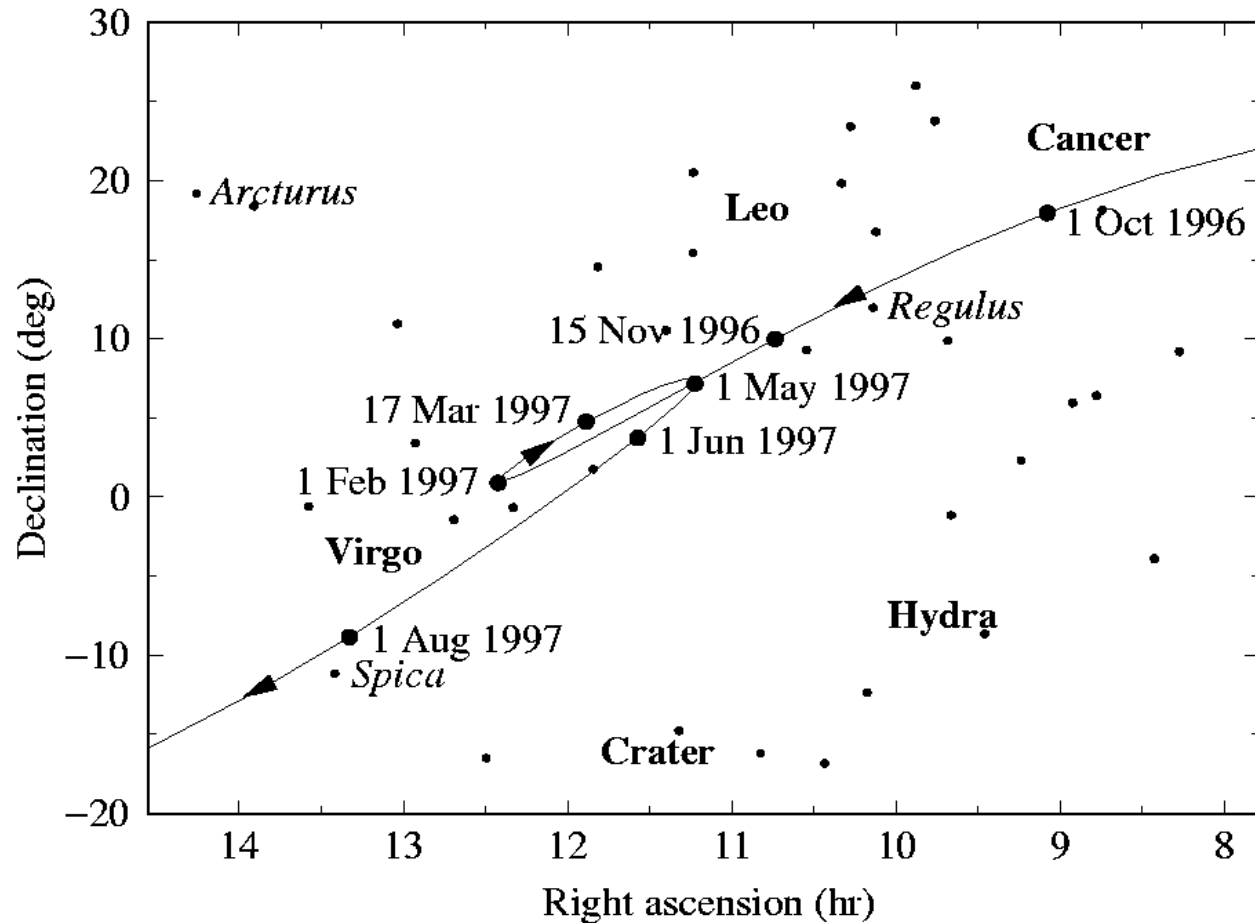
Knowledge of the Ancient Greeks IV

- Claudius Ptolemy (AD 83-161)
 - Geocentric universe model
 - Adopts Hipparchus' epicycles to reproduce retrograde motion of planets
 - Added equants to better match speeds of planets
 - Writings on Optics, Geography, Music
 - Astronomy: “Mathematike Syntaxis” = “The Almagest”
 - Astrology: “Tetrabiblos” relates horoscopes to Aristotelian philosophy



The Appearance of the Planets

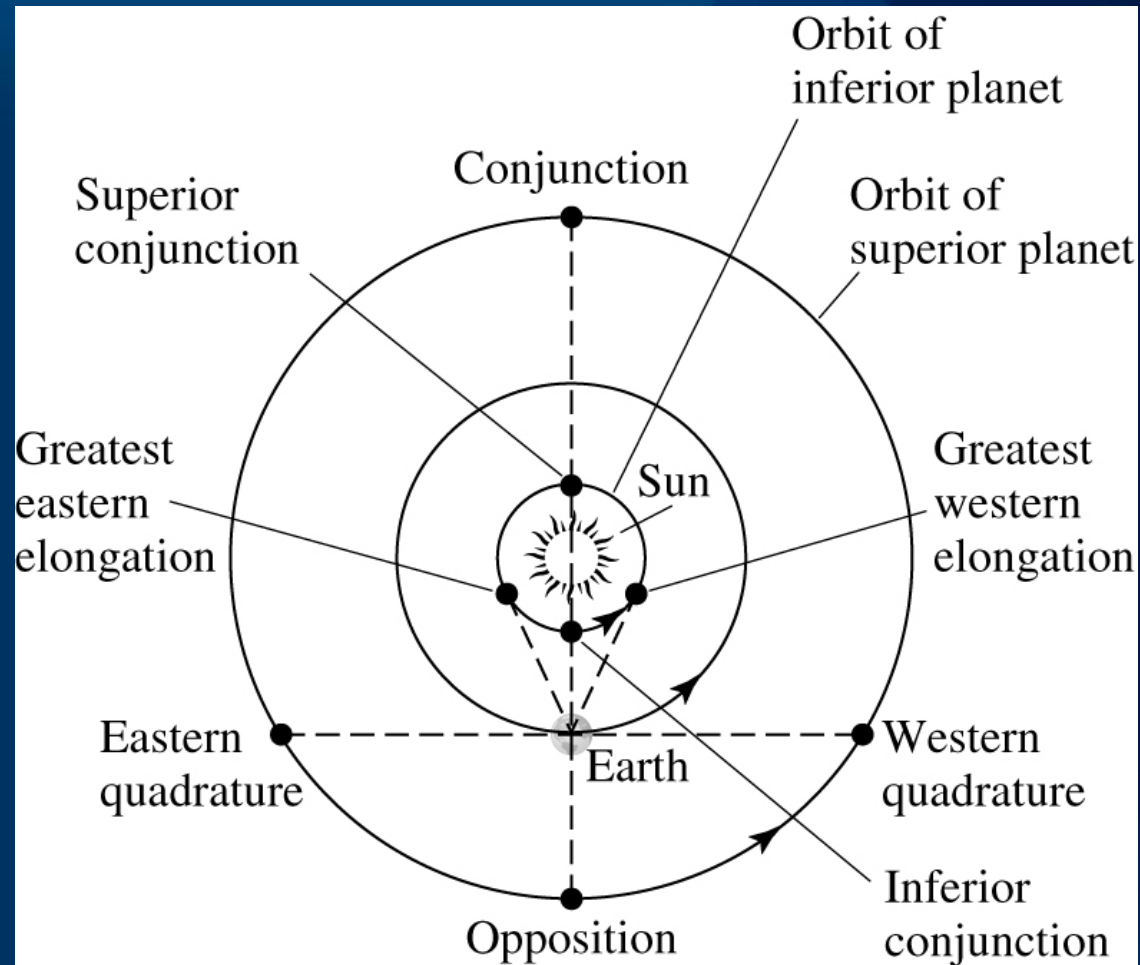
- Daily motion
- Change in the sky.
- All orbit
- Usually we call



Retrograde Motion!

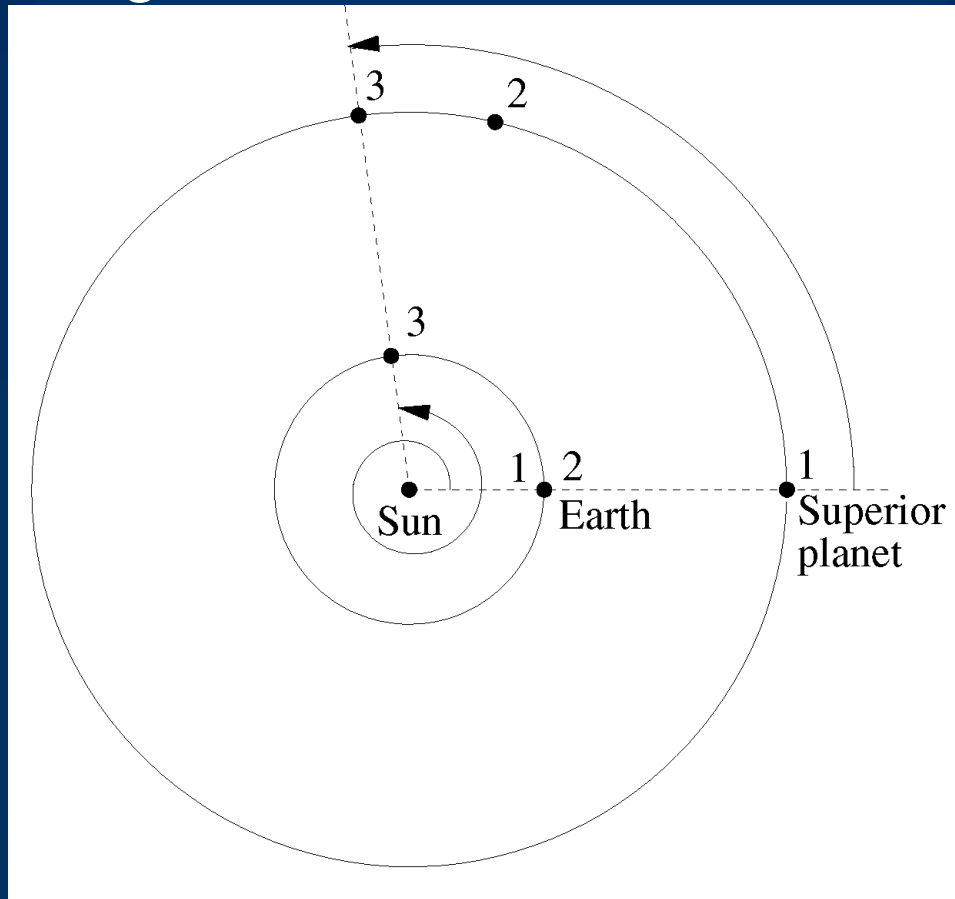
Planetary Configurations

- Inferior planets
 - Two conjunctions
- Superior planets
 - One conjunction
 - Opposition



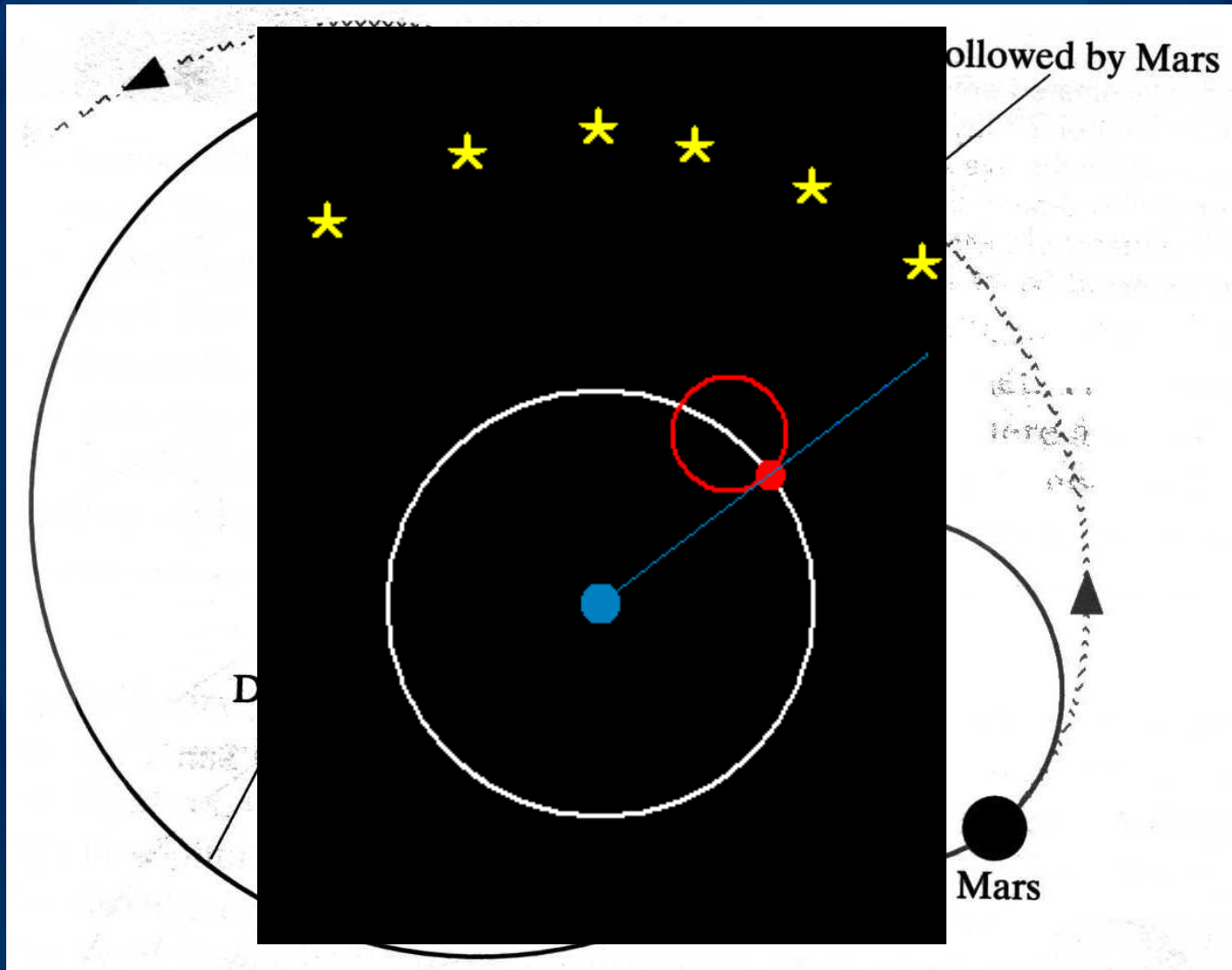
Synodic and Sidereal Periods

- Synodic period: time interval between successive conjunctions or oppositions, $1 \rightarrow 3$
- Sidereal period: time interval for one complete orbit relative to background stars, $1 \rightarrow 2$



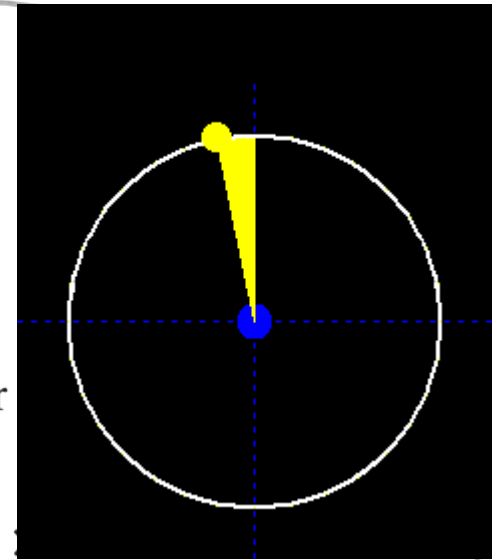
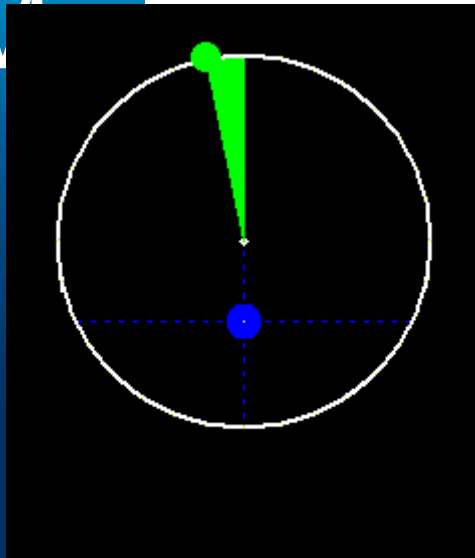
Epicycles on Deferents

- Ptolemy et al. desired uniform circular motions

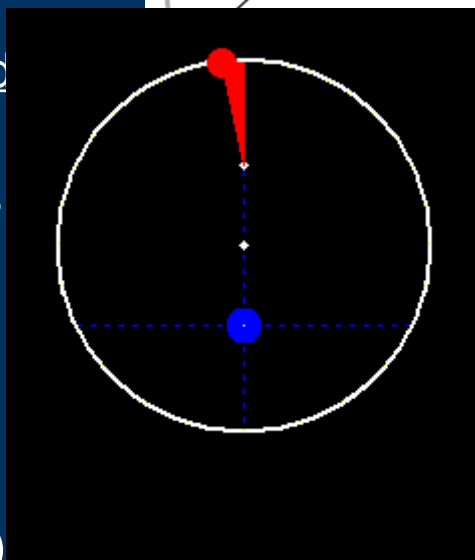


Ptolemy's Model

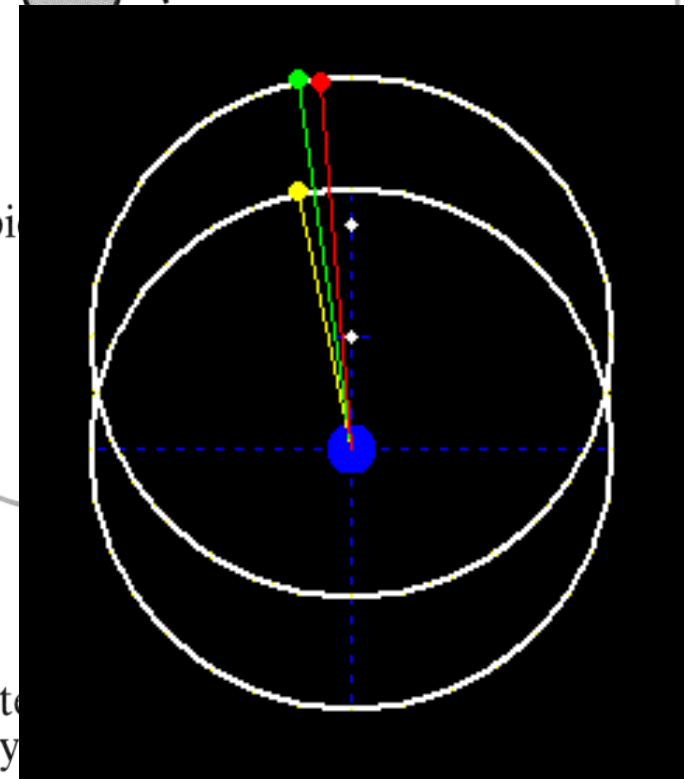
- Eccentric - displaces Earth from center
- Equant – center of epicycle has uniform angular speed when viewed from this point
- Period of planet around epicycle is synodic period
- Period of epicycle center around deferent center is sidereal period.
- 80+ epicycles
- It works pretty well!
- Occam's Razor (1348)
 - Accept the simplest explanation



Center



Epi



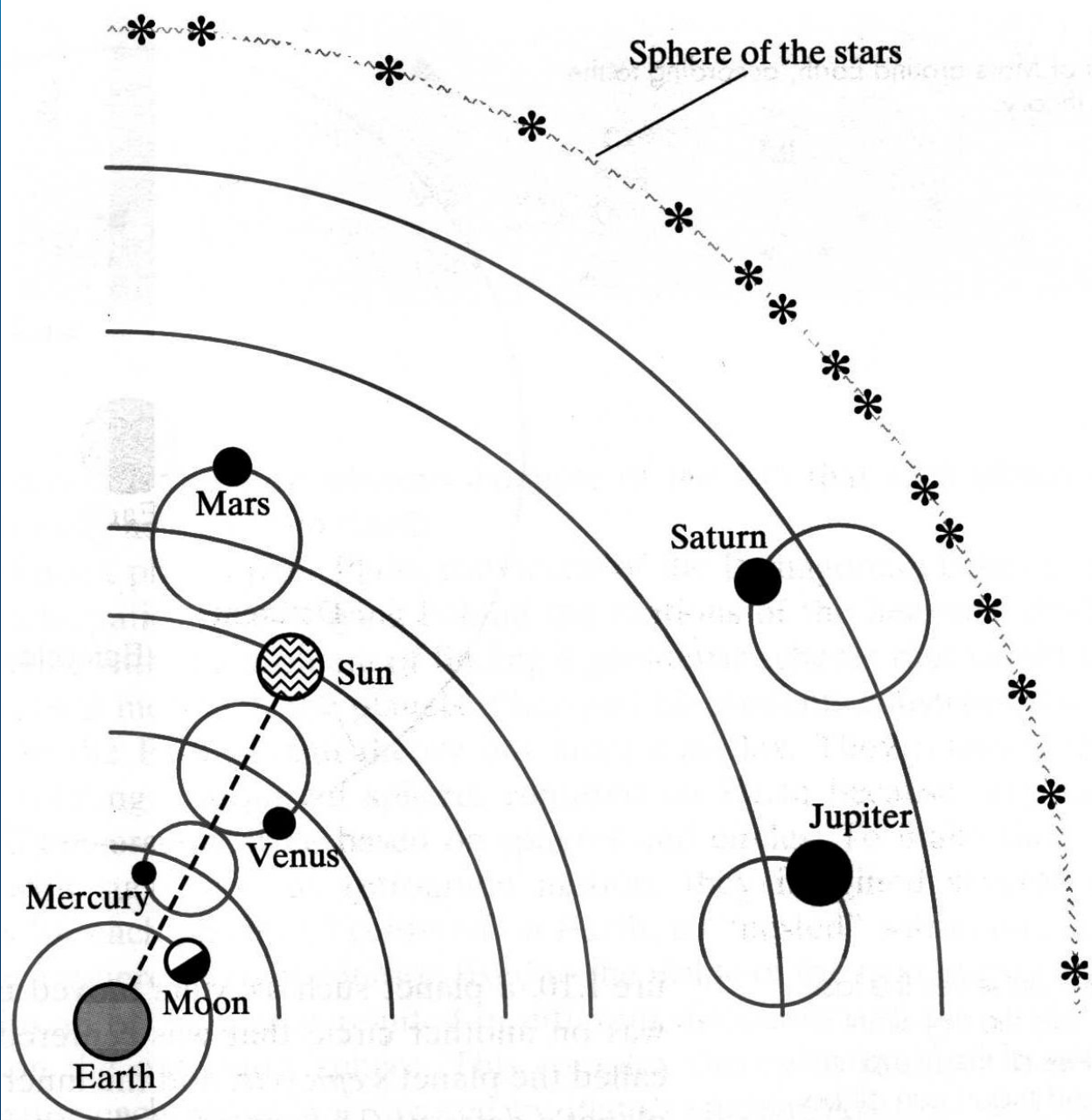
Center
epicy

Ptolemy's Model

- Venus and Mercury on invisible “bar”
- Speed is still a problem



FIGURE 1.12
The ancient astronomer Ptolemy, A.D. 85–165. Using epicycles and many other theoretical devices, he perfected the Earth-centered theory of the layout of the universe.



THE COPERNICAN REVOLUTION

. 1473

NICOLAUS COPERNICUS



. 1512 1st Comment

. 1543 De Revolutionibus

. 1546

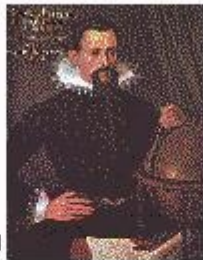
TYCHO BRAHE



. 1601

JOHANNES
KEPLER

. 1571



. 1609

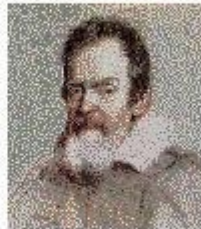
New Astronomy

. 1619 The Harmony
of the Worlds

. 1630

. 1564

GALILEO GALILEI



1632

Dialogue of the Two Chief World Systems

1633 Trial at Rome by the Inquisition

. 1642

. 1642

. 1512 1st Comment



1543 De Revolutionibus

1546

TYCHO BRAHE



. 1601

JOHANNES
KEPLER



. 1571

. 1609

New Astronomy

. 1619 The Harmony
of the Worlds

. 1630

. 1564

GALILEO GALILEI



1632

Dialogue of the Two Chief World Systems

1633 Trial at Rome by the Inquisition

. 1642



. 1642

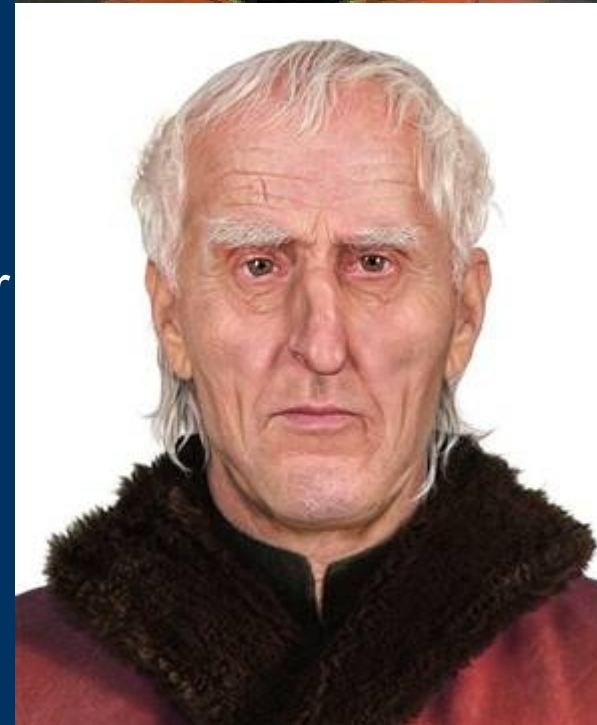
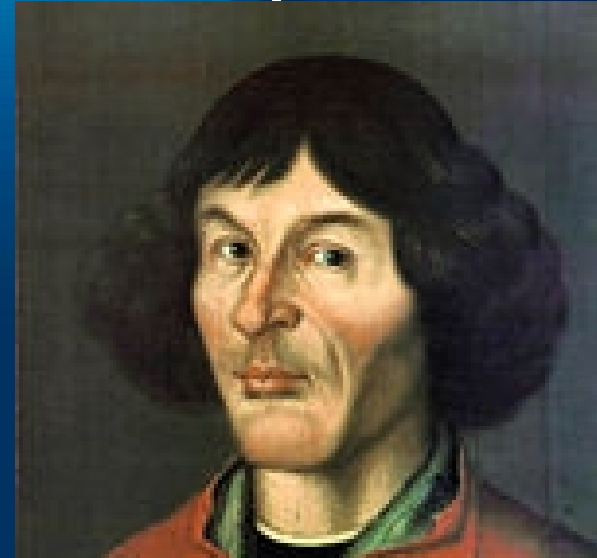
SIR ISAAC NEWTON

. 1686 Principia

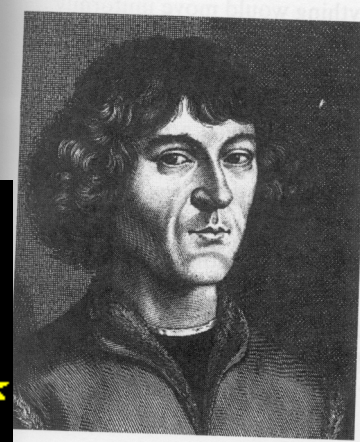
. 1727

Copernicus (1473-1543)

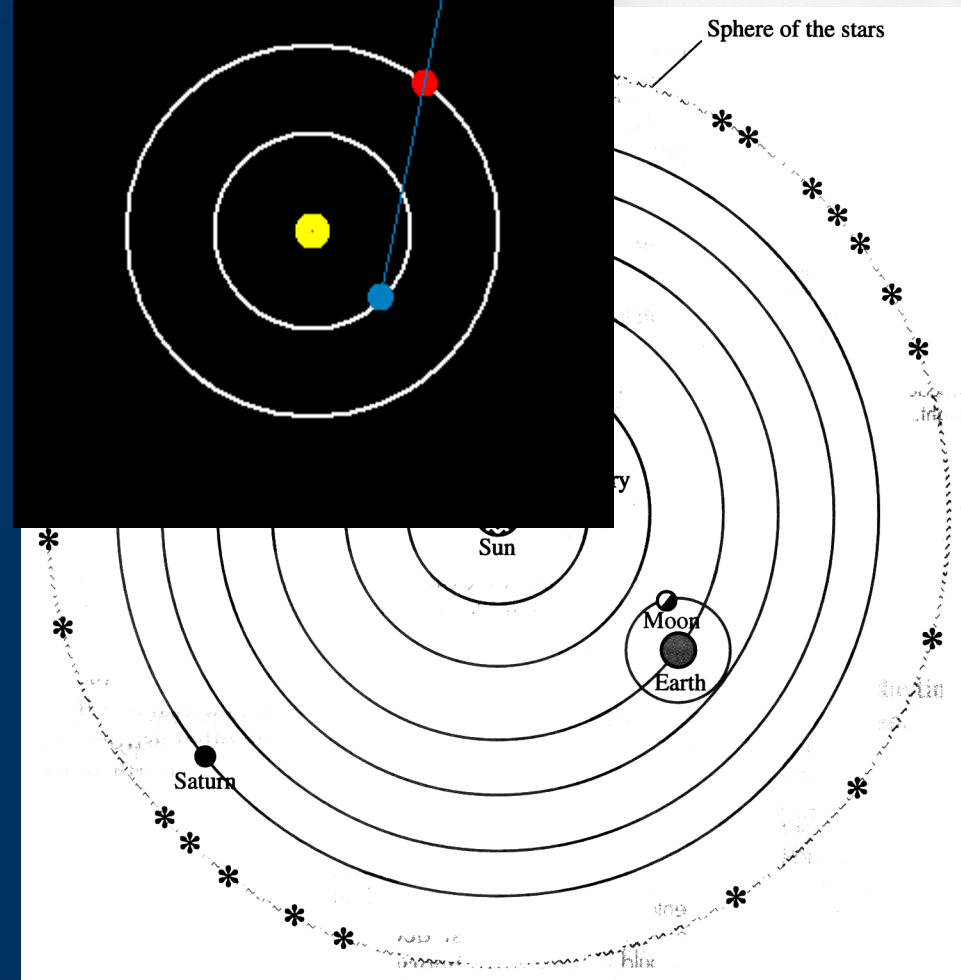
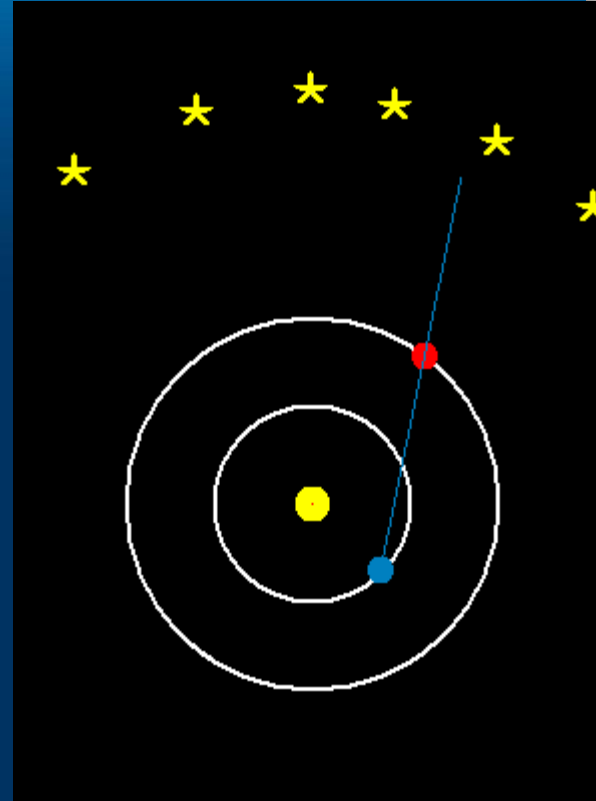
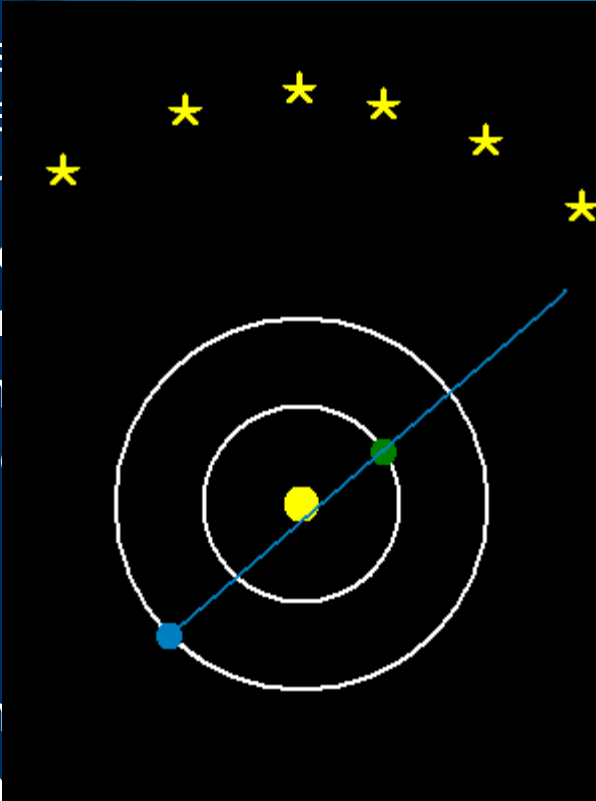
- Polish Son of copperworker
- a mathematician, astronomer, physician, classical scholar, translator, Catholic cleric, jurist, governor, military leader, diplomat and economist
- Astronomy is avocation
- Publications
 - On the Revolutions of the Heavenly Spheres (1543)
 - Little Commentary (1514)
 - Trigonometry, Narratio Prima (Rheticus)
 - Prutenic tables (1551)
- Reluctant to publish because of fear of criticism, or fear of persecution by church
- In 2005, skull recovered in Cathedral of Frauenberg



Copernicus



- Is there something wrong with the geocentric model?
- Keep some of the geocentric model
 - spherical Earth
 - uniform motion
- Major Changes
 - Sun at center
 - Earth orbits Sun
 - Earth rotates on axis
 - other planets orbit Sun
- Established heliocentric model
- Less complex explanation for retrograde motion



Copernicus

- Predictions of existing observations are not better than Ptolemy's!!
- Slightly simpler
 - No equants
 - Fewer epicycles (still a lot)
 - If you remove epicycles?
 - Copernicus does okay
 - Ptolemy's is a disaster
- Discriminating experiments not available

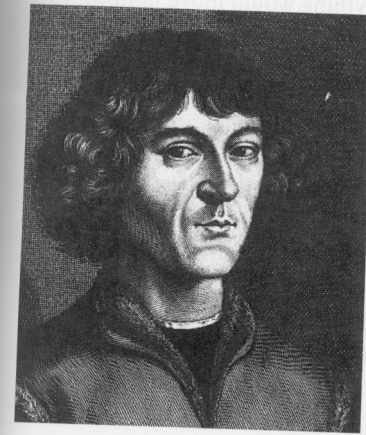


FIGURE 1.14
Renaissance astronomer Nicolaus Copernicus, 1474–1543. Finding Ptolemy's system to be "neither sufficiently absolute nor sufficiently pleasing to the mind," he devised a simpler theory. Copernicus's theory placed the sun at the center of the universe, with Earth moving around it. The odd idea that Earth moved and was a planet like the other planets met with much resistance because it conflicts with the intuitive notion that Earth is at rest at the center of things and because it conflicted with prevailing philosophies.

Tycho Brahe (1546-1601)

- Danish nobleman
- Wore metal nose
- Death (bladder or mercury)
- Built “Uraniborg” in Hven
- Meticulous measurements
- Observed supernovae of 1572
- Could not detect parallax
- Develops Tychonic System
- Hired Kepler in 1600



Tycho Brahe

- Left Kepler with 20 years of meticulous planet measurements.
 - 5x better precision
 - 2 arc-minutes ($1/30$ of a degree) compared to 10 arc-minutes ($1/6$ of a degree)
 - 20 years of data
 - Neither Ptolemy nor Copernicus's models are able to produce the observations!

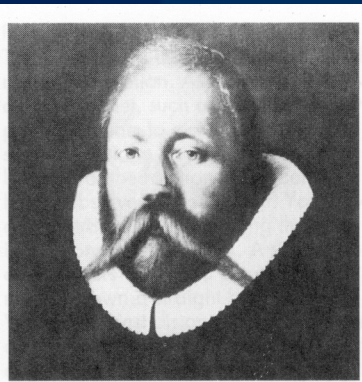


FIGURE 1.18
Tycho Brahe, 1546–1601. By making measurements of the planetary positions that were five times more accurate than were previous measurements, he overthrew two theories of the architecture of the heavens.

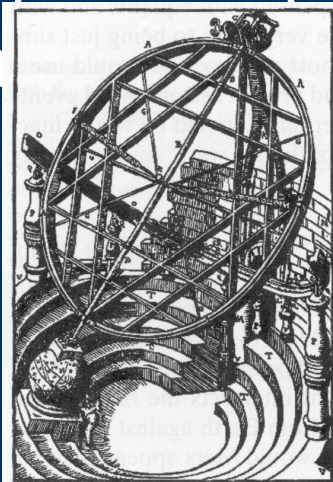


FIGURE 1.19
Brahe's sextant for measuring the positions of the planets. Brahe's work was done without telescopes.

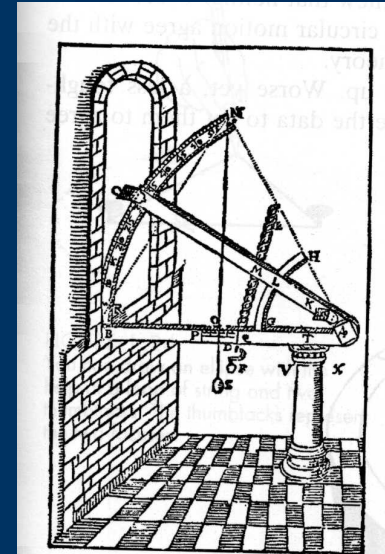


FIGURE 1.20
An instrument that Brahe used for

Johannes Kepler (1571-1630)



- Mathematician, astronomer, astrologer
- Had religious convictions - *God had created intelligible the nature*
- Geometrical regular solids
- Astrologer
- “mother”

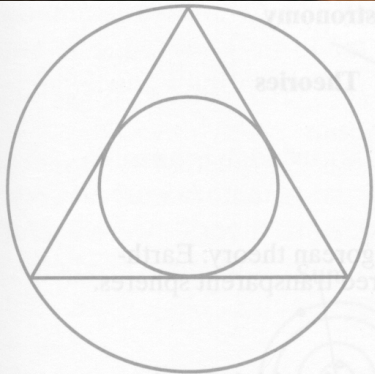
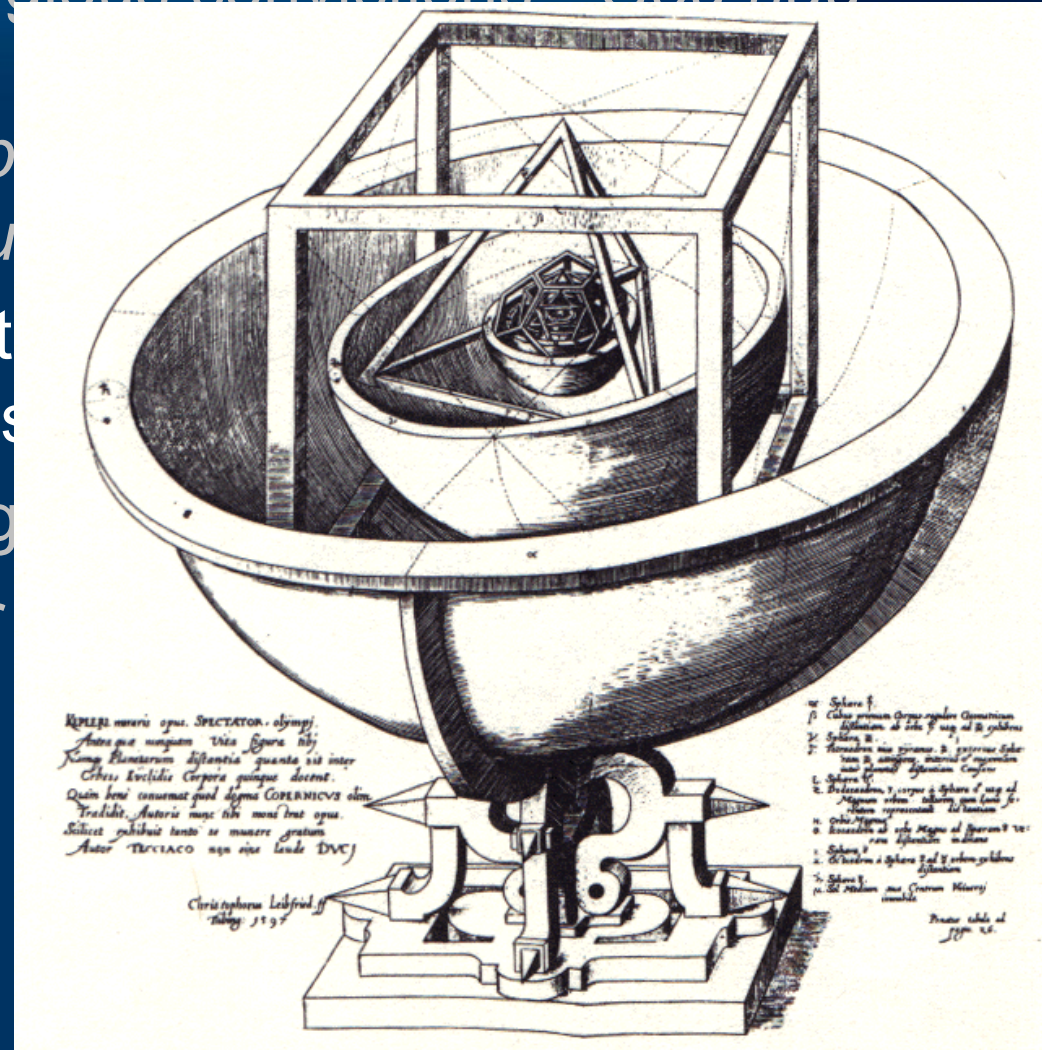


FIGURE 1.23
A blackboard diagram similar to this gave Kepler the original inspiration for his planetary theory based on the five perfect solids. In this diagram, two circles are separated by a triangle.



Johannes Kepler

- Sun
- Co
- S
- T
- Tri
- A
- E
- P

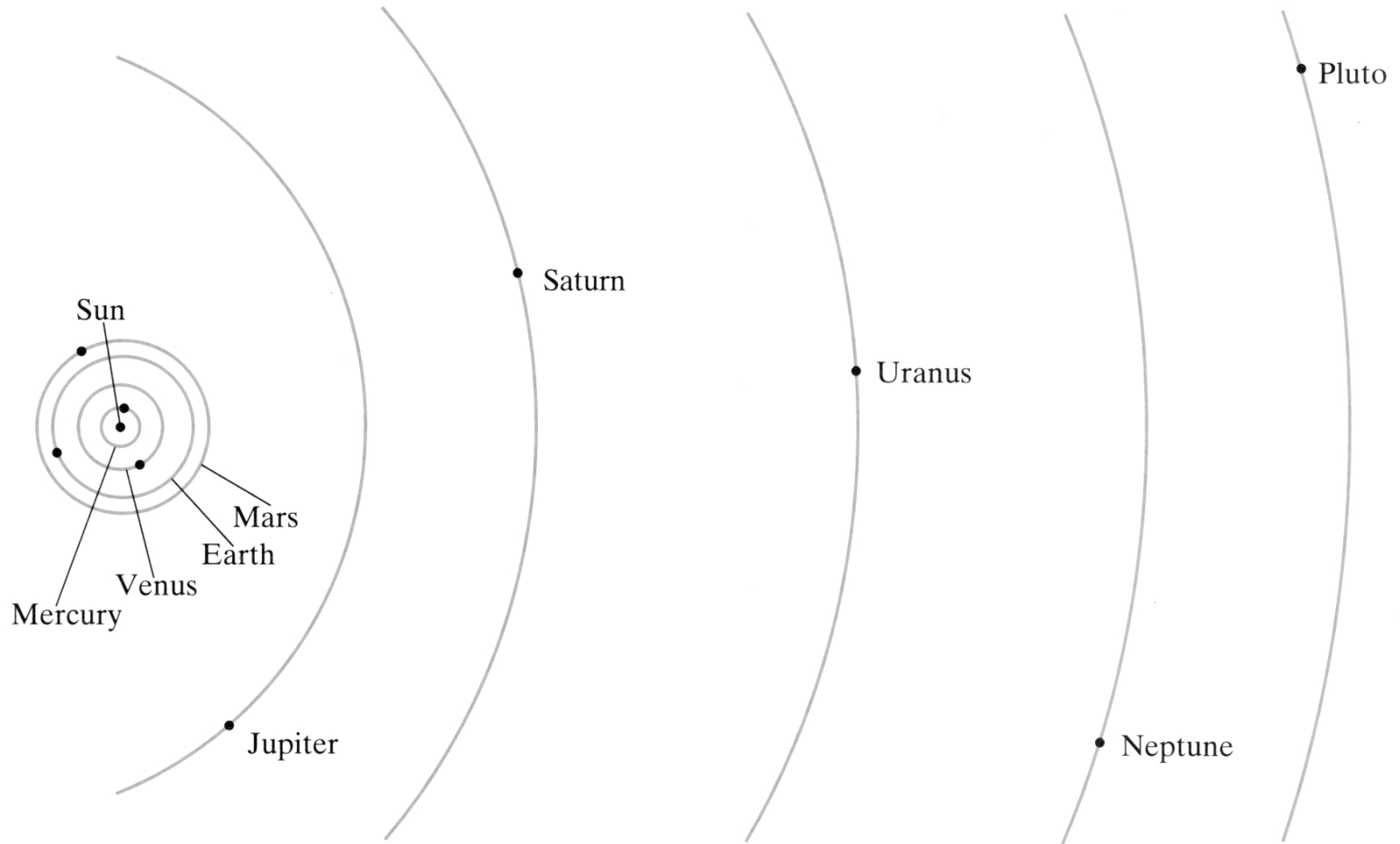
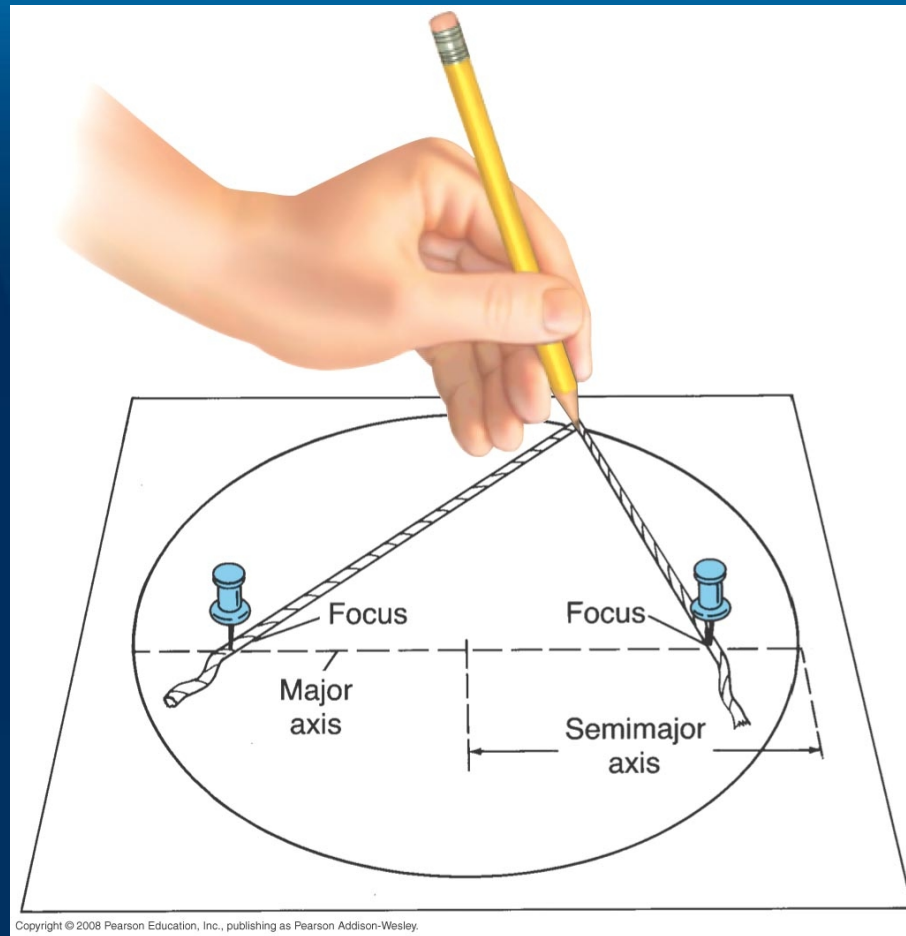


FIGURE 1.26

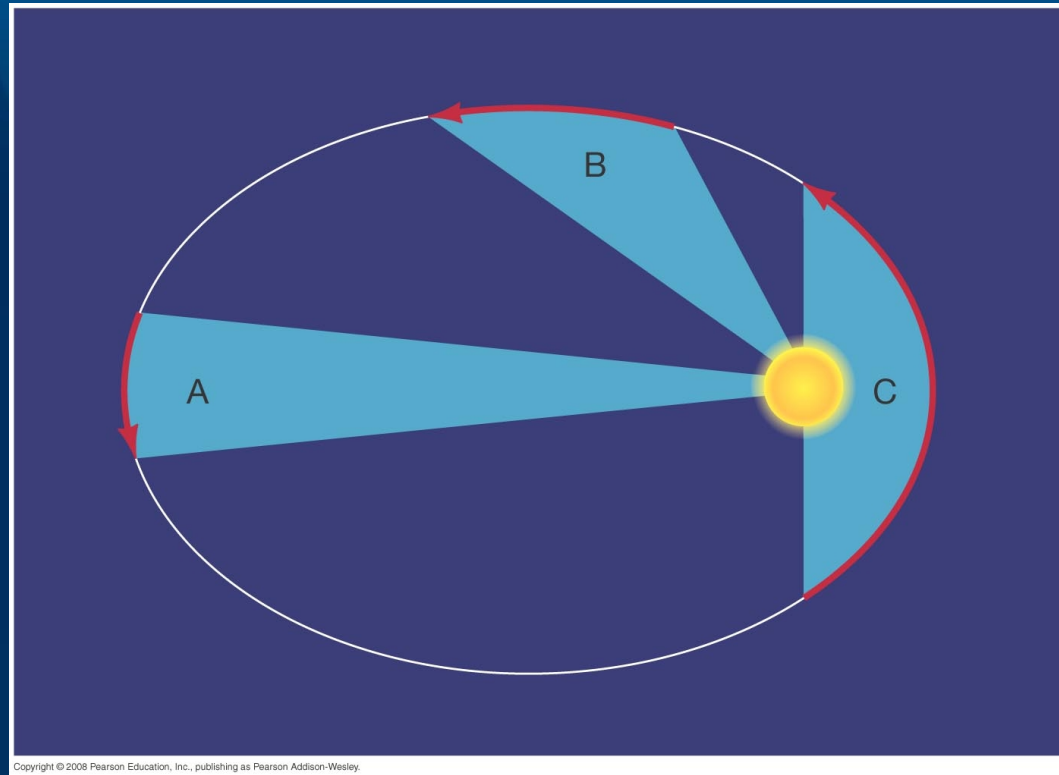
The arrangement of the solar system as it is now known. Uranus, Neptune, and Pluto are visible only with a telescope. The orbits are elliptical, although their ellipticity is too small to be visible in this diagram.

Kepler's 1st law



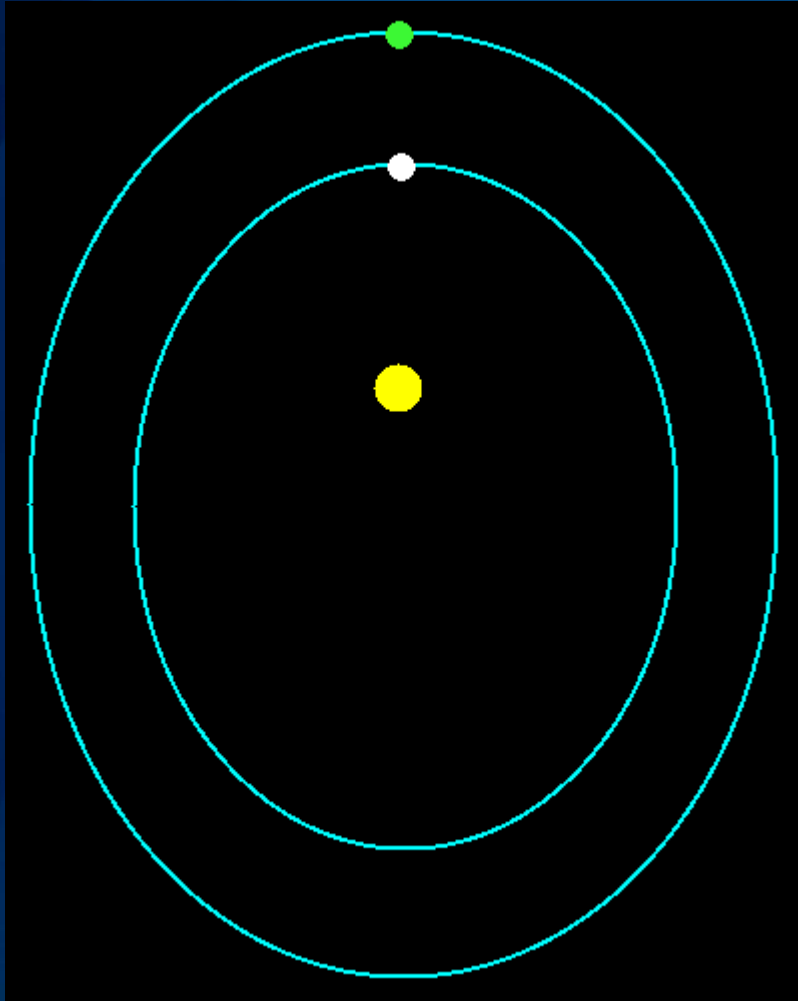
The planets follow elliptical paths with the Sun at one focus.

Kepler's 2nd Law



The planets vary their orbital speed such that they sweep out equal areas in equal time intervals, as seen from the Sun.

Kepler's 3rd law

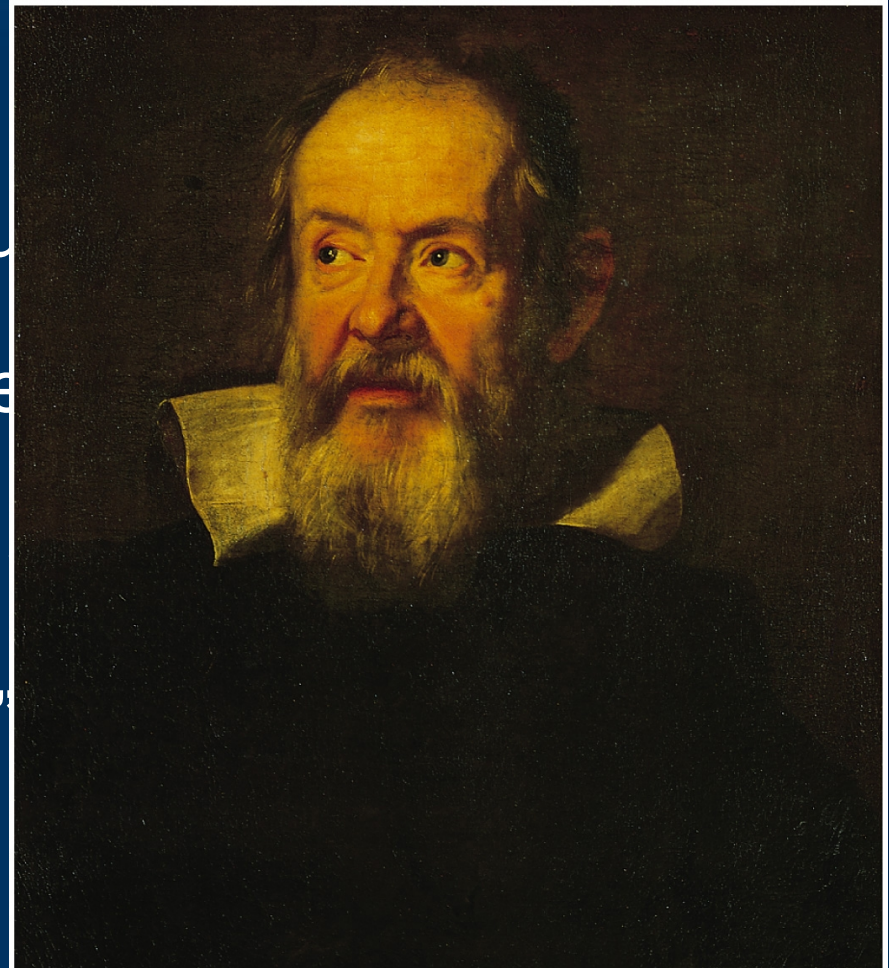


$$P^2 = a^3$$

Period increases
with distance from
the Sun.

Galileo (1564-1642)

- He supports Copernicus, Kepler
- 1609 - uses telescope for astronomical observations
- Experiments & observations refuted Aristotelian physics
 - Free-fall, inclined plane, experiments
 - Moons of Jupiter orbit Jupiter
 - Earth not the center!
 - Phases of Venus include crescent
 - Spots on Sun
 - Milky Way resolves into stars
 - Saturn has ears?
- “Father of Modern Physics”



Galileo and Jupiter

The “Galilean Moons”: Io, Europa, Ganymede, and Callisto.

How could these moons be used to measure the speed of light?

Ole Roemer 1677

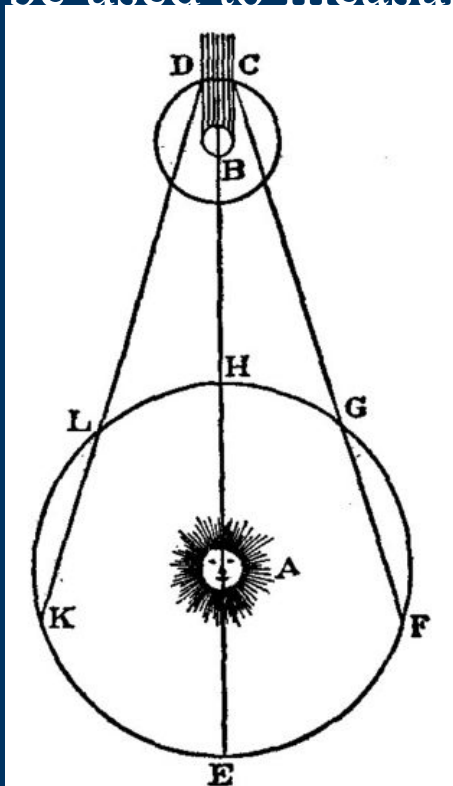
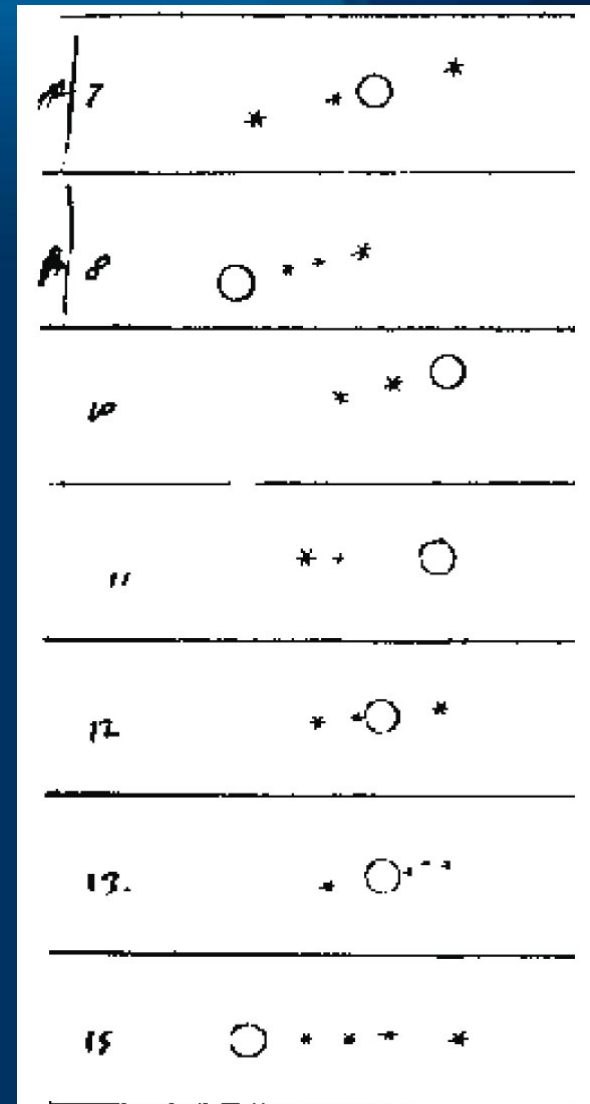
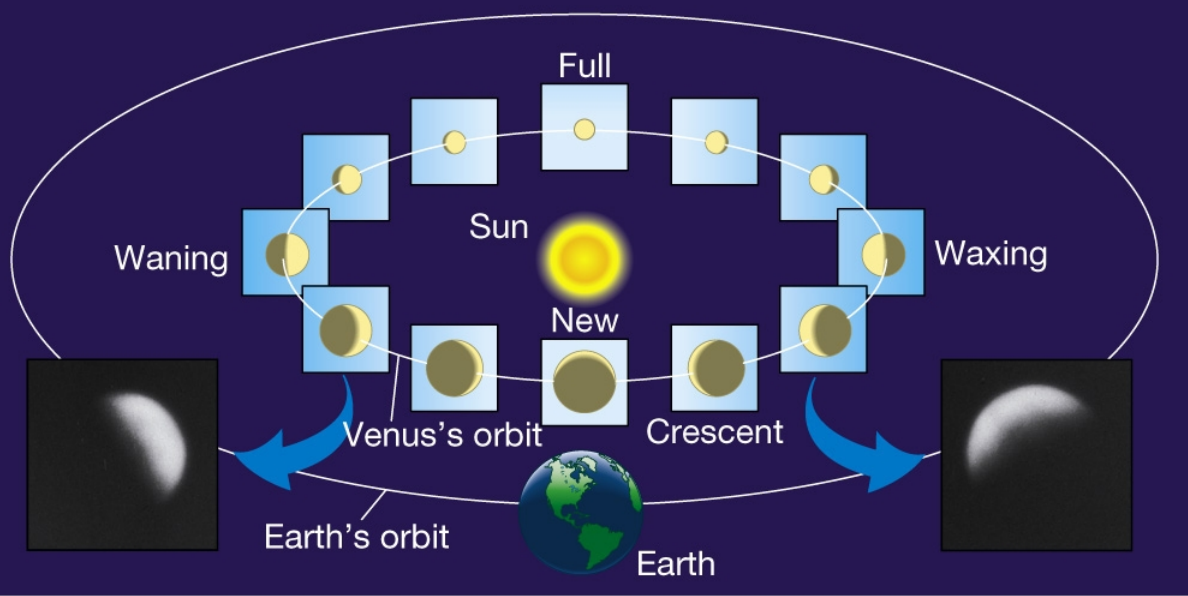


FIG. 70.

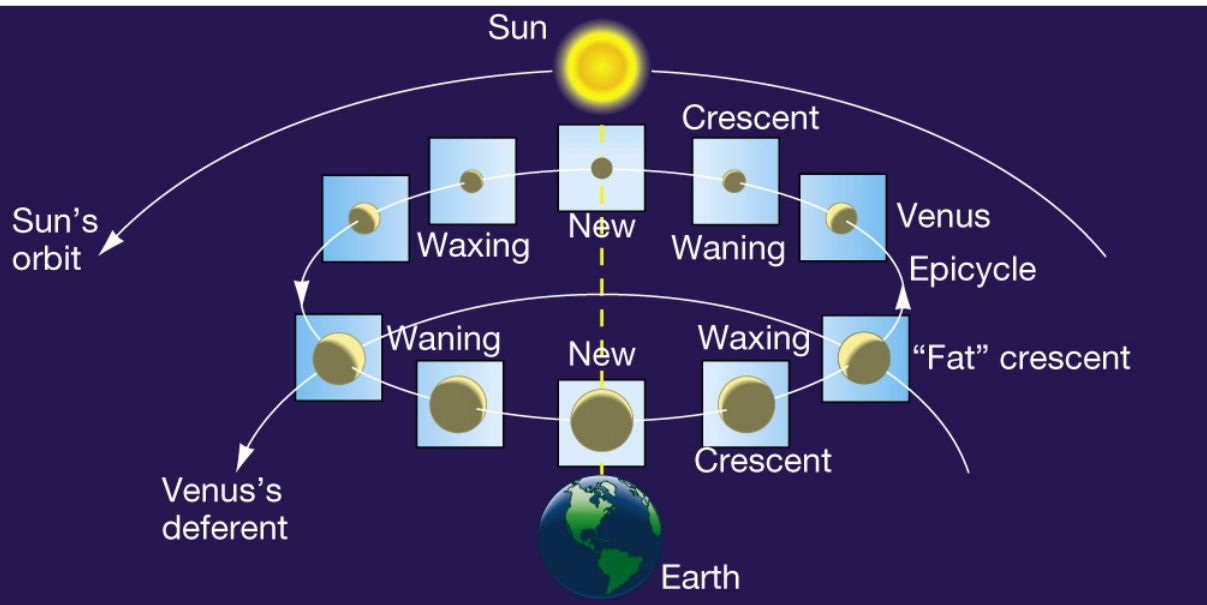
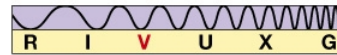


nus

Galileo observed Venus in a gibbous phase. Which of these two models predict a gibbous phase?



(a) Sun-centered model



(b) Ptolemy's model

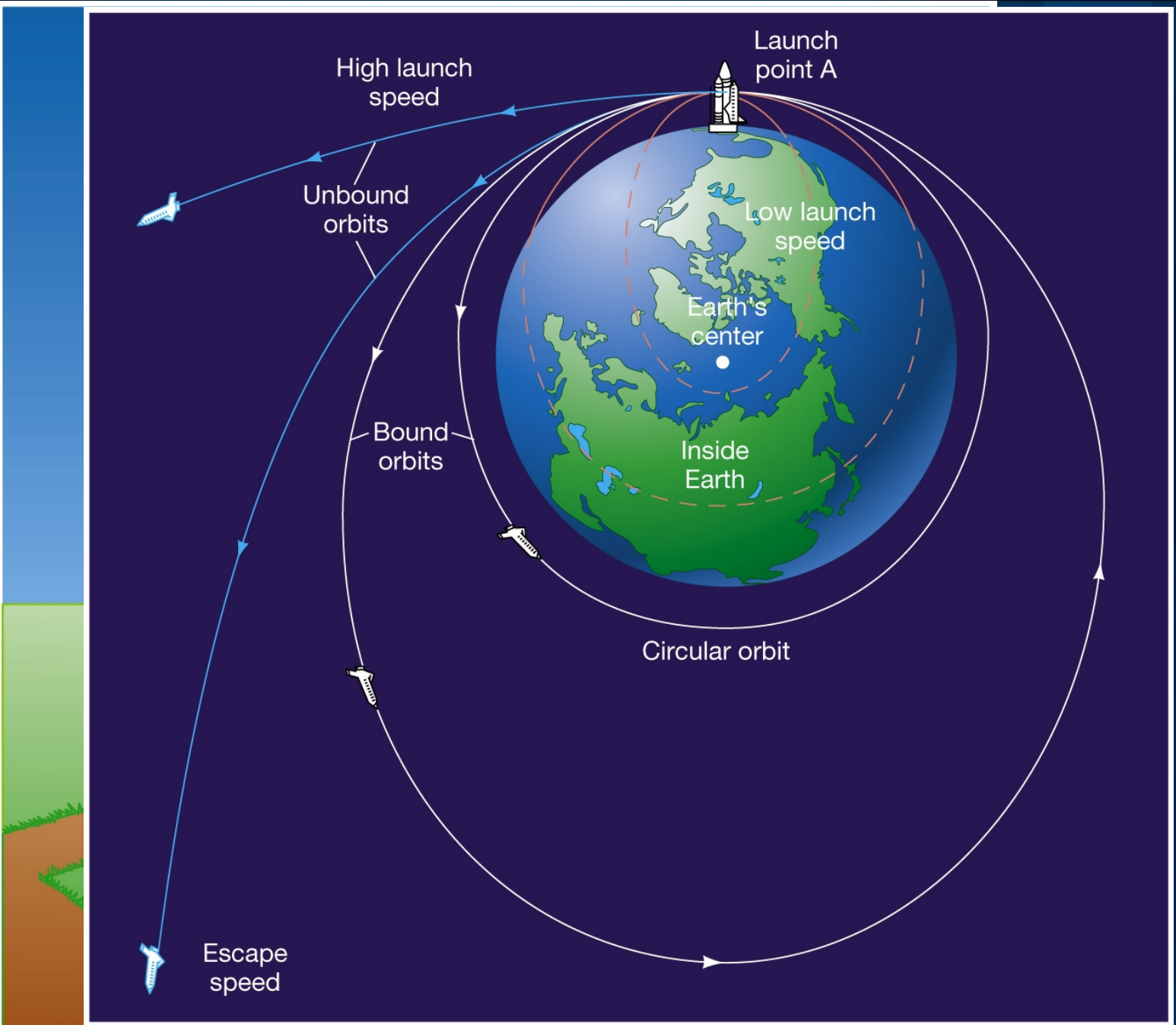
Venus, in different phases

Ptolemy's model

Galileo's troubles

- Galileo was more vociferous and brash than Copernicus and Kepler.
- 1610: Published *Sidereal Nuncius* (Starry Messenger)
- 1616: Galileo's book judged heretical and banned
- 1632: Published *Dialogue Concerning the Two Chief Systems*.
- Simplicio speaks words of Pope Urban VIII.
- Published in Italian
- 1633: Sentenced to house arrest.
- 1642: Dies in house arrest.

- English
- theolo
- Inven
- Urge
- Philos
- 3 law
- Unive
- Can
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- or can



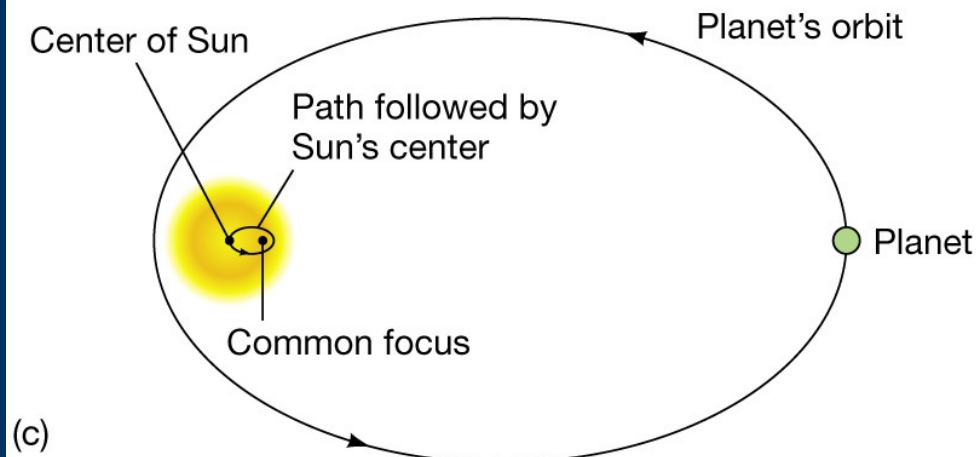
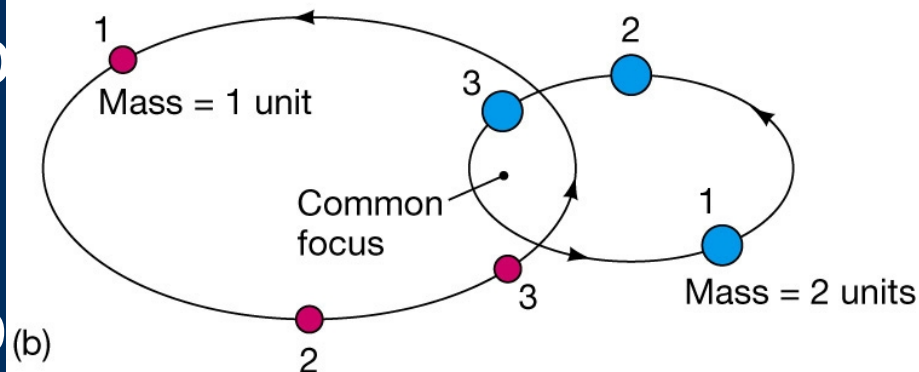
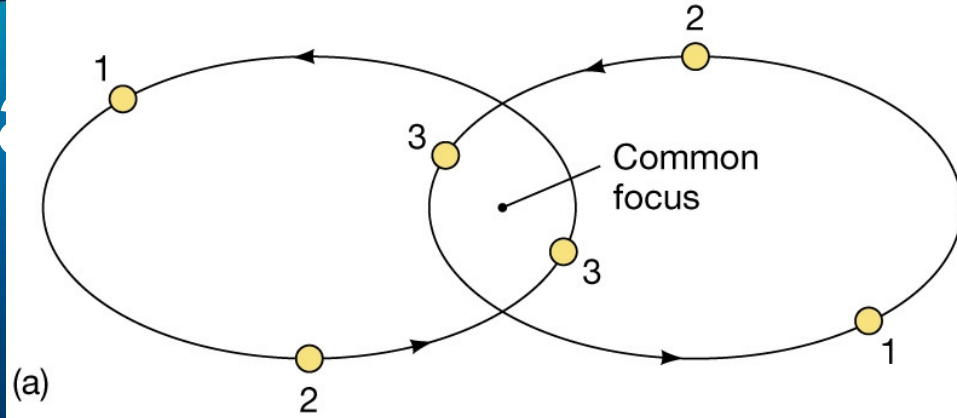
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Is

S”

- Kepler I: with the p of mass o (Sun)
- Kepler III: system to



$$= \frac{a^3}{M_{tot}}$$

The Copernican Revolution ...

matching!

Observed gibbous phase of Venus

Nicolaus Copernicus

Made precision measurements of planets

Tycho Brahe

Johannes Kepler

Used ellipses to model solar system

Galileo

Newton

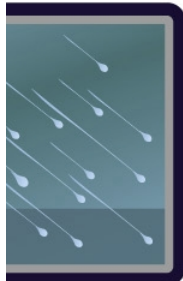
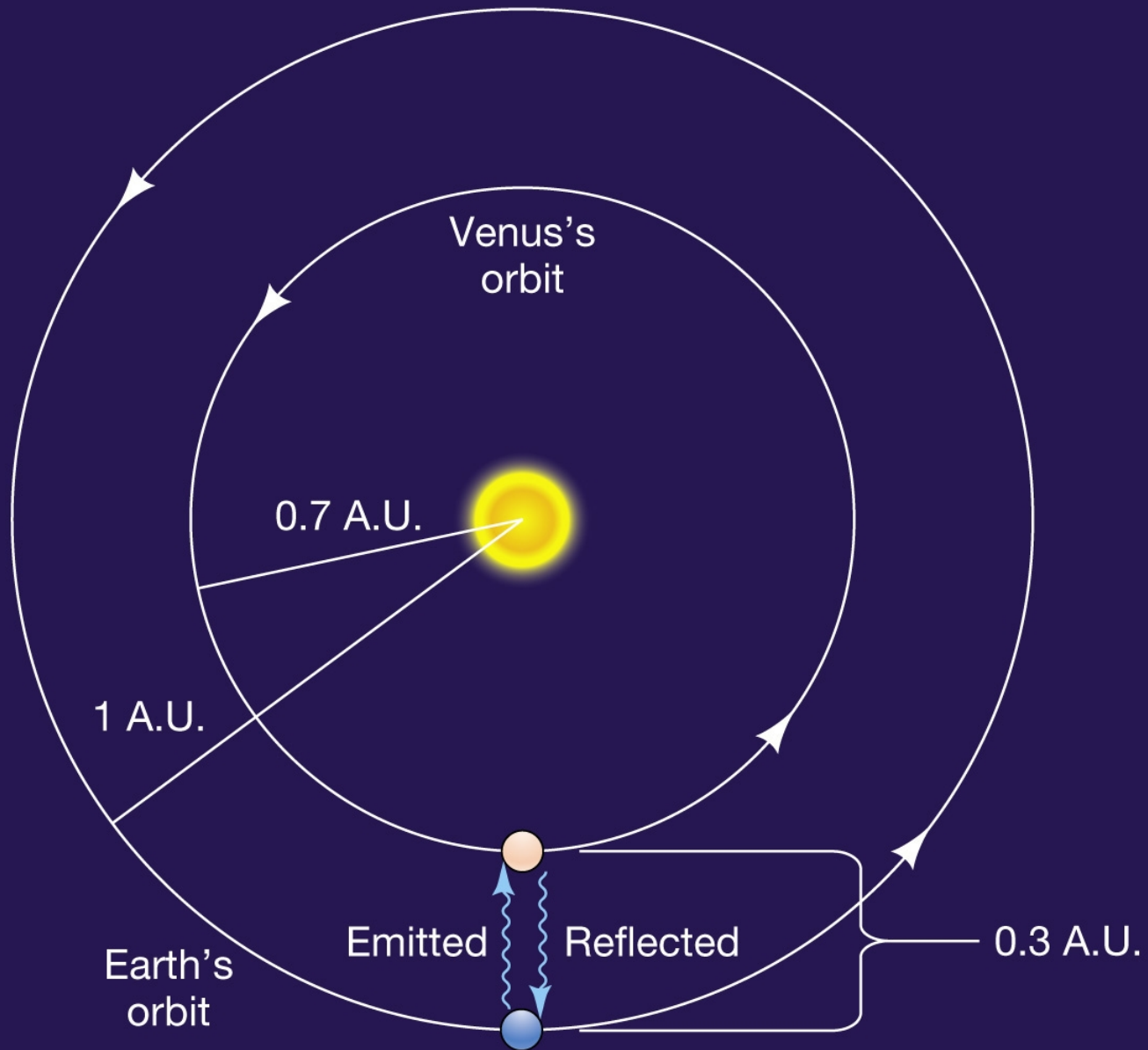
Said gravity accelerates the planets

Revived the heliocentric model

Fi

- V

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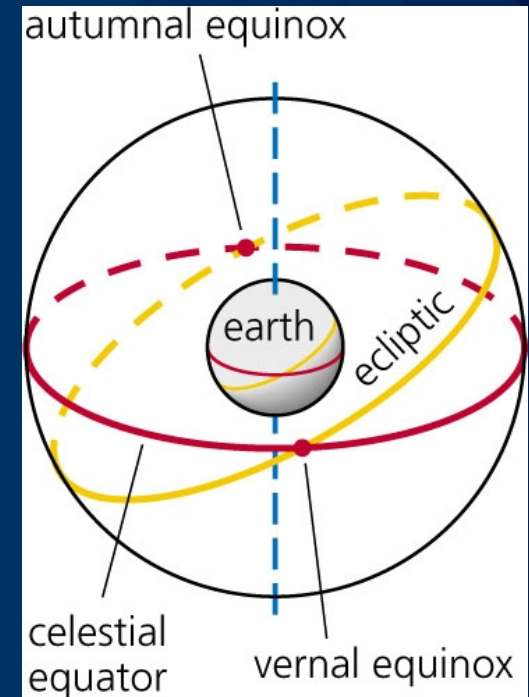
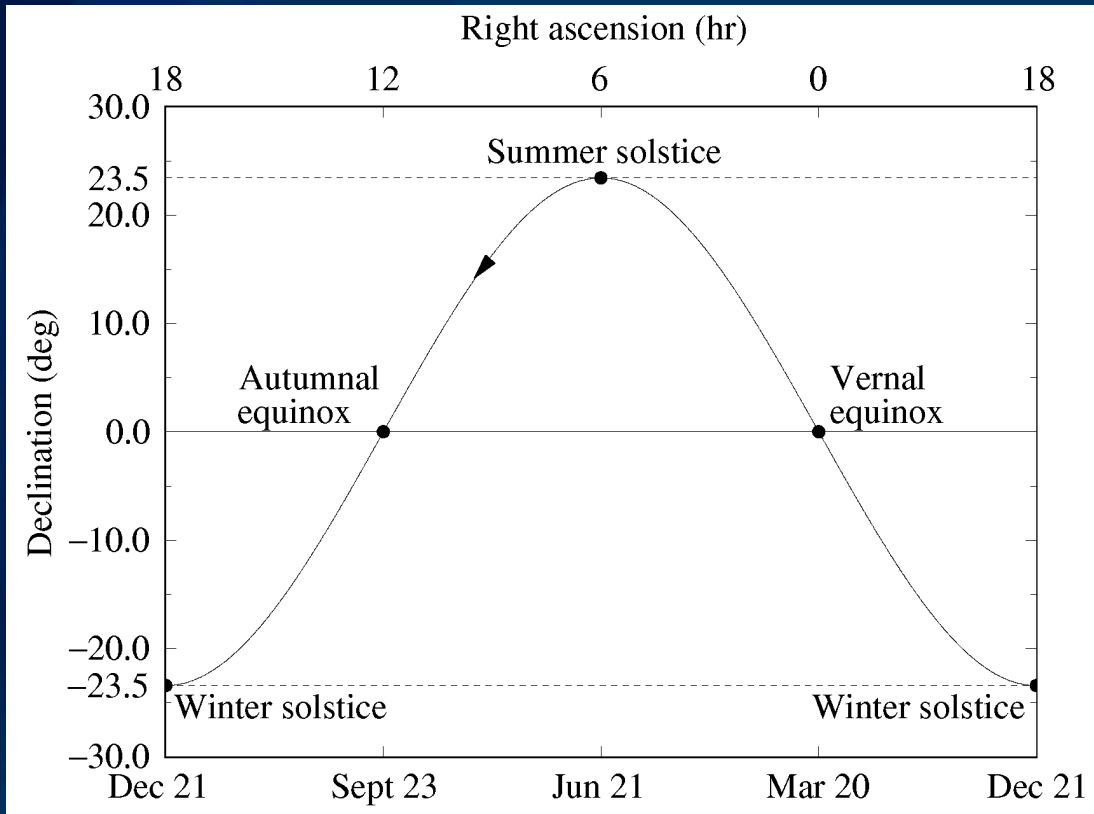
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Science vs Superstition – it never ends

- *The Copernican Principle*
 - Sun not at center of galaxy, or of Local Group, or of Local Supercluster, or of expansion of universe. *Are humans the only intel. life?*
- “Crazies” coming out of the woodwork
 - There are people at both extremes; pure skepticism and belief.
- Each of us has to reconcile facts with beliefs. Follow Kepler's Lead!
- See “The Demon-Haunted World: Science As a Candle in the Dark” - C. Sagan

Ecliptic

- Seasonal variations due to orbital motion and the 23.5° tilt of Earth's rotational axis



General philosophy of science

Karl Popper: Logic of falsification

Theories can never be verified by observation.

Theories can be falsified by observation, and so discarded.

The only acceptable theories are those which are falsifiable.

Thomas Kuhn: Paradigms and paradigm shifts

“Normal science” -- investigation within a paradigm

Revolutions -- paradigm shifts driven by anomalous data

Niels Bohr: Correspondence principle

New theories must reduce to good old theories in some limit.

A Summary of the Early History of Astronomy

