The Copernican Revolution - Separating Science and Superstition

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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

Legacy of the Ancient Greeks

- 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: “Tetrabiblios” relates horoscopes to Aristotelian philosophy

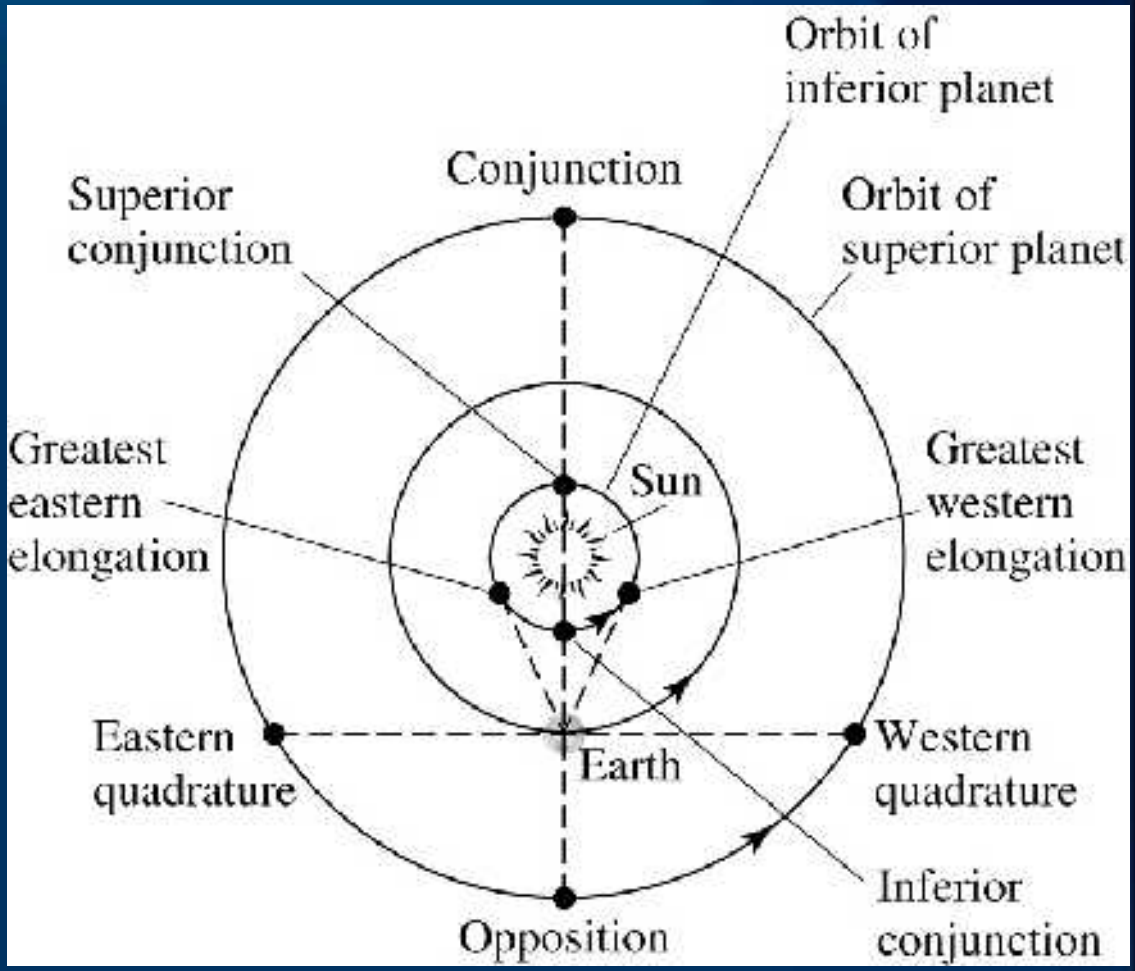
The Appearance of the Planets

- Daily motion
- Change brightness, position and angular speed across sky.
- All orbit CCW as seen from “North”.
- Usually eastward motion, occasional westward motion we call ...

Retrograde Motion!

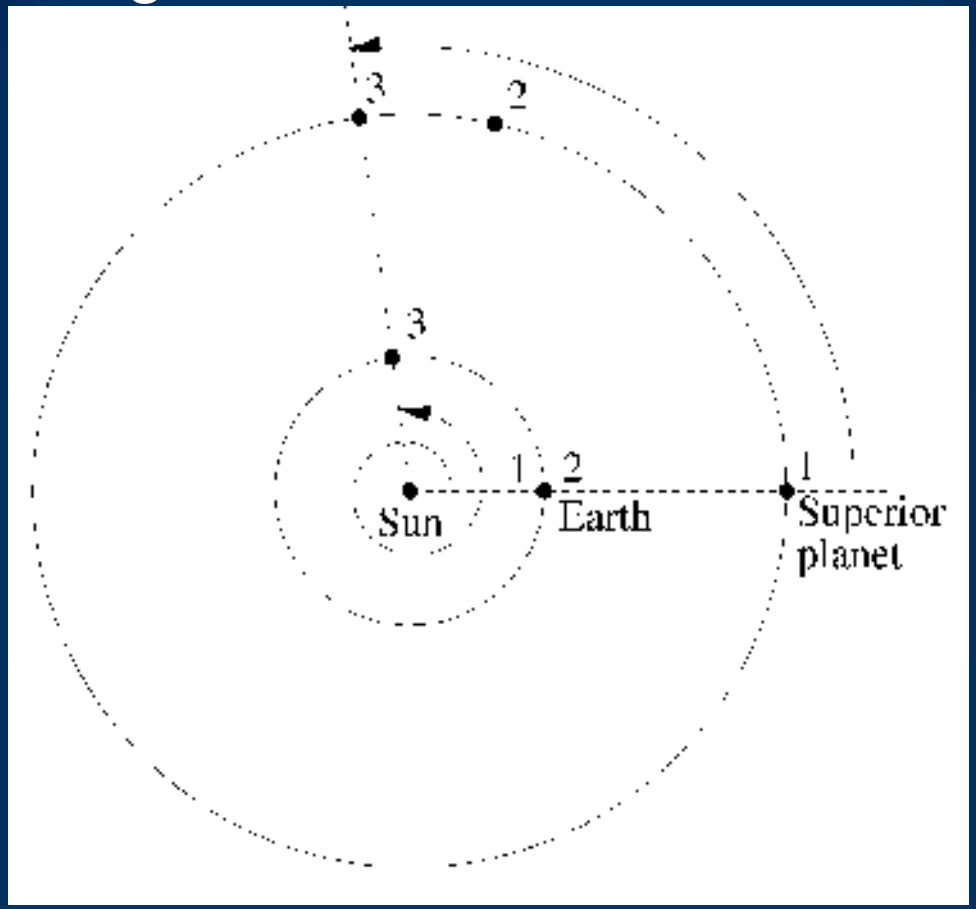
Planetary Configurations

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



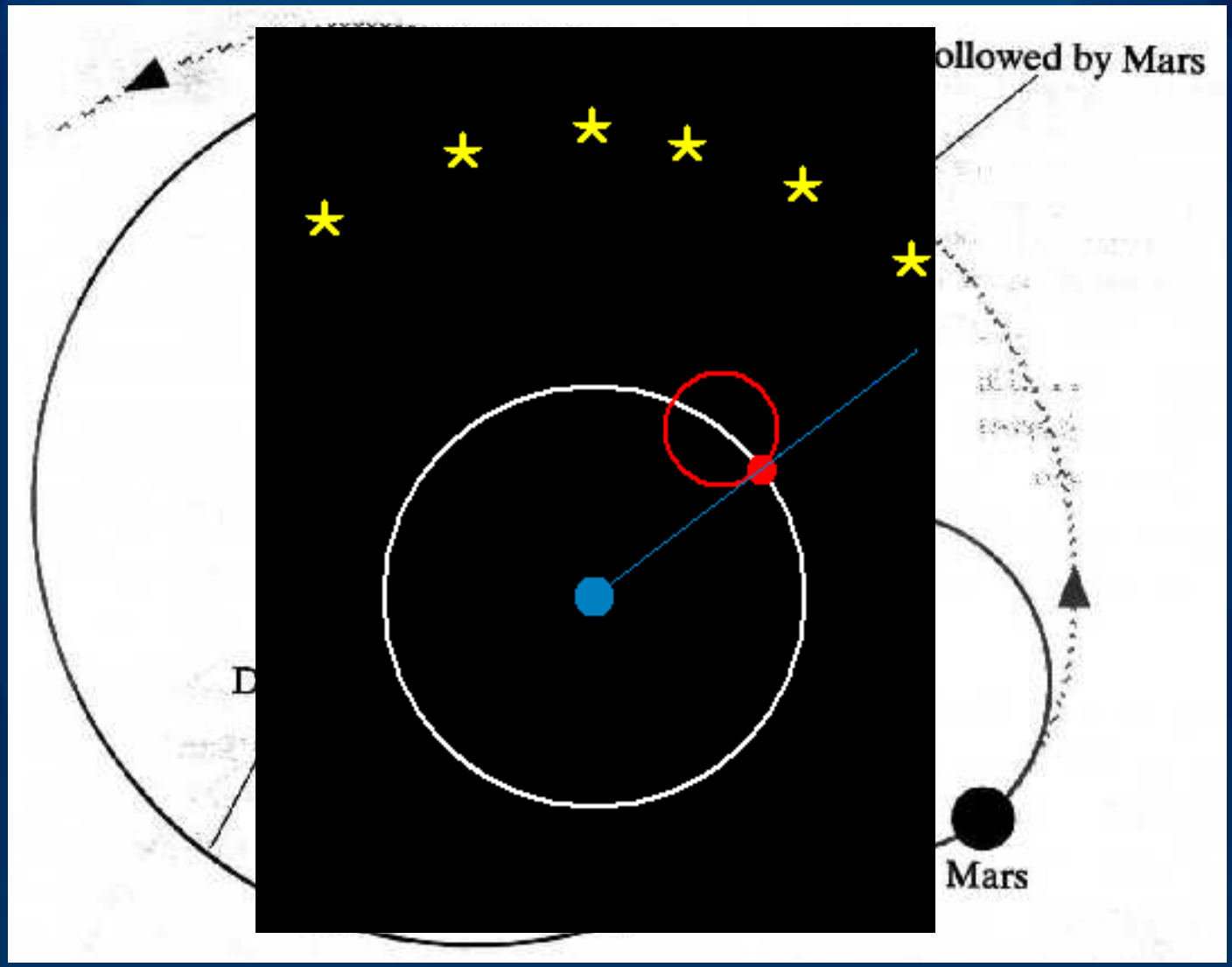
Synodic and Sidereal Periods

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



Epicycles on Deferents

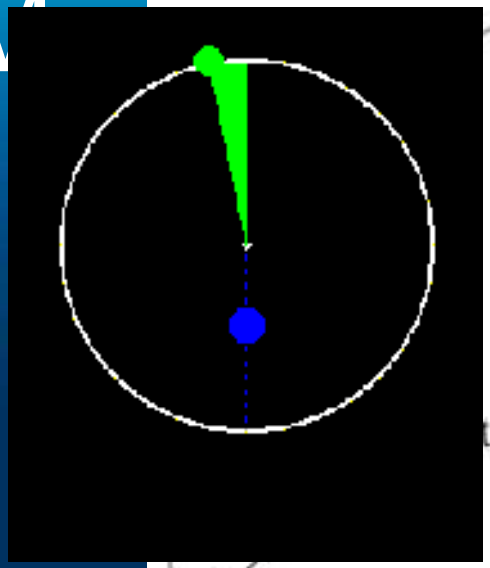
- Ptolemy et al. desired uniform circular motions

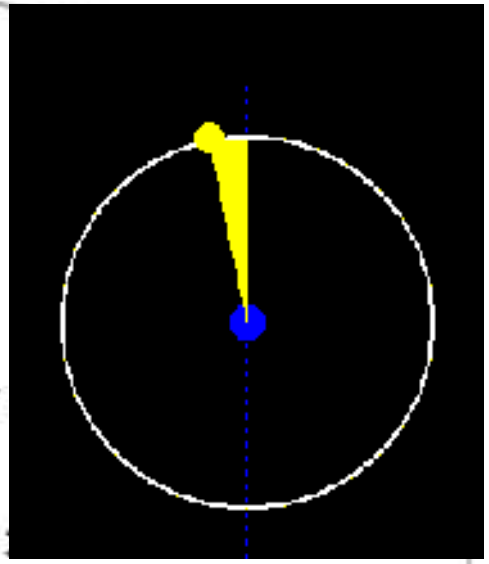


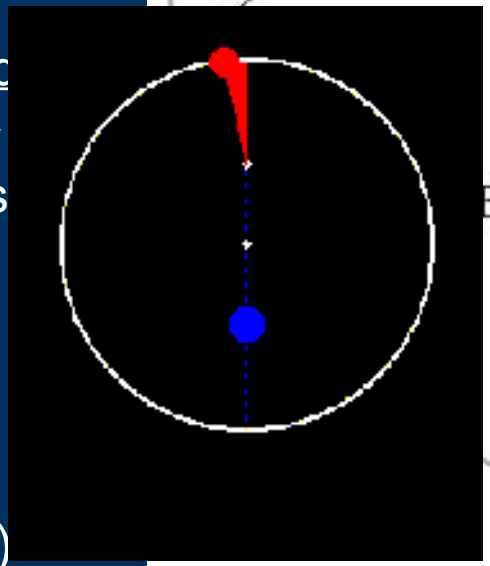
Ptolemy's M

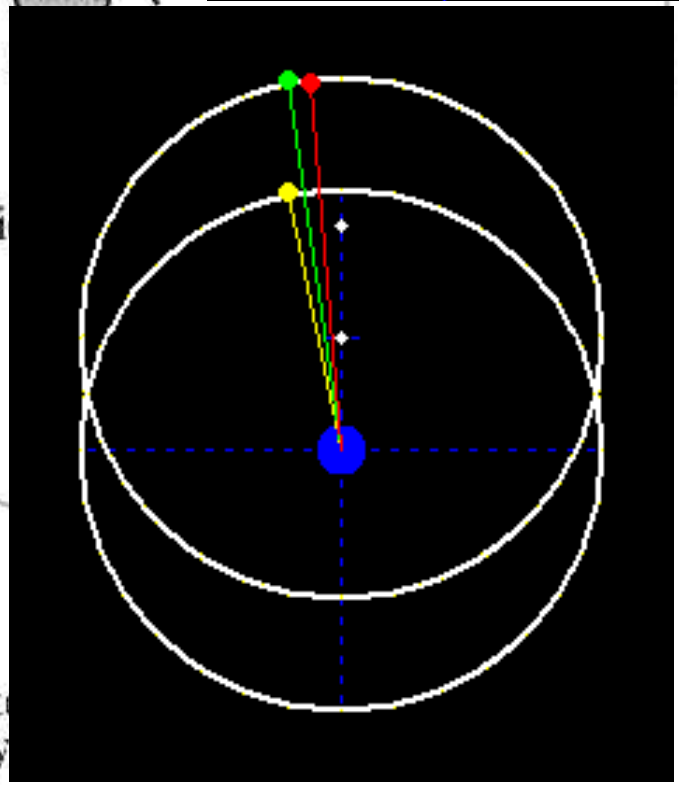
- Eccentric - displaces Earth from center
- Equant – center of epicycle has uniform angular speed when viewed from this point
- Period of planet around epicycle is synodic period
- Period of epicycle center around deferent center is sidereal period.
- 80+ epicycles
- It works pretty well!

- Occam's Razor (1348)
  - Accept the simplest explanation





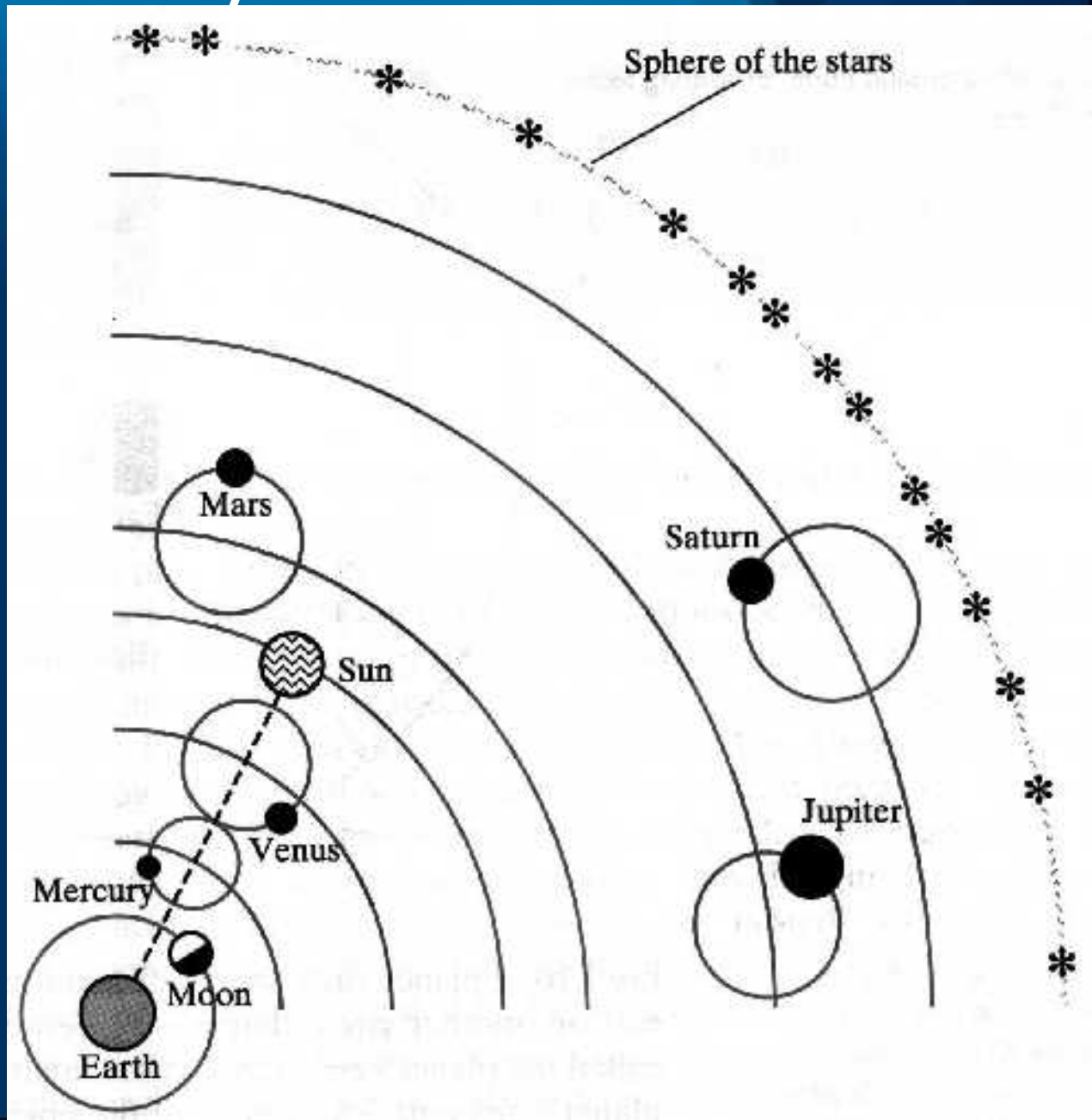




Ptolemy's Model

- 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 prefected 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

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. 1642

. 1642

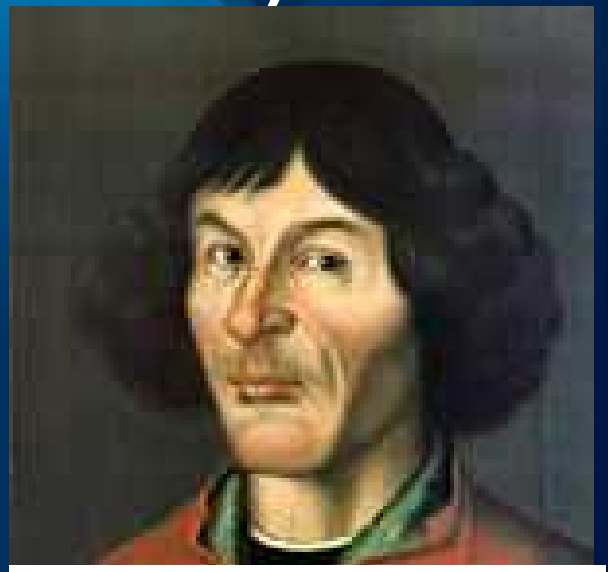
SIR ISAAC NEWTON

. Philli Principia

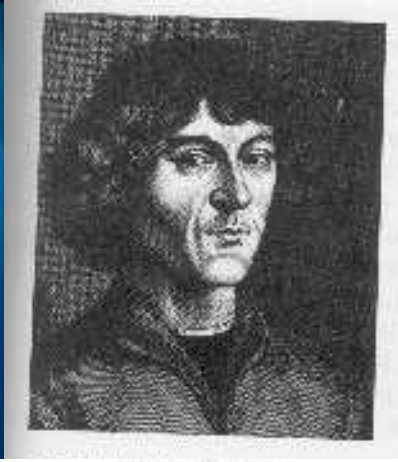
. 1727

Copernicus (1473-1543)

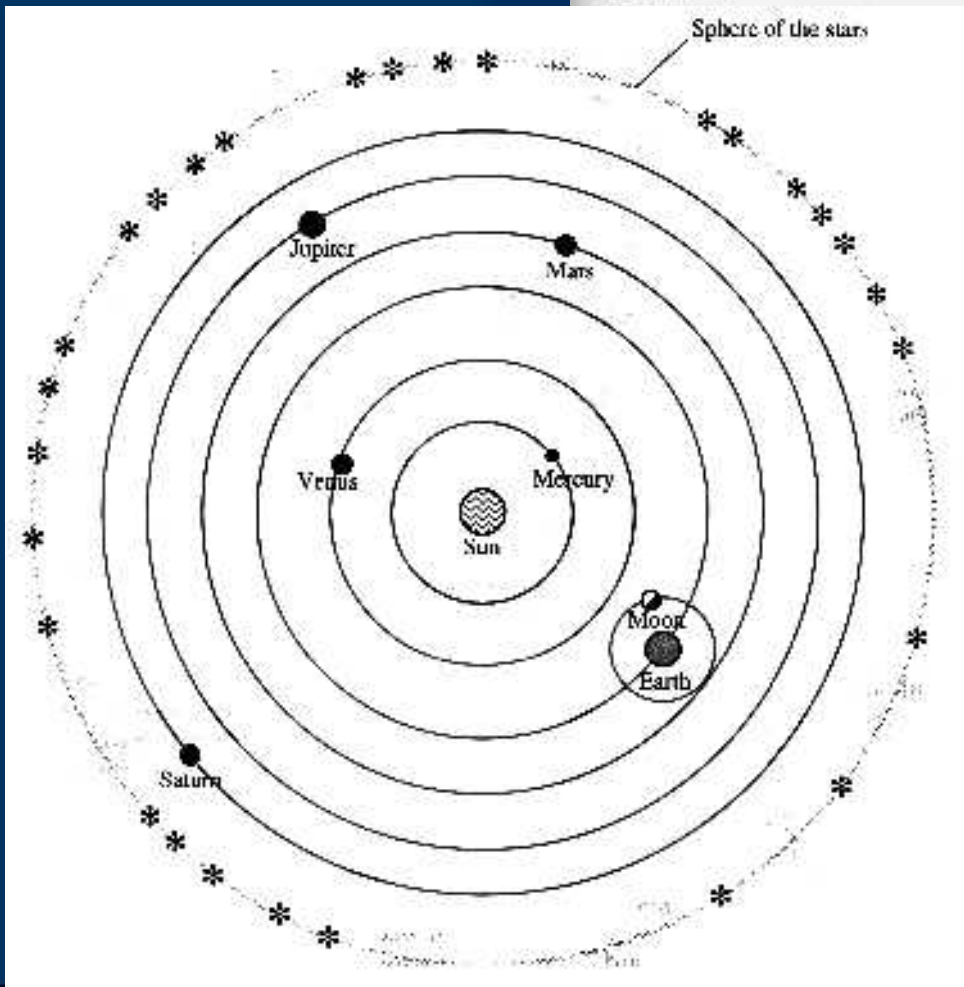
- Polish Son of copperworker
- a mathematician, astronomer, physician, classical scholar, translator, Catholic cleric, jurist, governor, military leader, diplomat and economist
- Astronomy is avocation
- Publications
  - On the Revolutions of the Heavenly Spheres (1543)
  - Little Commentary (1514)
  - 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

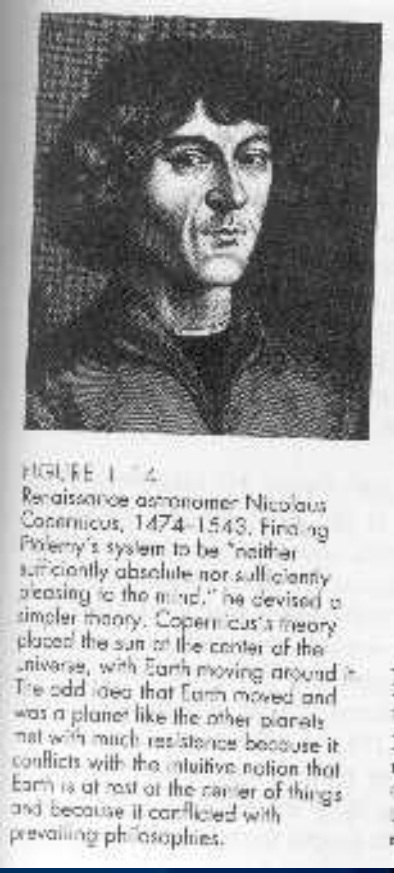


- Is there something simpler? How about the Sun in the Center!!!?
- Keep some Aristotelian ideas
  - spheres (circles)
  - uniform motion
- Major Changes
  - Earth centered (heliocentric)
  - Earth rotates
  - Earth is no different from the other planets and stars!
- Established order of the planets
- Less complicated 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 predictions not available



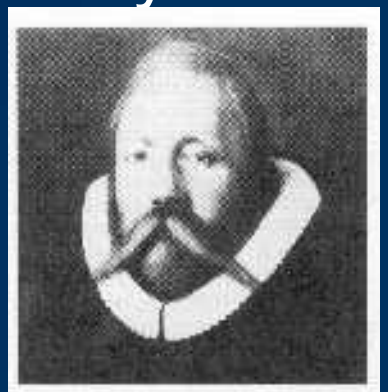
Renaissance astronomer Nicolaus Copernicus, 1474–1543. Finding Ptolemy's system to be "neither sufficiently absolute nor sufficiently pleasing to the mind," he devised a simpler theory. Copernicus's theory placed the sun at the center of the universe, with Earth moving around it. The odd idea that Earth 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)

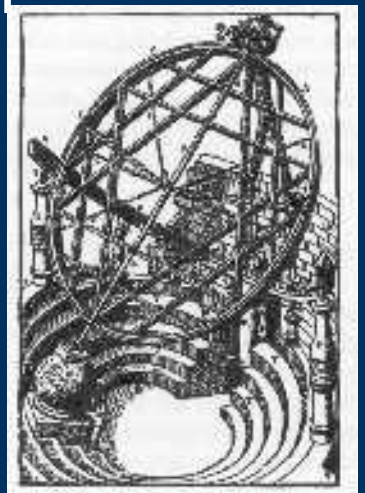
- Danish nobleman
- Built “Uraniborg” in Hven
- Observed supernovae of 1572
- Could not detect parallax
- Develops Tychonic System
- Wore metal nose
- Hired Kepler in 1600
- Furnished patrons with astrological predictions
- Death (bladder or mercury)

Tycho Brahe

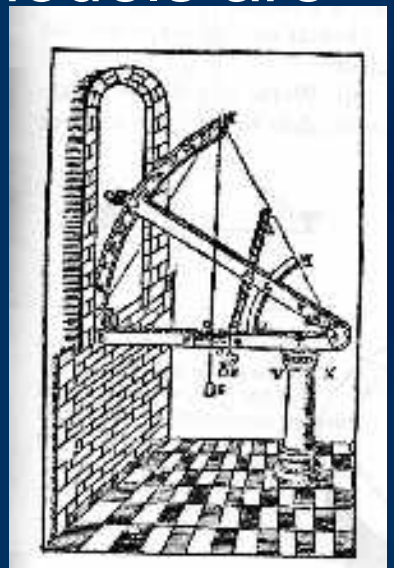
- Left Kepler with 20 years of meticulous planet measurements.
  - 5x better precision
    - 2 arc-minutes (1/30 of a degree) compared to 10 arc-minutes (1/6 of a degree)
    - 20 years of data
  - Both Ptolemy and Copernicus's models are wrong!



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.



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



An instrument that Brahe used for

Johannes Kepler (1571-1630)

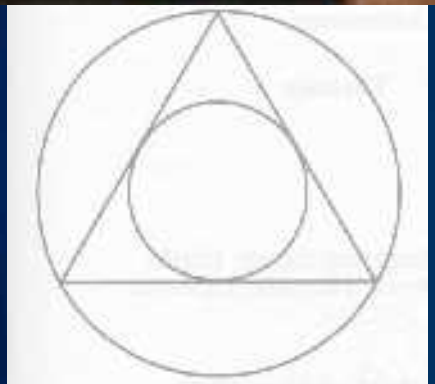


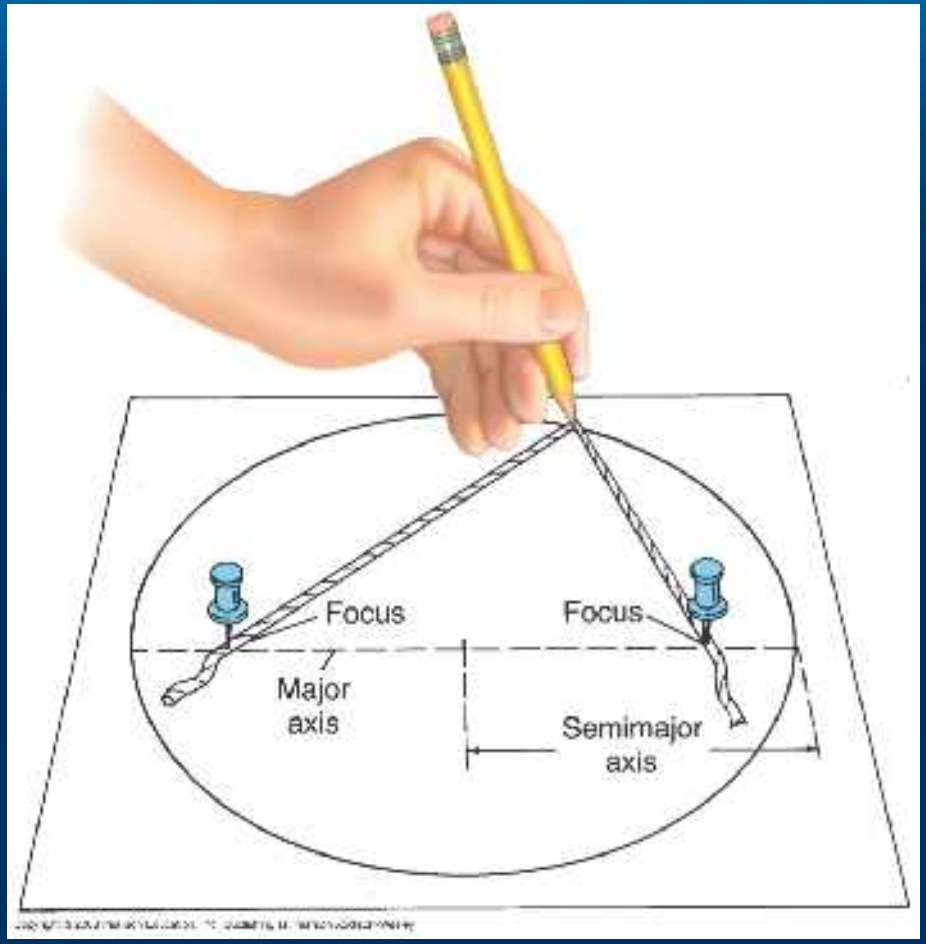
FIGURE 1.23
A blackboard diagram similar to this gave Kepler the original inspiration for his planetary theory based on the five perfect solids. In this diagram, two circles are separated by a triangle.

- Mathematician, astronomer, astrologer
- Had religious convictions - *God had created the world according to an intelligible plan that is accessible through the natural light of reason*.
- Geometry in nature – tries concentric regular solids for 4 years.
- Astrology, numerology
- “mother sold drugs”

Johannes Kepler

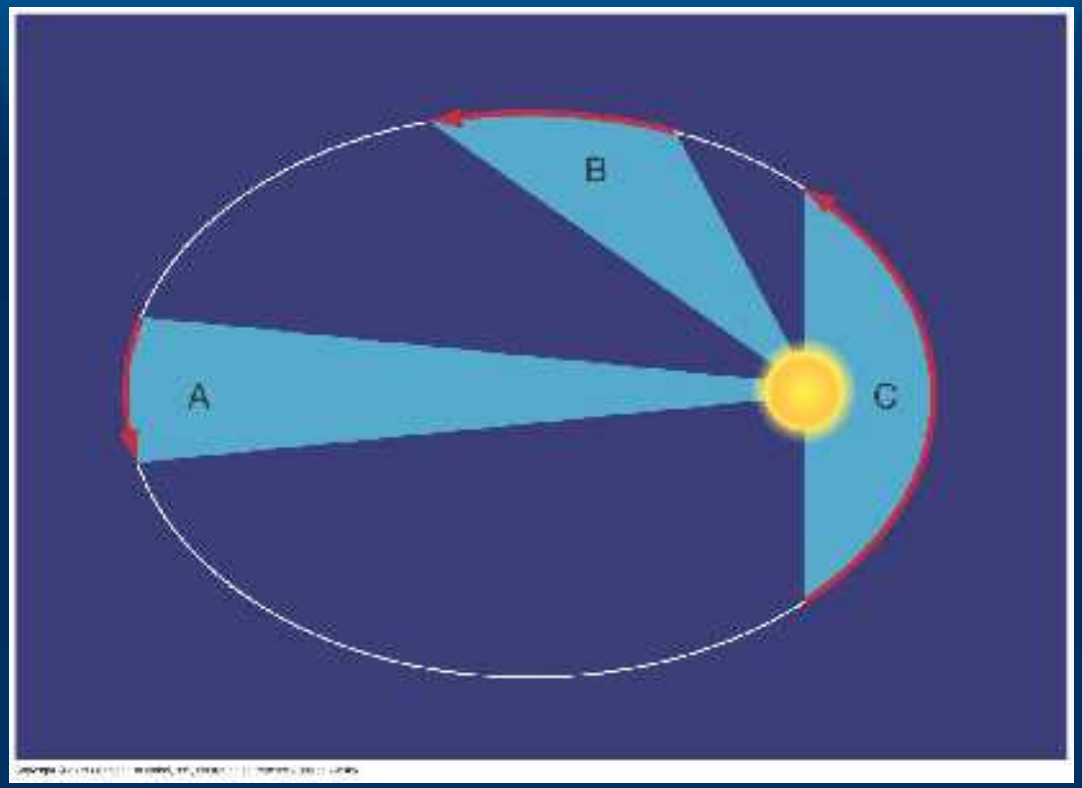
- Supported Copernicus (heliocentric) and Galileo
- Copernicus's Model
  - Struggles to make it work
  - Throws out circles and uniform motion
- Tries Sun-focused ellipse idea
  - A mistake causes him to put it aside
  - It works!!
  - Predicts all existing data including Tycho's
  - Kepler's 3 laws

Kepler's 1st law



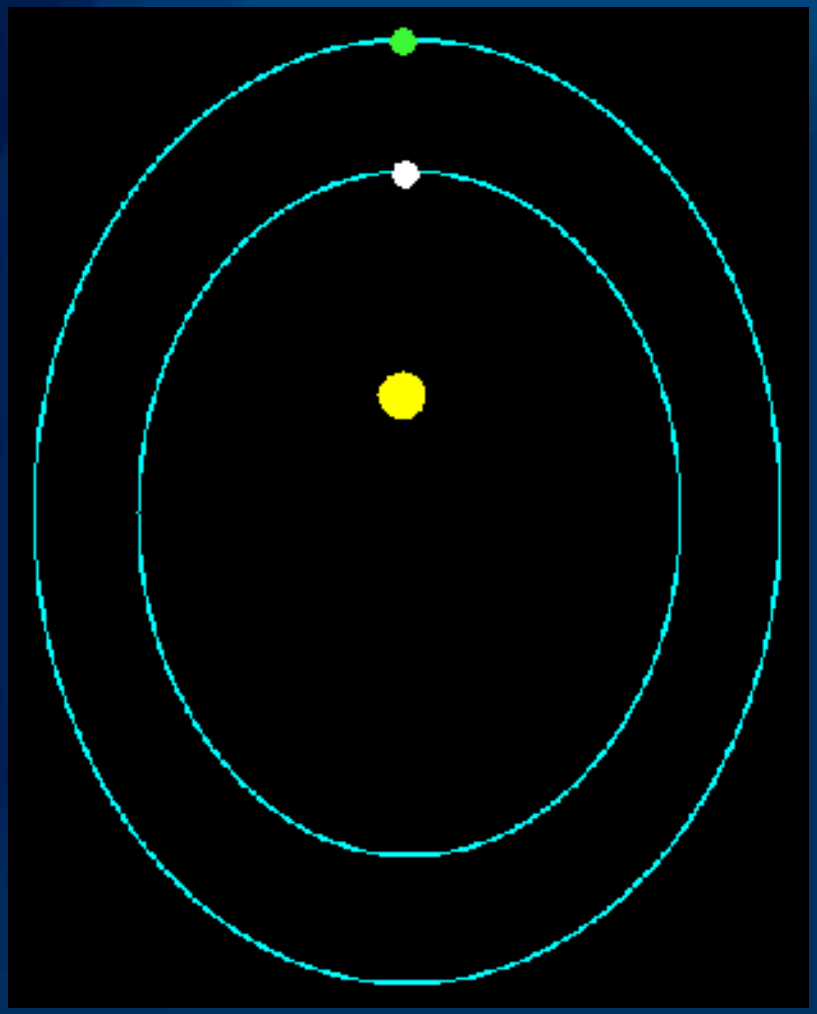
The planets follow elliptical paths with the Sun at one focus.

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, speed of light experiments
  - Moons of Jupiter orbit Jupiter!
  - Earth not the center!
  - Phases of Venus include the gibbous phase!
  - 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

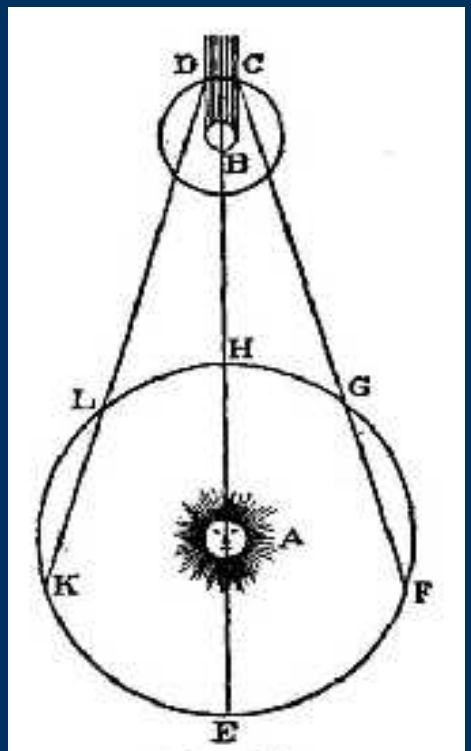
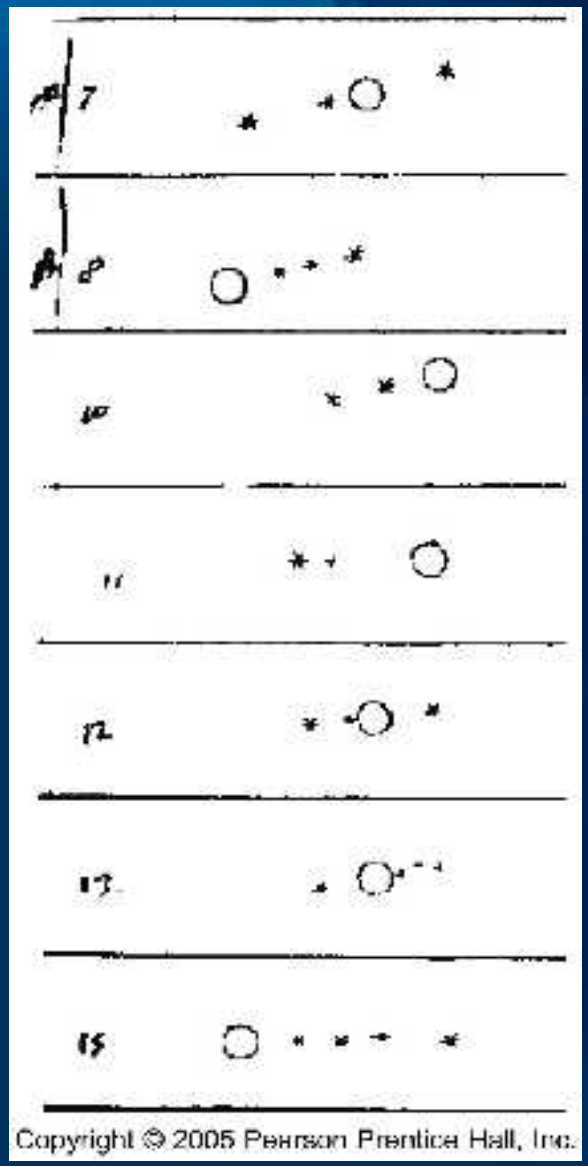
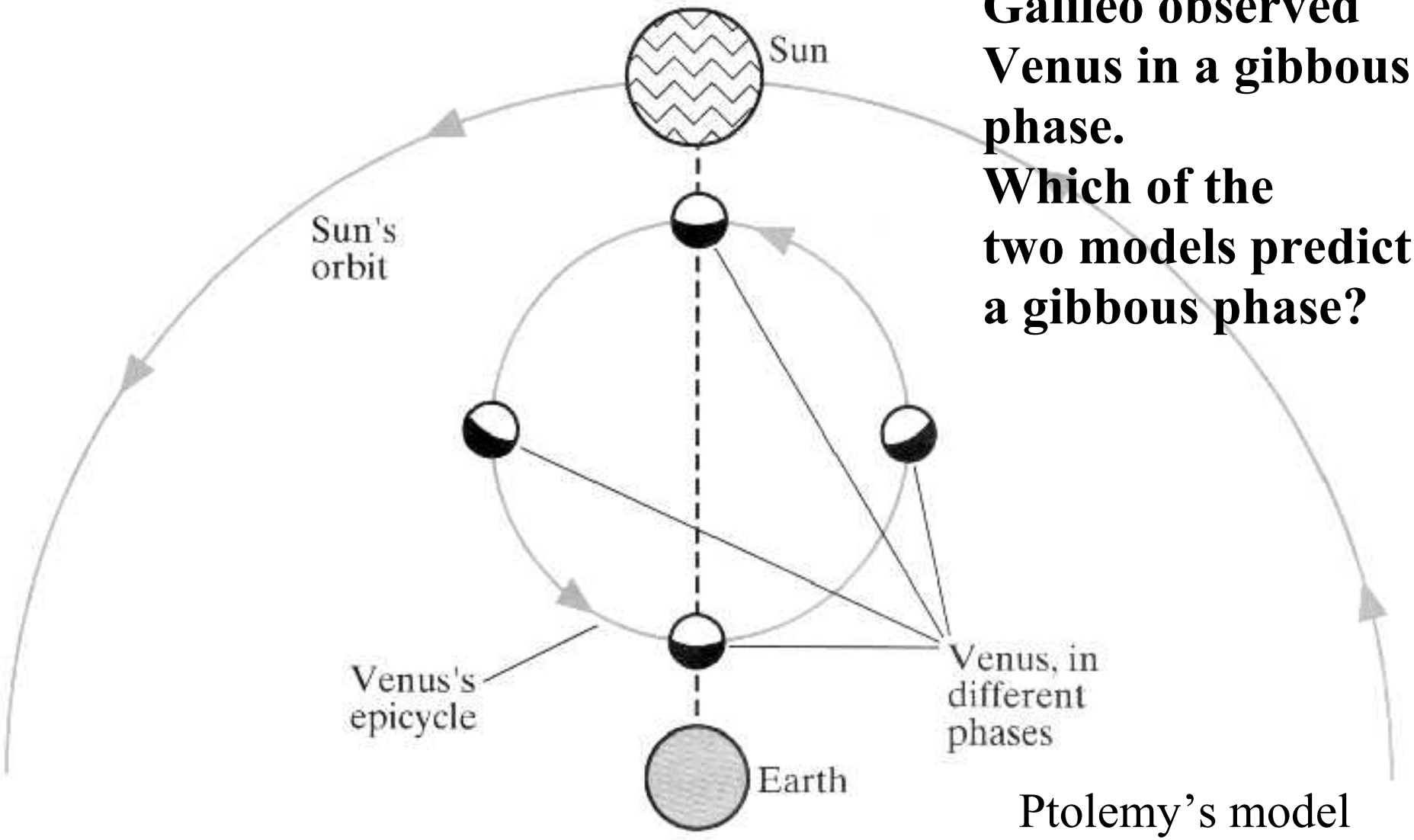


FIG. 70.



Galileo and Venus



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

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.

Isaac Newton (1643-1727)

- English physicist, mathematician, theologian, alchemist
- Invents calculus
- Urged by Halley to publish "Principia"
  Philosophiæ Naturalis Principia Mathematica
- 3 laws of motion
- Universal law of gravitation

$$F = G\frac{m_1 m_2}{r^2}$$

  - Can explain Kepler's laws!
  - Finally, we have a reason for the orbits!
- *"God governs all things and knows all that is or can be done."*

Isaac Newton's “Fixes” to Kepler's Laws

- Kepler I: The planets orbit in ellipses with the principle focus on the center of mass of the solar system, (not the Sun)
- Kepler III: add the total mass of the system to the denominator ...

$$P^2 = \frac{a^3}{Mtot}$$

The Copernican Revolution ... *matching!*

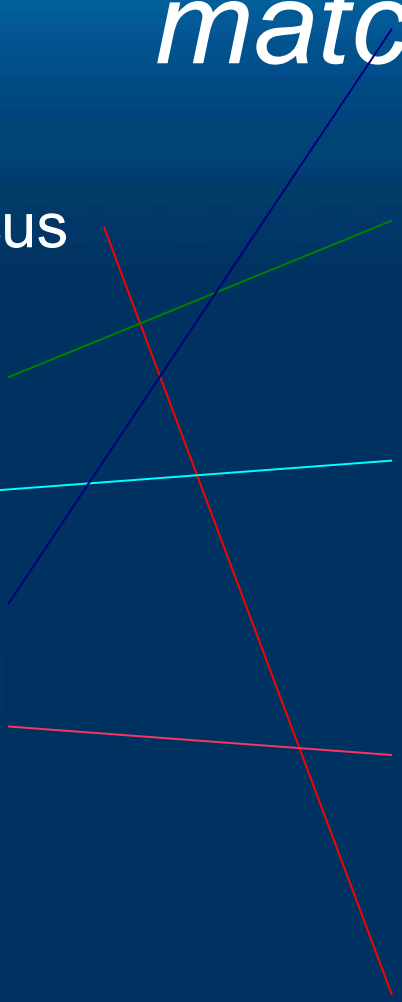
Nicolaus Copernicus

Tycho Brahe

Johannes Kepler

Galileo

Newton



Observed gibbous phase of Venus

Made precision measurements of planets

Used ellipses to model solar system

Said gravity accelerates the planets

Revived the heliocentric model

Figuring out the remaining loose ends of the Solar System

- Verification that Earth is in motion
  - Ole Roemer's, 1677 - Jupiter Moon delays
  - James Bradley, 1728 – aberration of starlight
  - Frederick Bessel 1838 – first parallax
- What is 1 Astronomical Unit???
  - Use timings of Venus during transits across Sun
  - Bounce radar off of Venus when near inferior conjunction

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

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.