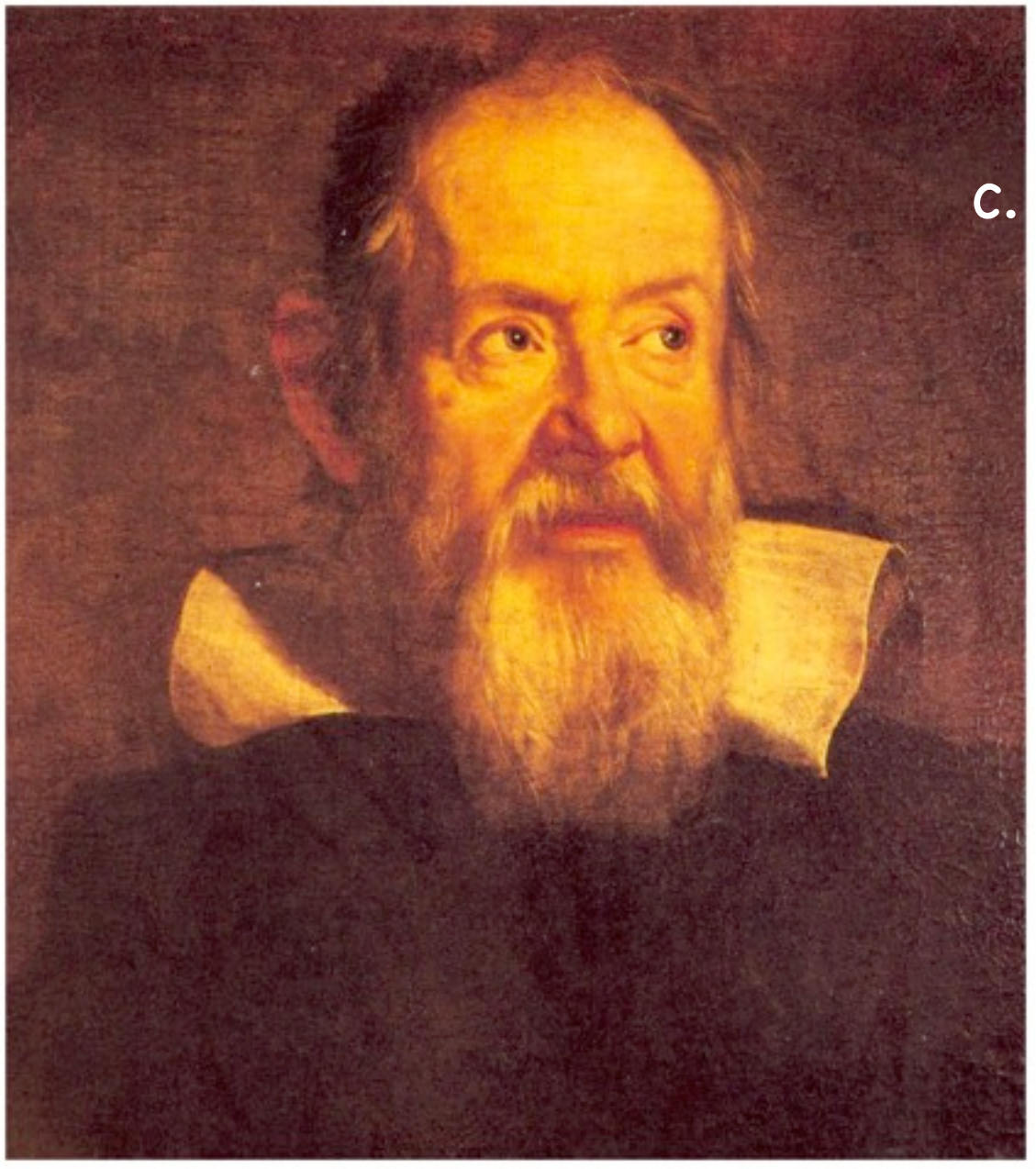
Today

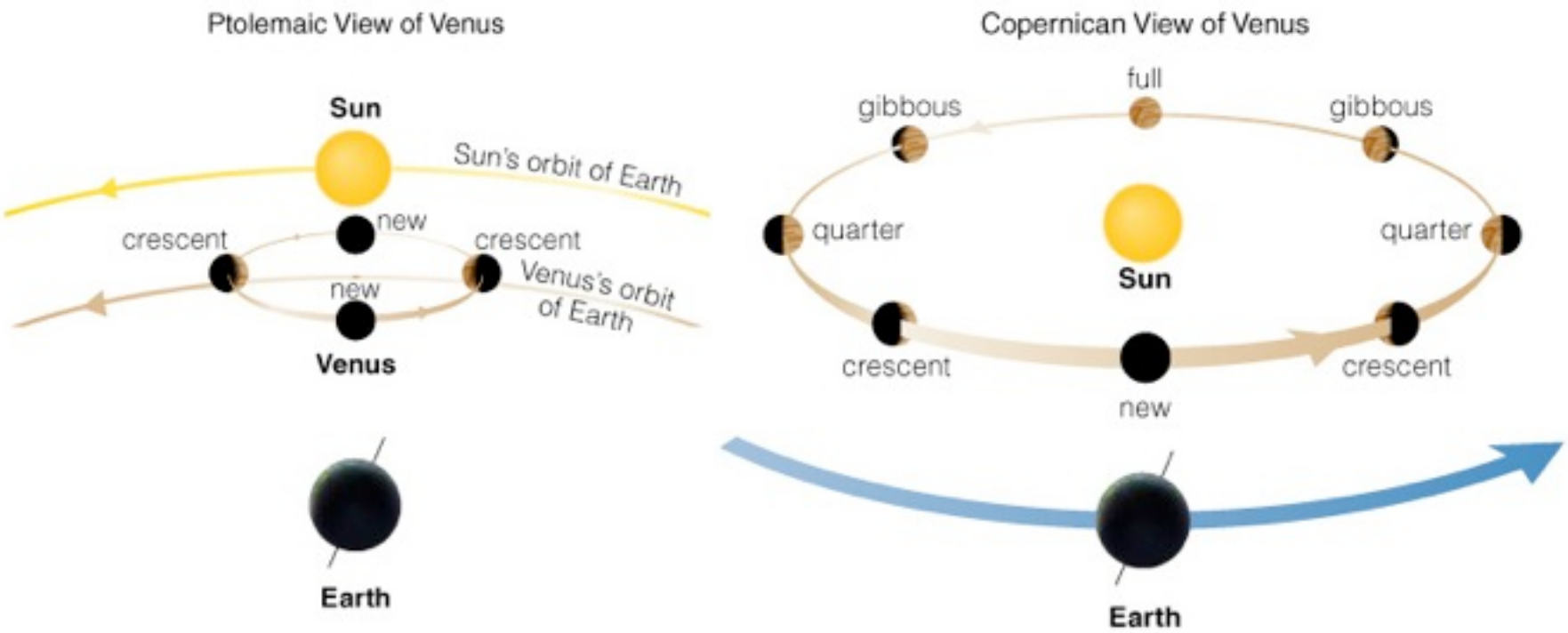
- The Copernican Revolution
- Galileo
- Planetary Motion
  - Tycho Brahe's Observations
  - Kepler's Laws

Galileo



c. 1564-1640

First telescopic astronomical observations



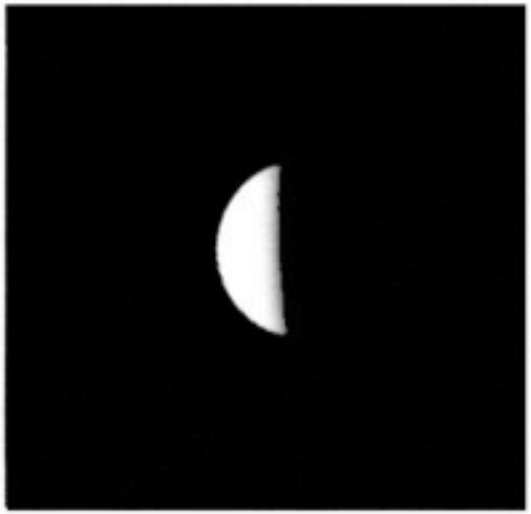
Galileo's observations of phases of Venus proved that it orbits the Sun and not Earth.

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

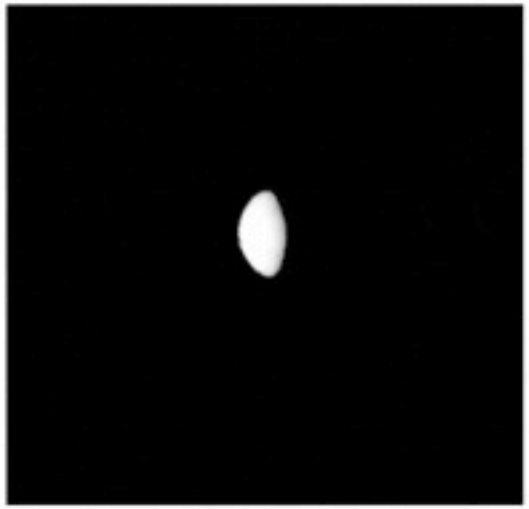
$\alpha = 58°$

$\alpha = 42°$

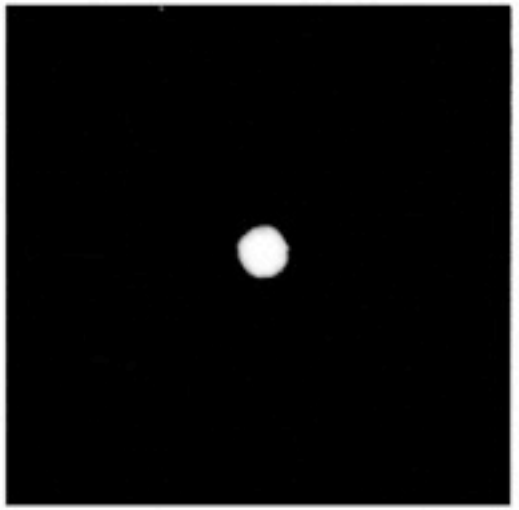
Phase and angular size of Venus depend on elongation



$\alpha = 24°$



$\alpha = 15°$



$\alpha = 10°$

Competing Cosmologies

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

The sun is the source of light in both models

Explains	**Explains**
• **Motion of Sun** • **Motion of Moon** • **Solar and Lunar Eclipses** • **Phases of Moon**	• **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 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?
  - Undetectable if stars VERY distant
    - Finally detected in 1839

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

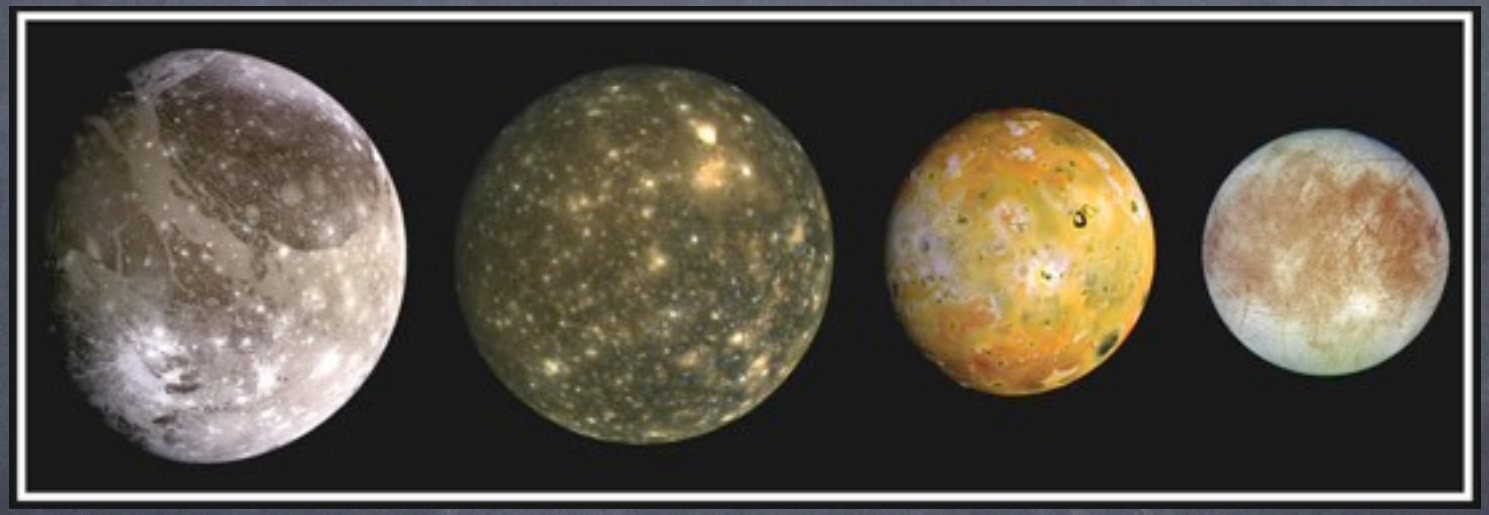
Galileo's telescopic discoveries

- 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

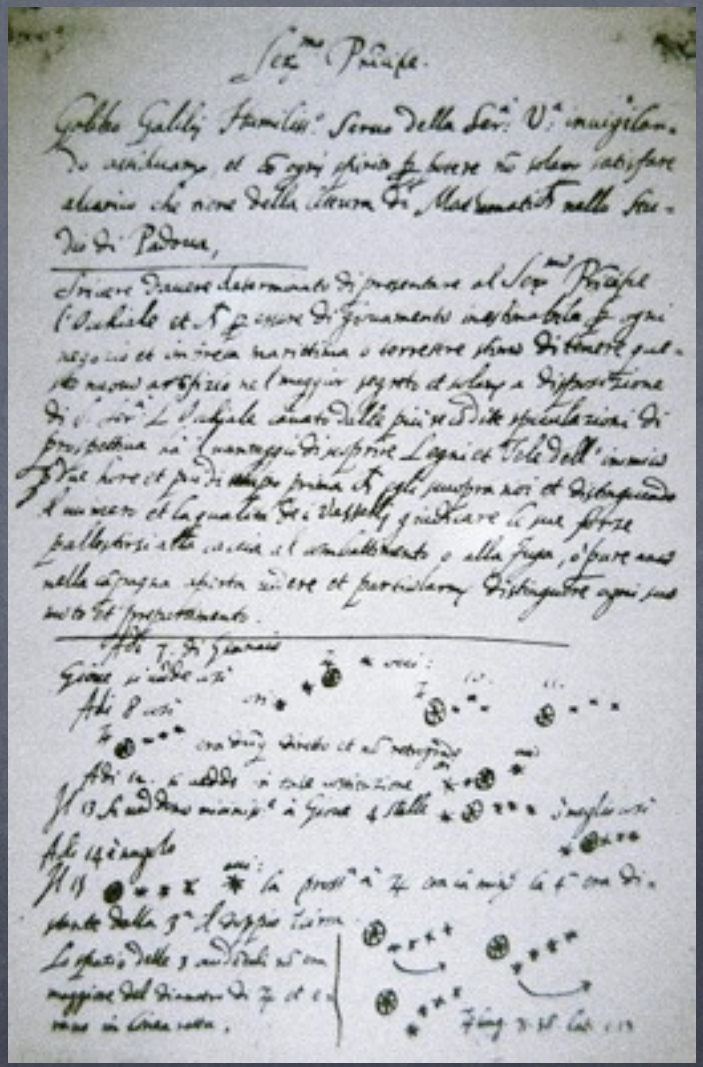
Fig. 4.16

Galilean moons (from Galileo spacecraft!)



NASA

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



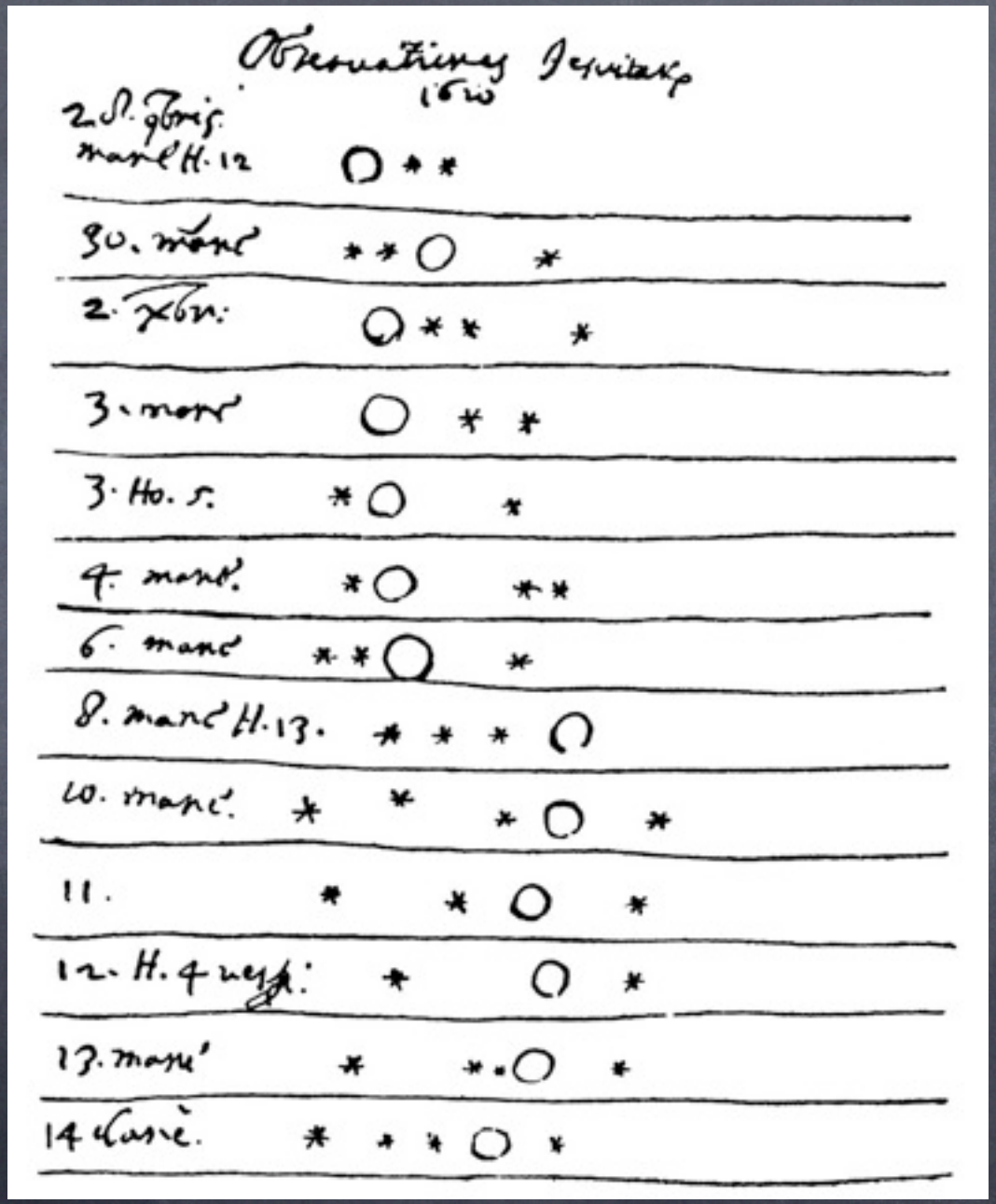


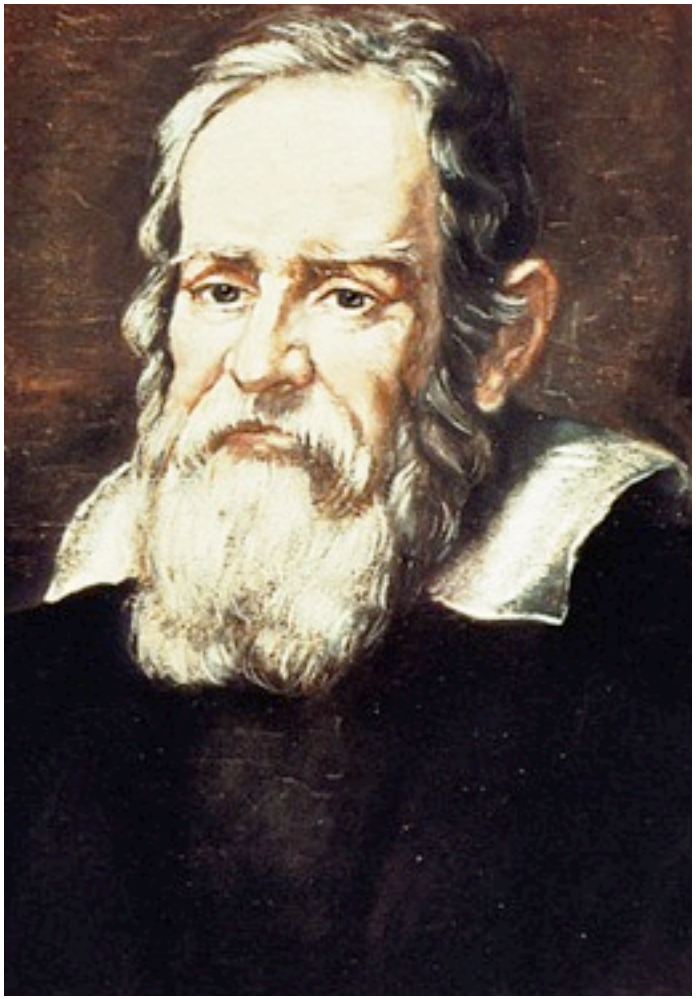
Fig. 4.17

"Medician stars"

Heavenly spheres NOT perfect

The moon has geographical features like mountains & craters

Even the sun has spots!



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.

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Tycho Brahe

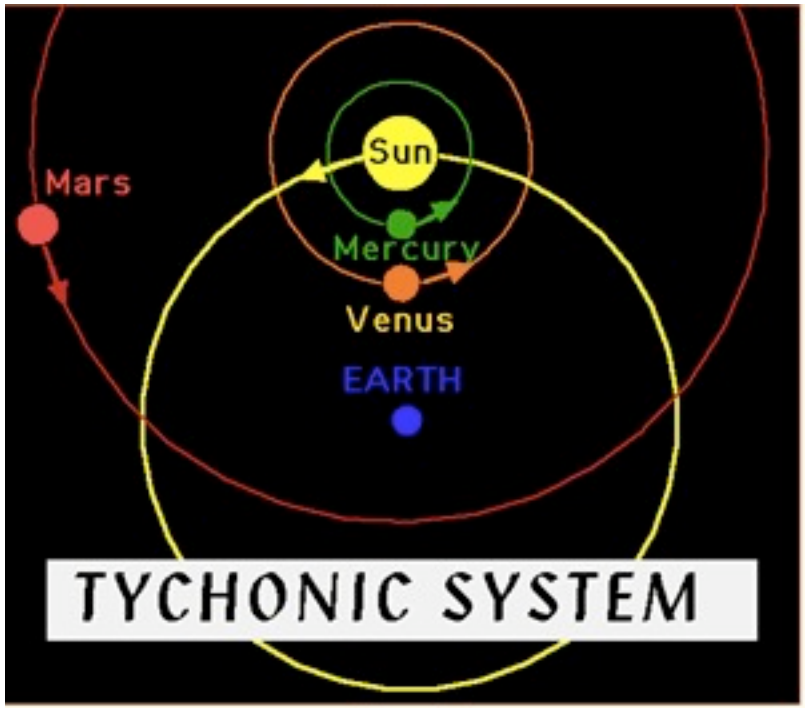
the last great naked-eye observer

1546-1601

Tycho Brahe

© 2005 Pearson Education, Inc., publishing as Addison Wesley

- Brahe compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- He still could not detect stellar parallax, and thus still thought Earth must be at the center of the solar system (but recognized that other planets go around Sun).



© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Johannes Kepler
(1571–1630)

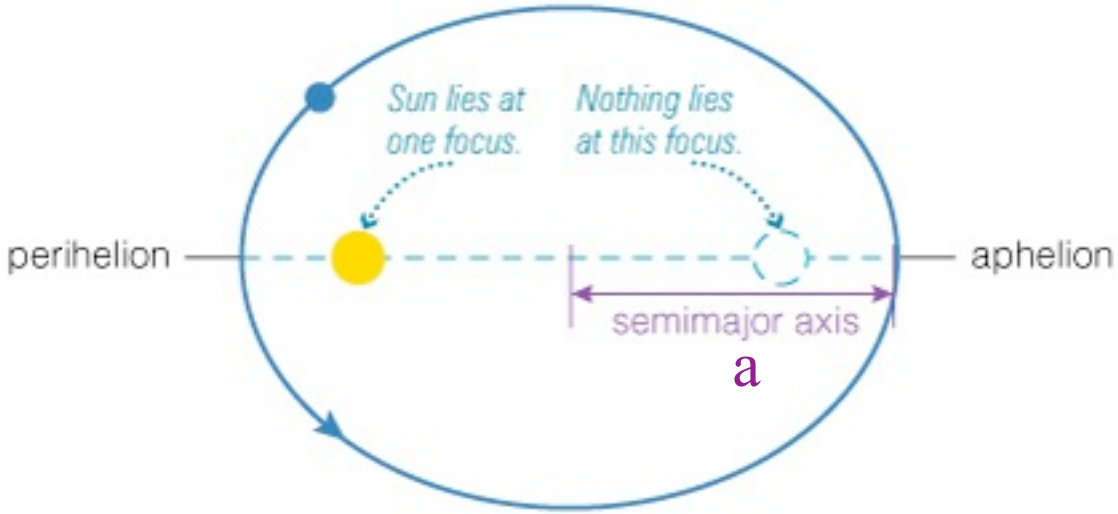
- Kepler analyzed Brahe's data
- Kepler first tried to match Tycho's observations with circular orbits.
- But an 8-arcminute discrepancy led him eventually to ellipses.

"If I had believed that we could ignore these eight minutes [of arc], I would have patched up my hypothesis accordingly. But, since it was not permissible to ignore, those eight minutes pointed the road to a complete reformation in astronomy."

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Kepler's Laws of planetary motion

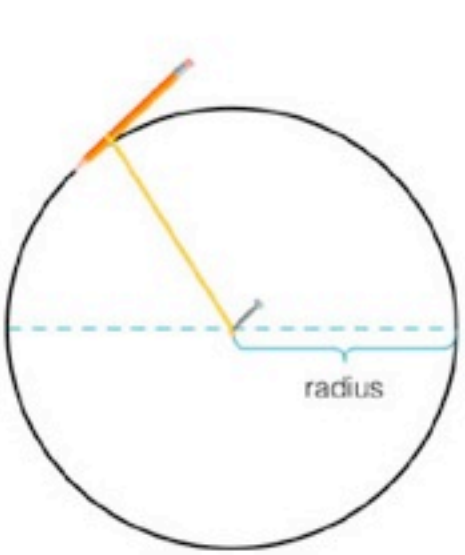
Kepler's First Law: The orbit of each planet around the Sun is an ***ellipse*** with the Sun at one focus.

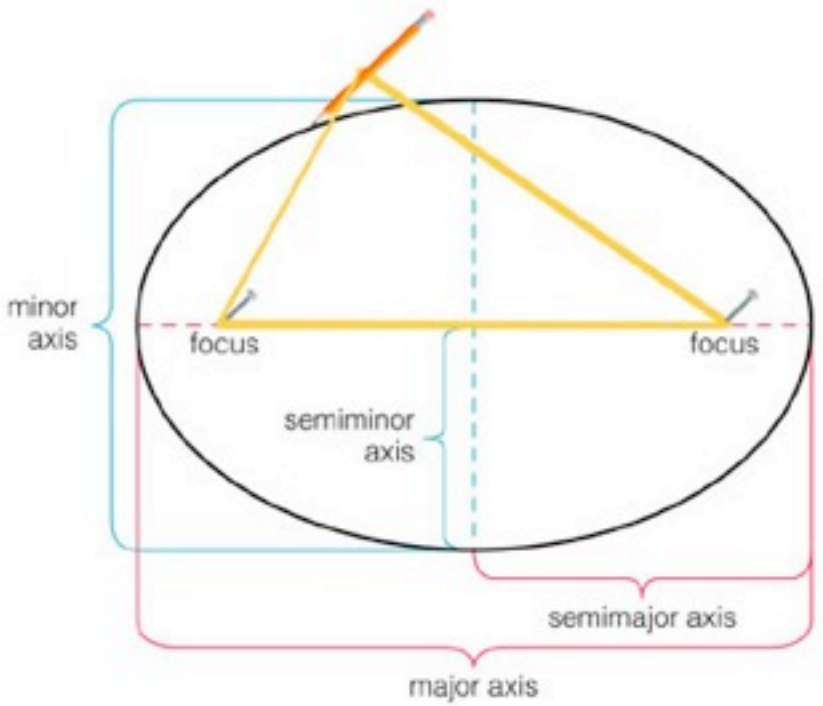


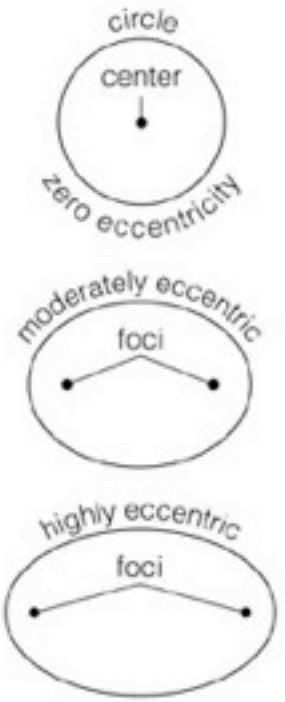
© 2006 Pearson Education, Inc., publishing as Addison Wesley

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

An ellipse is the shape that is equidistant from two **foci**. The **eccentricity** of an ellipse depends on the ratio of the long and short axes. Half of the long axis is the **semimajor axis**, **a**.





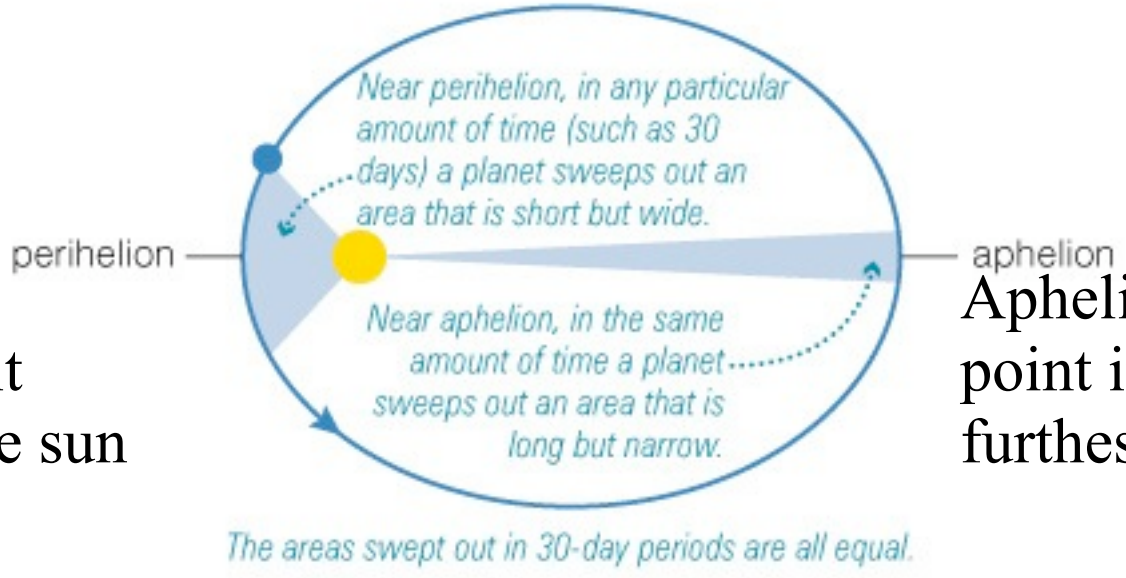


An ellipse looks like an elongated circle. Indeed, a circle is a special case of an ellipse where the two foci overlap.

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Kepler's Second Law: As a planet moves around its orbit, it sweeps out equal areas in equal times.

Perihelion: point in orbit closest to the sun



Aphelion: point in orbit furthest from the sun

© 2006 Pearson Education, Inc., publishing as Addison Wesley

This means that a planet travels faster when it is nearer to the Sun and slower when it is farther from the Sun.

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Kepler's Third Law

More distant planets orbit the Sun at slower average speeds, obeying the relationship

$$P^2 = a^3$$

p = orbital period in years
a = distance from Sun in AU
(semi-major axis of orbit's ellipse)

Earth: **P** = 1 year, **a** = 1 AU

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Kepler's Third Law

- A worked example: Mercury: P = 0.24 year

$$P^2 = a^3$$

$$a = P^{2/3}$$

$$a = (0.24)^{2/3}$$

$$a = 0.39 \text{ AU}$$

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Kepler's Third Law

- A worked example: Jupiter: a = 5.2 AU

$$P^2 = a^3$$

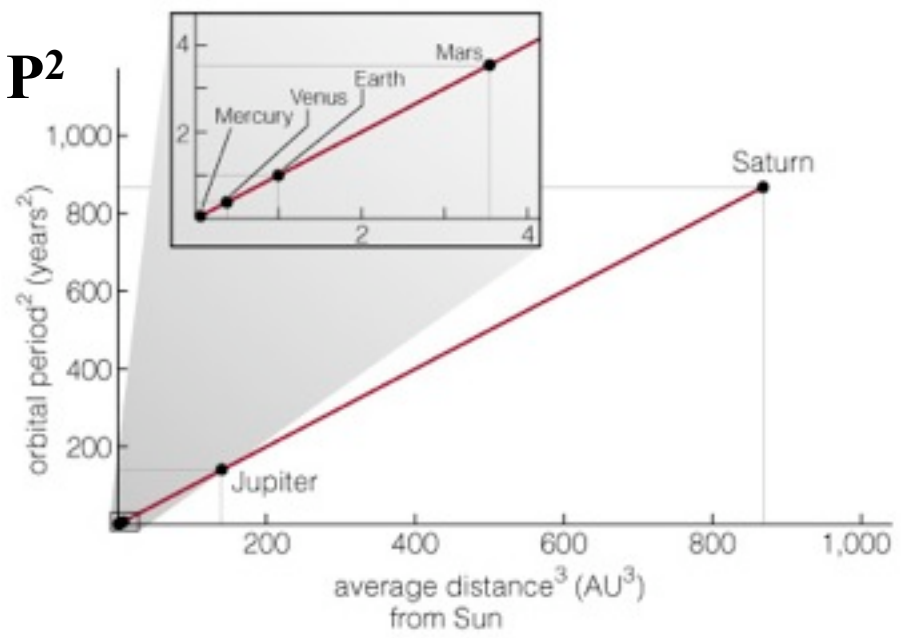
$$P = a^{3/2}$$

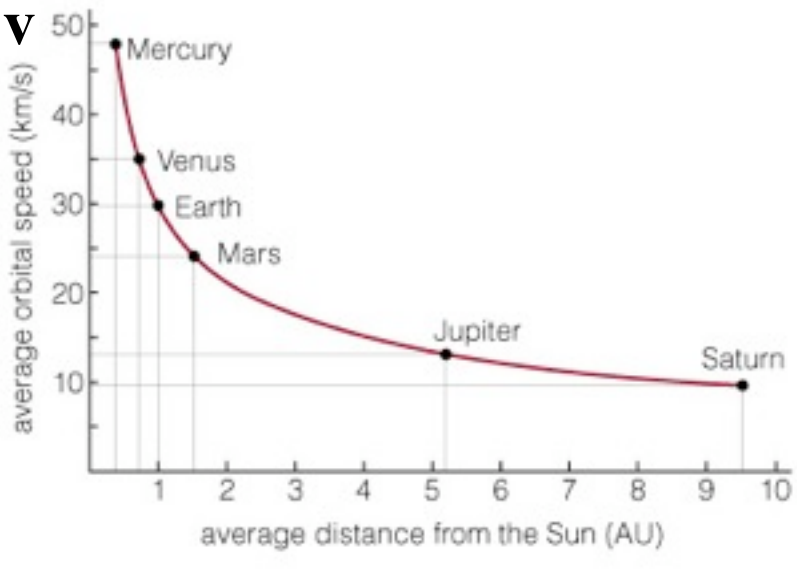
$$P = \sqrt{(5.2)^3}$$

$$P = 11.9 \text{ years}$$

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Graphical version of Kepler's Third Law





© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

- Kepler's Laws:
  1. The orbit of each planet is an ellipse with the Sun at one focus.
  2. As a planet moves around its orbit it sweeps out equal areas in equal times.
  3. More distant planets orbit the Sun at slower average speeds: $p^2 = a^3$.

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley

Major Figures in Copernican Revolution

- Copernicus: [Re]Invented Heliocentric model.
- Tycho Brahe: Collected large, accurate database on planetary positions & motions. Failed to detect parallax; suggested hybrid.
- Kepler: Used Brahe's data to discern his three Laws of planetary motion.
- Galileo: telescopic observations and physical arguments in favor of heliocentric model.

© 2007 Pearson Education Inc., publishing as Pearson Addison-Wesley