The Two Universes: Geocentric versus Heliocentric

Physical Sciences
Broward College
Prepared for AST 1002
Horizons in Astronomy

What is a Scientific Model?

- An attempt to explain observations made of a system usually using scientific laws/theories to constrain the model.
- A scientific model states the aesthetic, geometric, and physical bases of the model.
- A scientific model states clearly the assumption behind the model and evaluate how well they are supported.
- A scientific model states the key observations the model attempts to explain and evaluate how well it succeeds.
- A scientific model succeeds or fails based on its postdictions and predictions
- Postdictions: Describe the relative importance of various aspects of the model, making clear the connections between parts.
- Predictions: Indicate how the model deals with new observations and suggest predictions it can make for new situations.

Contributions to the Geocentric Model

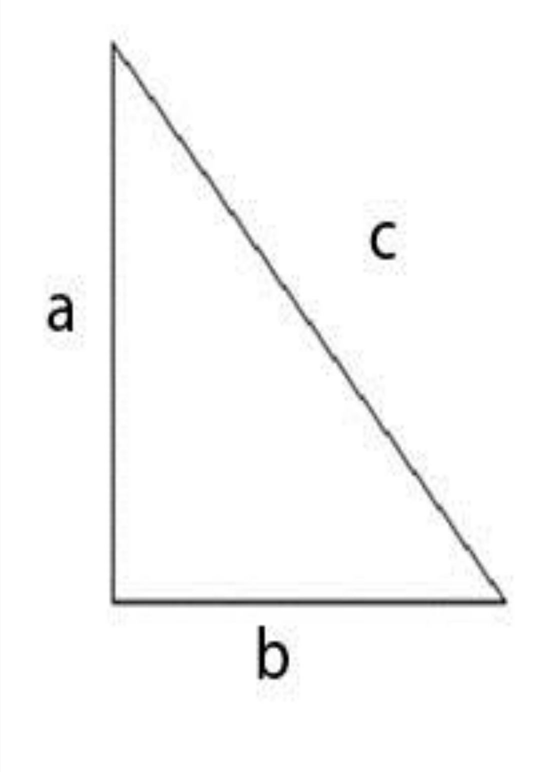
- Pythagoras
  - Established Earth as the central object and nested the planet in concentric spheres.
- Aristotle
  - Expanded number of concentric spheres and established the physical laws
- Hipparchus
  - Explained the retrograde motion of planets by adding the epicycle sphere to the concentric spheres.
- Ptolemy
  - Introduced the equant to allow for the correct speeds of the planets along the ecliptic..

Pythagoras

- **6th Century B.C.**
- **Believe beauty and harmony ruled nature**

Figure 1. Pythagoras (Wiki)

The Pythagorean Theorem



$$a^2 + b^2 = c^2$$

Figure 2. Pythagorean Theorem

Angular Sizes

- Pythagoras studied the heavens and saw that items were spherical in nature.
- He measured angular sizes of items and used these to calculate the linear sizes and distances to astronomical objects.
- $\frac{d}{D} = \frac{\theta}{206265}$

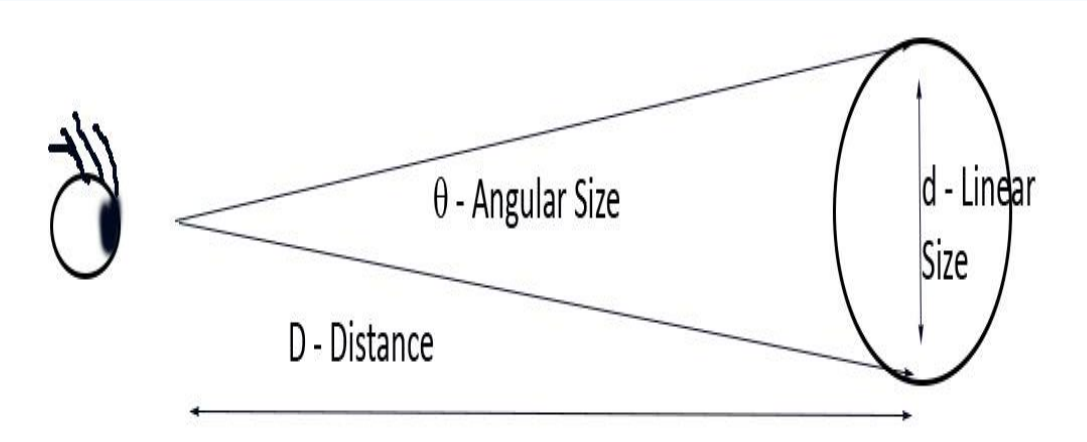


Figure 3. Pythagorean Theorem

Pythagorean Model

- Introduced the idea that the Universe was a series of simple spherical shells centered around the Earth.
- The model explained the motion of stars, but did not address the retrograde motion of the planets.
- He based the radius of the spheres based on the angular size of objects.

Aristotle

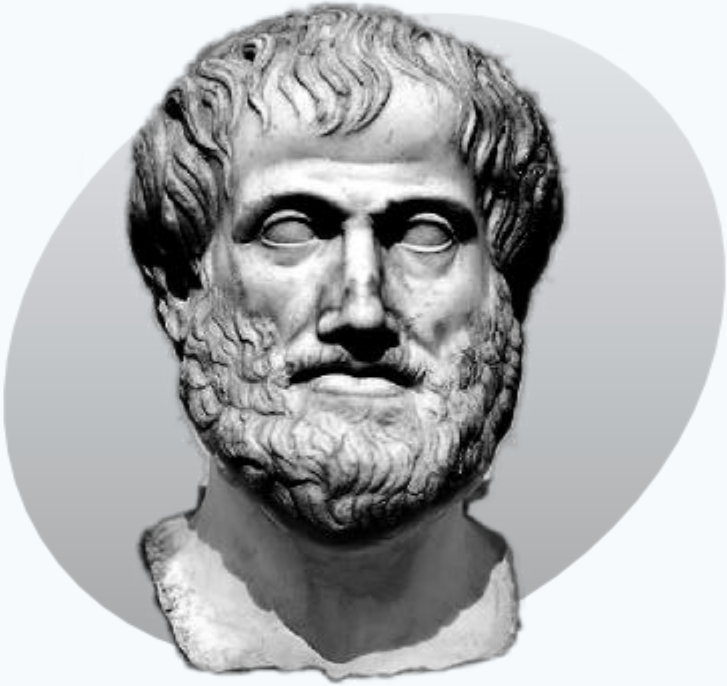


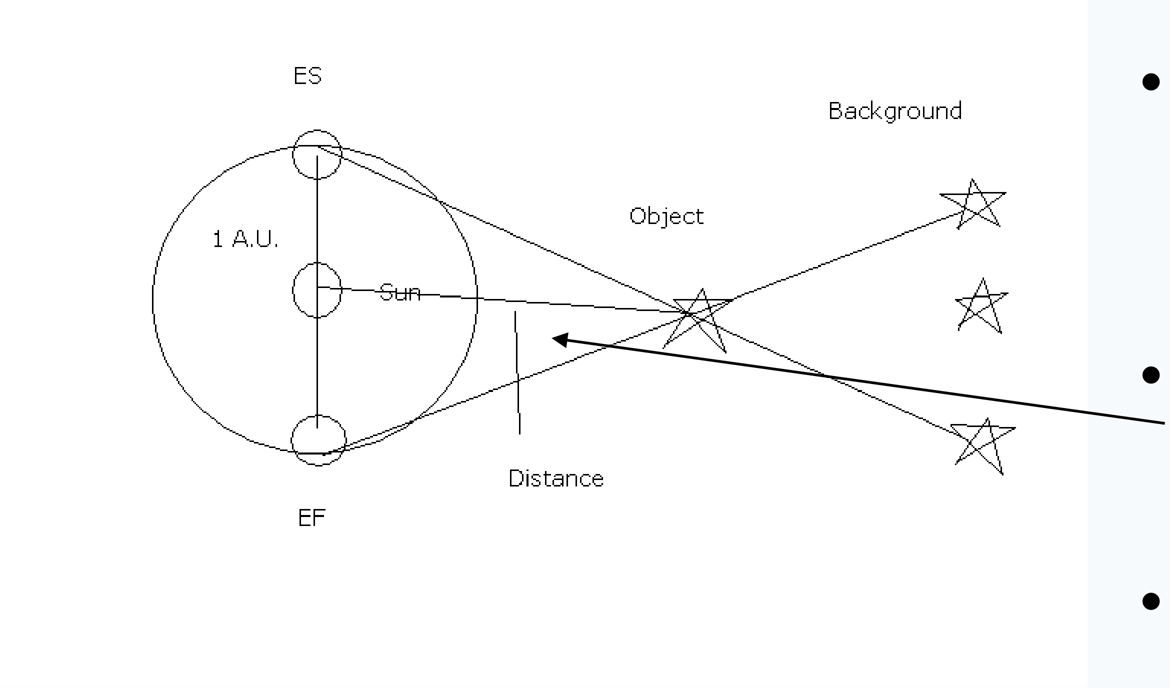
Figure 4. Aristotle (Wiki)

- 365 –232 B.C.
- Main court philosopher of Alexander the Great. Taught the Emperor the ways of science and thought.
- His influence was felt for many years due to his presence in the court of Alexander.

Aristotelian Model

- Expanded the number of shells to 56 shells centered on Earth.
- Thought Earth was 5,100 km in diameter.
- Believed in two spheres
  - Sphere of Perfection: The Celestial Sphere
  - Sphere of Change: Earth
- The Earth had two types of motion
  - Natural: motion due to air, fire, water, and land
  - Forced: motion due to man
- Earth did not rotate because items would be thrown up due to natural action.
- No stellar parallax

Stellar Parallax



- Stellar parallax is observed due to the Earth orbit the Sun.
- The Earth makes different angles with a nearby star with respect to a background star making the star appear to “move” through the sky.
- We can measure the distance to the star using the parallax angle (p) using geometry.
- The closer the star the bigger the angle.

Figure 5. Parallax

Hipparchus

Figure 6. Hipparchus (Wiki)

- 160 – 127 B.C.
- Worked at an observatory on Rhodes
- Created the stellar magnification system.
- A satellite bearing his name observed parallaxes in modern times.

Hippacratic Model

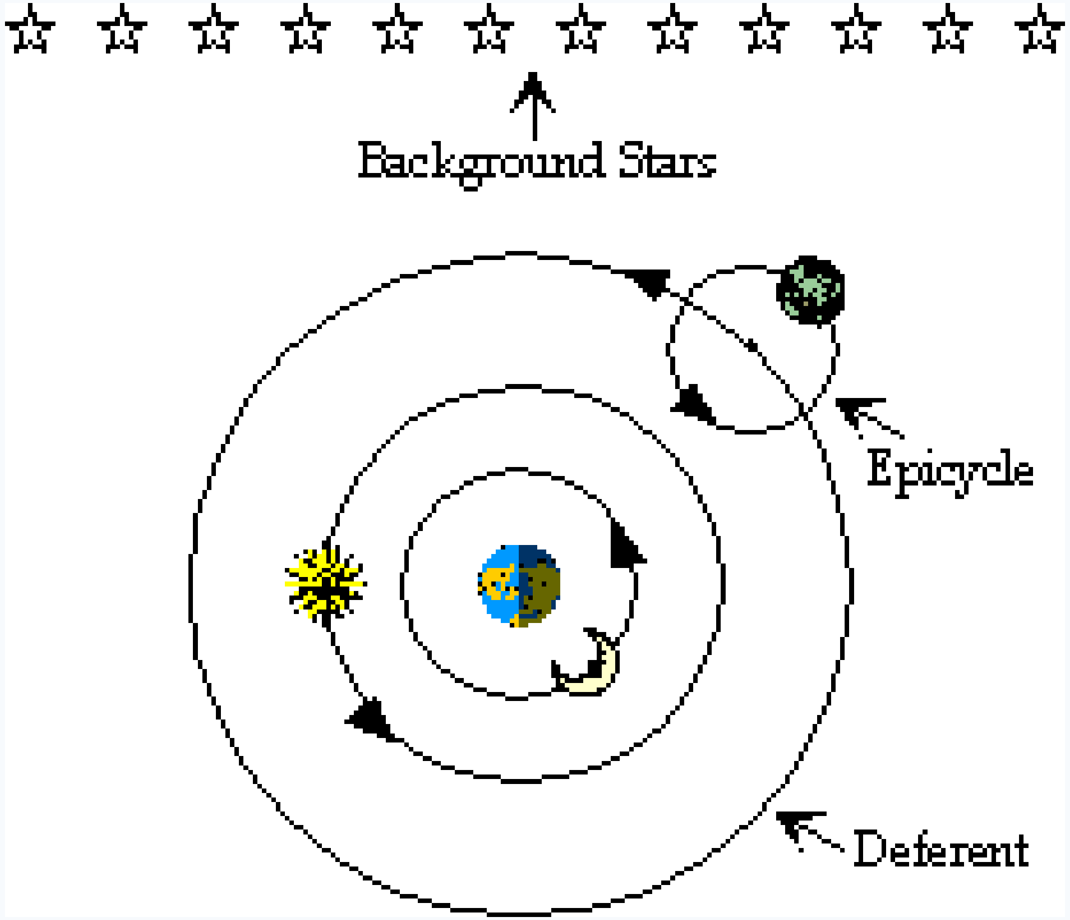


Figure 7. Hippacaratic Model (Anderson, 2006)

- Hipparchus introduced the idea that smaller crystal spheres (Epicycles) rotated and were supported on the main crystal spheres (Deferents).
- This motion explained why retrograde motion was observed.

Ptolemy

Figure 8. Ptolemy (Wiki)

- 127 A.D. his first astronomy text was produced, *The Almagest.*
- His model was used for 1,400 years
- Good for optical observations up to 5°
- Universe: 20,000 Earth Radii

Ptolemaic Model

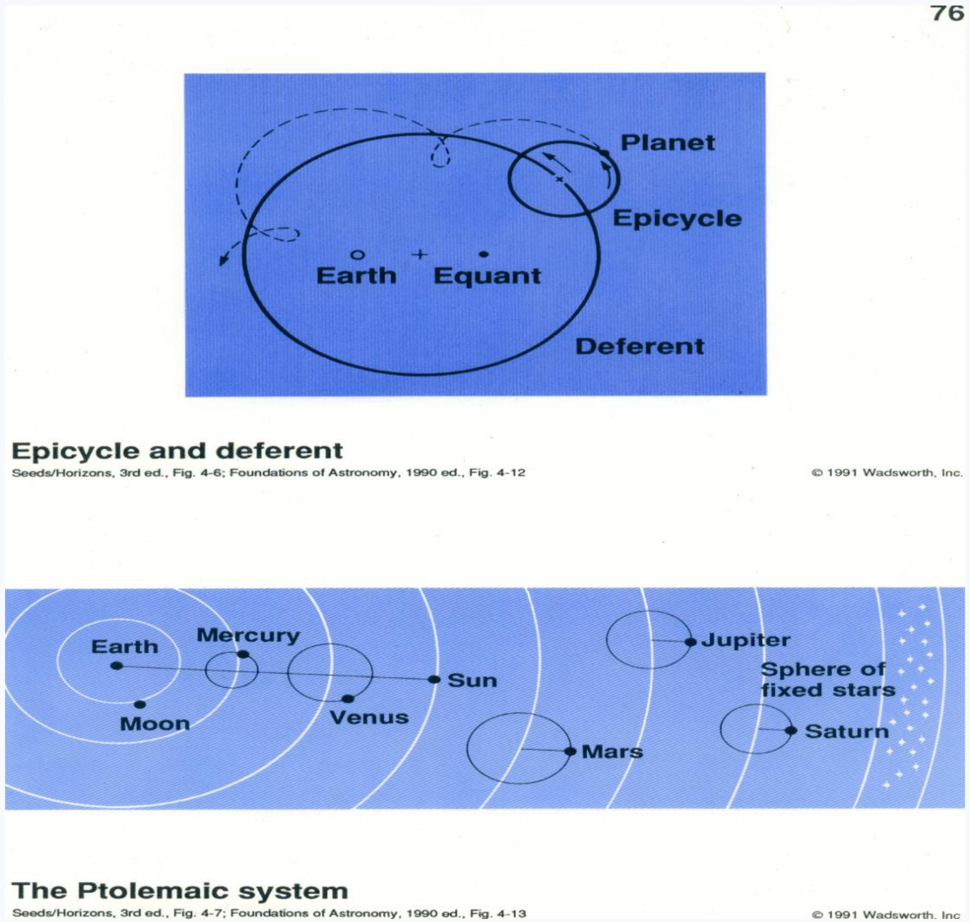


Figure 9. Ptolemaic Model (Hartmann, 1989)

- Ptolemy introduced the idea the spheres were spheroidal (slightly elongated).
- The Earth had a invisible twin call the Equant that balanced out the Earth.

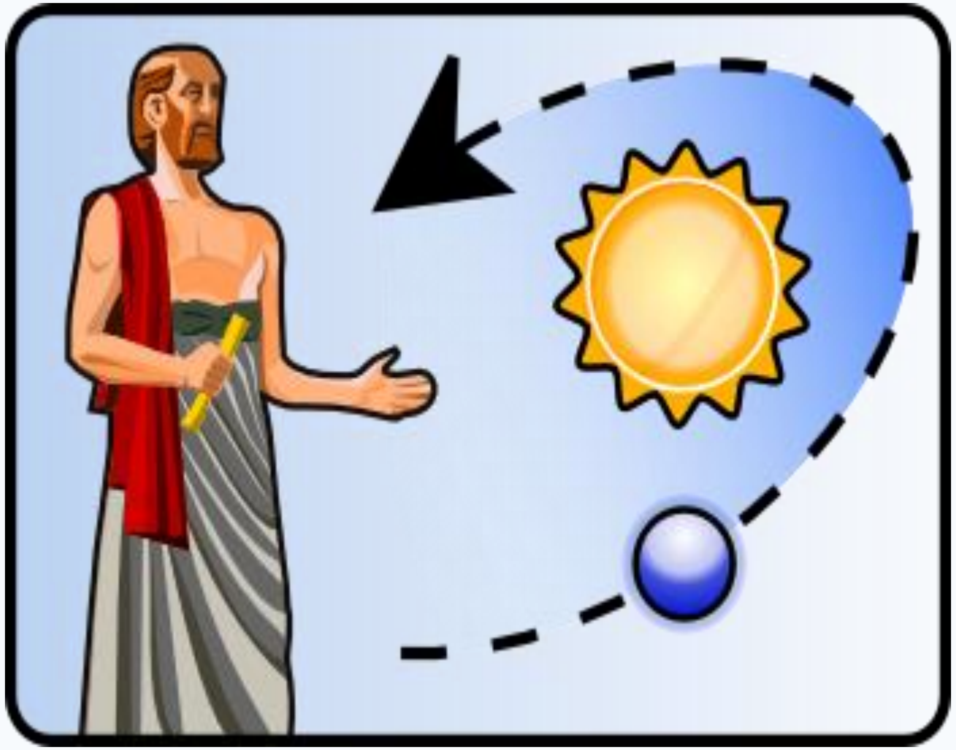
What explanations needed to be explained by the Ptolemaic Model?

- The uneven motion of the planets along the ecliptic.
- A simple, physical model for explaining retrograde motion.
- An explanation for stellar parallax.
- The size of our sun, moon system.

Contributions to the Heliocentric Model

- Aristarchus
  - Put the Sun in the center
- Nicholas Copernicus
  - Heliocentric Universe
  - Motions of Earth and Planets
- Tycho Brahe
  - Observations of Planets
  - Observation of stars, astrometry
- Johannes Keppler
  - Modeling Brahe’s observations
  - Brings physics into astronomical models.

Aristarchus



- 365 – 323 B.C.
- Work lost with the fire of the library at Alexandria
- Eratosthenes, Hypatia were colleagues

Figure 10. Aristarchus (Wiki)

Aristarchus’ Model

- First to propose a Heliocentric model

- Moon receives light from the sun.

- But his model was rejected due the lack of observations of stellar parallax.

Eratosthenes

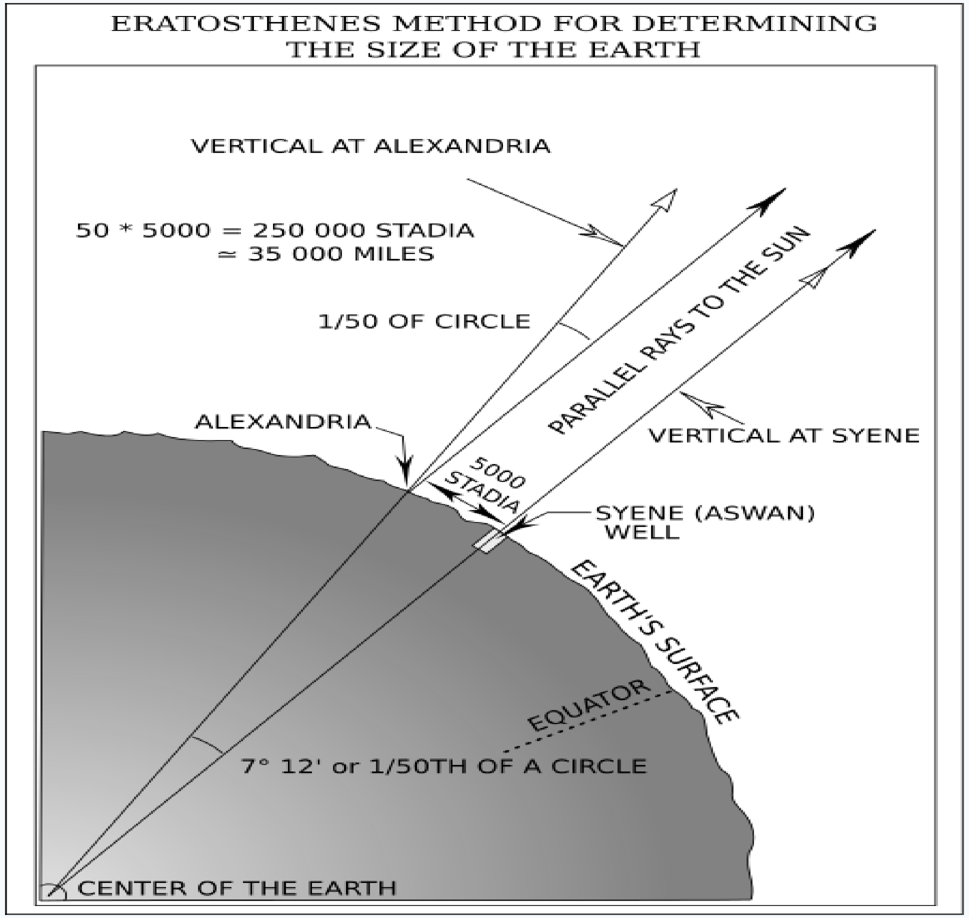


Figure 11. Eratosthenes model of the Earth (Wiki)

- Noticed a shadow differences between Alexandria and Syene.
- Found the Earth to be 41,000 km, only 1,000 km over the modern value.

Eratosthenes versus Modern Calculations

Eratosthenes Calculations

$$\frac{7.00^\circ}{360^\circ} = \frac{800\,km}{X\,(\text{Circumference of Earth})}$$

$$7.00^\circ X = 800\,km(360^\circ)$$

$$X = \frac{800\,km(360^\circ)}{7.00^\circ}$$

$$X \approx 41{,}000\,km$$

Modern Calculations

$$Radius\ of\ Earth = 6{,}378\,km$$

$$C = 2\pi R$$

$$C = 2\pi(6{,}378\,km)$$

$$C \approx 40{,}000\,km$$

Nicholaus Copernicus

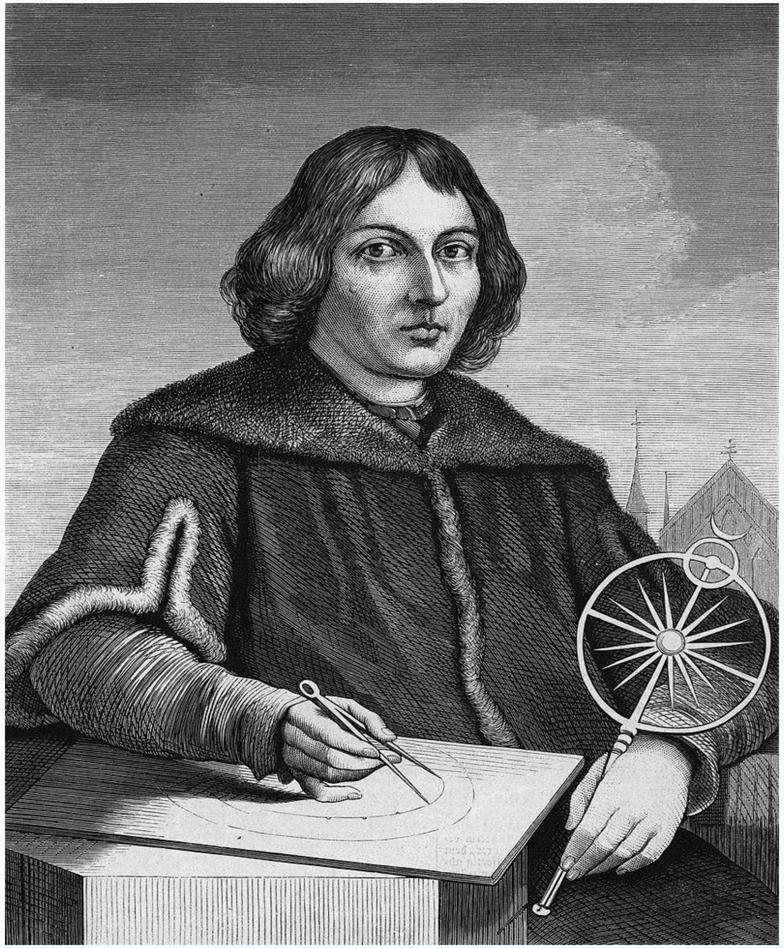


Figure 12. Copernicus (Wiki)

- 1473 – 1543 A.D.
- Born in Poland.
- Studied medicine in Krakow, Bologna, Rome, Padua, and Ferrara.
- Worked as a cleric in the Roman Catholic church as well in medicine.

Development of the Copernican Model

- 1541
  - He wrote a summary to Georg Rheticus about his ideas of the universe.
  - Based on a book he was writing for 20 years.
- Georg Rheticus
  - Encouraged Copernicus to publish his results
  - *De Relutionibus Orbium Caelestium (On the Revolutions of the Heavenly Orbits)* which was similar to Ptolemy's *Almagast.*
- Suffered a stroke in 1543, book published on his deathbed.

The Copernican Model

- All heavenly bodies orbit the Sun.
- The stars are much further than the Sun.
- The diurnal motion is explained by Earth’s rotation.
- The Earth revolves around the sun along with the other heavenly bodies.
- Retrograde motion is explained by the relative motion of the bodies around the sun.

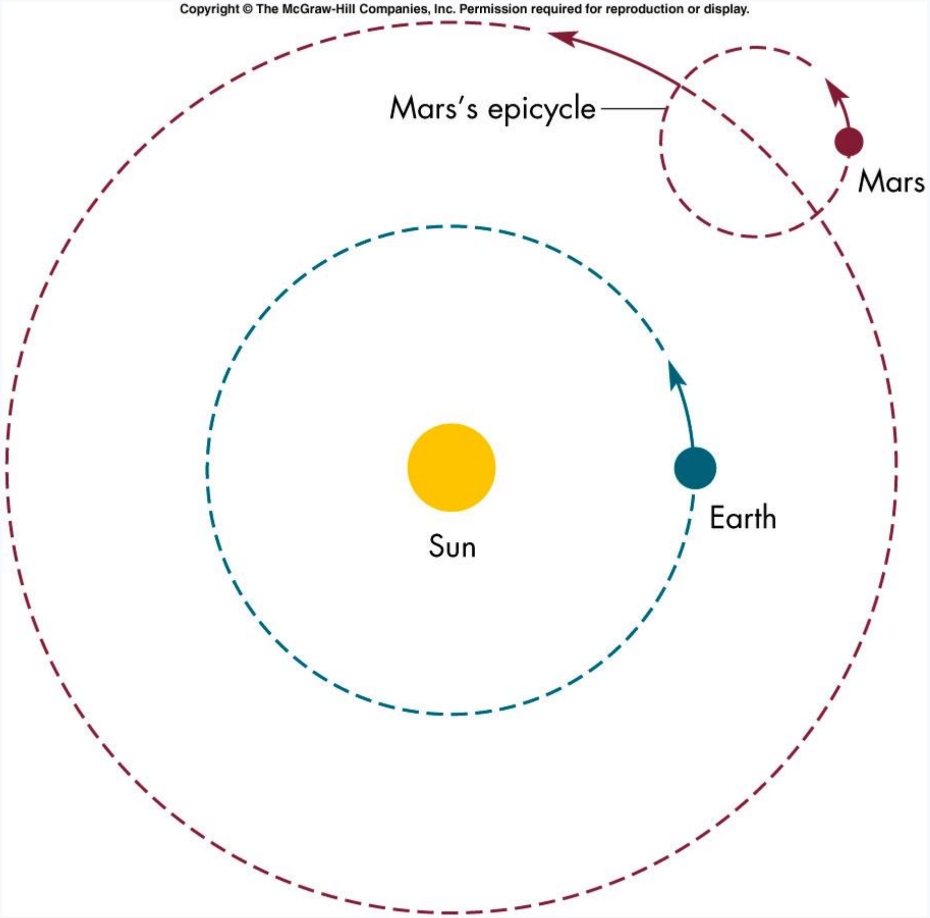


Figure 13. The Copernican Model (Fix, 2004)

Results of the Copernican Model

- The distance from the Earth to Sun, the Astronomical Unit (A.U.) (1.4960×10^8 km).
- Earth passes other planets at opposition.
- Introduced the ideas synodic period (geocentric) versus sidereal period (heliocentric)
- Relative distances of the planets
  - Found by elongation for inferior planets
  - Found by intersection of opposition for superior planets.

Sidereal Periods

Sidereal Period Calculation

$$P = siderial\ period$$

$$S = synodic\ period$$

$$\frac{1}{P} = \frac{1}{P_{Earth}} - \frac{1}{S};\ \text{superior planets}$$

$$\frac{1}{P} = \frac{1}{P_{Earth}} + \frac{1}{S};\text{inferior planets}$$

Sidereal Period of Venus Example

$$\frac{1}{P} = \frac{1}{P_{Earth}} + \frac{1}{S}$$

$$P_{Earth} = 1\,year$$

$$S = 1.60\,years$$

$$\frac{1}{P} = \left(\frac{1}{1} + \frac{1}{1.6}\right)\frac{1}{years}$$

$$\frac{1}{P} = \frac{1.63}{years}$$

$$1\,year = P(1.63)$$

$$P = 0.62\,years$$

Planetary Configurations

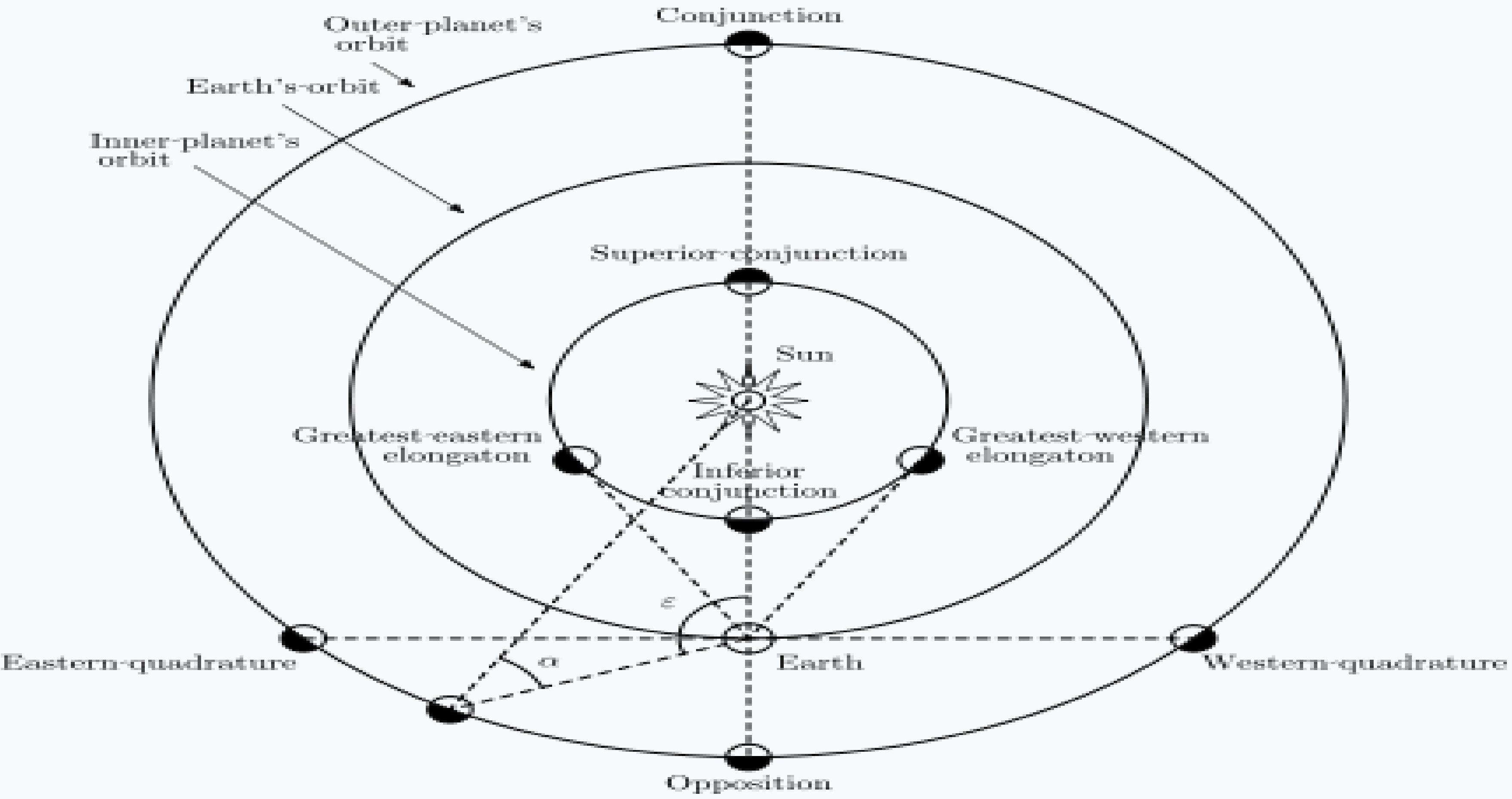


Figure 14. Planetary Configurations (Wiki)

Distances of the Planets

Greatest Elongation

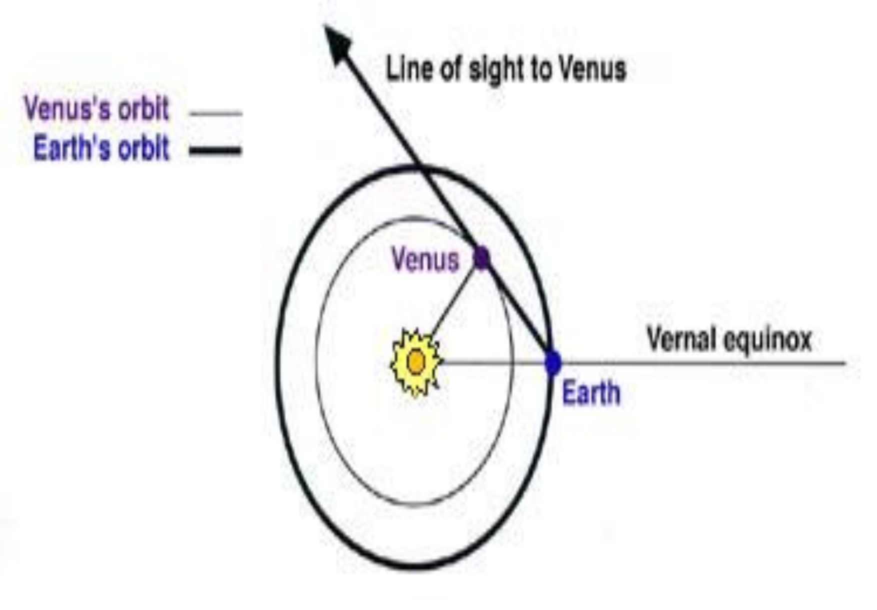


Figure 15. Greatest Elongation (Becker, 2010)

Intersection of Opposition

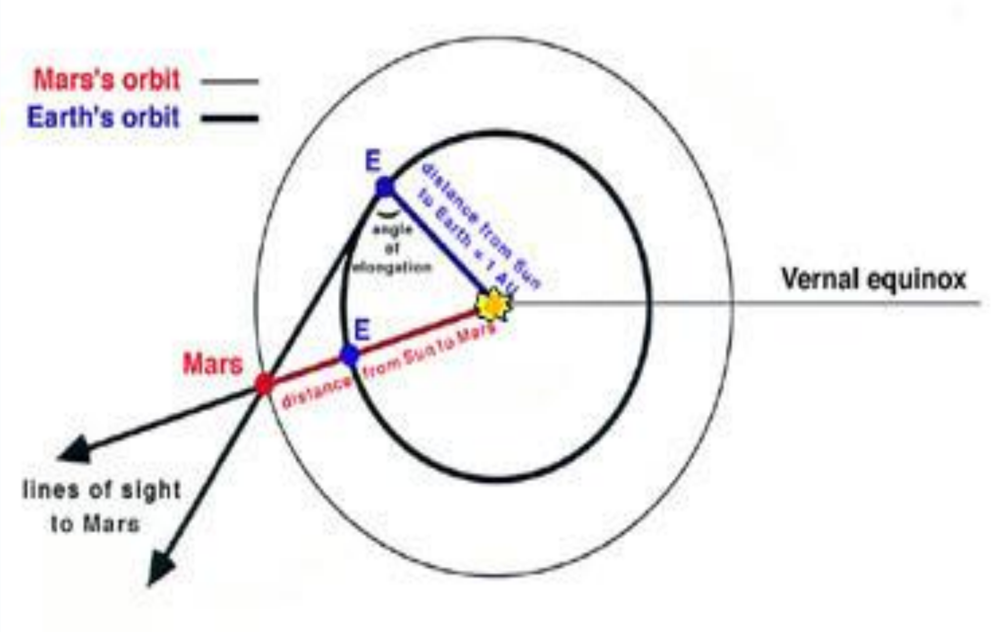


Figure 16. Intersection of Opposition (Becker, 2010)

Problems of the Copernican Model

- Did not predict any better positional results than Ptolemaic.
- Also, the model did not include any physical force that moved Earth and the planets, just merely a new geometrical model.
- Violated Aristotelian physics, therefore not widely accepted, even censored in Italy.
- Better observations and the addition of physical law helped shape the modern heliocentric model.

Tycho Brahe

Figure 17. Tycho Brahe (Van Heldon, 1995)

- 1546 – 1601 A.D.
- Born in Skane, Denmark
- Raised by his uncle in Denmark
- Traveled Germany and learned about the law
- Served as court astronomer to Fredrick II in Germany

Tycho’s Observations

- 1576 to 1591 A.D.
- Made in Unniborg, The Castle of the Heavens.
- The science of astrometry was born by the observation of position of planets and stars.

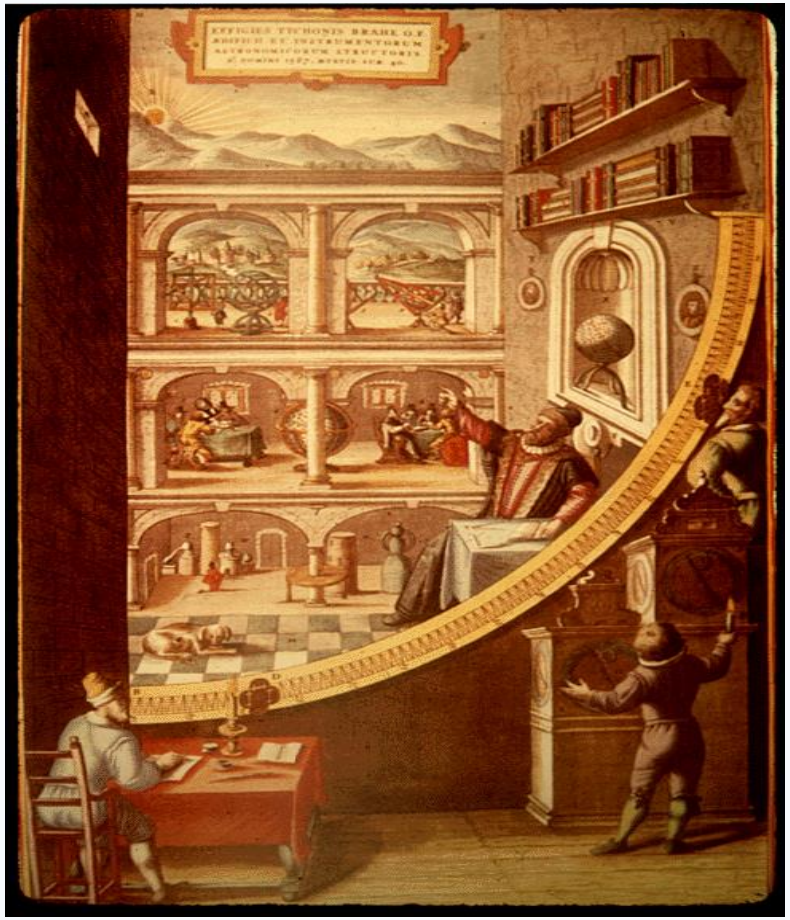


Figure 18. Unniborg (Van Heldon, 1995)

The Discovery of a Nova

- A nova, a star’s death, was witnessed in the constellation of Cassiopeia in 1572.
- Tycho observed the star from different locales on Earth.
- Discovered that the stars did not change position depending the location on Earth.
- Result: Stars too far away for stellar parallax

Tycho in Prague

- Moved to the university in Prague when Fredrick II died.
- Embraced the geocentric model in his later years due to his observations
- Tycho invited Johannes Kepler to model his data.

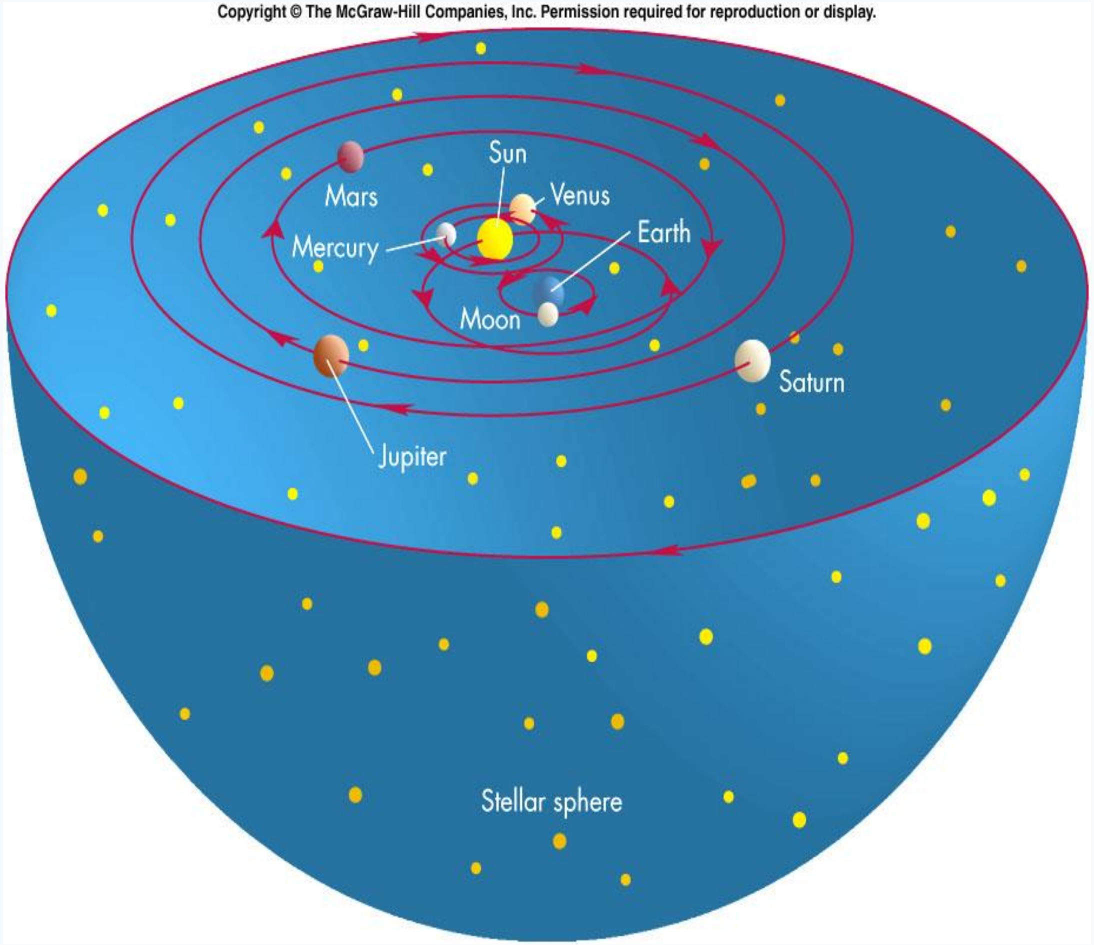


Figure 19. Tycho's Model (Fix, 2004)

Johannes Kepler

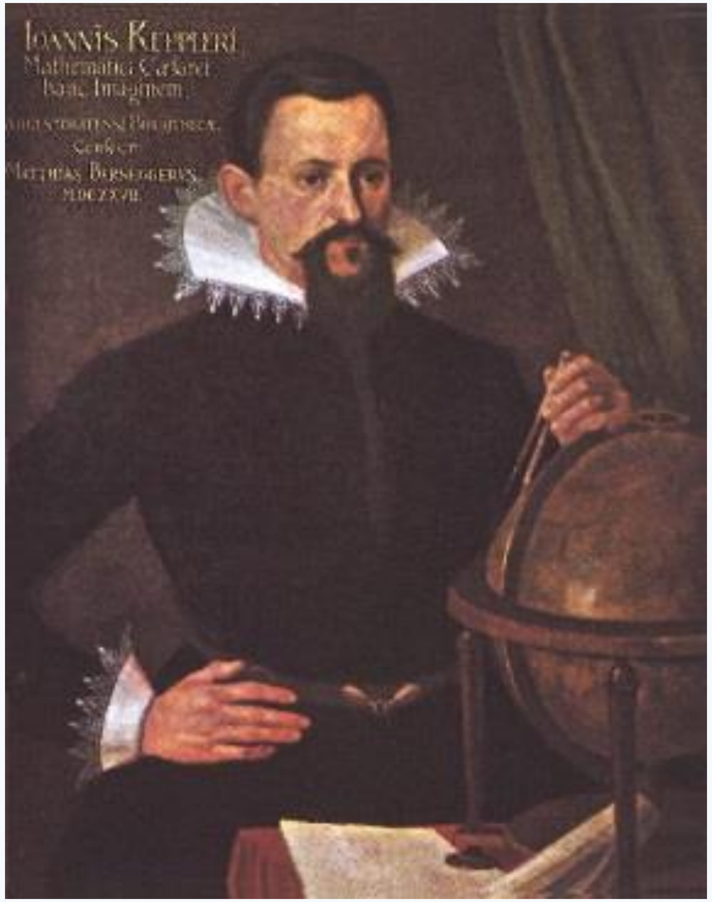


Figure 20. Johannes Kepler (Wiki)

- 1571 – 1630 A.D.
- Born in Wielder Stadt, Germany
- Went to study and the seminaries in Tubingen, Germany and Graz, Austria
- A modern telescope bearing his name observes the eclipsing of planets outside of our Solar System

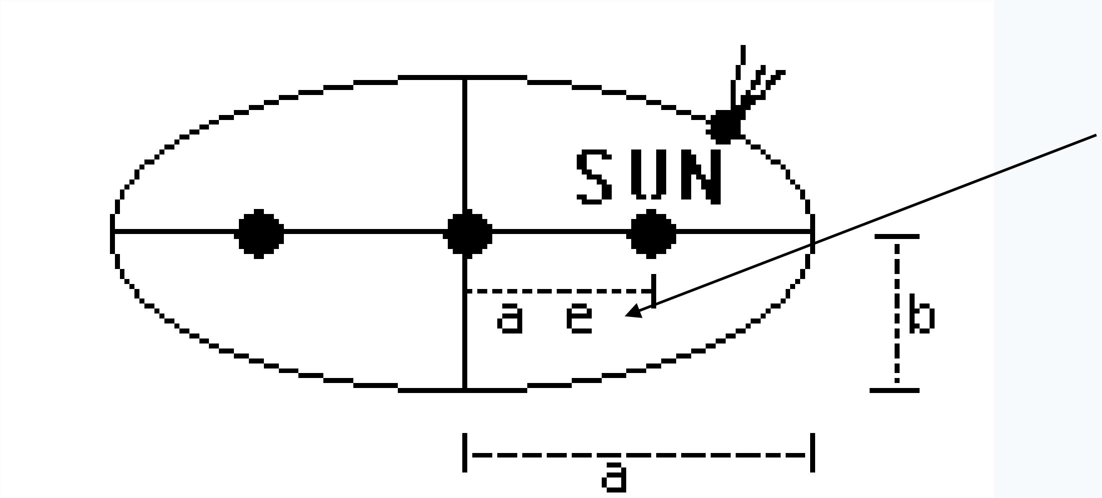
Jupiter and Saturn

- Conjunctions seemed to occur at regular intervals.
- Kepler noted at 1 to 2 ratio of their radii using the Copernican method.
  - Compared to the 1 to 1.8 ratio Copernicus received
- Led to a idea that different basic shapes could explain the different planetary distances
- Published *Mysterium Cosmographicum* in 1594 to explain his results.

Tycho & Kepler

- Met in Prague in February 4, 1600
- Incompatible in life because of Kepler’s religious devotion and Tycho’s courtly adventures.
- But Tycho softened in death and gave Kepler his observations on Mars.

Kepler's First Law



- A planet orbits in an ellipse with the Sun at one focus.
- The more eccentric the orbit; the flatter the ellipse.

Figure 21. Kepler's First Law (Drennon, 1997)

Kepler's Second Law

- A planet sweeps out equal area is in equal time.
- An object travels faster at periapsis (called perihelion for the Sun and perigee for the Earth).
- An object travels slower farther way at apoapsis (called aphelion for the Sun and apogee for the Earth).

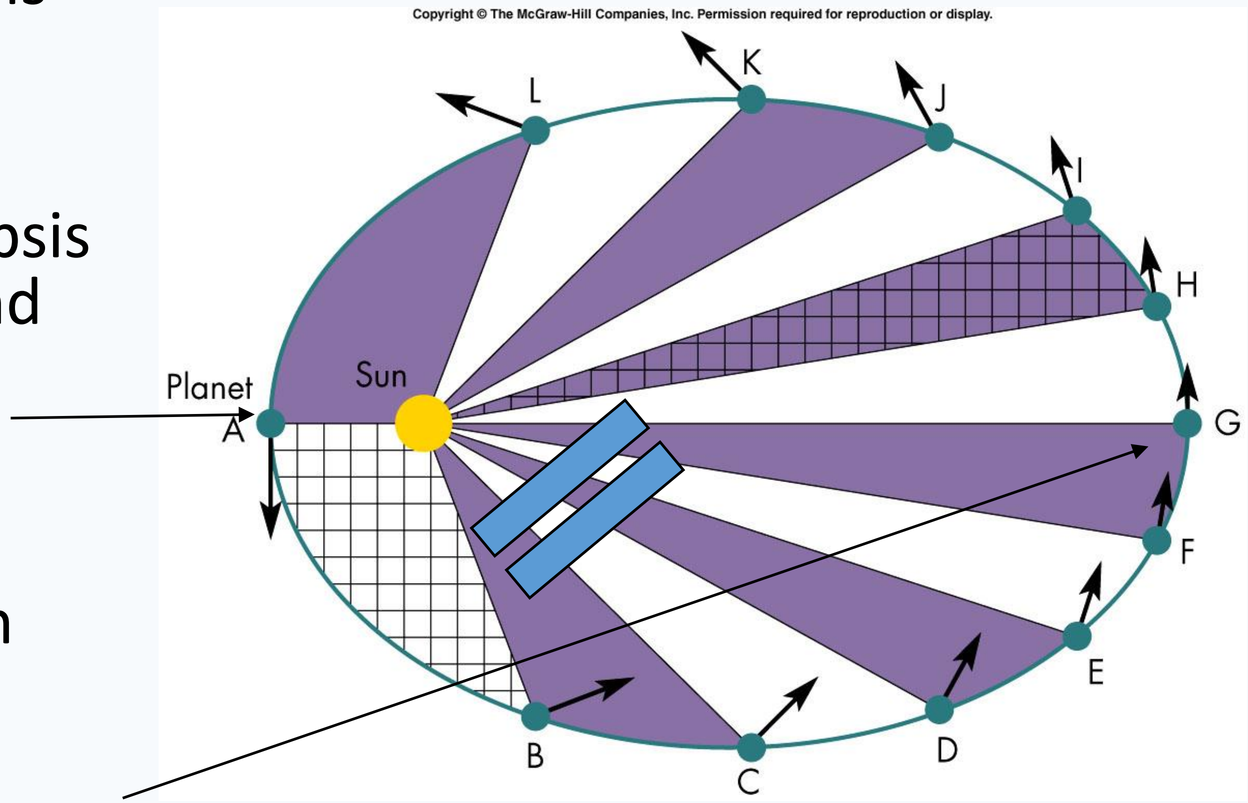


Figure 22. Kepler's Second Law(Fix, 2004)

Kepler's Third Law

$$P = period\ (in\ Earth\ years)$$

$$a = semimajor\ axis\ (in\ A.U.)$$

$$P^2 = a^3$$

Period of Venus

$$a = 0.7233\,A.U.$$

$$P^2 = a^3$$

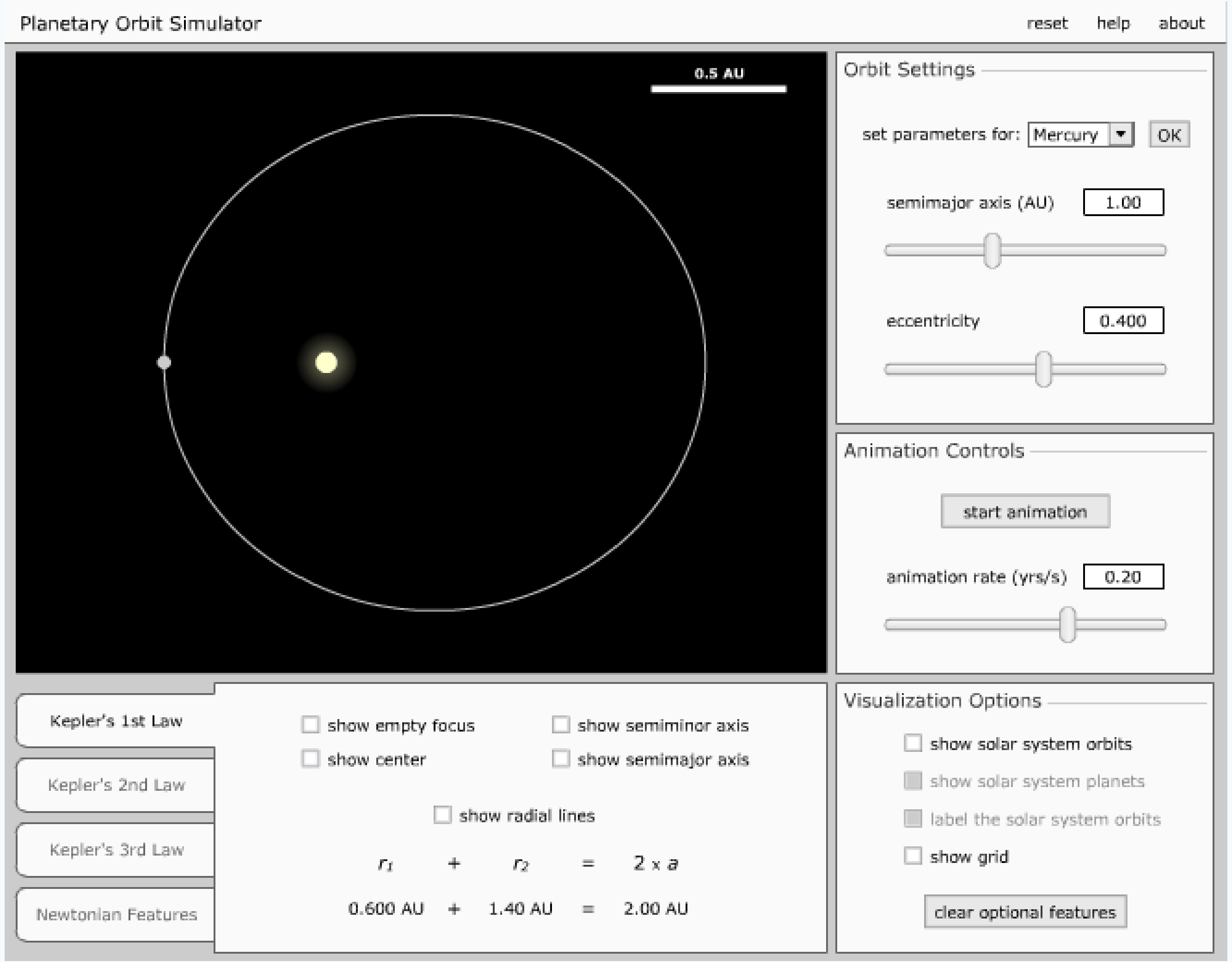
$$P^2 = (0.7233)^3$$

$$P^2 = 0.3784$$

$$\sqrt{P^2} = \sqrt{0.3784}$$

$$P = 0.62\,years$$

Kepler's Laws in Action



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