

Lecture 4: History of Cosmology II: The Renaissance

Aristotle (~350 B.C.): First coherent physical model

- Everything on Earth composed of four elements: earth, water, air and fire
- Each of these elements moves differently: earth toward the center of the Universe, fire away from the center, water and air occupy the space between.
- Earth at the center of the Universe
- Objects of different composition fall differently
- Concept of force: Motions that deviate from the natural motion of the element must be sustained by a force.

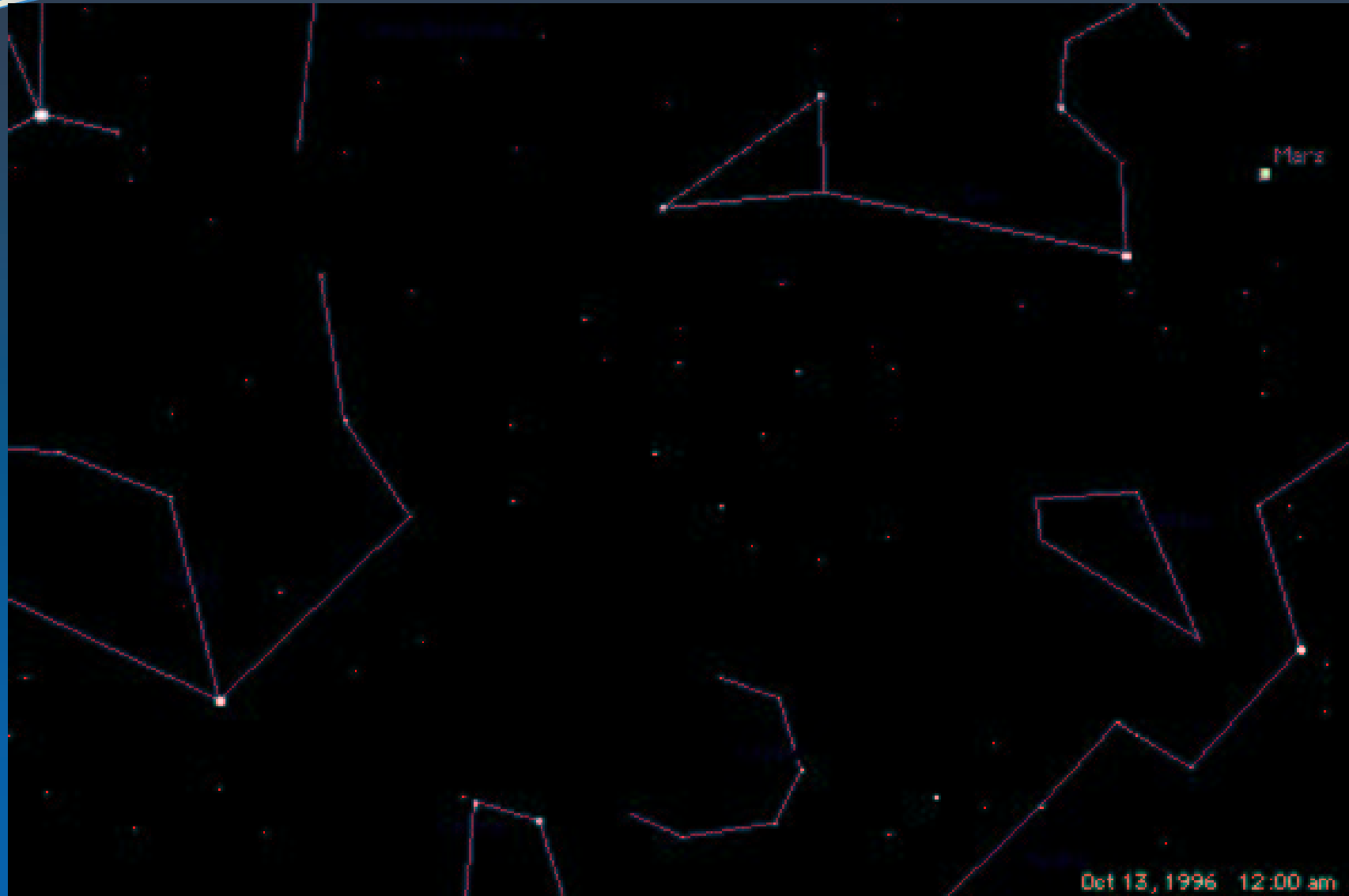
Aristotle's cosmology

- In contrast to Earthly motions, celestial motions do continue indefinitely \Rightarrow two types of motion: limited, straight towards/away from the center (Earthly realm) and continuing on circles in the heavens
- Celestial bodies cannot be composed of Earthly elements \Rightarrow ether as a fifth element
- limited motion on Earth/indefinite motion in the heavens reflect imperfect Earth/perfect heavens
- eternal and unchanging heavens \Rightarrow Universe without beginning or end
- Universe has a finite size

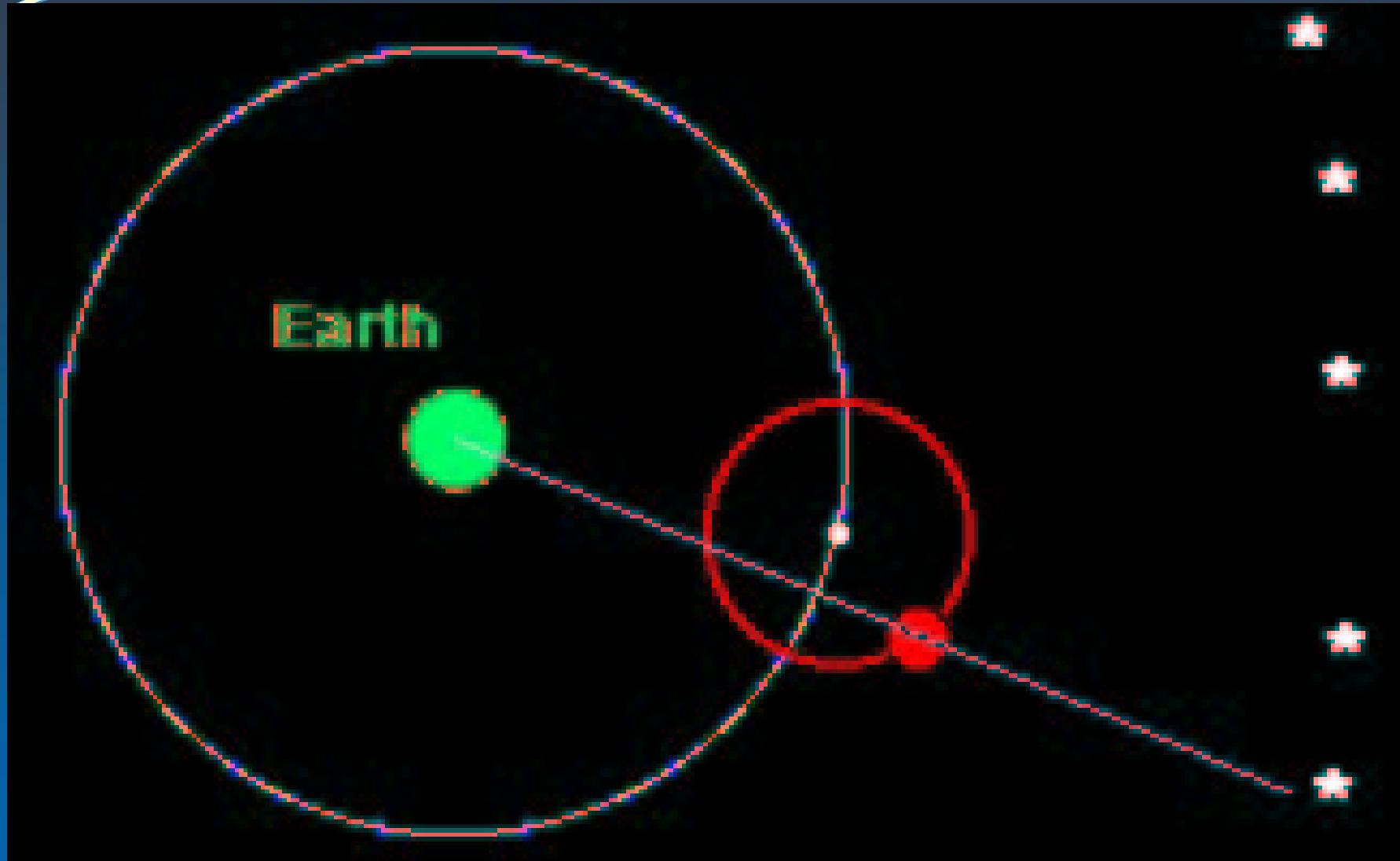
Ptolemy (~100 A.D.): defines the cosmology for the next 1500 years

- Assembled the astronomical knowledge (basically Aristotle's cosmology and Hipparchus' observations) \Rightarrow Almagest (The Great System)
- Expanded and improved the models
- Patched up inconsistencies \Rightarrow Epicycle theory
- but at the expense of giving up simplicity

Retrograde motion



Epicycle model

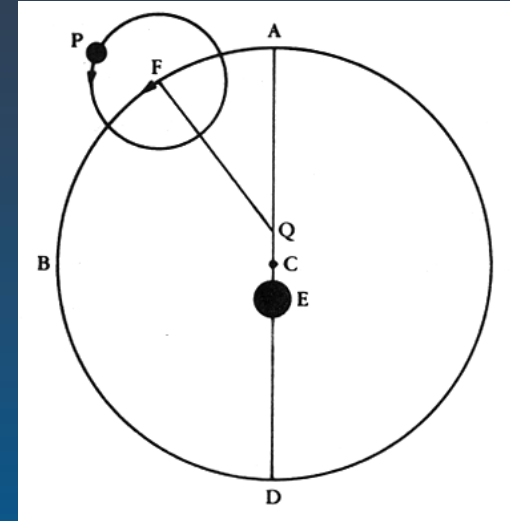


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- Thomas Aquinas \Rightarrow cornerstone of Christian doctrine
 - Believe that all that could be discovered had already been discovered

Problems of Ptolemy's model

- Model couldn't fit observations
 - put the Earth off center
 - epicycles upon epicycles
 - total of more than 100 epicycles
 - Nevertheless errors in the predicted positions of planets accumulated to several degrees by ~ 1400 A.D.



King Alfonso: “If the Lord Almighty had consulted me before embarking upon Creation, I should have recommended something simpler”

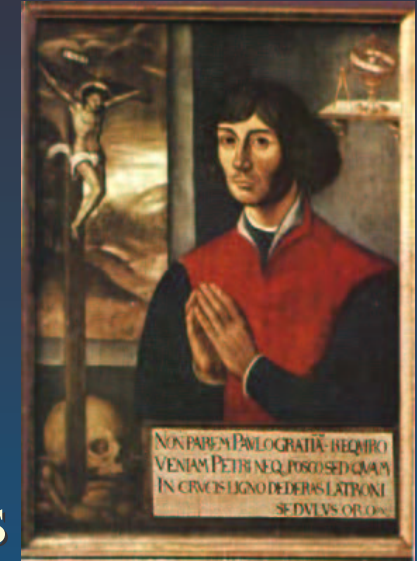
The Copernican Revolution

(~1500)

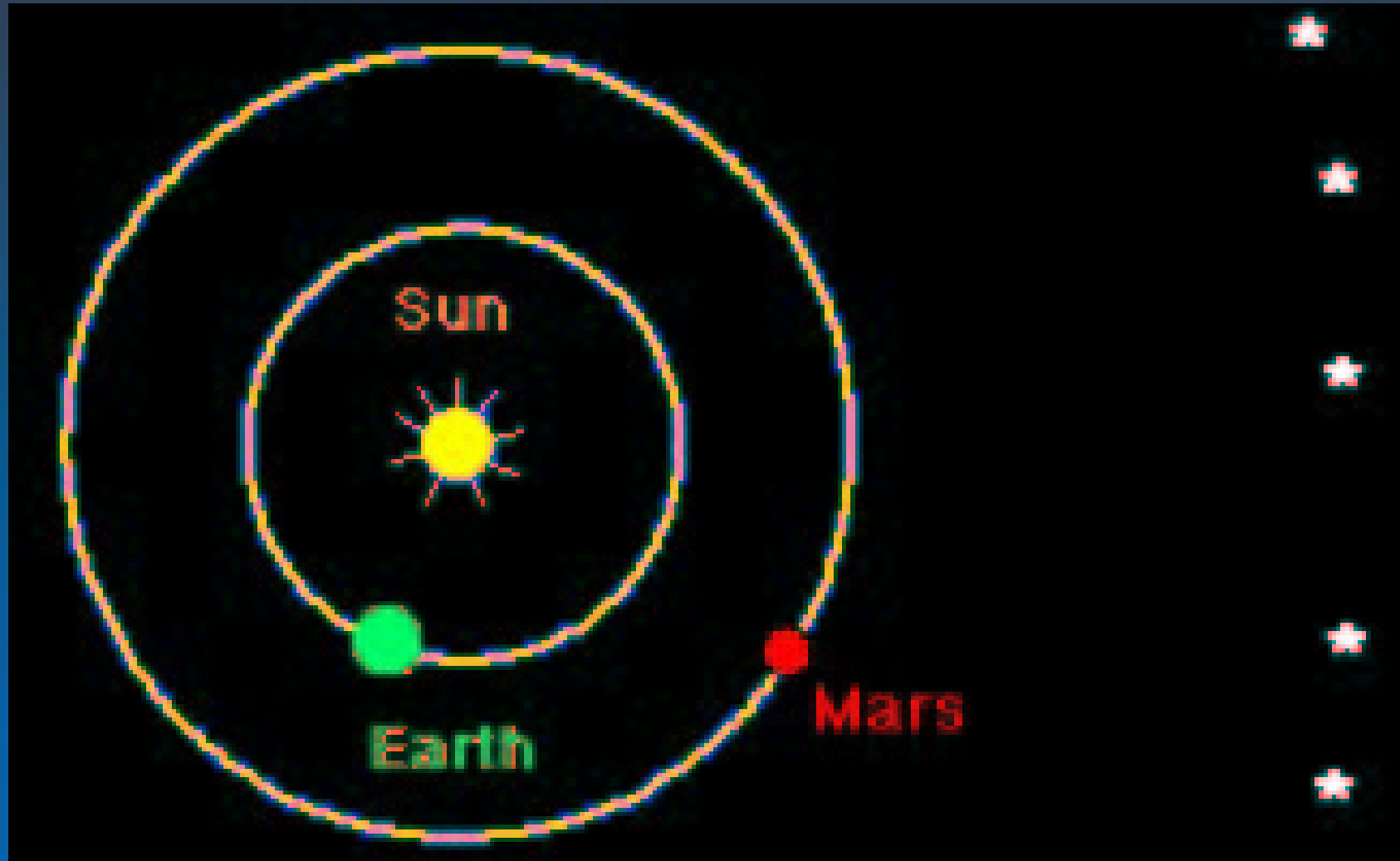
- 15th century: rediscovery of Greek scientific thought
- Shape and size of the Earth were well known among educated people (Columbus myth)
- Nicholas Copernicus *De revolutionibus orbium coelestium* [On the Revolution of Heavenly Spheres]: put the Sun at the center ⇒ heliocentric world model [inspired by the work of Aristarchus ?]

Why is the heliocentric model so attractive ?

- It's simple
- It naturally explains why the inner planets [Mercury and Venus] never travel far from the Sun
- Reproduces much better the observed change in brightness of planets
- It provides a natural explanation for the seasons
- It provides a natural explanation of retrograde motions without relying on epicycles



Heliocentric model



Problems of the heliocentric model

- Against Christian Scriptures
- New discovery
- Predicts parallaxes ✖ observation
- Problem rotating Earth ✖ Aristotle's physics
- Less accurate than the Ptolemaic model \Rightarrow working model required even more epicycles
- **Question:** Why did he published his work only near the end of his life ? Was he afraid of the authority of the Church or was he embarrassed because of the “failure” of his model ?

Just being smart is not enough ...

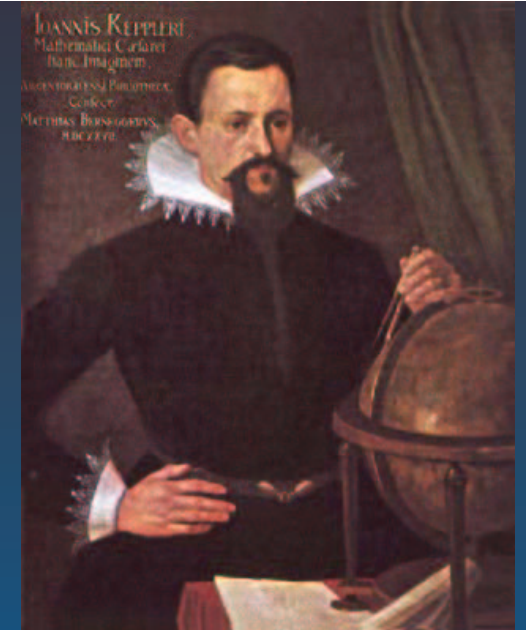
- Better data Tycho Brahe
- Final touch-up of
the model Johannes Kepler
- Promotion of the
new model Galileo Galilei

Tycho Brahe (1546-1601)

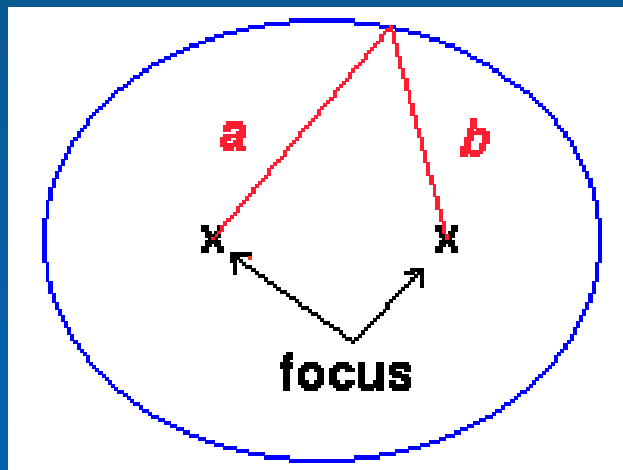
- Last of the great naked-eye observers
 - exceptionally careful and systematic observer \Rightarrow first modern scientist
 - Earth at center, planets orbit the Sun
 - detailed measurement of Mars' orbit over 30 years
 - Observed comets and parallax of comets \Rightarrow Comet behind the orbit of the Moon
 - Observed a supernova [“new star”] in Cassiopeia, no parallax measurable \Rightarrow supernova must be on celestial sphere
- \Rightarrow Challenge of the Aristotelian idea of the perfect, eternal, unchanging heavens



Johannes Kepler (1571-1630)



- Tycho's successor in Prague
- He realized that neither the Ptolemaic nor Tycho's nor the heliocentric model can fit Tycho's data within the stated accuracy
- Proposal: planets move on ellipses, not circles

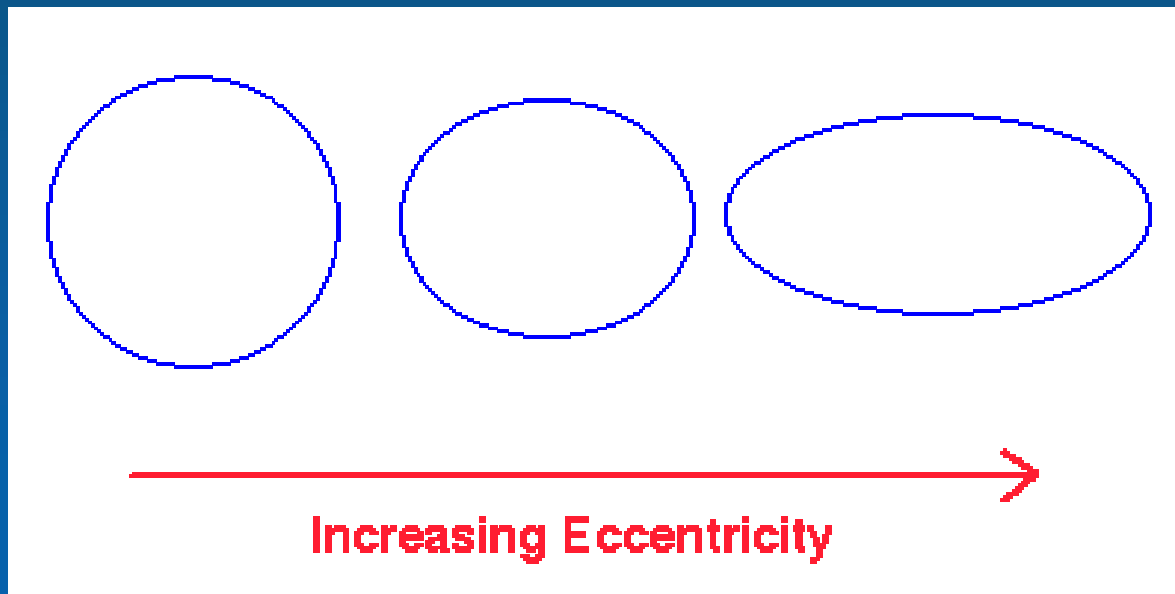
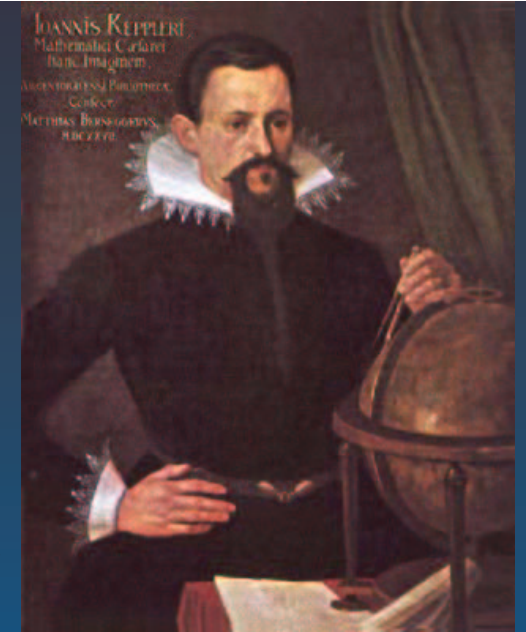


Circle: distance to the center is constant

Ellipse: sum of the distances to the two foci ($a+b$) is constant

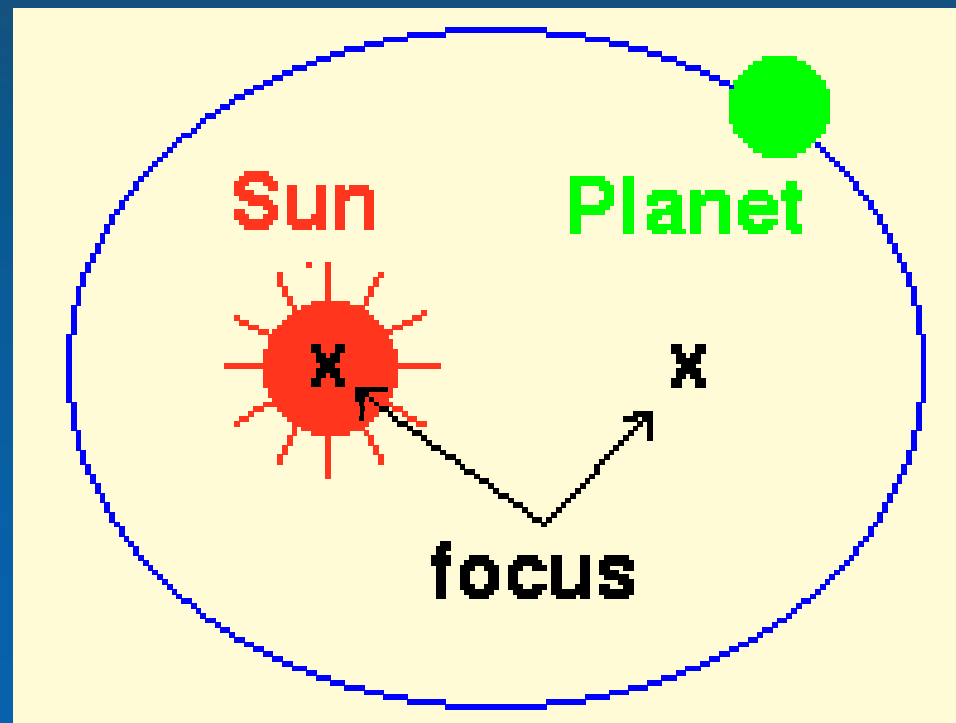
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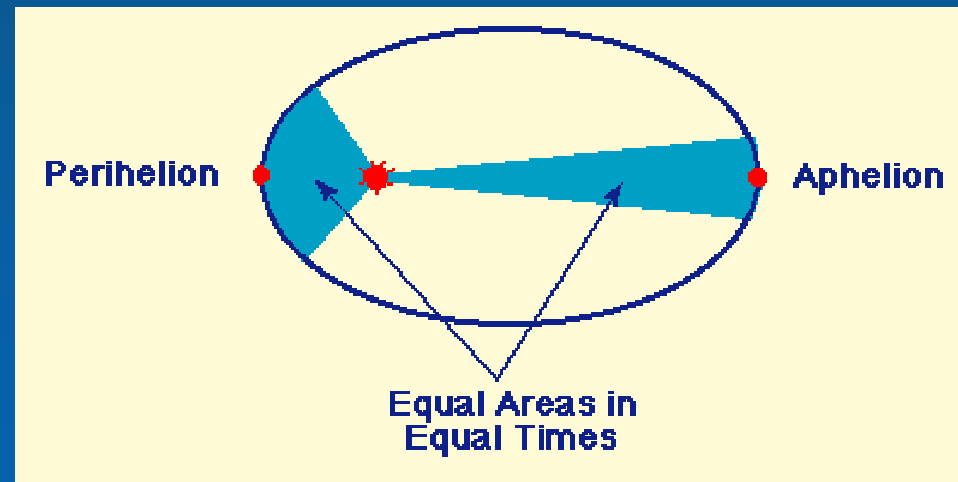
Kepler's three laws of planetary orbits

Kepler's first law: Planets orbit the Sun in an ellipse, with the Sun at one focus.



Kepler's three laws of planetary orbits

Kepler's second law: The line from the Sun to the planet sweeps out an equal area in an equal time. Thus planets move faster if they are nearer the Sun.



Kepler's three laws of planetary orbits

Kepler's third law: The square of the period of the orbit is equal to the cube of the semimajor axis of the ellipse.

$$\frac{P_1^2}{P_2^2} = \frac{R_1^3}{R_2^3}$$

