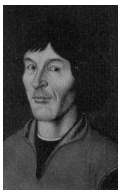
Renaissance Astronomy

The Rebirth of Astronomy

- The Islamic world had many astronomical works that originated from Spain to Asia.
  - Some works were translated Greek works which were otherwise lost
- In Europe the birth of universities started critical thinking of the ancient Greek ideas
  - Oresme (1330 -1382): relative motion
  - Buridan (c1300 -1358): impetus
- New Observations
  - Bacon (c1220 -1292) – experimentation the best way to acquire knowledge
  - Purbach, Regiomontanus – found errors in the Ptolemy tables (mid 1400s)

Nicolaus Copernicus (1473 – 1543)



- Copernicus, a contemporary of Columbus, worked 40 years on a heliocentric (sun-centered) model for two reasons:
  - Ptolemy's predicted positions for celestial objects had become less accurate over time.
  - The Ptolemaic model was not aesthetically pleasing enough.

Renaissance Astronomy

The Copernican System

- His system revived many of the ideas of the ancient Greek Aristarchus.
- The Earth rotates under a stationary sky (which gives the same observations as a rotating celestial sphere and a stationary Earth).
- The Earth revolves around a stationary Sun, which appears to move among the background stars.

Renaissance Astronomy

The Copernican System

Motions of the Planets

- His model explains the generally west to east motion of the planets.
- Observed retrograde motion of planets beyond Earth (such as Mars) is explained more simply and conclusively.
- The relation between sidereal period and synodic period

Renaissance Astronomy

The Copernican System

- Copernicus had the Moon revolving around the Earth. All others circled the Sun.
- The Sun's apparent motion north and south of the equator is explained by having the Earth's equator tilted with respect to the planet's orbit around the Sun.
- The tilt of Earth's axis causes the ecliptic to be sometimes above and sometimes below the celestial equator.

Renaissance Astronomy

Comparing The Two Models

1. *Accuracy in Fitting the Data*

- A good model accurately fits all observed data.
- Copernicus's model, though more aesthetic than Ptolemy's, still was *no more* accurate in predicting all observed planetary motions.
- Copernicus was forced to add small epicycles of his own to improve accuracy.

Renaissance Astronomy

Comparing The Two Models

2. Predictive Power

- Using the **Astronomical Unit (AU)** - the average distance between Earth and Sun - Copernicus predicted with amazing accuracy the Sun-to-planet distances for the 5 planets visible from Earth in the 1500s.

Renaissance Astronomy

Comparing The Two Models

3. *Aesthetics: Mercury and Venus*

- The Copernican model was more aesthetic since it could explain the motions of Mercury and Venus without resorting to special rules needed by the Ptolemaic model.
- Copernicus offered a simpler explanation for retrograde motion that required no use of epicycles.

Renaissance Astronomy

Tycho Brahe (1546 – 1601)

- Tycho was born 3 years after Copernicus died.
- Tycho built the largest and most accurate naked-eye instruments yet constructed.
- He could measure angles to within 0.1º, close to the limit the human eye can observe.

Renaissance Astronomy

Tycho's Obserservations

- Tycho opposed the heliocentric model because he could not observe stellar parallax
- Nearby stars would shift relative to faraway stars if the earth were moving around the sun
- Since no parallax was observed (to observational limits), either the stars were over 7000 AU away or the earth did not move around the sun
- Tycho had thought he had measured angular sizes of the stars and this vast distance would have implied stars to be several AU in size, so he concluded that Earth did not move
- Proposed "compromise" model which had planets going around Sun but Sun going around Earth

Renaissance Astronomy

Johannes Kepler (1571 – 1630)

- In 1600, a year before Tycho died, Kepler accepted a position as Tycho's assistant, working on models of planetary motion.
- Tycho's best data had been gathered for Mars.
- Based on circles and epicycles Kepler's best model for Mars matched Tycho's data to an accuracy of 0.13º (8 arcminutes).
- Yet, this error exceeded the error in Tycho's measurements, which bothered Kepler.
- Kepler's persistence led him to abandon circles and try other shapes. The shape that worked for Mars and all other planets was the ellipse.

Renaissance Astronomy

From Circles to Conics

The Ellipse

- The ellipse is a geometrical shape every point of which is the same total distance from two fixed points (the foci, one is called focus).
- Eccentricity is the distance between the foci divided by the longest distance across (major axis).
- Astronomers refer to the semi-major axis distance and eccentricity.

Renaissance Astronomy

Kepler's First Two Laws of Planetary Motion

- *1st Law:* Each planet's path around the Sun is an ellipse, with the Sun at one focus of the ellipse (the other focus is empty). [Note: perihelion vs aphelion]
- *2nd Law:* A planet moves along its elliptical path with a speed that changes in such a way that a line from the planet to the Sun sweeps out equal areas in equal intervals of time.

Renaissance Astronomy

Kepler's Third Law

- *3rd Law:* The ratio of the cube of a planet's average distance *a* from the Sun to the square of its orbital period *p* is the same for each planet: $a^3/p^2 = C$
- Example: Mars's period is 1.88 year. Its distance from the sun is calculated as:

$$a^3/(1.88\ \text{yr})^2 = 1\ \text{AU}^3/\text{yr}^2$$

$$a^3 = 3.53\ \text{AU}^3$$

$$a = 1.52\ \text{AU}$$

Renaissance Astronomy

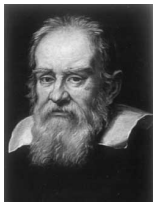
Kepler's Contribution

- Kepler's modification to the Copernican model brought it into conformity with the data. Finally, the heliocentric theory worked better than the old geocentric theory.
- Kepler's breakthrough choice of ellipses to explain planetary motion was empirical - ellipses worked but he did not know why they worked.

Renaissance Astronomy

Galileo Galilei (1564 – 1642)

- Galileo was born in 1564 and was a contemporary of Kepler.
  - He built his first telescope in 1609, shortly after hearing about telescopes being constructed in the Netherlands.
  - He was the first person to use a telescope to study the sky ***(and publish the results!).***

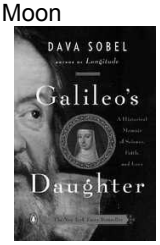


poor Thomas Harriot (1560-1621)

Renaissance Astronomy

Galileo Galilei and the Telescope

- **Galileo made 6 important observations**:
  - Mountains and valleys on the Moon
  - Sunspots
  - More stars than can be observed with the naked eye
  - The nature of Earthshine
  - Four moons of Jupiter
  - Complete cycle of phases of Venus



Renaissance Astronomy

Galileo Galilei and the Perfect Cosmos

The Moon, the Sun, and the Stars

- Though Galileo's first four observations do not disprove the geocentric theory, they cast doubt on the the assumption of perfection in the heavens.
- The existence of stars too dim to be seen with the naked eye also cast doubt on the literal interpretation of some Bible passages.

Renaissance Astronomy

Galileo Galilei and Jupiter

Satellites of Jupiter

http://www.webpersonal.net/parabolix/castro/satgali.en.html

- In 1610 Galileo discovered that Jupiter had four satellites of its own, now known as the **Galilean moons** of Jupiter.
- Jupiter and its orbiting moons contradicted the Ptolemaic notions that the Earth is the center of all things and if the Earth moved it would leave behind the Moon.

Renaissance Astronomy

Galileo Galilei and Venusian Phases

The Phases of Venus

- Galileo observed that Venus goes through a full set of phases: **full, gibbous, quarter, crescent**.
- Venus's full set of phases can be explained by the heliocentric theory.
- The Ptolemaic theory predicts that Venus will always appear in a crescent phase, which is not borne out by the observations.

Renaissance Astronomy

Galileo Galilei's Major Works

- ***The Starry Messenger*** (*Sidereus Nuncius*, 1610)
  - First telescopic discoveries
- ***Letters on Sunspots*** (1613)
  - Correspondence with German amateur
  - Realized the general nature of sunspots
- ***Letter to the Grand Duchess Cristina*** (1615)
  - The Bible and Science
- ***The Assayer*** (1623)
  - Opinions on Comets (dismissed as atmospheric [!])

Renaissance Astronomy

Galileo Galilei's Major Works

- ***The Dialogue Concerning the Two Chief World Systems*** (1632)
  - Discourse between three characters (Salviati, Sagredo, Simplicio) about the geocentric and heliocentric theories of the universe
  - Led to his condemnation
  - This wasn't his first controversy…

Renaissance Astronomy

Galileo Galilei's Controversy

- ***Sunspots*** (1613) irked some Jesuits
- Copernicus' book banned by Catholic Church
  - Led to decree of 1616 about the heliocentric universe
- Jesuit Orazio Grassi wrote book about Comets in 1619
  - Had correct view of extraterrestrial nature of comets
- Urban VIII becomes Pope in 1623
  - Good friend and supporter of Galileo
  - ***Assayer*** written in response to Jesuit book
    - Dedicated to Urban VIII
- ***Dialogue*** met with ire of some Jesuits and Pope Urban VIII
  - Thought to be personal attack (Simplicio→Pope's view)
  - Book banned and led to heresy trial and conviction in 1633

Renaissance Astronomy

Galileo and Science

- Galileo is credited with setting the standard for studying nature through reliance on observation and experimentation to test hypotheses.
- Galileo was the first to develop our modern ideas of motion
  - Inclined planes
- He proposed that all objects fall at the same rate regardless of mass