Ptolemy’s Solar System

- Earth in the middle, unmoving
- Stars fixed on the Celestial Sphere, which rotates around Earth
- Planets & Sun also orbit around the Earth along deferents and epicycles

Retrograde Motion: A Problem

- Epicycles explained why planets would sometimes move backwards
- More and more epicycles were needed to fine-tune the model
  - Predictions were always a bit off
  - Some versions had hundreds of epicycles!

Copernican Model (published 1543)

- The Sun is in the middle (Heliocentric)
- The Earth and other planets orbit the Sun in perfect circles
- Retrograde motion is caused by the planets orbiting at different speeds
  - Planets closer to the Sun orbit faster
  - Planets farther from the Sun orbit slower

Retrograde Motion in a Heliocentric Solar System

Copernicus: ALMOST right!

- Planets orbit around the Sun: correct
- Planets orbit in circles: incorrect!

- Copernicus’s predictions weren’t any better than Ptolemy’s!
Galileo (1564-1642)

- Telescopes were being made by glassworkers in the Netherlands
- Galileo hears about them, builds his own around 1610
- Made many important observations:
  - The Milky Way
  - Sunspots
  - Jupiter’s four largest moons
  - The phases of Venus

Sketches of the planets
Galileo’s telescope revealed that Jupiter had moons which orbited Jupiter instead of Earth.

Tycho Brahe (1546-1601)
- Danish nobleman with an interest in astronomy (also fake nose & pet moose)
- Very comprehensive, very accurate measurements of planet & star positions
- Moved to Prague in 1596, hired a mathematician named Kepler
- Developed his own geocentric “Tychonic” model of the universe

Johannes Kepler (1571-1630)
- A believer in the Copernican model
- Tried to explain the spacing of the planets using geometrical shapes
- Began working as an assistant mathematician to Tycho

Tycho and Kepler
- Upon Tycho’s death, his family sued Kepler to get back Tycho’s things
- Kepler gave back the instruments, but not the books
- Tycho’s observations helped Kepler deduce laws describing planetary motion

Kepler’s First Law
Planes orbit the Sun along elliptical paths with the Sun at one focus.

Kepler’s First Law
- An ellipse is like a squashed circle
- Eccentricity (e) : How squashed is it?
  - If $e = 0$, it’s a circle (not squashed at all)
  - If $e = 1$, it’s a line (completely squashed)
- Most planets have very low $e$ (A almost = B)
Kepler’s 2nd Law
A line joining the Sun and a planet sweeps out equal areas in equal amounts of time.

If \( t_2 - t_1 = t_4 - t_3 \), then \( A_1 = A_2 \)

Kepler’s 3rd Law
The square of the period is proportional to the cube of the semi-major axis (or average distance from the Sun).

- Period: Time to orbit the Sun once
- Semi-major axis: Large distance from center to orbit

\[ P^2 = k \times a^3 \]

- \( k \) is a constant
  - \( k = 1 \) if \( P \) is measured in years, \( a \) in AU

Astronomical Units (AU)
- AU is based on the average distance between Earth & the Sun
- \( 1 \text{ AU} = 1.5 \times 10^8 \text{ km} \)
- Easy way to compare semimajor axes of planets
  - Earth: 1 AU
  - Jupiter: 5 AU
  - Saturn: 10 AU
  - Neptune: 30 AU

Example: Kepler’s 3rd Law
An asteroid has an average distance to the Sun of about 3 AU. What is its period in years?

\[ P^2 = a^3 \]

\[ (P^2)^{1/2} = (a^3)^{1/2} \rightarrow (x^{1/2} \text{ is the same as } \sqrt{x}) \]

\[ P = a^{3/2} \]

\[ P = (3 \text{ AU})^{3/2} \]

\[ P = 5.2 \text{ years} \]

Kepler’s Third Law Lecture
Tutorial: Page 25-28

- Work with a partner or two
- Read directions and answer all questions carefully. Take time to understand it now!
- Come to a consensus answer you all agree on before moving on to the next question.
- If you get stuck, ask another group for help.
- If you get really stuck, raise your hand and I will come around.