

How do we know how the Solar
System is organized and how
objects move within it?

(The history of the development of ideas about
the Solar System)

Key items that underlie theories

- Cultural world view, or preconceptions about how the world is laid out
- Ability of a culture to make measurements, i.e. How accurately can things like the positions of stars and planets be measured
- Development of new technology that influences one or both of the above

Basic observations

- Sun goes around in the sky
- Stars go around, but at slightly different rate
- Moon goes around, but at yet another rate
- Planets are objects with irregular motion in the sky.
 - Some, like Venus, are only visible at certain times of day (sunrise and sunset)

The view from ancient Greece

- Earth is located at the center of the Universe, and stands still
 - Partly motivated by preconception
 - Partly motivated by lack of observed parallax of stars
- Objects move in circular orbits around the Earth
 - Circles preferred because of simplicity (pre-conception?)
- Motions of planets (retrograde motion) can't be explained in simplest picture!
 - Introduction of epicycles to explain retrograde motion

Geocentric model of Ptolemy

- Most elaborate geocentric model was developed by the astronomer Ptolemy
- Ptolemy made lots of small adjustments to the basic picture to try to better match the observed position of planets
- Always preserved Earth at center (geocentric) and circular orbits, but had some orbits off center, some orbits tied to other orbits, etc. --> complicated
- Even with complications, model didn't perfectly predict planetary position
- Still, this was the main model of the Solar System for ~1700 years!

The Renaissance and birth of heliocentric models

- In the 1500s and 1600s, Europe went through Renaissance, where many ideas were reconsidered
- Copernicus, a Polish astronomer, suggested a dramatically different model of the Solar System, a heliocentric model, with the Sun at the center
- Copernicus preserved the idea that planets orbited in circular orbits around the Sun, however.
- Big debate ensued, between geocentric and heliocentric models
 - Debate was partly scientific, based on how well each model did in predicted where planets would be observed. Unfortunately, neither made perfect predictions!
 - Debate was partly philosophical, as some people/institutions had strong opinions about Earth being centrally located

The impact of new technology

- At the same time, new technology started to be used for astronomical observations
- Galileo used optics to make telescopes to look at the sky
 - Discovered moons around planets (Jupiter in particular) that clearly moved in orbit around the parent planet --> strong philosophical implication that there are objects that orbit something beside the Earth!
 - Discovered that planets are resolved disks. Observed that Venus went through phases, which could be explained by the heliocentric model, but not by the geocentric model

The value of accurate data

- Despite the evidence for a heliocentric model, there was still the problem that the model of Copernicus failed to predict locations of planets perfectly
- Tycho Brahe was an astronomer who realized that getting the most precise measurements of planetary positions would be of great value to constrain theories about how the Solar System is laid out
 - He spent several years in the late 1500's collecting precise data on planetary positions, and made these available for others to think about
- Many people (including Tycho) tried to devise models to reproduce the observations

Kepler's laws

- Finally, Johannes Kepler came up with a model that was able to fit the observations perfectly, and predict locations of planets.
- Key points:
 - model was tied to reproducing observations: data is what it is!
 - had to release preconceptions: Earth is not at the center, and orbits aren't circles!
- Kepler's model was characterized by his 3 Laws of Planetary Motion

Kepler's first law

- Planets travel in elliptical orbits with the Sun located at one of the foci of the ellipse
 - Understand what an ellipse is
 - Kepler's laws correctly state that planets travel in elliptical orbits around the Sun, with the Sun at one focus of the ellipse
 - In fact, ALL objects (e.g., comets and asteroids) orbit in elliptical orbits
 - Most planetary orbits, while elliptical, are only slightly elongated, so they are close to circles
 - Many comets, however, orbit in very eccentric orbits

Kepler's 2nd law

- In their elliptical orbits, planets travel faster when they are closer to the Sun, and slower when they are farther from it
- More specifically, law of equal areas: planetary orbits sweep out equal areas (between Sun and planet) in equal times

Kepler's 3rd law

- The time it takes for a planet to go around the Sun is related to the size of its orbit; more distant planets take longer to go around.

$$(\text{Period in years})^2 = (\text{semimajoraxis in a.u.})^3$$

Why do Kepler's laws work?

- Kepler's model correctly describes the Solar System and motions within it
- However, it does NOT explain WHY the planets orbit according to Kepler's law
- The understanding of WHY the planets move as they do was developed in the late 1600's by Isaac Newton, who introduced the concept of gravity