Chapter 2 Goals

- What paths do the planets take through space?
- Why do they follow these paths?
- To answer these questions, we need a **model** of how the Solar System works.
- ... and we need to test that model with **observations**.
How Science Works

1. Make observation or do experiment
2. Analyze results
   - If pre-existing theories explain observation/experiment equally well, choose simplest theory; publish peer-reviewed results
   - If no theory is adequate to explain observation/experiment, modify existing theory or develop new theory
3. Prepare test of theory in new realm
4. Propose new or higher precision experiment or observation to extend the theory’s realm of validity
5. Make predictions from new or modified theory
6. Prepare test of new theory
Science and Theories

Science does not provide “absolute truth”, it is not always correct. It provides hypotheses and theories.

A theory is reliable: it has been repeatedly tested and always passed the test.

You can bet your life on it... in fact you already have.

For example, Fluid Dynamics and Aerodynamics – explains how airplanes are able to fly.

Electromagnetism – explains how power can be delivered to homes.

Nevertheless, theories that have been used for many years are sometimes abandoned or refined if disproven: thus, science is self-correcting.
Wandering Stars

- Ancient Greek astronomers observed that five stars were not fixed to the Celestial Sphere...
- ...they called these stars, aster planetēs.
- However, these wanderers exhibit motion that is hard to explain.
Mars’ retrograde motion in 2014.
Ptolemy of Alexandria, A.D. 90 - 168
• Ptolemy designed a geocentric explanation for the observed motion of the planets, Moon, and Sun – *Almagest*.

• Each planet is assumed to move in a small circle called an **epicycle**.

• The center of each epicycle moves along a larger circle called a **deferent**.

• The center of each deferent (*equant point*) is offset from Earth.

• This model worked for the most part...
Geocentric Model

- Planet moves rapidly westward along epicycle
- Epicycle moves slowly eastward along deferent

As seen from Earth, planet moves westward (retrograde motion)
The Geocentric Model

- Because it could explain the observed retrograde motion, Ptolemy’s theory was very influential in the study of astronomy for many centuries.
- When the Geocentric Model did not agree with later observations, astronomers added small adjustments to the model.
- Although complicated, the Geocentric endured for nearly 1,600 years!
Under the rug...

- To account for the observed changes in speed of the Moon, the Moon’s deferent was largely offset from Earth.
- This offset should have noticeably changed the apparent size of the Moon over a month.
- The Ptolemaic system makes a prediction about the Moon, but fails that test under inspection.
- This isn’t a good description of the Universe!
Copernicus’ Heliocentric Theory

*De Revolutionibus Orbium Coelestium* – 1543
Nicolaus Copernicus, a 16th century Polish astronomer is credited with our modern view of the Solar System.

Copernicus suggested a *heliocentric* theory...

...the Sun was at the center of the Solar System...

...and planets moved in *circles* around the Sun.
The Heliocentric Model could also explain retrograde motion.
• Copernicus’ Heliocentric model allowed him to calculate the relative distances to the planets...
• ...as well as the length of time the planets take to orbit the Sun.
• These predictions proved correct...
• ...but Copernicus’ model was no more accurate than the Ptolemaic model!
• Although simpler, he still needed to use epicycles to match observations.
● The heliocentric view was controversial and not readily accepted at the time of Copernicus.
● Philosophical and religious views held that humanity and thus Earth must be the center of the universe.
● Copernicus did not publish his work until the year of his death in 1543.
Tycho Brahe – 1546 - 1601, Danish astronomer of nobility
Before the invention of the telescope, Tycho was one of the greatest naked eye observers of stars, planets.

Danish king granted Tycho an island to build an observatory.

Tycho Brahe spent decades making the most accurate observations of the positions of the planets for his time.

In 1600, Tycho hired a more mathematically inclined assistant, Johannes Kepler.
Kepler had studied the ideas of Copernicus and acquired Tycho’s records after Tycho died in 1601.

Kepler was responsible for next step in understanding the motions of the planets.

Used Tycho’s observations of Mars, deduced 3 empirical rules to describe the planets’ motions.
Kepler’s 1st Law:

*The orbit of each planet is an ellipse with the Sun at one focus.*

- Kepler expected to confirm circular orbits from Tycho’s data, but instead found disagreement.
- Replaced Copernicus’ circular orbits with elliptical orbits and found an almost perfect match with the observations.
When a planet is closest to the Sun: **perihelion**

When a planet is furthest from the Sun: **aphelion**
Kepler’s 2nd Law:

Planets Sweep Out Equal Areas in Equal Times

- observed that planets move fastest in their orbit close to Sun, slowest when furthest from Sun.
- the imaginary line connecting the Sun to a planet sweeps out equal areas in equal times, no matter where the planet is in orbit.
Kepler’s Second Law

- Planet on elliptical orbit
- These three areas—A, B, and C—will be equal...
- ...if these time intervals are equal.
Kepler’s 3rd Law:

The square of a planet’s orbital period is proportional to the cube of the orbit’s semimajor axis.

- \((P_{\text{years}})^2 = (A_{\text{AU}})^3\)
- 1 AU is the average Earth-Sun distance.
- Referred to this law as the ‘Harmony of the Worlds’
Galileo Galilei and the telescope – 1609
• Arguably the ‘first scientist’ applying the modern scientific method to his work
• Galileo supported the Heliocentric model and was first to obtain observational evidence to confirm a Sun-centered cosmology.
Galileo reinvented the telescope for astronomy (originally invented in Holland in early 1600s).

Discovered moons orbiting Jupiter (not Earth)!
Additional evidence supporting the Heliocentric model (check notes):

- Galileo observed Venus with his telescope.
- He reported seeing crescent and gibbous phases on Venus.
- Gibbous phases are only possible if Venus is opposite the Sun from us.
- Can’t happen in the Geocentric view.
Geocentric model
Of Ptolemy
- Heliocentric model challenged beliefs held for nearly 2000 years.
- The Church felt threatened by this.
- Galileo was arrested and tried for heresy.
- Giordano Bruno, a previous advocate of the Heliocentric model, was tried by the Inquisition.
- Bruno was burned at the stake for heresy!
• As punishment, Galileo was not allowed to advocate the Heliocentric model in any way.
• However, word of his discoveries spread...
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