Fundamental Questions of Astronomy (life?)

• What is the shape of the Earth?
• How big is the planet we live on?
• Why do the stars move across the sky?
• Where is Earth in relation to the Sun?
• How do objects orbit the Sun?
• Why do objects orbit the Sun?
The Scientific Method

• Based on natural inquisitiveness and skepticism of human nature.

• **Scientific Method:**
  a. Make high quality observations of natural phenomenon
  b. Come up with a theory that explains the observations
  c. Use the theory to predict future observations
  d. Make further observations to test the theory
  e. Refine the theory, or if it no longer works, make a new one

**You can prove a theory WRONG but not RIGHT**
Tycho Brahe

• Tycho Brahe was born 3 years after Copernicus died (2 years after Galileo was born) into Dutch nobility.
• Brahe was the last and greatest of the pre-telescopic observers in Europe.
• Brahe made a continuous record of the positions of the Sun, Moon, and planets for almost 20 years.
• Measurements did not agree with Ptolemy.
• To assist him in analyzing his extensive planetary data, he hired Johannes Kepler.
Johannes Kepler

- Kepler was born into a poor German family during the 30 year war.
- He learned the principles of the Copernican system and then was hired by Brahe.
- Goal: find a theory that explained planetary motion.
- Copernicus said that orbits are circular and the Sun is in the center, but Kepler wanted to find the underlying relations.
- After about 30 years, Kepler was about to deduce three laws of motions for planets.
Kepler’s First Law

The orbits of the planets are elliptical (not circular) with the Sun at one focus of the ellipse.
**Ellipses:**

Eccentricity = distance between foci / major axis length

Describes ‘flatness’ of ellipse.

<table>
<thead>
<tr>
<th>Planet</th>
<th>Orbital Semimajor Axis, $a$ (AU)</th>
<th>Orbital Period, $P$ (Earth Years)</th>
<th>Orbital Eccentricity, $e$</th>
<th>$P^2/a^3$</th>
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<td>0.387</td>
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<td>163.7</td>
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Kepler’s Second Law

A line connecting the Sun and a planet sweeps out equal areas in equal times.

This means:
Planets move faster when closer to the Sun.
Kepler’s Third Law

The square of a planet’s orbital period is proportional to the cube of its semi-major axis.

P: Period – the time to complete one full orbit
a: semi-major axis

\[ P^2 \propto a^3 \]

This means:
The larger a planet’s orbit, the longer the period
Kepler’s Three Laws

• Kepler’s three laws provide a precise geometric description of planetary motion within the framework of the Copernican system.

• With these tools, it was possible to calculate planetary positions with greatly improved precision.

• Laws are still purely descriptive. Answers how but now why.

✓ How do objects orbit the Sun?
Isaac Newton Asking Why

• Isaac Newton is the lesser know brother to Fig Newton
• Famous for his contribution to Alchemy.
• Suffered several nervous breakdowns because of chemical poisoning from alchemy work.
• Spent much time looking for the Philosopher’s Stone (later found by Harry Potter and Gang) and the Elixir of Life.
• Also invented Calculus, a comprehensive theory of motion and gravity, and contributed greatly to the field of optics.
Isaac Newton Asking Why

• Newton, born a year after Galileo’s death, used the framework laid down by Galileo, Brahe, Kepler, and others to create a comprehensive theory of gravity.

• Newton invented Calculus, a mathematical framework, in order to complete his theory. Three laws were derived:
  • **Newton’s first law**: Every object will continue to be in a state of rest or move at a constant speed in a straight line unless it is compelled to change by an outside force.
  • **Newton’s second law**: The change of motion of a body is proportional to and in the direction of the force acting on it.
  • **Newton’s third law**: For every action there is an equal and opposite reaction.
Newton’s First

• Newton’s first law is a statement of conservation of momentum.

• Momentum depends on mass and speed. Momentum has a direction.
  \[ p = m \times v \]

• Momentum is not conserved on Earth generally because of many outside forces (Friction).
Newton’s Second

• Momentum only changes when an outside force acts on it.

• A force is a strain, push, or pull in a certain direction on an object.

• To speed up, slow down, or change direction, a force must be applied to the object.

\[ F = m \times a \]
Newton’s Third

• Forces in nature do not occur alone.

• Rockets use Newton's third law to propel themselves. Gas is ejected down and to conserve momentum, the rocket is propelled up.
Planetary Motion

• People knew about gravity. Newton generalized it to the whole universe.

• Newton’s First says objects move in a straight line unless acted on by an outside force. Planets move in ellipses because of an outside force called gravity.

• Gravity is an attractive force that is pulling objects together to change their momentum (Newton’s Second).

• The Earth’s gravity pulls on us. Our gravity pulls on the Earth with the same force. (Newton’s Third)
Newton’s Law of Universal Gravitation

\[ F = G \left( \frac{mM}{r^2} \right) = ma \]

\( F = \) gravitational force between two objects
\( m = \) mass of first object
\( M = \) mass of second object
\( r = \) distance between objects
\( G = \) universal constant of gravitation

- If the masses are measured in kilograms and the distance between them in meters, then the force is measured in Newtons
- Laboratory experiments have yielded a defined value for \( G \) of
  \[ G = 6.67 \times 10^{-11} \text{ Newton} \cdot \text{m}^2/\text{kg}^2 \]
To make a ball move at a high speed in a small circle requires a strong pull.

To make the same ball move at a low speed in a large circle requires only a weak pull.

To make a planet move at a high speed in a small orbit requires a strong gravitational force.

To make the same planet move at a low speed in a larger orbit requires only a weak gravitational force.
Stable Orbits

- The type of orbit depends on the initial speed of the object.
- Stable orbits are either circular or elliptical.
- Too slow and gravity pulls the object back in.
- Too fast and gravity is not strong enough. This is called the escape velocity.
Newton’s Third: Center of Mass

Forces in nature do not occur alone. Objects orbit each other around a common point.
Conservation of Angular Momentum

• Two types of momentum:
  • Linear Momentum – moving in a straight line
  • Angular Momentum – rotational movement

• Related to Kepler’s second law

\[ L = mrv \]

• Depends on mass
• Distance to center of rotation
• Speed of rotation
Finding Exoplanets

The star orbits about the system’s centre of mass, when the star moves towards the earth the spectrum is ‘Blue-shifted’, as it moves away it is ‘Red-shifted’.