Chapter 1
The Copernican Revolution
The Birth of Modern Science

1.1 The Motions of the Planets

- Wanderers in the Heavens
  - Ancient Astronomers noticed most of the stars in the night sky moved in smooth orderly paths along the sky on regular intervals, but there were a few that did not
    - The bodies that seemed to wander about the sky were called *planetes* because the Greek word *planete* means "wanderer"
      - Mercury, Venus, Mars, Jupiter, and Saturn were the objects that wandered
      - The word planet is now what we call these objects
  - As objects move east in the sky, they are said to be moving forward
    - Prograde Motion is the forward (east) movement of planets in the sky
  - As objects move west int eh sky, they are said to be moving backward
    - Retrograde Motion is the backward (west) movement of planets in the sky
  - Astronomers noticed that the planets would change their brightness in the sky throughout the year
    - The determined that the planets did not shine with their own light like the Sun, but rather reflected light from the Sun like the Moon.
    - They reasoned that the brightness is related to the distance from Earth the planet is
      - The closer to the Earth they are, the brighter they shine
        - However, Mars, Jupiter, and Saturn are always brightest during Retrograde Motion which did not make sense at the time
    - The subject of Astrology arose from this as some people tried to use the locations of the planets at someone's birth to predict their destiny or the future.
- The Geocentric Universe
  - The earliest models of the solar system followed the teachings of Aristotle (384–322 B.C.) and placed the Earth at the center of the universe and all other bodies moved around it in space
    - Geocentric means "Earth-Centered", as Geo means Earth and centric means at the center
    - Aristotle believed that the circle was the perfect form and all heavenly bodies were circles and traveled in circles around the Earth
      - This model is good at predicting the Sun and Moon, but not for planets
  - There needed to be a way to explain the fact that planets appear to move backward in the sky as evidenced by Retrograde Motion as well as the fact that planets change distance from the Earth as evidenced by their changing brightness
    - The Greek Philosopher Plolemy (100–170 A.D.) created a model of the solar system keeping Earth at the center, but had each of the planets moving in small circles around their large circular orbit
      - Epicycle is the name of the small circles the planets were thought to travel in
      - Deferent is the name of the large circle the planet orbited the Earth in
    - Ptolemy's model at the time required more than 80 circles to be working together at the same time in an attempt to explain the motion of the planets
  - Greek astronomer Aristarchus of Samos (310–230 B.C.) believed that all of the planets moved around the Sun and that earth is the one rotating on its axis, which would make it appear that the sky is moving around the Earth
    - His ideas did not gain acceptance for a long time due to the influence of Aristotle.
    - Despite being much more accurate than Aristotle, Aristotle's model dominates for 13 centuries based on proper scientific thinking, but lack of measurable evidence
- The Heliocentric Model of the Solar System
  - It wasn't until the 16th century that Aristarchus' idea takes hold and the Sun is placed at the center of the solar system with the Earth revolving around the Sun while rotating around its axis
    - Heliocentric means "Sun-Centered", as Helio means Sun and centric means at the center
  - Nicholas Copernicus (1473–1543) asserted that Aristotle's model of the solar system was too complex to be correct, and that Aristarchus' ideas were a much better explanation for observations

        - The Copernican Revolution is the critical realization that Earth is not at the center of the solar system and it leads to an explosion of planetary science that will eventually become what we know today as Astronomy
            - Unfortunately, Copernicus never lived to see his ideas change the world. He did not publish his book *On the Revolution of the Celestial Spheres* until the year of his death to avoid issues with the Catholic Church.
            - It was the scientists that came after him, who took his ideas and used them to discover everything that we know today

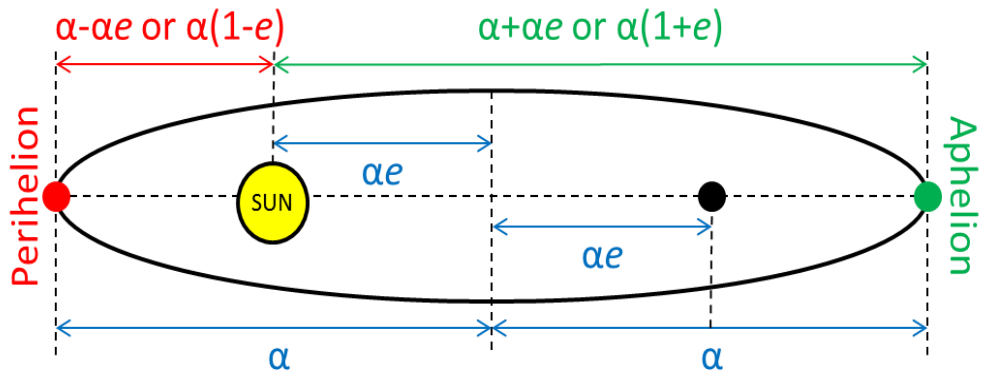
1.2 The Birth of Modern Astronomy

- Galileo's Historic Observations
    - The Italian mathematician and philosopher Galileo Galilei (1564–1642) used the newest technological advancement of the time (telescope) and used it to discover many new things
        - Contrary to popular belief, Galileo did not invent the telescope, but the inventor Hans Lippersley (1570–1619) invented it in Holland in 1608
        - In 1609, Galileo having heard of the telescope, built his own, pointed it at the sky, and Astronomy was born. Here is what he noticed:
            - The Moon has mountains, valleys, and craters – just like Earth
            - The Sun has impoerfections
                - Dark spots we now call *sunspots*
                - The Sun also rotates, just like the Earth, Moon, and planets
            - There are 4 small points of light that invisible to the naked eye that orbit Jupiter
                - These are Moons!!!
                    - Proving that not everything goes around the Earth officially
            - Venus has a complete cycle of phases much like the phases of the moon
                - Venus has to be moving around the Sun
                    - Again proving not everything goes around the Earth
        - Galileo published his findings in 1610 and in 1616, the Catholic Church declared any Copernicus or Galileo Astronomy heresy.
            - During the Inquisition, the church tried to force him to retract his sayings that the Earth goes around the Sun, but he refused so he was placed under house arrest in 1633 until his death in 1642
- Ascendancy of the Copernican System
    - Despite the idea that the Sun was the center of the solar system being around for more than 2000 years, until enough evidence that can only be explained by that system is discovered, differing views are used.
        - The scientific process works with the understanding that no idea is "incorrect" until there is direct observable evidence that cannot be explained using the idea/theory

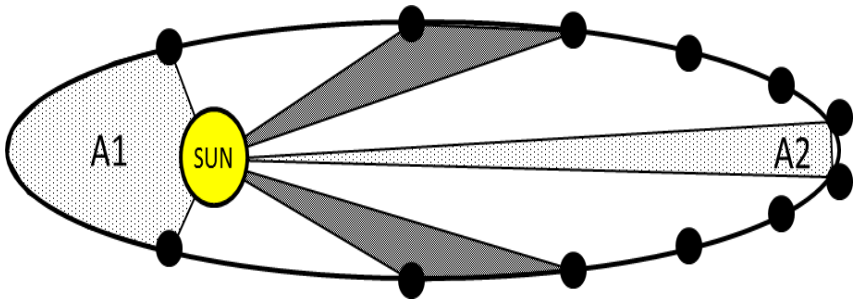
1.3 The Laws of Planetary Motion

- Brahe's Complex Data
    - A Danish Astronomer named Tycho Brahe (1546–1601) was known as possibly the greatest experimental Astronomer of all time.
        - Using instruments that he had created on his own, he kept meticulous and accurate records of the stars, planets, and other celestial events
            - He viewed, tracked, and documented everything he saw for decades
    - In 1600, he moved to Prague where he met another Astronomer named Johannes Kepler (1571–1630) and they worked together until Brahe's death in 1601
        - For the last 29 years of his life, Kepler used the data left to him by Brahe to come up with the first scientific laws regarding celestial bodies
            - The summary of Kepler's calculations using Brahe's planetary data become three laws that describe how all objects orbiting another object behave
                - The Laws of Planetary Motion are the three laws that Kepler discovered and are now known as *Kepler's Laws of Planetary Motion*

- Kepler's Simple Laws
  - Kepler's First Law – The Shapes of Planetary Orbits
    - "The orbital paths of the planets are elliptical with the Sun at one focus"
      - An Ellipse is a flattened circle
        - An ellipse is constructed by using two thumbtacks and a piece of string pinned down using the two thumbtacks.
        - If you place a pencil against the string and stretch the string as far as it will go directly between the two tacks and try to draw a circle, the pencil will not go in a circle because one of the thumbtacks will not let the string push equally in all directions
      - The parts of an ellipse have special mathematical importance
        - The Focus is the location of the two thumbtacks
        - The Major Axis is the long axis of the ellipse that contains both foci
          - The Semimajor Axis(α) is ½ the distance of the Major Axis
        - The Eccentricity (*e*) of the ellipse is the distance between the foci divided by the semimajor axis:
          - The closer the foci, the more circular the ellipse becomes
          - The further the foci, the more flat the ellipse becomes
          - A circle is just a special ellipse with eccentricity of 0
      - There are two special points on the orbit of a planet with respect to the Sun
        - The Perihelion is the point where the planet is closest to Sun
        - The Aphelion is the point where the planet is furthest from Sun



  - Kepler's Second Law – The Speed of Planetary Orbits
    - "An imaginary line connecting the Sun to any planet sweeps out equal areas of the ellipse in equal intervals of time"
      - If you plot the locations of the planet across equal time intervals, the planet moves further along the ellipse when it is closer to the Sun and nearer along the ellipse when it is further from the Sun
      - However, the areas of the near triangular shapes made between two points is always equal to one another making the area of orbit equal during all intervals
        - The area of A1 is equal to the area of A2 as well equal to both the areas of the darker regions of the orbit



- Kepler's Third Law – Period and Distance of Planet from Sun
  - "The square of a planet's orbital period is proportional to the cube of its semimajor axis"
    - The Period (P) of a planet is the time needed for a planet to complete one circuit around the Sun (sidereal year)
    - The Astronomical Unit (AU) is the average distance from the Earth to the Sun
      - 1 AU is equal to 93 million miles or 150 million kilometers
    - Kepler discovered that the period of a planet in Earth years was related to the distance of the semimajor axis measured in AU's in this way:

$$P^2(in\ Earth\ years) = a^3(in\ astronomical\ units)$$

- The Dimensions of the Solar System
  - Units we use on Earth are not good to use in the solar system due to the very large distances between objects. Instead we use a scale where the distance from the Sun to Earth is equal to 1
    - Radar is the bouncing of radio waves off of an object then calculating the time it takes for the signal to bounce off of the object and return to Earth
      - **RADAR** is an acronym that stands for **RA**dio **D**etection **A**nd **R**anging
    - The astronomical unit was determined using radar to measure how far Venus is from Earth at its closest point.
      - Knowing that Venus is 70% of the distance from the Sun to the Earth, determining that Venus is 45 million kilometers from Earth tells us that the full distance from Earth to the Sun is 150 million kilometers, which is the value for the astronomical unit

1.4 Newton's Laws

- The Laws of Motion
  - In the 17th century, the British physicist and mathematician Isaac Newton (1642–1727) developed an understanding of how ALL objects move and interact with one another
    - Newtonian Mechanics consists of three basic laws of motion, the law of universal gravitation, and calculus (which Newton invented) that explains how virtually everything in the universe interacts
      - This is what is today called Physics
  - Newton's First Law of Motion – State of Motion
    - "An object at rest remains as rest, and a moving object continues to move forever in a straight line with constant speed, unless some external force changes their state of motion"
      - A Force is any push or pull on an object
      - Inertia is the tendency of an object to stay in its state of motion due to its mass
        - Mass is the total amount of matter within an object
  - Newton's Second Law of Motion – Changes in State of Motion
    - "The acceleration of an object is directly proportional to the net applied force and inversely proportional to the object's mass"
      - The more mass an object has, the less it will change its velocity
      - The more force you place on an object, the more it will change its velocity
      - Velocity is an object's speed and direction
      - Acceleration is any change in an objects velocity (speed or direction)
      - Newton calculated that the Force, Mass, and Acceleration were exactly related:

$$F = ma$$

  - Newton's Third Law of Motion – Forces Come in Pairs
    - "To every action there is an equal and opposite reaction"
      - Every time object A exerts a force on object B, object B exerts the exact same force on object A, but in the exact opposite direction

- Gravity
  - Newton hypothesized that any object having mass exerts an attractive force on all other objects and that the more mass an object has, the stronger its pull
    - Gravitational Force is the attractive force between any two objects with mass
      - This is the infamous story of the apple falling from the tree and hitting Newton on the head, leading him to 'discover' gravity
  - As he studied the acceleration of the planets as they orbit the Sun, he discovered that if the distance from the Sun is doubled, the gravitational force the Sun exerts decreases by a factor of 4
    - This is a non-linear relationship with distance that shows up in many aspects of physics including electricity, magnetism, and light
  - Inverse Square Law
    - Relationships between objects that are inversely proportional with the square of the distance between the two objects are said to follow this law
  - Universal Law of Gravitation
    - "Every particle of matter in the universe attracts every other particle with a force that is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them"

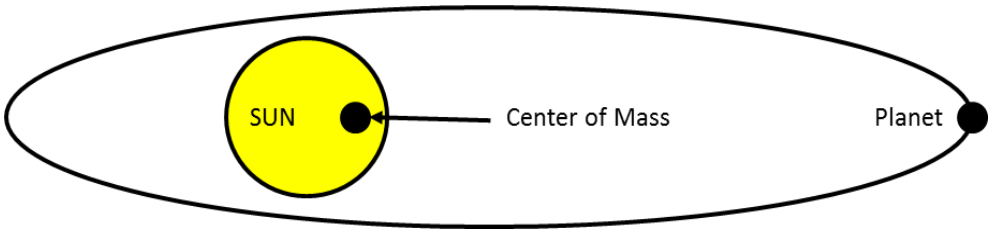
$$F_g = \frac{Gm_1m_2}{d^2}$$

- Orbital Motion
  - Combining Newton's Laws, the Sun-planet attraction is responsible for the orbits of the planets.
    - Plugging in the distance the Earth travels in basically a circle ($2\pi r$, with r being 93 million miles or 150,000 km) within 1 year (8766 hours) you obtain the average orbital speed of the planet Earth as it soars thru the solar system

$$\frac{2 * 3.14 * 93\ million\ miles}{365.25\ days * 24\ hours} = \frac{5.84x10^8 miles}{8766\ hours} = 66{,}621 mph$$

- Kepler's Laws Reconsidered
  - With Newton's laws explained, Kepler's laws must also be slightly changed
    - Newton's laws state that as the objects pull on each other, they both orbit a location that is the center of the distribution of all mass in the system, this changes Kepler's 1st Law
      - The Center of Mass is the is the point where the amount of mass in a system is distributed evenly in all directions from that point
        - Any system can be considered a single object located at the COM, and any gravitational forces within the system act from the COM
      - This means the planets do not orbit the center of the Sun, but rather the center of mass
        - The Sun and planet orbit the center of mass of the Sun-planet system
          - Due to size/mass of the Sun, the center of mass the system is located inside the Sun, but not in its center.
    - Kepler's 3rd Law can now be changed to include the mass of the system which will slow the period down, placing it below the right side of the equation

$$P^2(in\ Earth\ years) = \frac{\alpha^3(in\ astronomical\ units)}{M_{Total}(in\ solar\ units)}$$



- The Circle of Scientific Progress
    - The astronomers before Newton were not "wrong" but with the newer technology and observations that can be made, they are modified and continually tested throughout time
        - Newton's mechanics still remain in use today as its applications can still be used to accurately predict almost all circumstances
            - It is not until the 20th century when Albert Einstein theory of relativity again shakes up our view of gravity and the universe. (more on that in chapter 13)