Lecture 1:

Foundations of Astrodynamics

1500 – 1800: Golden Age of Astronomy and Astrodynamics

- 1530: Copernicus' *Revolutionibus*
- Early 1600's: invention of the telescope in Holland
- 1604: Galileo improves the telescope
- 1609/1619: Kepler's laws
- 1687: Newton's *Principia*
- 1700's: analytic orbit determination solutions of Euler, Lambert and Gauss

Orbit Mechanics Key Individuals

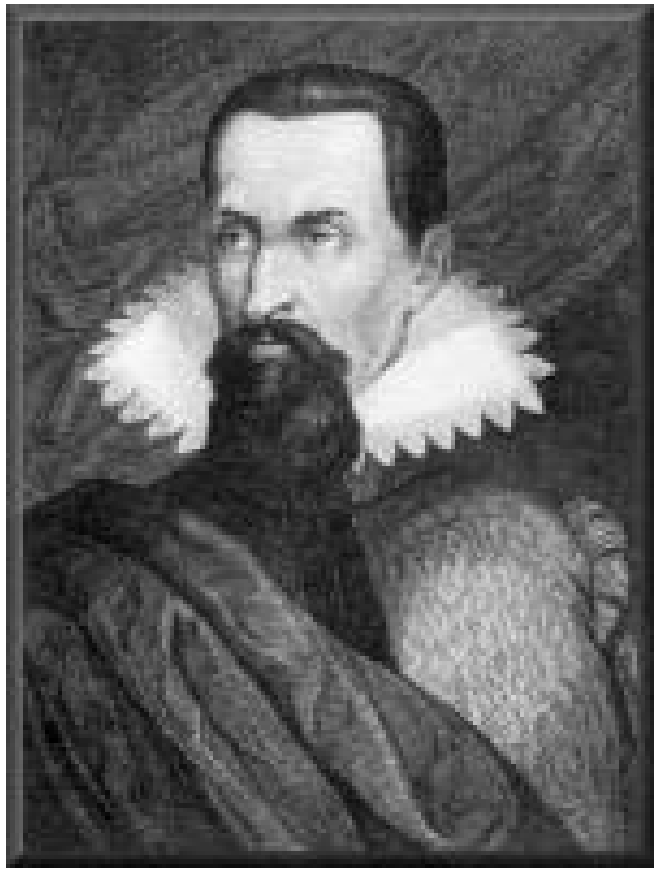
- Tycho Brahe (experimentalist)
- Johannes Kepler (mathematician)
- Isaac Newton (physicist or engineer)

Tycho Brahe

- 1546 - 1601
- Danish nobility and aristocracy
- Exceptional mechanical ingenuity and meticulous in the collection and recording of data
- Made accurate observations of planetary positions without the use of telescopes
- Not a theoretician or mathematician, but rather an experimentalist

Johannes Kepler

- 1571 - 1630
- German
- Poor and sickly
- Met Brahe in 1600
- Realized that Brahe's data did not precisely fit a Copernican view the solar system
- Applied mathematical reasoning to Brahe's observations to create Kepler's Laws (after 8 years of hard work)



Kepler's Three Laws

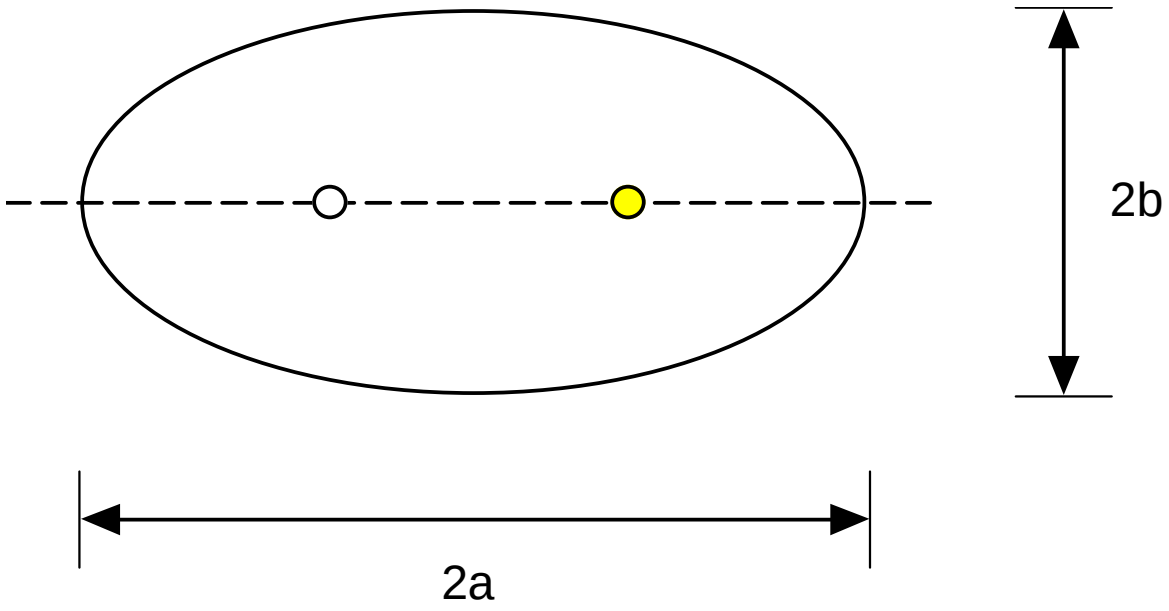
First Law: The orbit of each planet is an ellipse, with the Sun at a focus (1609).

Second Law: The line joining the planet to the Sun sweeps out equal areas in equal times (1609).

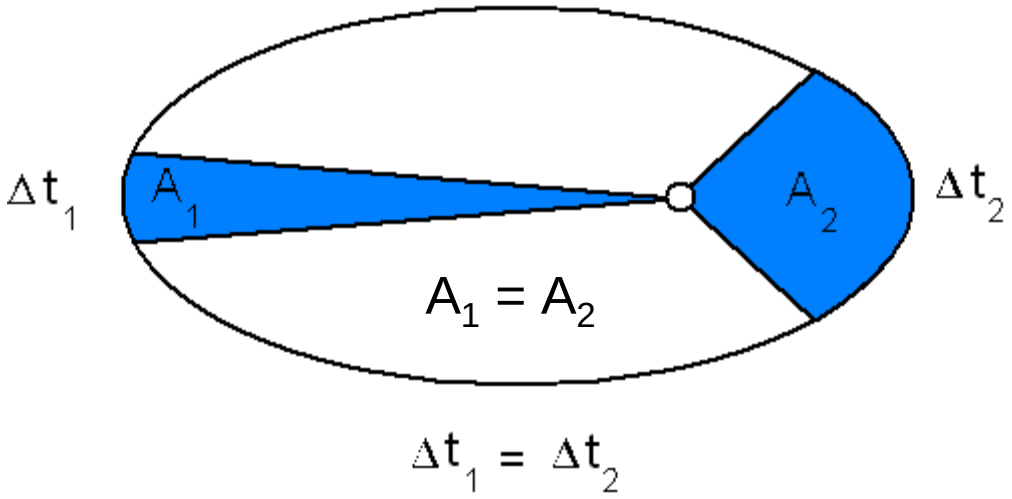
Third Law: The square of the period of a planet is proportional to the cube of its mean distance from the Sun (1619).

Kepler's Laws

- First Law
  - Planets move in elliptical orbits with the Sun at one focus



- Second Law
  - A line joining a planet and the Sun sweeps out equal areas in equal time



  - Application of Kepler's 2nd law is what allows time to be brought into the orbit determination problem – for this reason, orbit prediction (given $\vec{r}, \vec{v}$ and Δt) has been termed Kepler's problem.

- Third Law
  - The square of the period of a planetary orbit is proportional to the cube of its mean distance from the Sun

$$\frac{P_1^2}{P_2^2} = \frac{(a_1)^3}{(a_2)^3}$$

Where a is the semi-major axis, to be defined in Lecture 3

Isaac Newton

- 1642 – 1727, English
- In 1665, while a student at Cambridge University, conceived of the law of universal gravitation, the laws of motion, and the fundamental concepts of differential calculus
- In 1685, Sir Edmund Halley asked Newton what paths the planets would follow if they were pulled by the Sun with a force inversely proportional to the square of their distance.
- Newton immediately knew the answer and two years later published the *Principia* (1687)

First Law: Every body continues in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed upon it.

Second Law: The rate of change of momentum is proportional to the force impressed and is in the same direction as that force.

$$\sum \vec{F} = \frac{d}{dt}(m\dot{\vec{r}})$$

Third Law: To every action there is always an opposed and equal reaction.

Orbit Determination: Newton and Halley

- The first method of orbit determination from three observations was devised by Isaac Newton and published in the *Principia* (1687)
  - Empirical technique based on graphical construction
- Applying Newton's technique, Sir Edmund Halley calculated the orbits of 24 comets which had been observed between 1137 and 1698.
  - Halley concluded that a comet observed in 1531 (by Apianus) was the same comet as that observed in 1607 (by Kepler) and in 1682 (by himself). He then predicted this comet's return to the Earth in 1758.
    - On Christmas day, 1758, Haley's comet returned. It has since been observed in 1835, 1910 and 1986.

Orbit Determination: Euler, Lambert and Gauss

- In 1744, Euler published the first analytic method for parabolic orbit determination from three observations
- In 1771, Lambert extended Euler's results to elliptic and hyperbolic orbits
- In 1801, Gauss predicted the position and time which Ceres would re-emerge from behind the Sun from three observations taken over the period of 1 month.
- Gauss also published a technique for determining an orbit from two observations (position vectors) and the time of flight between them – Gauss' problem, which remains fundamental to orbit determination today.

By 1800, the physical laws which govern Astrodynamics were known. These same principles are used today for Orbit Prediction, Orbit Determination and Mission Design

Practical Applications of Orbital Mechanics