Week 4–6: Physics I – Newton's Law of Universal Gravitation

Kyeong Soo (Joseph) Kim

XJTLU

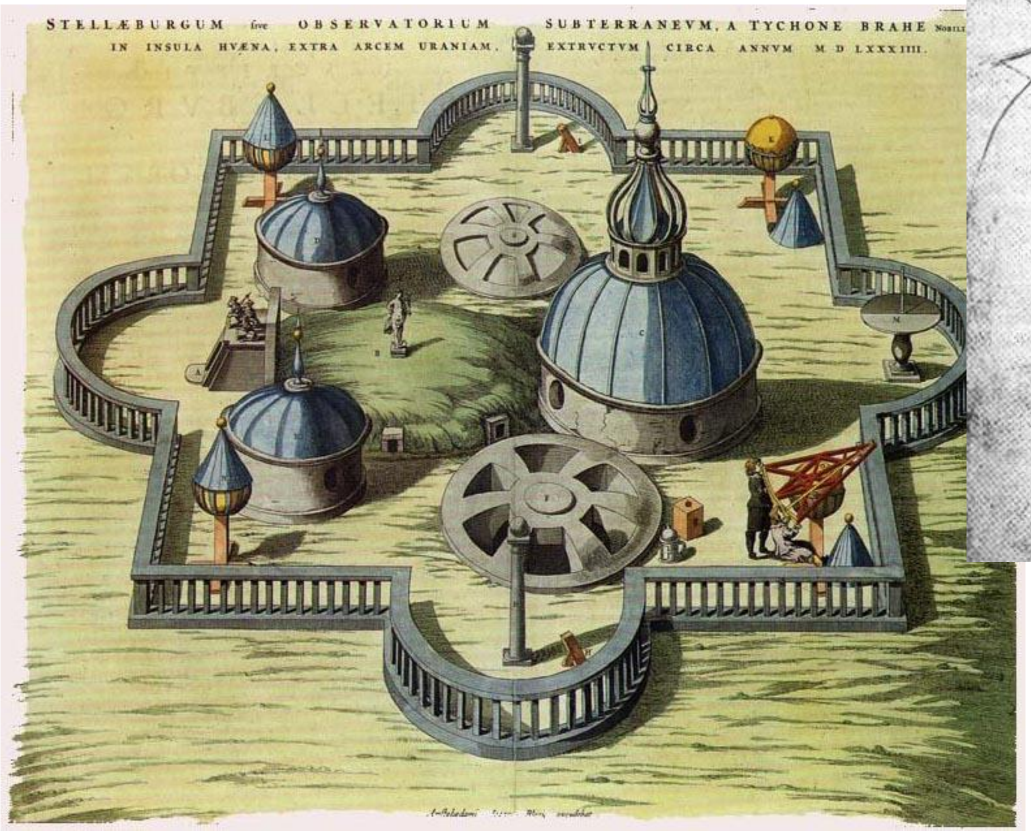
Outline

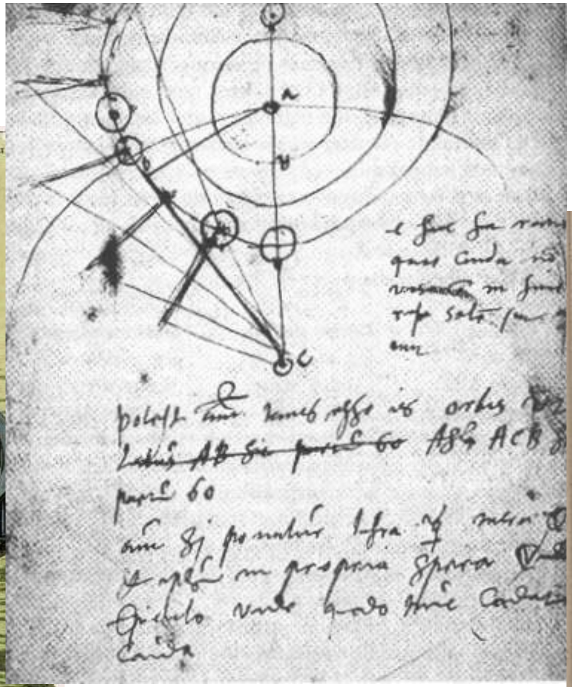
- Kepler’s Laws of Planetary Motion
- Newton’s Law of Universal Gravitation

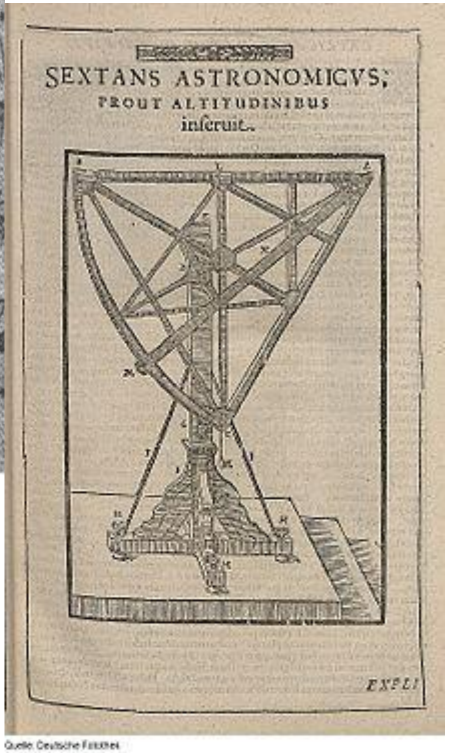
Kepler’s Laws of Planetary Motion

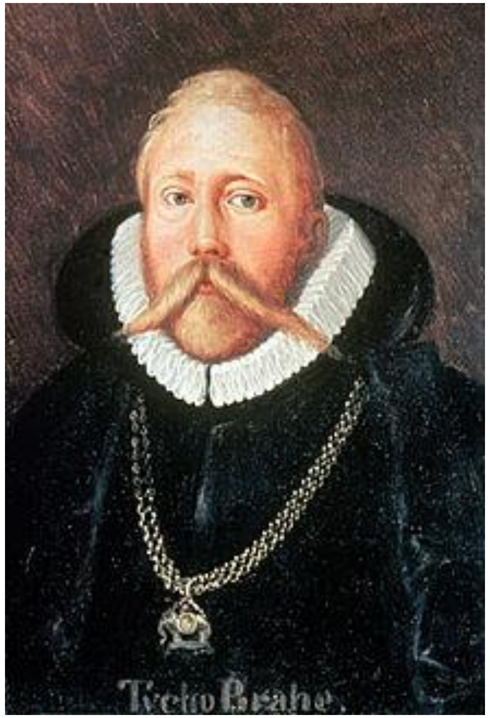
Tycho Brahe (1546-1601)*

- Danish nobleman known for his ***accurate and comprehensive astronomical and planetary observations***.







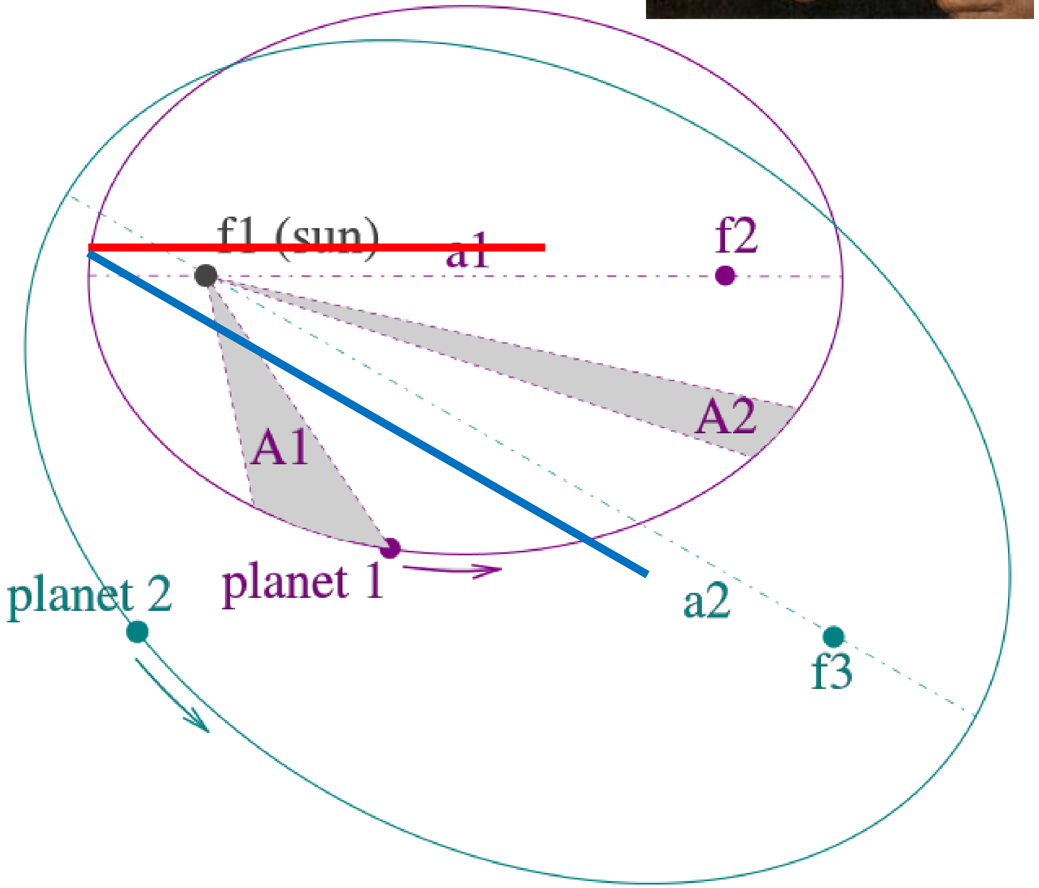


*** Based on Wikipedia.**

Johannes Kepler (1571-1630)*

- German mathematician, astronomer, and astrologer known for his ***laws of planetary motion***.
  1. The orbits are *ellipses*, and the Sun is placed in focal point f1.
  2. A1 and A2 have the same surface area, and the times for planet 1 to cover A1 and A2 are the same.
  3. The square of the *orbital period (T)* of a planet is proportional to the cube of the *semi-major axis of its orbit (a)*, i.e.,

$$\frac{T1^2}{a1^3} = \frac{T2^2}{a2^3} = constant$$

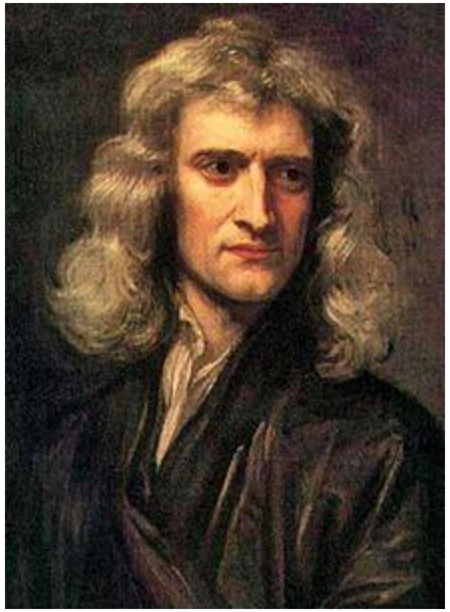


***** Based on Wikipedia*.**

Kepler’s Laws of Planetary Motion

Newton’s Law of Universal Gravitation

Isaac Newton (1642-1727)*

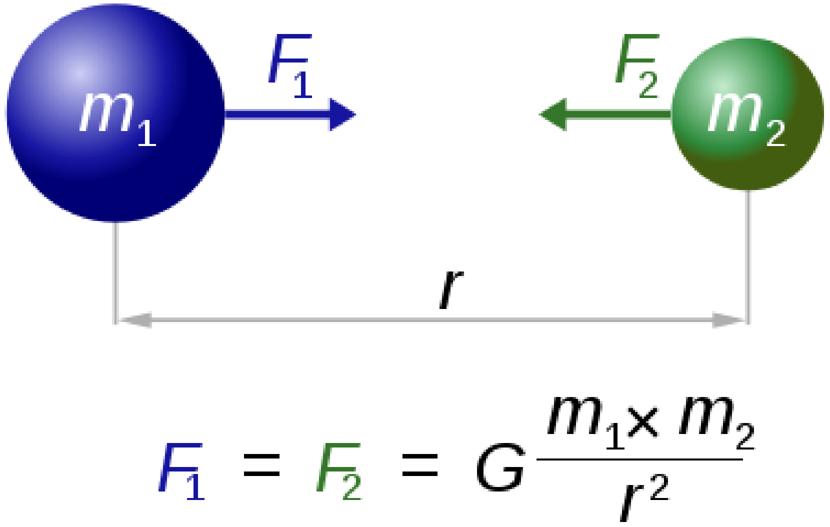


- English mathematician, astronomer, and physicist who is widely recognised as one of the most influential scientists of all time for his contributions to scientific revolution, including the following ***laws of motions (below)*** and ***law of universal gravitation***:
  1. **관성의 법칙**: In an inertial reference frame, an object either remains at rest or continues to move at a constant velocity, unless acted upon by a force.
  2. **가속도의 법칙**: In an inertial reference frame, the vector sum of the forces F on an object is equal to the mass m of that object multiplied by the acceleration a of the object: $\boldsymbol{F = ma}$.
  3. **작용/반작용의 법칙**: When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

****Based on Wikipedia.***

Newton's Law of Universal Gravitation*

$$F = G\frac{m_1 m_2}{r^2}$$



where:

- F is the force between the masses;
- G is the gravitational constant (6.674×10^{-11} N · (m/kg)^2);
- m_1 is the first mass;
- m_2 is the second mass;
- r is the distance between the centers of the masses.

**** Based on Wikipedia.***

Kepler's Laws of Planetary Motion and Newton's Law of Universal Gravitation*

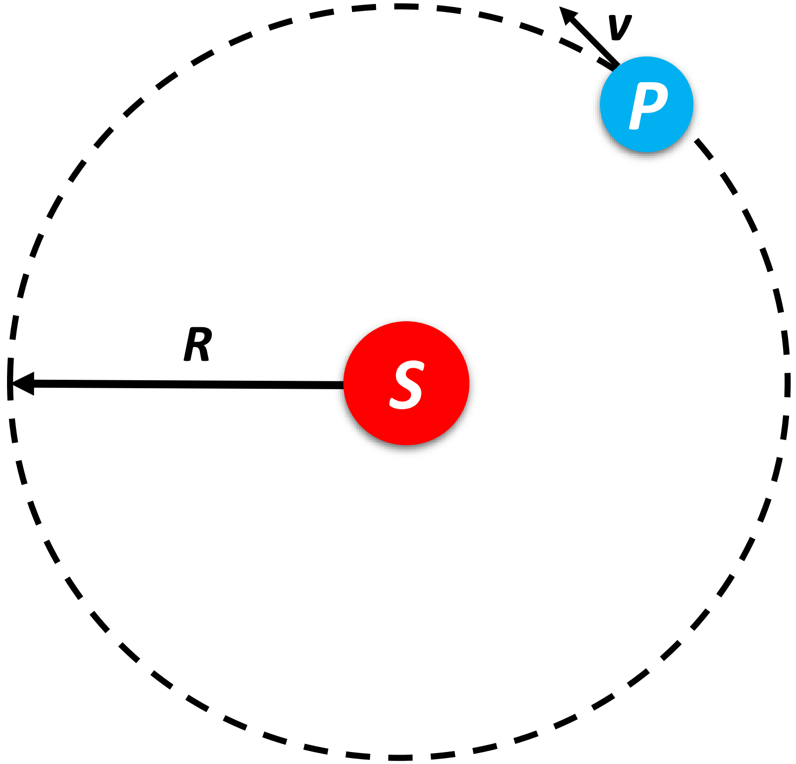
We consider a planet with mass M_{Planet} to orbit in *nearly circular motion* about the sun of mass M_{Sun}.

- Centripetal force (구심력):

$$\frac{M_{Planet} \times v^2}{R}$$

- Gravitational force (중력):

$$\frac{G \times M_{Planet} \times M_{Sun}}{R^2}$$



*** Based on the Physics Classrom.**

$$\frac{M_{Planet} \times v^2}{R} = \frac{G \times M_{Planet} \times M_{Sun}}{R^2}$$

Note that the velocity of the planet in a circular orbit is given by

$$v = \frac{distance}{time} = \frac{2\pi R}{T}$$

Therefore

$$\frac{M_{Planet} \times v^2}{R} = \frac{M_{Planet} \times \left(\frac{2\pi R}{T}\right)^2}{R} = \frac{M_{Planet} \times 4\pi R}{T^2}$$

$$= \frac{G \times M_{Planet} \times M_{Sun}}{R^2}$$

After simplification, we obtain

$$\frac{T^2}{R^3} = \frac{4\pi^2}{G \times M_{sun}} = constant$$