Cartesian Universe

- Descartes (1596-1650)
  - French philosopher, mathematician
  - Cartesian coordinate (x,y,z)
  - Mechanical world of matter and motion which obey natural laws
- The Cartesian universe is infinite and full of matter (no empty space allowed)
  - All motion was explained by direct contact (such as pressures and tensions).
  - Planetary motion was explained by vortical motions of interplanetary matter (or fluid).

Newtonian Universe

- Newton (1642-1726)
  - Laws of motion, laws of gravity
  - Differential and integral calculus
- The Newtonian universe is infinite, but the material world is finite.
  - Empty space (which is extended infinitely) is allowed (sprit lives in empty space)
- Correspondences with Robert Bentley in 1692-1693 have changed Newton's view of the universe
  - Betley pointed out that the material world cannot be finite; if it is, all matter will collapse into a single body
  - Matter evenly distributed over infinite space can exist without collapse (but this is a highly unstable configuration).
  - The material world was extended infinitely.

Laws of Motion

- Aristotelian picture
  - A body must be continuously pushed by forces in order to keep its motion (idea also adopted by Descartes).
  - *The role of resistance*: the bigger the resistance is, the bigger the applied forces must be.
    - Force = Resistance x Velocity
  - If this law is correct, no vacuum can exist because zero resistance means infinite velocity.
  - Proof of the existence of ether, and disproof of the existence of atoms.
- What was wrong?

Momentum

- No force is necessary to keep motion.
  - A body carries momentum, which keeps its motion.
  - Momentum of a body represents how hard it is to change its motion (speed and/or direction of motion)
  - Momentum = Mass x Velocity
  - Force = Rate of change in momentum
- Angular momentum represents how hard it is to change angular motion of a rotating object.
  - Angular momentum = Distance from the axis of rotation x Momentum
  - Torque = Rate of change in angular momentum
- Important fact: momentum conserves in the absence of force or torque.

Newton's laws of motion

- 1st law: *In the absence of a net force acting upon it, an object moves with constant velocity*
  - Momentum (= mass x velocity) of a body is constant in the absence of a net force.
- 2nd law: *Force = Rate of change in momentum*
  - Force = Mass x (Rate of change in velocity)
  - Force = Mass x Acceleration
- 3rd law: *for any force, there always is an equal and opposite reaction force*
  - Total momentum of all bodies is conserved even in the presence of forces.
  - Centrifugal force, weightless astronaut

Newton's law of gravity

- Gravitational force between two bodies is given by
  - Force = (Gravitational constant) x (Mass of object 1) x (Mass of object 2) divided by squared distance between two objects.
  - $F = G\ m\ M / r^2$
- Discovery of this law was made possible by Kepler's laws.
  - Conflict between Isaac Newton and Robert Hooke: "who did it first?"
  - "*If I have seen further, it is by standing on the shoulders of giants*." -- Isaac Newton

Kepler's laws explained by Newton

- Kepler's 1st law: *The orbit of each planet about the Sun is an ellipse with the Sun at one focus*
  - Natural orbits under the $1/r^2$ force (provided by the Sun) are ellipses, parabolas, and hyperbolas.
- Kepler's 2nd law: *As a planet moves around its orbit, it sweeps out equal areas in equal times*
  - Conservation of angular momentum (= m r v)
- Kepler's 3rd law: *More distant planets orbit the Sun at slower average speeds, obeying the following precise mathematical relation ship:* $P^2=R^3$
  - The $1/r^2$ force from the Sun balances the centrifugal force (Newton's 3rd law), giving this relationship.