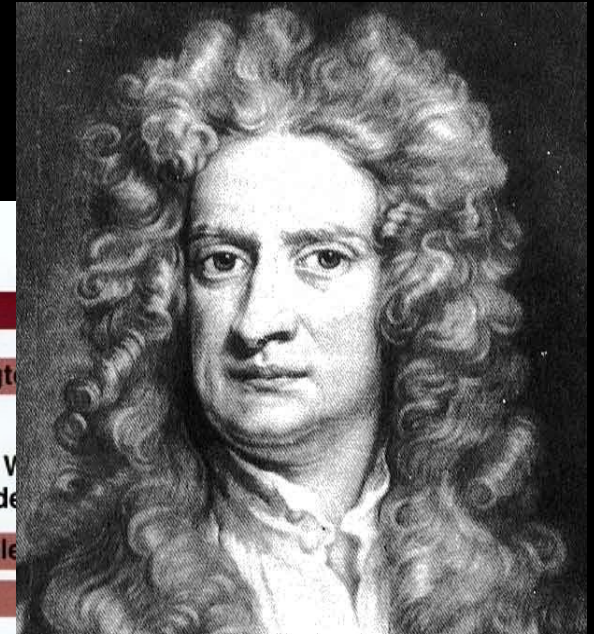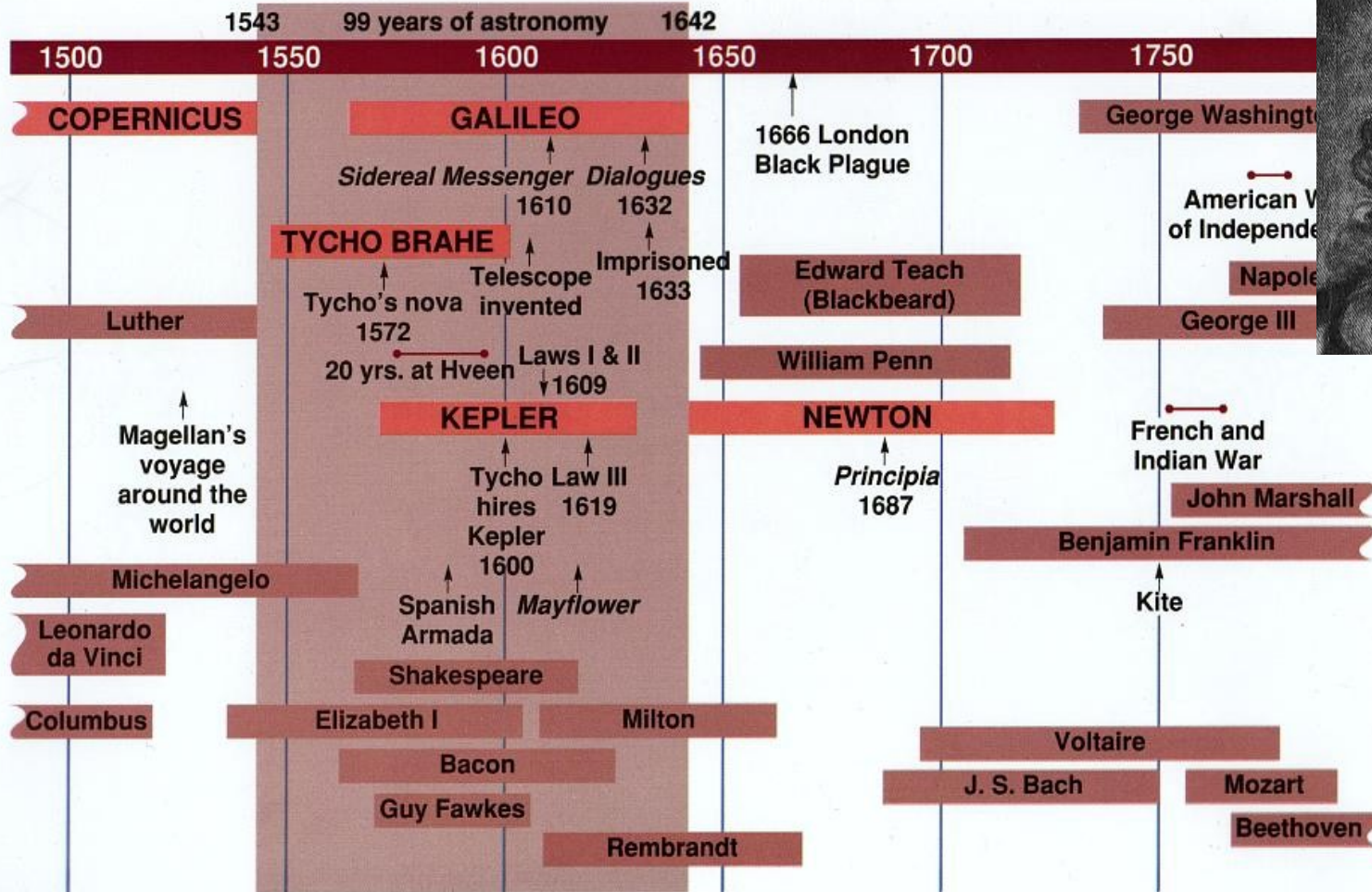# Newton's Laws of Motion

Newton's Laws of Motion: First Law

- Law of Inertia

  - An object at rest remains at rest unless acted upon by an outside force.

    - provides a qualitative definition of force.

    An object in motion will continue moving in a straight line at constant speed unless re-directed by an outside force.

Newton's Laws of Motion: Second Law

- Always referred to as the "Second Law"

  - Force = (mass) x (acceleration)   F = ma

  - Provides the quantitative relationship between quantities.

  - Rewrite as

$$a = \frac{F}{m}$$

  -- "mass" represents an objects resistance to being accelerated by a force.

  – given the same mass, larger forces yield greater acceleration

Newton's Laws of Motion: Third Law

- Action and re-action

  - Forces do not operate in isolation

  - A force exerted by one object upon another produces and equal and oppositely directed force upon the first object.

    - Throwing an object produces a force back upon the thrower.

    - The gravitational tug of the Earth on the Moon implies an equal and opposite tug back on the Earth. The Earth traces out a small ellipse of its own while the Moon goes around it.

Newton's Third Law and Rocketry

- Rockets work by throwing objects (gas atoms) out the back end at high speed.

- The force exerted on the atoms to throw them out produces a reaction force that propels the rocket in the opposite direction.

Newton's Third Law and Rocketry

- Rockets work by throwing objects (gas atoms) out the back end at high speed.

- The force exerted on the atoms to throw them out produces a reaction force that propels the rocket in the opposite direction.

  - Rockets do not push against anything except their own fuel.

  - They work equally well on the ground, in the atmosphere, and in the vacuum of space.

A Bit of History

- Misconceptions run deep...
  see the editorial on Robert
  Goddard's exploits in the New
  York Times – Jan 13, 1920

… That Professor Goddard with his "chair"
in Clark College and the countenancing of
the Smithsonian Institution, does not know
the relation of action and reaction, and of
the need to have something better than a
vacuum against which to react... Of course
he only seems to lack the knowledge
ladled out daily in high schools.

- The Times did issue a
  correction... July 17, 1969

Further investigation and experimentation have
confirmed the findings of Isaac Newton... and it is
now definitely established that a rocket can
function in a vacuum.   The Times regrets the
error...

NASA GSFC

Newton's Law of Gravitation

- The Moon does not move in a straight line at constant velocity. A force acts upon it.

- Newton realized that the force that causes, say, an apple to fall to the ground must be the same one that causes the Moon to follow a nearly circular path.

  - When you swing a ball on a string you feel a tug which is the force required to get the ball to follow its circular path.

  - Newton reasoned that if the force on the apple and on the Moon had the same cause then the force should be related to the masses of the objects involved and their separation:

$$Force = \frac{G\,(mass_A)\,(mass_B)}{(separation)^2}$$

Newton's Law of Gravitation

- In words...

  - every object with mass attracts every other object gravitationally.

  - the greater the product of the two masses the greater the force.

  - for any given pair of objects the force decreases with their separation squared.

    - move two objects 5 times further apart and the gravitational force between them will be 25 times weaker.

$$Force = \frac{G\,(mass_A)(mass_B)}{(separation)^2}$$

Newton's Law of Gravitation

- The Law of Gravitation combined with the Laws of Motion require that all orbits of objects around the Sun be "conic sections" - circle, ellipse, parabola, hyperbola

Orbital Equations
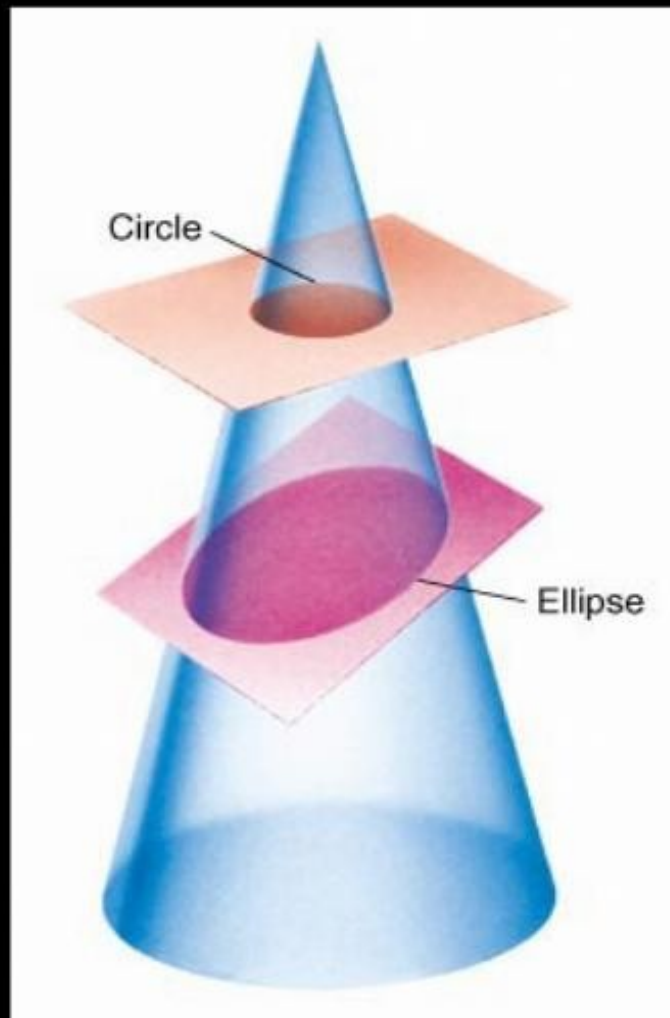
Mass vs. Weight

- The Second Law implicitly defines mass – the resistance an object has to being accelerated by a force.

  - The mass of an object is the same, no matter where it is in the Universe.

- The weight of an object is the force exerted on that object by gravity at a given instant.

  - An object has a different weight depending on its environment. For example, on the surface of the Moon a mass will weigh 1/6th of what it does on Earth.

$$acceleration = \frac{Force}{mass_{Object}}$$

$$Force = \frac{G\,(mass_A)(mass_B)}{(separation)^2}$$

LOSE WEIGHT
GUARANTEED!

Falling Objects

- Dating back to Aristotle, people believed that heavier objects fall faster than lighter ones – it just makes sense...

    - everday experience seems to reinforce this MISTAKEN assumption.

- The equations below, however, say that although gravity tugs more strongly on a more massive object, a more massive object is proportionally more difficult to accelerate.

    - the competing effects cancel – all objects fall at the same speed.

$$Force = \frac{G(mass_{Earth})(mass_{Object})}{(separation)^2}$$

$$acceleration = \frac{Force}{mass_{Object}}$$

¿

Falling Objects

- Galileo is famous for his experiments demonstrating this principle, although stories of him using the Tower of Pisa may be apocryphal.

    - In the end, air resistance causes lightweight low-density objects to fall more slowly than heavier ones.

Apollo 15