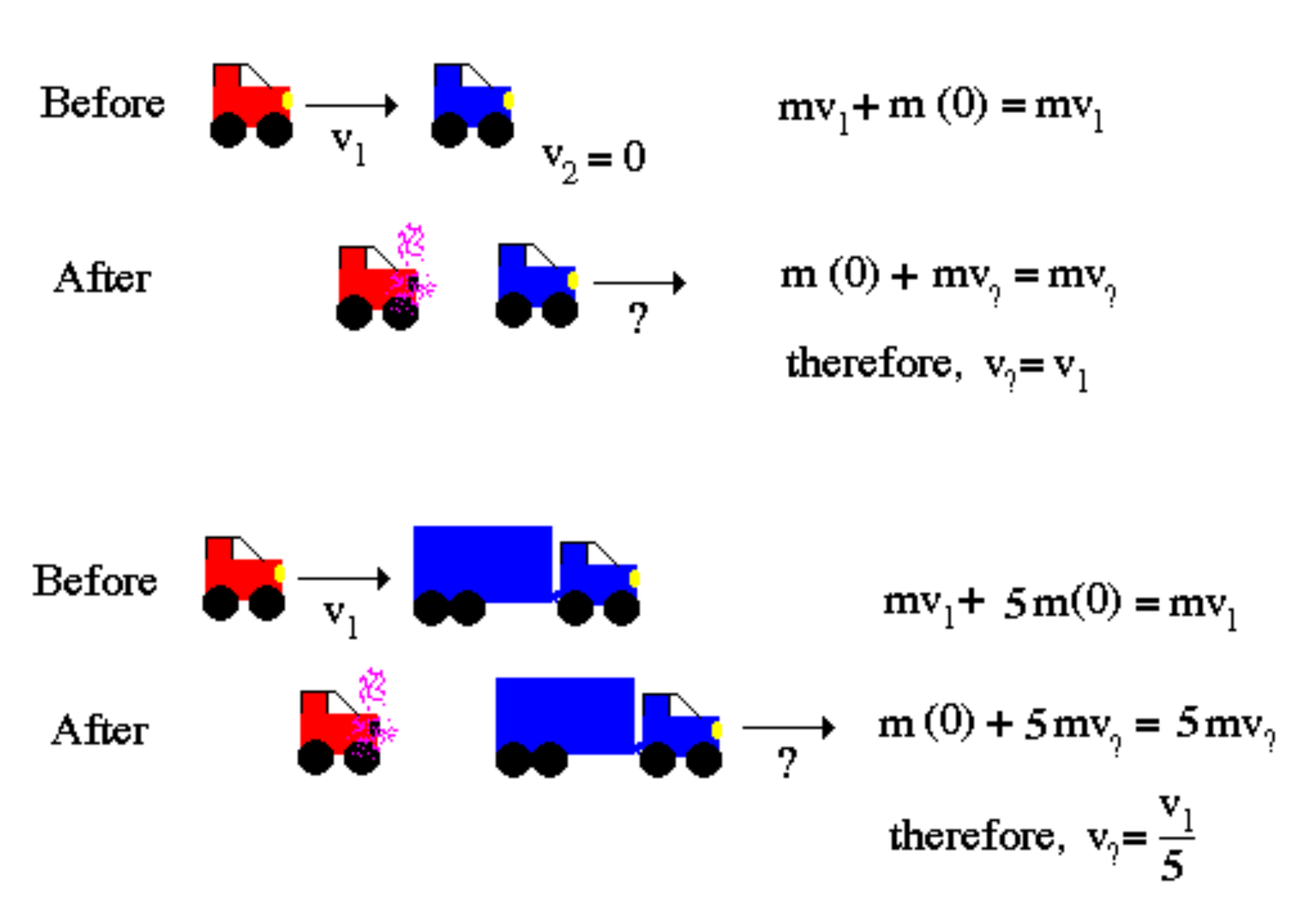
Newton expanded on the work of Galileo to better define the relationship between energy and motion. In particular, he developed the following concepts:

1) change in velocity = acceleration -> caused by force

2) inertia = resistance to change in velocity and is proportional to the mass of the object

3) momentum = quantity of motion energy and is equal to mass times velocity

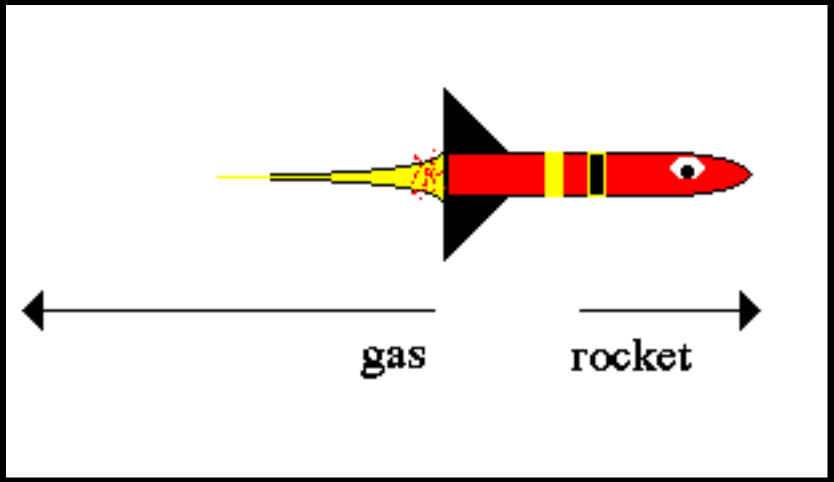
4) law of conservation of momentum = total momentum (mass x velocity) of an interaction is conserved -> is the same before and after



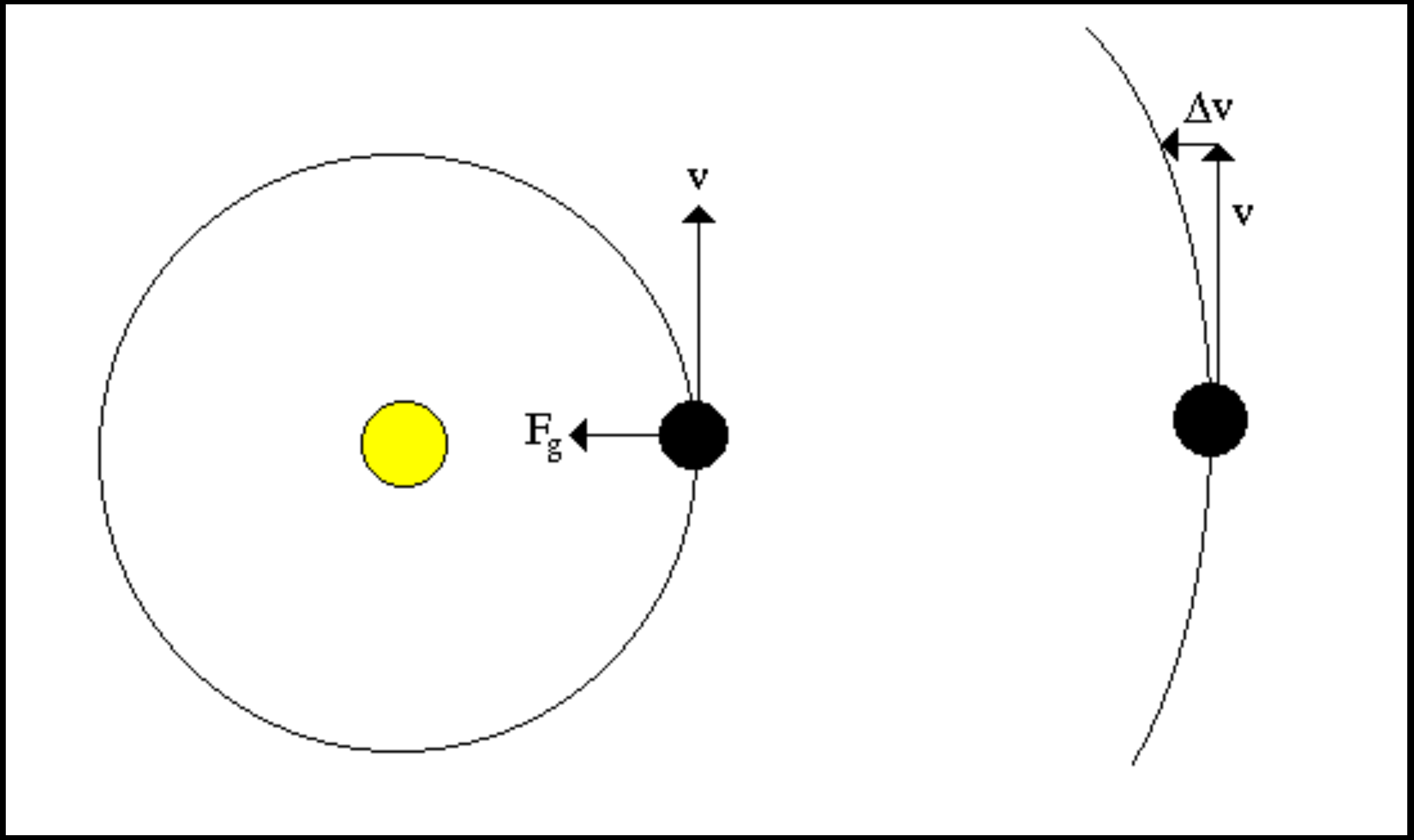
Newton's laws of motion:

1st law: a body remains at rest or moves in a straight line of constant velocity as long as no external forces acts on it

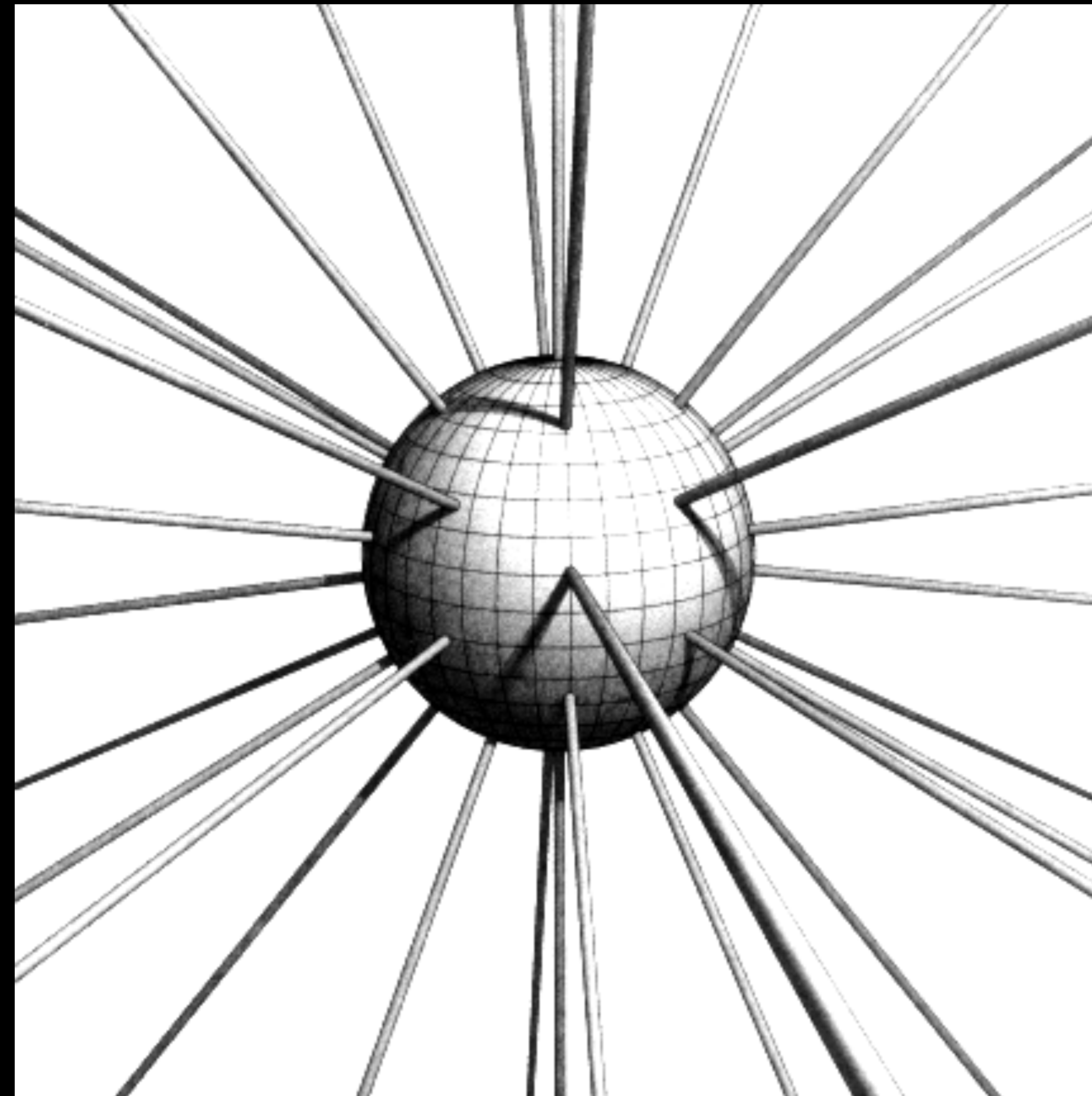
2nd law: a body acted on by a force will accelerate such that force equals mass times acceleration (F=ma)



3rd law: for every action there is an equal and opposite reaction



Newton's 1st law states that an object travels in a straight line unless acted upon by an external force. A circular orbit is clearly not a straight line, what is the force? Newton showed that the planets are acted on by the force of gravity arising from the Sun. Each orbit is a constantly changing velocity where gravity adds a small ``delta-vee'' at each moment. This ``delta-vee'' is what produces the elliptical curvature that is the orbit.



Newton's Law of Universal Gravitation

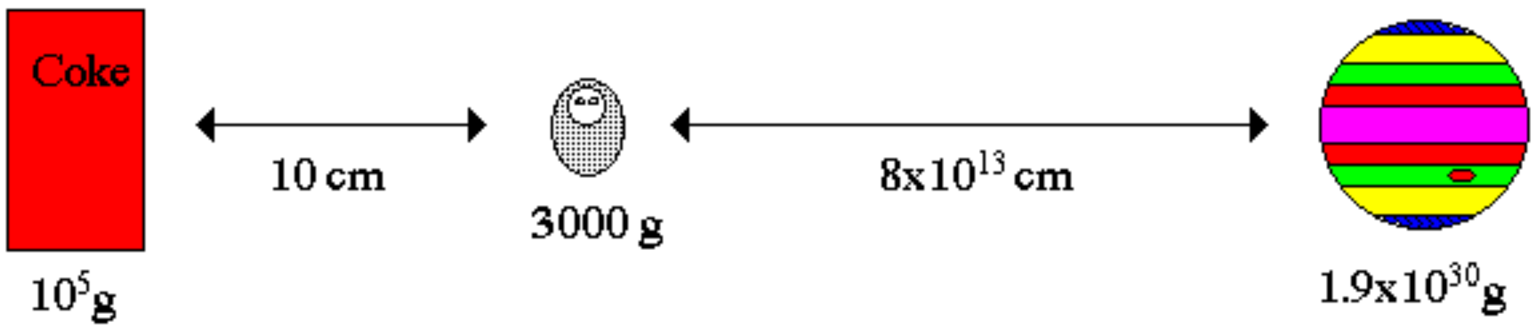
The force of gravity, F_g, is given by

$$F_g = \frac{G\, m_1 m_2}{R^2}$$

where,

G = gravitational constant = 6.668×10^{-8} dynes $cm^2\, g^{-2}$
m_1 = mass of object #1
m_2 = mass of object #2
R = distance between the objects

Example: what is the force of gravity from Jupiter on you at birth compared to the force of gravity from a nearby Coke machine?



$$F_{Coke} = \frac{G(10^5 g)(3000 g)}{(10\ cm)^2} = 2x10^{-1}\ dynes$$

$$F_{Jupiter} = \frac{G(1.9x10^{30} g)(3000 g)}{(8x10^{13}\ cm)^2} = 5.9x10^{-2}\ dynes$$

therefore, the force of gravity from the Coke machine is about 3 times more than the force of gravity from Jupiter.

kinematic description of the Solar System (Kepler)

+

dynamic description of the Solar System (Newton)

↓

development of celestial mechanics

↓

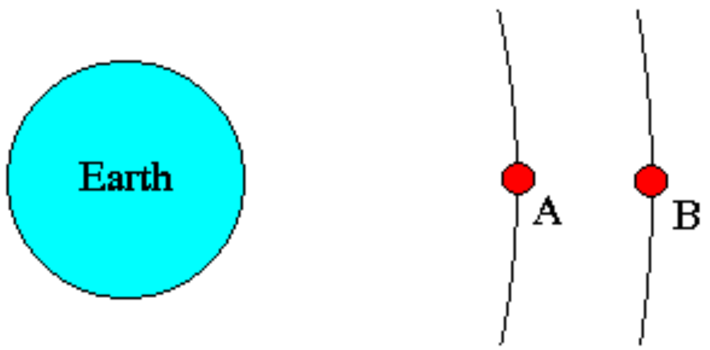
1650's to 1700's –> improvements in the telescope = more precise measurements of planet positions = more accurate tests to theory of gravity

↓

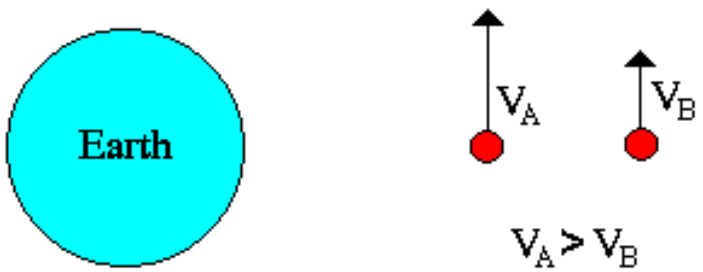
1780 –> Herschel accidentally discovers Uranus (new planet to test theory)

↓

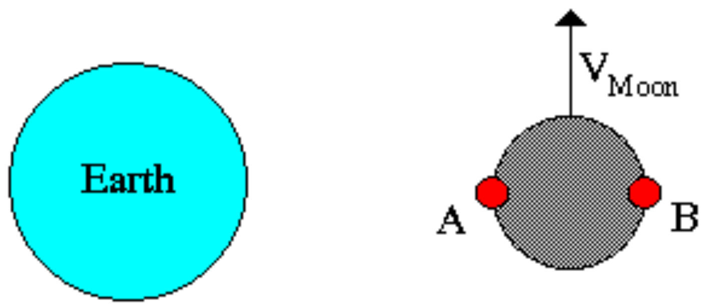
1845 –> perturbations in Uranus orbit used to predict the position of a new planet by Adam/Leverrier = Nepture (crowning achievement for celestial mechanics) consider two identical masses, A and B, in orbit around the Earth



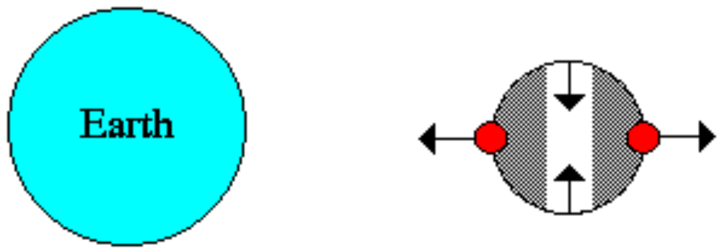
the force of gravity is greater on A than B (R is smaller for A)
thus, the orbital velocity of A is greater than B (see also Kepler's 3rd law)

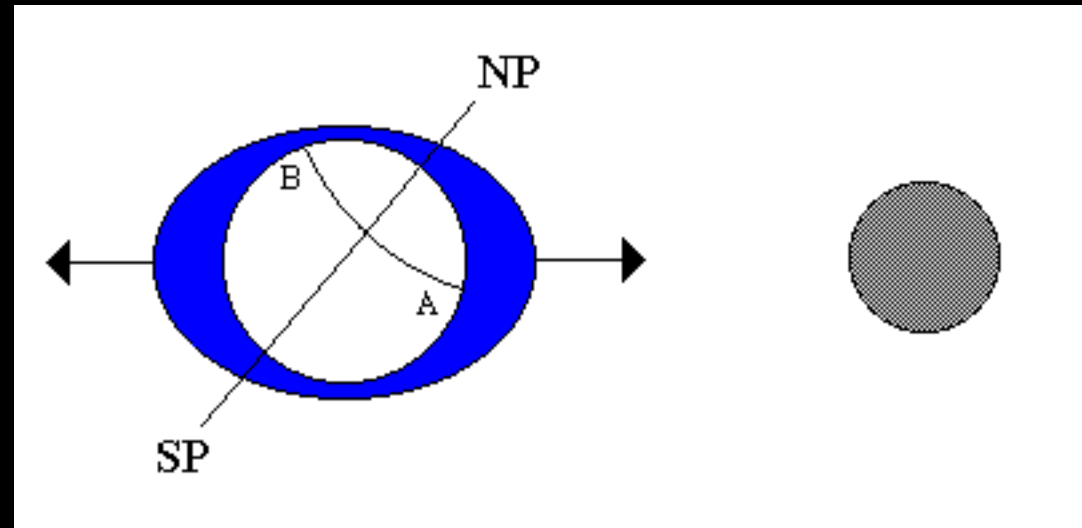


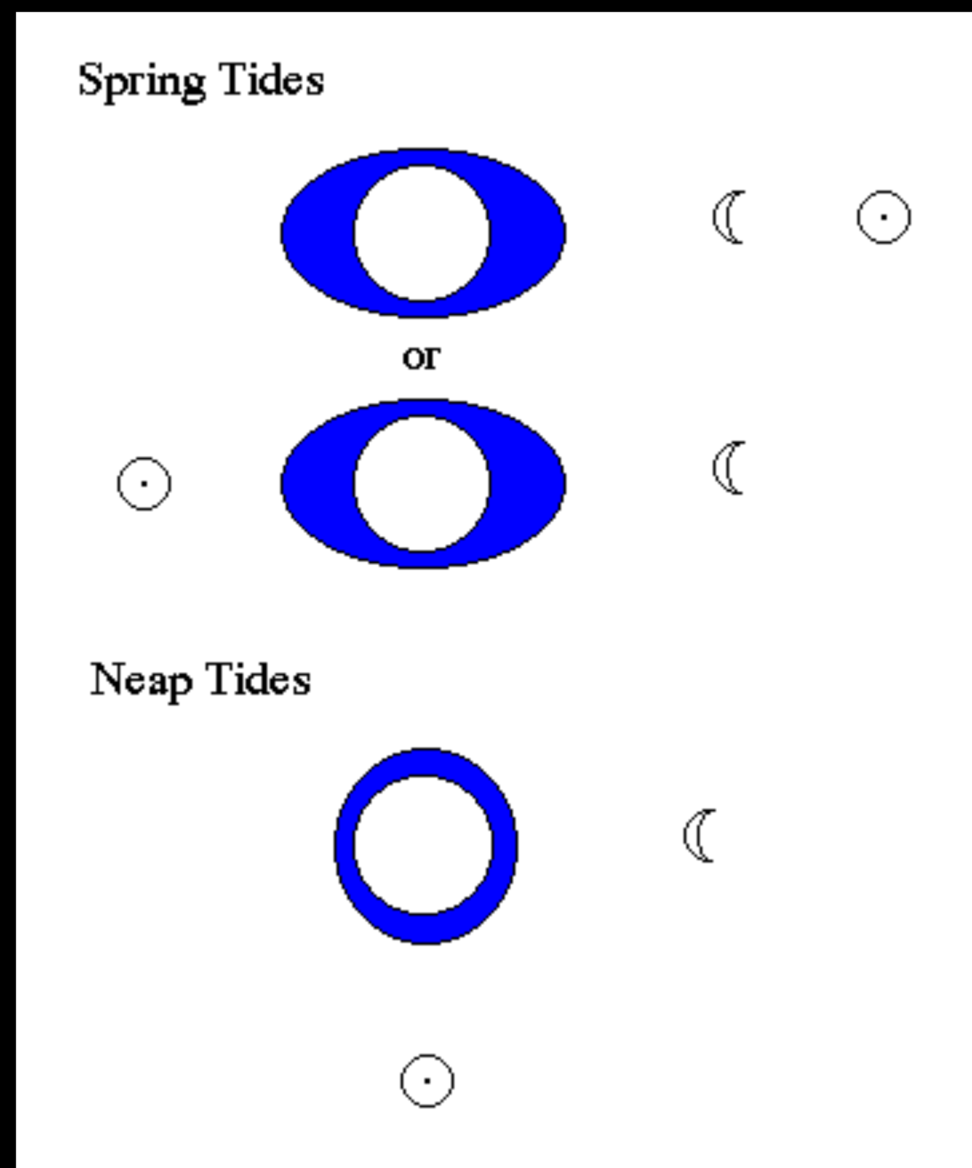
now consider these same two masses on the surface of the moon



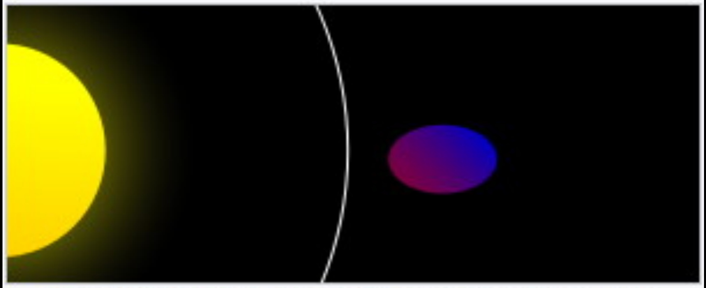
note that A would normally move at velocity V_A, which is greater than V_{Moon} and B would move a V_B, which is less than V_{Moon}. Thus, the result is a differential force on A and B as shown below
-> this is the origin of tides



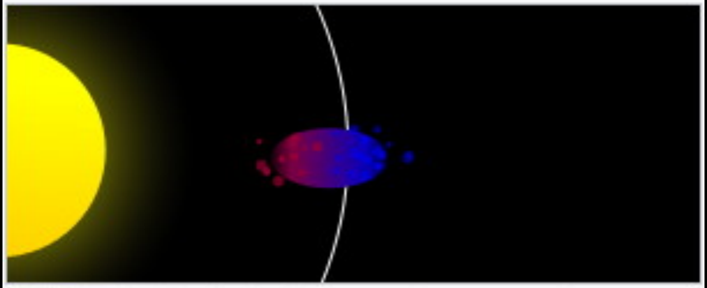

NP
B
A
SP


Spring Tides
or
Neap Tides

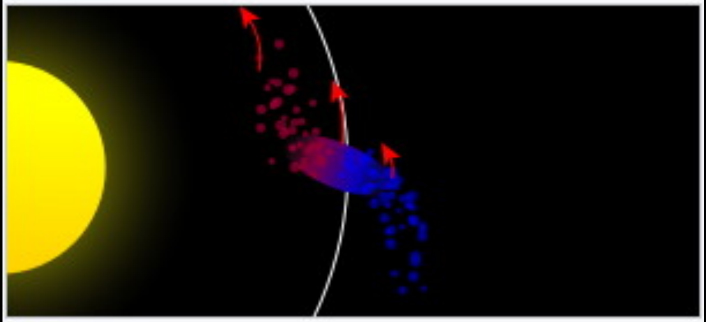
An orbiting mass of fluid held together by gravity, here viewed from above the orbital plane. Far from the Roche limit the mass is practically spherical.



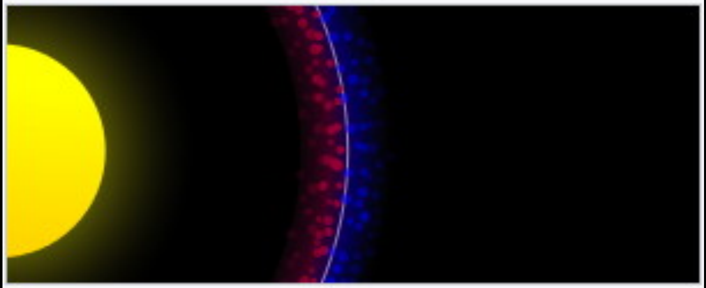
Closer to the Roche limit the body is deformed by tidal forces.



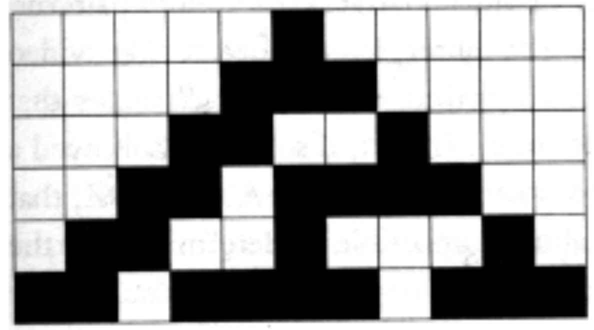
Within the Roche limit the mass's own gravity can no longer withstand the tidal forces, and the body disintegrates.



Particles closer to the primary move more quickly than particles farther away, as represented by the red arrows.



The varying orbital speed of the material eventually causes it to form a ring.



5 generations

The growth of a two-state (on or off) one-dimensional cellular automaton. The row of eight boxes on top shows the rule set: for each combination of three cells in generation 0, there is a determined result for the next-generation cell below the triplet. Beginning from a single seed, these rules are applied consistently, each generation represented by a horizontal row of cells. The first image shows five generations of growth, the second image shows fifty, and the third shows 100 generations, by which time it is clear that simple rules have generated considerable complexity.

50 generations

100 generations

A comparison between the natural pattern on a mollusk shell and the pattern of a simple one-dimensional cellular automaton.