Lecture: October 4, 2010

- Estimation: Challenge Me

Announcements:

No, I haven’t graded them yet.

Next Observatory Opportunity: Wednesday October 6

Problem Set 3 posted

Newton's Laws of Motion

1 A body at rest or in motion at a constant speed along a straight line remains in that state of rest or motion unless acted upon by an outside force.

Newton’s Laws of Motion

2 The change in a body’s velocity due to an applied force is in the same direction as the force and proportional to it, but is inversely proportional to the body’s mass.

$$F = m\,a$$

Newton’s Laws of Motion

3 For every applied force, a force of equal size but opposite direction arises.

Newton's Laws of Motion

A baseball accelerates as the pitcher applies a force by moving his arm. (Once released, this force and acceleration cease, so the ball's path changes only due to gravity and effects of air resistance.)

A spaceship needs no fuel to keep moving in space.

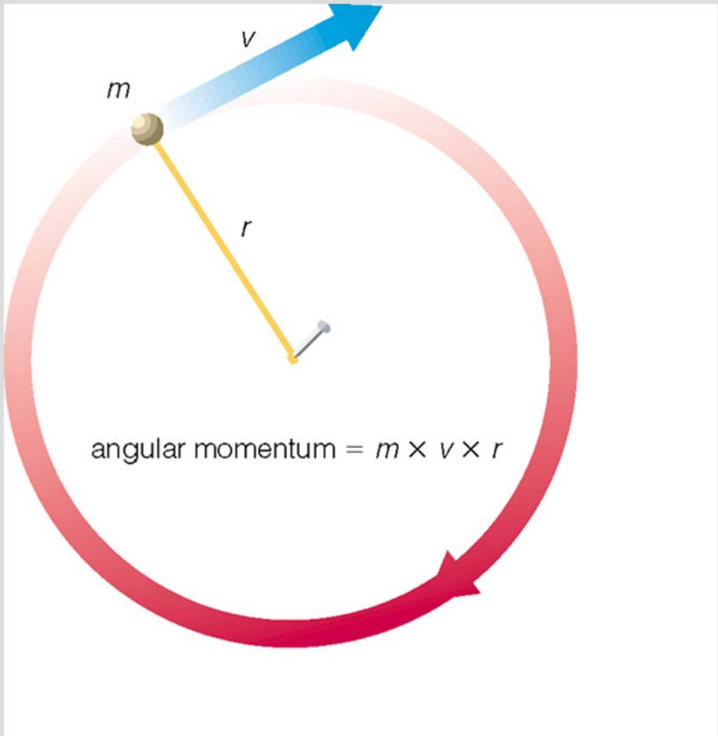
A rocket is propelled upward by a force equal and opposite to the force with which gas is expelled out its back.

Conservation of Momentum

- Like energy, the total amount of momentum in the Universe is conserved and does not change.

Angular Momentum

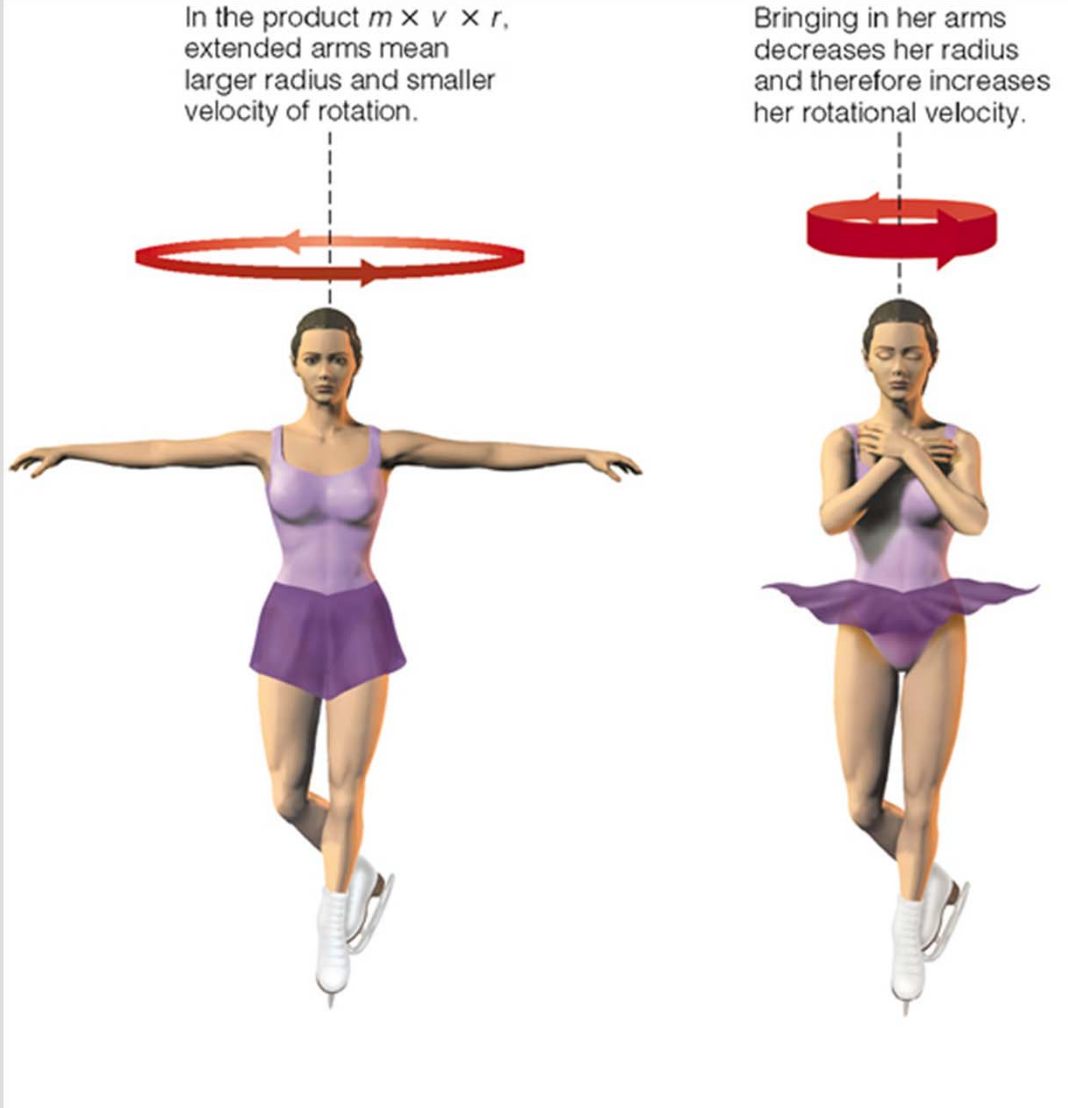
- **angular momentum** – the momentum involved in spinning /circling = mass x velocity x radius
- **torque** – anything that can cause a change in an object's angular momentum (*twisting force*)



$$p = mv$$

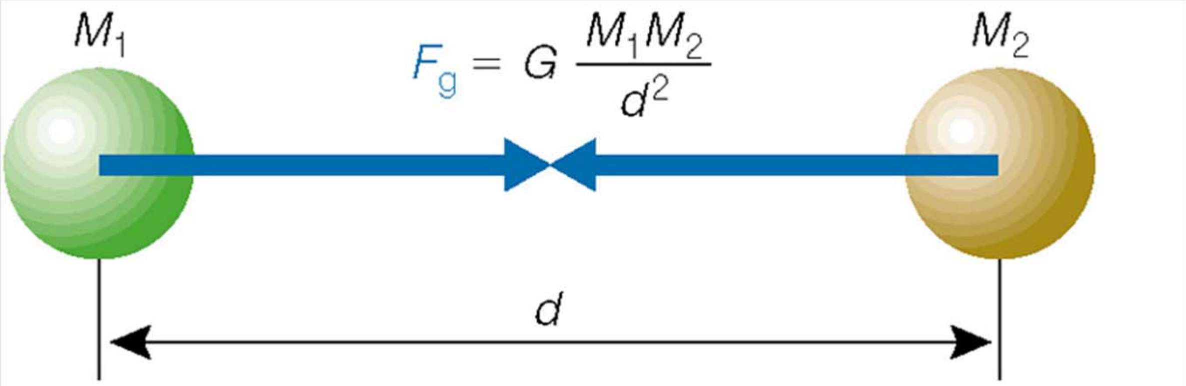
Conservation of Angular Momentum

- In the absence of a net torque, the total angular momentum of a system remains constant.



Universal Law of Gravitation

Between every two objects there is an attractive force, the magnitude of which is directly proportional to the mass of each object and inversely proportional to the square of the distance between the centers of the objects (inverse square law).



Gravity

$$F = \frac{GMm}{r^2} \qquad E_{pot} = \frac{GMm}{r}$$

$G=6.7\times10^{-11}$ (in mks)

Where did the value of G come from?

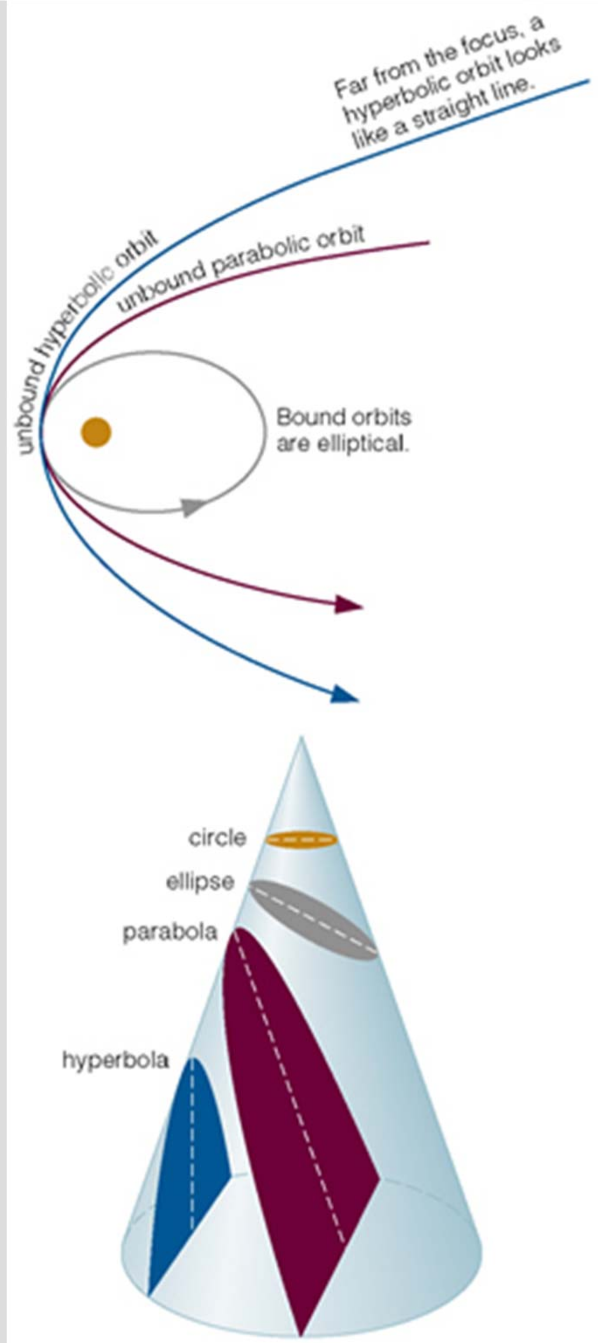
Surface Gravity

$$\text{ma}= \frac{GMm}{r^2}$$

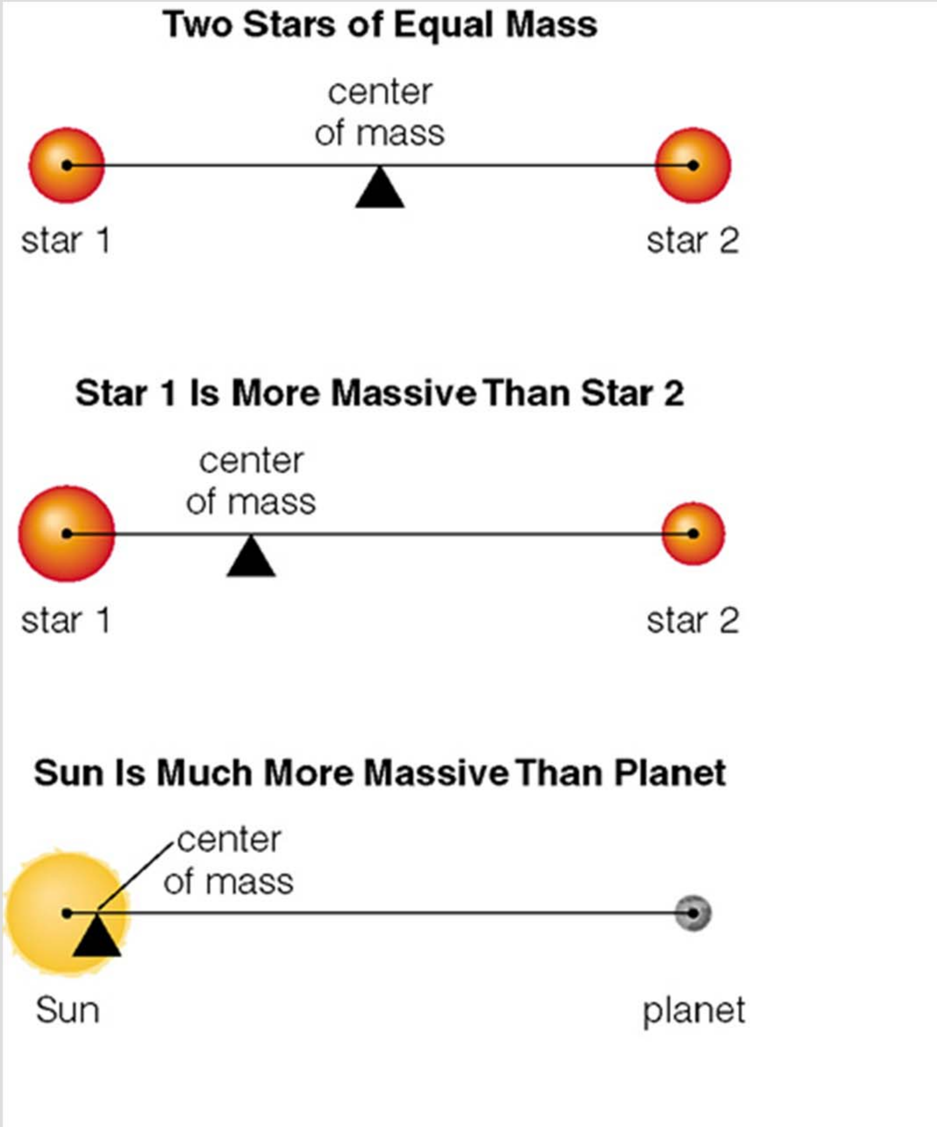
$$a = \frac{GM}{r^2} = \frac{6.7x10^{-11}x6.0x10^{24}}{(6.4x10^6)^2}$$

Orbital Paths

- Both objects in an orbital system follow ellipses with the center of mass (balance point) at one focus.
- Extending Kepler's Law #1, Newton found that ellipses were not the only orbital paths.
- possible orbital paths
  - ellipse (bound)
  - parabola (unbound)
  - hyperbola (unbound)



Centers of mass



Newton’s Version of Kepler’s Third Law

Using the calculus, Newton was able to derive Kepler’s Third Law from his own Law of Gravity.

In its most general form:

$$P^2 = 4\pi^2 a^3 / G (m_1 + m_2)$$

If you can measure the orbital period of two objects (P) and the distance between them (a), then you can calculate the sum of the masses of both objects ($m_1 + m_2$).

Orbits

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$v = \sqrt{\frac{GM}{r}}$$

$$P = \frac{2\pi r}{v} = 2\pi\sqrt{\frac{r^3}{GM}}$$

Kepler’s Third!

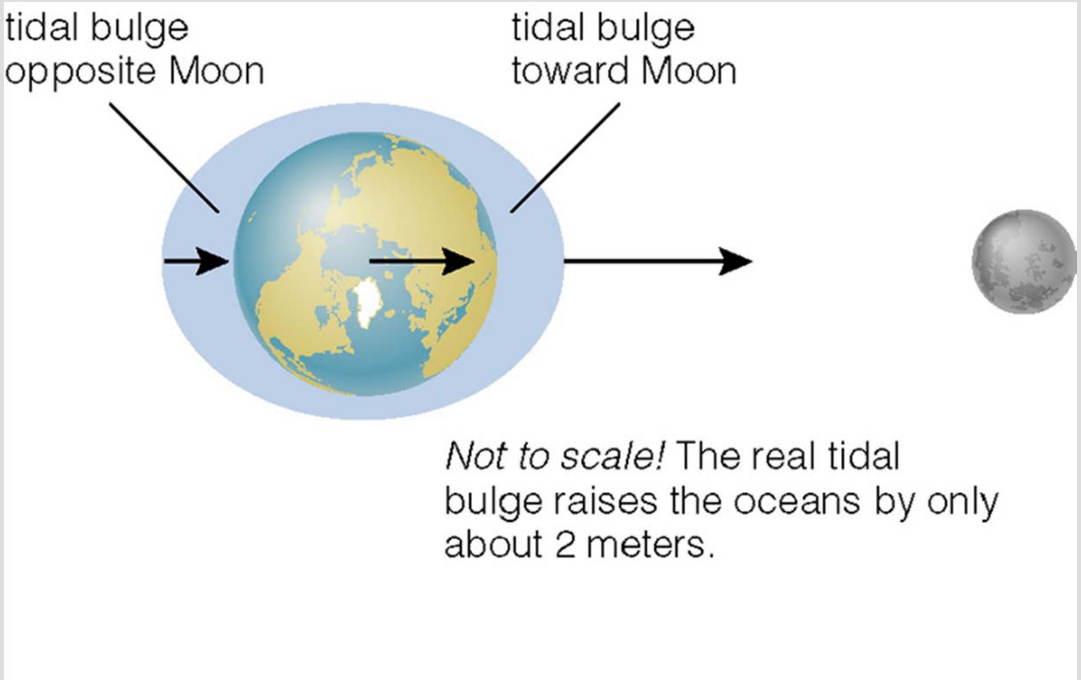
$$P^2 = \frac{4\pi^2}{GM}a^3$$

Escape Velocity

$$\frac{1}{2}mv^2 = \frac{GMm}{R}$$

$$v = \sqrt{\frac{2GM}{R}}$$

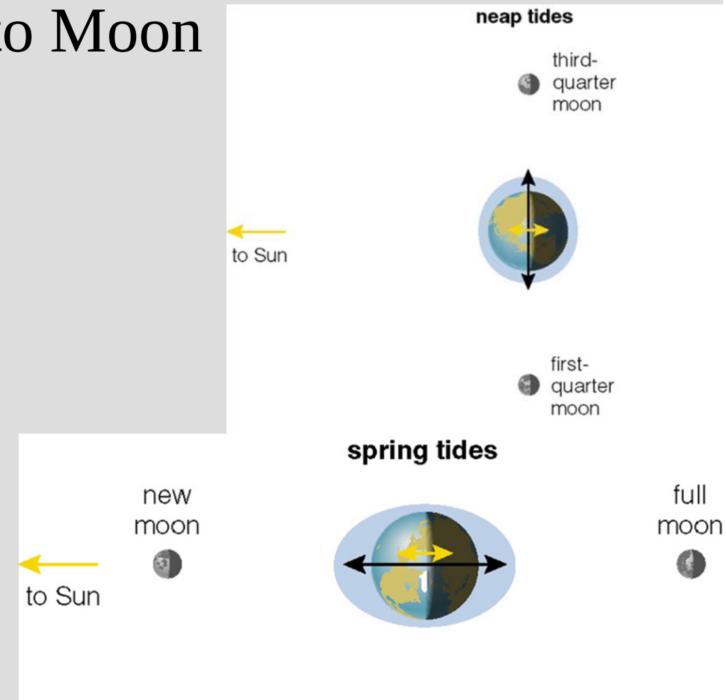
Tides



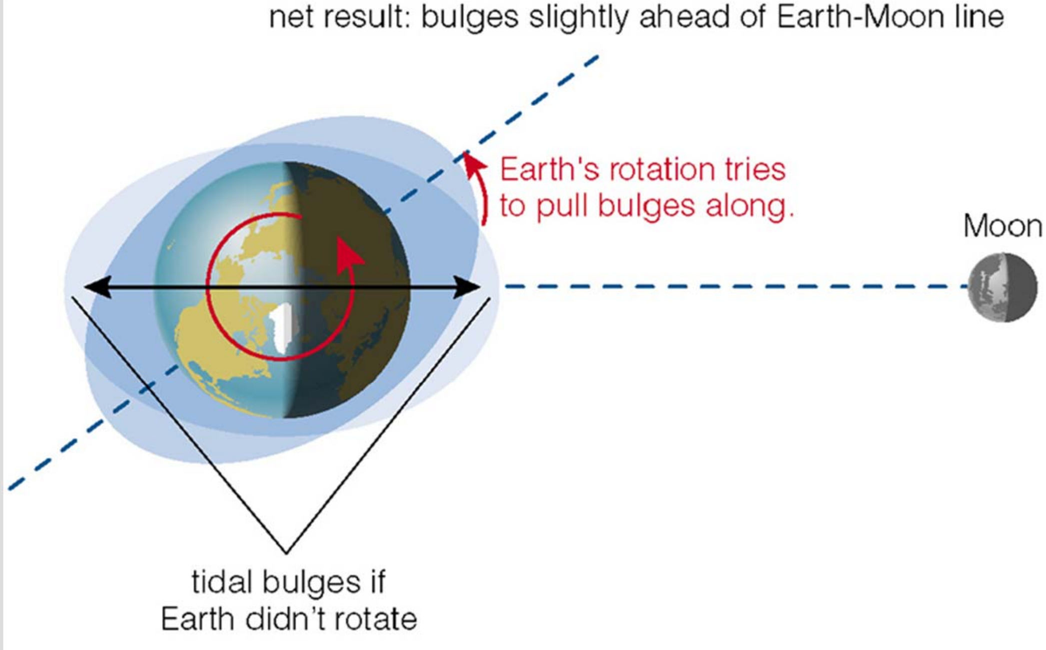
- Since gravitational force decreases with (distance)^2, the Moon’s pull on Earth is strongest on the side facing the Moon, and weakest on the opposite side.
- The Earth gets stretched along the Earth-Moon line.
- The oceans rise relative to land at these points.

Tides

- Every place on Earth passes through these points, called **high tides**, twice per day as the Earth rotates.
- High tides occur every 12 hours 25minutes
  - remember, the Moon moves!
- The Sun's tidal effect on Earth is not as strong.
  - the ratio Earth's diameter : distance to Sun is much less than ratio Earth's diameter : distance to Moon
- When the Sun & Moon pull in the same direction (new & full phases)
  - high tide is higher than usual (**spring**)
- When the Sun & Moon pull at right angles (first & last quarter phases)
  - high tide is lower than usual (**neap**)



Tidal Friction



- This fight between Moon's pull & Earth's rotation causes friction.
- Earth's rotation slows down (1 sec every 50,000 yrs.)
- Conservation of angular momentum causes the Moon to move farther away from Earth.

Synchronous Rotation

- …is when the rotation period of a moon, planet, or star equals its orbital period about another object.
- Tidal friction on the Moon (caused by Earth) has slowed its rotation down to a period of one month.
- The Moon now rotates synchronously.
  - We always see the same side of the Moon.
- Tidal friction on the Moon has ceased since its tidal bulges are always aligned with Earth.

Changing Orbits

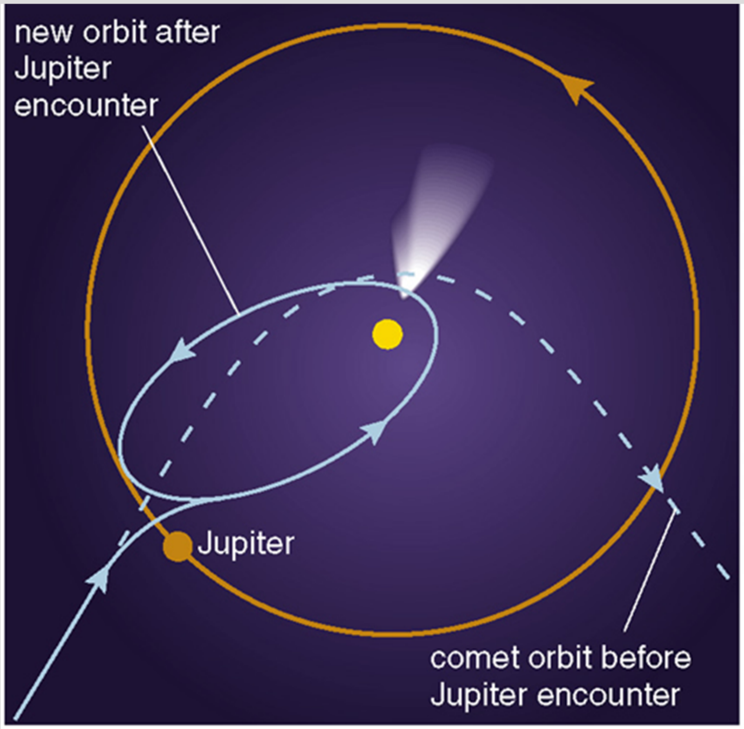
orbital energy = kinetic energy + gravitational potential energy

conservation of energy implies:

orbits can't change spontaneously

An object can't crash into a planet unless its orbit takes it there.

An orbit can only change if it gains/loses energy from another object, such as a gravitational encounter:



If an object gains enough energy so that its new orbit is unbound, we say that it has reached **escape velocity**.