Physics and Astronomy 5 Fall 2009

# Cosmology Notes: Lecture 11

$$F_g = GMm/r^2$$

Where $M$ and $m$ are the masses of the two objects which have a mutual, attractive gravitational force, $F_g$. The two objects are separated by a distance $r$, measured from their centers. For spherical objects, gravity acts as if all the mass were concentrated at a point at their centers.

The concept of force, $F$, can be defined operationally as that which produces an acceleration according to Newton's second law:

$$F=ma$$

Colloquially, you can think of a force as a push or a pull

Note that the two masses, $m$, in the two equations have very different conceptual standing: In Newton's second law, the mass, $m$, represents a *sluggishness;* a resistance to being pushed or to having its momentum changed. It is *inertial* mass, $m_i$. In the gravitational law, though, the mass, $m$, is an interaction strength. It's completely analogous to charge, $q$, with respect to the electric force. This *gravitational* mass, $m_g$, dictates how strong the gravitational interaction will be with another massive object.

The equivalence of $m_i$ and $m_g$ is why all objects fall with the same acceleration due to gravity (on the surface of the Earth or of the Moon, say).

Comparing gravity on the surface of the Earth (r ~ 3200 km, measured from the center of the Earth) to gravity in low-earth orbit (on the space shuttle, 300 km above the Earth's surface, r ~ 3500 km), we find that it's only reduced by 16% in orbit. Why are astronauts "weightless"? …They are in free-fall!

The astronaut floating in the space shuttle is like the sphere at the center of a first-law detector. …Free-fall is a truly inertial reference frame!

Einstein's *equivalence principle* – the basis of general relativity:

***The effects of gravity and acceleration are indistinguishable.***

Stop thinking of gravity as a force.