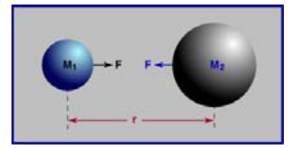
Today

- Announcements:
  - HW#2 is due Wednesday Sept. 20th by 8:00 am; HW#3 is due Wednesday Sept. 27th by 8:00 am.
  - Extra Credit project #1 in on the LONCAPA website; due Sept 16. See the lecture on Sept. 1 for an explanation. Length should be about 1 paragraph. An excellent description will get 4 points.
  - I will be away next week, but hopefully you won't notice.
- Gravity
- General Relativity

Newton's Universal Law of Gravity

Newton's Universal Law of Gravity:

$$F = \frac{Gm_1 m_2}{r^2};\ G = 6.673E-11\ {Nm^2}/{kg^2}$$



The Law of Gravity

What is the force of gravity on a 90 kg professor standing on the surface of the Earth?

$$F = \frac{Gm_e m_p}{r_e^2} = \frac{\left(6.673E-11\ {Nm^2}/{kg^2}\right) 90kg \times 5.974E24\,kg}{(6.378E6\ m)^2} = 882\ N$$

Note: We get the same answer if we ask what is the force a professor exerts on the Earth.

Clicker Questions

What is the force of gravity on a 90 kg astronaut in orbit, 300 km above the Earth? Choose the best answer:

A). Nearly 0 N

B). 800 N

C). 200 N

D). 200,000 N

Force of gravity on an astronaut

What is the force if the 90 kg professor is in the space shuttle at 300 km above the Earth?

$$300km = 300km \times \frac{1000m}{km} = 3.00E5\,m$$

$$F = \frac{Gm_e m_p}{r_e^2} = \frac{\left(6.673E-11\,{}^{Nm^2}\!/_{kg^2}\right)90kg \times 5.974E24\,kg}{\left(6.378E6\,m + 3.00E5\,m\right)^2} = 804\,N$$

r_e + r_{orbit}

Clicker Questions

Why is an astronaut in orbit weightless?

A). Because they are always in free fall, but constantly miss the Earth.

B). Because gravity from the Earth and moon cancels.

C). Because gravity from the Earth and Sun cancels.

D). Because there is no gravity in space.

More on Gravity

On the surface of the Earth:

$$F = \frac{Gm_e m}{r_e^2} = \left(\frac{Gm_e}{r_e^2}\right)m = gm$$

$$G = 6.673E-11\,{}^{Nm^2}\!/_{kg^2}$$

$$g = 9.81\,{}^{m}\!/_{s^2}$$

All objects fall at the same rate

- $F_{Gravity}$ = mg (the mass and radius of Earth are in the g)
- Also F = ma = mg
- Therefore, neglecting other forces

g = a

- Examples
- Why is the m in ma the same as the m in mg?

Newtonian View of the Universe

- Loss of free will
- French Scientist/Mathematician Pierre-Simon Laplace (1749-1827)

"An intelligence which at a given instant knew all the forces acting in nature and the positions of every object in the universe - if endowed with a brain sufficiently vast to make all the necessary calculations – could describe with a single formula the motions of the largest astronomical bodies and those of the lightest atoms. To such an intelligence, nothing would be uncertain; the future, like the past, would be an open book."

Energy – The ability to do work

- Work done on or done by an object: **Work = force x distance** (units N*m)
- The SI unit of energy is Joules (J)
- Work (and energy) are scalars
- There are two kinds of energy
  - Energy of position – potential energy
  - Energy of motion – kinetic energy
- Other types of energy; thermal, chemical, etc. are special cases of kinetic and potential
- Power is the rate of chance of energy: **Power = work/time**
  - Unit is Watts (W)
  - 1 horsepower (hp) = 760 W

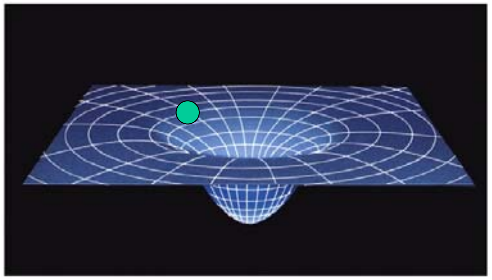
General Relativity

- Why is gravitational mass (mg) the same as inertial mass (ma)?
- This is one of the questions Einstein worked on; his answer is General Relativity.
- Recall – Special Relativity was for non-accelerating frames of reference.

General Relativity continued

- Main Postulate: Acceleration in one direction is like gravity in the other direction. It is not possible distinguish the two. This is called the principle of equivalence.
- Mass warps space
- Space and times are combined into a 4-dimensional space-time

Pictorial



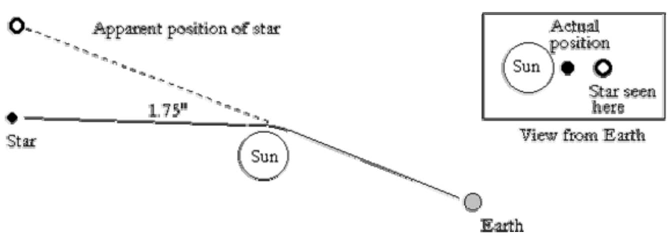
Gravity is actually the result of warped space.

Gravitational Time Dilation

- Mass stretches space, but since space and time are connected (space-time) it also affects time.
- Near a mass, time runs more slowly. On the surface of the Earth this affect is only 10^{-9} s, but near a black hole it could be infinite.
- Why? As you travel through space you travel through time. Where space is stretched, time is compacted.
- Metric equation: $(\Delta s)^2 = (\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2 - (c\Delta t)^2$

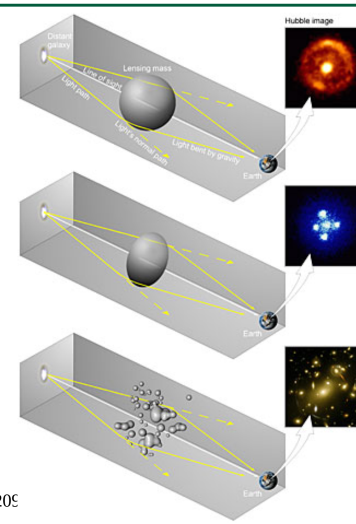
Proof of General Relativity I

- Bending of star light – the gravitational field of the Sun bends star light by 1.75 arcseconds. This was observed by A. Eddington in 1919 during an eclipse.

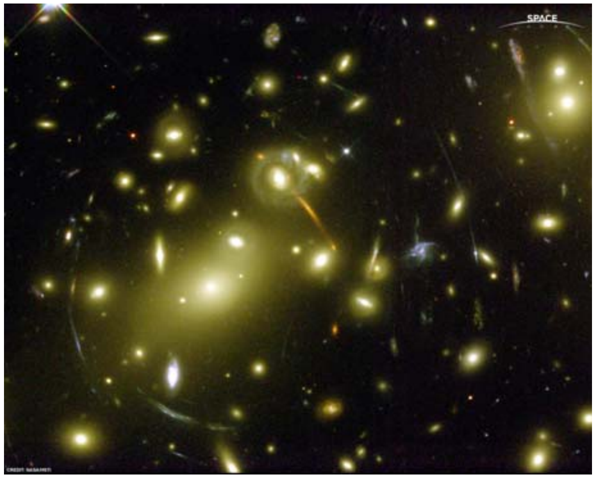


Proof of General Relativity II

Gravitational Lensing: Routinely observed and used to measure the mass of distant clusters of galaxies.

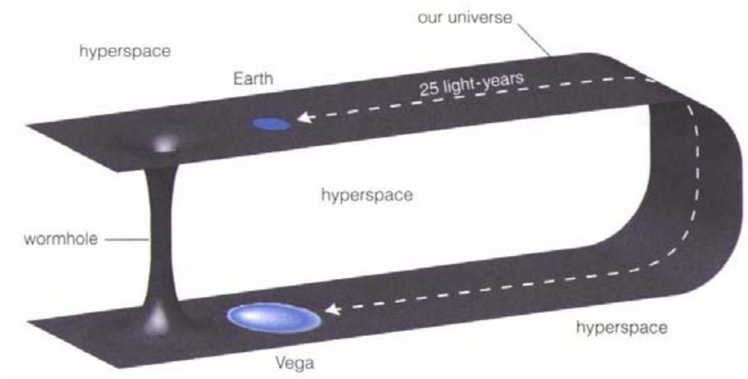


Real picture from the Hubble Telescope



Abel galaxy cluster

Wormholes



This could be the basis for a time machine.

Paradoxes in Time Travel

- If we can travel back in time, it would be possible for use to influence things so that we are not born.
- Three theories to resolve the paradox
  - Travel back in time is not possible
  - There are a very large number of parallel universes
  - Something about nature prevents us from influencing the past

Einstein Equation

$$R_{ij} - \frac{1}{2} R g_{ij} - \lambda g_{ij} = \frac{8\pi G}{c^4} T_{ij}$$

• A tensor equation that describes how space-time is influenced by mass.

• The details of what the symbols mean does not matter. Approximately, the left side is the curvature and motion of space and the right side is the location and motion of mass.

• Rij is the Ricci tensor, g is the metric of space, G is the gravitational constant, etc.