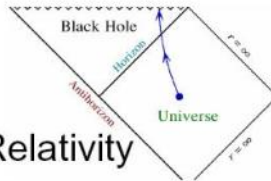
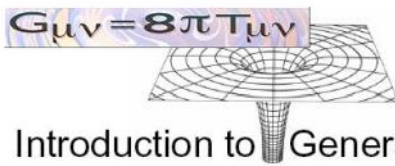


# General Relativity

Thursday, September 18, 2008  
7:07 AM

## A Theory of Gravity

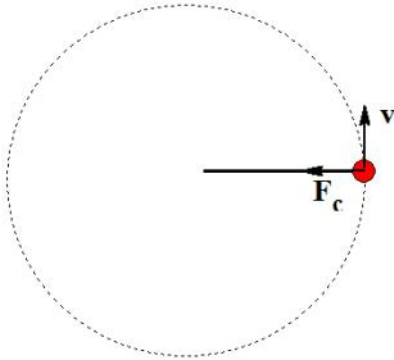
- What is General Relativity?
- Fictitious Forces
- Einstein's Principle of Equivalence
- Spacetime
- Schwarzschild's Solution
- Black Holes
- The Big Bang
- Cosmology Today



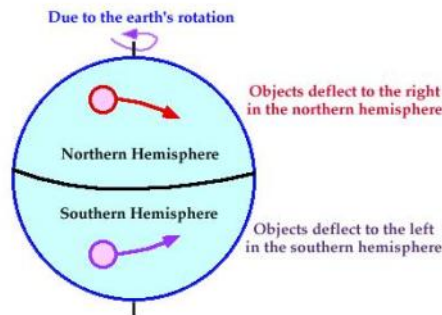
## Introduction to General Relativity

### Fictitious Forces

#### Uniform Circular Motion Centripetal vs Centrifugal Force



#### Coriolis Force



[http://www.physics.orst.edu/~mcintyre/coriolis/General\\_GIF.html](http://www.physics.orst.edu/~mcintyre/coriolis/General_GIF.html)

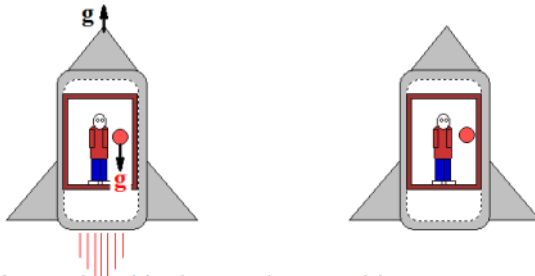
### The Equivalence Principle

Bodies freely falling in a gravitational field all accelerate at the same rate.  
All inertial forces are proportional to the mass of the body.

EP 1: There are no (local) experiments which can distinguish non-rotating free fall under gravity from uniform motion in space in the absence of gravity.

EP 2: A frame in constant acceleration relative to an inertial frame in special relativity is (locally) identical to a frame at rest under gravitation.

### Elevator in Space - Far From Other Bodies



1: An elevator is in a rocket ship that accelerates with a constant acceleration  $g$  relative to the observer. The observer releases a ball from rest and sees it fall to the floor with acceleration  $g$ .

2: The rocket motor is switched off and the elevator undergoes uniform motion relative to the inertial observer. The released ball remains at rest relative to the observer.

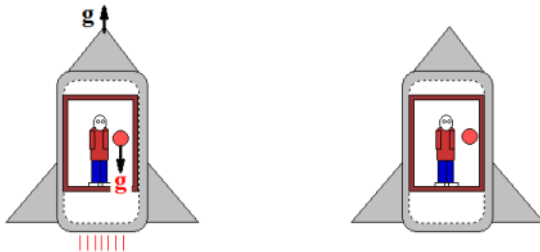
### Elevator on Earth



3: The elevator is on the surface of the earth. Ignoring rotational and orbital motions, the released ball falls to the floor with acceleration  $g$ .

4: The elevator falls freely in an evacuated elevator shaft towards the center of the earth. The released ball remains at rest relative to the observer.

### Elevator Summary



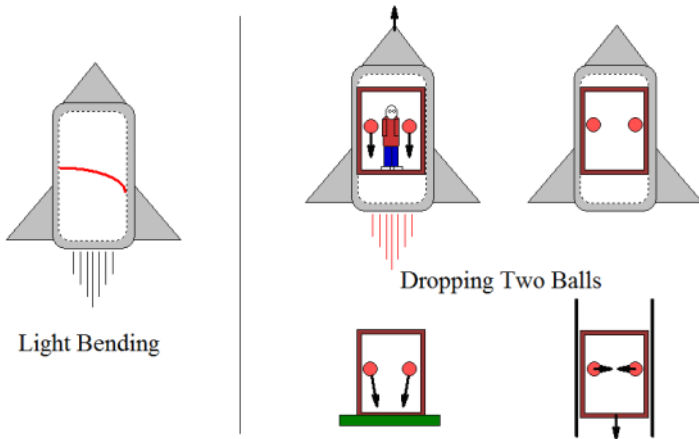
From the point of view of the observer:

Cases 1 and 3 are indistinguishable - EP 2.

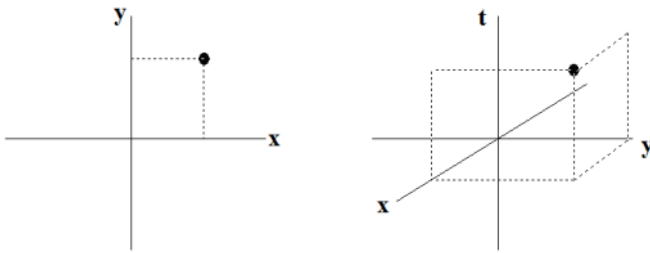
Cases 2 and 4 are indistinguishable - EP 1.



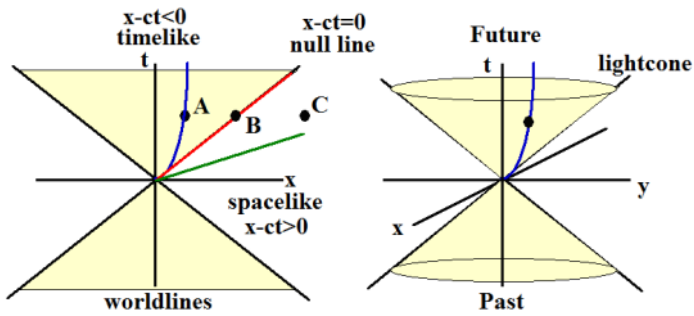
Other Effects



Space and Time - Coordinates

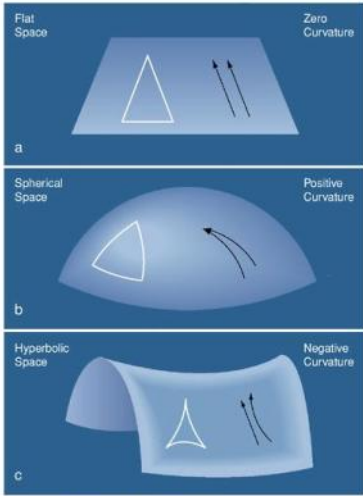


Minkowski Spacetime - Flat



$$s^2 = (ct)^2 - x^2 - y^2 - z^2$$

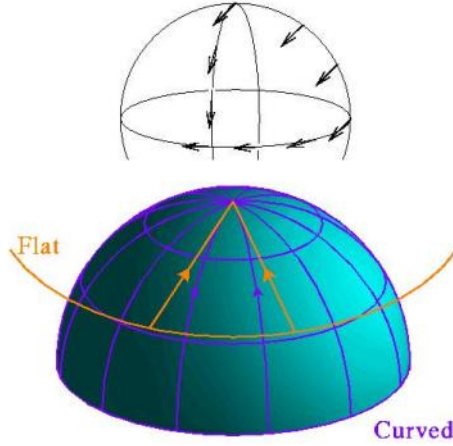
metric:  $ds^2 = c^2 dt^2 - dx^2 - dy^2 - dz^2$



Hyperbolic Geometry

**Curved Space**

Parallel Transport - Measuring Curvature

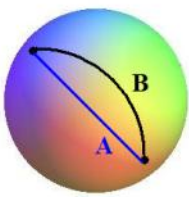


**Curved Surfaces**

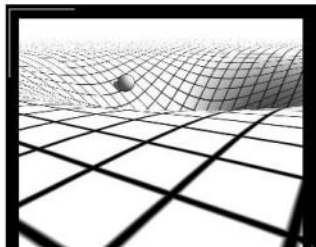
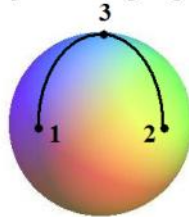


**Curvature or Force?**

Geodesic - the shortest distance between two points



Following geodesics from points 1 and 2, two objects end up at point 3.



## Schwarzschild's Solution

1916 - Schwarzschild - Spherically Symmetric Solutions  
Derivation



$$ds^2 = - \left(1 - \frac{2GM}{c^2 r}\right) c^2 dt^2 + \left(1 - \frac{2GM}{c^2 r}\right)^{-1} dr^2 + r^2 (d\theta^2 + \sin^2 \theta d\phi^2)$$



## Classical Tests of GR

1. Gravitational redshift - clocks in a gravitational field observed from a distance tick slower. (1960s- Pound-Rebka-Snider experiment)
2. Deflection of light - when light passes near a large mass its path is slightly bent. (1919 observed on an island near Brazil and near the westcoast of Africa. made the front page of most international journals and made Einstein and his General Relativity world famous.)
3. Perihelion shift of the planet Mercury (Ellipse axis shifts 43 seconds of an arc/century)

## Problems with Schwarzschild Solution

The metric becomes infinite at  $r$  proportional to  $M$

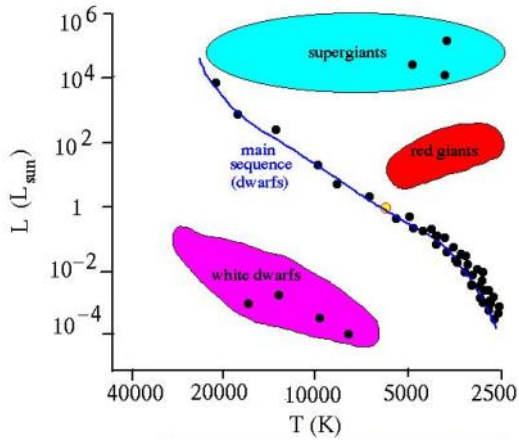
- Schwarzschild radius or the Event Horizon
- Light is trapped at this distance => **Black Hole!**
- Smaller distances, time and space swap properties!

According to a person who falls into a Black Hole:  
the event horizon does not exist  
when they cross it, they can no longer send messages out  
The person then continues to fall towards the center.

According to a person a stays at a constant distance from the black hole,  
the person who falls in never reaches the event horizon.  
They appear to slow down forever,  
messages sent from the person seem to slow down.

## HR Diagram

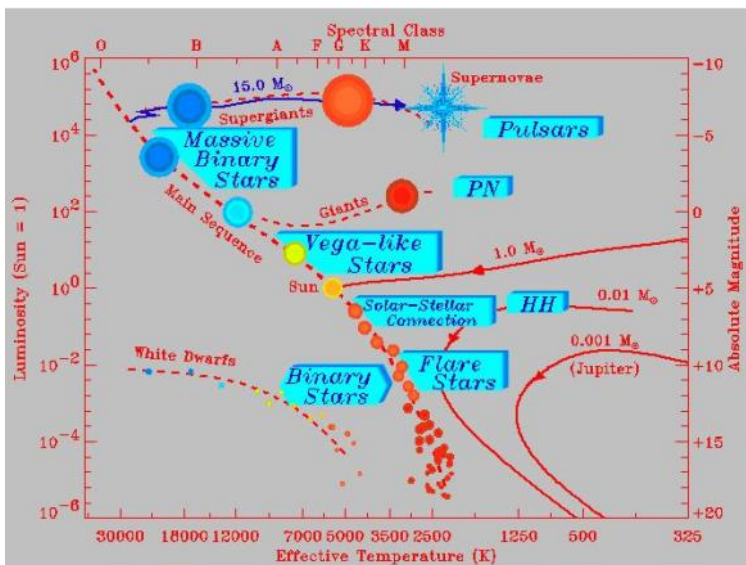
### Hertzprung-Russell Diagram - Star Classification



[http://astrosun2.astro.cornell.edu/academics/courses/astro201/hr\\_diagram.htm](http://astrosun2.astro.cornell.edu/academics/courses/astro201/hr_diagram.htm)

### Stellar Evolution

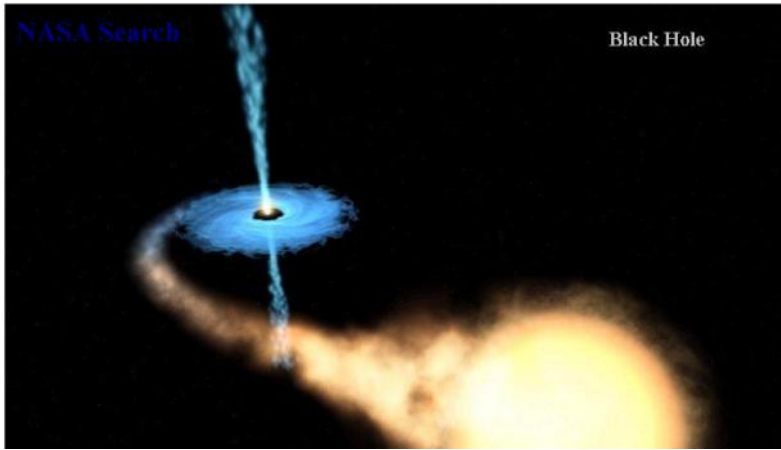
$M < 8 M_{\odot} \Rightarrow$  planetary nebulae  $\Rightarrow$  white dwarfs.  
 $M > 8 M_{\odot}$  end their lives by exploding as supernovae  
 leaving neutron stars or black holes.



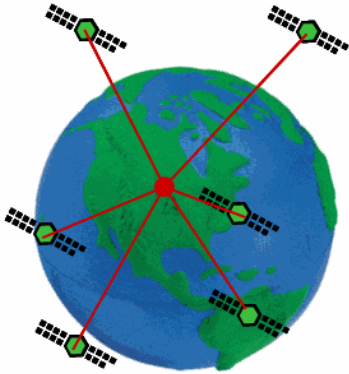


## Do Black Holes Exist?

### Going Beyond Einstein: Spacetime Wave Orbits Black Hole

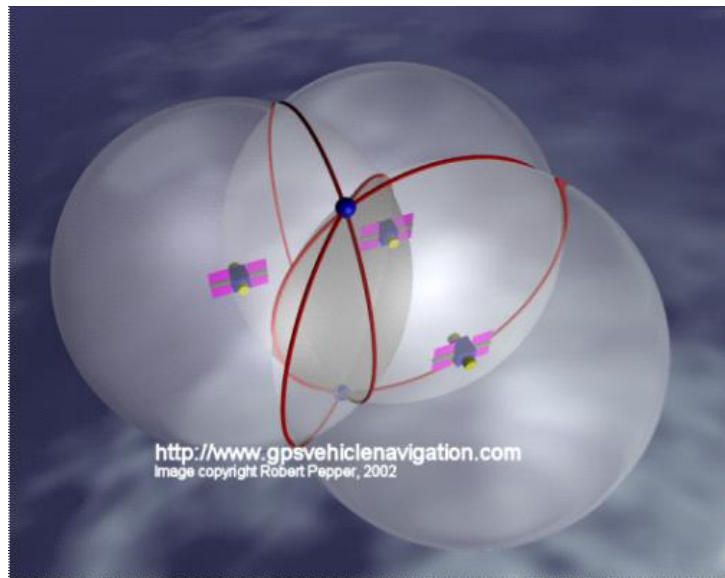


### Is General Relativity Useful?



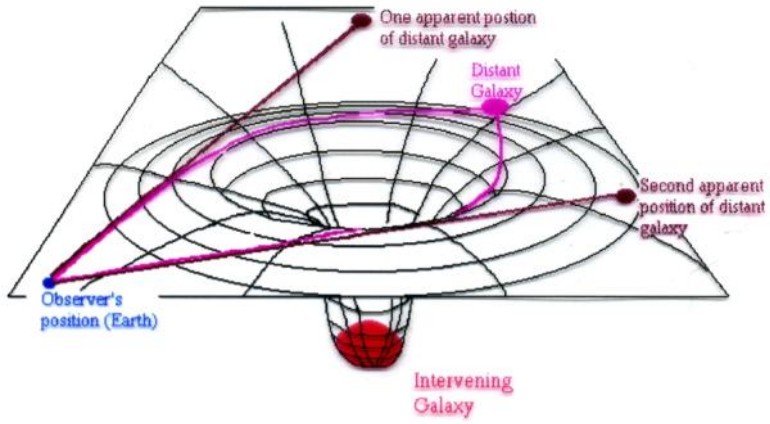
GPS Satellites orbiting at 12,000 miles, moving at 7,000 mph. The distance from each one is measured by the time it takes for the signal to arrive. Comparing the time for at least 3 satellites allows the earth location to be calculated.

Pasted from <<http://www.technologyevangelist.com/images/gps.gif>>

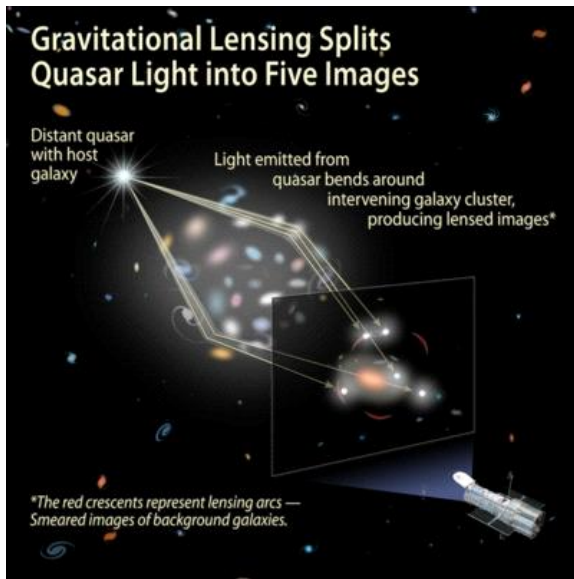


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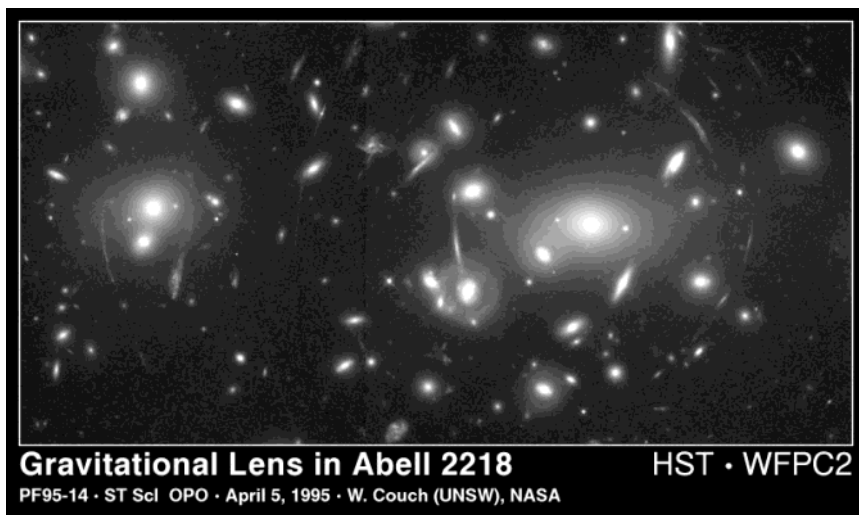
### Gravitational Lenses



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