Astronomy 150:
Killer Skies

This Class (Lecture 25):
Death by Black Hole: Spaghettification

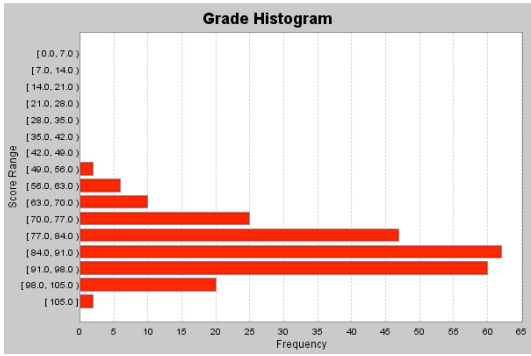
Next Class:
Compact Objects in the Solar System

Night Obs/Computer labs due in class on Nov 9th.

http://www.youtube.com/watch?v=P5_Msrdg3Hk

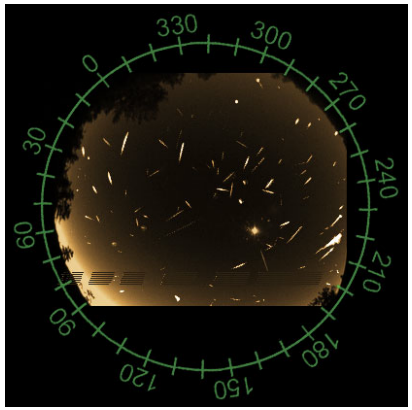
Exam 2

- Good job!
- Average = 85.9
- Median = 87.5
- A little lower than Exam 1, but harder topics



Leonid Meteor Shower

- Nov. 17, 2009
- The 2009 Leonids could produce more than 500 shooting stars/hour
- US will not have the best view, but it should be the strongest shower in quite some time.
- Peak should occur at 21:34 and 21:44 UT on the 17th, look as soon as it gets dark.



Outline

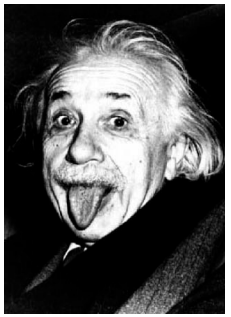
- Einstein's General Theory of Relativity
  - What is gravity?
- Don't fall into a black hole!

Relativity

- We have talked about special relativity, where time and distance are actually relative to the observer.
- Of and by itself this is not so relevant to class except in the way it interfaces with general relativity.
- Now, we will talk about how some aspects depend on where you are relative to massive objects.

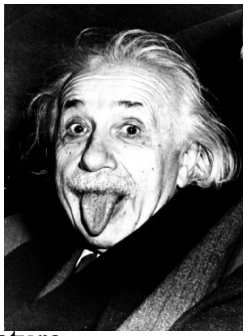
The Theory of General Relativity

- Recall Galileo/Newton: free body motion is a straight line, constant speed
- Important to note that ALL free bodies move this way. straight line, constant speed, INDEP of size, mass
- Q: Why?
- A: That's the way it is!
- Q: Be more specific: that's the way WHAT is?
- A: Einstein: that's the way space and time are if nothing else going on (no forces) space and time constructed so that free bodies move in straight lines at constant speed independent of nature of the object
- **That's the way space and time are**



The Theory of Relativity

- Einstein's Theory of Relativity tells us how gravity works
  - Space and time are not distinct
  - They are bound together in 4-dimensional **spacetime**
  - Gravity is not a force, but a curvature
  - Matter tells spacetime how to curve
  - Curved spacetime tells matter how to move



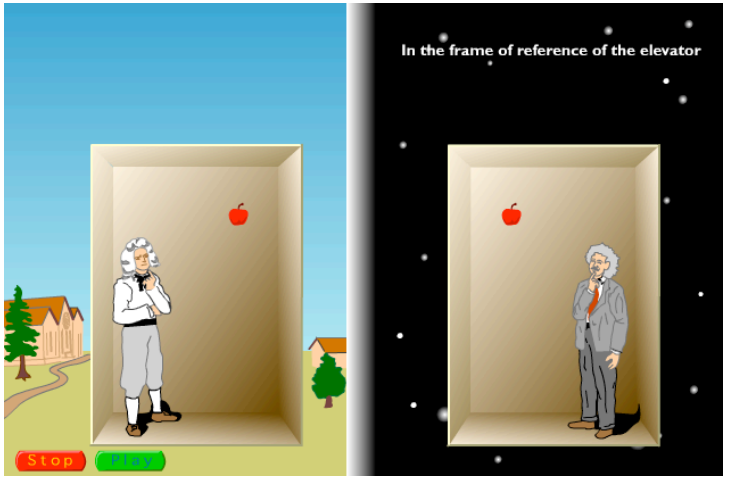
Free Fall

- Recall Galileo's experiment.
- The objects in the gravity field, move independent of mass or even object.
- For Newton, the object mass cancels out of the gravity equation.

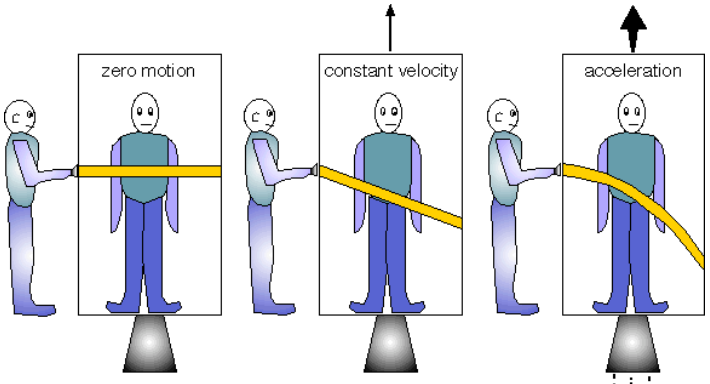
The Theory of General Relativity

- Since objects move the same in a gravity field, INDEPENDENT of object, then gravity is not a force, but also a feature of space-time!
- Objects do their best to move in a straight line.
- **Newton:** Matter causes force (gravity) ⇒ particles follow curved lines in "flat" (Euclidean geometry) space
- **Einstein:** Matter causes spacetime to be "curved" ⇒ particles follow straight lines ("geodesics") in curved space

The Theory of General Relativity



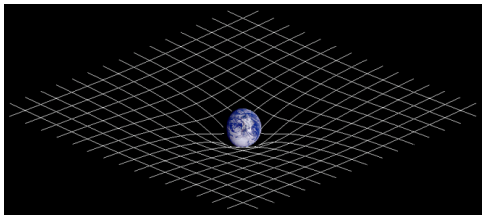
The Theory of General Relativity



The path of a light beam in three different types of reference frames moving with respect to the person *outside* the elevator. The light path shown is what the person ***inside*** the elevator sees. Under large acceleration, the beam of light will curve downward. It should also do that in a region of strong gravity.

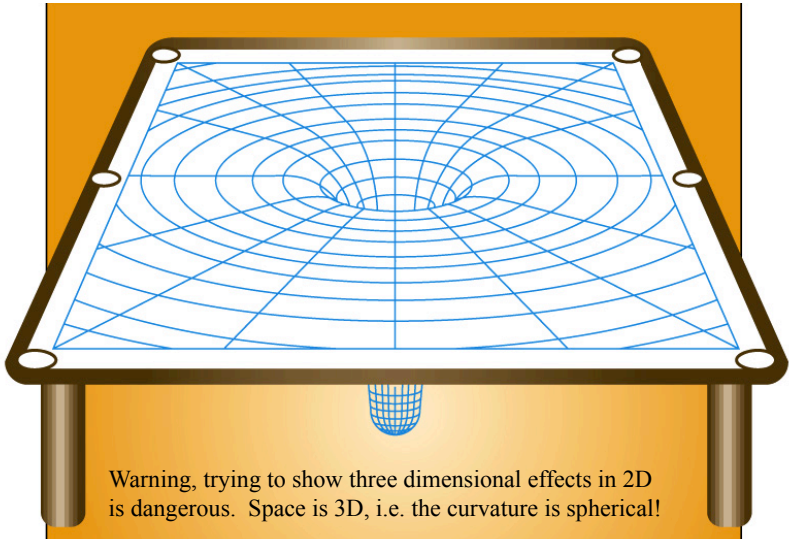
Curved Spacetime

- No matter = Flat Spacetime
- Massive object = Dent in Spacetime
  - Everything follows curvature of spacetime including light (photons)

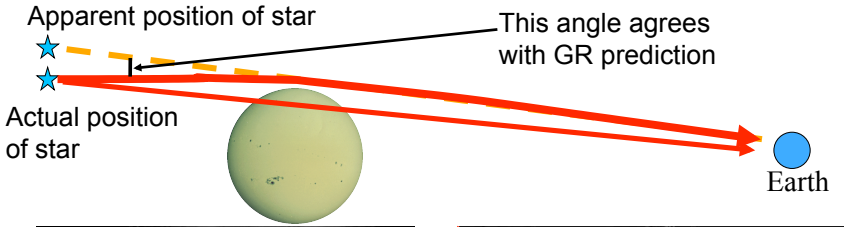


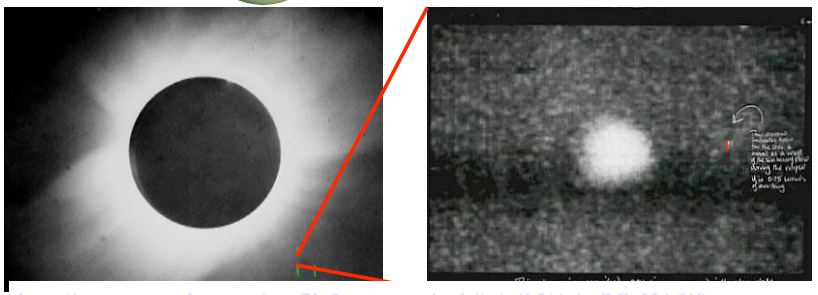
http://www.youtube.com/watch?v=0rocNtnD-yI
3:37-4:05 6:07-

Curved Space



Eddington and the 1919 Eclipse





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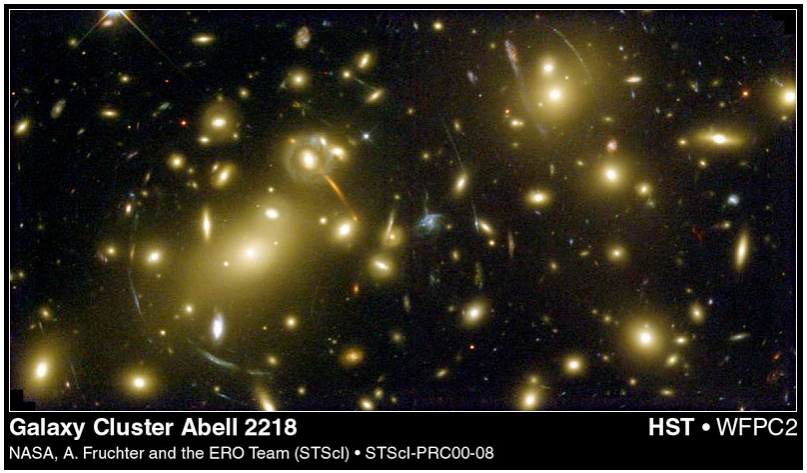
Einstein Lens



http://antwrp.gsfc.nasa.gov/apod/ap000201.html

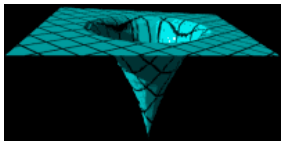
Question

In Einstein's general relativity,

a) It's all relative.
b) The force you feel as weight can only be from a gravity field.
c) Mass tells space-time how to curve, and the curvature of space-time tells mass how to accelerate.
d) Mass and space-time curvature are not related.
e) Being in a closed elevator freaks out Einstein.

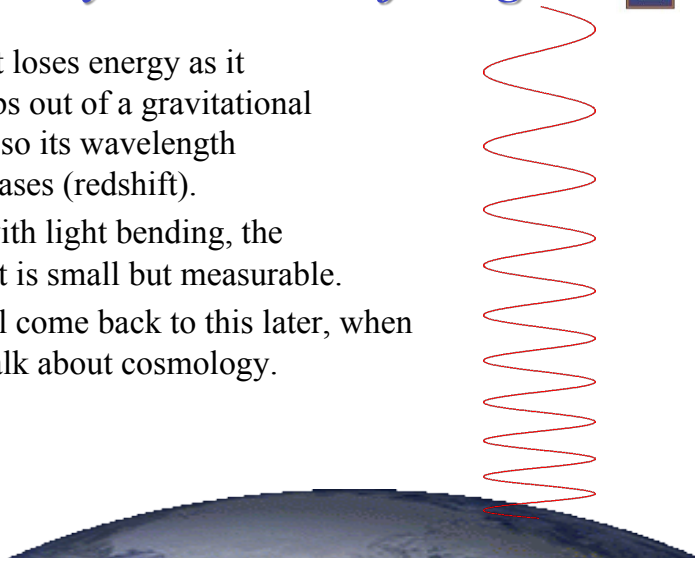
General relativity

- Gravitational fields also change space and time
  - A clock runs more slowly on Earth than it does in outer space away from any mass, i.e. planets.
- Einstein revealed that gravity is really 'warped' space-time.
- A black hole is an extreme example.

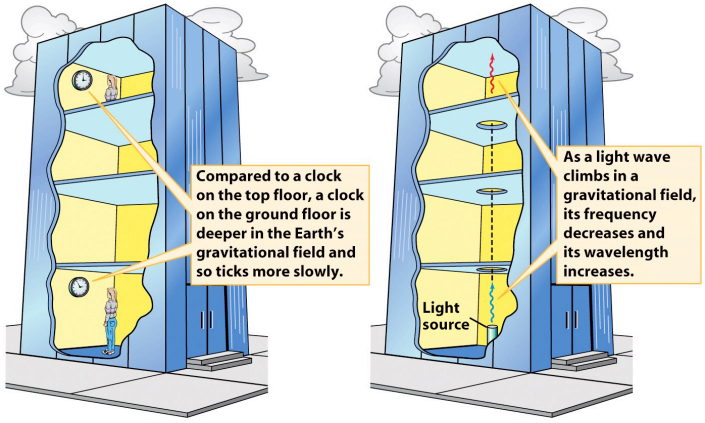


Gravity Also Redshifts Light

- Light loses energy as it climbs out of a gravitational field so its wavelength increases (redshift).
- As with light bending, the effect is small but measurable.
- We'll come back to this later, when we talk about cosmology.



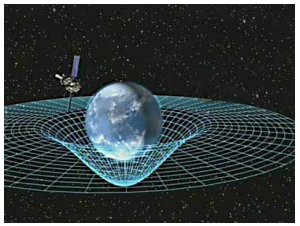
Gravity Affects Effects



(a) The gravitational slowing of time (b) The gravitational redshift

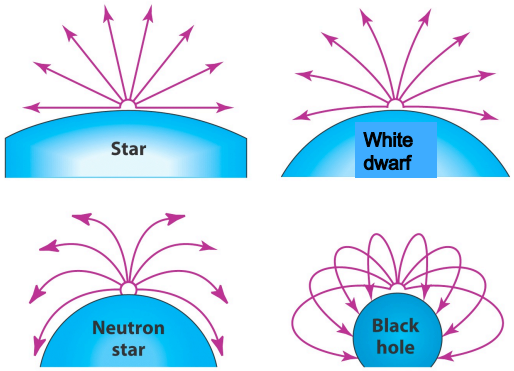
Gravity: Is relative?

- Gravity you feel is really the distance away you are from the mass of the object.
- It goes like distance squared.
- Compare the Earth's gravity now, then collapse it to the ½ the size, your gravity would increase by 4 times.
- Keep halving the size, the pull of gravity gets more and more as you get closer.



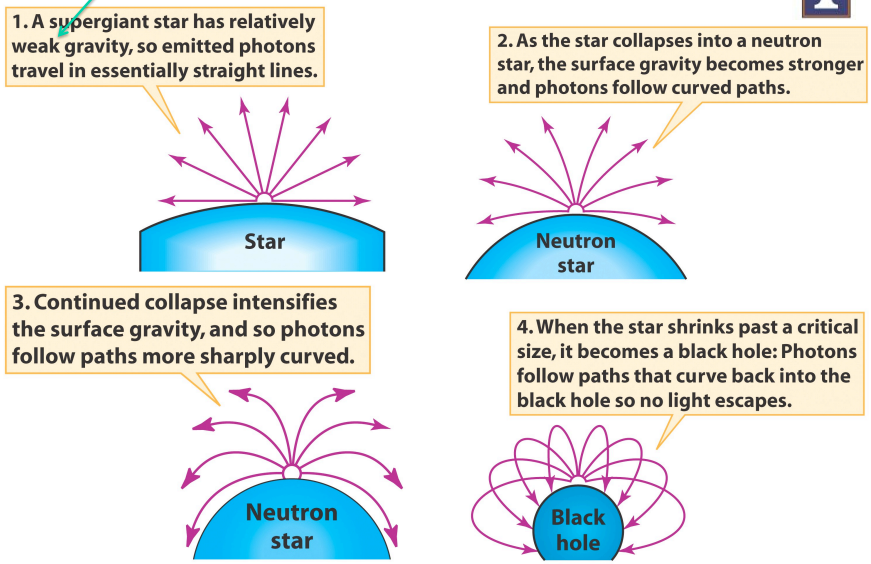
Back to Black Holes

- When matter gets sufficiently dense, it causes spacetime to curve so much, it closes in on itself
- Photons flying outward from such a massive object arc back inward!
- Neither light or matter can escape its gravity, it is a **black hole!**



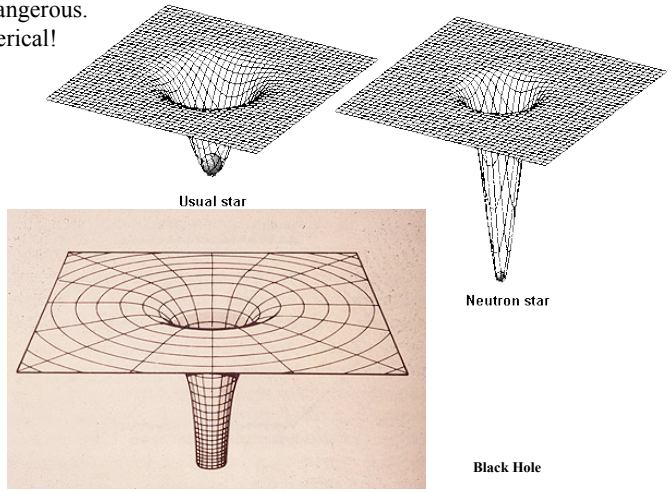
Black Holes

Really important is the density.



Comparison in GR

Warning, trying to show three dimensional effects in 2D is dangerous. BH is spherical!



Question

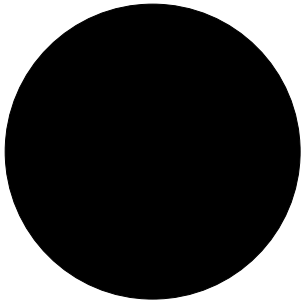
In Einstein's general relativity, a black hole is

a) slightly yellow in color.
b) only affected by other black holes.
c) where space is curved so much that light can never escape.
d) where mass and space-time curvature are not related.
e) related to the curvature of the surface of the body.

Black Holes Are Very Simple

They can have only

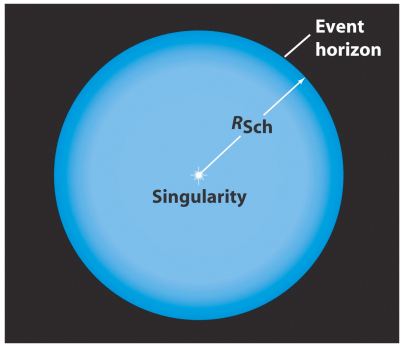
- Mass
- Electric charge
- Rotation (spin)



Black holes have no hair!

Black Hole

- The matter in a black hole collapses to a point – called a **singularity**
- Black hole is dense and massive, but only a point. Everything is at the exact center.
- Still, a black hole is separated from the rest of the Universe by a boundary, the **event horizon**
- Nothing can escape from within its radius
- This radius is called the Schwarzschild radius

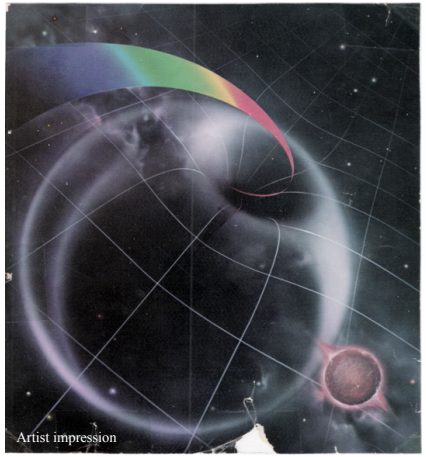


Black Holes

Lasciate ogni speranza,
o voi ch'entrate.

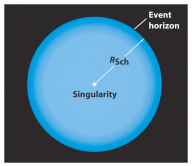
Abandon all hope,
you who enter here.

Dante Alighieri
(Divina Commedia-Hell)



Black Hole = Waterfall

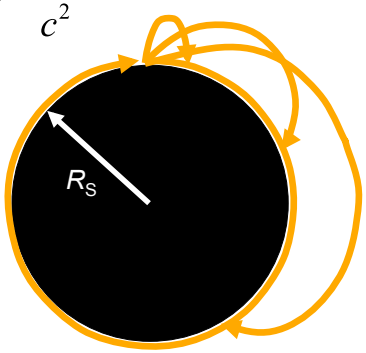
- Can think of it as trying to paddle up a waterfall.
- Space is falling into black hole faster than light, so light can paddle all it likes, but it's going down.
- Again, this only really close to the black hole, above the waterfall the water is smooth and you can paddle away.



Black Hole

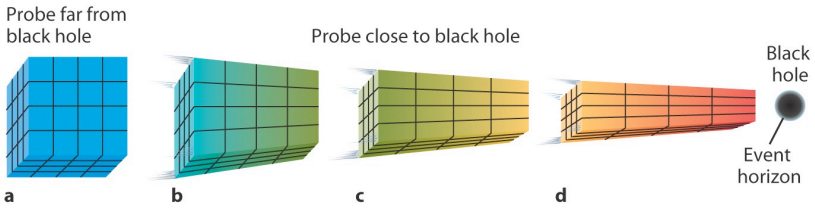
- More massive black hole ➔ larger the event horizon
  - $R_{Sch} = 3\ (M/M_{\odot})$ km
  - If object's mass in radius < R_{Sch} then it's a BH
  - For Earth $R_{Sch} = 1$cm
- The radius of no return
- Cosmic roach hotel
- As you get closer, your clocks appear to slow down to someone farther away.

$$R_{Sch} = \frac{2GM}{c^2}$$



Probing a Black Hole

- We send a glowing blue cube into a black hole… What happens?
  - As the probe approaches the black hole, it gets stretched by the gravity of the black hole
  - The light it emits redshifts more and more as it gets closer to the black hole
  - Eventually, tidal forces rip it apart

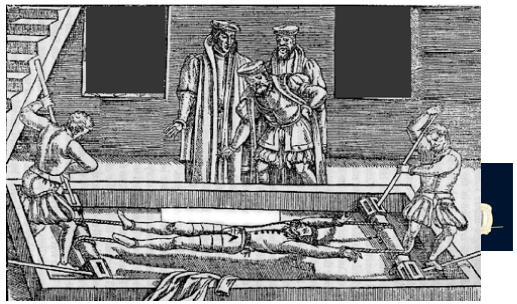


Death by Black Hole

- Black holes themselves are not deadly… just a point.
- The warped space around them are deadly!
- Let's say you go toward one, feet first.
- This discussion is for solar mass-ish black holes.

Death by Black Hole

- At first you would not feel a thing….
- Microgravity… SOP for an astronaut.
- But as you get closer, the pull of gravity on your feet is stronger than the pull on your head– tidal forces.

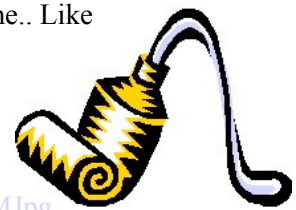


Death by Black Hole

- The tidal pull…
- If you were made out of rubber, this would not be bad, but humans are made out of bones, muscles, etc.
- Molecular bonds are overcome, you snap in 2 at the midsection. Those pieces snap in two, and so on..

The Ultimate Rack

- The shreds of organic molecules headed toward the center of the black hole begin to feel that stretching feeling.. getting ripped into atoms
- Then, the atoms rip apart…
- Now we have an unrecognized stream of subatomic particles that use to be you only minutes ago.
- All of these parts are moving toward the black hole center, extruding through the fabric of space-time.. Like toothpaste squeezed through a tube..



http://www.youtube.com/watch?v=h1iJXOUMJpg