Killer Skies

- Homework 8 due Monday (but suggest completing now since material on exam 2)
- Solar Observing this week
- Exam 2 Friday
- Last time: Compact Objects
- Today: Spaghettification

Professor McGuire was fast regretting becoming the first man to successfully create a mini black hole in the laboratory.

Music: '*39* – Queen

Solar Observing This Week

Happens now:

W-Th, 10:30am-1:30pm, weather permitting (extending)

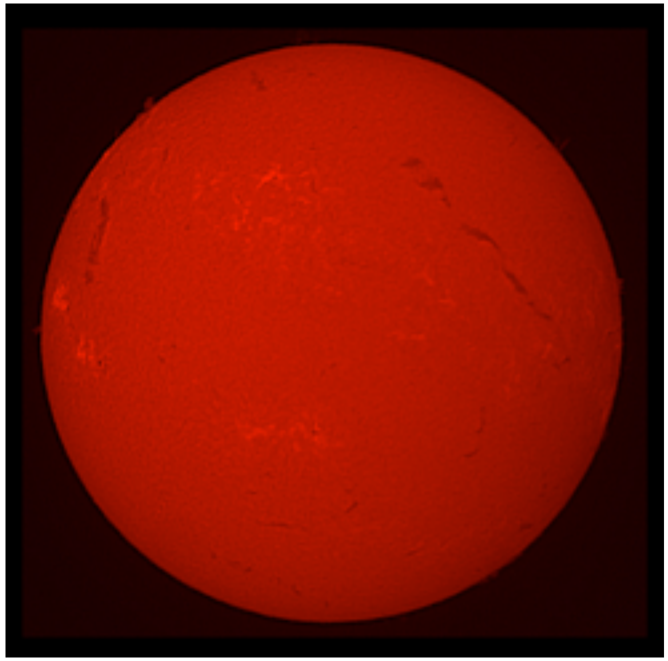
At Campus Observatory
(behind building)

Assignment details and report form on class website

Report due Nov 22^{nd}

Subscribe to Solar Observing Status Blog for weather-related notices

http://illinois.edu/blog/view/414



Hour Exam 2

Hour Exam 1 Friday, Nov 8th, in class

information on course website

40 questions (cover material from Oct 7th to Nov 1: Lect 14-24)

May bring 1-page of notes

both sides

printed, handwritten, whatever

Most useful study materials

class notes

iClicker questions

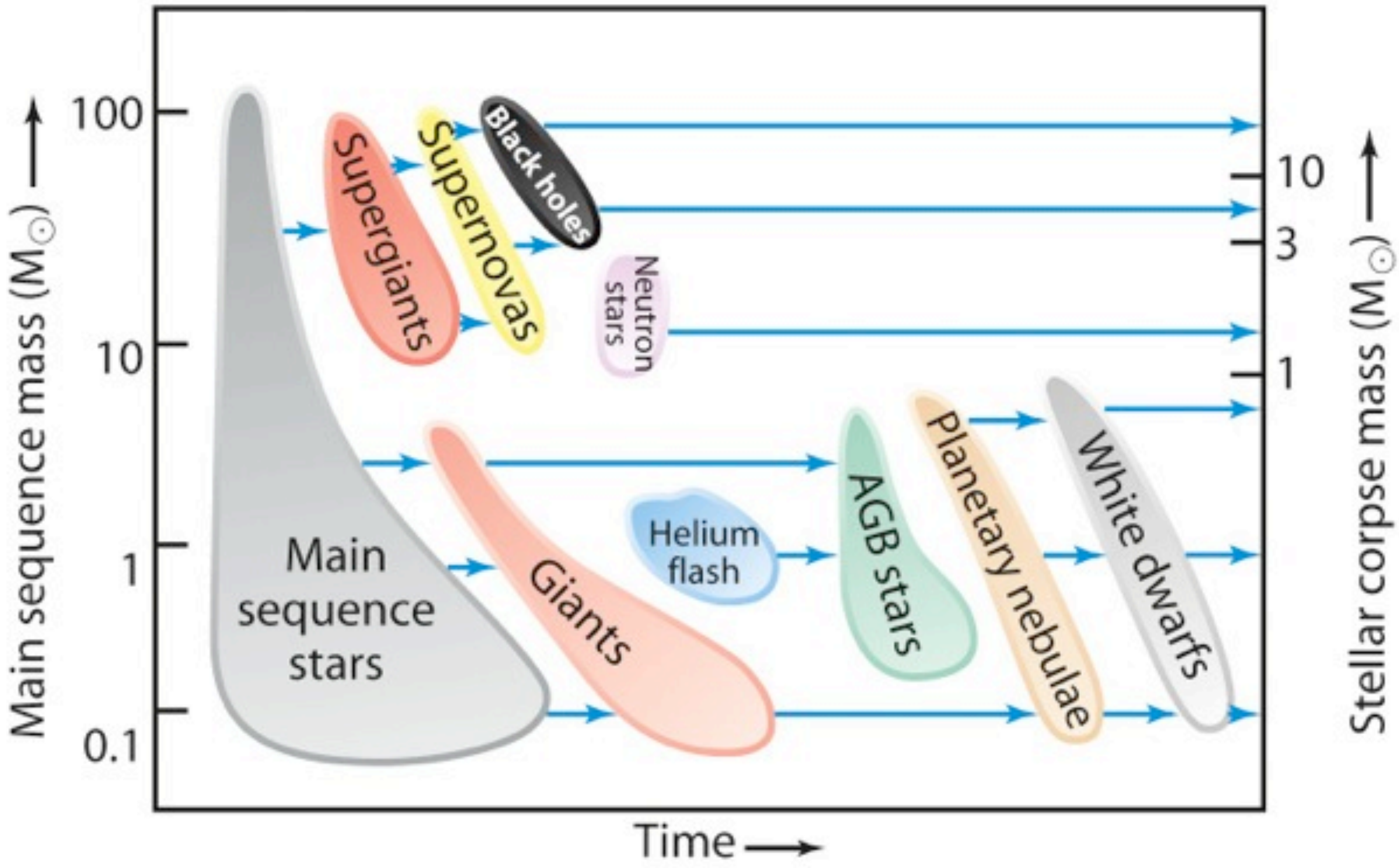
study guide

homework questions

old exam

Focus on concepts, main ideas

Stellar Evolution Recap



Actually any compact object can cause issues when they get too close.

Einstein's Equivalence Principle

Einstein notes:

- Gravity causes acceleration, but in "democratic" way:
- all objects accelerate the same

Einstein's Equivalence Principle:

- in a closed room, no experiment can distinguish between acceleration and gravity

But note:

- acceleration is aspect of motion
- relates to objects' travel through space and time
- so equivalence of gravity=acceleration will have impact (=bizarreness) on nature of space and time

Experiments Inside an Accelerating Rocket

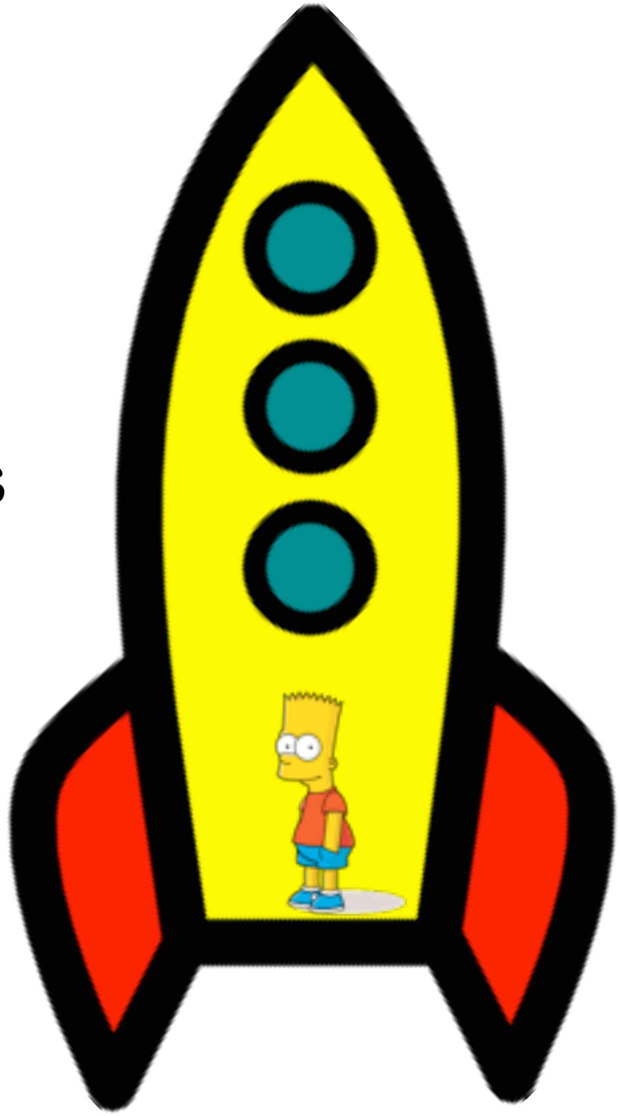
Consider a rocket in otherwise empty space

that is, no gravity!

rocket moves with constant acceleration

Experiment: Astronaut Bart, standing on floor of rocket, has flashlight

- holds flashlight at height h
- points horizontally
- shines towards wall



iClicker Poll: Light Beam in Accelerating Rocket

in rocket with constant acceleration Bart hold flashlight at height h, shoots beam horizontally

At what height will beam hit opposite wall?

A. at same h

B. higher than h

C. lower than h

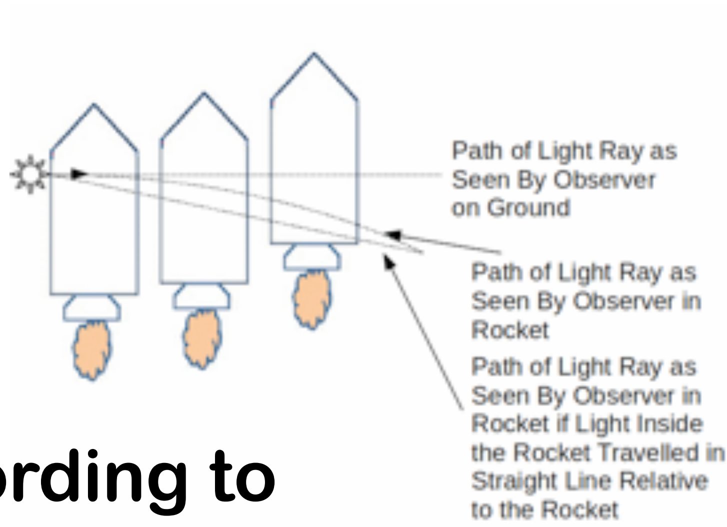
hint: easier to think about when looking at experiment from non-accelerating viewpoint

Answer is surprisingly C

Rocket Experiment

in non-accelerating viewpoint (bystander "frame"), see that

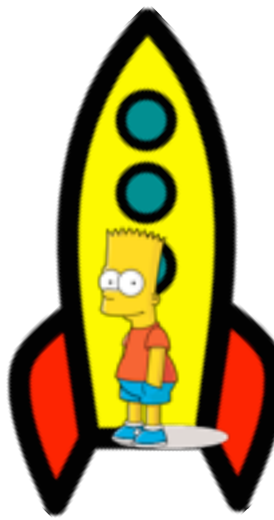
- light path is straight (horizontal) line
- but spaceship has vertical motion
  - → far wall moved higher
  - ⇒ light hits below where aimed



in accelerating frame (i.e., according to Bart):

- agrees that light hits below where aimed, and so concludes
- light ray deflected
- entire light path bent (in fact, a parabola!)

Q: but what does this mean, according to Big Al's Equivalence Principle?



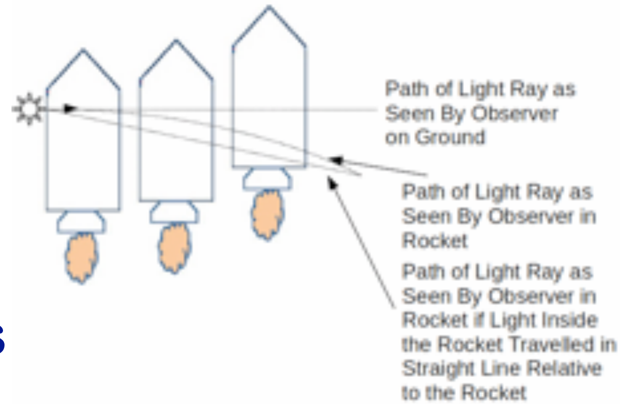
Gravitational Effects

In accelerating spaceship:

- light rays observed as bent!

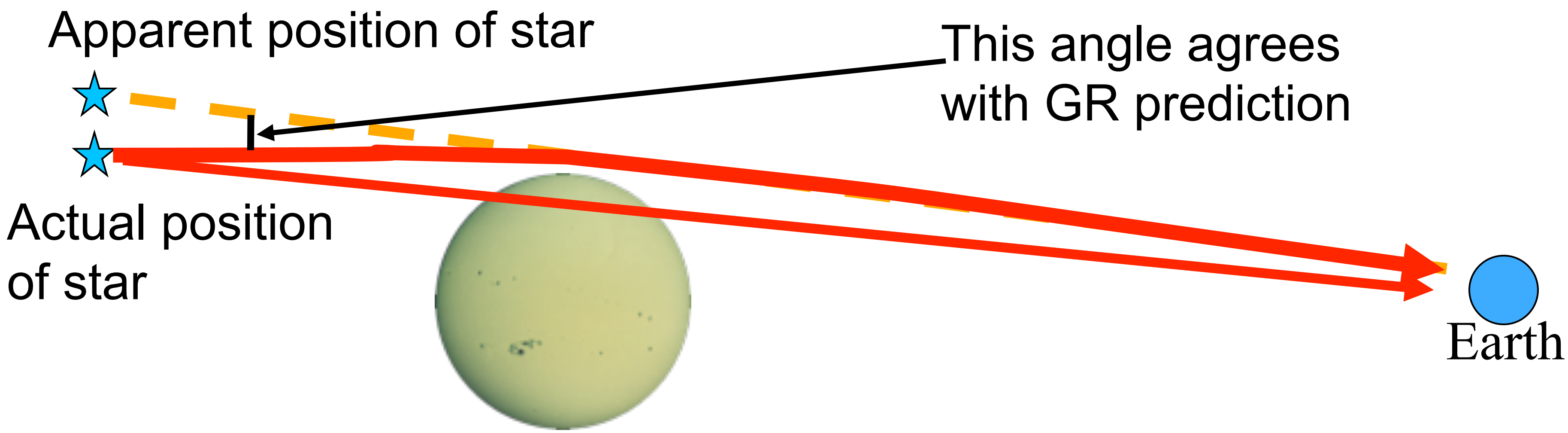
But by equivalence principle:

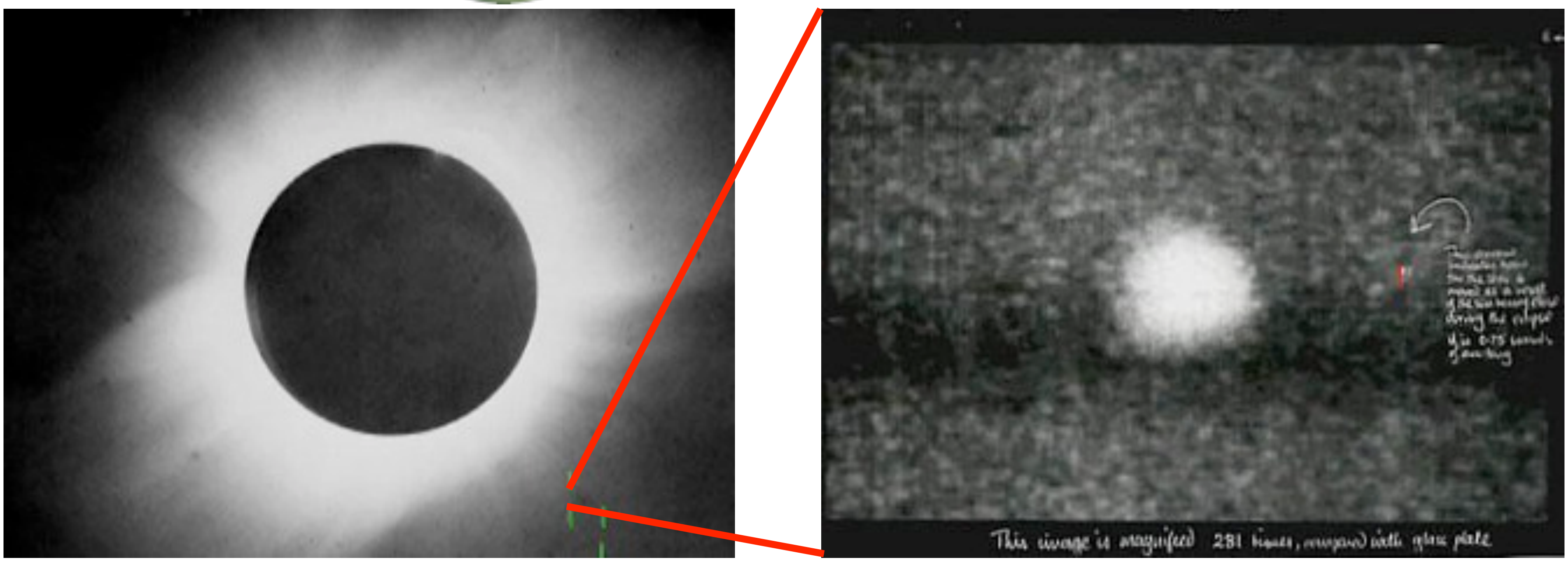
- must find same result due to gravity
- so: gravity bends light rays
- light “falls” too!
- gravitating objects “attract” light rays
- distorts light paths differently depending on how strong the gravity over each path



Q: but this is all theory--how to test in real world?

Eddington and the 1919 Eclipse



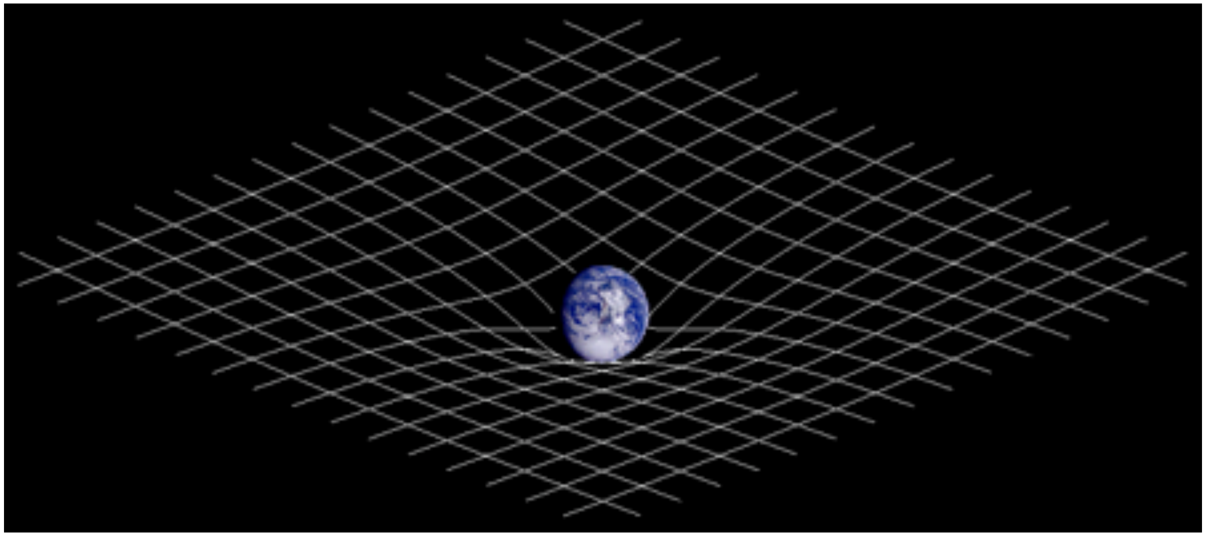


According to predictions by Albert Einstein, a ray of light from a star very close to the Sun (as seen from Earth) will be bent (deflected) as it passes by the edge of the Sun. Such a deflection would make the star look slightly farther away from the edge of the Sun than it really is.

Astronomers would get the best results the more stars around the Sun during a solar eclipse and the more photographs they took. This would provide greater accuracy in comparing Dr. Einstein's predictions to Newton's. Each year on May 29 as the Earth revolves around the Sun, the Sun appears to pass in front of a cluster of stars in the constellation of Taurus. This cluster of stars, called Hyades, is so bright that it is clearly visible in the night sky even without a telescope months later during the winter. The only time this star cluster could be viewed on May 29 would be if the Sun were totally eclipsed and its light was blocked. On May 29, 1919 such an eclipse did occur, and this bit of good fortune allowed Dr. Einstein's prediction to be accurately tested. Guess what? He was right! And an overnight sensation.

Curved Spacetime

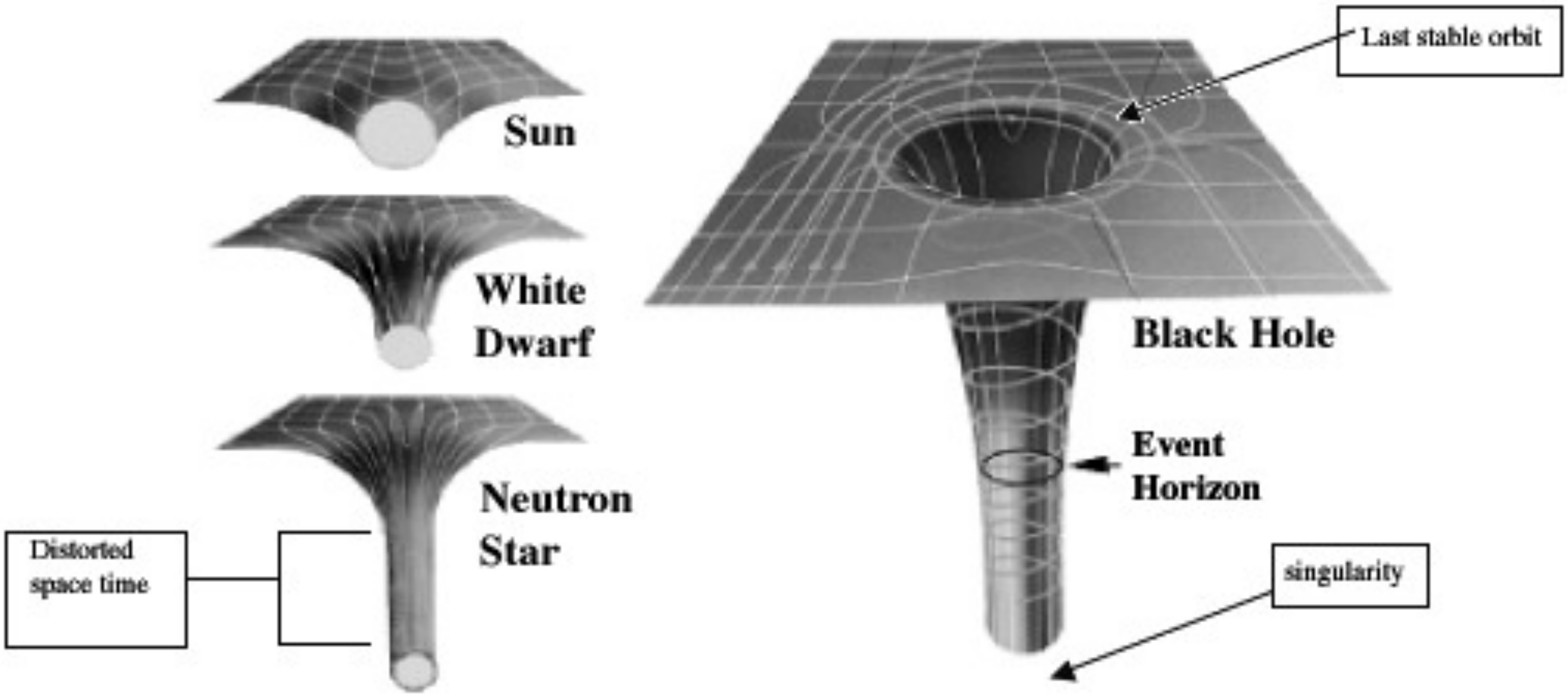
- No matter = Flat Spacetime
- Massive object = Dent in Spacetime
  - Everything follows curvature of spacetime including light (photons)
  - traveling in a straight line in a warped space



Einstein's Gravity

http://www.youtube.com/watch?v=AAqSCuHAOj8

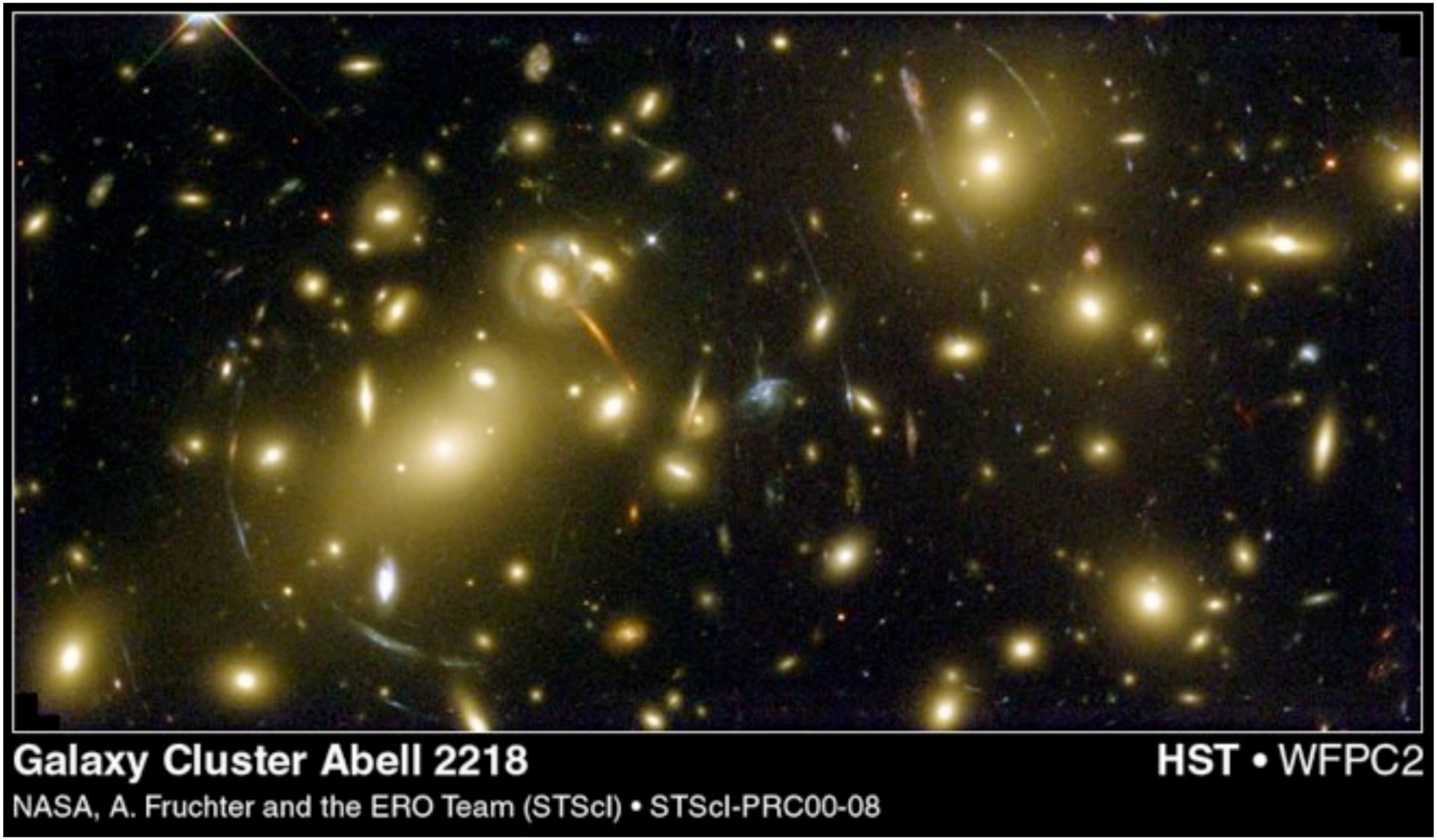
Mass *curves* spacetime



The greater the mass, the greater the curvature of spacetime

Einstein discovered that space and time are actually bound up together as four-dimensional spacetime, and that gravity arises from curvature of spacetime. Imagine space as giant rubber sheet, stretched tight. If you drop a mass on it, the mass creates a "dip" in the sheet, space "curves". The stronger the gravity, the more curved it gets. In this analogy, a black hole is like a bottomless pit in spacetime. Gravity gets stronger and stronger as we get closer and closer to the black hole, so the sheet curves more and more. Keep in mind that the illustration is only an analogy, and black holes are actually spherical, not funnel-shaped. Nevertheless, it captures the key idea that a black hole is like an inescapable hole in the observable universe.

Einstein Lens



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

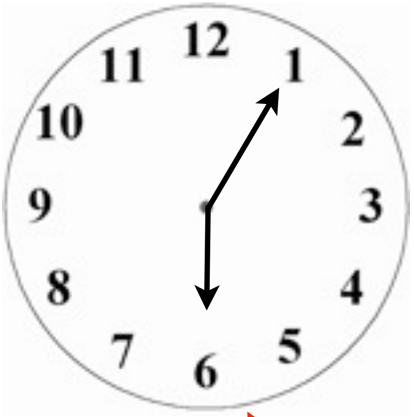
Question

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.

Answer C

Gravitational Time Dilation



Clocks in a gravity field run slower than clocks in space. The more massive the objects, the slower the clocks run to an outside observer. To the observer on the object, they seem to move at regular speed.

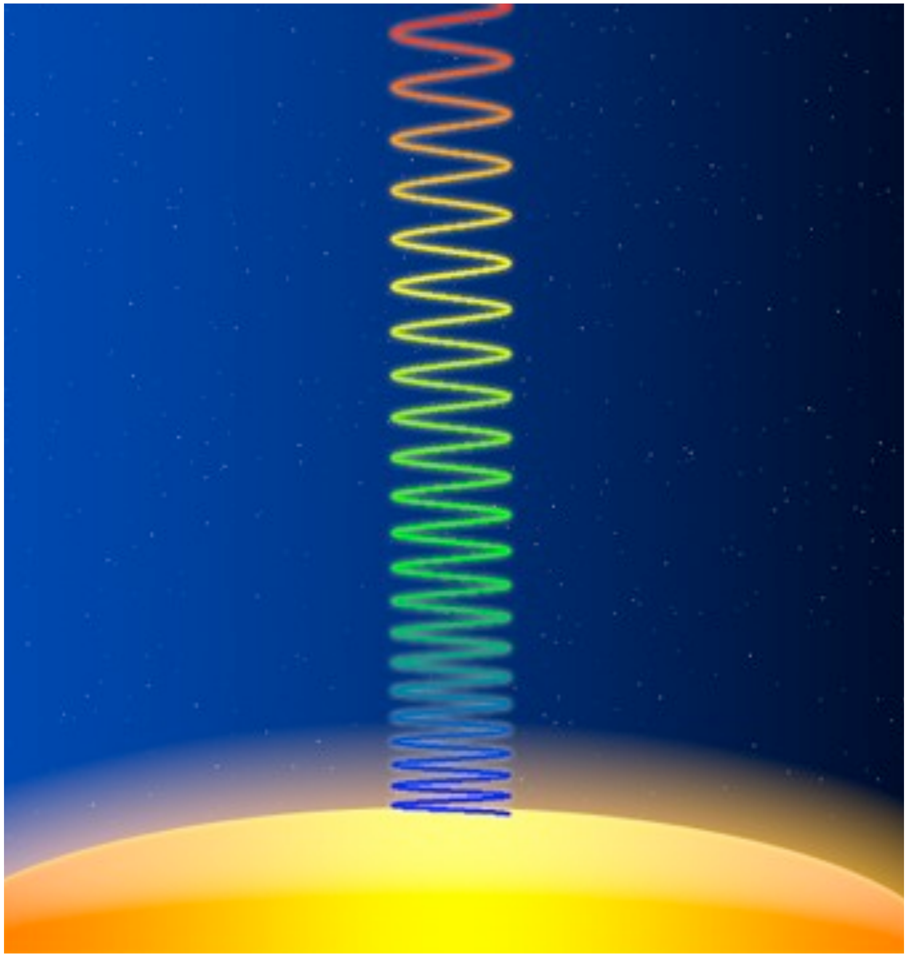
Hafele–Keating experiment

- In 1971, scientists took 4 atomic clocks aboard airliners and flew around the world
- Compared clocks afterward to clocks at Naval Observatory
- A difference in the clocks was observed - consistent with the effects of relativity

Hafele-Keating experiment: a test of the theory of relativity

The observed time gains and losses were different from zero to a high degree of confidence, and were in agreement with relativistic predictions to within the ~10% precision of the experiment. Nowadays such relativistic effects are, for example, routinely incorporated into the calculations used for the Global Positioning System.

Gravitational Redshift

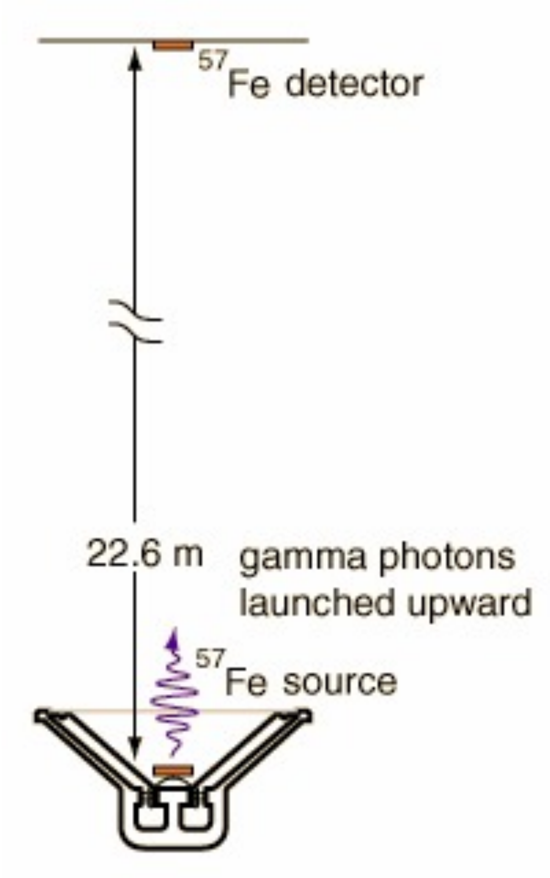


Light emitted from a large mass is <u>redshifted</u> as it escapes its gravity

Light escaping from a large mass loses energy – uses up energy to climb out of gravity well. The wavelength must increase since the speed of light is constant. Stronger surface gravity produces a greater increase in the wavelength. Note, if the light were emitted within the black hole's event horizon, it could not escape.

Harvard Tower Experiment

- In 1959, a light source was placed at the bottom of a stairway in the Physics Building and a detector at the top
- Stairway was 74 ft high
- Detected a redshift in the wavelength of 0.00000000000005%
- Consistent with GR!

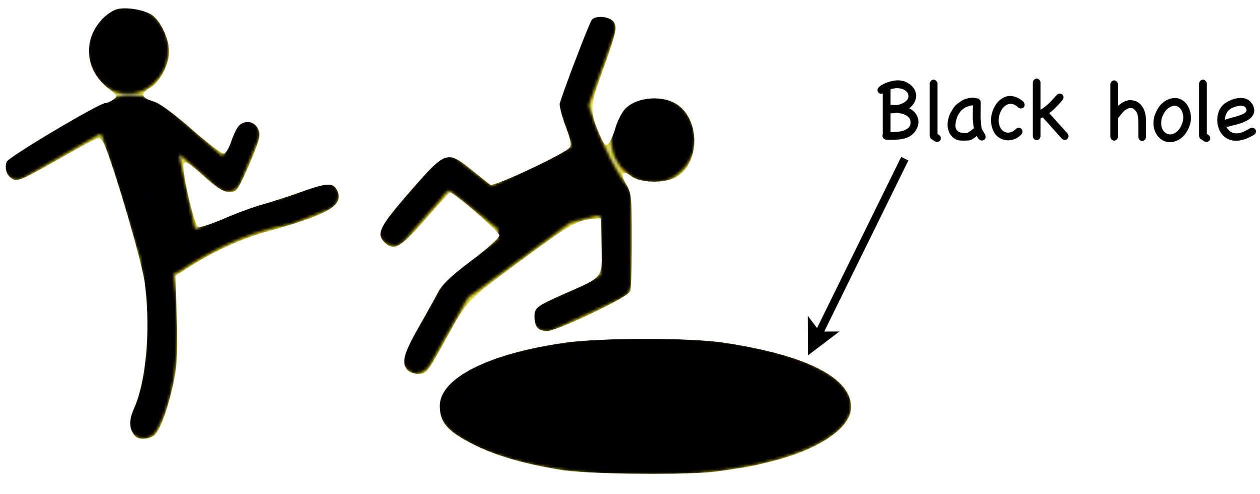


As light climbs in a gravitational field, its wavelength increases!

In the early 60's physicists Pound, Rebka,and Snyder at the Jefferson Physical Laboratory at Harvard measured the shift to within 1% of the predicted shift.

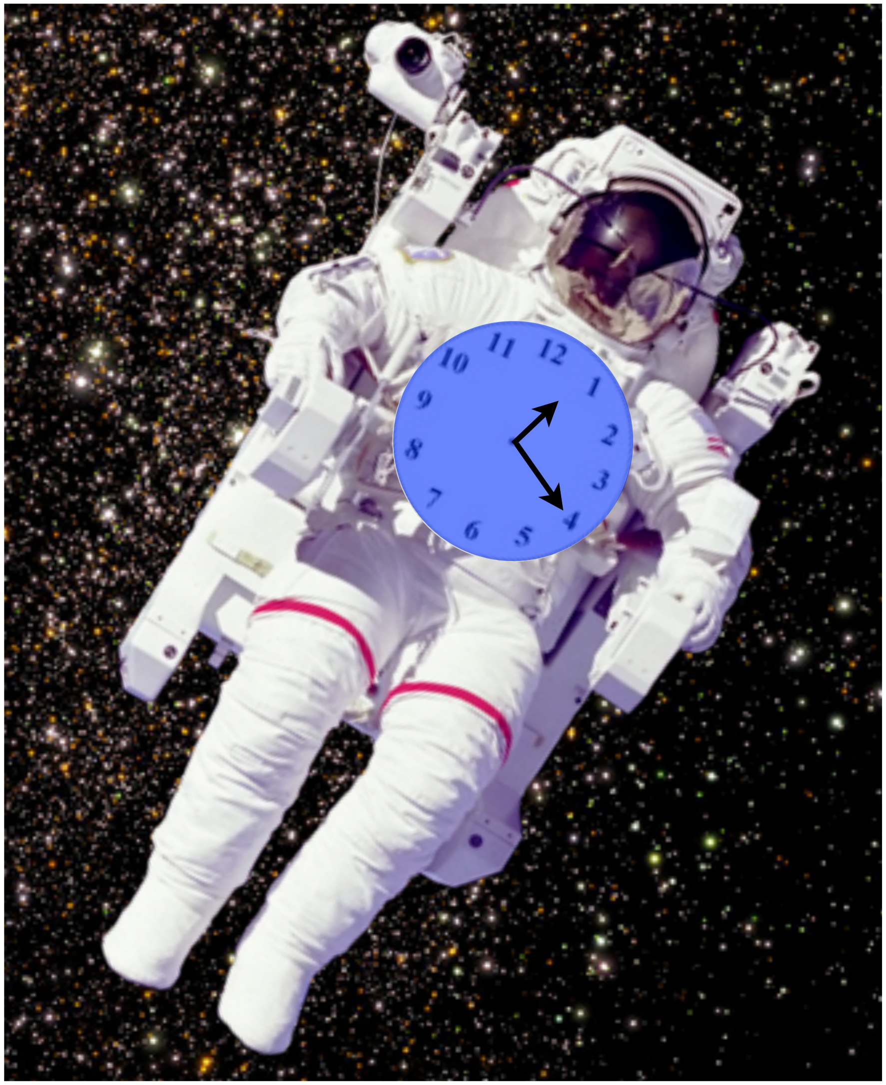
What would it be like to fall into a black hole?

- Imagine you and a ~~friend~~ enemy are orbiting a black hole at a safe distance
- He "jumps" out of the airlock and falls (yeah, he falls...) into the black hole
- What would happen to him?
- What would you see?



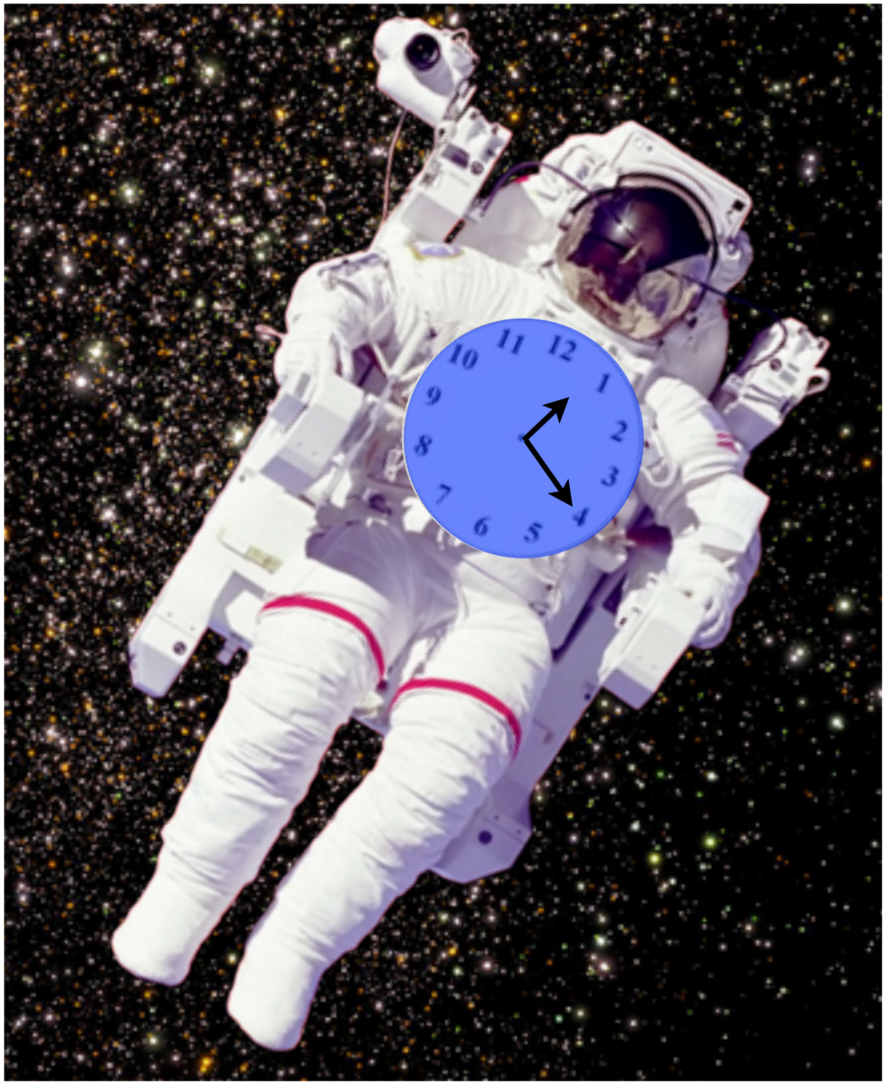
What would it be like to fall into a black hole?

- Lets assume both you and your ~~friend~~ enemy have clocks that were synchronized aboard the ship.
- Both clocks are BLUE
- He holds his clock in a way that you can observe it as he falls into the black hole



What you observe

- As your ~~friend~~ enemy falls toward the black hole:
- His clock slows down
- Light from his clock becomes **dim** and **red**
- Since his clock seems to stop, you never see him cross the **event horizon!**



What you observe

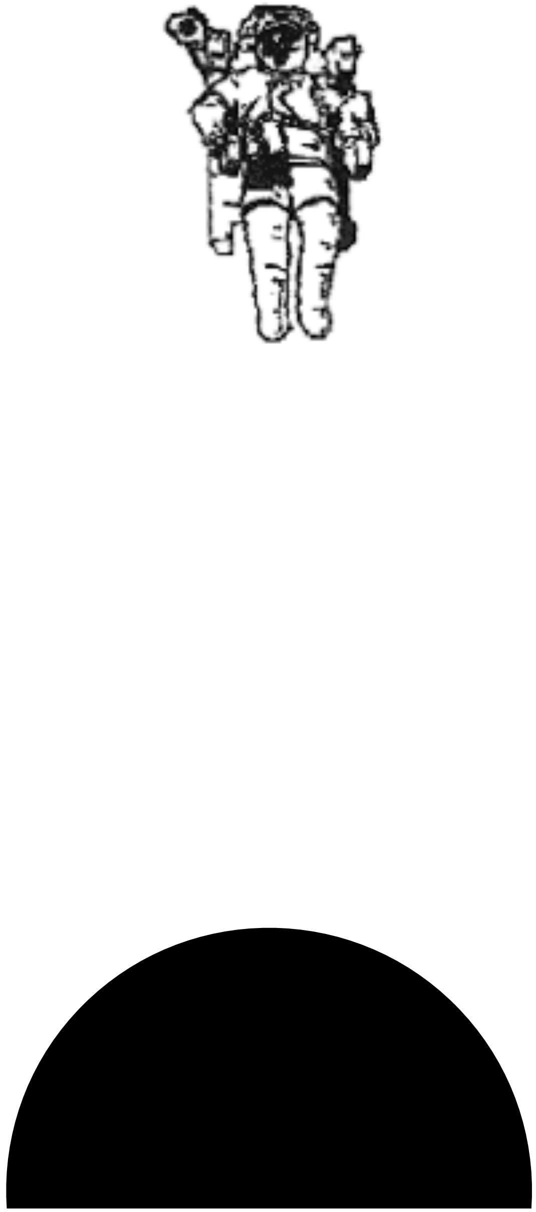
- As your ~~friend~~ *enemy* falls toward the black hole:
- His clock slows down
- Light from his clock becomes **dim** and **red**
- Since his clock seems to stop, you never see him cross the **event horizon!**

What happens to your ~~friend~~ enemy: His point of view

- His clock keeps ticking normally, stays bright and blue
- You appear to speed up! Light from your clock is blueshifted!
- He crosses the event horizon.
- No barrier - the event horizon is not a physical boundary

“Spaghettification”

- Unfortunately, he does not live to experience crossing the event horizon
- Near the event horizon, gravity would act more strongly on his feet than his head
- His body would get stretched out like a spaghetti noodle



If you fell in feet-first, your body would be scrunched sideways and stretched along the length of your body by the tidal forces of the black hole. Your body would look like a spaghetti noodle! The stretching happens because your feet would be pulled much more strongly than your head.
The sideways scrunching happens because all points of your body would be pulled directly toward the center of the black hole. Therefore, your shoulders would be squeezed closer and closer together as you fell closer to the center of the black hole. The tidal stretching/squeezing of anything falling into a black hole is an effect conveniently forgotten by hollywood movie writers and directors.

Death by Black Hole

- The tidal pull… pull on feet more than on head
- 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..

Great, but long, YouTube vidoe of Neil discussing this: http://www.youtube.com/watch?v=h1iJXOUMJpg

"Spaghettification"

http://www.thedailyshow.com/watch/tue-january-30-2007/neil-degrasse-tyson-pt--2

This is just as good and shorter.