Astronomy 150:

Killer Skies

This Class (Lecture 26):
Death by Black Hole: Spaghettification

Next Class:
Review & Black Holes and the Solar System

HW 9 due Tonight
Exam 2 is Friday
Computer lab due on Nov 15th

Music: Space Oddity– *David Bowie*

Exam 2

- Exam 2 in this classroom next Friday
- 40 Multiple choice questions (graded out of 105, i.e. 5% extra credit)
- Will cover material from Lecture 13 to 25
- May bring 1 sheet of paper with notes
  - Both sides
  - Printed/handwritten/whatever.. I don't really care
- Major resources are lecture notes, in-class questions, and homeworks
- Created and posted a study guide
- Short review on Wednesday

Solar Observation: Extra Credit

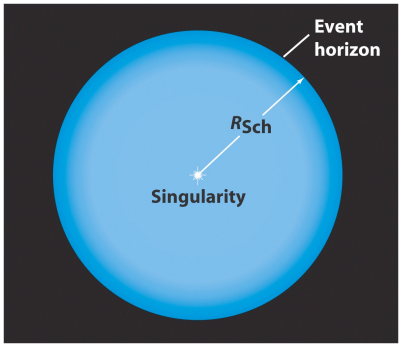
- Chance to see sunspots using the 12 inch in the dome
- Solar Observations:
  - Monday, Nov. 1st, 10:30am-3:30pm
  - Tuesday, Nov. 2nd, 10:30am-3:30pm
  - Wednesday, Nov. 3rd, 10:30am-3:30pm
  - Thursday, Nov. 4th, 10:30am-3:30pm
- Need to download form from class website before you go.
- Check webpage to make sure open (i.e. no clouds or rain)
- Due Nov 15th in class & worth 1% extra credit.

Outline

- Don't fall into a black hole!
  - Spaghettification
- Maybe black holes aren't black
  - Hawking radiation
- We have strong evidence of black holes
  - Accreting ones anyway

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

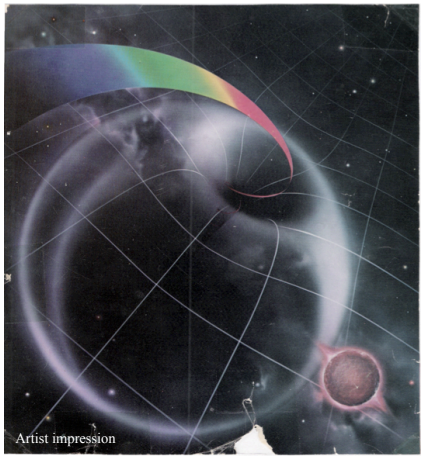


Black Holes

Lasciate ogni speranza,
o voi ch'entrate.

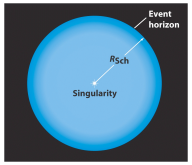
Abandon all hope,
you who enter here.

Dante Alighieri
(Divina Commedia-Hell)



Black Hole = Waterfall

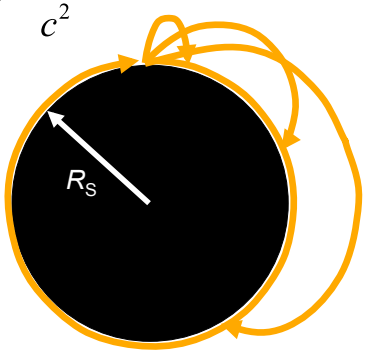
- Can think of it as trying to paddle up a waterfall.
- Space is falling into black hole faster than light, so light can paddle all it likes, but it's going down.
- Again, this only really close to the black hole, above the waterfall the water is smooth and you can paddle away.



Black Hole

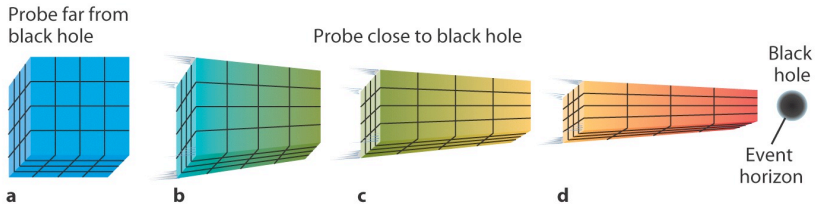
- More massive black hole ➔ larger the event horizon
  - $R_{Sch} = 3\ (M/M_{\odot})$ km
  - If object's mass in radius < R_{Sch} then it's a BH
  - For Earth $R_{Sch} = 1$cm
- The radius of no return
- Cosmic roach hotel
- As you get closer, your clocks appear to slow down to someone farther away.

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



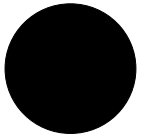
Probing a Black Hole

- 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



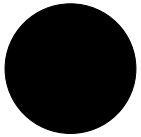
Death by Black Hole

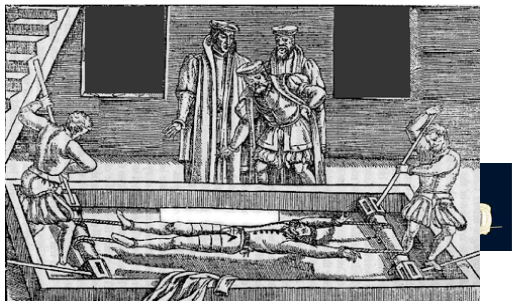
- Black holes themselves are not deadly… just a point.
- The warped space around them are deadly!
- Let's say you go toward one, feet first.
- This discussion is for solar mass-ish black holes.



Death by Black Hole

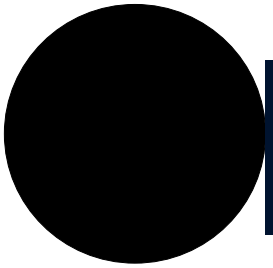
- At first you would not feel a thing….
- Microgravity… SOP for an astronaut.
- But as you get closer, the pull of gravity on your feet is stronger than the pull on your head– tidal forces.





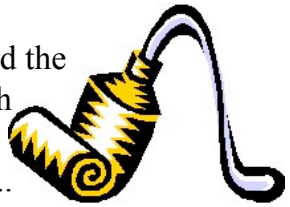
Death by Black Hole

- 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..



Spaghettification

- If someone falls into a black hole, they will get pulled apart.
- They turn into a stream of sub-atomic particles.
- Human into spaghetti.

- And all of this is still outside the event horizon!

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

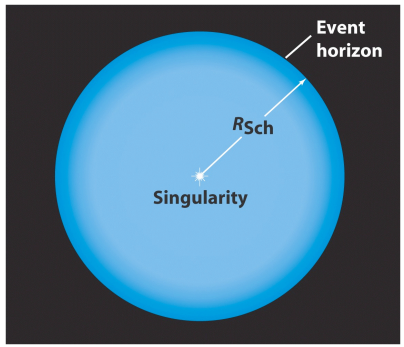
Question

As something falls directly into a black hole, it is stretched out because

a) orbital dynamics are circular, but under length contraction, everything will appear to be a thin long line.
b) the speed of light is constant.
c) of tidal forces.
d) that is how asteroids hit the Earth.
e) the laws of physics break down.

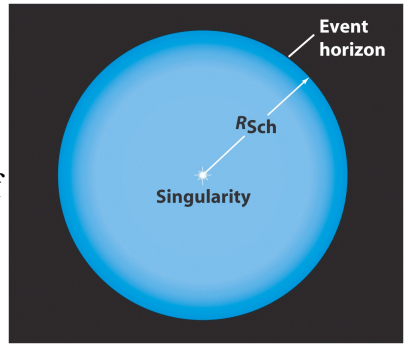
Life inside a Black Hole?

- From someone far away, material seems to take infinite time to fall in, clocks stop near the horizon.
- Once inside event horizon (R_{Sch}), no getting out
- All matter ⇒ center ⇒ point (?) "singularity"
- Known laws of physics break down



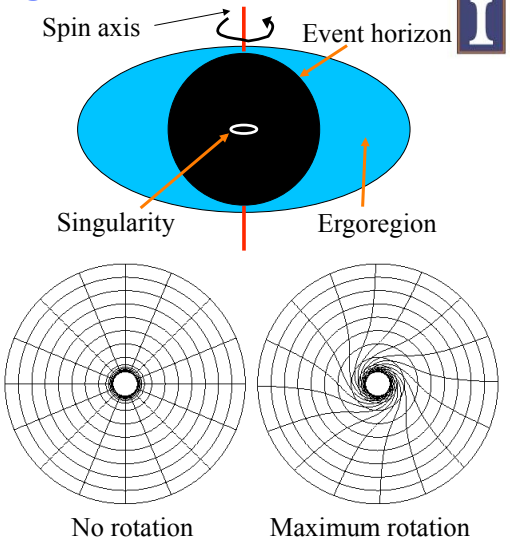
Life inside a Black Hole?

- A few points to make:
  - We know that all observers travel to center
  - Don't know what happens there
  - Regardless, certain that you die if you go in
  - In a way, it's not a relevant question, since can't get info out even if went in
  - Active subject of research!



Rotating Black Holes

- First studied by Roy Kerr in the early 1960s
- Region just outside horizon where you are dragged along by spacetime
- Can't stand still in ergoregion without falling in
- Singularity is a torus



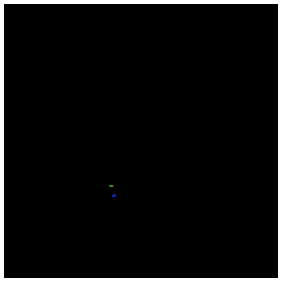
Question

The Schwarzschild radius of a black hole is the distance at which

a) the mass of the black hole is distributed; the outer rim of the back hole.
b) the speed of light is zero.
c) nothing can escape as the escape speed is greater than, or equal to, the speed of light.
d) pictures of penguins painting pandas become only red.
e) the laws of physics break down.

Approaching a Black Hole

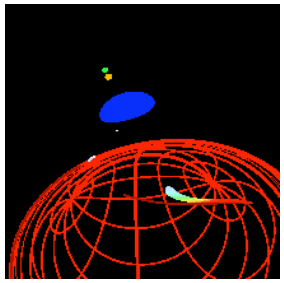
- A quad system with a black hole (30 $M_\odot$), a blue star (60 $M_\odot$), a yellow star, and a green star.
- Schwarzschild radius is marked in red.
- Up to last stable orbit $3R_{Sch}$



http://casa.colorado.edu/~ajsh/schw.shtml

Orbiting the Black Hole: Our POV

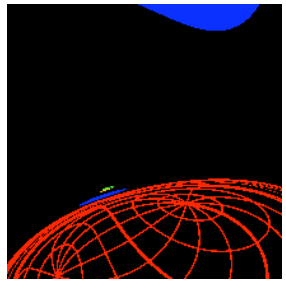
- Orbiting (unstable) at 2 R_{Sch}, we fire a white probe.
- The probe appears to freeze at the horizon of the black hole, joining the frozen images of probes fired on previous orbits. If we could see a probe clock, it would appear to halt.
- The changing colors of the probe show how it becomes more and more redshifted, from our point of view.
- From the probe point of view, it neither freezes nor redshifts, but careers on through the horizon toward the singularity of the black hole.



http://casa.colorado.edu/~ajsh/schw.shtml

Going In

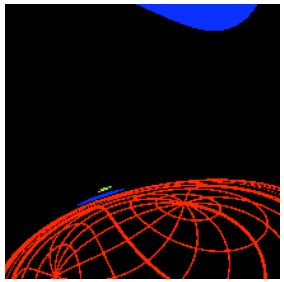
- Start out at 1.5 R_{Sch}, the last orbital position, requiring light speed.
- Inside of that, orbits go inside R_{Sch}
- Tidal forces at R_{Sch} for this object is about 1 million g's along a human.
- As we fall in, we free-fall quickly to the singularity
- The blue-shifted Universe is mostly x and γ-rays.
- The tidal force has become so strong that all images are concentrated into a thin line about (what is left of) our waist.



http://casa.colorado.edu/~ajsh/singularity.html

Going In

http://jila.colorado.edu/~ajsh/insidebh/schw.html

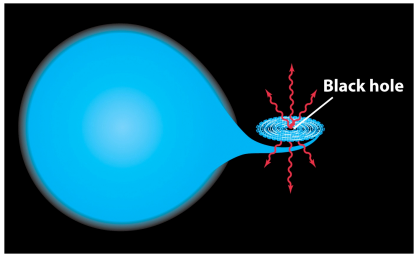


http://www.youtube.com/watch?v=GYKyt3C0oT4&NR=1

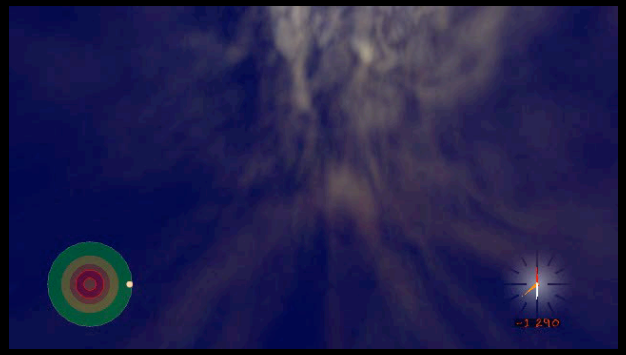
http://casa.colorado.edu/~ajsh/singularity.html

How To See A Black Hole

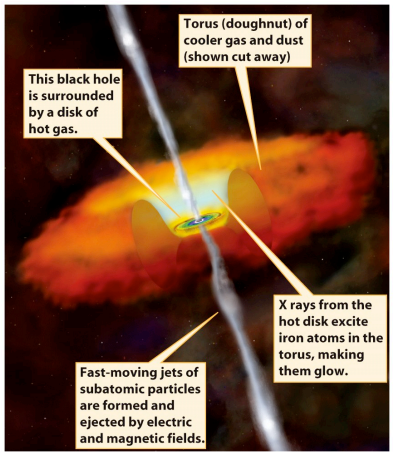
- If a black hole emits no light, how do we see it?
  - Have to look for ones with accretion disks!
- We look for interactions between the black hole and a companion
  - Black hole pulls mass from the companion which forms a disk
  - The gas in the disk is compressed and heated so that it gives off X-rays



Realistically?



Black Holes

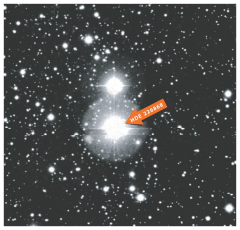


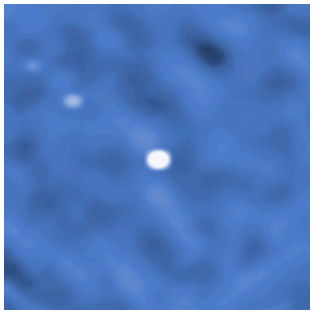
An artist's impression of Cygnus X-1

http://www.youtube.com/watch?v=MD5lOpxDEII
1:35-2:20

Cygnus X-1

- Binary system with unseen 7 solar mass companion
- Spectrum of X-ray emission consistent with that expected for a black hole
- Rapid fluctuations consistent with object a few km in diameter





Question

How do we detect a black hole without an accretion disk?

a) We can't easily.
b) X-rays, black holes are still very bright.
c) Infrared light since black holes are still at some temperature.
d) Optical light, watching the stars disappear.
e) Gamma-Rays in space, since gamma-rays are not affected by the atmosphere.

Hawking Radiation

- Black holes are not truly black!
- Quantum mechanical effects near event horizon cause them to produce blackbody-like radiation
- Temperature **increases** as mass **decreases**
- Too dim/cool to see for stellar-mass black holes