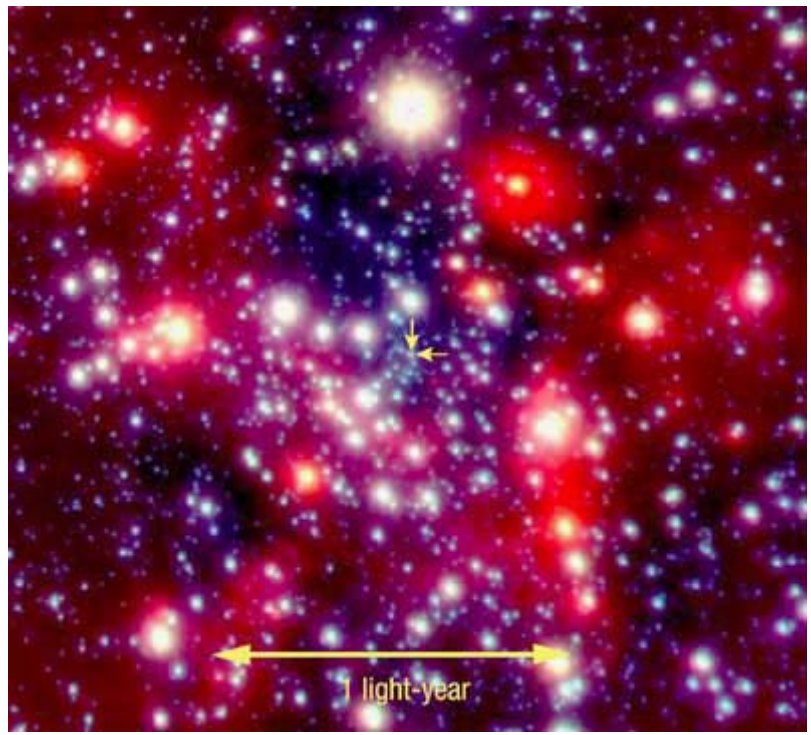
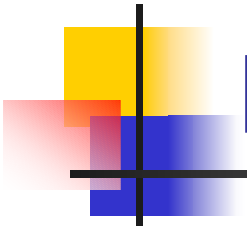
Black Holes and Gravity

April 7, 2003

1) Type II Supernova
2) Neutron Stars
3) Black Holes
4) More Gravity



http://www.hep.fsu.edu/~tadams/courses/spr03/ast1002/Lecture040703.pdf

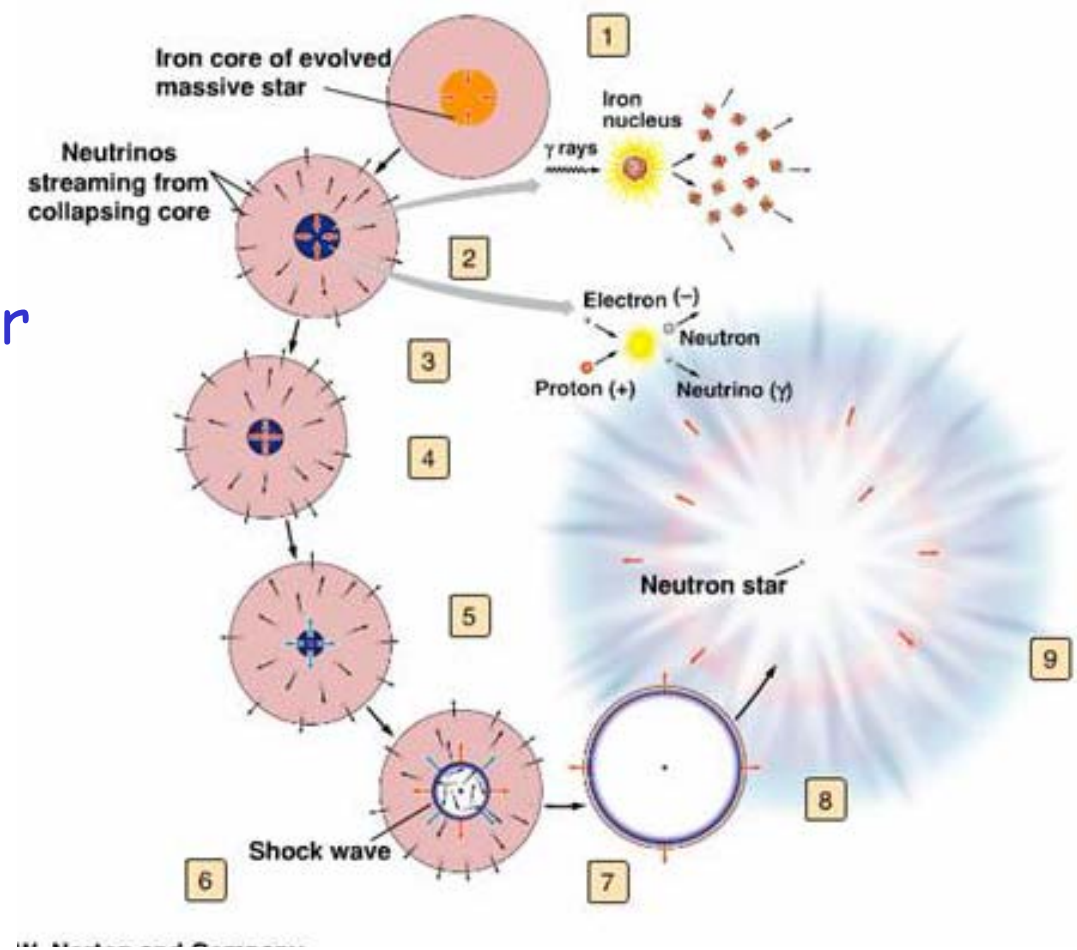


Review

- Galaxies
  - elliptical, spiral, irregular
  - globular clusters
- Parts of spiral galaxies
- Dark matter
  - rotational speed of galaxies
  - MACHOs or WIMPs?
- Star clusters

Type II Supernova

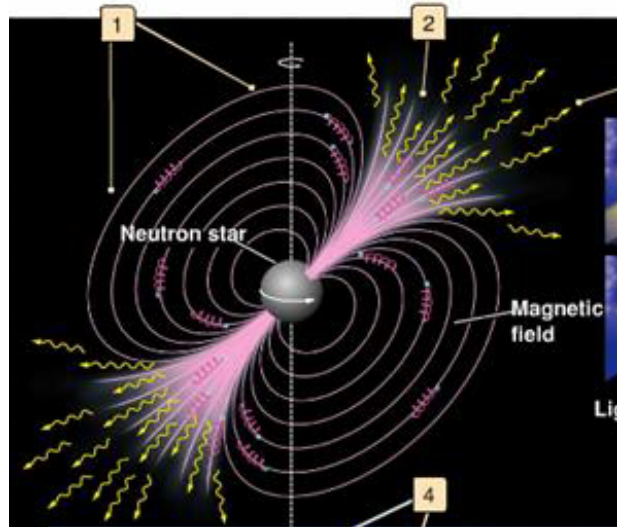
- Core collapses
- Density skyrockets
  - nuclei get so close together the nuclear force repels them
- Core bounces
  - particles falling inward sent back outward
  - up to 30,000 km/s
- Type II supernova



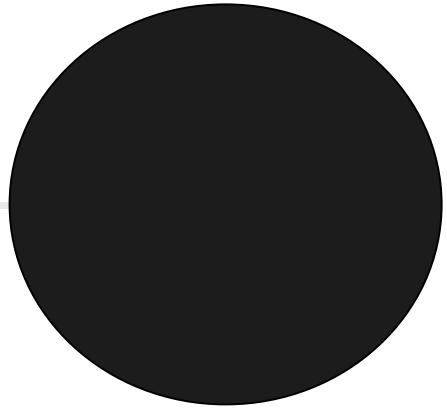
One heck of an explosion

A Neutron Star Is Born

- After the supernova explosion, a very dense core is left behind
- Nuclei are incredibly dense
  - as closely packed as inside of nucleus
  - 1 billion times density of Sun
  - as if the Earth were condensed to the size of Doak Campbell Stadium
- Called a neutron star
  - somewhat similar to white dwarf



Black Holes



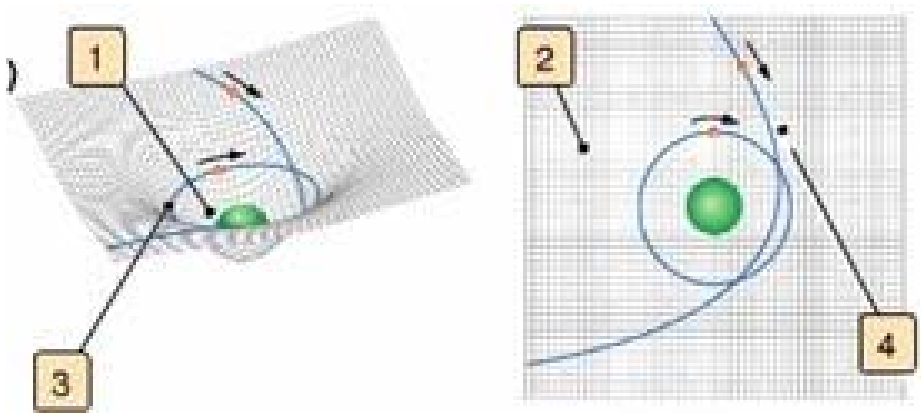
- If the neutron star is more than 3 solar masses, it will become a black hole
  - collapses to the densest material known
- Black holes have very interesting attributes
- We need to learn a bit more gravity…

General Theory of Relativity

- Developed by Einstein to handle gravity
  - Special Relativity didn't account for gravity
- Mass is a distortion of space-time
  - we live in 4 dimensional space
    - 3 space dimensions + time
  - mass distorts this space
- Effects
  - bending light
  - time dilation
  - gravity waves
  - more…

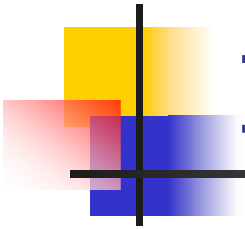
A New Way of Thinking

- Imagine a flat rubber sheet (or foam pad)
- Objects moving across sheet move in a straight line (Newton again!)
- Now place a heavy object on the sheet
  - the sheet distorts
- Now objects moving across the sheet will curve due to the distorted space



Interesting Effects

- Gravity has a number of interesting effects
  - besides keeping you from floating out of your chair
- Because space is distorted, even light will bend
  - must follow path across the sheet
- Time is also distorted
  - time appears to run slower closer to mass
  - GPS systems must correct for this



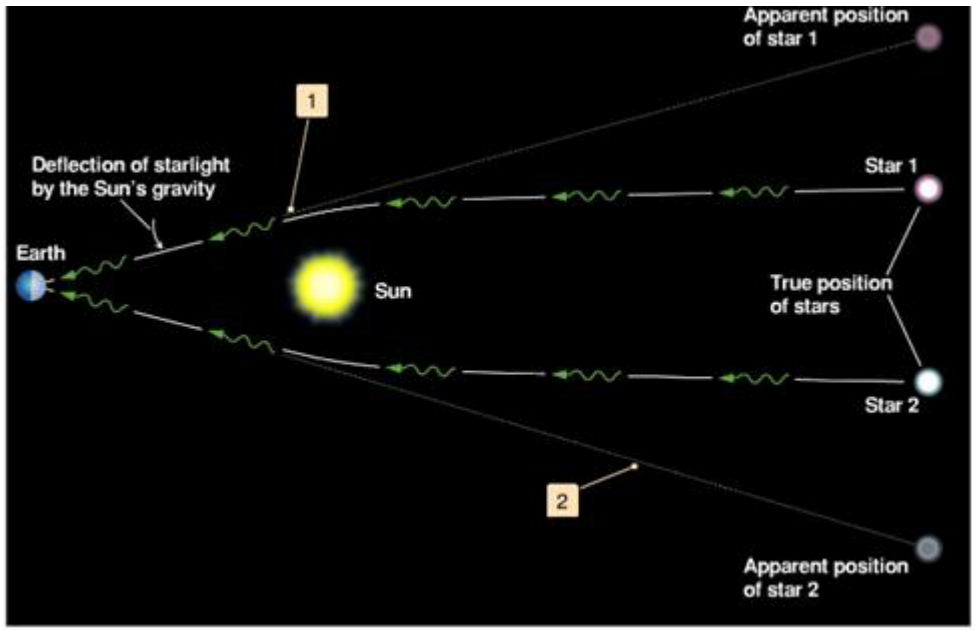
Interesting Effects

- Gravitational red-shift
  - light from a massive object will be red-shifted
    - can't tell difference between Doppler shift and gravitational shift
  - due to time being distorted
    - "light's clock" runs differently than our clock
- Gravity waves
  - collapsing masses send ripples through space time
  - various experiments are searching for gravity waves

Gravitational Lensing

- Bending of light by gravity
  - observed by measuring location of stars during solar eclipse
  - light passing near the Sun was bent, stars appeared farther apart

first demonstration of general relativity



Gravity and Black Holes

- Escape velocity – velocity necessary to escape gravitation pull of an object
  - Earth – 11 km/s
  - Sun – 618 km/s
  - as mass goes up or radius goes down, escape velocity increases
- Anything moving at less than escape velocity will eventually be pulled back to object
- What happens when escape velocity is greater than the speed of light?

Event Horizon

- If mass is large/dense enough, there is some radius at which escape velocity is larger than speed of light
  - not even light can escape the object
  - event horizon
- Anything within the event horizon is lost forever
- But remember, gravity outside the event horizon is the same as for a star of that mass

Schwartschild Radius

- Schwartschild radius
  - defines event horizon
  - maximum radius a black hole can be
  - for 1 M_{Sun}, it's about 3 km
  - for 2 M_{Sun}, it's about 6 km

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

  - G = gravitational constant, c = speed of light

Example

- For 3 x M_{Sun}:
  - $G = 6.67 \times 10^{-11}\ m^3/kg \times s^2$
  - $c = 3.0 \times 10^8\ m/s$
  - $M = 3 \times M_{Sun} = 5.97 \times 10^{30}\ kg$

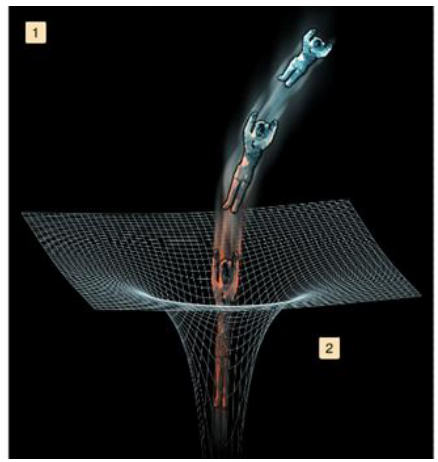
Black Holes

- From the viewpoint of general relativity, a black hole is an infinitely deep hole in space-time
  - called a singularity
- Properties of black holes
  - mass – all the material which is inside the event horizon
  - angular momentum – from material which fell in
  - charge

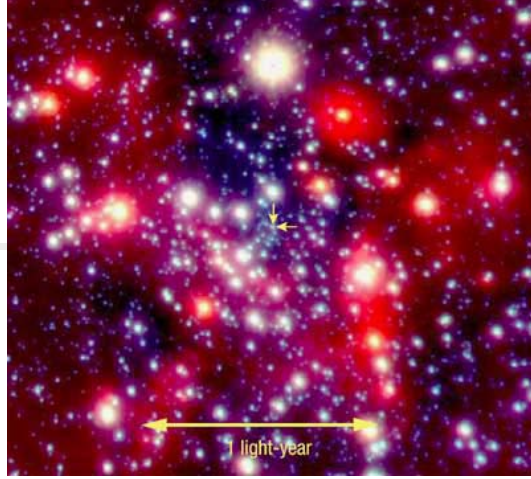
ALL OTHER INFORMATION IS LOST!

Falling Into A Black Hole

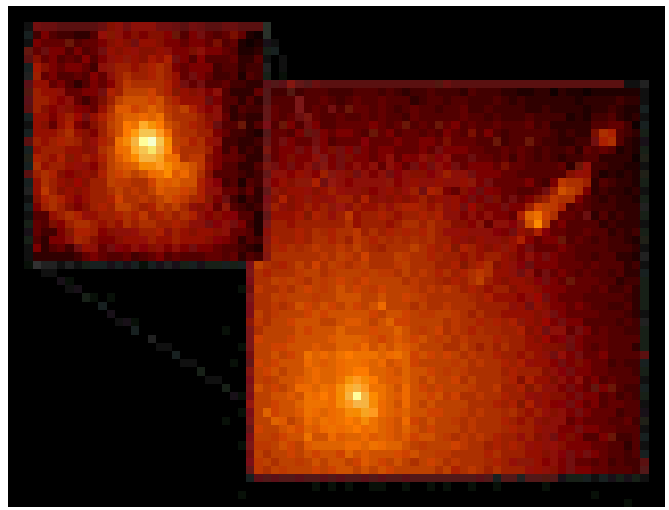
- Imagine a clock falling into black hole
- Appears to run slower – longer between ticks
- Appears to slow down its fall
- Gets "redder"
  - longer wavelength
  - Gets harder to see
- Tidal forces tear it apart
- At event horizon
  - length between ticks is infinite, wavelength is infinite, appears to stop (but we can't see it anyway
- To the clock it just keeps ticking away normally until torn apart or enters the singularity



Observing Black Holes



- Impossible to "see" directly
- Gravitational lensing is small
- Easiest to see if lots of material around
  - binary system
- Cygnus X-1
  - large visible star (B class)
  - invisible partner
  - strong x-ray emitter
  - mass of partner must be at least 8 solar masses and very small
- Colliding black holes?
- Black hole at center of galaxy?



Summary

- Black holes are the densest objects in the Universe
- Anything which falls within the event horizon is lost
  - Schwartschild radius
- Gravity and general relativity
- Remember, the exam is on Weds.