Massive Stars After The Main Sequence
Explosions, Neutron Stars and BlackHoles

It’s all about gravity…….

• Quiz #4 next class (wed April 2) covers Lectures 9-16
• Exam #2 1 week from today (April 7th), covers Lectures 9-16 (everything about stars).
• “Sample exam”/review sheet posted soon.
• Review sessions (Me on Wednesday 7-8 pm: Ella on Thursday 7-8 pm)
• Next assignment is posted (Lab #1 write-up, due April 14th (mon after exam).
Stellar Corpses

A type II supernova leaves behind the collapsed core of neutrons that started the explosion, a neutron star.

If the neutron star is massive enough, it can collapse, forming a black hole...

Interior Structure of a Neutron Star

- Rigid crust—perhaps iron
- Neutron superfluid in interior
- Approx. a few hundred meters
- Approx. 10 km (about 6 miles)
The Escape Velocity Limit

- The velocity necessary to avoid being gravitationally drawn back from an object (the escape velocity) is:
  \[ V_{\text{esc}} = \sqrt{\frac{2GM}{R}} \]

- Note that as \( R \) decreases, the escape velocity increases.

- A white dwarf’s escape velocity is around 6000 km/s, ten times faster than the Sun’s.

- (A white dwarf is around 100 times smaller than the Sun)

- Also recall that nothing can travel faster than the speed of light, \( c \), or \( 3 \times 10^8 \) m/s.

- If a stellar core is compressed so much that its radius is smaller than the Schwarzschild radius:
  \[ R_S = \frac{2GM}{c^2} \]

- The core would become a black hole.

What would happen to the earth if the sun were instantly turned into a solar-mass black hole?

- A) We would fall into the center of the BH.
- B) We would instantly be turned into spaghetti.
- C) We would immediately be vaporized.
- D) Nothing, the Earth would continue to orbit the BH, (although it would be cold.)
Mass Warps Space

- Mass warps space in its vicinity
- The larger the mass, the bigger "dent" it makes in space
- Objects gravitationally attracted to these objects can be seen as rolling "downhill" towards them
- If the mass is large enough, space can be so warped that objects entering it can never leave – a black hole is formed.

Black Holes

- If a stellar core is massive enough, it will not stop collapsing when it becomes a neutron star.
- The radius of the core continues to shrink, and density continues to increase
- Eventually the core is compressed to a single point, called a singularity.
- Again, nothing can escape from this black hole. Once something, including a photon, crosses the Schwarzschild radius (or event horizon), escape is impossible.
You may be asking, “If light cannot escape a black hole, how can we see one?”

If a black hole is in orbit around a companion star, the black hole can pull material away from it.

This material forms an accretion disk outside of the event horizon and heats to high temperatures.

As the gas spirals into the black hole, it emits X-rays, which we can detect!
Einstein predicted that not only space would be warped, but time would be affected as well.

The presence of mass slows down the passage of time, so clocks near a black hole will run noticeably slower than clocks more distant.

The warping of space has been demonstrated many times, including by observations of the orbit of Mercury.

The slowing of clocks has been demonstrated as well!
Gravitational Redshift

- Photons traveling away from a massive object will experience a gravitational redshift.
  - Their frequency will be shifted toward the red end of the spectrum