Wednesday, Oct. 22

Syllabus, class notes, and homeworks are at: <u>www.as.utexas.edu</u> \rightarrow courses \rightarrow AST 301, Lacy

Reading for this week: chapter 10

The second exam will be this Friday. If you didn't get a review sheet on Friday, there are more in the homework return boxes.

The Wednesday help session is in GRG 424 at 5:00 (for the entire semester).

Topics for this week

- Describe how a star (or protostar) changes if it generates more (or less) energy by nuclear fusion than it radiates from its surface.
- Describe the changes that occur near the center of a star as it changes from a main-sequence star into a red giant.
- Describe how a red giant becomes a planetary nebula and a white dwarf.
- How does the pressure inside a white dwarf differ from normal gas pressure?
- How does nuclear fusion inside of very massive stars differ from the fusion that will occur inside of the Sun?
- How do the processes that occur inside of massive stars lead to supernova explosions?

Becoming a Red Giant

- (The complete explanation for how a main-sequence star becomes a red giant is complicated, and I'm not really giving you the whole story. But the conclusion is right. Don't worry if you don't follow all of the explanation.)
- When all of the hydrogen in the core of a main-sequence star is all turned into helium, fusion will stop in the core, and the core will contract and heat up.
- Fusion will continue in a shell around the helium core, and will generate more energy than fusion in the core did.
- The extra energy going out from the core+shell will make the envelope expand and cool off.

Red Giants

When the Sun becomes a red giant, its radius will increase to about ½ AU, and it will become more than 100 times more luminous than it is now.

Life will not be pleasant on Earth.

The core of the Sun will be mostly helium, and will continue to contract and heat up.

When the temperature in the core reaches about 10⁸ K (about 1 million years after the Sun leaves the main sequence), helium will begin to fuse to make carbon.

A Red Giant with helium fusion

- When helium fusion starts generating energy in the core of a red giant, the core expands and hydrogen fusion in the shell around the core slows down.
- As a result, less total energy is being generated, and the envelope contracts and warms up some.
- But pretty soon all of the helium in the core is converted into carbon and fusion stops again in the core.
- Then the core again contracts, surrounded by two shells, one with He \rightarrow C fusion, and one with H \rightarrow He fusion.
- The envelope again expands and cools off.

Is stellar evolution just a theory? Or is it even a (scientific) theory?

- For a hypothesis to be a scientific theory it must be testable.
- Almost all of stellar evolution occurs so slowly that we cannot watch it happen.
- Our tests of stellar evolution must be indirect.
- The primary test involves observing stars in a star cluster, which we have reason to believe all formed at the same time, so have the same age.
- Stellar evolution theory predicts the pattern they should form on an H-R diagram.







Have we proved the theory right?

- The theory of stellar evolution provides a very good explanation for the H-R diagrams of star clusters.
- We have tested the theory and it passed the test.
- But for a hypothesis to be a scientific theory it must be testable, and a test only makes sense if it is conceivable that the theory will fail.
- In that sense, we can never prove a scientific theory right.
- If a hypothesis can be proved right, it may be a valid mathematical or logical theorem, but it's not a scientific theory.
- We are confident that the theory of stellar evolution is essentially correct, but we will keep testing and refining it.

Becoming a Planetary Nebula

- When the red giant has a contracting carbon core and two fusion shells, it is generating so much energy that radiation pressure from the high energy light trying to get out of the star pushes away the envelope, exposing the very hot core.
- The ultraviolet radiation from the core ionizes and heats the expelled envelope, causing it to glow like our gas lamps.
- The glowing envelope is called a planetary nebula, because it looks somewhat like a planet through a small telescope. It actually has nothing to do with planets.



Death of a Planetary Nebula

After 10,000-20,000 years the gas in a planetary nebula spreads out so that it no longer is bright enough to be seen easily.

The core of the red giant is left behind.

Without its envelope it radiates energy away faster than it generates it by fusion.

From what I've told you, what should happen then?

What happens

- You should expect it to contract and heat up so fusion will go faster.
- If loss of energy made the star contract, contraction would heat it.
- But when a white dwarf loses energy it does not contract.

Instead it cools off and fusion stops.

The reason it doesn't contract and heat up is that it has an unusual form of pressure: electron degeneracy pressure, which doesn't depend on temperature.

Electron degeneracy pressure

- Pressure in a gas is caused by the particles in the gas bouncing off of the walls of its container.
- In a normal gas the speed of the particles is determined by the temperature.
- In a very dense gas of electrons, quantum mechanics provides an additional reason for the electrons to move.
- The uncertainty principle says that if an electron is restricted to a small region of space it must move rapidly, even if it is cold.
- If a degenerate gas loses energy, the electrons don't slow down, so the pressure doesn't decrease.
- So the star doesn't contract, and as a result it doesn't heat up and restart nuclear fusion. It just cools off.

Radiation Pressure

A different kind of pressure pushed the envelope away from the red giant to form a planetary nebula.

Radiation pressure is the force exerted by photons when they bounce off of matter.

It is normally too small to measure, but there is so much radiation inside of a red giant that it can be stronger than the red giant's gravity.