Monday, Oct. 27

Syllabus, class notes, and homeworks are at:
www.as.utexas.edu → courses → AST 301, Lacy

Reading for this week: chapter 11

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

New Schedule

Aug 27:	Ch 1+App A	The Scale of the Cosmos
Sep 3:	Ch 2+3	The Sky, Cycles in the Sky
Sep 8:	Ch 4	The Origin of Modern Astronomy
Sep 15:	Ch 5	Telescopes
		Sep 19: Exam #1, Ch 1-5
Sep 22:	Ch 6	Starlight and Atoms
Sep 29:	Ch 7	The Sun
Oct 6:	Ch 8	The Family of Stars
Oct 13:	Ch 9	The Formation and Structure of Stars
Oct 20:	Ch 10	The Lives and Deaths of Stars
		Oct 24: Exam #2, Ch 6-10
Oct 27:	Ch 11	Neutron Stars and Black Holes
Nov 3:	Ch 12	The Milky Way Galaxy
Nov 10:	Ch 15	Cosmology
Nov 17:	Ch 16	The Origin of the Solar System
Nov 24:	Ch 17	The Terrestrial Planets
Dec 1:	Ch 18	The Outer Solar System
		Dec 5: Exam #3, Ch 10-12,15-19

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 leftover core of the red giant is called a white dwarf.

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.

White Dwarfs

Because the pressure of degenerate electrons doesn’t decrease when they lose energy, the core of the red giant doesn’t contract, and so it doesn’t heat up.

It simply cools off.

Fusion stops and never starts up again.

It is then a white dwarf.

White dwarfs have masses ½ - 1 times that of the Sun.

They start out very hot, about 100,000 K, but cool off.

Their sizes are about like that of the Earth.

Density of matter in a white dwarf

Density = mass / volume

The density of the Sun is about equal to the density of water, and the mass of a white dwarf is about equal to the mass of the Sun.

The radius of a white dwarf is about 100 times smaller than the radius of the Sun.

How does the volume of a white dwarf compare to the volume of the Sun?

A. 100 times smaller

B. 1,000 times smaller

C. 10,000 times smaller

D. 1,000,000 times smaller $(100)^3 = 1{,}000{,}000$ (10^6)

Density of matter in a white dwarf

Density = mass / volume

The density of the Sun is about equal to the density of water, and the mass of a white dwarf is about equal to the mass of the Sun.

The volume of a white dwarf is about 1,000,000 times smaller than the volume of the Sun.

How does the density of a white dwarf compare to the density of the Sun?

Density of matter in a white dwarf

Density = mass / volume

The density of a white dwarf is about 1,000,000 times the density of the Sun or the density of water.

The density of a white dwarf is about 10^6 grams/cubic cm, or 1 ton/cm^3, or 16 tons/cubic inch.

Evolution of high mass stars

More massive stars burn their fuel faster.

Higher gravity causes higher pressure, which means higher density and temperature, which causes faster fusion.

They also don't lose mass as easily.

Higher gravity prevents radiation pressure from removing the envelope as quickly.

So they get farther into the sequence of fusion reactions, making additional elements.

Life stages of an 8 solar mass star

H → He in core

contracting He core, H → He in shell

He → C in core, H → He in shell

contracting C core, He → C, H → He in shells

C → Mg in core, He → C, H → He in shells

contracting Mg core, C → Mg, He → C, H → He in shells

…..

contracting Fe core,
Si → Fe, Mg → Si, C → Mg, He → C, H → He in shells

Each successive nuclear reaction requires higher temperature and generates less energy, so keeps the core in thermal equilibrium for a shorter time.

The last stage

Fusion of iron absorbs energy instead of releasing it.

That makes the Fe core unstable, and it collapses.

As the core collapses, electrons fuse with protons in the iron nuclei: $p^+ + e^- \rightarrow n + \nu$

But this reaction absorbs even more energy, decreasing the pressure even more.

The collapse stops when the density reaches that of an atomic nucleus, and the core is made of neutrons.

Neutron degeneracy pressure (and repulsion between neutrons when so tightly packed) stops the collapse.

A Supernova

The shells fall onto the core and also fuse to make neutrons.

The envelope falls onto the neutron core and bounces.

It thrown off at speed as high as 1/10 the speed of light.

The hot exploding gas can emit as much light as 10^8 stars for a few days.

This happened in the Large Magellanic Cloud (a group of about 10^8 stars about 60,000 pc from here) in 1987.

(Is it really right to say the explosion happened in 1987?)

Supernova Remnants

No supernova has been seen any closer to us since the invention of the telescope. (Tycho saw one without a telescope.)

But we can see the remnants of nearby explosions.

And we see supernova explosions in more distant galaxies.

How were the atoms in your body made?

The hydrogen atoms (or the protons and electrons they are made of) were made in the big bang.

Many of the helium atoms in the Universe were also made in the big bang.

The other atoms were made inside of stars.

When the Sun becomes a red giant, carbon and maybe oxygen will be made in its core.

But the core will be the left-over white dwarf.

The gas put back out into space will come from the red giant's envelope, which hasn't been hot enough for fusion to make new elements.

Most of the elements in space were put there by supernova explosions.