AST 301
Introduction to Astronomy

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Topics for this week

How do the life stages of a high-mass star differ, and why?

Describe the events that lead up to the two types of supernova.

What is a white dwarf?

- What is a typical white dwarf mass, radius, composition?
- How does pressure in a white dwarf differ from normal gas pressure?

What is a neutron star?

- How big is it, what is it made of?
- How could one form?

What is a black hole?

Office hours

I will be at a meeting during my normal office hours this week.

I will not have office hours tomorrow (Tuesday).

I will probably have an office hour Wednesday afternoon.

How does the life story of a massive star differ?

For stars up to about 8 M_{sun}, the story is like that for the Sun. It just runs faster. For each doubling of the mass, the luminosity goes up by about 10, so fusion must be running 10 times faster, so it uses up its fuel about 5 times faster.

An 8 M_{sun} star will use up it fuel in about $(8 / 10^3) \times 10^{10}$ yr $= 8 \times 10^7$ yr.

Even more massive stars burn out even more quickly, and they also die differently.

The reason is that their greater gravities prevent them from pushing off their envelopes to become planetary nebulae, so they can go through more nuclear fusion reactions.

Life stages of a 10 solar mass star

H → He in core for ~60 Myr

contracting He core, H → He in shell for ~6 Myr

He → C in core, H → He in shell for <1 Myr

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 collapse of a massive star

Stars more massive than about 8 M_{sun} can go through a series of fusion reaction leading up to iron.

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 Fe 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.

The dense ball of neutrons is a neutron star.

Type II Supernova

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

The envelope falls onto the neutron core and bounces.

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

The hot exploding gas can emit as much light as 10^{10} Suns for a few days. (Even more energy comes out in the form of neutrinos, but they are very hard to detect.)

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

Around supernova 1987A, before and just after the event

AAO image reference AAT 50. « Previous || Next »

Quiz

I said that the supernova in the Large Magellanic Cloud, which is 60,000 pc from here, occurred in 1987.

That's when we saw it, but when did it actually explode?

Figure it out and compare answers with your neighbors.

Hint: a parsec is about 3 light-years.

Testing the theory

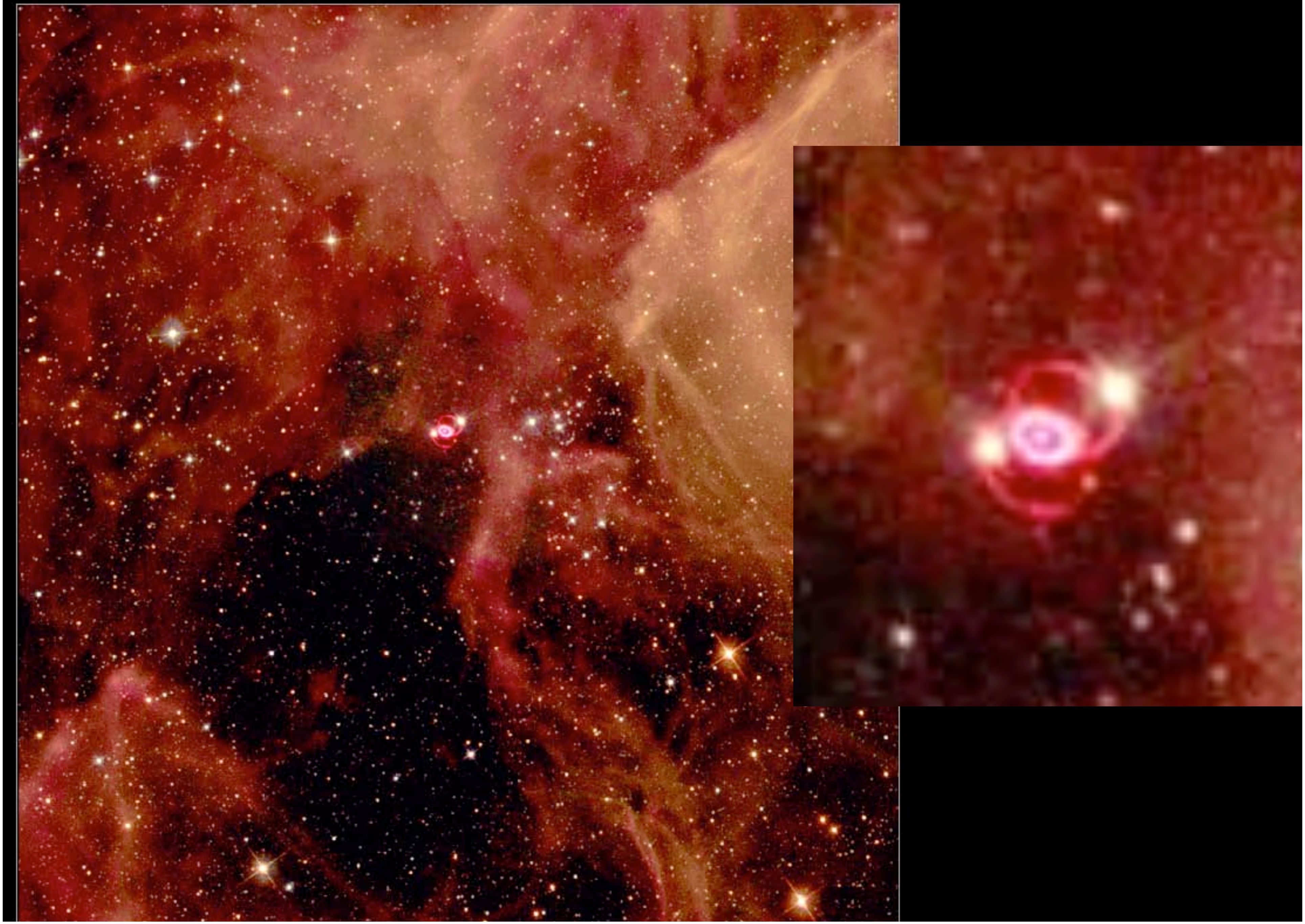
What kind of a star was it that exploded in the Large Magellanic Cloud?

We can see the star on photographs taken before the explosion. We know it’s the right star, since it’s not there in photos taken after the explosion.

It was a luminous blue star, near the top end of the main sequence.

Is this what the theory predicts?

Supernova 1987A



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 or during explosions 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.

After the planetary nebula

A planetary nebula can be seen for about 10,000 years.

After that, it expands and becomes faint.

And the central star (the core of the red giant) cools off and no longer lights it up.

The central star is then called a white dwarf.

Why does the white dwarf cool off?

It has lost its envelope, which served as a blanket to keep its heat in.

But that means it can lose heat faster. Shouldn't it then contract and heat up?

It turns out it doesn't contract because it is no longer a normal gas.

Normal gas and degenerate gas

Pressure is the force a gas exerts on its surroundings.

It is caused by the motion of the atoms.

Or in a star, it is mostly the free electrons that cause pressure, since it is too hot for atoms to hold onto their electrons.

In a normal gas, the electrons’ motion is caused by heat.

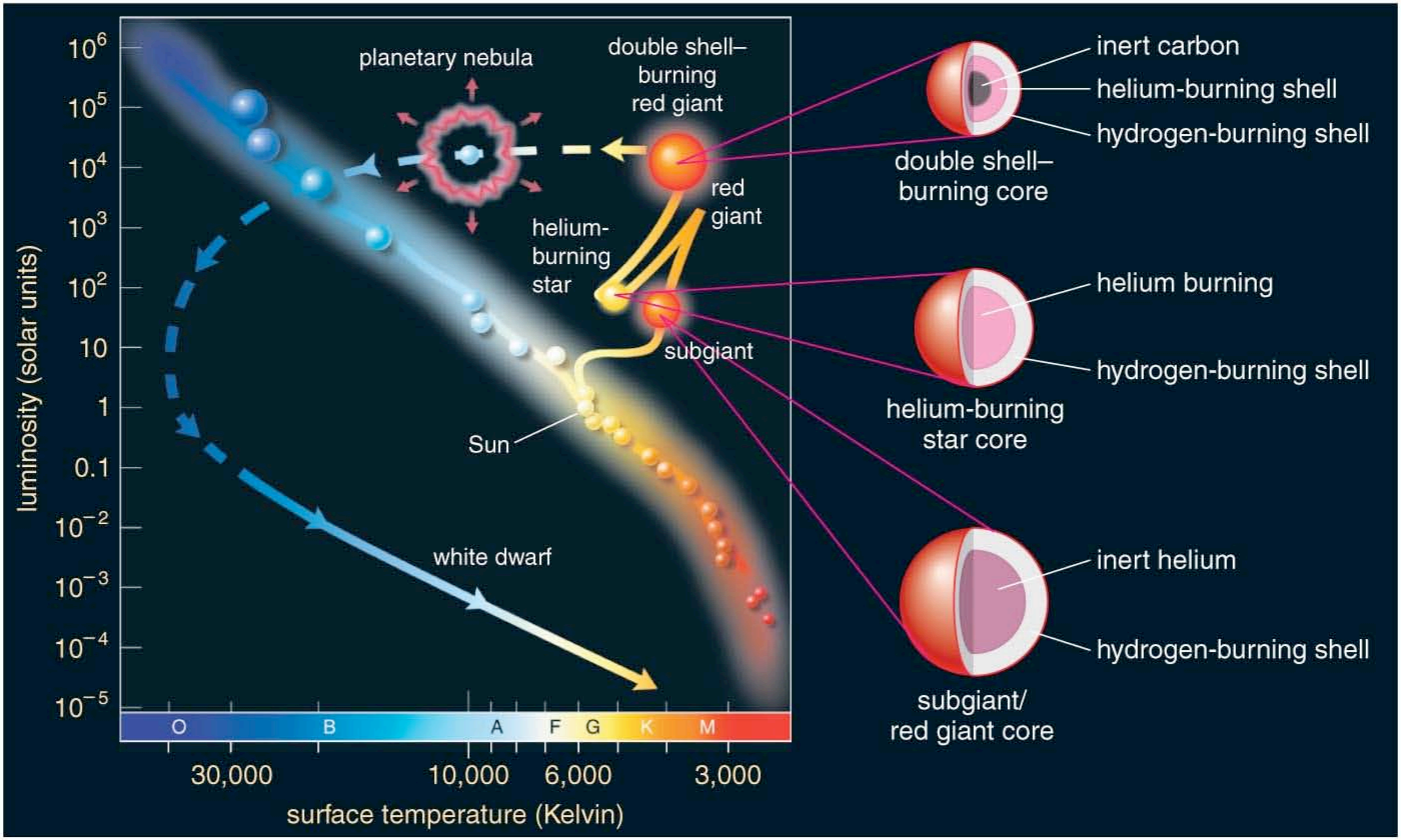
But at very high densities, the wave properties of the electrons become important, and the electrons must move fast even if the temperature is low.

The result is that when a white dwarf loses energy, its electrons don’t slow down, so its pressure doesn’t decrease, so it doesn’t contract.

So it cools off instead of heating up.

Display stellar evolution with the HR diagram

(pictures on right show only the inner parts of the star)



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

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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.

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