Technology Services > Astronomy & Cosmology > Stellar Astrophysics > What happens to stars smaller than ours?

What happens to stars smaller than ours?

Cheman - What happens to stars smaller than ours?

What happens to stars smaller than ours? (eg - red dwarfs) Do they swell to red giants and lose their outer layers or do they simply shrink, getting hotter as they do so to form white dwarfs? Thanks.

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quartodeciman - What happens to stars smaller than ours?

There used to be a number of good programs available for simulating stellar evolution theory based on selected protostar mass. They seem harder to find online now.

link to Cornell U. stellar evolution applet for Astronomy course --->
http://instruct1.cit.cornell.edu/courses/astro101/java/evolve/evolve.htm

(don't forget to "clear" before repeating the same size star)

Do the yellow star (closest to 1 solar mass) case, then compare to one of the red dwarfs and maybe a green/blue star (much larger than 1 solar mass).

As the text states, red dwarfs tend to stay on the main sequence (uniform hydrogen->helium production at the stellar core) until they run out of hydrogen fuel. If the protostar mass was way too small, the protostar won't make it to the main sequence at all (it becomes a brown dwarf star or planet).

Historically, the mass bound in a protostar has been considered the primary determinate of stellar evolution. But there are other factors involved too: initial content of elements other than hydrogen, layer mixing, instabilities (both periodic and catastrophic) and so on.

Just for completeness: protostars "condense" inside enormous gas cloud nebulosities, the process of which is still being investigated. It seems to start with separation from the enveloping nebula followed by collapse under gravitation until pressure balance is achieved.

Labguy - What happens to stars smaller than ours?

That site and simulation was interesting, but on the ones I tried, 1.5 Ms to 15 Ms, it ended with the giant stages and didn't show the expulsion (to planetary nebulae) and the move from there to the bottom and left to the white dwarf stage (for those that wouldn't supernova; up to ~ 8.0 Ms). ..(?)

quartodeciman - What happens to stars smaller than ours?

Alas! No one has worked this into a comprehensive demonstration of stellar evolution, including all the finales. At least no one has placed such a demonstration online and advertised it AFAIK. Now that would be really neat!

Cheman - What happens to stars smaller than ours?

So, what does happen to a red dwarf? does it run out and shrink to white dwarf, swell and lose its outer layers, etc?

quartodeciman - What happens to stars smaller than ours?

what does happen to a red dwarf?I checked with my textbook (Kartunen et al.,Fundamental Astronomy,Springer (1987). It's not so current, but things probably haven't changed that much concerning low mass stars.

I chirped before:red dwarfs tend to stay on the main sequence (uniform hydrogen->helium production at the stellar core) until they run out of hydrogen fuelI must alter that answer a bit. There is a threshold of opacity about 26% of a solar mass.

Below 26% of a solar mass on the main sequence (a very red dwarf star), the entire star is opaque to the radiation generated in the core and the material is entirely convective (hotter material circulates with cooler material). Therefore, all of the hydrogen gets a chance to convert to helium in the core and the process runs very, very slowly and smoothly. As the very red dwarf slowly contracts, the surface heats up slowly, which means it crawls a bit up the main sequence.

When practically all of the hydrogen has been converted the star becomes a degenerate helium white dwarf (not necessarily "white"-colored) star, gradually sliding horizontally off the main sequence to higher temperature (but not higher luminosity).

At and above 26% of a solar mass on the main sequence (less red-orange-yelloworange-yellow dwarf star) the core is transparent and transfers its radiation to an opaque convective outer envelope. Only the hydrogen in the core gets converted to helium in this phase. A helium core develops and eventually shrinks to degeneracy (can't expand even with higher temperature). The outer envelope expands and the star leaves the main sequence along an upward track. The lower part of the envelope is heated up and there starts a shell of hydrogen->helium processing above the helium core. The outer atmosphere expands and the temperature moves rightward to red temperature with higher luminosity(red giant phase). Next, Helium->Carbon conversion ignites in the core. A helium flash occurs, throwing the core out of degeneracy. Later, the outer envelope gets ejected and may form a planetary nebula around the star. The remnant of total {EDIT}carbon and {/EDIT}helium produced becomes a white dwarf. All this proceeds at a much faster rate than the (boringly) slow process in the first case.

However, at about 150% of a solar mass, another threshold is crossed. Things get much more complicated, with hotter interior temperatures, more elaborate phases of nuclear conversion and much faster evolution. And the Chandrasekhar limit has been crossed: the star must ultimately blow up. But this is no longer about red dwarf stars.

By the way, a star must have mass at least 8% of a solar mass to make it to the main sequence at all.

Labguy - What happens to stars smaller than ours?

Mostly agreed with a post above except for a little expansion and small correction:

However, at about 150% of a solar mass, another threshold is crossed. Things get much more complicated, with hotter interior temperatures, more elaborate phases of nuclear conversion and much faster evolution. And the Chandrasekhar limit has been crossed: the star must ultimately blow up.

Stars from the 0.08 Msun minimum threshold (to form a star at all) up to stars of about 1.25 Msun have a core temp. < 16 million K and fuse H to He mostly by the Proton-Proton Chain process. Our sun's core is ~14.5 million K. Above 16 million K, the predominant H fusion process is the CNO Cycle. Here we are talking about Main Sequence stars, before He fusion starts at much higher temperatures; approaching 100 million K. He burning is by the Triple-Alpha process, and all three of these fusion reactions are nicely explained at:

http://www.shef.ac.uk/physics/people/vdhillon/teaching/phy213/phy213_fusion3.html

At 1.5 Msun mentioned in the quote above, the star would have a core temperature of about 19 million K (and the CNO Cycle), but the mention of the Chandrasekhar limit and its result (supernova) is not correct. Here's why, and I'm posting it because the "Chandrasekhar limit" has been mentioned here on PF forever but often in the wrong, or mis-understood, context.

When Chandrasekhar was on the boat to England in 1930-x (?) he calculated the effects of gravity against electron degeneracy pressure and came up with the famous limit of ~1.44 Msun above which any mass, including White Dwarf stars, would further collapse. In most cases we know of today this would be into a neutron star. He also calculated another "limit" of ~3.2 Msun above which any mass would collapse again; black hole. But, these masses were not, and had no direct relation to, a star's initial, or main sequence mass.

As main sequence stars evolve, and no two are exactly the same, they go through various fusion reactions dependant upon core temperatures and various degrees of expansion into giants / supergiants, etc. Almost all star types go through some process of mass ejection, mass loss CME's, etc. even including mass blasted away by way of a supernova (either type). It is only the mass of the stellar remnant (core) after mass ejection that we need to consider as to when Chandra's Limit(s) would apply. As a general rule, which I happen to hate, a star of less than about 5 Msun would either never form a core of >1.44 Msun or would eject enough mass so that any remaining core would still be less than that limit. A lot of this was posted in the recent topic about Planetary Nebulae.

Stars from ~ 5-10 solar masses (main sequence) would have a remaining core of 1.44 or more and collapse into neutron stars. Above about 10, there would usually be enough mass in the remaining core to go supernova, and the core after even that blast would still be over 3.2 solar masses and do the black hole thing.. :eek: Most books for this purpose usually just state an original, main sequence mass of 8 solar masses or less which would end up as white dwarfs, not neutron stars.

[Edit]:
"General rules" don't cut the mustard. From one site we get:
"The stars that eventually become neutron stars are thought to start out with about 15 to 30 times the mass of our sun. These numbers are probably going to change as supernova simulations become more precise, but it appears that for initial masses much less than 15 solar masses the star becomes a white dwarf, whereas for initial masses a lot higher than 30 solar masses you get a black hole instead." [End edit]

quartodeciman - What happens to stars smaller than ours?

Thank you for the correction about the Chand. limit, Labguy, and thanks for joining the discussion.

I fooled myself reading the Karttunen text's double-page evolution tree diagram and accompanying text in composing my reply. It shows a branch at M >=1.5 solar mass but only carries it forward to finale for 3<=M<15 and M>15 cases. As shown, both subcases end up supernovae.

I suppose a more thorough and up-to-date chart would require a lot more pages.

hydrogen and helium burning

We turn now to look at the most important nuclear reactions which occur in stars.

hydrogen burning reactions

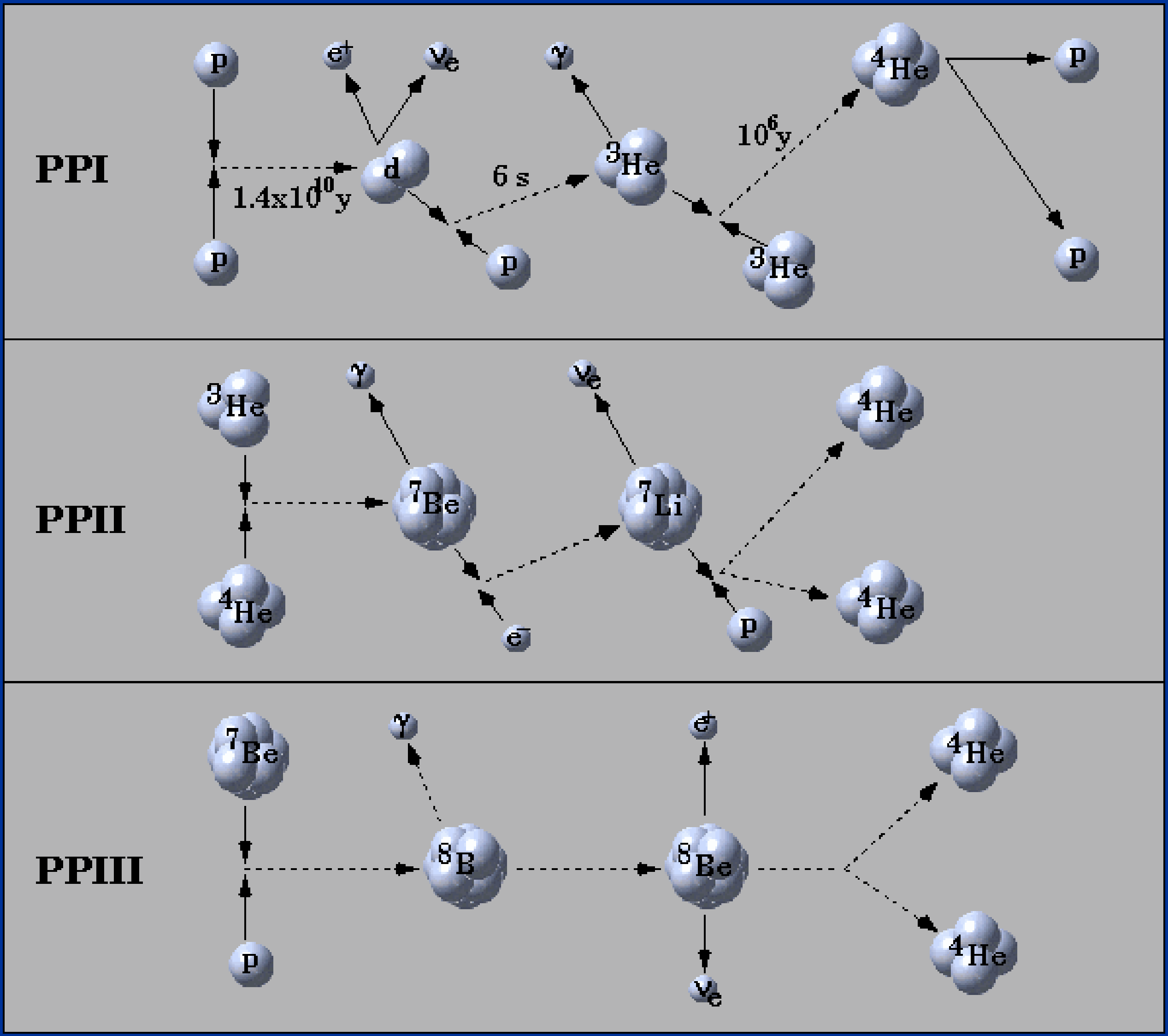
The most important series of fusion reactions are those converting hydrogen to helium in a process known as *hydrogen burning*. The chances of four protons fusing together to form helium in one go are completely negligible. Instead, the reaction must proceed through a series of steps. There are many possibilities here, but we will be looking at the main two hydrogen-burning reaction chains: the *proton-proton (PP) chain* and the *carbon-nitrogen (CNO) cycle*. The PP chain divides into three main branches, which are called the PPI, PPII and PPIII chains. The first reaction is the interaction of two protons (p or ^{1}H) to form a nucleus of heavy hydrogen (deuteron, d, or ^{2}H), consisting of one proton and one neutron, with the emission of a positron (e^+) and a neutrino (ν_e). The deuteron then captures another proton and forms the light isotope of helium with the emission of a γ-ray. The ^{3}He nucleus can then either interact with another ^{3}He nucleus or with a nucleus of ^{4}He (an α particle), which has either already been formed or has been present since the birth of the star. The former case is the last reaction of the PPI chain, whereas the latter reaction leads into either the PPII or the PPIII chain, as shown below:

PPI chain		**PPII chain**		**PPIII chain**	
		this starts with reactions 1 and 2		this starts with reactions 1, 2 and 3'	
1	$p + p \dashrightarrow d + e^+ + \nu_e$	**3'**	$^3\mathrm{He} + {}^4\mathrm{He} \dashrightarrow {}^7\mathrm{Be} + \gamma$	**4''**	$^7\mathrm{Be} + p \dashrightarrow {}^8\mathrm{B} + \gamma$
2	$d + p \dashrightarrow {}^3\mathrm{He} + \gamma$	**4'**	$^7\mathrm{Be} + e^- \dashrightarrow {}^7\mathrm{Li} + \nu_e$	**5''**	$^8\mathrm{B} \dashrightarrow {}^8\mathrm{Be} + e^+ + \nu_e$
3	$^3\mathrm{He} + {}^3\mathrm{He} \dashrightarrow {}^4\mathrm{He} + p + p$	**5'**	$^7\mathrm{Li} + p \dashrightarrow {}^4\mathrm{He} + {}^4\mathrm{He}$	**6''**	$^8\mathrm{Be} \dashrightarrow 2\,{}^4\mathrm{He}$

It can be seen that there is another choice in the chain when ^{7}Be either captures an electron to form

^{7}Li in the PPII chain or captures another proton to form ^{8}B in the PPIII chain. At the end of the PPIII chain, the unstable nucleus of ^{8}Be breaks up to form two ^{4}He nuclei. The PP chain reactions are summarized pictorially in figure 17.

Figure 17: The proton-proton chain.



The reaction rate of the PP chain is set by the rate of the slowest step, which is the fusion of two protons to produce deuterium. This is because it is necessary for one of the protons to undergo an inverse β decay:

p --> $n + e^+ + \nu_e$.

This reaction occurs via the weak nuclear force and the average proton in the Sun will undergo such a reaction approximately once in the lifetime of the Sun, i.e. once every 10^{10} years. The subsequent reactions occur much more quickly, with the second step of the PP chain taking approximately 6 seconds and the third step approximately 10^6 years in the Sun.

The relative importance of the PPI and PPII chains depend on the relative importance of the reactions of ^{3}He with ^{3}He in PPI as compared to the reactions of ^{3}He with ^{4}He in PPII. For temperatures in excess of 1.4×10^7K, ^{3}He prefers to react with ^{4}He. At lower temperatures, the PPI chain is more important. The PPIII chain is never very important for energy generation, but it does generate abundant high energy neutrinos.

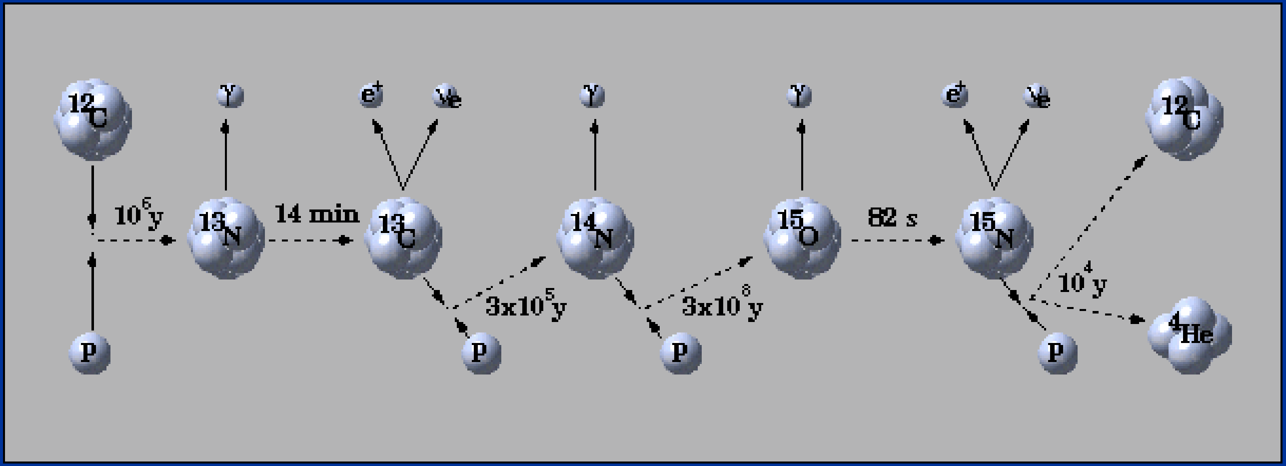
The other hydrogen burning reaction of importance is the CNO cycle:

CNO cycle

1 $^{12}\mathrm{C} + p$ --> $^{13}\mathrm{N} + \gamma$
2 $^{13}\mathrm{N}$ --> $^{13}\mathrm{C} + e^+ + \nu_e$
3 $^{13}\mathrm{C} + p$ --> $^{14}\mathrm{N} + \gamma$
4 $^{14}\mathrm{N} + p$ --> $^{15}\mathrm{O} + \gamma$
5 $^{15}\mathrm{O}$ --> $^{15}\mathrm{N} + e^+ + \nu_e$
6 $^{15}\mathrm{N} + p$ --> $^{12}\mathrm{C} + {}^{4}\mathrm{He}$

The reaction starts with a carbon nucleus, to which are added four protons successively. In two cases the proton addition is followed immediately by a β decay, with the emission of a positron and a neutrino, and at the end of the cycle a helium nucleus is emitted and a nucleus of carbon remains. The reactions of the CNO cycle are shown pictorially in figure 18.

Figure 18: The CNO cycle.



Note that there are less important side reactions of the CNO cycle which are not listed here. Carbon is sometimes described as a *catalyst* in the above reaction because it is not destroyed by its operation and it must be present in the original material of the star for the CNO cycle to operate. When the cycle is working in equilibrium, the rates of all of the reactions in the chain must be the same. In order for this to be so, the abundances of the isotopes must take up values so that those isotopes which react more slowly have the higher abundances. It can be seen from figure 18 that the slowest reaction in the CNO cycle is the capture of a proton by ^{14}N. As a result, most of the ^{12}C is converted to ^{14}N before the cycle reaches equilibrium and this is the source of most of the nitrogen in the Universe.

helium burning reactions

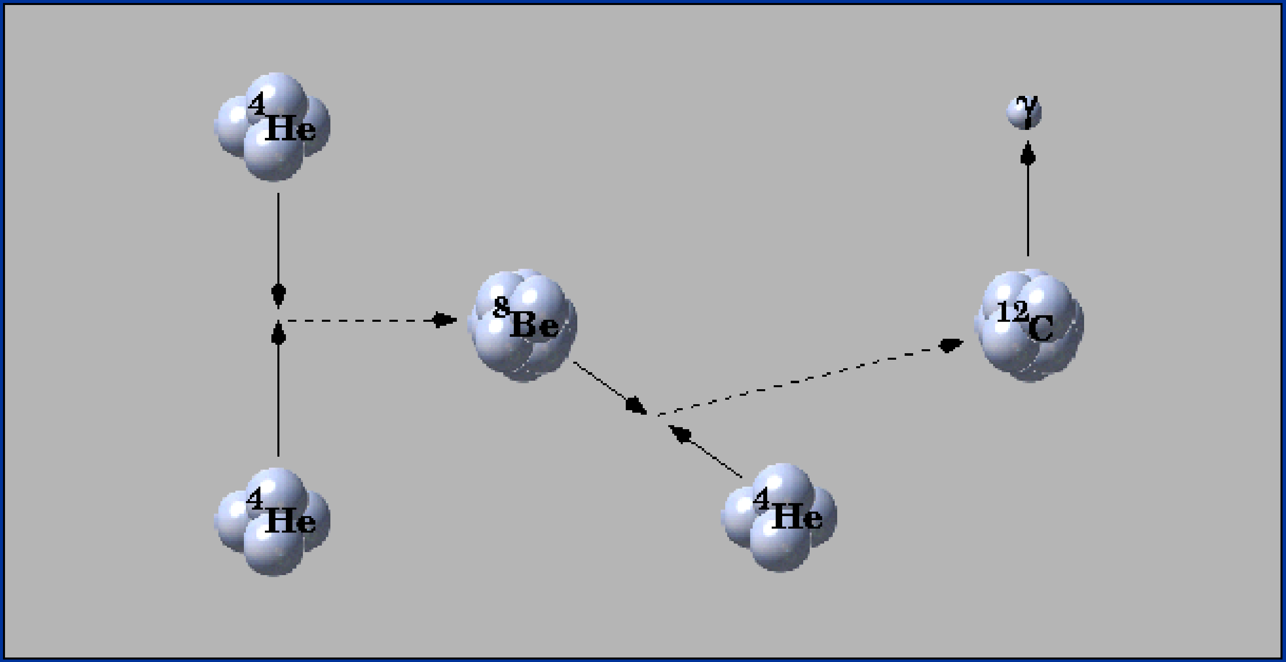
When there is no longer any hydrogen left to burn in the central regions of a star, gravity compresses the core until the temperature reaches the point when helium burning reactions become possible. In such reactions, two ^4He nuclei fuse to form a ^8Be nucleus, but this is very unstable to fission and rapidly decays to two ^4He nuclei again. Very rarely, however, a third helium nucleus can be added to ^8Be before it decays, forming ^{12}C by the so-called *triple-alpha reaction*:

$$^{4}He + {}^{4}He \dashrightarrow {}^{8}Be$$

$$^{8}Be + {}^{4}He \dashrightarrow {}^{12}C + \gamma$$

The triple-alpha reaction is shown pictorially in figure 19. It can be seen that the reaction leaps from helium to carbon in one go, by-passing lithium, beryllium and boron. It is no coincidence that these three elements are over 10^5 times less abundant by number than carbon.

Figure 19: The triple alpha reaction.



Once helium is used up in the central regions of a star, further contraction and heating may occur, and that may lead to additional nuclear reactions such as the burning of carbon and heavier elements. We will not discuss these reactions here as the majority of the possible energy release by nuclear fusion reactions has occurred by the time that hydrogen and helium have been burnt.