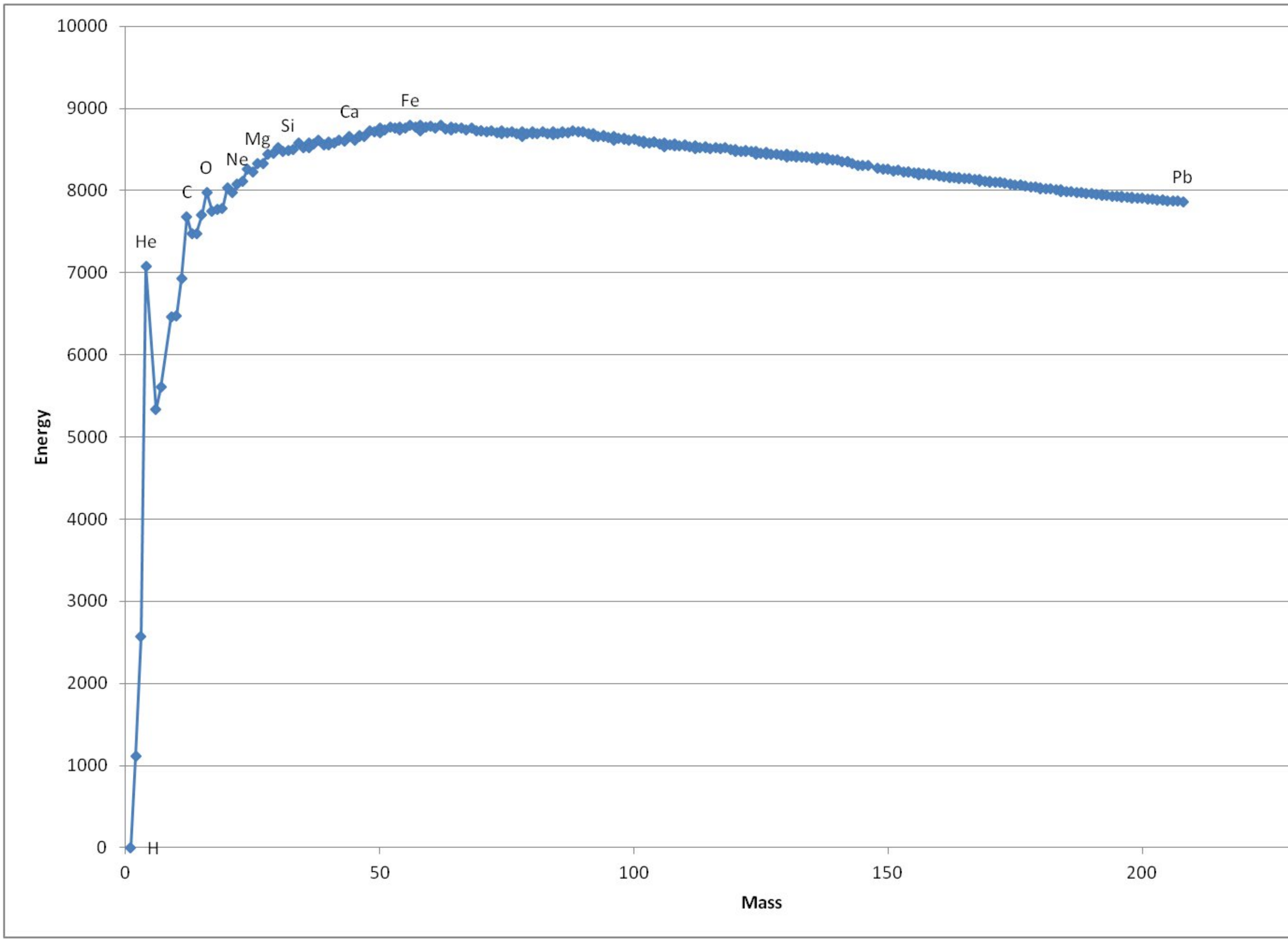
When stars die

So we've seen how stars live, and how they can extend their lives by switching to helium, an available but less efficient forms of fuel. Why is helium less efficient? Well the secret is in the graph below.

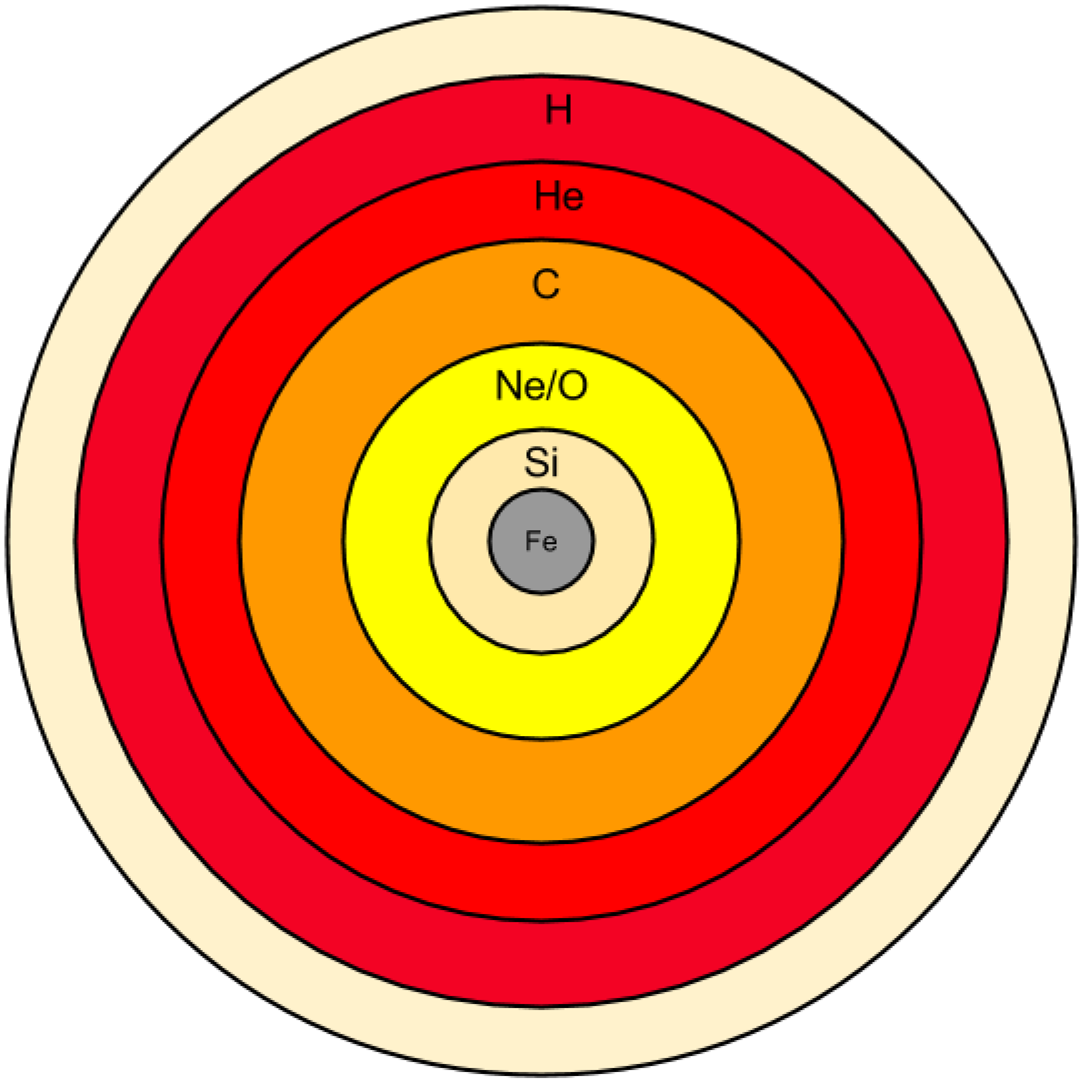


[Graph of binding energy]

The Y axis is the amount of energy for each particle in the nucleus. You can see hydrogen way down the bottom, and helium at just over 7000 (the units are keV but it doesn't really matter). What is important is the difference in levels. So from H to He we get lots of energy released - over 7000 units. From He to C, not very much in comparison, maybe a few hundred. So it's no wonder hydrogen is the preferred fuel. There are other elements that can be "burnt", carbon (C) to oxygen (O), to Neon (Ne), magnesium (Mg), and silicon (Si), and to Iron (Fe) - however from

the graph it’s clearly not very efficient. After iron (Fe), you can see the graph goes down. So to make anything after iron you have to put energy in. You can go the other way - from big nuclei to small ones, and things beyond lead (Pb) like uranium, you can split up, and make energy. This is what atomic power stations use. You can see compared to the H->He jump, it’s also pretty inefficient.
So burning hydrogen to helium is the best bang for the nucleus, helium to carbon is the next best, but not nearly as good. After that there are more exotic schemes. Burning two carbons to neon, or making oxygen (C+He) or magnesium are all options. Hotter temperatures allow neon burning and oxygen burning producing silicon. This is an increasingly desperate rush for burning whatever is available. It’s like starting with a nice big wood pile, and then having to burn the chairs and table, and finally the house to keep warm. Carbon burning, for instance, will typically give the star extra burning time of a few hundred years, contrasting with millions or billions of years for hydrogen burning. Oxygen/neon burning is only good for a few months to a year to support the star against gravitational collapse.

In the final phase, it can burn silicon, but its clear from the graph above, there is very little energy available from this. Silicon burning, which is only available to the very biggest stars, and requires temperatures around 2-3 billion degrees, can only keep the star going for a matter of hours or days. Typically a star in this late stage of its life can be doing several types of burning at once, in shells



[Shell burning in a massive star]

In this mode of extended shell burning, large solar winds are generated, and a lot of mass is emitted from the star as it swells up and the outer surface becomes very tenuous.

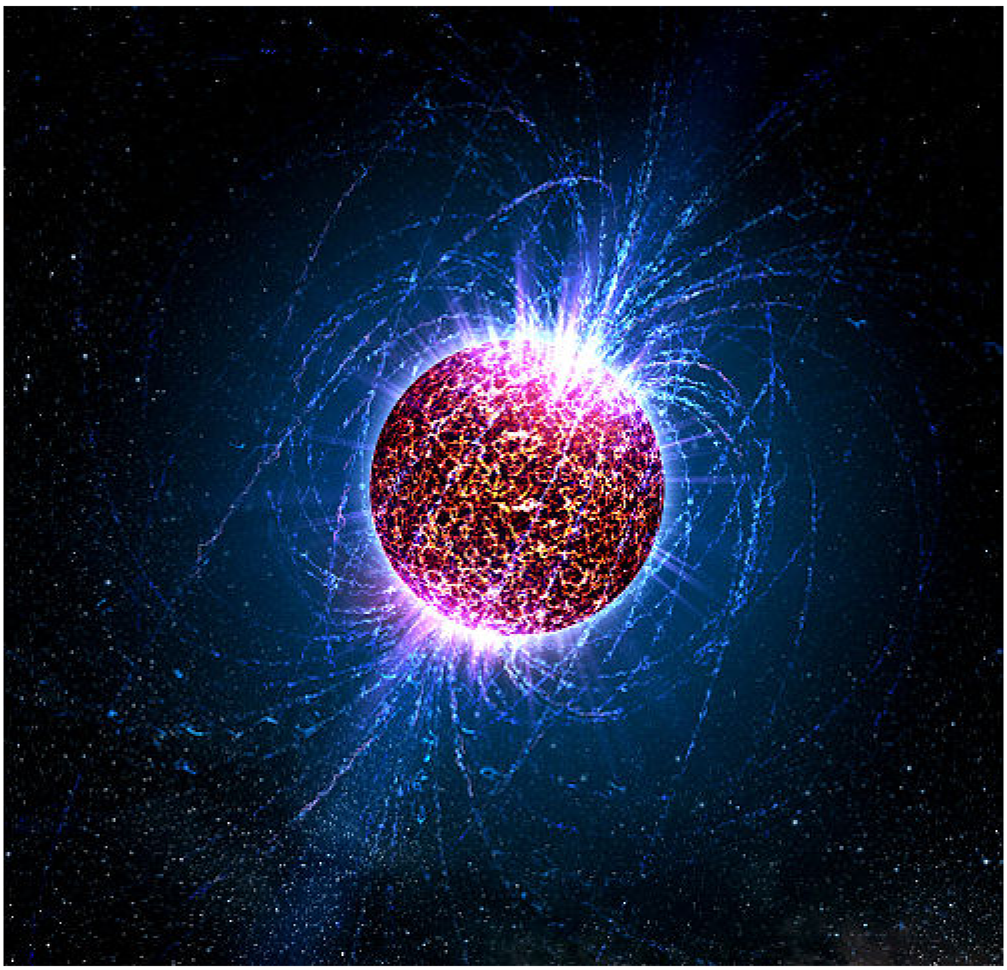
Eventually - there is nothing else left to burn, or at least not enough to keep up the mass of material that makes a star. It's like a weightlifter, holding a weight above his head. Sooner or later their arms will give and it will all come crashing down.

So what happens next? It depends on how massive the star is. Stars the size of our Sun and less just slowly collapse in on themselves.
In the case of our Sun the core will be mostly carbon with perhaps some oxygen. The Sun will shrink until it is about the same size as the earth. It will still be very hot, but no longer burning. Known as a white dwarf (not to be confused with a red dwarf, *the type of star or the tv show*), it will sit there glowing for billions of years slowly cooling down. The structure will be compressed into degenerate matter, which is how you get a suns worth of mass into something the size of

the Earth. Carbon's most compact form is diamond, so we will end up with one very large, very hot diamond. Oddly enough, the more matter you put into a white dwarf, the smaller it gets - such is the odd nature of degenerate matter. It is a very dense state of matter, and prevented from collapsing further only by the degeneracy pressure of electrons pushing back.

Theoretically it will then eventually turn into a black dwarf (not to be confused with a brown dwarf) - that is a white dwarf that is so cool it no longer even glows. However as this takes longer than the lifetime of the universe, no star has yet got into this state.

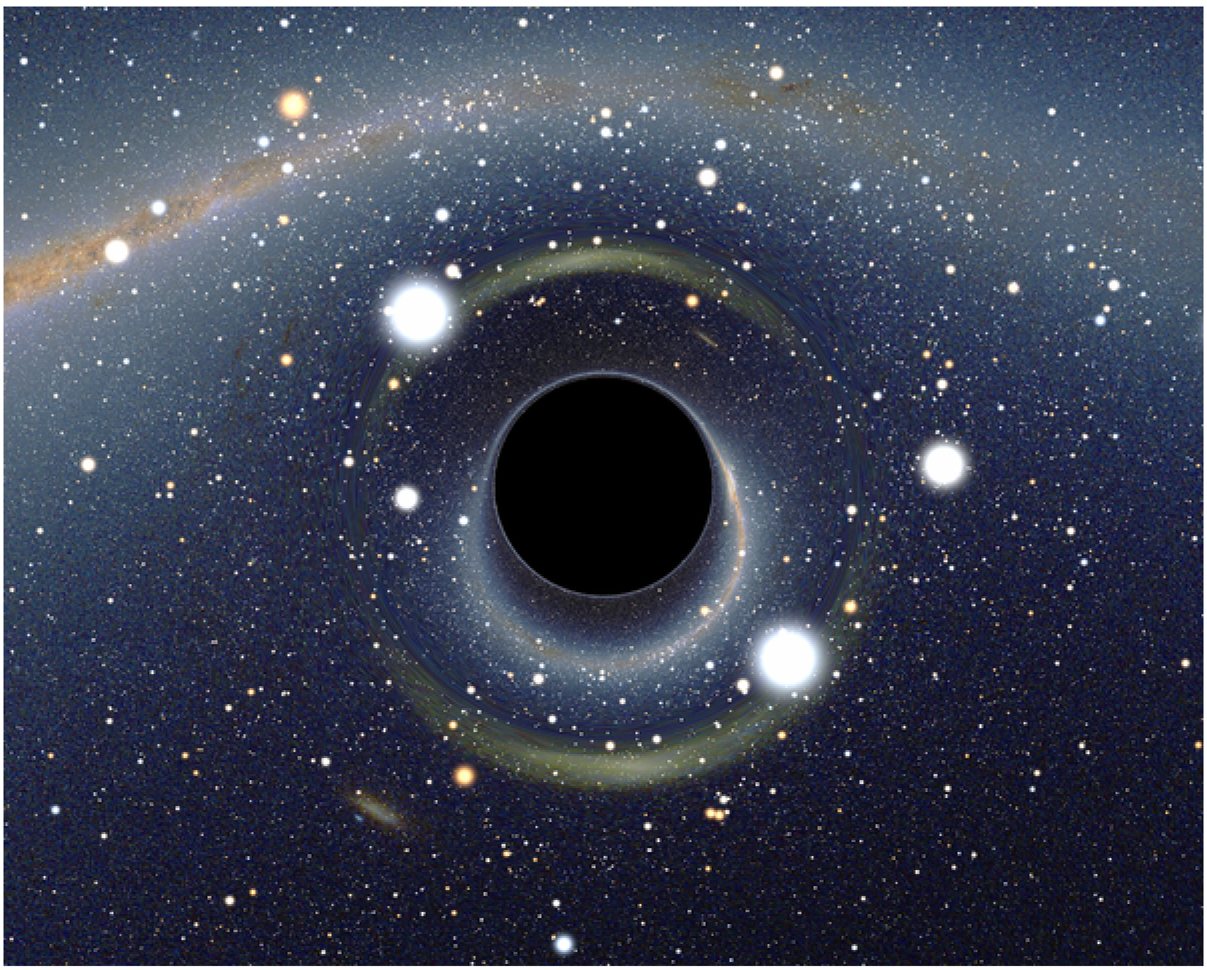
Anything bigger than about 1.4 times the mass of our Sun at the end of its life (and stars lose a lot of mass in their later stages) are too massive for the degenerate material to resist the collapse. In this case the electrons are squeezed further, and combine with protons to form neutrons. This neutron pressure can resist the squash, up to about 3 solar masses worth. The subsequent neutron star is very dense and very small. Maybe 10 km across, the size of a not particularly big city.



[Impression of a neutron star - wikipedia.]

Neutron stars have an impressive density, often quoted in various ways - such as - a grain of neutron star ‘sand’ weighs the same as a 747. Although no one has done the experiment - I suspect if you had a grain of neutron star material on it’s own, it would quickly expand back to its original size!

If the remains are bigger than somewhere in the 3-5 solar mass range, we run out of resistant forces. The star collapses in on itself, becoming that most famous of weird objects - the black hole. They are famous in science fiction and certainly have a few freaky properties, such as being so massive that even light can’t move fast enough to escape them. However they are not the cosmological hoovers that they are sometimes portrayed. Sure if something comes close enough it will get sucked into it, never to be seen, but the same will happen with our Sun.
The black hole has less “sucking” power than the star it formed from, as “suckiness” is the gravitational field it generates, which is dependant on it’s mass. The mass of the black hole is usually quite a lot less than the star that formed it, as there is a lot of material lost in the formation process. If we converted our Sun into a black hole, the Earth would carry on going around in orbit unchanged. Of course it wouldn’t shine so it would get awfully cold and dark, but we wouldn’t get sucked into it suddenly.



[http://upload.wikimedia.org/wikipedia/commons/thumb/5/5e/BH_LMC.png/600px-BH_LMC.png

Artists impression of a black hole - distorting space and everything!]

The death throws of these huge stars are the subject of the next article, and are quite the most spectacular of events.