STARS SMALLER THAN 8 SOLAR MASSES

--primarily fuses hydrogen

--star will run out of fuel after, maybe, 10 billion years

--when this happens, fusion in the core slows and the core begins to cool

--gravity takes over and the core begins to contract

--as the core contraction, it begins to heat in a non-nuclear way

--this heating begins fusion in the previously unburned shell of hydrogen just outside the core

--in other words, with fusion diminishing at the core, *the star's energy output (luminosity) increases*

--the energy being generated by the fusion happening in the shell outside the core additionally makes the outer portion of the star expand

--with the star expansion, the star's energy flux (energy per unit area per unit time) goes down while the total energy emitted--the luminosity--goes up

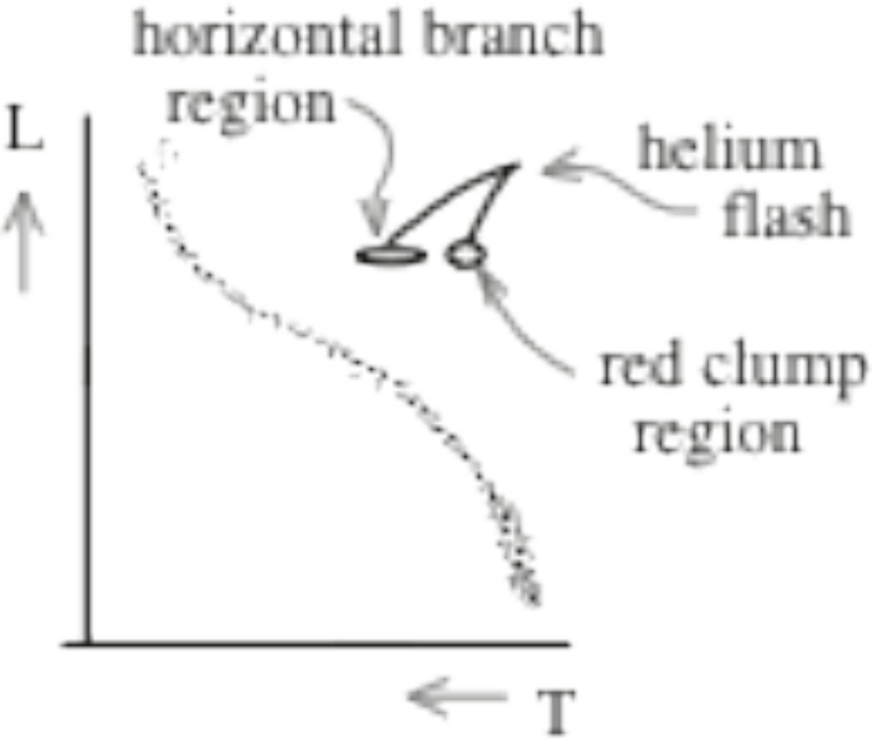
--put a little differently, the surface temperature goes down while the luminosity goes up . . . which means that from a distance, the star gets brighter but color suggests it is becoming cooler

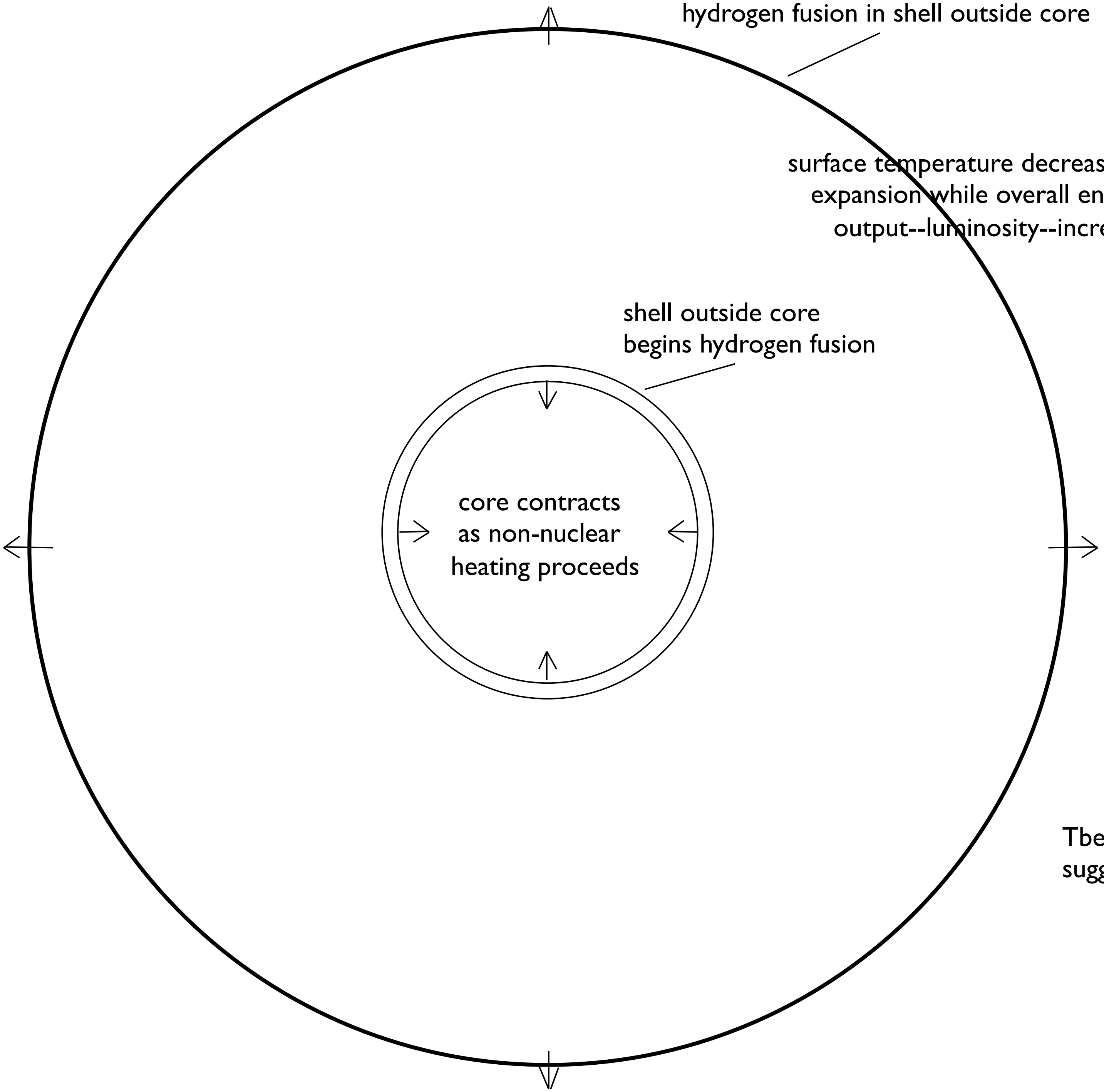
--this process takes around 10 million years to complete

--decreasing temperature and increasing luminosity means the star climbs upward and rightish on the H-R diagram--this path is called *the red giant branch* of the H-R diagram

--if the star is a first generation star, it will be made primarily of hydrogen and helium, and it will end up in what is called the *horizontal branch* region.

--if the star is a later generation star, it will have other elements in its body aside from hydrogen and helium, and it will end up in what is called the *red clump* region.





outer envelope expands due to
hydrogen fusion in shell outside core

surface temperature decreases due to
expansion while overall energy
output--luminosity--increases

shell outside core
begins hydrogen fusion

core contracts
as non-nuclear
heating proceeds

Luminosity: ↑

Energy density: ↓

Tbe star gets brighter but its color suggests its surface is cooler.

--toward the end of the process, a star that was originally the size of the sun will be around 100 times the radius of the sun

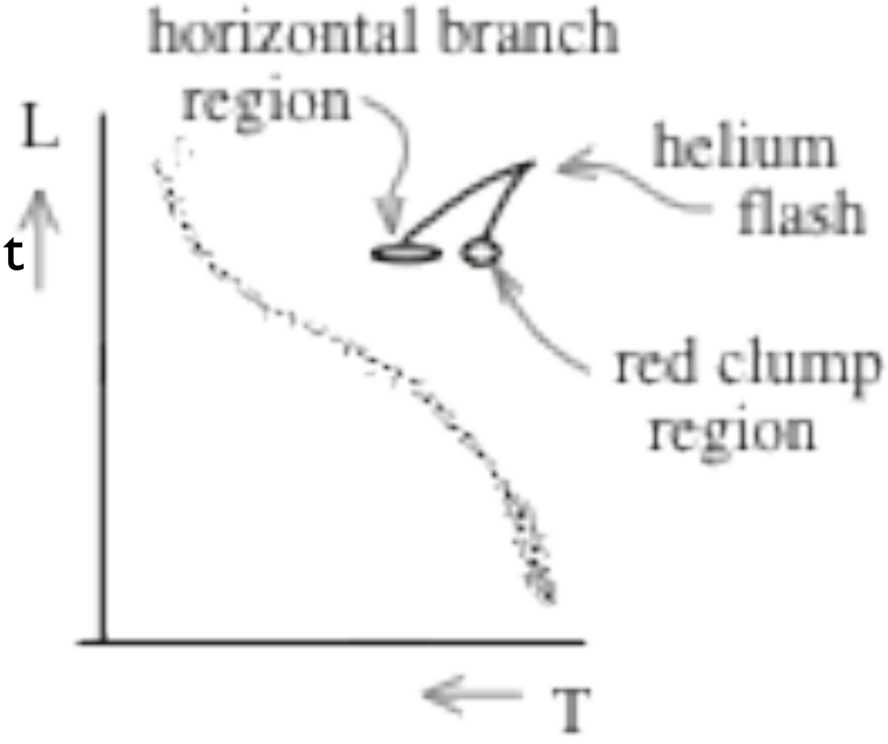
--the stars luminosity will be 100 times that of the sun

--25% of the star's mass will be compressed in the core

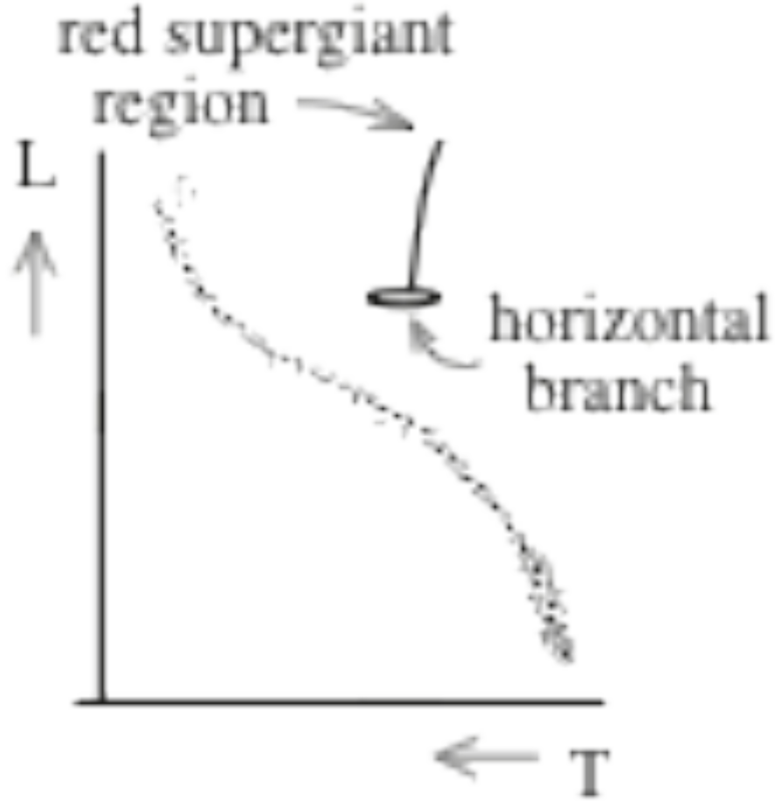
--when fusion in the shell outside the core and core contraction makes the core hot enough (around 100,000,000 degrees Kelvin), He fusion in the core begins to produce carbon in a runaway nuclear reaction

--called a *helium flash*, this process motivates the core to expand until gravity and the pressure produced by the newly begun helium fusion comes into equilibrium and we end up with a stable star that is no longer moving up the H-R diagram

--At this point, the whole process begins anew. That is, the helium supply will continue to fuse in the core until the core begins to run out of helium (this will take about 20 million years). At that point, fusion will slow, gravity will take over and the core will contract. With contraction will come non-nuclear heating of the core, the start-up of helium fusion in the shell just outside the core (there will also be a shell of hydrogen fusion happening outside that inner shell), and the outer part of the shell will once again expand.



--In other words, with fusion diminishing at the core, *the star gets more luminous*.



--this expansion will take the star into the *red supergiant* range (also called *the asymptotic giant branch)*.

--red supergiants can become as large as 400 to 600 times the size of the sun

--in this stage, the non-fusioning core continues to contract

--if the core were to reach 600 million degrees K, carbon fusion would begin and the process would repeat. Stars of the size we are talking about don't reach 600,000,000 degrees K. That means they never reach the carbon fusing stage.

--in the red supergiant stage, the non-fusioning core continues to contract while heating in a non-nuclear way

--this heating of the core ionizes the material in the core producing an enormous population of free electrons

--assuming no carbon fusion happens, the core will continue to contract until the electrons within can no longer be squeezed any closer (i.e., a quantum degeneracy pressure stops the shrinkage)

--what you end up with is a very hot core whose density is very high (compress a car into a marble and you have the approximate density of these entities)

--before the degeneracy pressure stops the collapse, temperatures in the shells around the core motivate both hydrogen and helium fusion to happen faster and faster

--the outer shell continues to expand outward, cooling in the process.

--finally, the outer shell is ejected into space

--the ejected material--an outwardly moving shell of glowing gas that surrounds a naked star core, is called a *planetary nebulae (* http://www.google.com/search?hl=en&q=planetary+nebula&btnG=Google+Search)

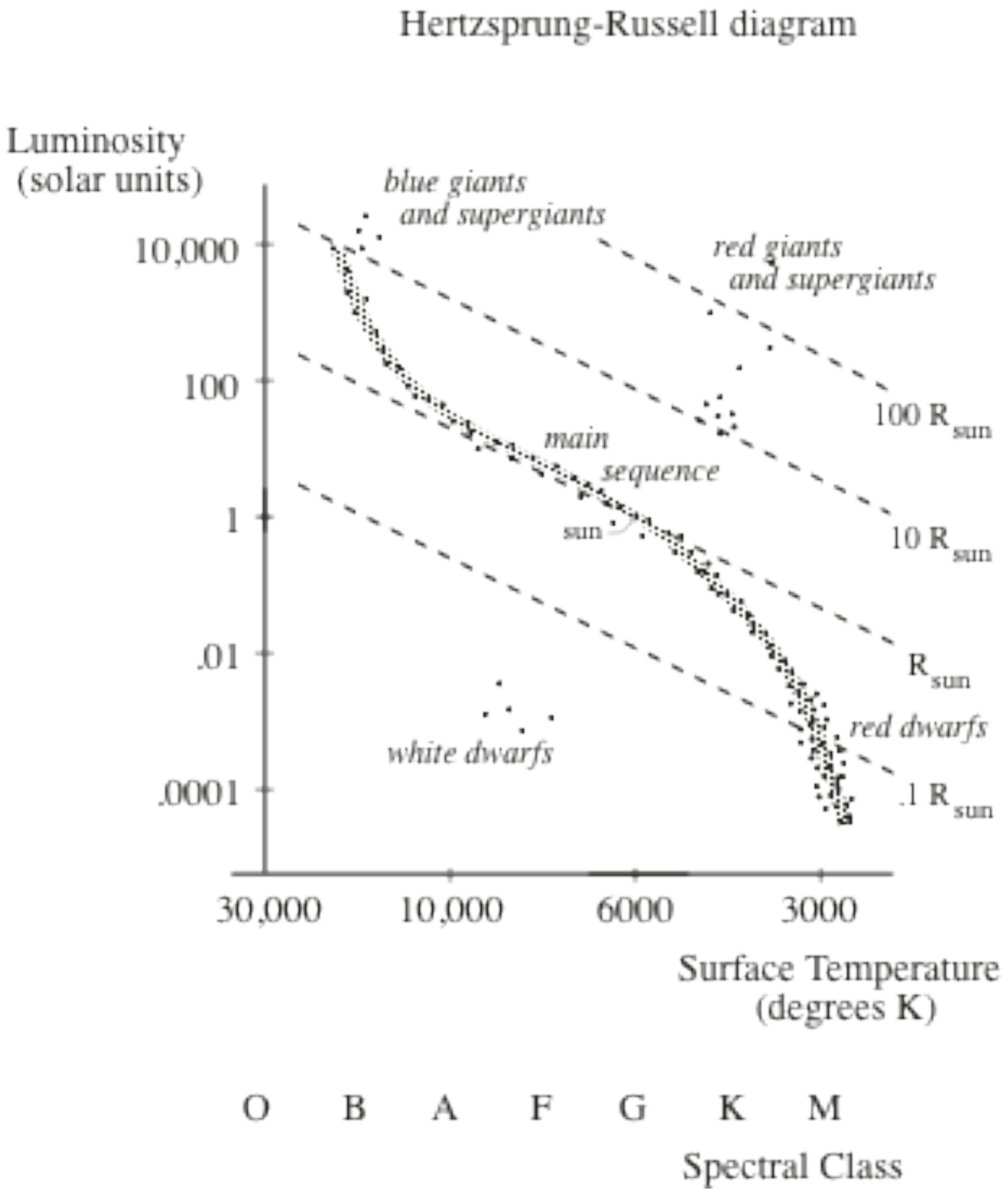
--with the core now exposed, the star is very small but glows white due to residual stored heat in the structure (remember, fusion is no longer taking place in the core)

--called a *white dwarf*, this is a high temperature but, due to its size, a low luminosity star (in fact, this kind of star is also called a carbon white dwarf)

--as fusion is no longer an option with these stars, they simply continue to cool, fading away in the process

--this is the way our sun will die

--what's interesting about all of this is that when you look into the night sky and see what appears to be so many different types of stars--main sequence stars like our sun, red giants, red supergiants like Betelgeuse in the left shoulder of the constellation Orion, white dwarfs, what you are really seeing is the same type of star at different stages in its life cycle.



--side note: when a white dwarf is found close to a binary partner, it is possible for the very dense, gravitationally massive white dwarf to gravitationally suck hydrogen and helium away from the envelope of the other star.

--if this happens, the stolen material swirls around the white dwarf forming an accretion disk. This material gradually spirals in and falls onto the white dwarf.

--as more and more gas accumulates on the white dwarf, the temperature at the bottom of the pile rises. When it reaches 10 million degrees K, hydrogen fusion is initiated and a huge amount of energy is released in a very short time (i.e., days).

--during the brightening, the star' s intensity can increase as much as 60,000 times only to slowly diminish back to normal

--also during the brightening, the top of the pile of accreted matter is ejected into space. This is called a NOVA.

--this process can be repeated dozens or even hundreds of times during a white dwarf' s lifetime