High Mass Stars

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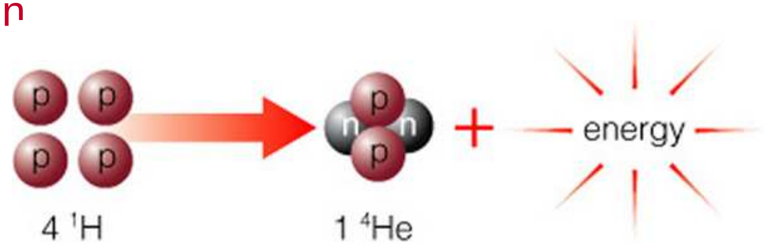
High mass star formation

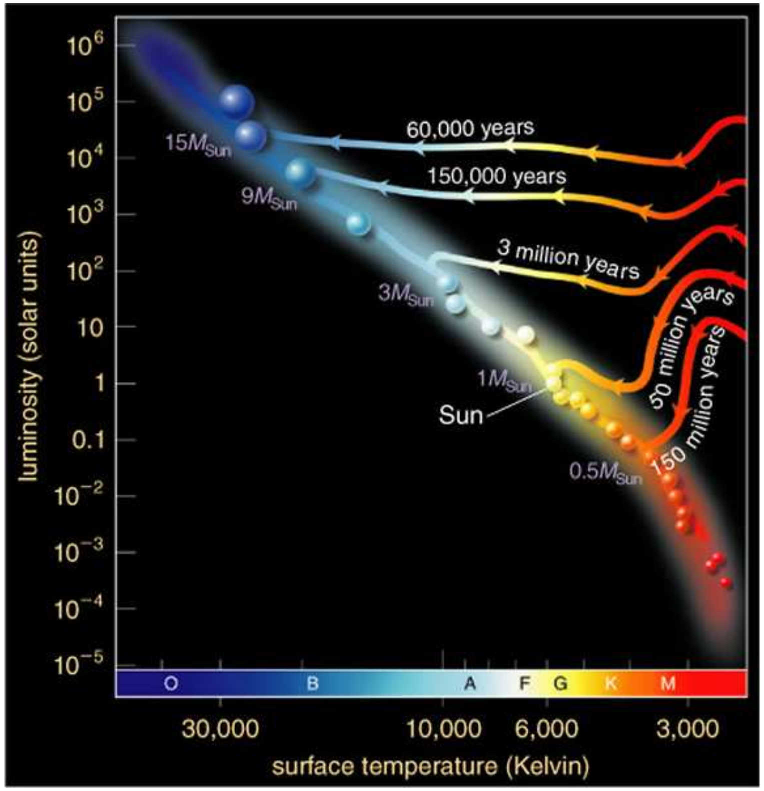
- High mass star formation is controversial!
- May form in the same way as low-mass stars
  - Gravitational collapse in molecular clouds.
- May form via competitive accretion
  - All stars form as low-mass stars.
  - Stars continue accreting gas until it is all depleted.
  - Some stars accrete more efficiently and grow to form high-mass stars.
- As with low-mass stars, hydrogen burning begins when the gravitational contraction makes the core hot enough for hydrogen fusion.
- Hydrogen fusion in a high-mass star differs to that in a low-mass star.
  - Low-mass star - proton-proton chain
  - High-mass star - CNO cycle.



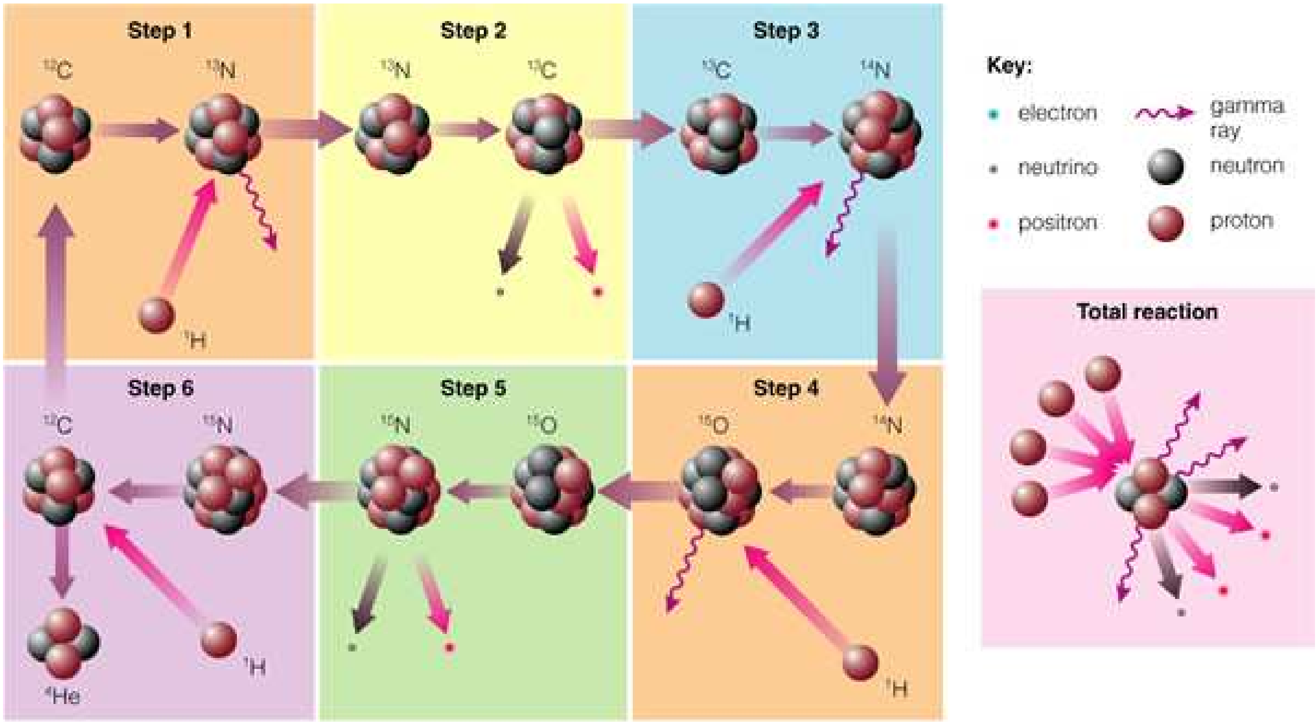
Proton-proton chain

High-mass stars

- Reach the main-sequence in less than 150000 years.
- Strong gravity compresses the hydrogen core to much higher temperatures than in low-mass stars.
- Fusion rate increases with temperature.
- In a high-mass star, hydrogen fusion occurs through the CNO cycle rather than through the proton-proton chain
  - Even though carbon, nitrogen and oxygen make up less than 2% of the material in stars, they can still act as catalysts for hydrogen fusion in high-mass stars.
- CNO cycle fuses hydrogen at a much higher rate than the proton-proton chain that occurs in low-mass stars.



CNO cycle



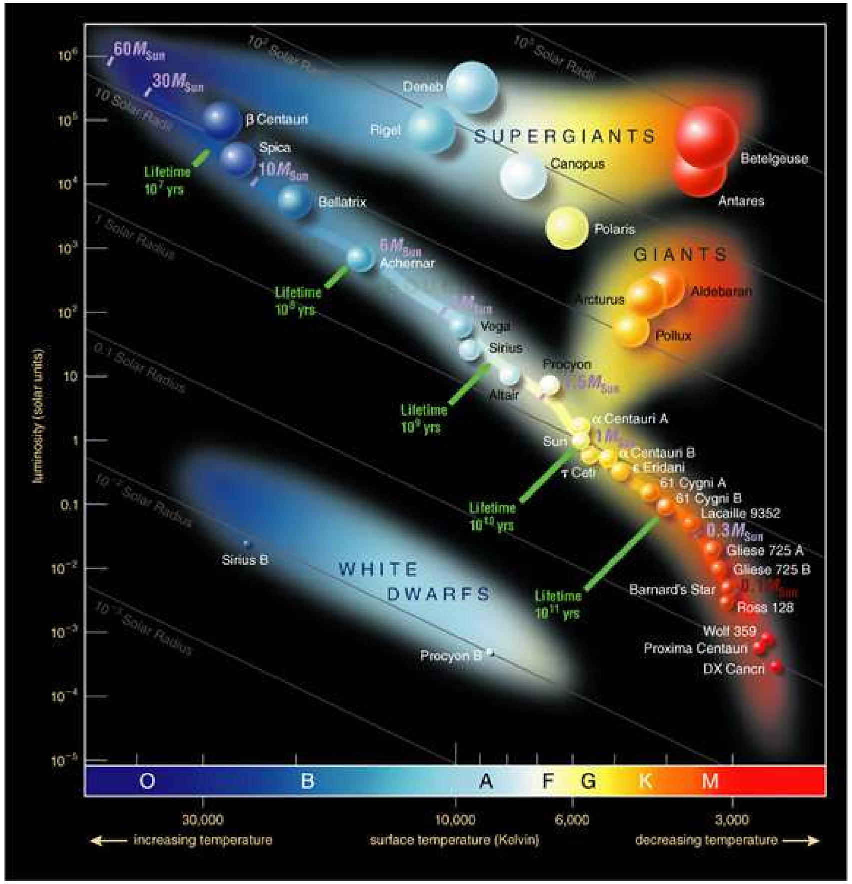
The end result of the CNO cycle is the same as for the proton-proton chain - 4 protons produce 1 helium atom and release energy - but the steps are different. Carbon, nitrogen and oxygen act as catalysts that speed up the reaction. They aid the reaction without being consumed.

Becoming a supergiant

- The incredibly rapid fusion rates mean that high-mass stars cannot live very long.
  - A 25 solar mass star only spends a few million years on the main-sequence (Remember the sun spends 10 billion years on the main sequence).
- When the core hydrogen is exhausted a high-mass star behaves like a low-mass star, only faster.
- Hydrogen burning in shell around helium core
  - Outer layers expand producing a *supergiant* star.
- Core temperature increases - helium burning in the core.
  - No helium flash - thermal pressure remains high.
- Core helium burning lasts only a few hundred thousand years - produces an inert carbon core.
  - Helium shell burning between core and hydrogen shell
- Core temperature reaches 600 million K - carbon fusion starts
  - Core carbon burning lasts only a few hundred years.
- Carbon burning in a shell around the inert core.
- Core shrinks until it becomes hot enough to fuse even heavier elements.

Lifetime of a massive star

- Sun's lifetime ~ 10 billion years
- Consider a star 25 times the mass of the Sun
  - From H-R diagram its luminosity is 100000 times greater than the Sun's.
  - It therefore burns fuel (uses it's mass) 100000 times faster than the Sun.
  - It has 25 times the mass of the Sun so its lifetime will be 25/100000 = 0.00025 times than the Sun's lifetime = 2.5 million years.



The Sun lives for 10 billion years

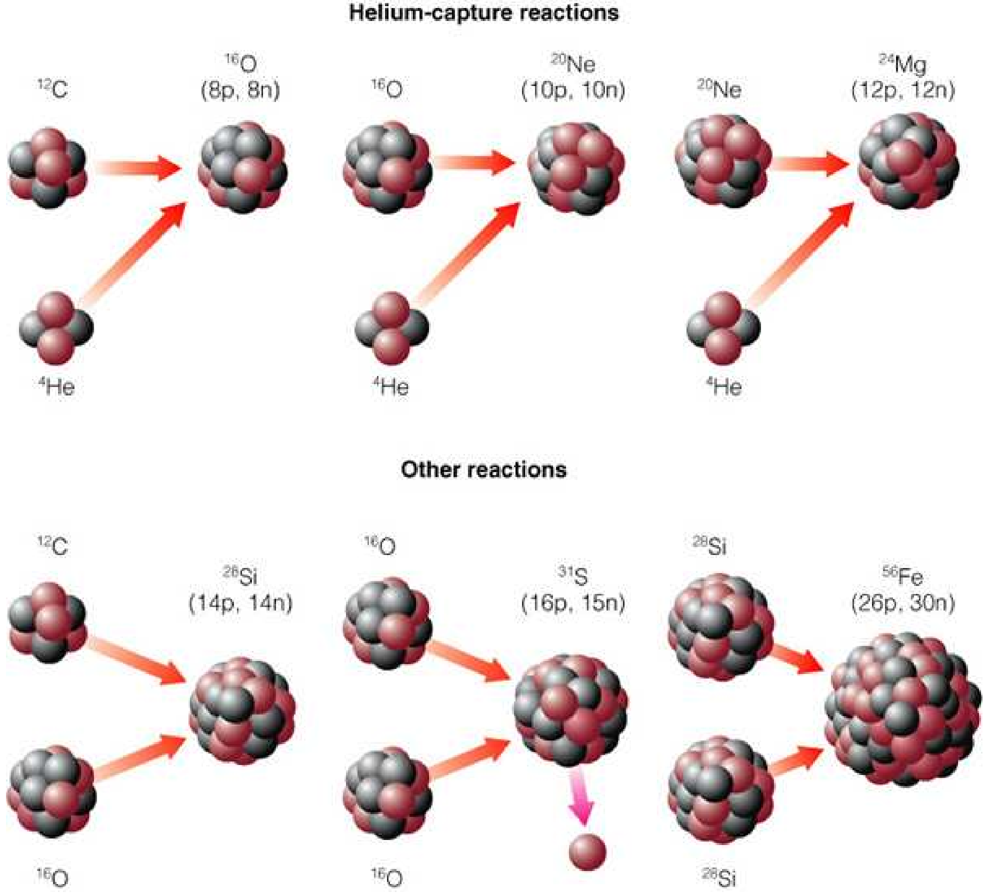
A star with a mass 25 times that of the Sun will live for about 2.5 million years.

Intermediate mass stars

- Stars with masses between 2 and 8 solar masses.
- Initially behave like high mass stars
  - Nuclear burning occurs through CNO cycle rather than through the p-p chain.
- During the supergiant phase, however, degeneracy pressure prevents their cores from reaching the temperatures required to burn carbon or oxygen.
- Intermediate stars eventually blow away their upper atmospheres and end their lives as white dwarfs.

Advanced nuclear burning

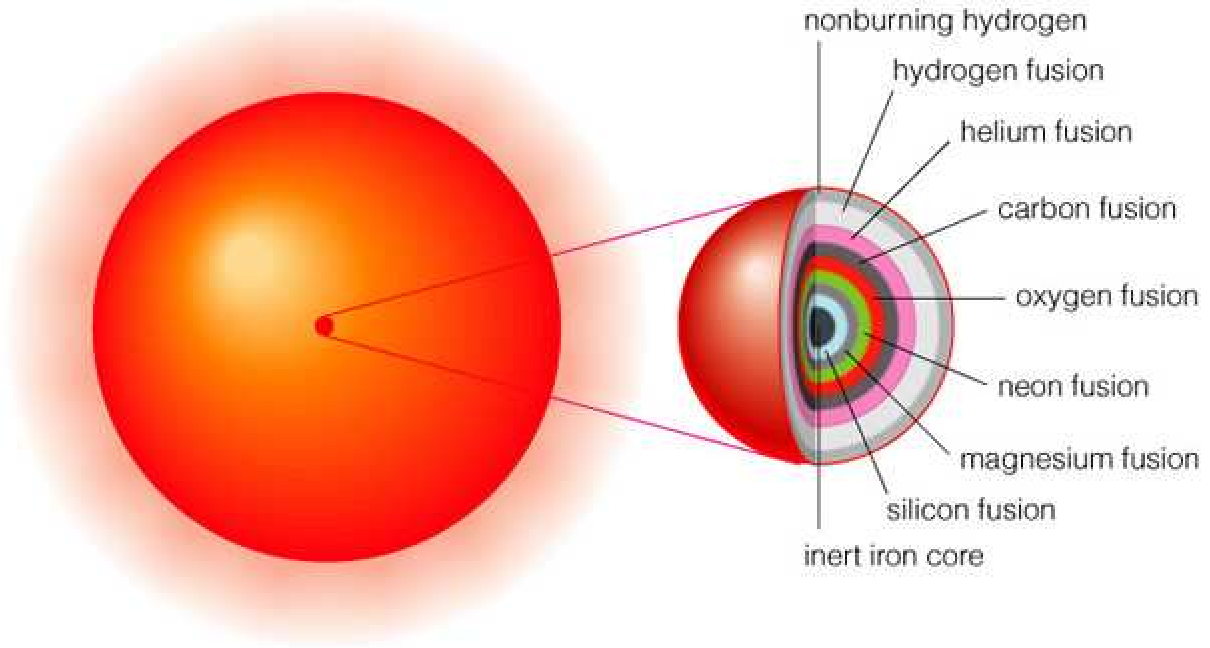
- Simplest are *helium-capture reactions.*
  - A helium nucleus is captured to produce another heavier element
  - e.g., carbon - oxygen
- If the core temperature is high enough - heavy nuclei may fuse together.



Discovering Astronomy G

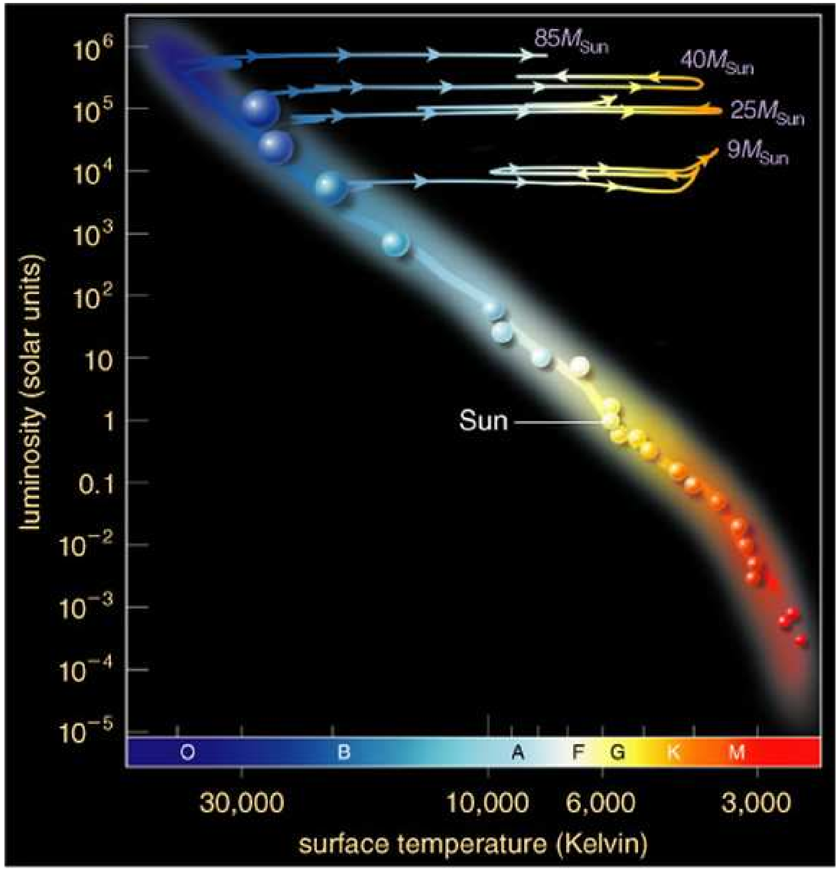
Multiple shell burning

- Each time the core depletes the element it is fusing, it shrinks until it becomes hot enough for other fusion reactions.
- A new type of shell burning ignites between the core and the overlying shells of fusion.
- Near the end, the stars central regions resemble an onion.
- During the final few days, iron (Fe) begins to pile up in the silicon-burning core.



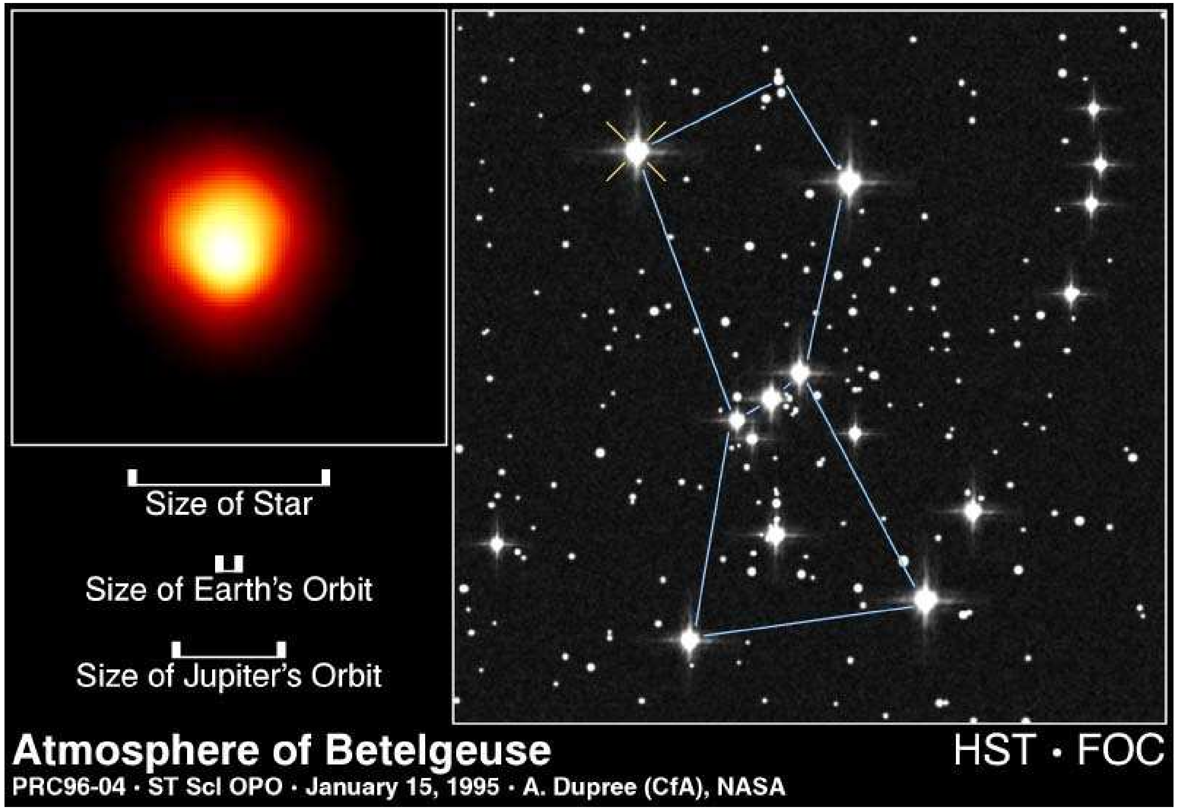
H-R life tracks

- Despite the dramatic events in the interior, the high-mass stars's outer appearance changes slowly.
- Each time core fusion ceases, shell burning intensifies, further inflating the outer layers.
- Each time the core flares up, the star contracts slightly, but the luminosity stays about the same.
- The star zigzags across the top of the H-R diagram
  - Temperature changes - luminosity almost constant.
- In the most massive stars, the core changes happen so quickly that the outer layers don't have time to respond.
- When at the far right of the H-R diagram, the star is known as a red supergiant.



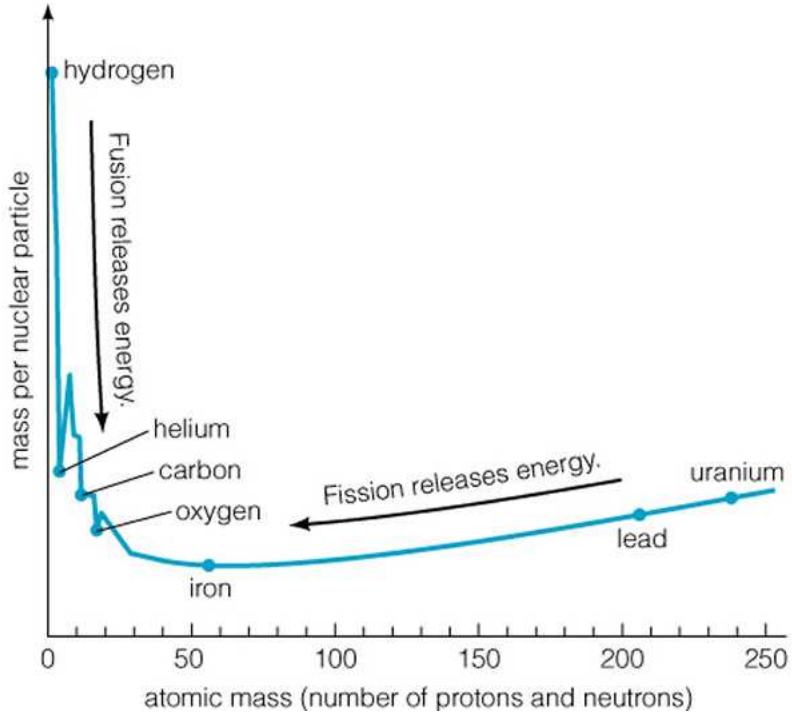
Betelgeuse

- Red supergiant - could be very near the end of it's life!
- About 6 million years old with a mass between 12 and 17 solar masses.
- Located in the constellation of Orion, about 427 light years from the sun.
- One of the only stars for which we can actually measure its radius - 650 solar radii.



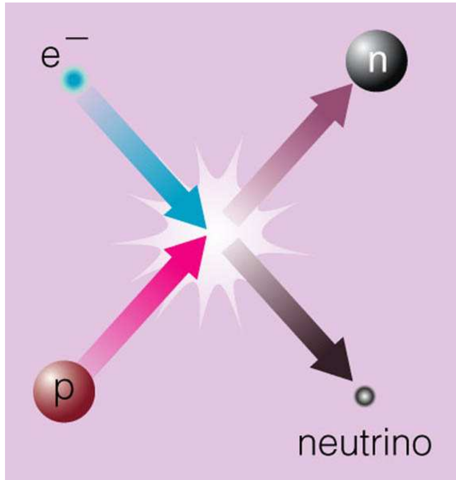
The problem with Iron

- During the final stages of a high-mass star's life, iron builds up in the core.
- Iron is unique in that it is the one element from which it is not possible to generate any kind of nuclear energy
  - Core iron burning does not occur
- Elements lighter than iron release energy through nuclear fusion.
- Elements heavier than iron release energy through nuclear fission.
- Iron has the lowest mass per nucleon - cannot release energy through fission or fusion!
- Remember $E = mc^2$



The death of a high-mass star

- With iron piling up in the core, it has no hope of generating any energy by the fusion of this iron.
- Core supported initially by degeneracy pressure.
- Once gravity pushes the electrons past the quantum mechanical limit, they combine with protons to form neutrons - releasing neutrinos.
  - Degeneracy pressure disappears - gravity wins.
- Within seconds, the iron core collapses into a ball of neutrons just a few kilometres across.
- Collapse halts due to the neutrons degeneracy pressure.
- Collapse releases an enormous amount of energy
  - Supernova
- Neutron core remains as a neutron star.
- If the remaining mass is large enough - gravity may overcome neutron degeneracy pressure to produce a *black hole*.



Supernova 1987 A

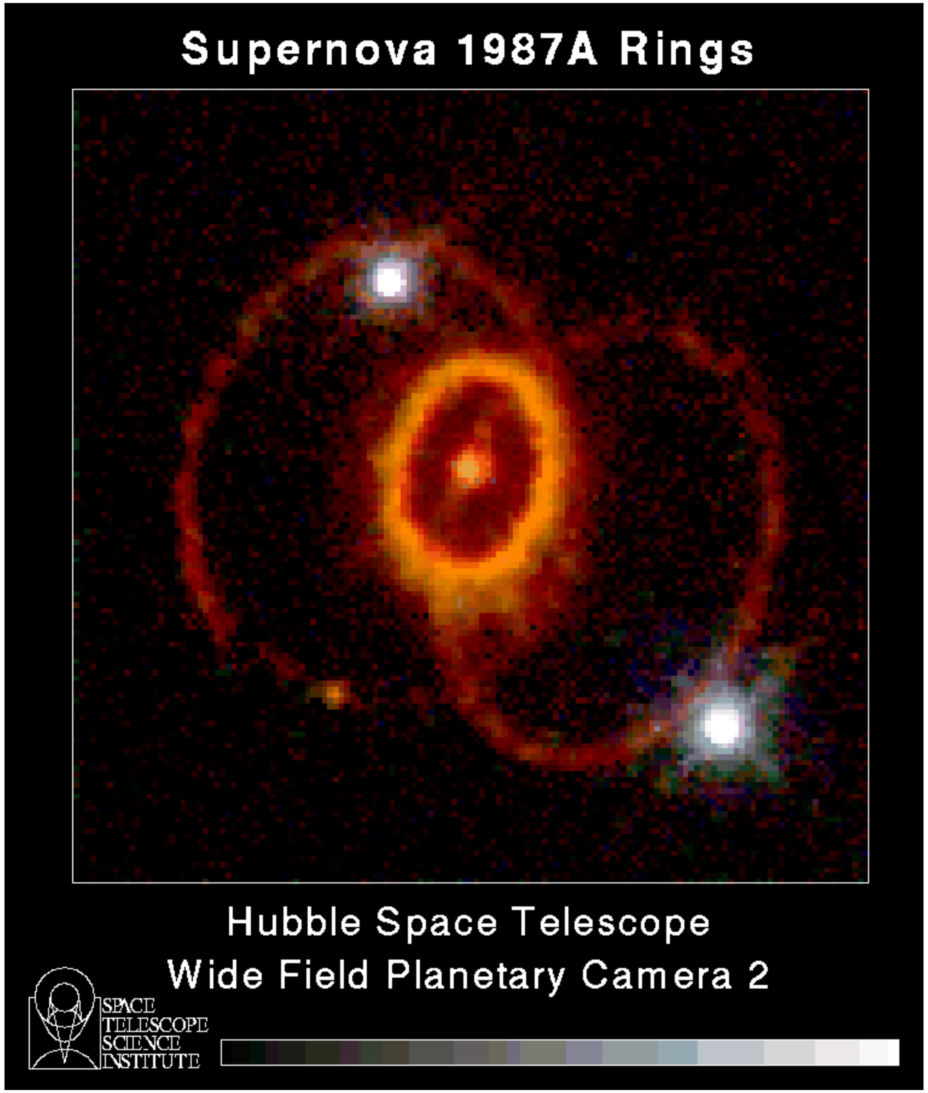
- No supernova in our own galaxy since 1604.
- In 1987 there was a supernova in the *Large Magellanic Cloud* - known as supernova 1987 A.

Before

After

Supernova 1987 A now

- Three glowing rings of gas now surround the location of supernova 1987 A.
- These glow because the gas was heated by ultraviolet light from the supernova.
- It was predicted that debris from the supernova would collide with the inner ring making it glow even brighter. This has indeed happened.

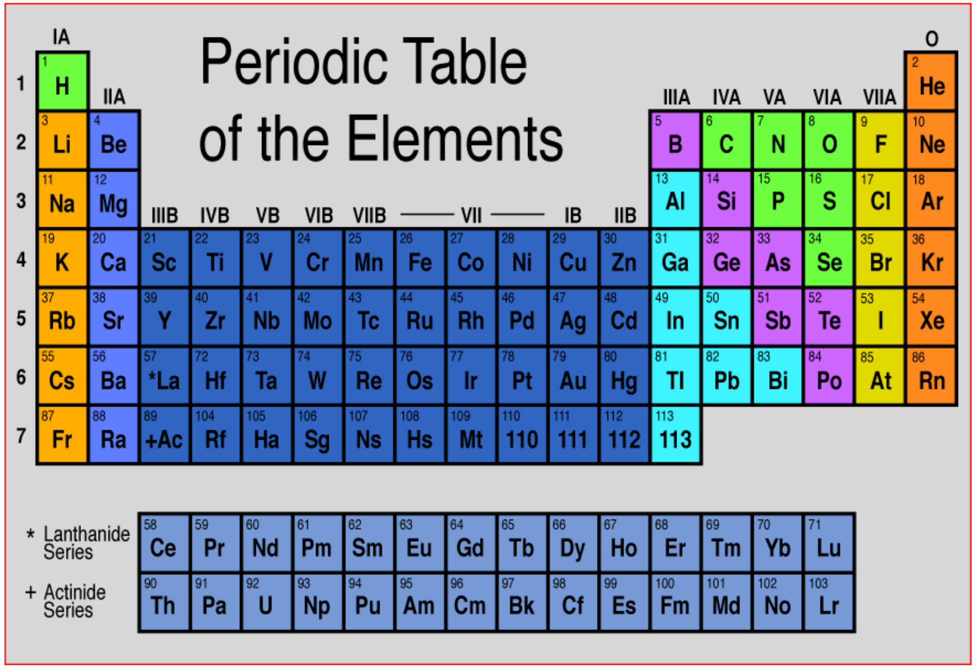


Supernova nucleosynthesis

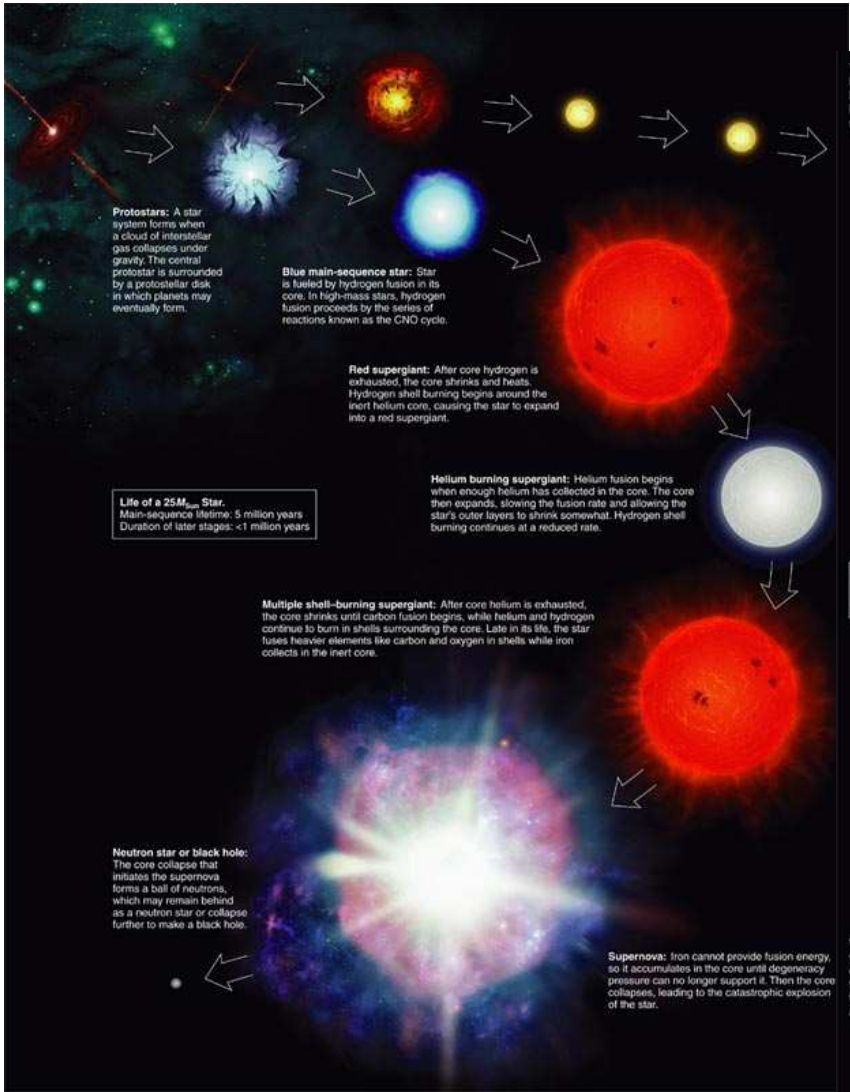
- No elements more massive than iron can be created in the cores of massive stars.

- Supernovae have so much energy that elements heavier than iron can be created in supernova explosions.
  - The resulting elements have more energy than the initial elements so the process is endothermic.

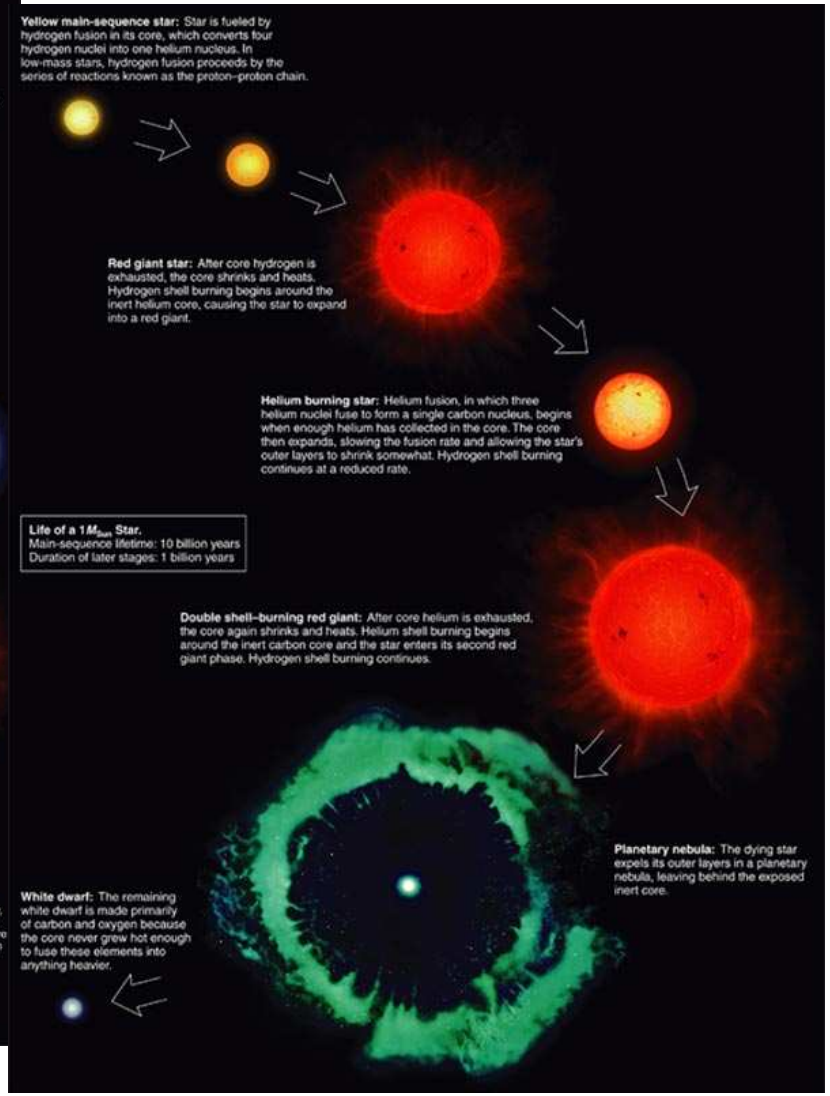
- Supernova nucleosynthesis occurs through the r-process.
  - Nuclei bombarded by neutrons
  - Form unstable neutron rich nuclei
  - Unstable nuclei decay via beta decay to form stable nuclei with higher atomic number but the same atomic weight.



Stellar life cycles



25 solar mass star



1 solar mass star

The evolution of binary stars

- Many stars have companions - known as a binary system
  - I.e., gravitational bound to another star.
- In many cases the separation is large enough that the two stars evolve as if in isolation.
- This may not be the case in close binary systems.
- E.g. Algol - the “demon star” in Perseus
  - Consists of two stars
    - 3.7 solar mass main-sequence star
    - 0.8 solar mass subgiant
  - Both stars born at the same time

Why is the low-mass star more evolved than the higher-mass star if they formed at the same time?

Close binary systems

- The higher mass star evolves more quickly than its lower-mass companion.
- When the more massive star becomes a red giant it may lose some of its mass to its normal, hydrogen-burning companion.
- As a result of this mass transfer, the red giant shrinks to a subgiant, and the normal star becomes the more massive of the two stars.