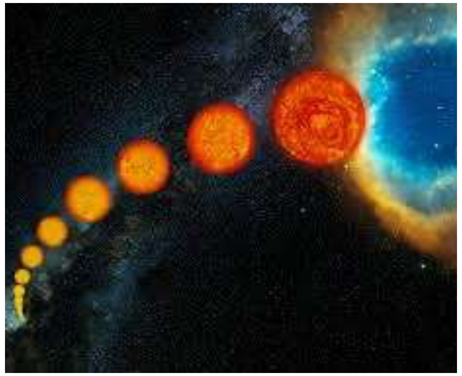
Life of Stars Unit

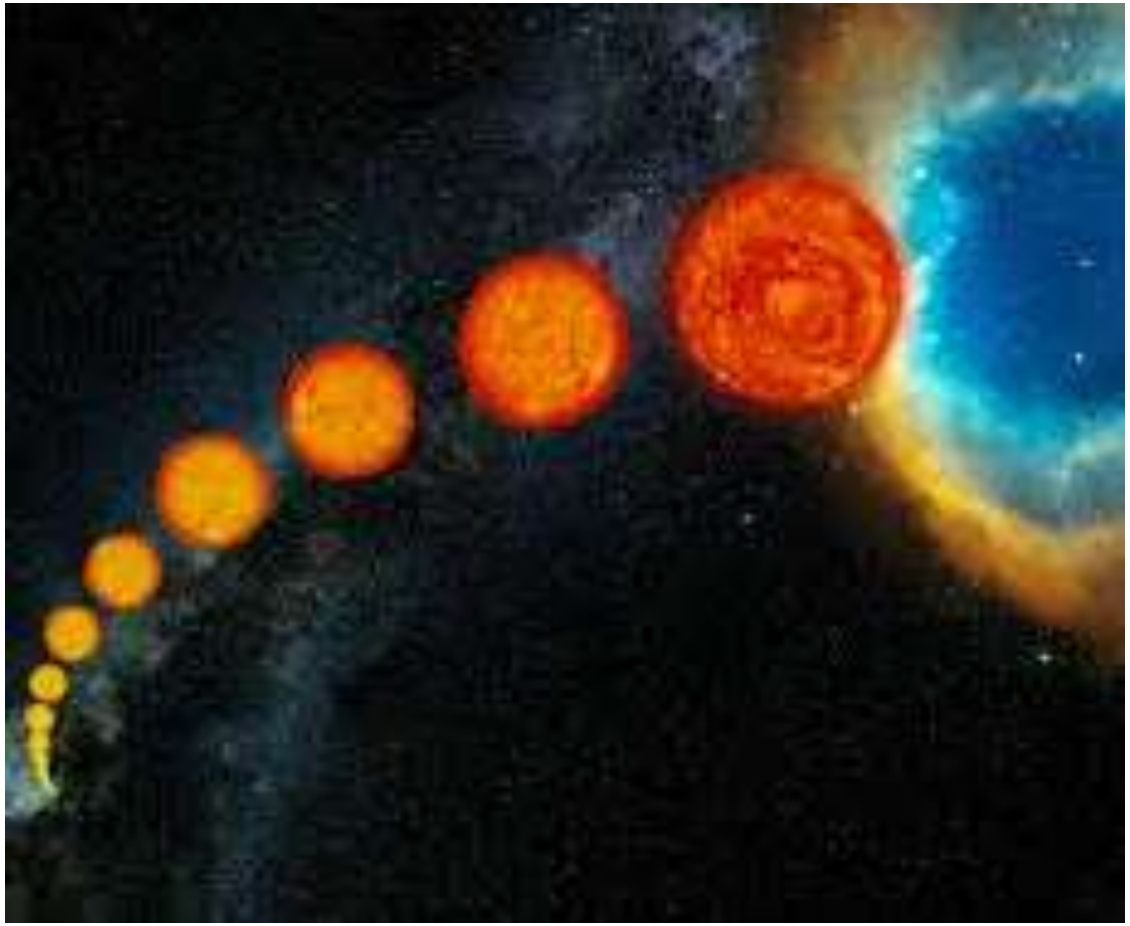
Week 1 – How long do stars last?

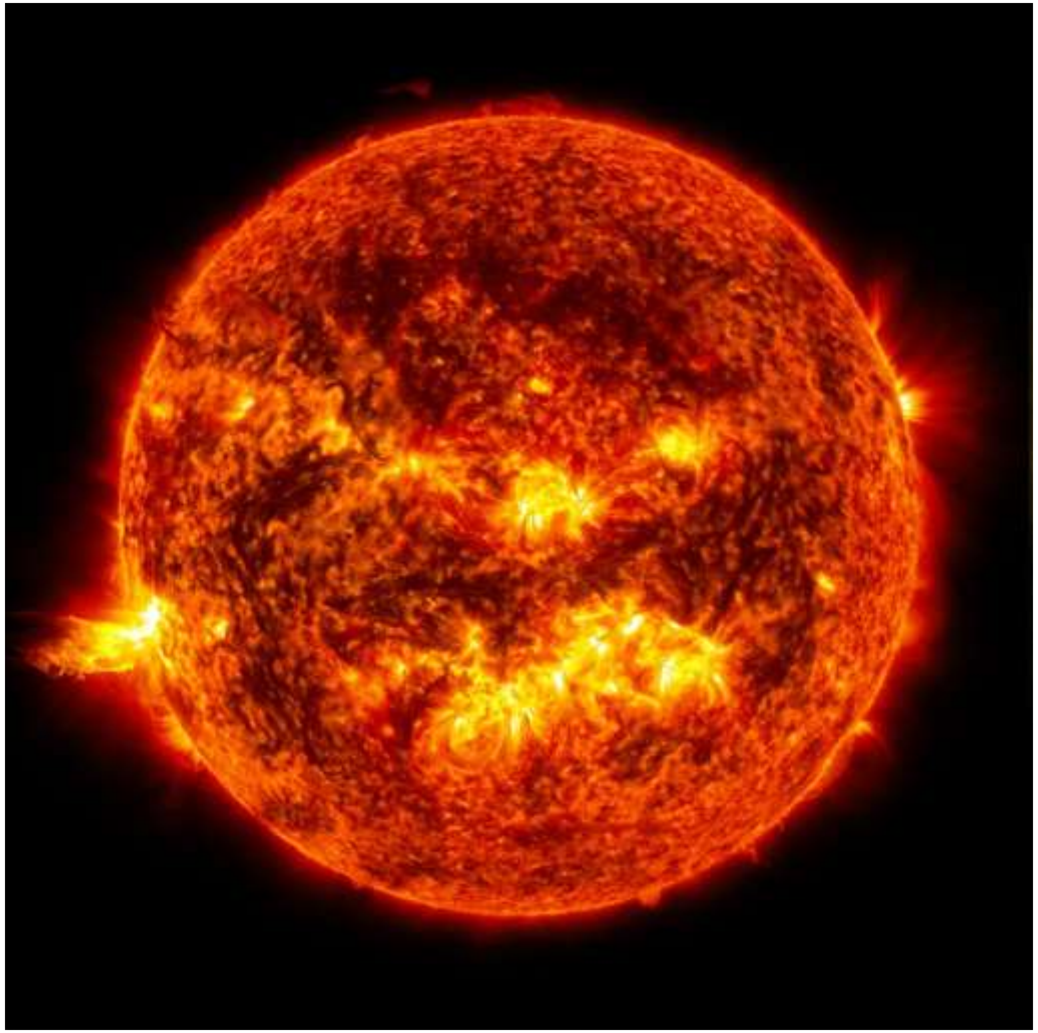


WATERFORD ASTRONOMY

Life of Stars Unit W1 Driving Question

- **This week's driving question:** How long do stars last?



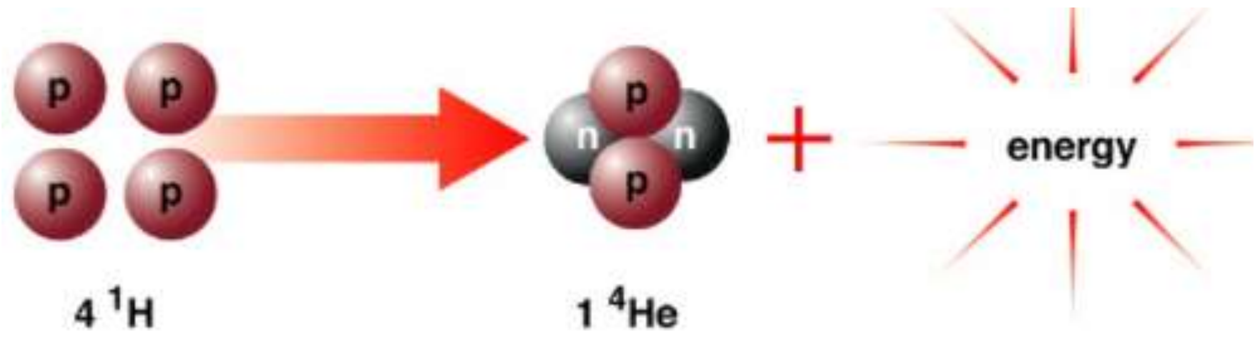


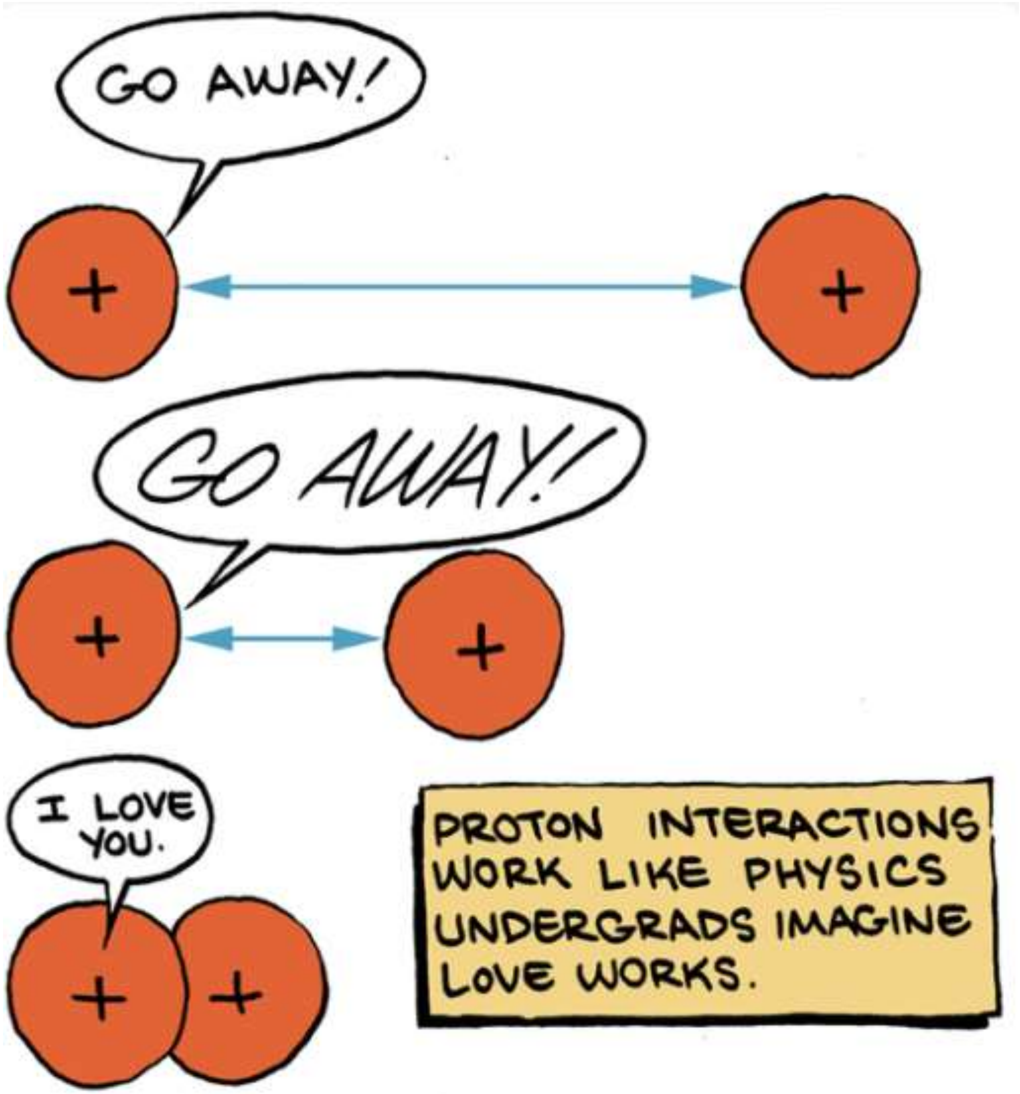
Sun Unit Recap

Unit 1, Weeks 1-4

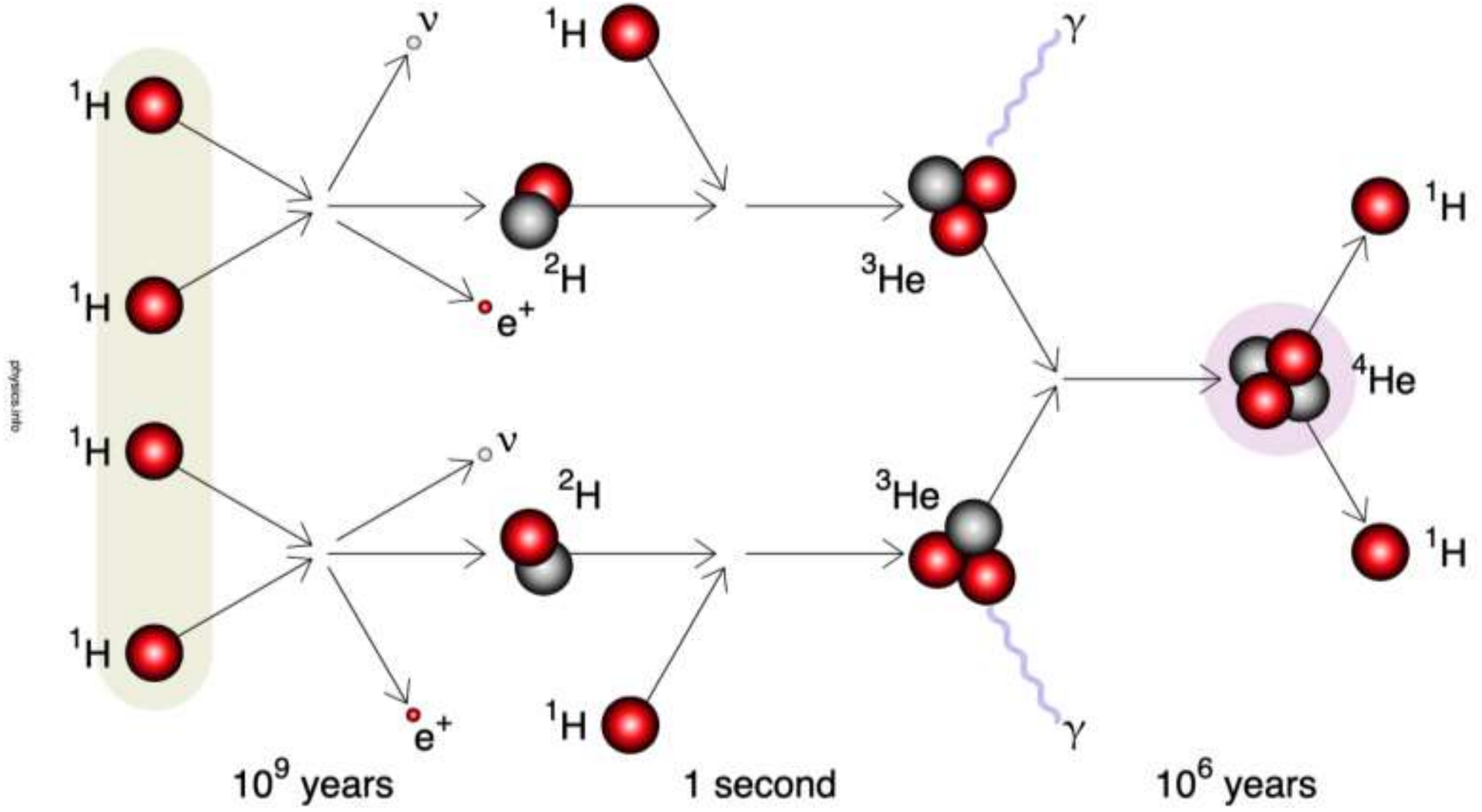
Sun Unit Recap

- **We know that the sun is primarily composed of hydrogen and helium.**
  - The sun is large enough to generate the heat and gravitational pressure needed to overcome Coulomb's barrier.
  - This enables nuclear fusion ($H \rightarrow He$) to transform matter into energy (gamma radiation).





Proton-Proton Chain



1. Two hydrogen protons (^{1}H) fuse, making deuterium (^{2}H, a proton & neutron). Because a proton becomes a neutron, a positive electron (or positron, e^{+}) and a neutrino are ejected.

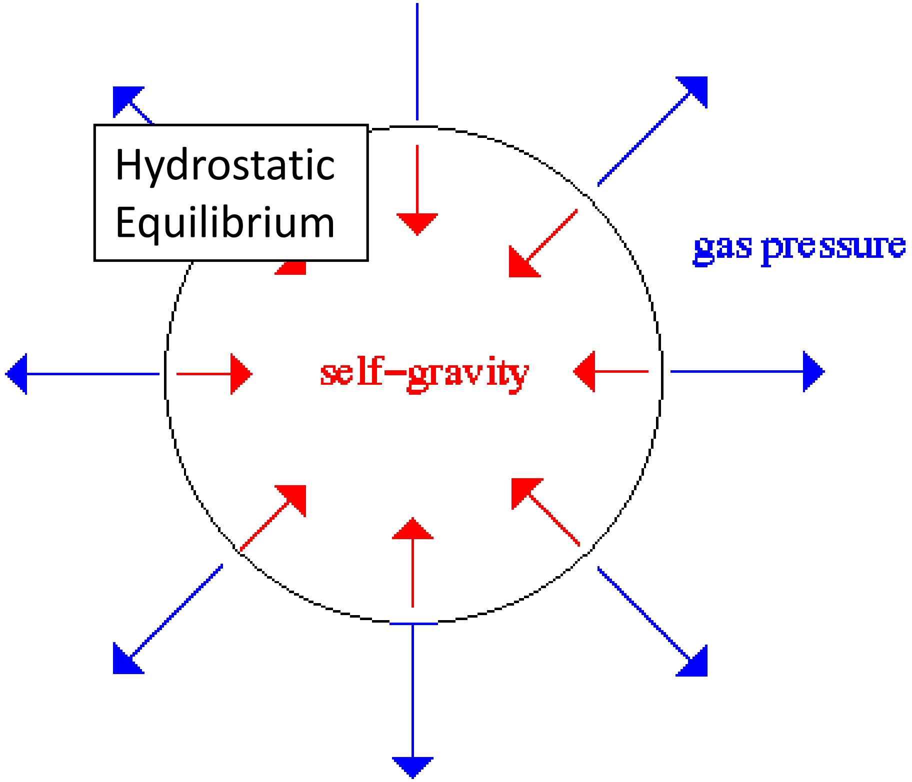
2. The deuterium (^{2}H) captures another ^{1}H proton to form Helium-3 (^{3}He). Radiation is emitted as gamma rays (γ).

3. Two Helium 3 (^{3}He) fuse to form one helium-4 (^{4}He) nucleus. They eject two hydrogen protons (^{1}H).

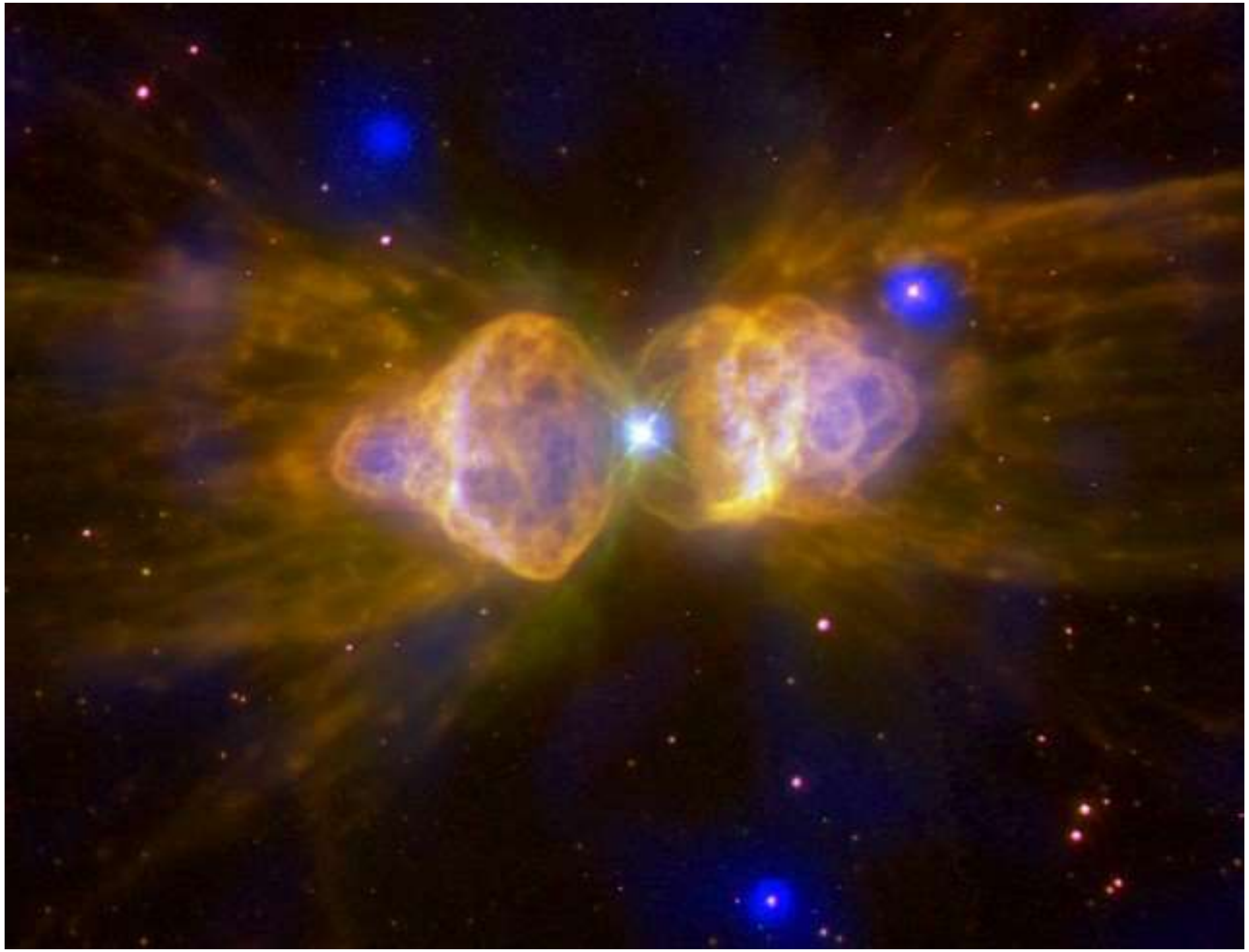
Image Source: https://physics.info/fusion/

Gas Laws

- **<u>Hydrostatic equilibrium</u> determines the structure and life of stars.**
  - The outward pressure of radiation from nuclear fusion must balance gravity`s inward pressure.
  - At every position in a star, the pressure of the gas must be just enough to support the ``weight'' of the star above it.
  - If this is not the case, the star would expand or contract and eventually become unstable.



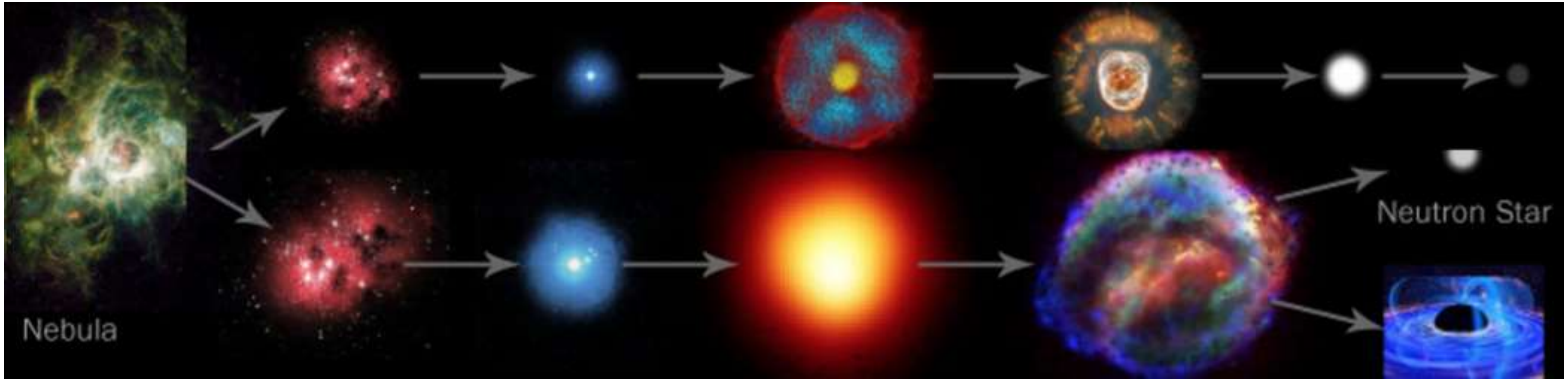
Source: http://ircamera.as.arizona.edu/NatSci102/NatSci102/text/hydrostat.htm



The Life of Stars

The Life of Stars

- **Every star, including our own sun, goes through a predictable life cycle.**
  - A star’s mass determines the rate and type of nuclear fusion as well as how the star ages.
- **The larger the mass of a star, the shorter its life cycle.**
  - Larger stars must ‘burn’ more vigorously to counteract their own gravitational pressure.
- **Our sun will fuse hydrogen into helium for 10 billion years.**
  - Stars burn for as little as a couple million years up to hundreds of billions of years. A star 25x our sun’s mass burns for 3 million years; a star 0.5x our sun’s mass can burn 200 *billion* years.
- **A star’s mass is determined by the amount of matter in its nebula**
  - A nebula is a cloud of gases outside of a star’s orbit.

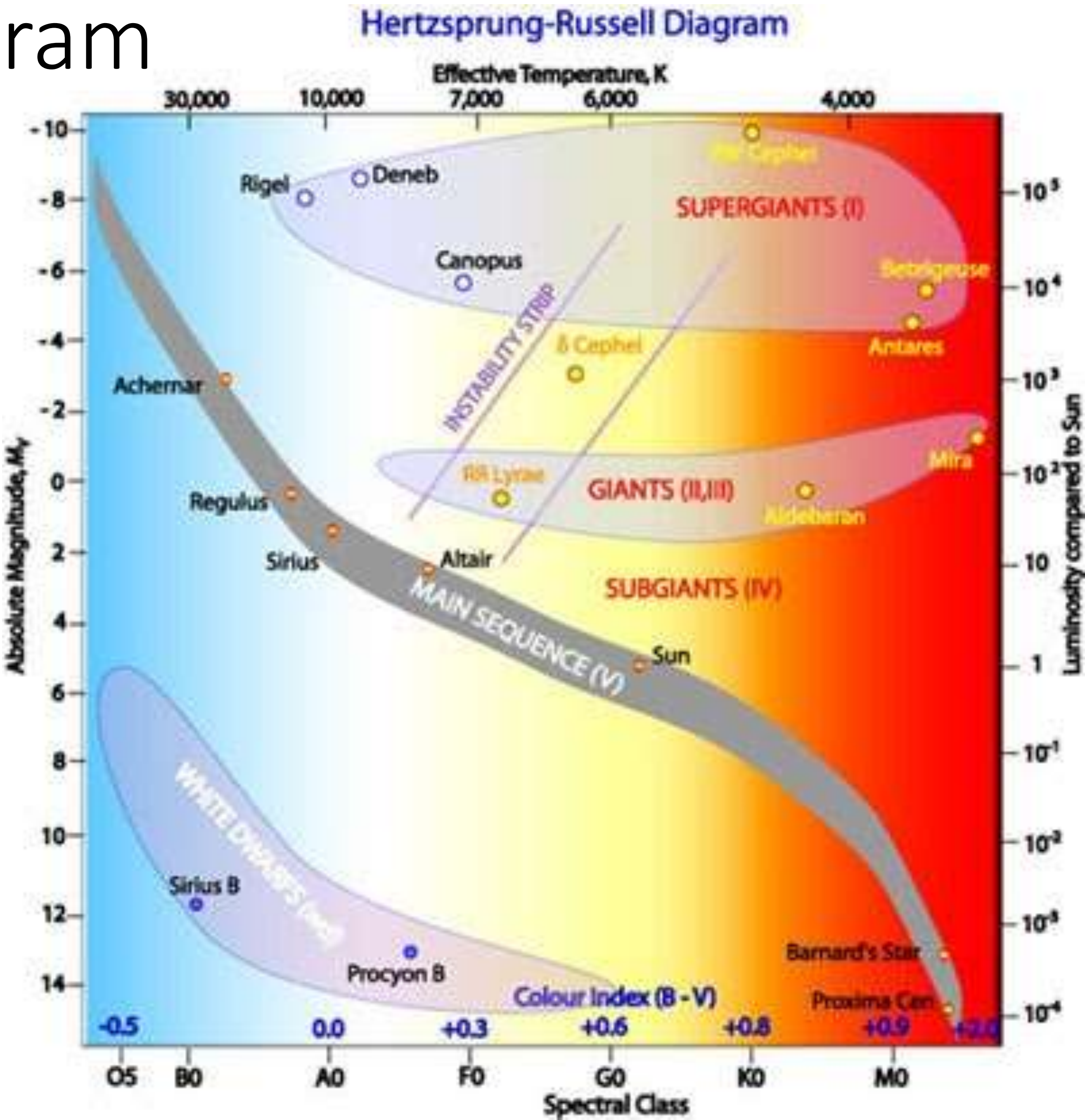


Credit: http://americanboard.org/Subjects/Images/gensci/img/Mod2Graphic4.jpg

Credit: *R. Hollow, CSIRO*

Hertzsprung-Russell Diagram

- **In the early 1900s, Hertzsprung and Russell graphed stars based on their internal temperature and luminosity.**
  - They also graphed stars based on their color (based on blackbody radiation) and their <u>absolute magnitude</u> (a star's standardized measure of size and brightness).
  - Both are shown in the image here →
- **The resulting graph, called the H-R Diagram, is one of the most important tools for analyzing and predicting the life cycle of stars.**
  - Astronomers can know a star's internal structure and evolutionary stage simply by determining its position in the diagram.

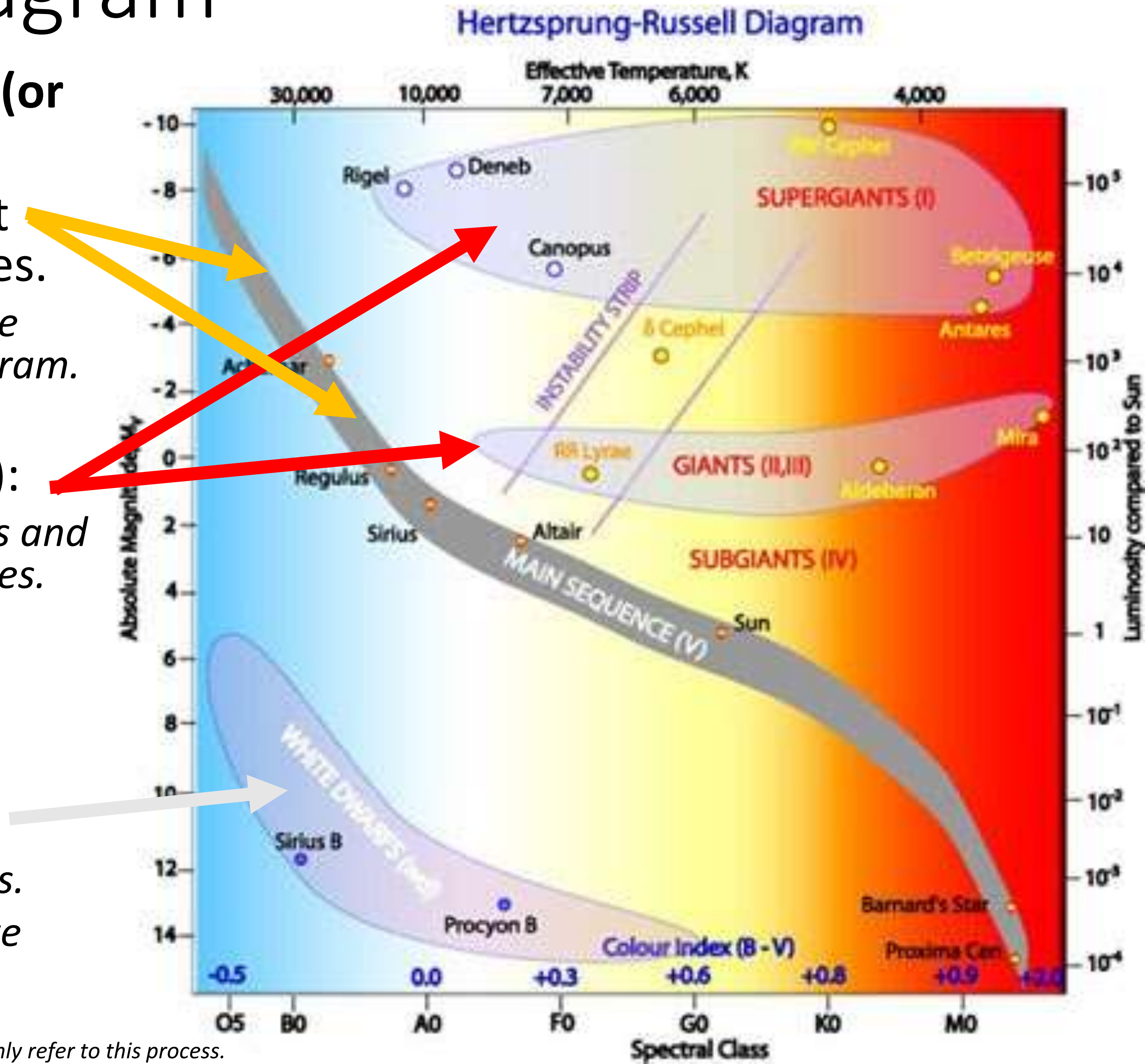


Credit: R. Hollow, CSIRO

Hertzsprung-Russell Diagram

The H-R Diagram has three main regions (or <u>stellar evolutionary stages</u>):

- The <u>Main Sequence</u>: these are stars that burn* hydrogen and helium in their cores.
  - *This is the S-shaped curve that runs from the upper left to the lower right of the H-R diagram.*
- The <u>Giants</u> (Red Giants and Supergiants):
  - *These stars (upper right) have a large radius and high luminosity but low surface temperatures.*
  - *These stars have exhausted the hydrogen in their cores and now burn helium and other heavier elements.*
- <u>White Dwarfs</u>:
  - *This is the final stage in the life cycle of stars.*
  - *These stars (lower left) are very hot but have low luminosities due to their small size.*

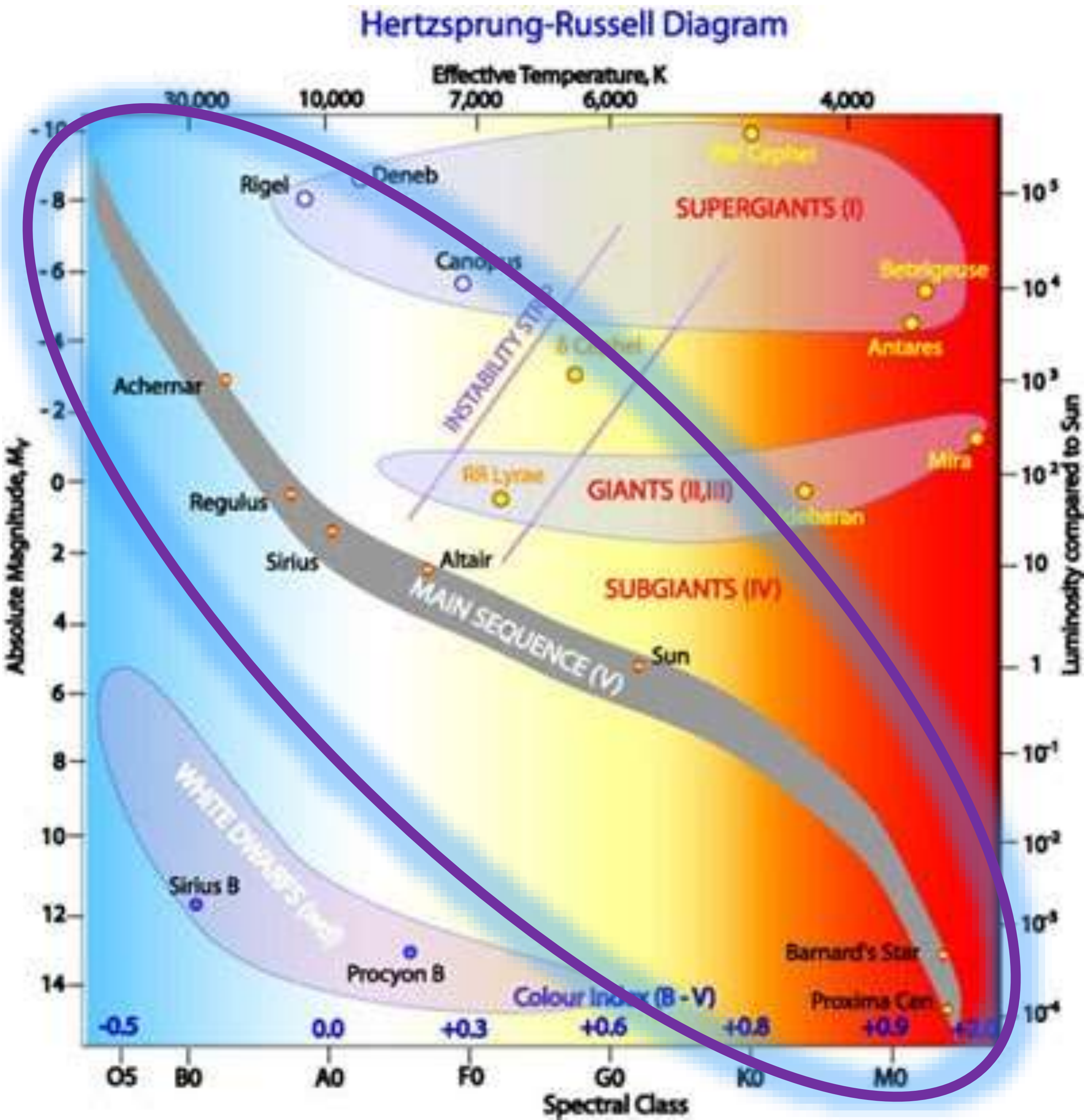


*Hydrogen isn't 'burned' but rather fused into helium. However, this is how astronomers commonly refer to this process.

Credit: R. Hollow, CSIRO

Main Sequence Stars

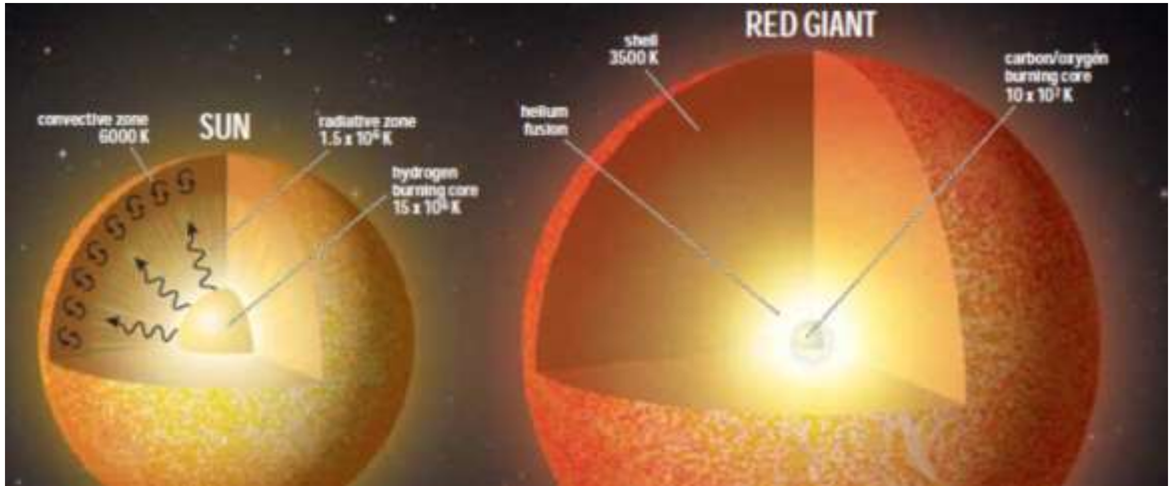
- **Main sequence stars are those that "burn" hydrogen (i.e., fuse hydrogen into helium).**
  - Our star is a main sequence star.
  - Stars will spend 90% of their lives in this stage.
- **As a main-sequence star ages, its core temperature rises.**
  - This causes both luminosity and radius to increase – the outward pressures from nuclear fusion exceeds the inward pressures of gravity.
- **As the hydrogen in the core is consumed, the star's internal balance starts to shift.**
  - Both its internal structure and outward appearance change rapidly.
  - This causes the star to leave the main sequence.



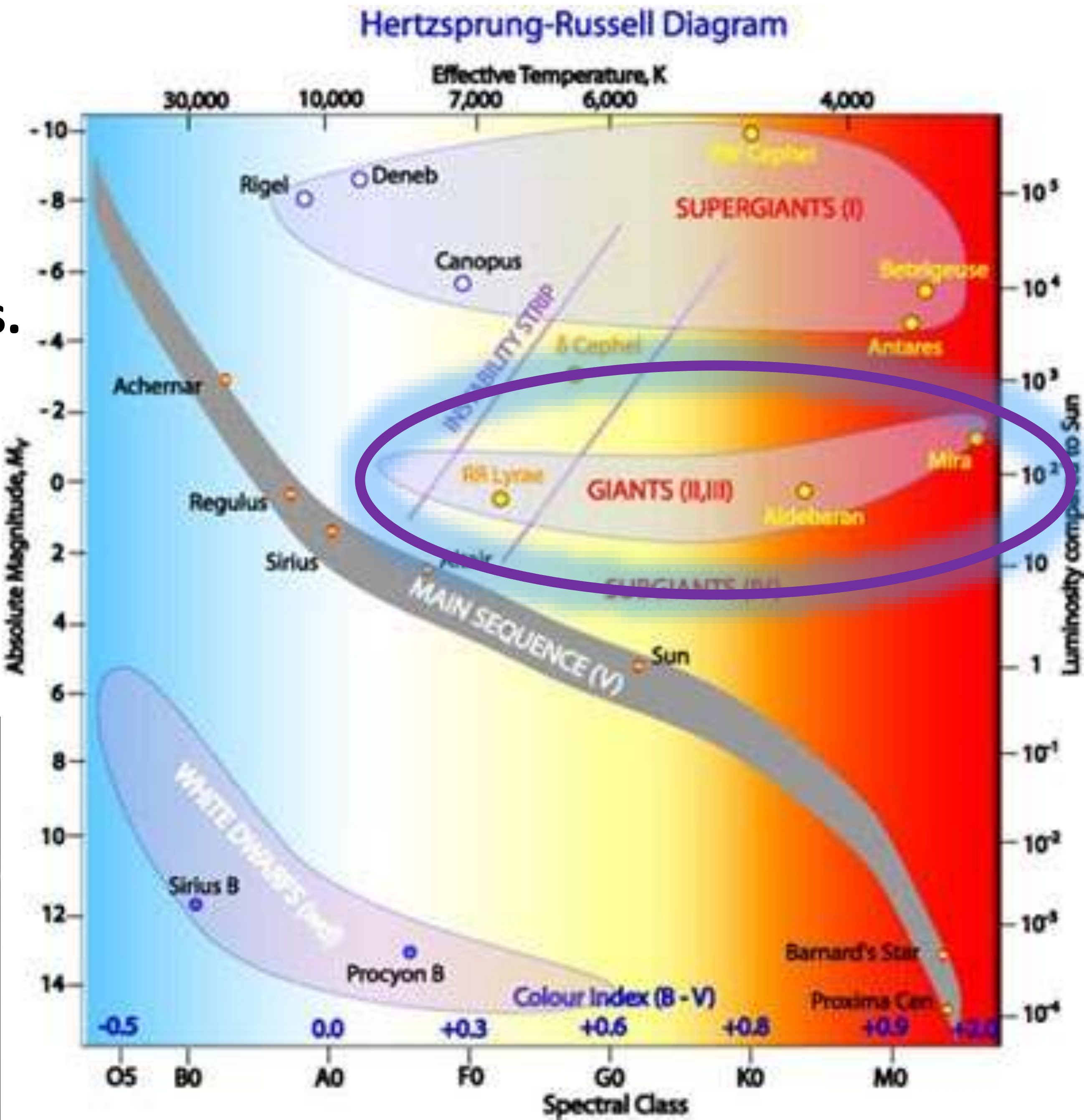
[**Credit**](#): R. Hollow, CSIRO

Red Giants

- **Eventually, most of the hydrogen in the core will be converted into helium.**
  - As nuclear fusion slows, the balance between inward and outward pressures is disrupted.
- **The core becomes unstable and contracts.**
  - Simultaneously, the hydrogen-dense outer shell of the star expands.
  - This causes it to cool and glow red.
- **This is the Red Giant phase.**
  - All stars will eventually reach this phase.
  - The mass of the star determines what occurs after this phase.



Credit: [Astronomy.com](#)



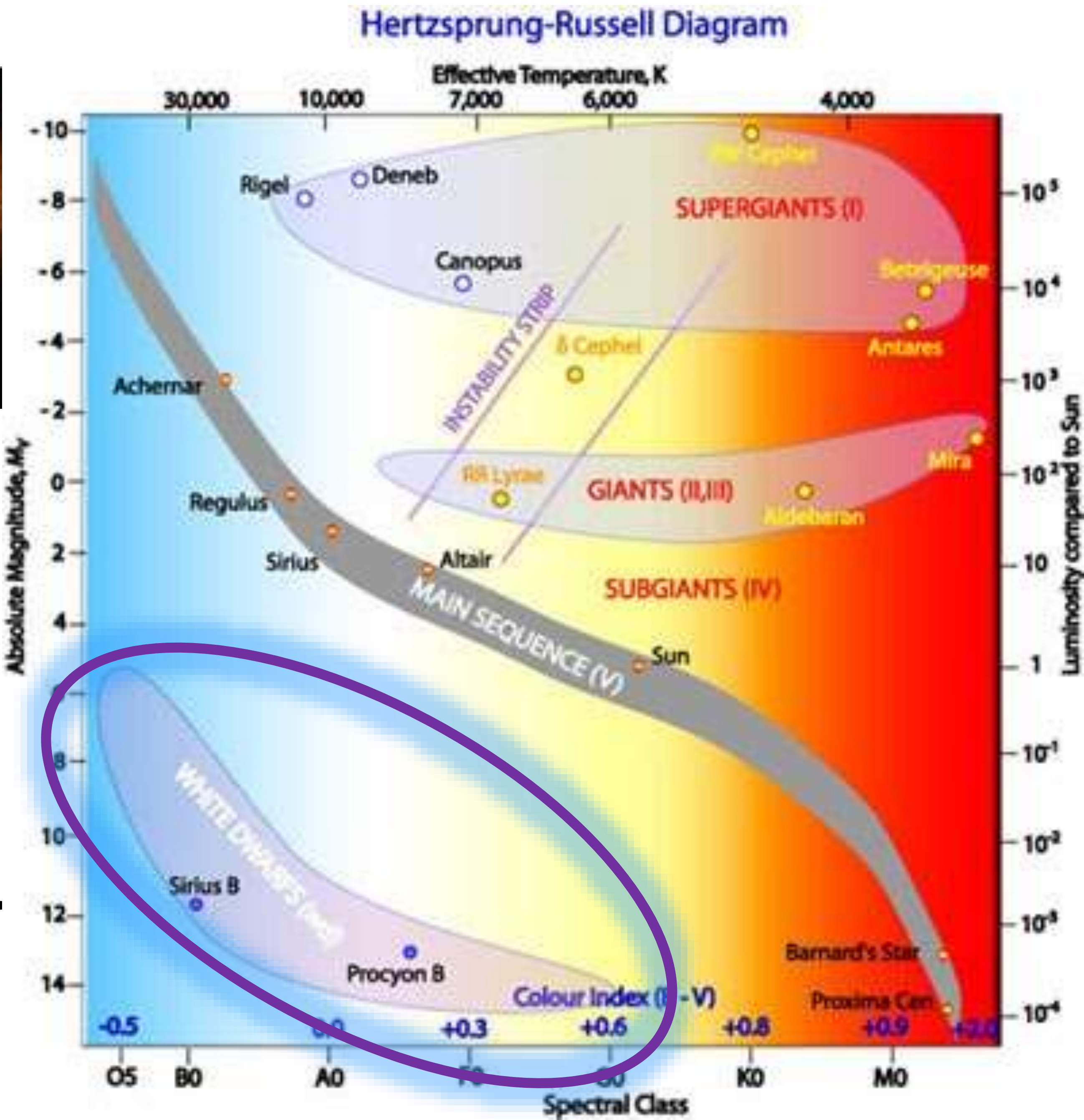
White Dwarfs

- **After reaching the Red Giant phase, stars with low mass will move to the White Dwarf phase.**
  - As nuclear fusion ceases, the star's core collapses.
  - The outer layers of the star expand away from the core, forming a planetary nebula (the cloudy remnants of a dying star ↑).
    - *This term has nothing to do with planets; this kind of nebula is also different from a nebula (cloud of gas) from which the star formed.*

Credit: Wikimedia Commons

- **Eventually only the core remains, creating a dim star called a White Dwarf.**
  - As it slowly cools, a white dwarf will darken in color to become a red dwarf and then a brown dwarf.

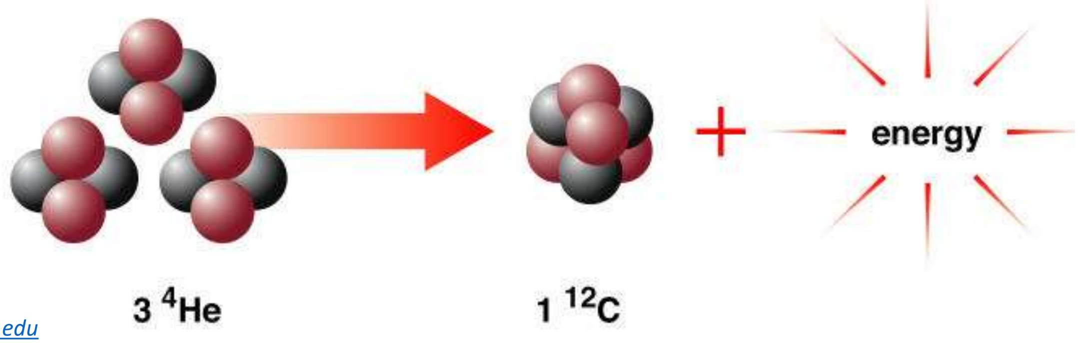
Credit: R. Hollow, CSIRO



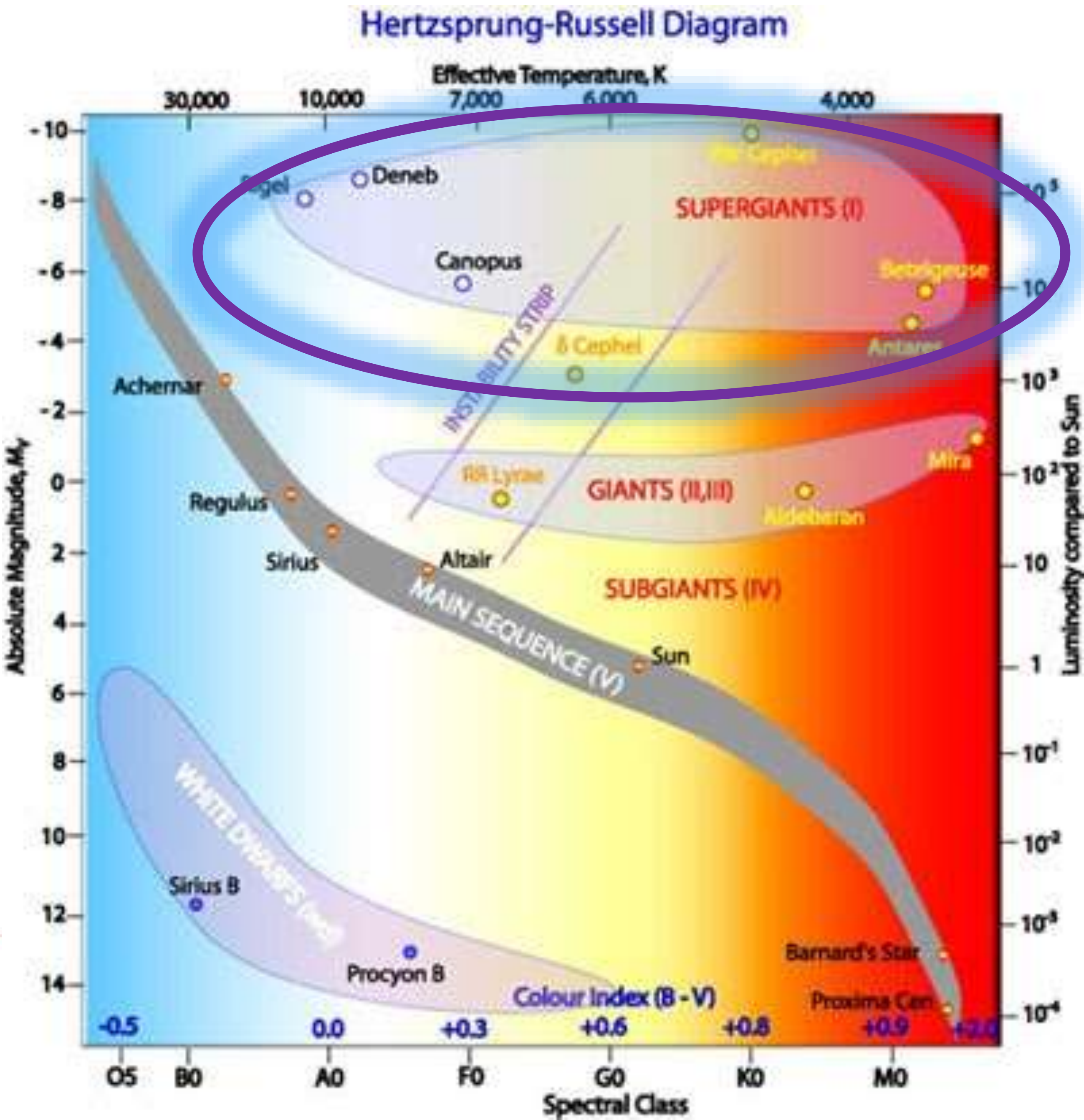
[Credit](#): R. Hollow, CSIRO

Supergiants

- **High-mass stars also form from nebula; like low-mass stars, most of their existence is in the Main Sequence.**
  - However, their life cycles are very different after they complete the Red Giant phase.
- **High-mass stars have enough gravitational pressure to enable the fusion reaction to continue with helium atoms.**
  - Due to greater gravitational pressures, helium atoms can fuse into carbon atoms.



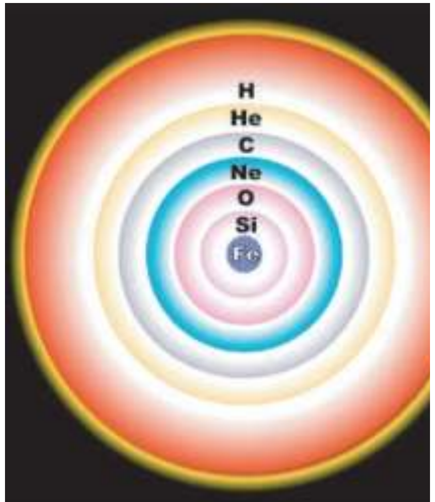
Source: [highline.edu](#)

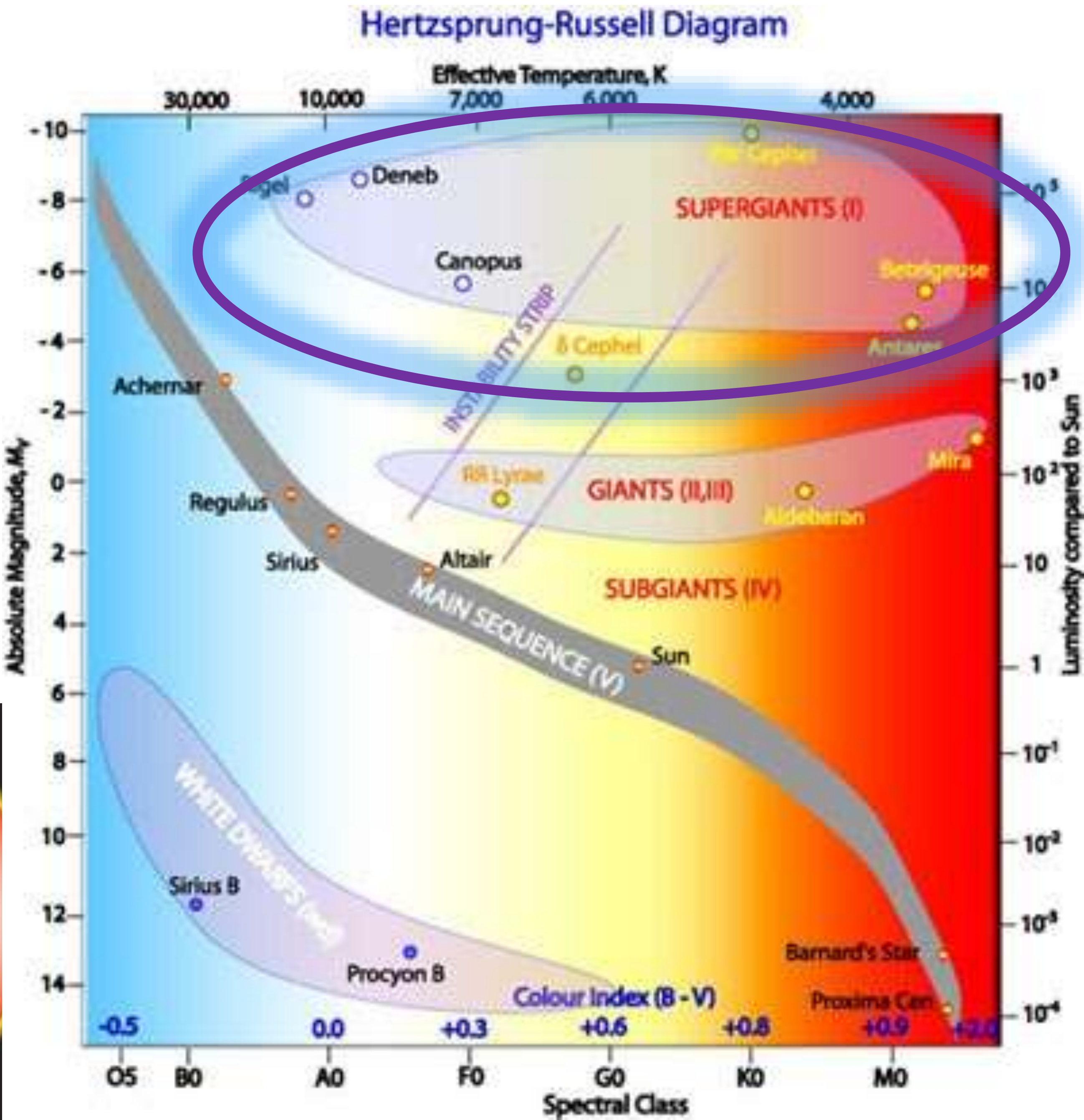


Credit: R. Hollow, CSIRO

Supergiants

- **As stars with a mass at least 5x greater than our Sun reach the Red Giant phase, they can continue to generate heat via fusion in their core to balance the force of gravity.**
  - Unlike small-mass stars, the core temperature of high-mass stars *increases* at this stage as carbon atoms are formed from the fusion of helium atoms.
  - Additional fusion forms oxygen, nitrogen, & iron creating ”onion skin” layers of elements →





Iron: End of Fusion

- **In high-mass stars, nuclear fusion will continue until iron is formed.**
  - More energy is needed to fuse iron than any other element.
  - Fusing iron into other elements requires an input of energy rather than resulting in a release of energy.

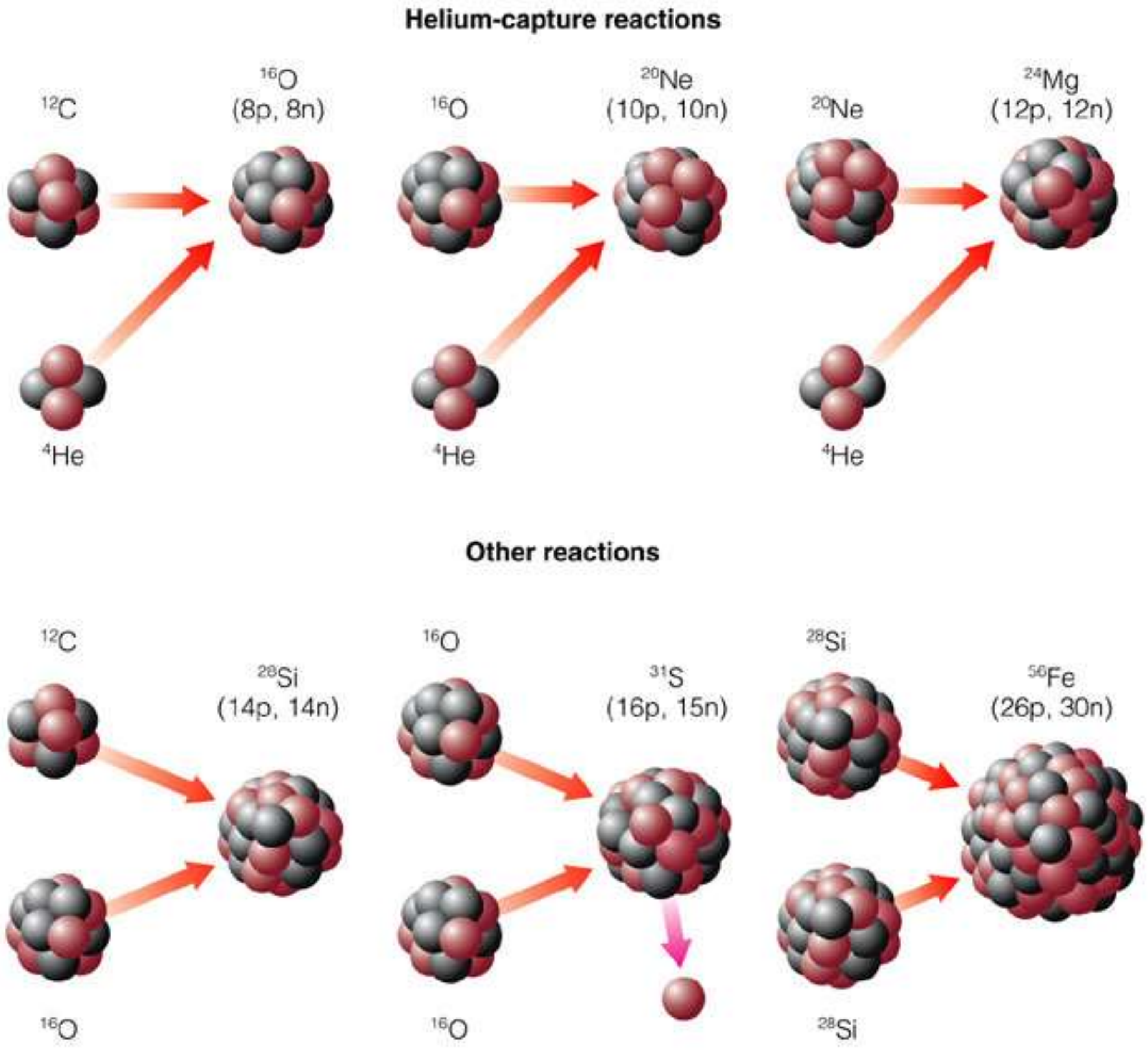


Image Source: uga.edu

Credit: *R. Hollow, CSIRO*

Supergiants

- **Eventually the core of high-mass stars will be entirely composed of iron.**
  - This is the beginning of the end of the star, as fusion is unable to continue any longer.
  - Iron is the most compact and stable element – it would take more energy to fuse elements above iron than could be produced from fusion.
- **As the amount of iron in the core increases, the star enters the phase of gravitational collapse.**
  - The energy radiated from the core decreases, upsetting the hydrostatic equilibrium with gravitational pressure.

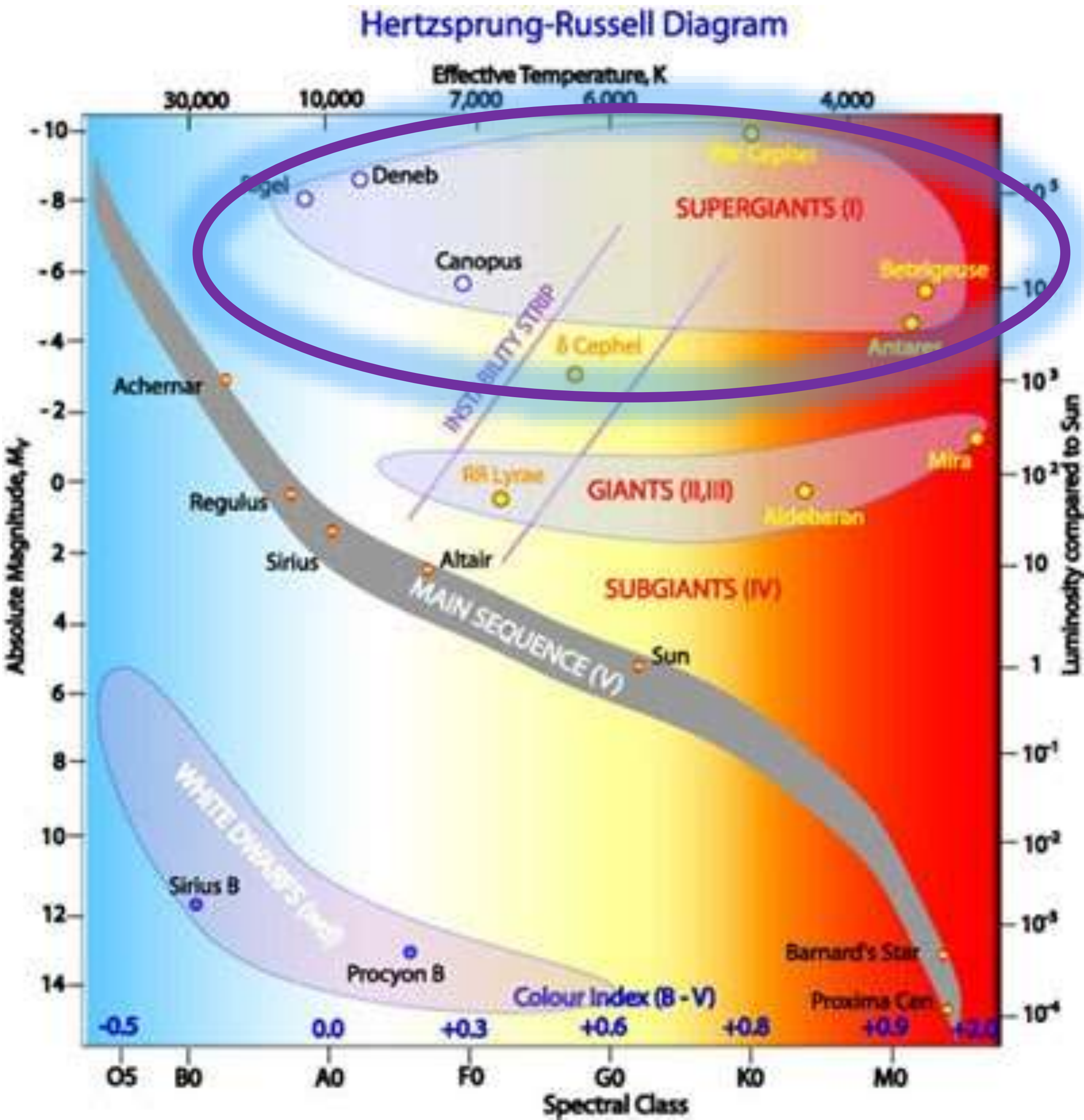


Image Credit: Wikimedia Commons

Supergiants

- **As iron atoms are crushed together by gravity, the core temperature rises to over 100 billion degrees.**
  - The repulsive force between the nuclei (Coulomb's Barrier) eventually overcomes the force of gravity.
  - This releases energy in a shockwave, causing a <u>supernova explosion</u>.
- **This shockwave moves outward, releasing enormous amounts of energy in the remaining outer layers.**
  - The heavier elements above iron are formed in the unstable conditions of the supernova explosion.
  - The shock wave propels the elements in the outer layers (as well as X-rays and gamma rays) into interstellar space.

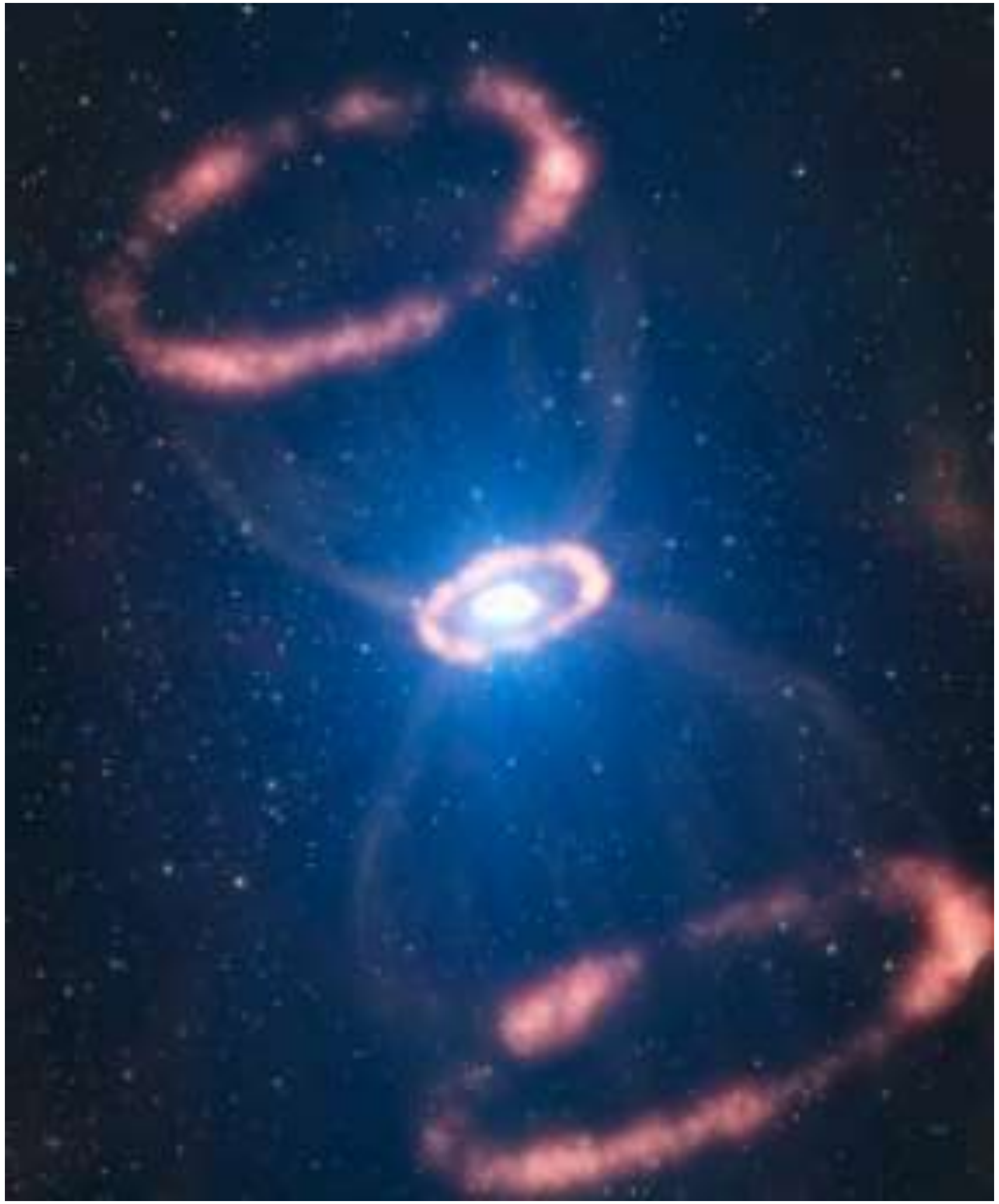


Image Credit: Swinburne Univ.

Neutron Stars

- **After a supernova explosion, the remaining stages in a star's life cycle are determined by its mass.**
  - If the remaining core of the star is less than 3x the mass of our own sun (i.e., a solar mass) the outward pressures of subatomic particles balances against the inward pressure of gravity.
  - This forms a neutron star.
- **Neutron stars are very dense.**
  - They contain the equivalent mass of two of our suns within the volume the size of a small city.
  - These stars also spin rapidly due to this density (much like an ice skater spins faster as they pull their arms closer).

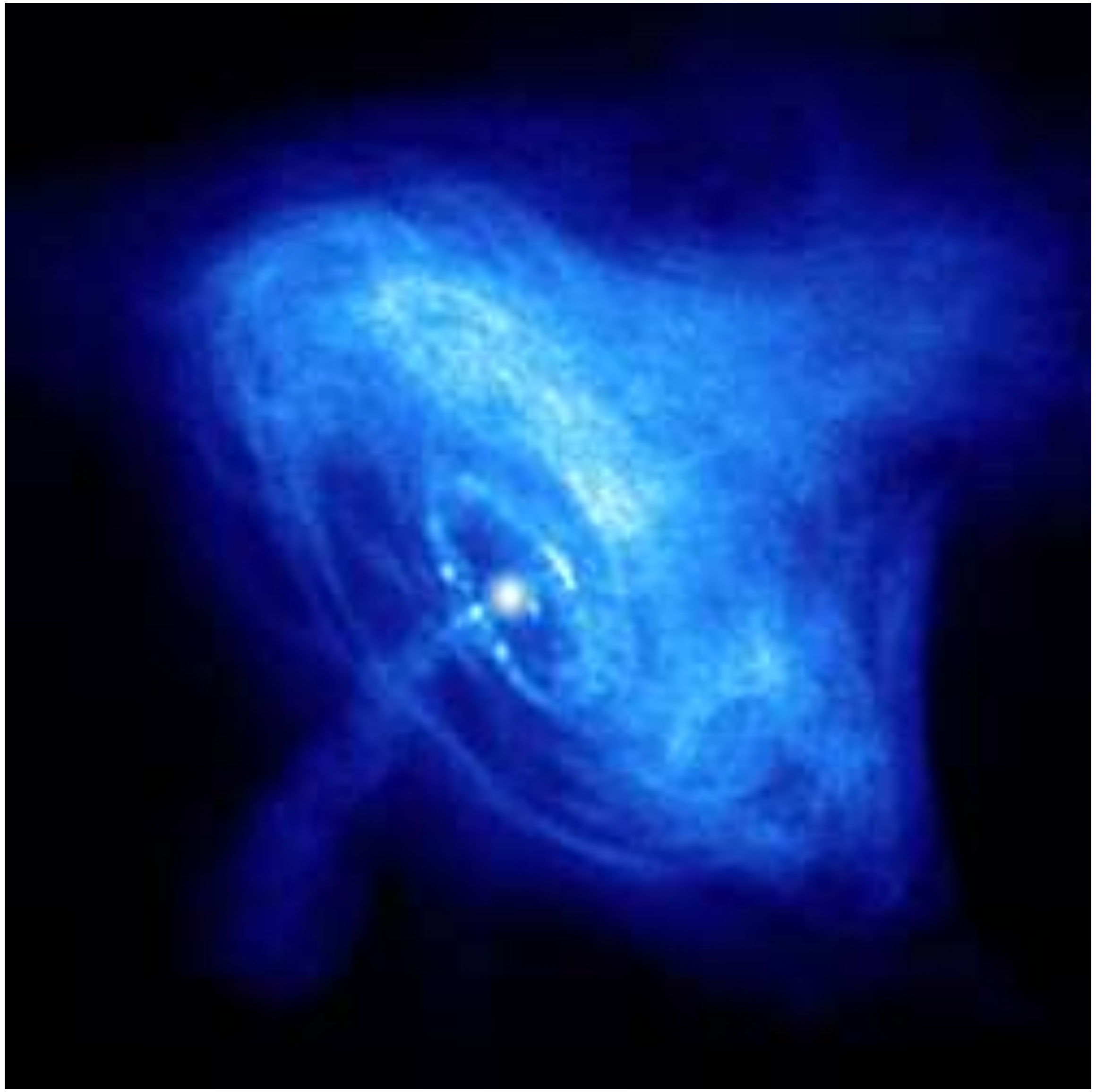
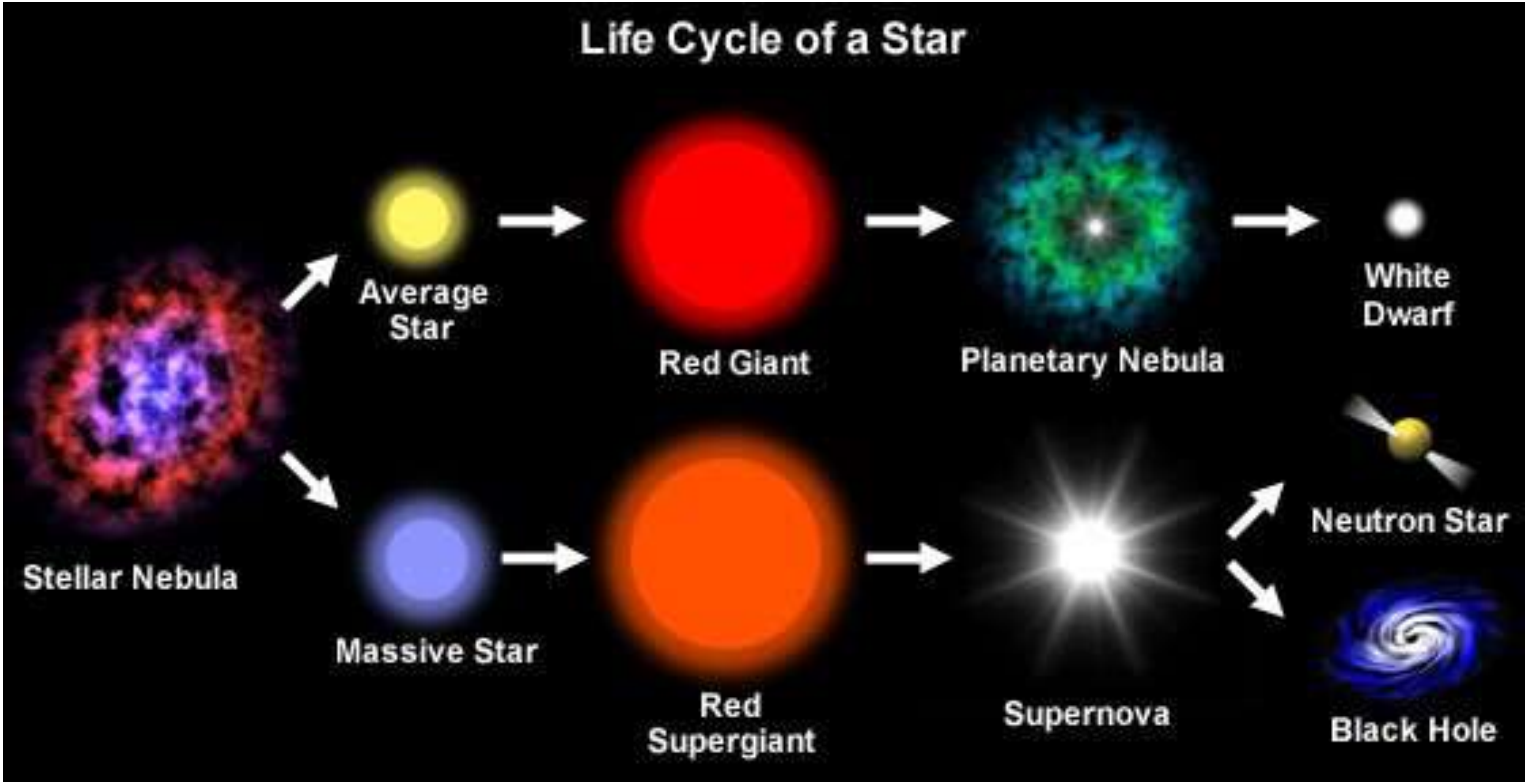


Image Credit: [NASA]

Black Holes

- **If the remaining core of the star has a solar mass *greater* than 3, the outward pressures of subatomic particles cannot balance the inward pressure of gravity.**
  - This forms a stellar black hole, or an stellar core so massive that the force of gravity overwhelms all other forces.
- **A black hole contains the equivalent mass of a star with 10+ solar masses squeezed into a sphere the diameter of New York City.**
  - The result is a gravitational field so strong that nothing can escape (including light).

Image Credit: Quora



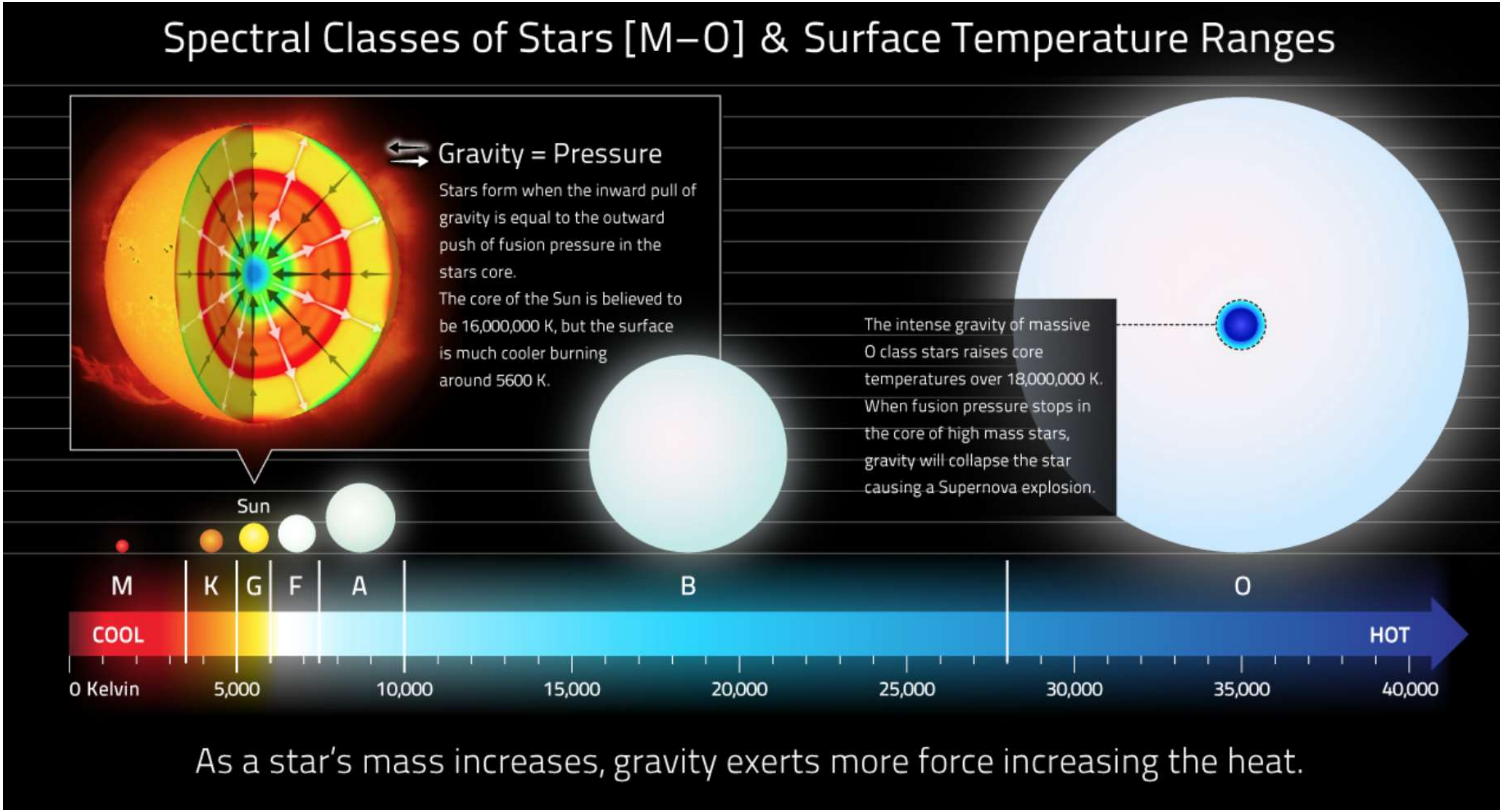


Image Credit: University of Chicago