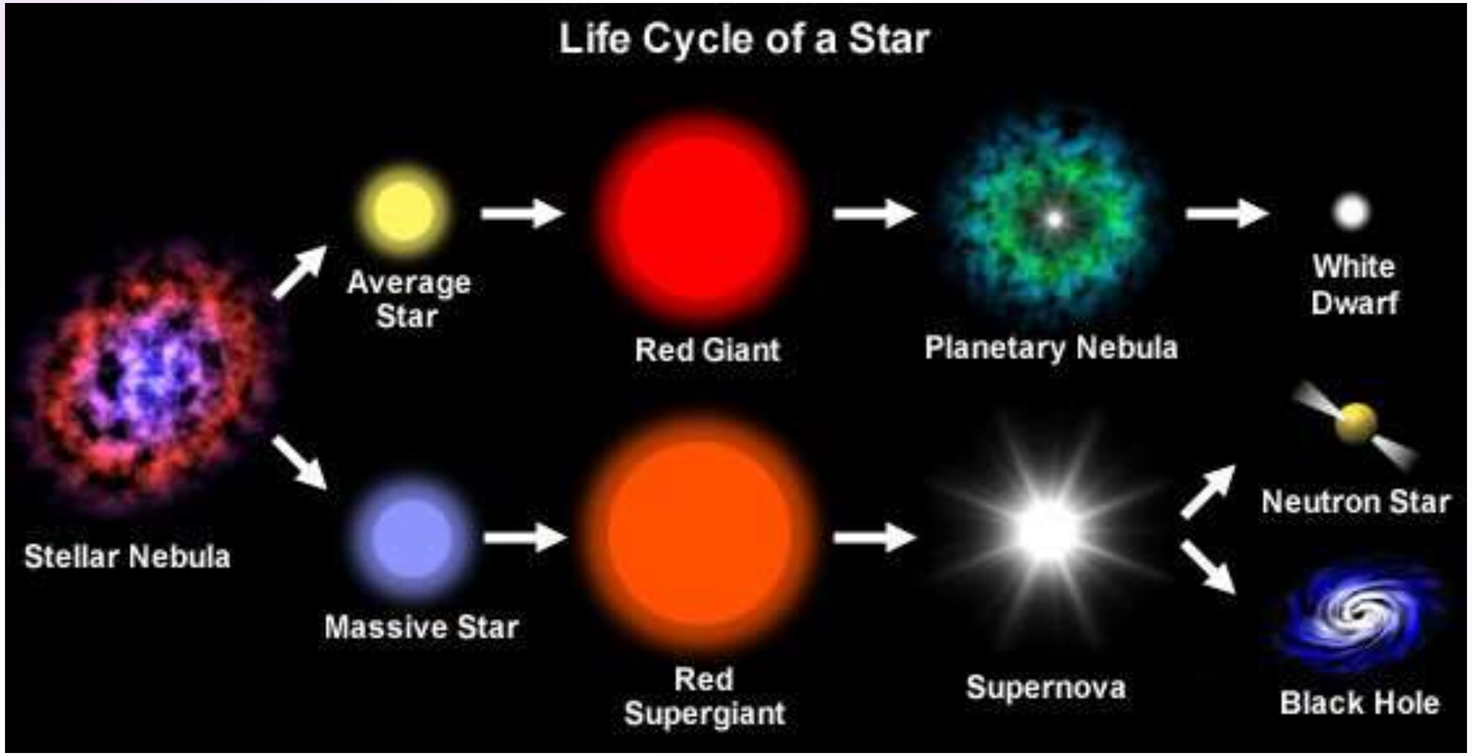
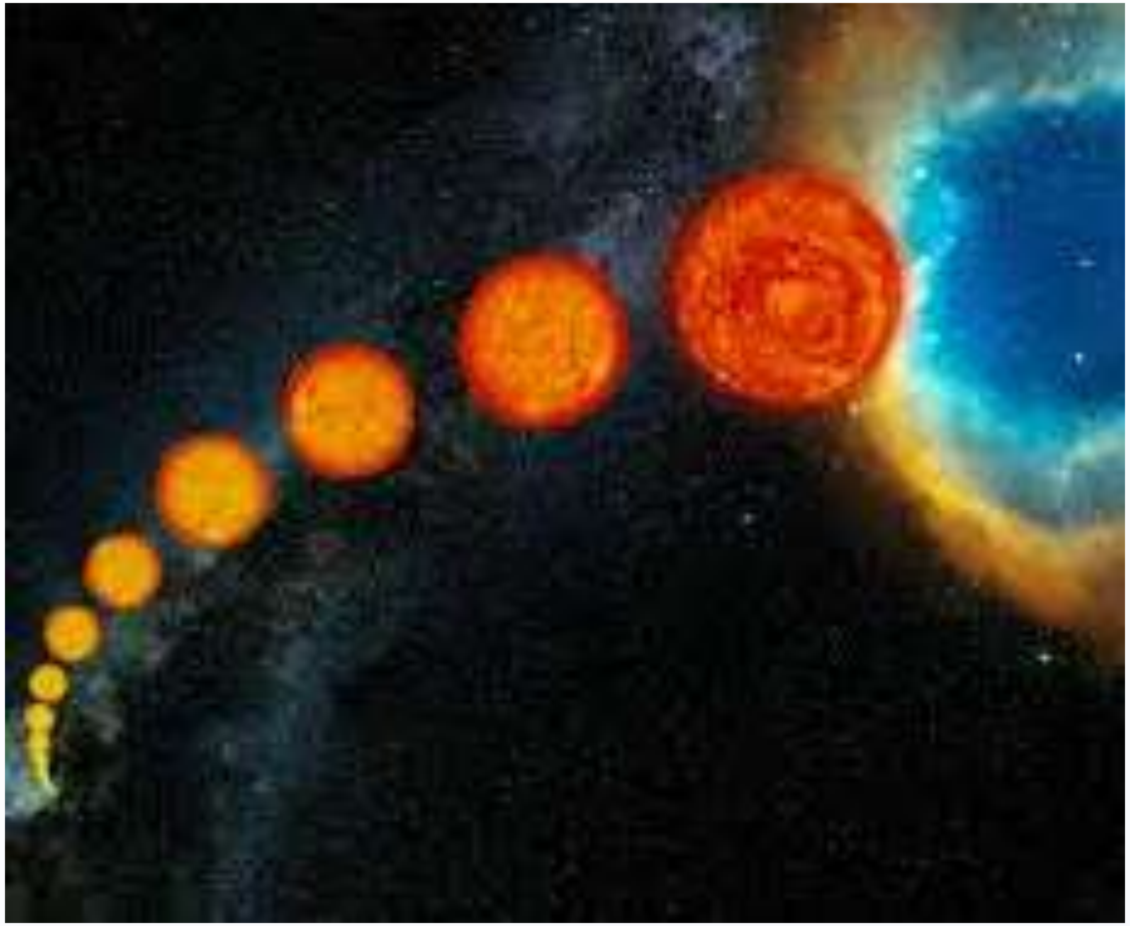


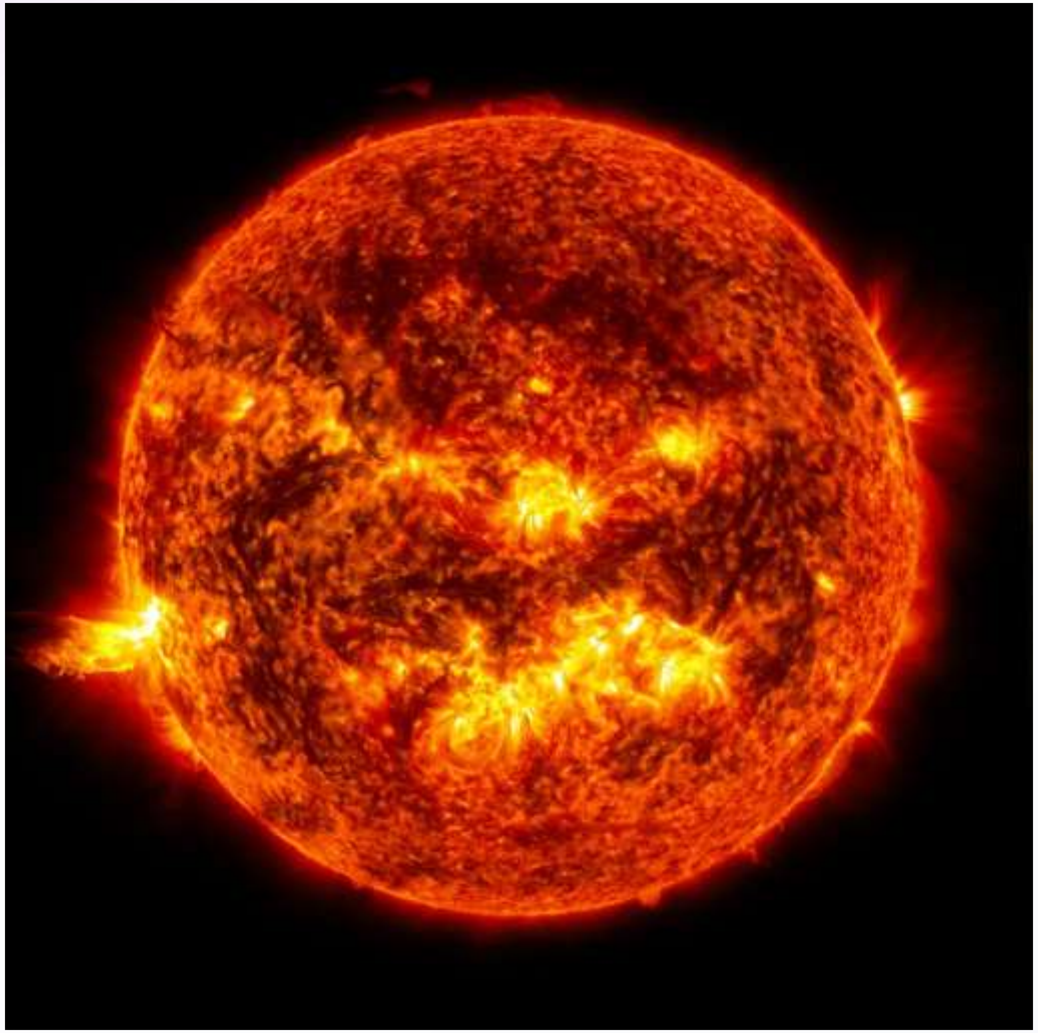
Week 1 – How Long Do Stars Last?

Life of Stars Unit - Waterford Astronomy

Life of Stars Unit W1 Driving Question

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



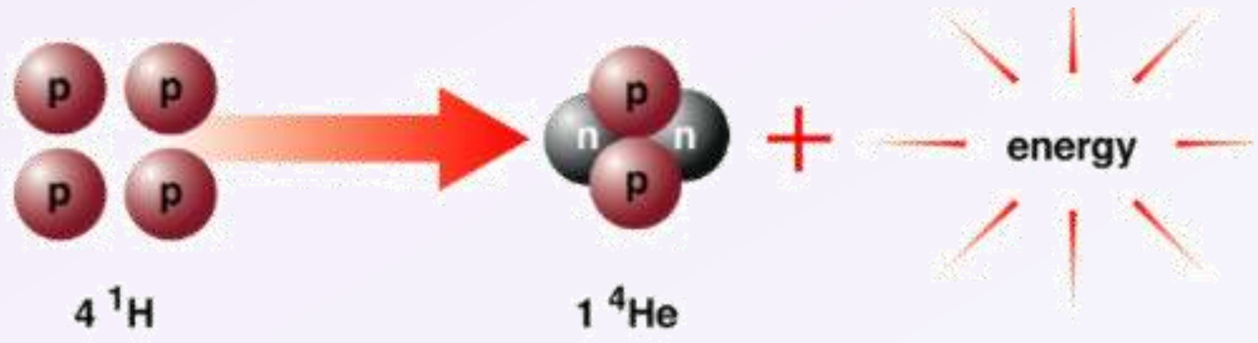


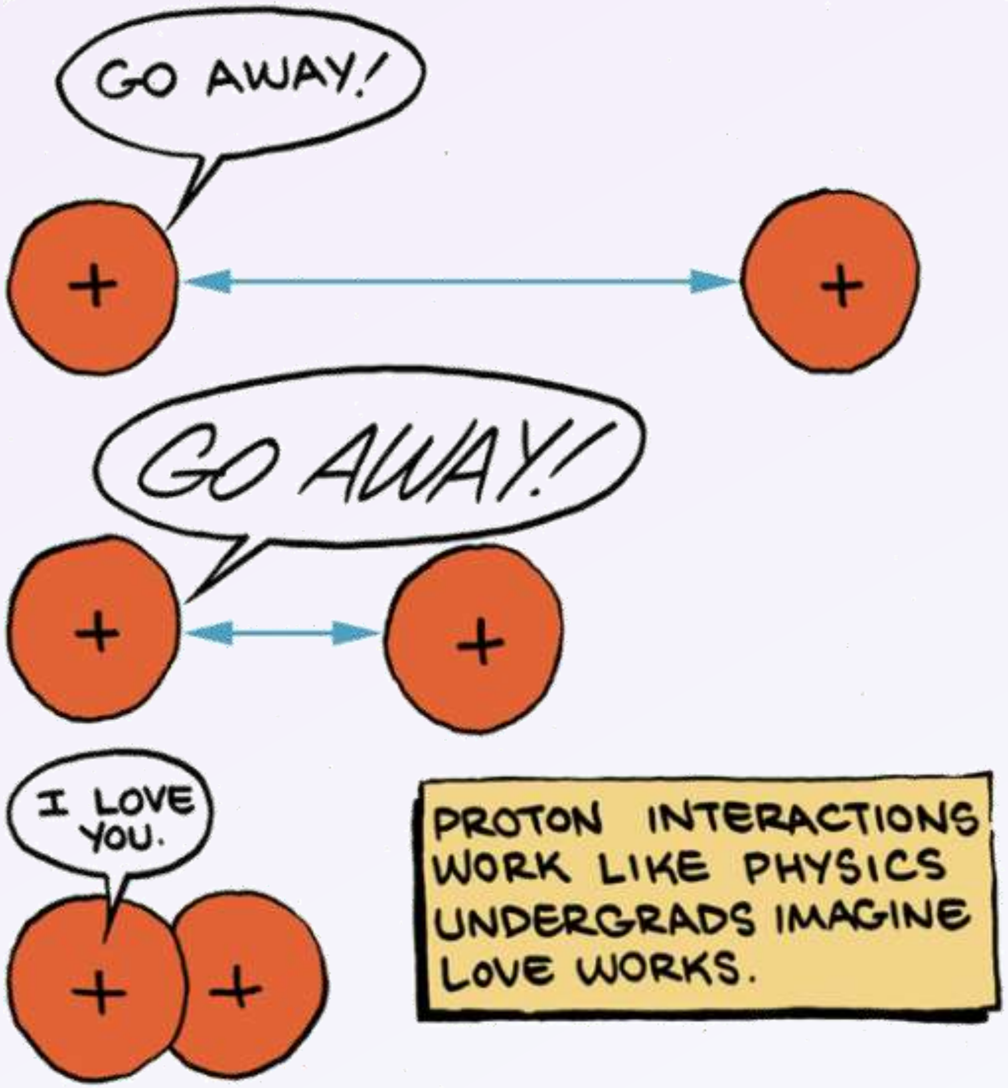
Sun Unit Recap

Unit 1, Weeks 1-4

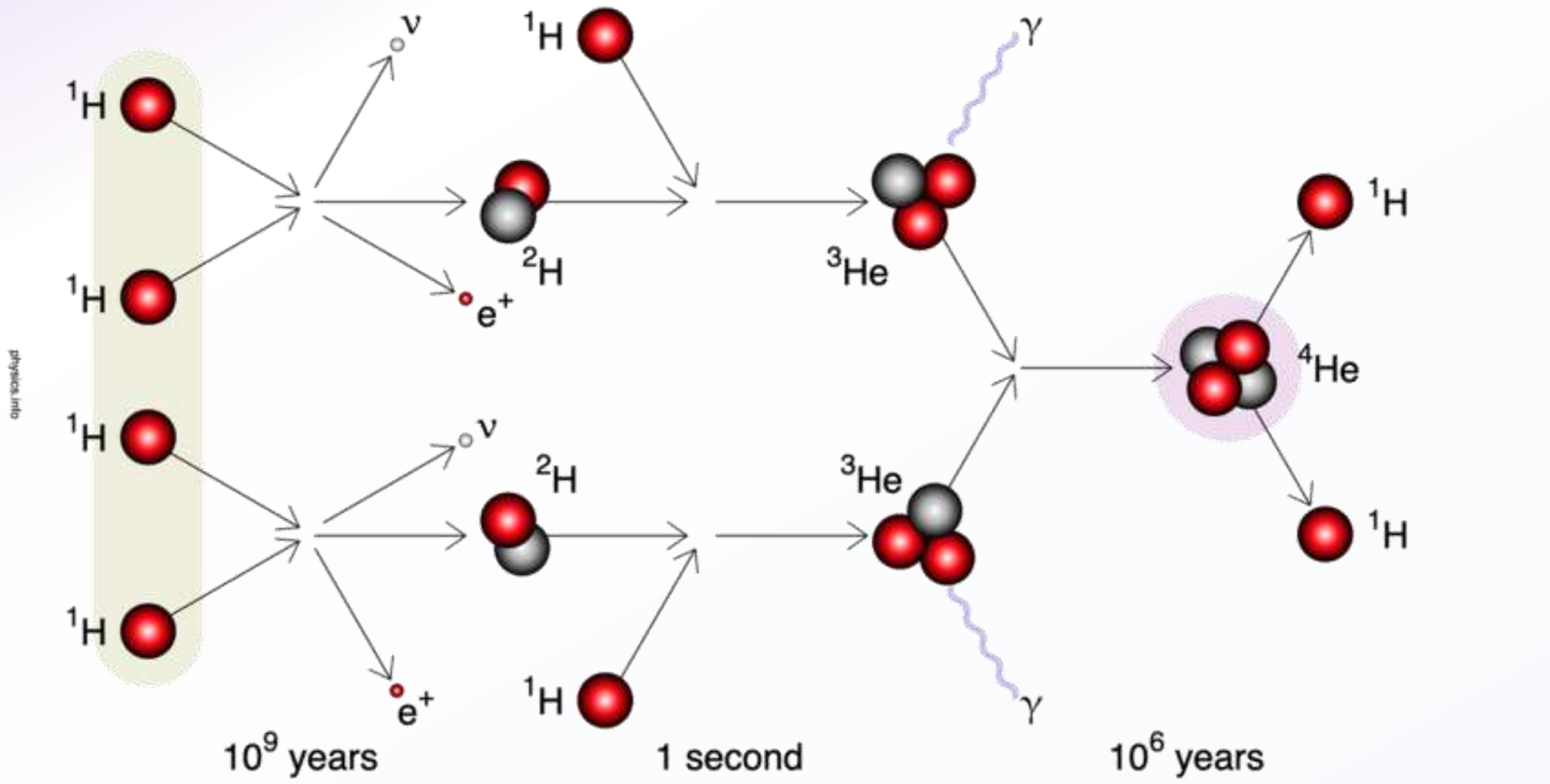
Sun Unit Recap

- **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 (^1H) fuse, making deuterium (^2H, a proton & neutron). Because a proton becomes a neutron, a positive electron (or positron, e^+) and a neutrino are ejected.

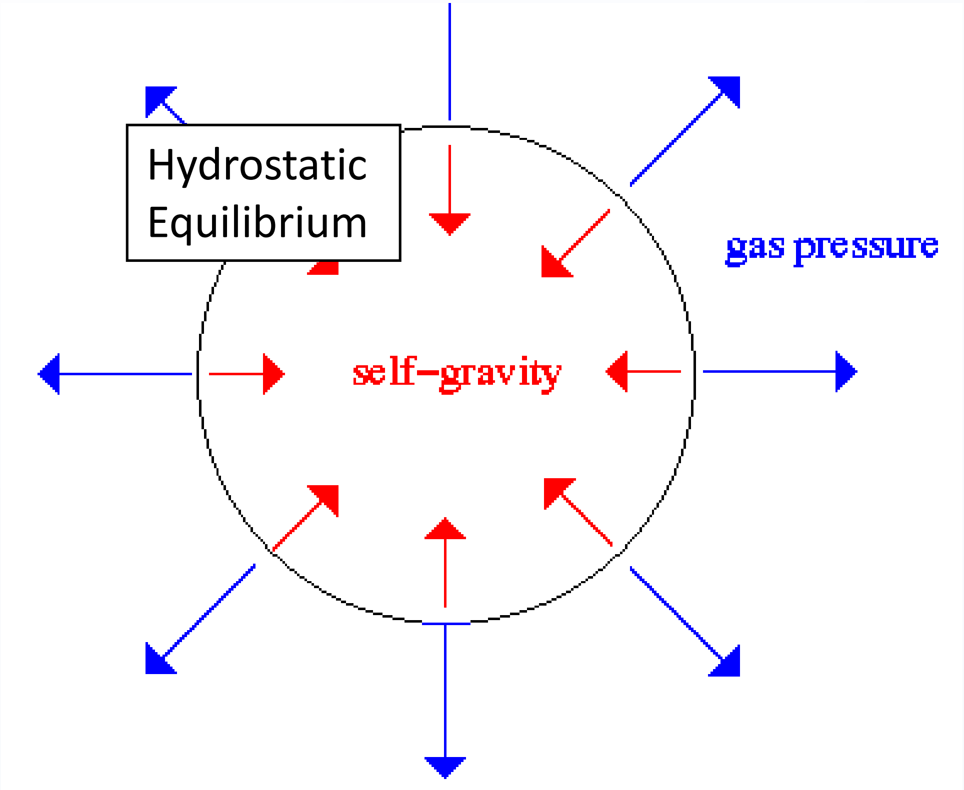
2. The deuterium (^2H) captures another ^1H proton to form Helium-3 (^3He). Radiation is emitted as gamma rays (γ).

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

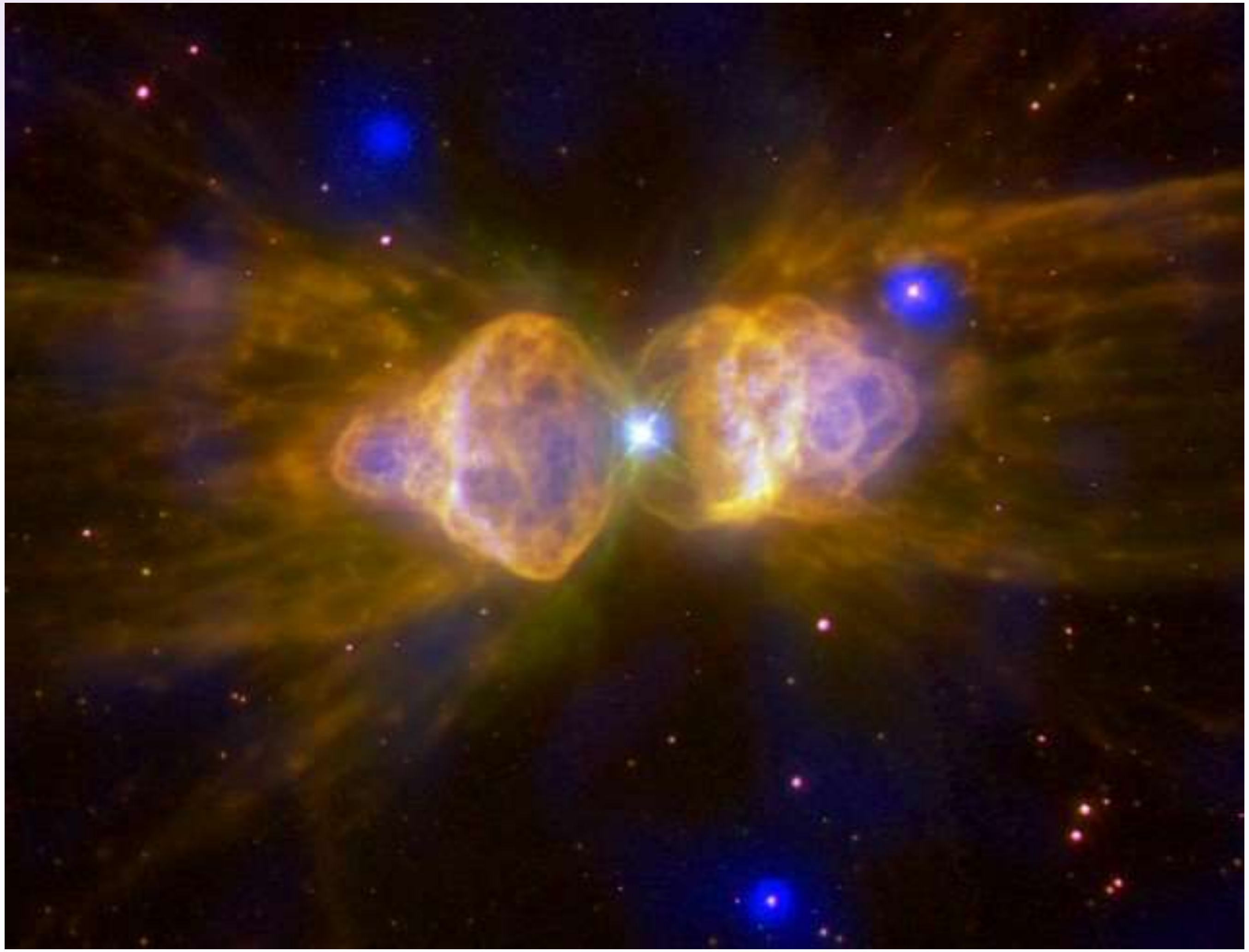
Image Source: https://physics.info/fusion/

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.



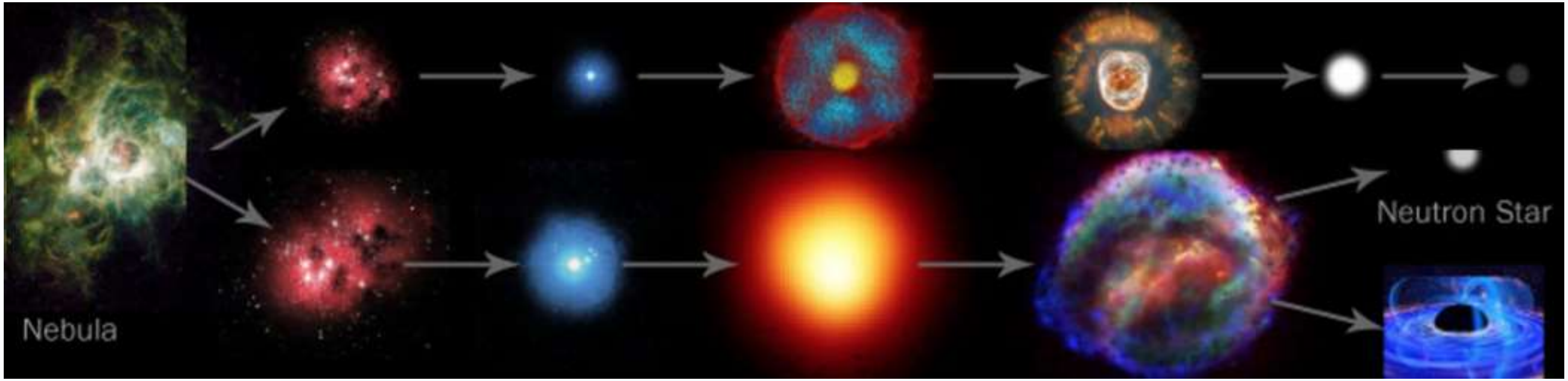
Source: http://ircamera.as.arizona.edu/NatSci102/NatSci102/text/hydrostat.htm



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 <u>nebula</u> is a cloud of gases outside of a star's orbit.



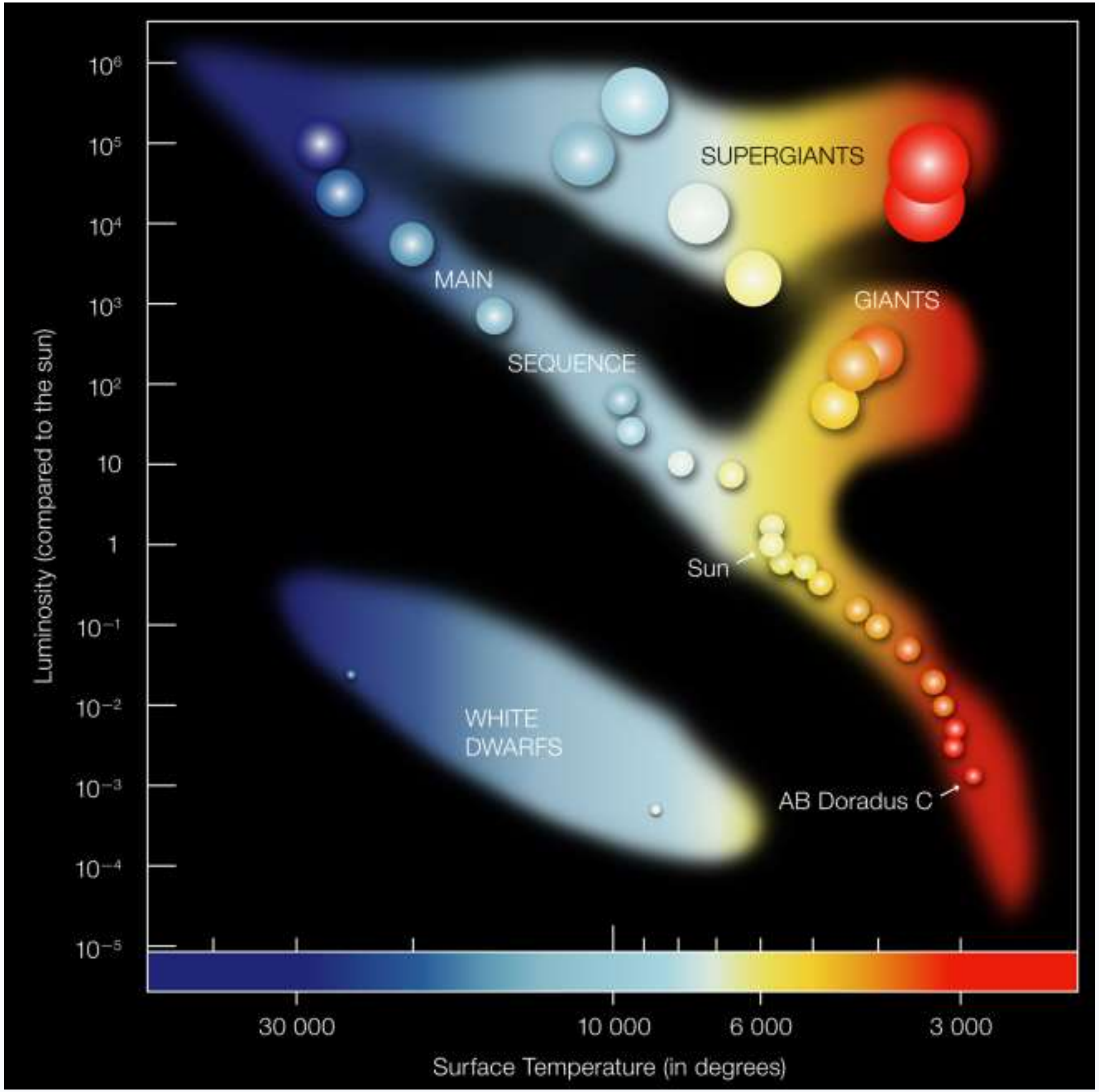
Credit: http://americanboard.org/Subjects/Images/gensci/img/Mod2Graphic4.jpg

Source: [Wikimedia]

H-R 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 absolute magnitude (a standardized measure of size and brightness).

- **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.

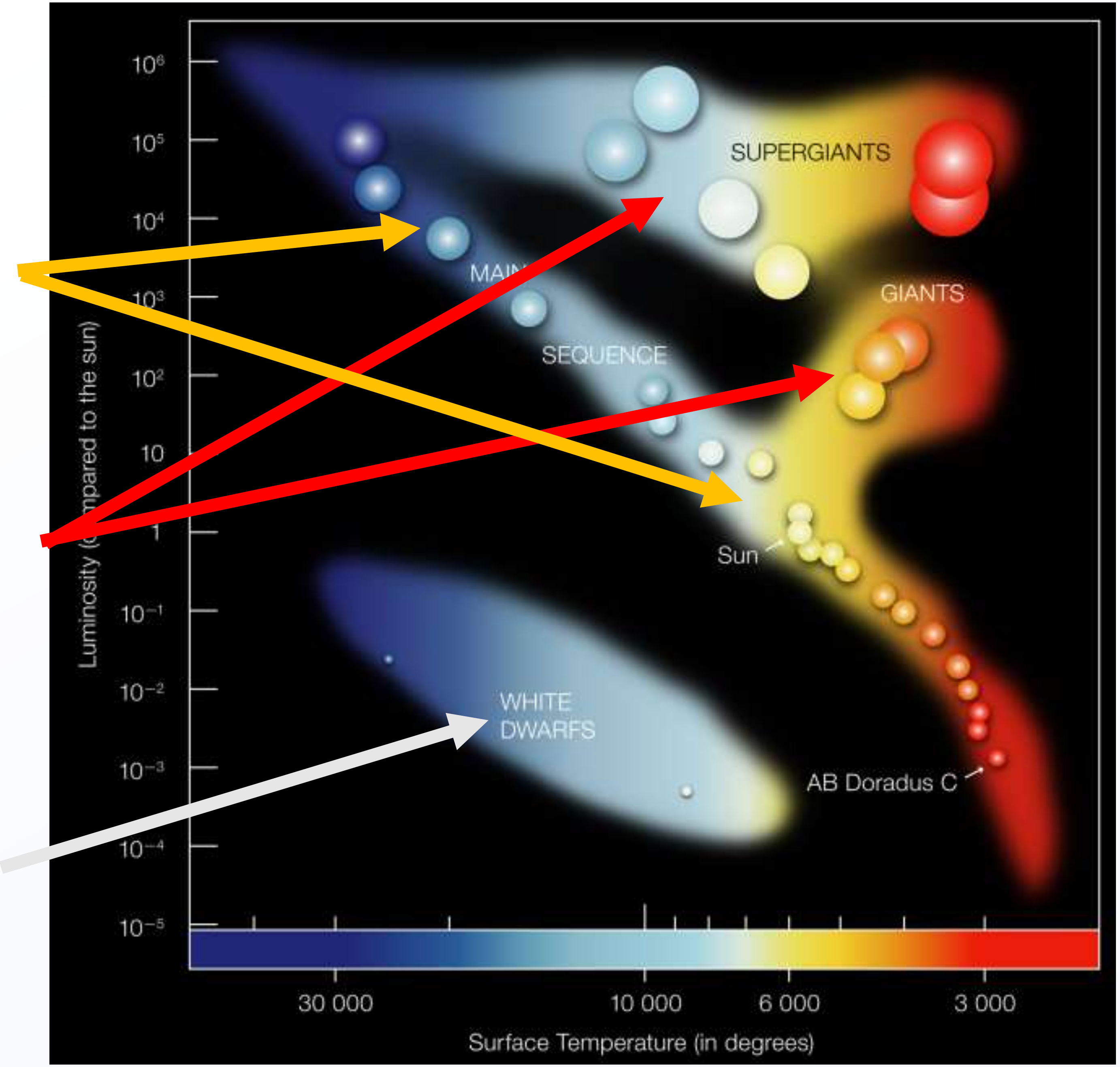


Source: [Wikimedia]

H-R Diagram

The H-R Diagram has three main regions:

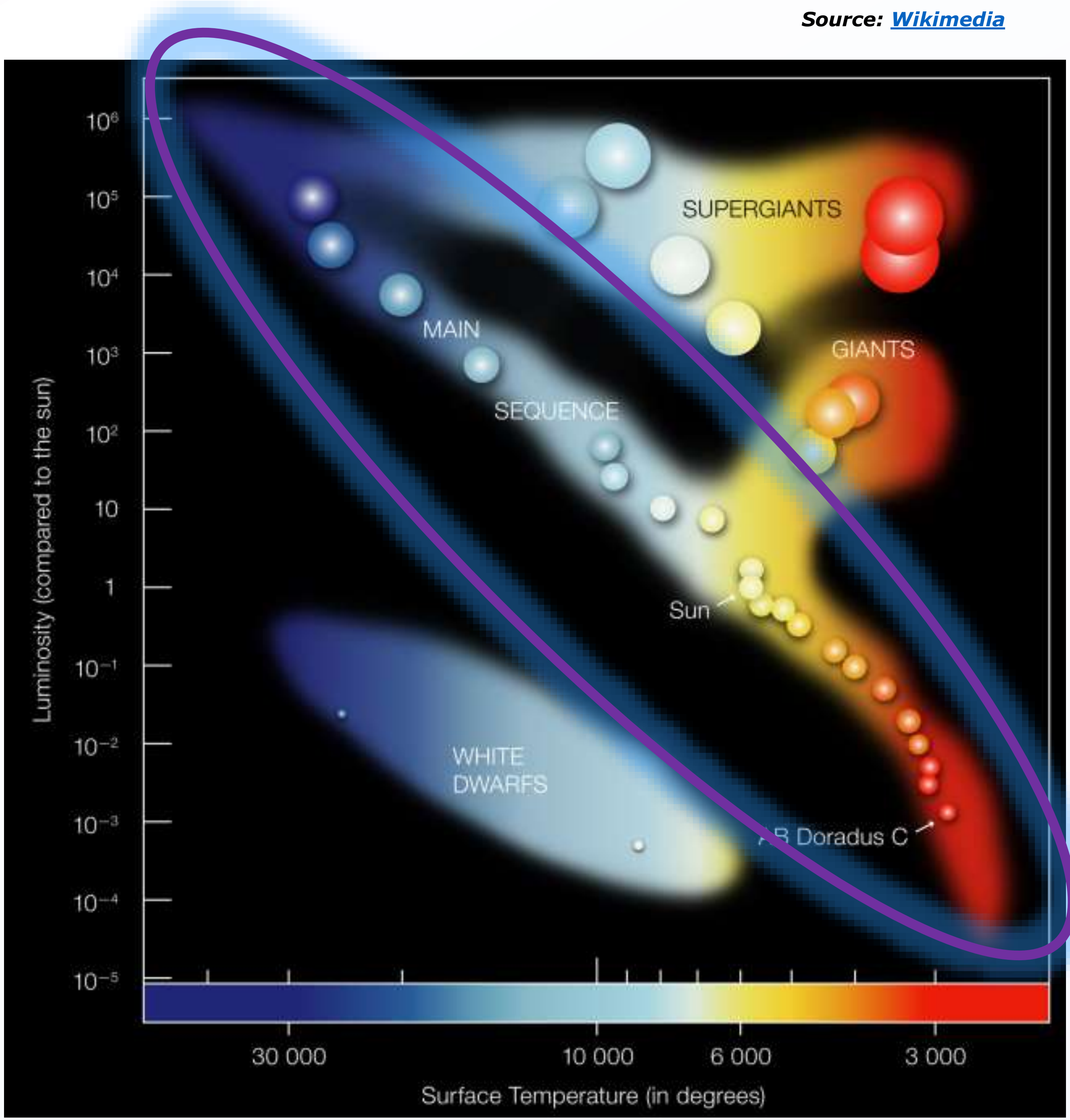
- Main Sequence: these are stars that burn hydrogen and helium in their cores.*
  - *This is the curve that runs from the upper left to the lower right of the H-R diagram.*
- Giants (Red Giants and Supergiants):
  - *These stars (upper right) have a large radius and high luminosity but low surface temperatures.*
  - *These stars have exhausted the hydrogen in their cores and fuse helium and other heavier elements.*
- White Dwarfs:
  - *This is the final stage in the life cycle of average 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.

Main Sequence Stars

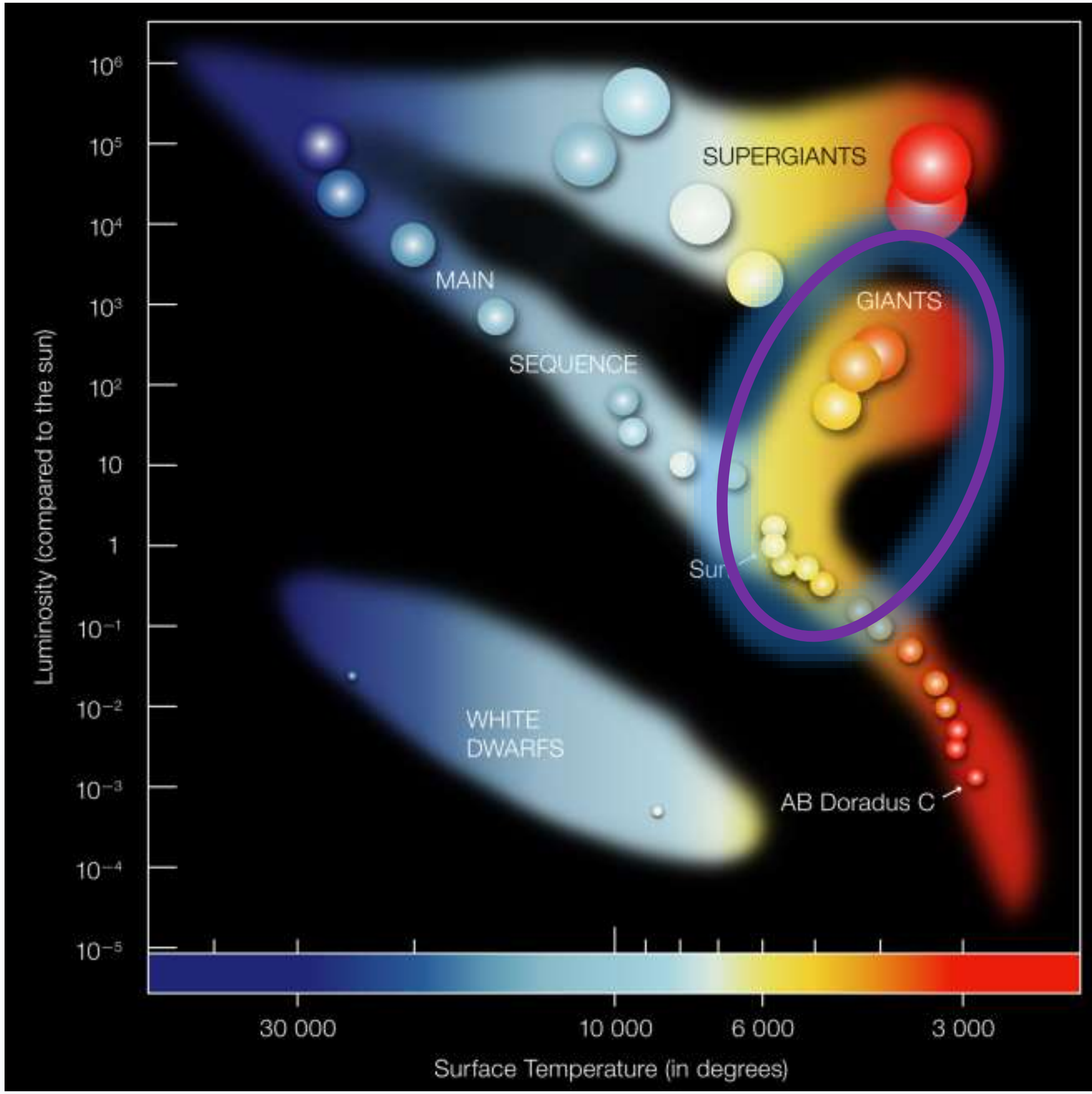
- **Main sequence stars are those that "burn" hydrogen (i.e., fuse hydrogen into helium).**
  - Our star is a main sequence star.
  - Stars spend 90% of their lives in this stage.
- **As a main-sequence star ages, its core temperature rises.**
  - This causes both luminosity and radius to increase – 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.



Source: [Wikimedia]

Main Sequence → Red Giant

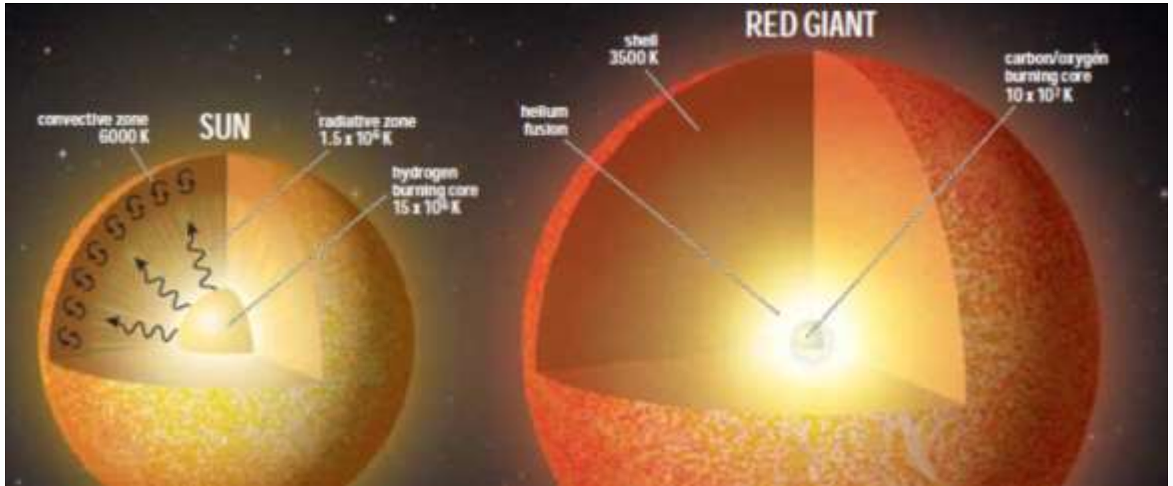
- **Eventually, the hydrogen in the star's core is completely converted to helium.**
  - As hydrogen is converted into helium, the rate of fusion in the core slows.
  - Fusion will primarily move to the outer layers that are richer in hydrogen.
- **Changes in the rate of core fusion upsets the hydrostatic equilibrium.**
  - As fusion slows in the core, outward pressure lessens, causing contraction.
  - Increasing temps from contraction result in additional fusion (e.g., fusion of helium to carbon).



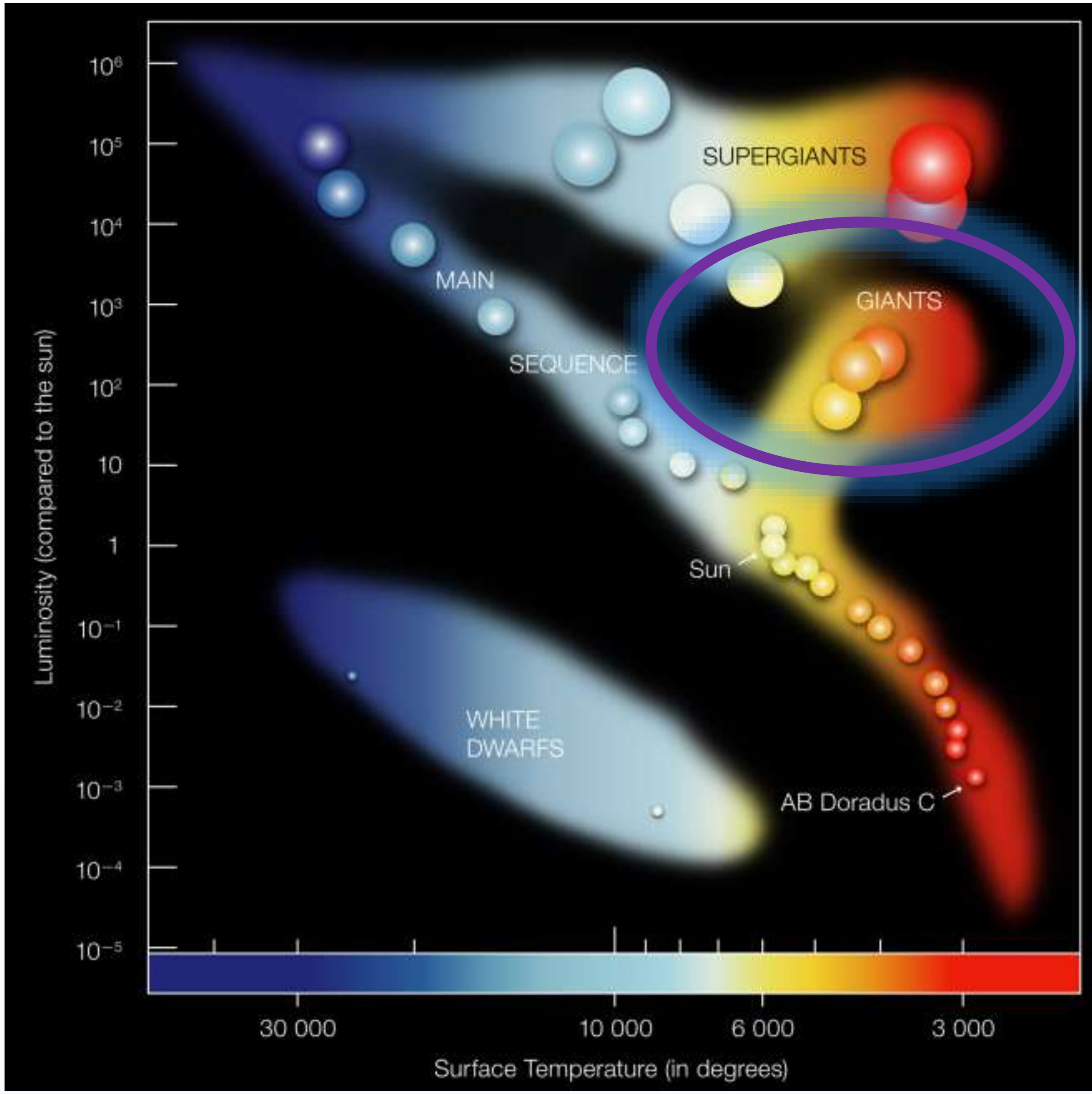
Source: [Wikimedia]

Red Giants

- **As the core contracts, it releases heat, causing outer layers to fuse hydrogen at a faster rate.**
  - This increases the outward pressure of the outer layers, causing them to expand.
  - As the outer shell of the star expands, it cools and turns red, forming a Red Giant.
  - In this phase, the core of sun-like stars is only a few times larger than earth, but the outer layers are larger than Mercury's orbit.

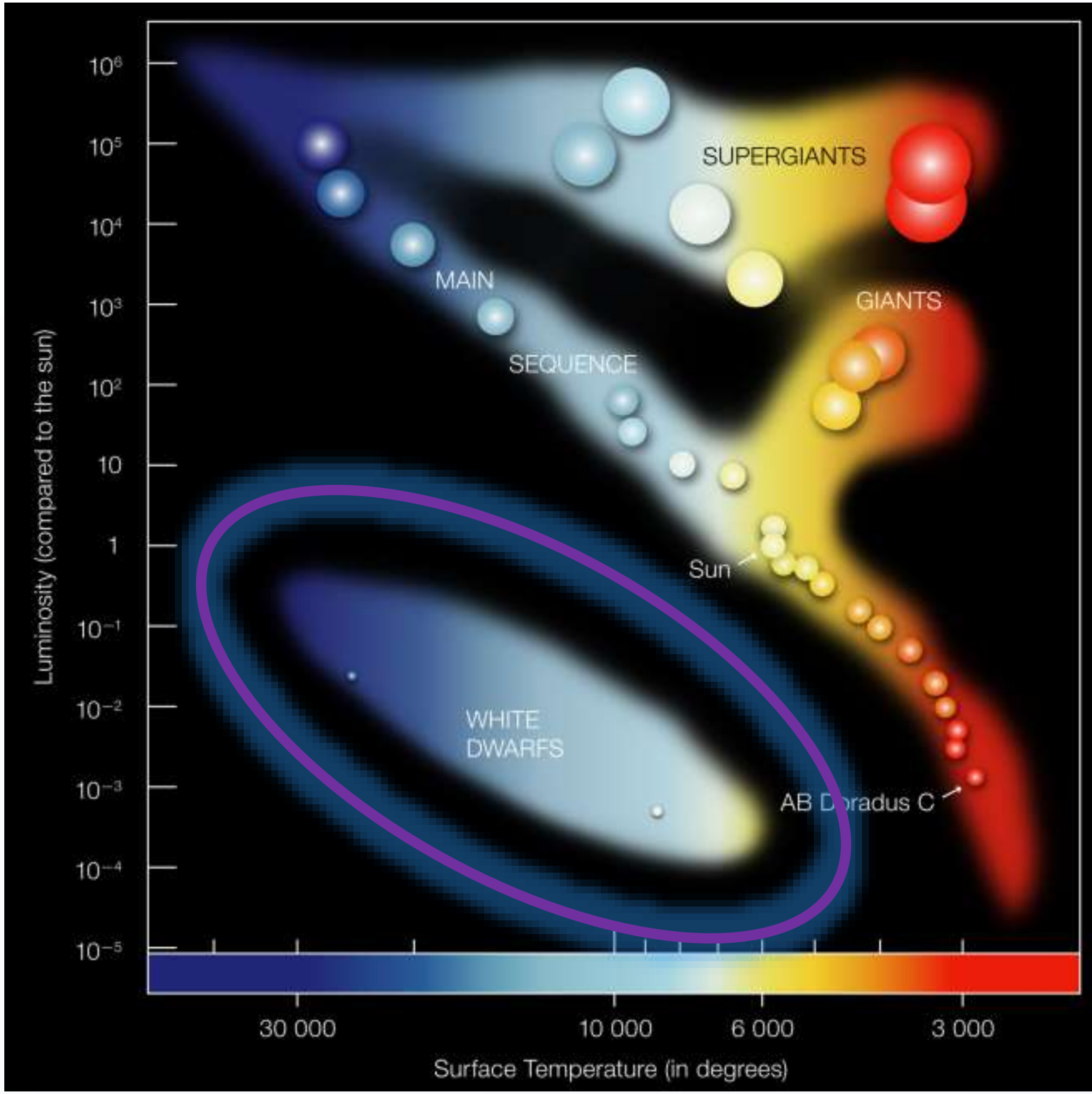


Credit: Astronomy.com



White Dwarfs

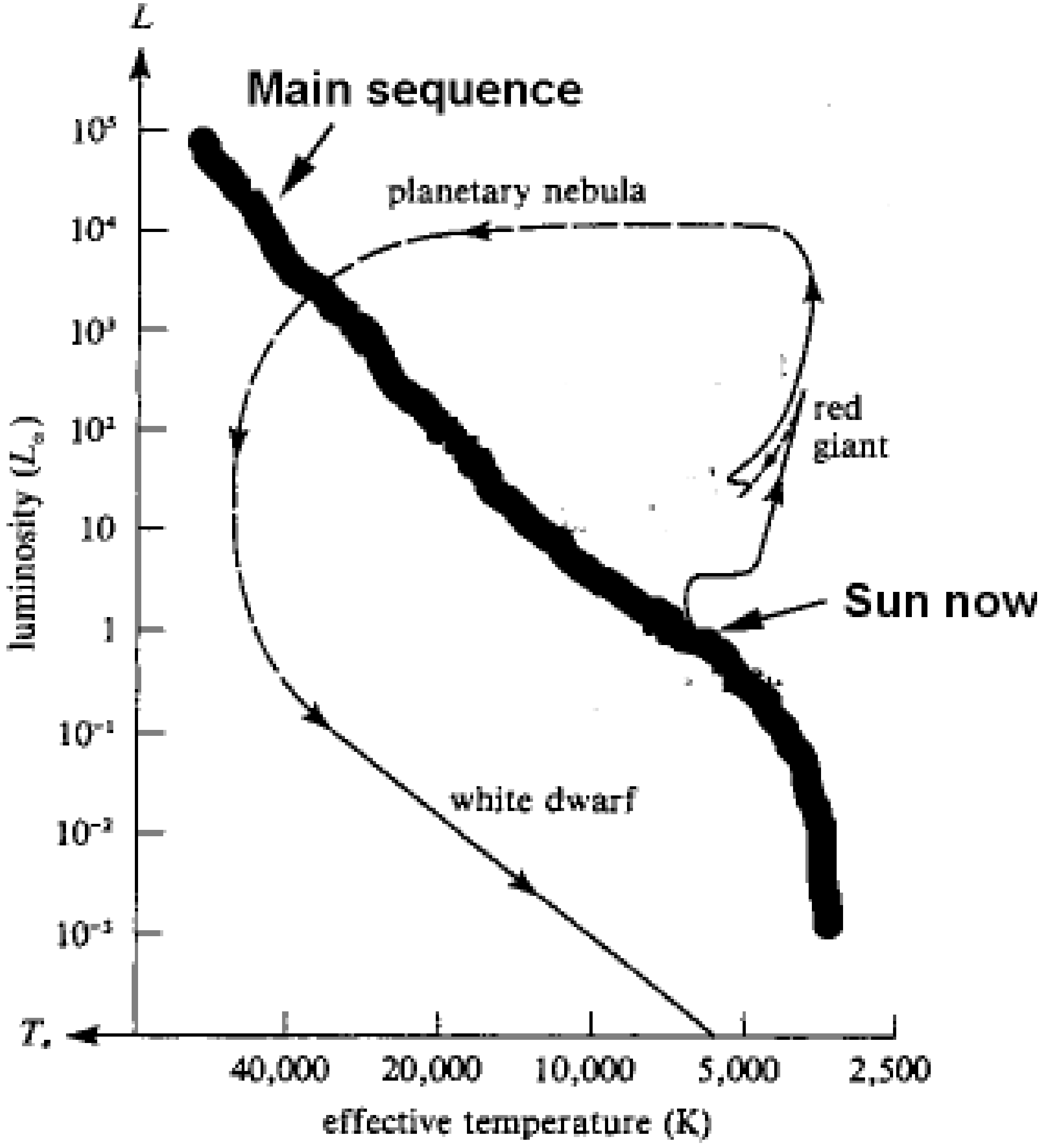
- **As helium fuses into carbon in the core, the rate of fusion slows.**
  - The core of low-mass stars is not hot enough to fuse carbon atoms and fusion eventually stops.
  - The outer layers of the star expand away from the core, forming a planetary nebula (the cloudy remnants of a dying star ↑).
    - *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.*
- **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 brown dwarf and then a black dwarf.

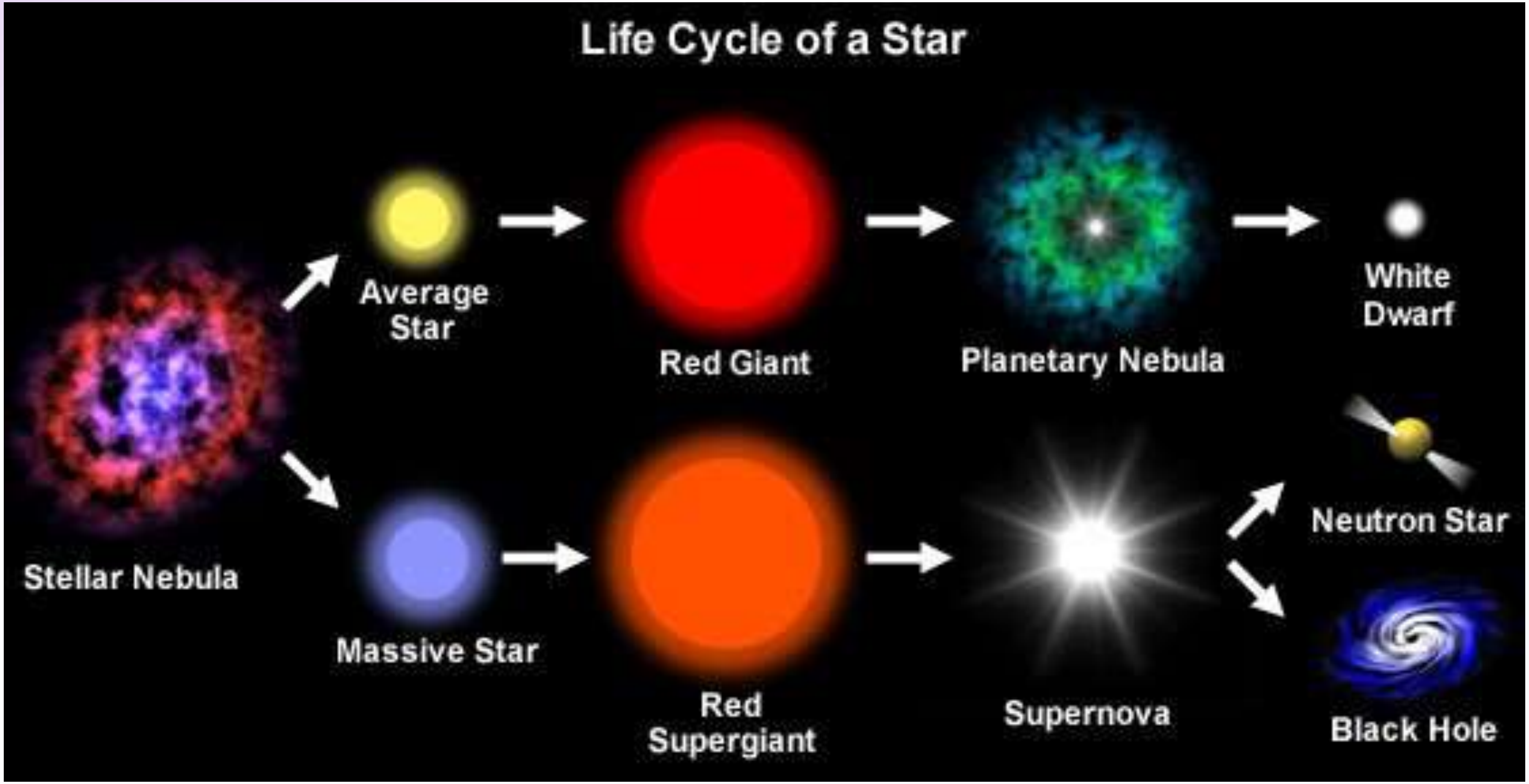


Source: [ASU]

Average Star Life Cycle

- **As stars like our sun exhaust their supply of hydrogen in the core, they will leave the main sequence.**
  - The core will contract and heat.
  - Hydrogen fusion will occur more rapidly in outer layers, causing them to expand to form a red giant.
  - Eventually the outer layers will cool, expand, and form a planetary nebula.
  - Core fusion will eventually stop as carbon accumulates, forming a white dwarf.

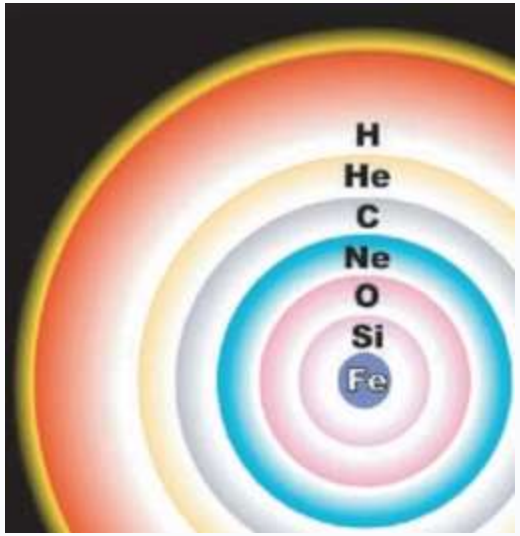


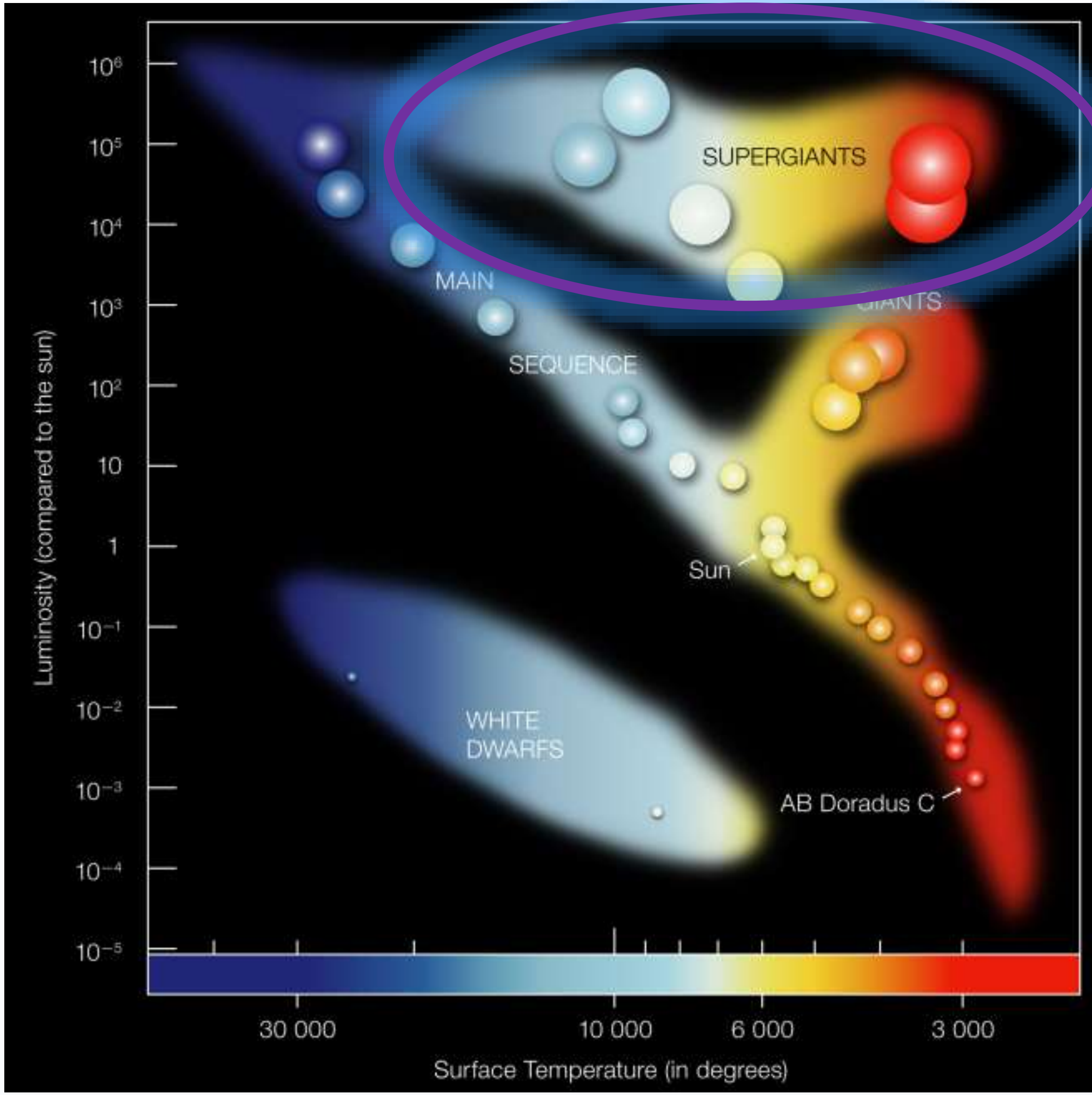


Life Cycles of High Mass Stars

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 more extensive forms of fusion.**
  - Due to greater mass, fusion can continue to fuse elements above carbon.
  - This creates ”onion skin” layers of elements →





Source: highline.edu

Iron: End of Fusion

- **In high-mass stars, nuclear fusion continues until iron forms.**
  - Iron is one of the most stable elements.
  - While energy is released as elements below iron are fused, energy needs to be absorbed to fuse elements above iron.

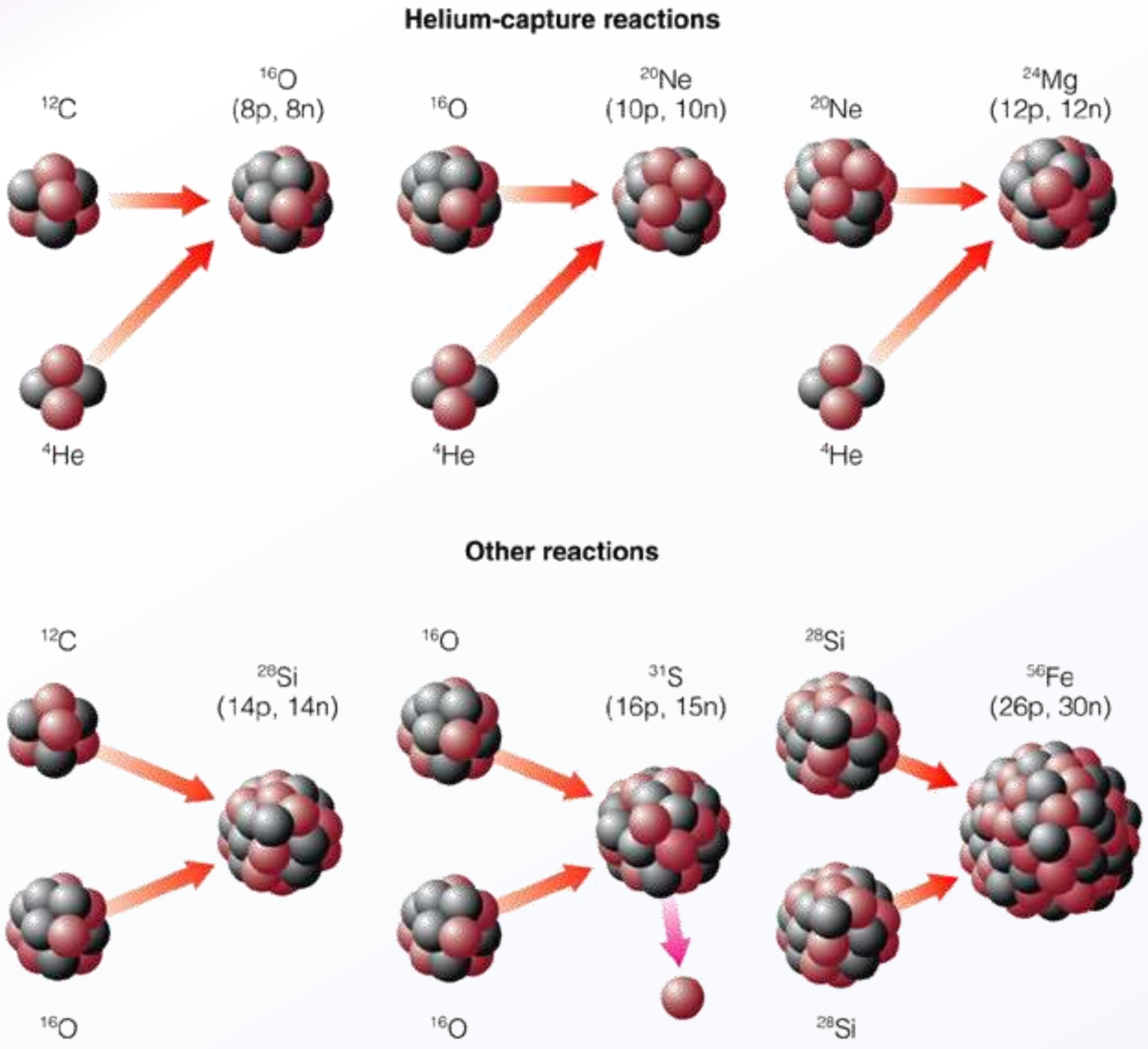


Image Source: uga.edu

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 core fusion is unable to continue any longer beyond iron.
- **As the amount of iron in the core increases, the star enters a phase of gravitational collapse.**
  - The energy radiated from the core decreases as the concentration of iron increases.
  - This upsets the hydrostatic equilibrium, causing contraction.

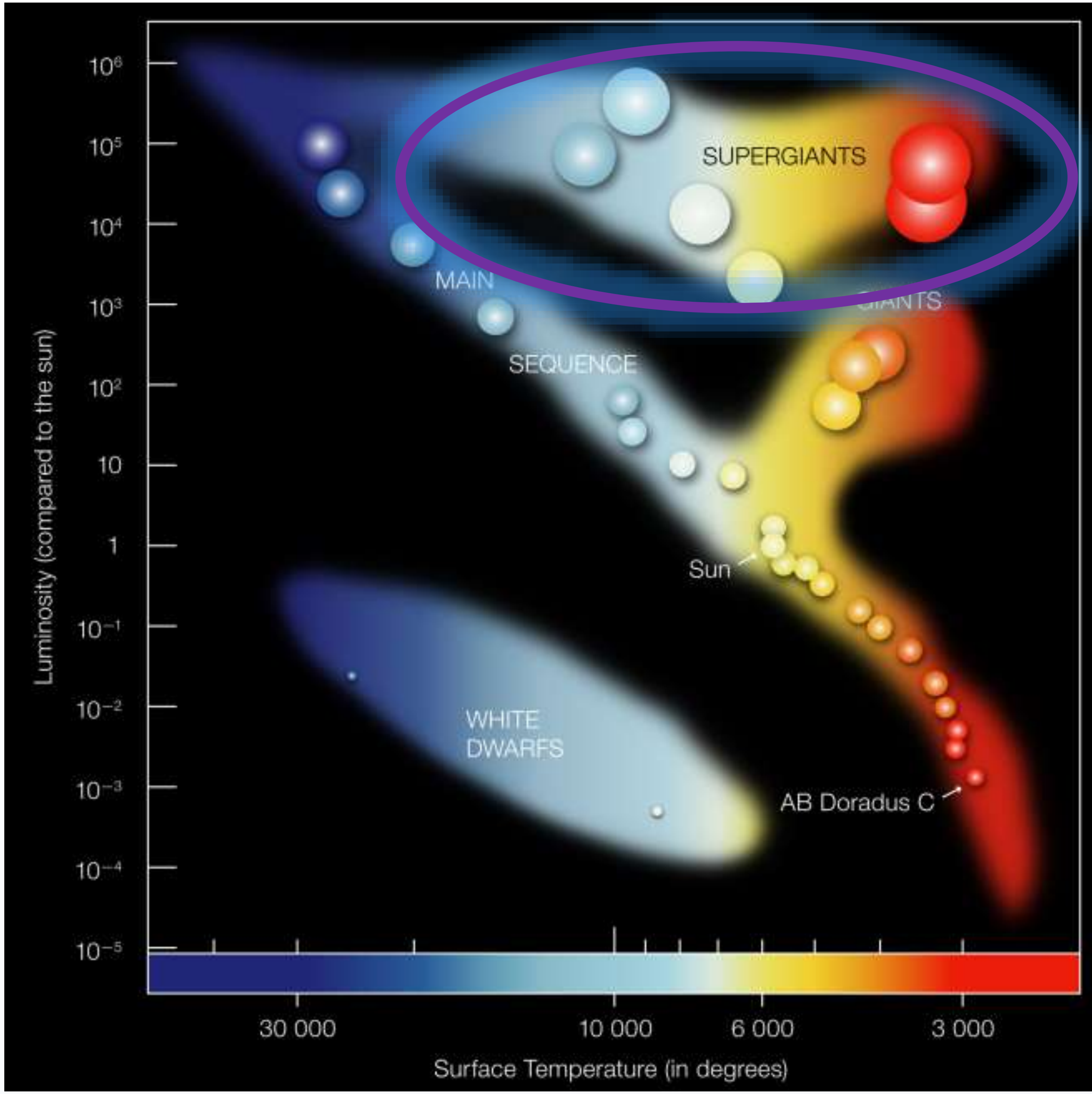


Image Credit: Wikimedia Commons

Supergiants

- **As a star's atoms are crushed together by gravity, protons and electrons are crushed together to form neutrons (and neutrinos).**
  - Eventually intense gravitational pressures cause neutrons to come in contact with each other.
  - This results in a shockwave, causing a supernova explosion.
- **This shockwave moves outward, releasing enormous amounts of energy in the remaining outer layers.**
  - The heavier elements above iron are formed from fusion through the energy released in the supernova explosion.
  - The shock wave ejects the star's matter as well as X-rays and gamma rays into interstellar space.
  - This provides the 'building materials' for new stars and solar systems.

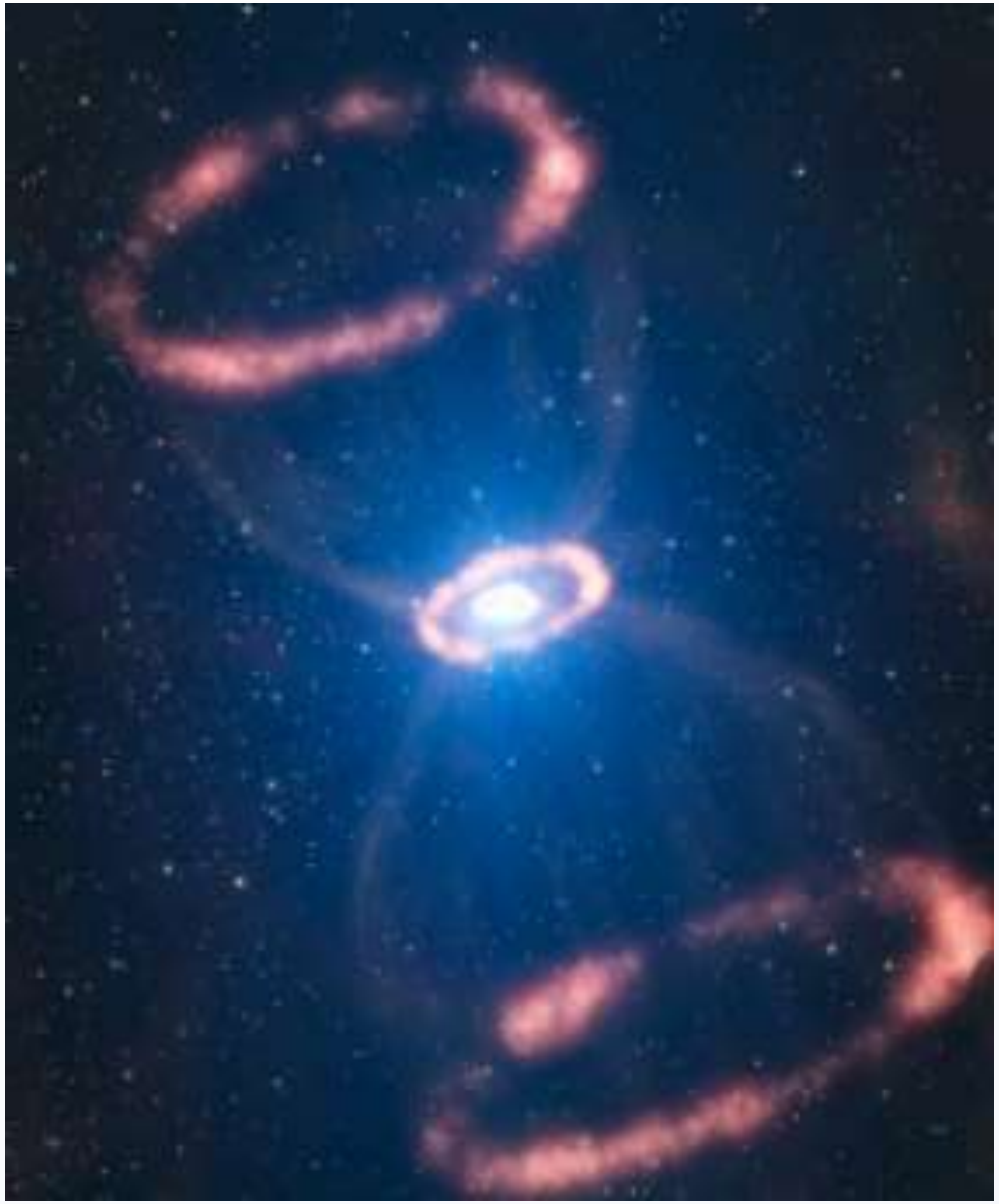


Image Credit: Swinburne Univ.

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 (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).

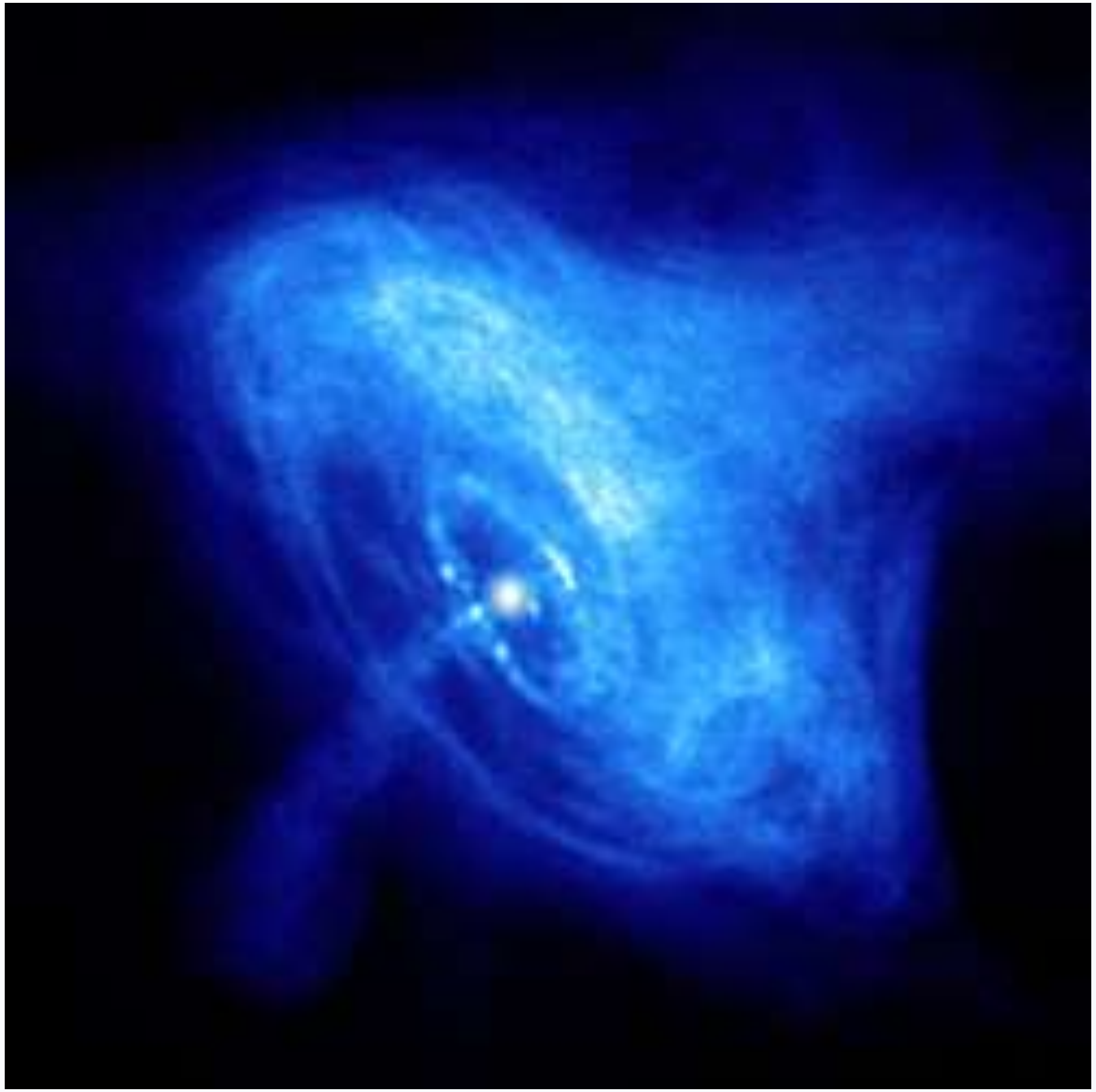
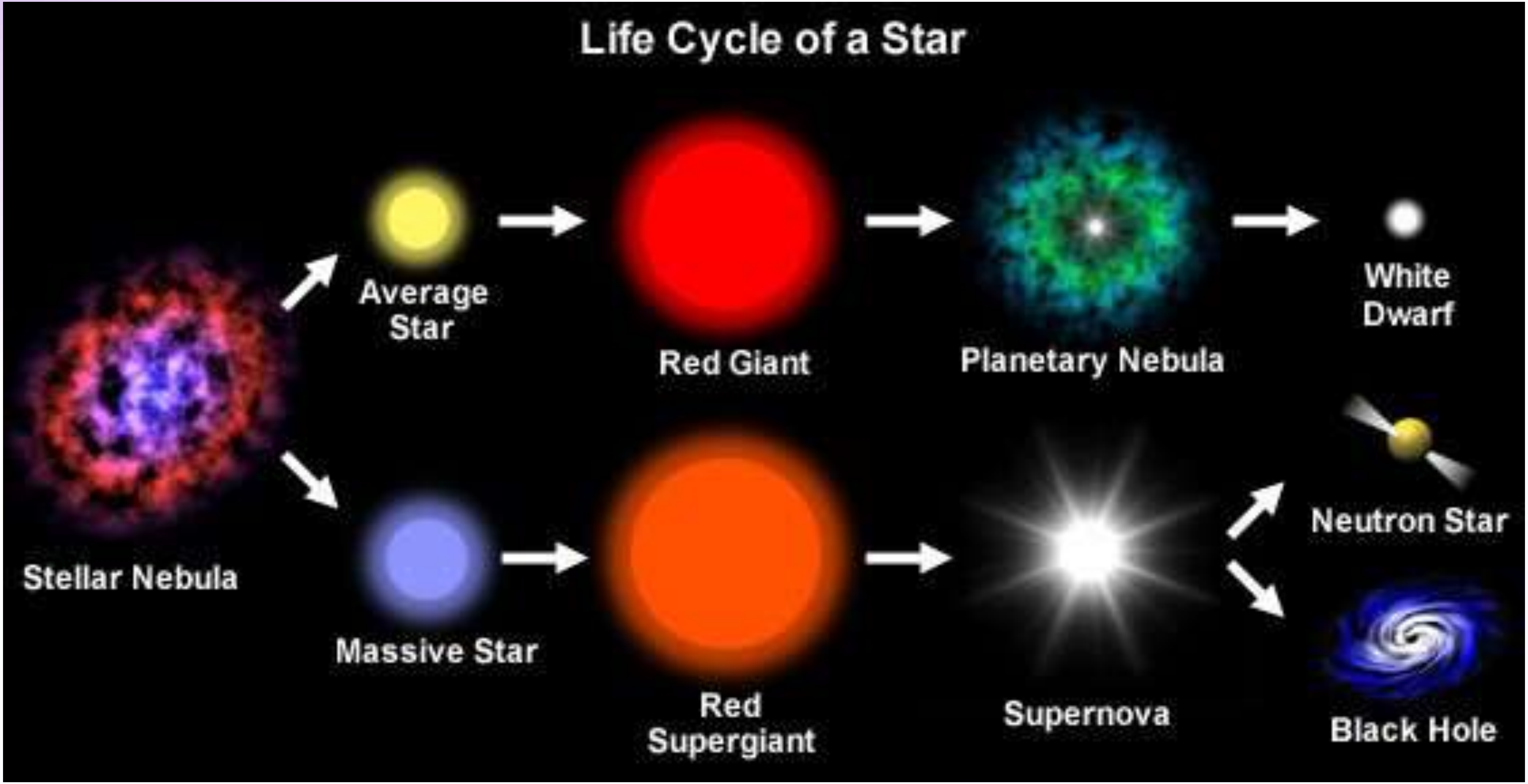


Image Credit: NASA

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



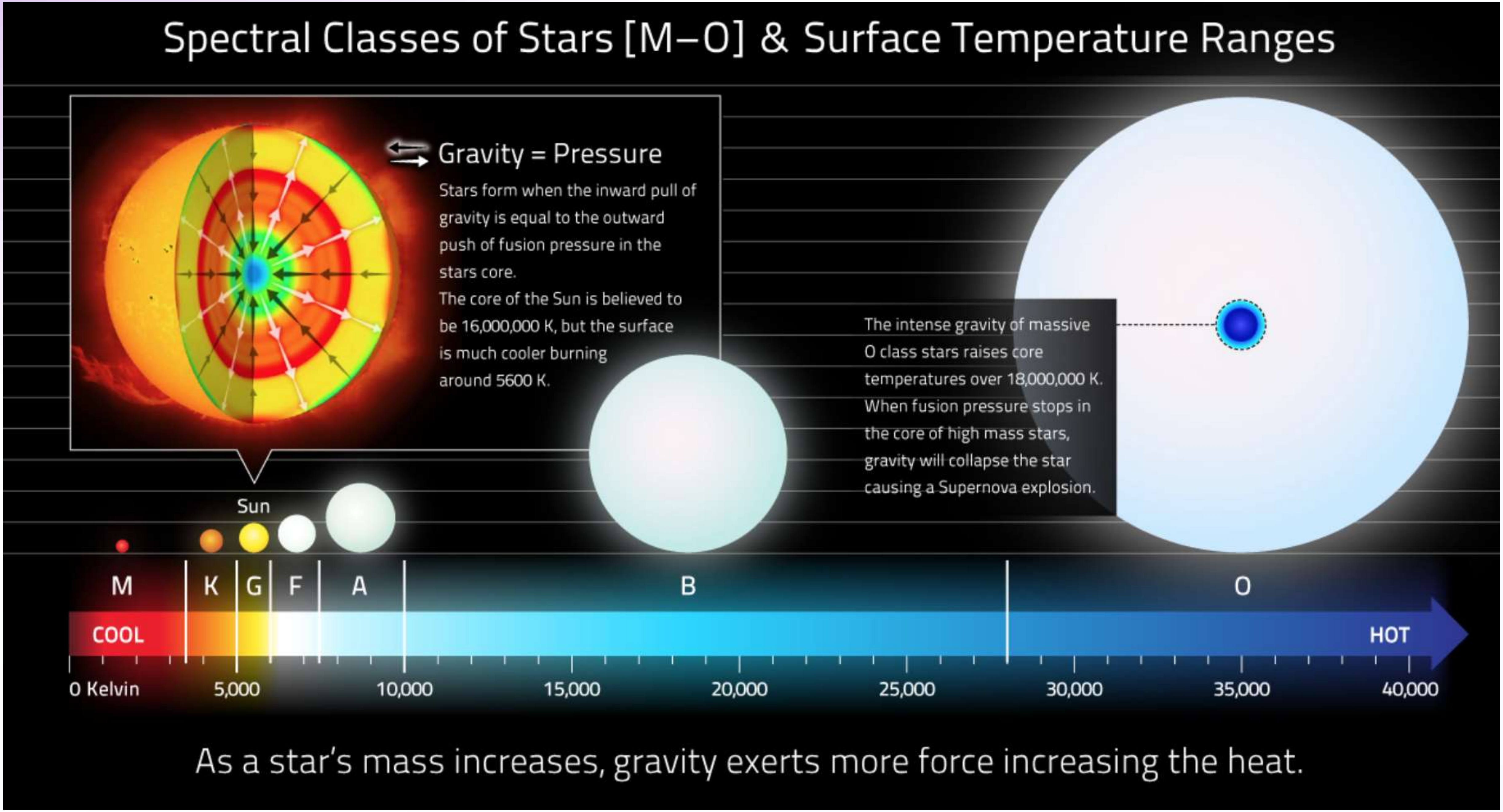


Image Credit: University of Chicago