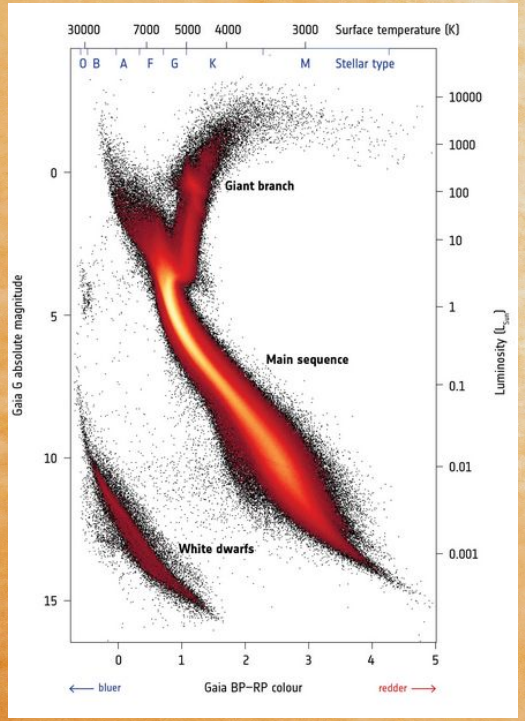
From “Normal Star” to Red Giant to White Dwarf



Credit: ESA GAIA

On the left is the European Space Agency’s version of the Hertsprung-Russell diagram, based on observed data from the Milky Way. It charts star’s surface temperatures, based on color, against their absolute magnitude. In the lower right are brown dwarfs and in the upper left are blue giants.

Hydrogen to Everything Else

- Stars in the main sequence are lit by Hydrogen fusion to Helium
- Most main sequence stars are 70% Hydrogen at birth
- ~99.95% of the Hydrogen exists as Protium-one proton with one electron-and no neutrons
- Fusion produces Helium-4: 2 Protons + 2 Neutrons
- The net reaction is 4 H —> 1 He

Comparative Energy Yields Per Pound

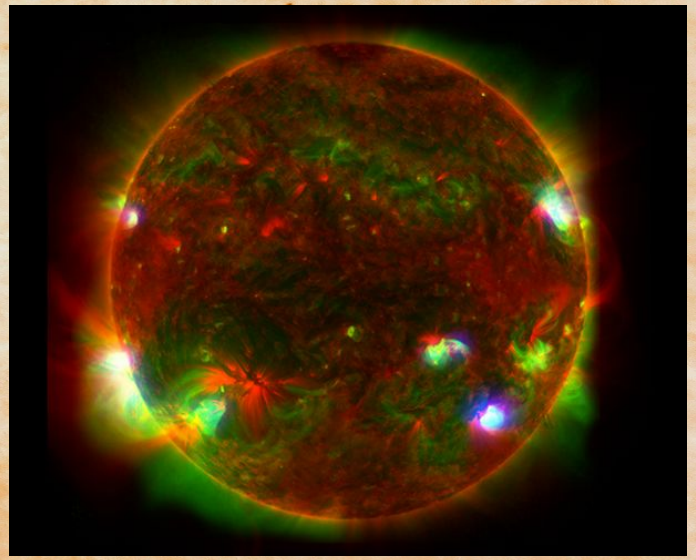
	Hydrogen Fusion	Uranium Fission	Gasoline
KCal	9.6 Trillion	8.2 billion	5140

Where do the Neutrons Come From?

1. High temperatures (~24M deg F) liberate electrons
2. High pressures push Hydrogen nuclei together
3. Nuclei get close enough for quantum tunnelling
4. 99.99% of Helium-2 atoms break apart in a few nano-seconds
5. 1 in 10,000 one of the protons releases a positron and a neutrino, becoming a neutron
6. The new Hydrogen atom is Deuterium
7. This process repeats, producing Deuterium and Tritium atoms
8. Dueterium and Tritium eventually fuse, producing Helium-4 and free neutrons

Hydrogen Depletes While Helium Accumulates

- During the “normal phase” a star Burns about 15% of its Hydrogen
- Helium is heavier and accumulates in the core
- Eventually Hydrogen fusion stops
- Without heat to push out, the sun’s atmosphere begins collapsing toward the center
- High speeds and pressure generate enough heat to ignite Helium fusion, at around 200M degrees F



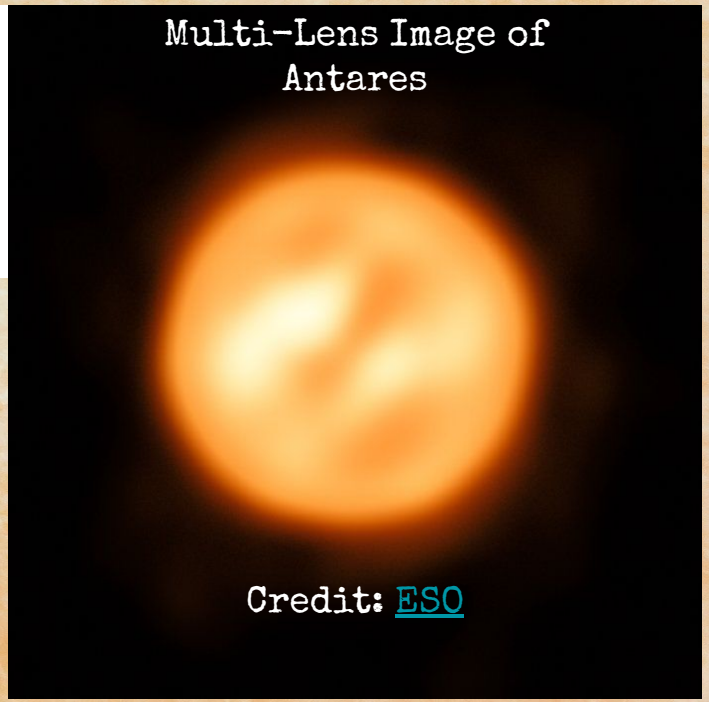
Red Giants Produce Many Elements

Wild men who caught and sang the sun in flight,
And learn, too late, they grieved it on its way,
Do not go gentle into that good night.

– Dylan Thomas

Temperatures (F) Required to Produce Elements

He	24 Million	B, Be	70 Million
C, O	180 Million	Mg, Na	900 Million
		Si, Cr, Fe	2 to 6 Billion

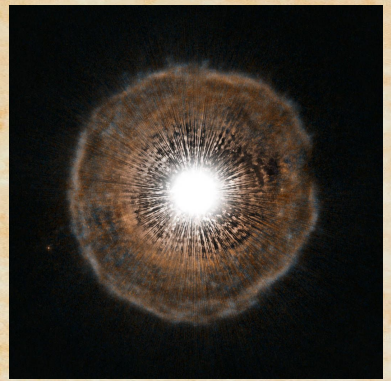


The Cycles Repeat for a Billion Years or So

- Much larger amounts of Helium and Hydrogen begin fusing at once, releasing much much more energy
- Sun's current radius = 432,000 miles and surface area is 7.23 trillion sq miles
- The atmosphere of a Red Giant is pushed out to anywhere from 50 to 150 million miles, with surface areas between 31 and 280 quadrillion sq miles
- Since the heat energy is diffused over an area 4,000 to 40,000 times larger the surface temperature is lower, therefore the color is redder
- The cycle of burning, halting, atmospheric collapse, and restarting fusion repeats several times over ~1 billion years

Red Giants Produce Badass Nebulae

- The long distance of an RG's atmosphere blows some gas and dust away
- Every time the star crunches down and reignites, a shockwave is produced that flings material outward
- The material is lit up by the Red Giant and later by a White Dwarf

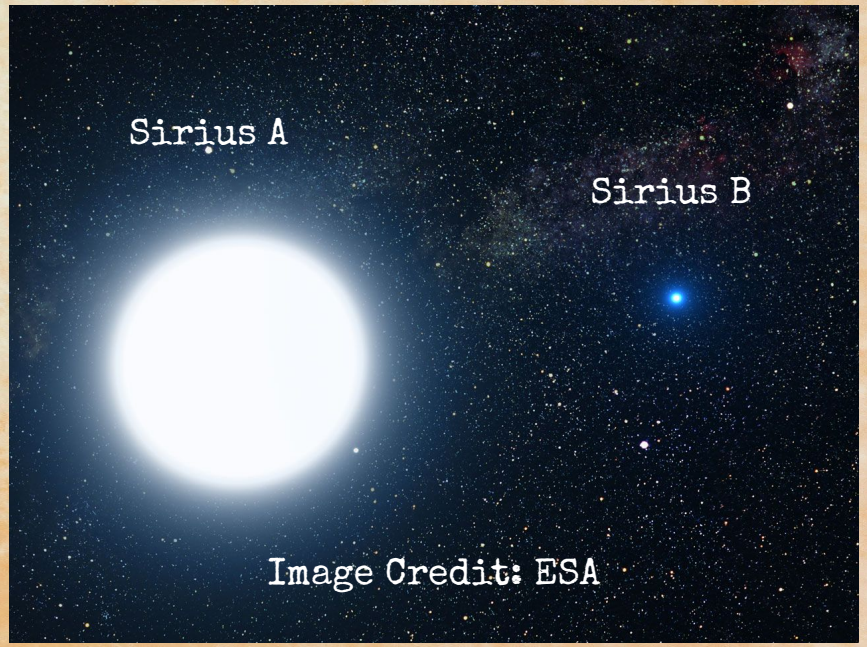


The Final State Is a White Dwarf

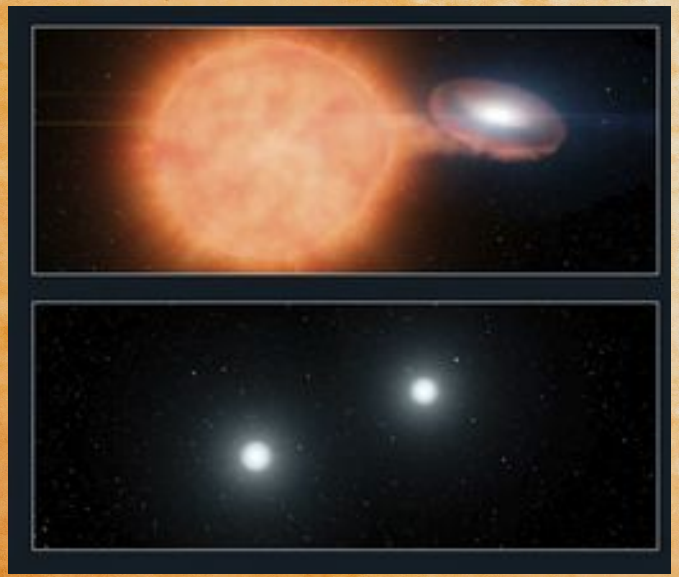
- Eventually the Red Giant sheds too much material for fusion to restart soon enough
- The material collapses onto itself until a core of material reaches the electron degeneracy density
- NASA: Avg White Dwarf density is 835,000 lbs/gal
- Theoretical mass limit is ~0.56 to 1.44 solar masses.
  - Sirius B is ~the mass of the sun, with about 77% of the Earth's volume
- The structure of white dwarfs is a matter of conjecture, but it's believed to be like a diamond consisting of carbon, oxygen, and traces of heavier elements
- White Dwarves have very thin "crusts" and atmospheres

The Natural Life of White Dwarfs

- The ‘crust’ seals in heat
- Core Temp: 35M deg F
- Crust Temp: 9000 deg F
- Heat escapes slowly. The coolest visible White Dwarfs are 7200 deg F.
- Complete cooldown to ash would take around 300 billion years
- If left undisturbed, would dissipate due to proton decay in 10^{43} to 10^{200} years



Unnatural Deaths of White Dwarfs



Prelude to a Type 1a Supernova
Photo Credit: NASA

- Sucked into a Black Hole
- Draws enough material from a companion star or crashes into another small enough white dwarf to create a Type 1a Supernova
- 2 heavy white dwarfs can merge to create a Neutron Star
- Merges with a Neutron Star to create a black hole
- Use your imagination