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Stellar Evolution

IB PHYSICS | ASTROPHYSICS

Measuring the Age of the Stars

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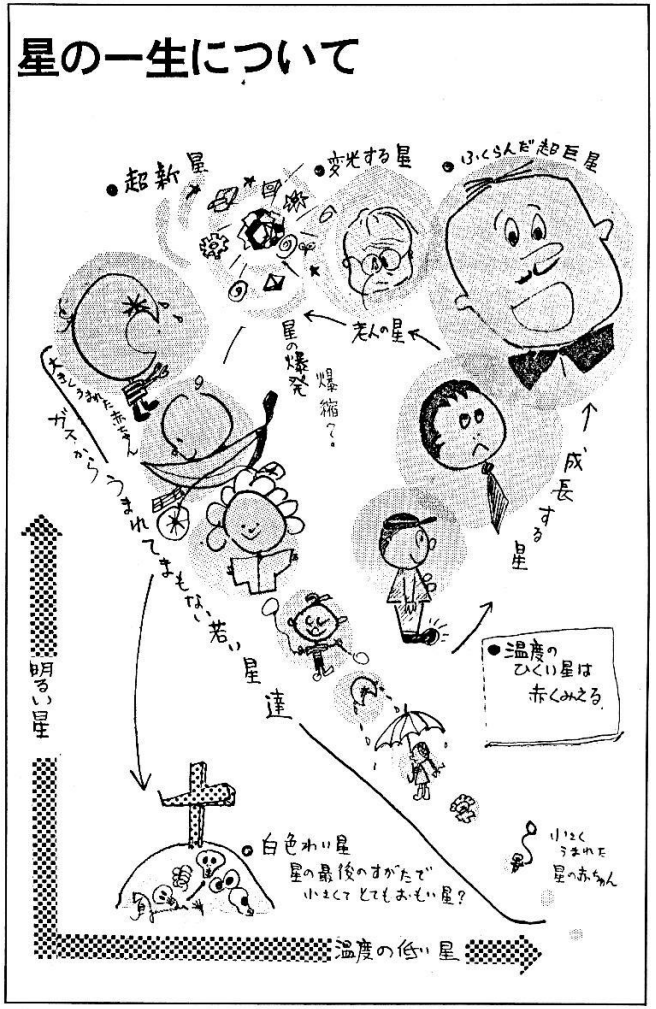

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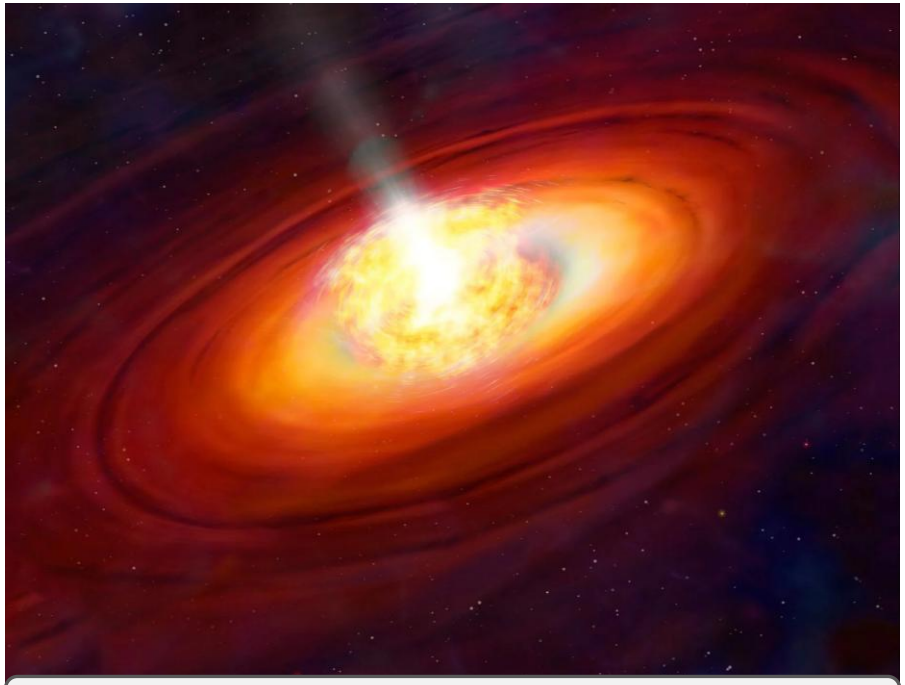
The Birth of a Star

Stellar Nebula

Cloud of “dust” where gravity begins to pull hydrogen together



Protostar

Beginning stage of a star where accumulated matter starts to heat up

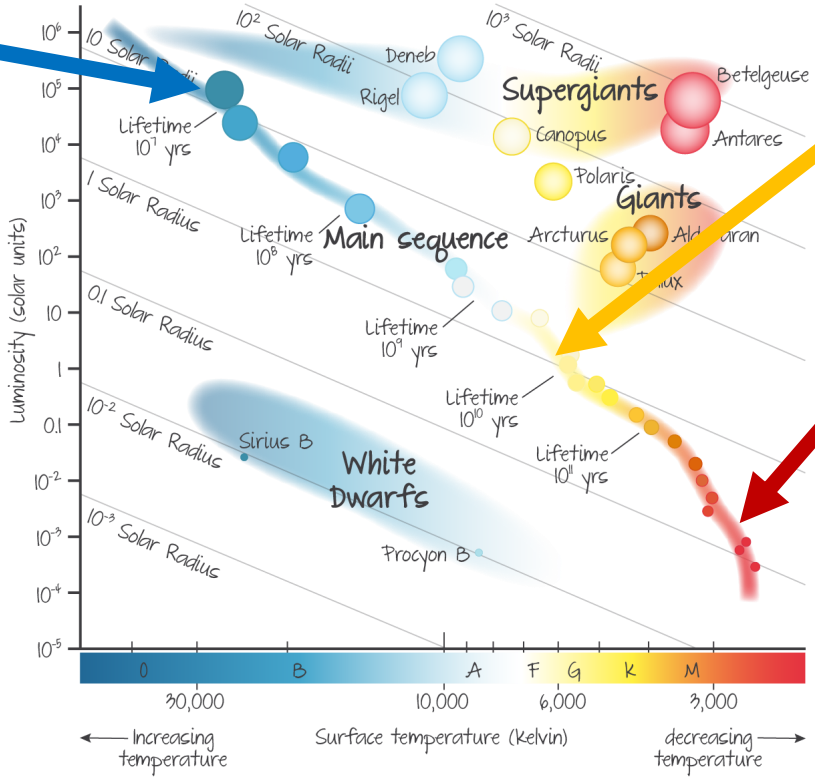
All stars start on main sequence

A star's position on the main sequence depends on how much matter was pulled together

This also sets into motion a series of stages that determine the star's evolution and death

Large Hot Stars
"Massive Stars"

Burns through fuel faster and die quicker



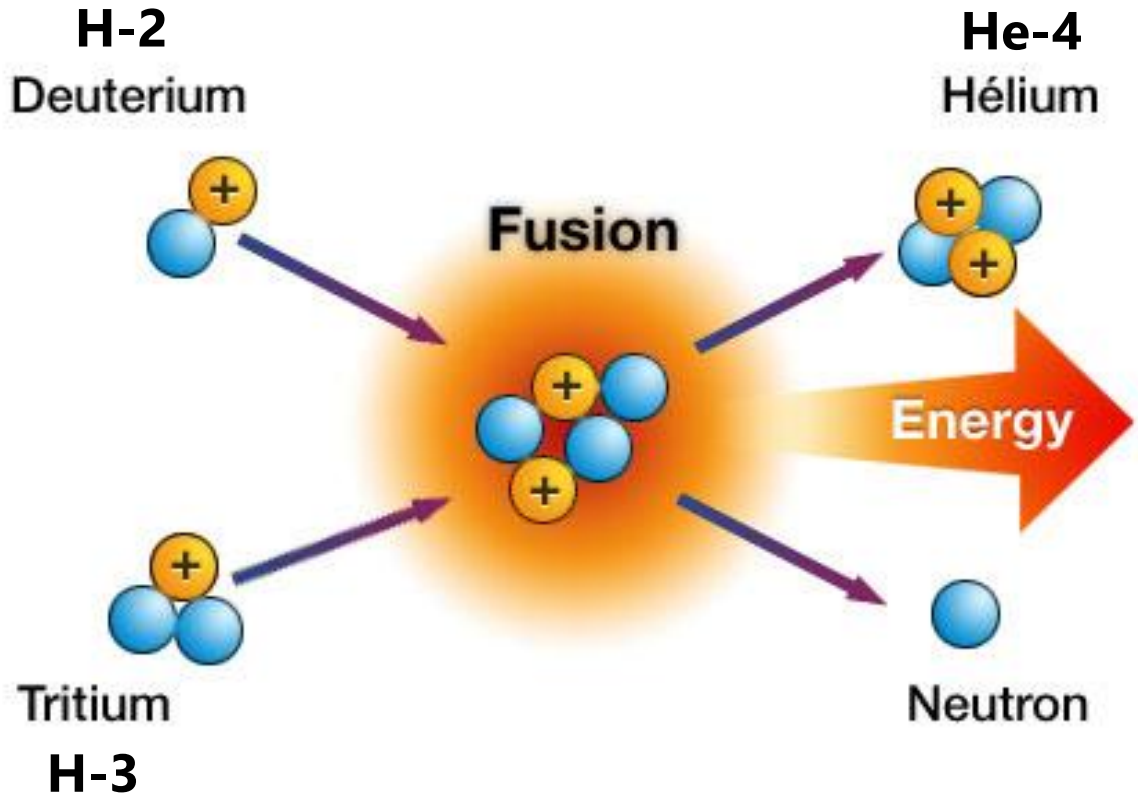
Average Stars

Small Cool Stars
"Brown Dwarfs"

Long lifetime because they burn through fuel much slower

Fusion

All stars begin by fusing hydrogen into helium



Fusion

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Hydrogen-2	2.0141 u
Helium-3	3.0161 u
Neutron	1.0087 u

$$^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + energy$$

(2.0141 u + 2.0141 u) – (3.0161 u + 1.0087 u) = 0.0034 u

4.0282 u 4.0248 u

0.0034 u × 931.5 = 3.1671 MeV

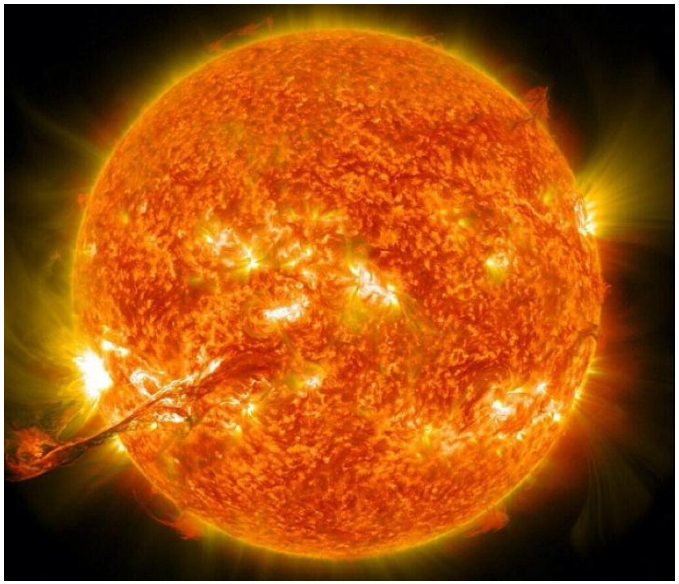
Mass Defect	0.0034 u

Energy Released	3.1671 MeV

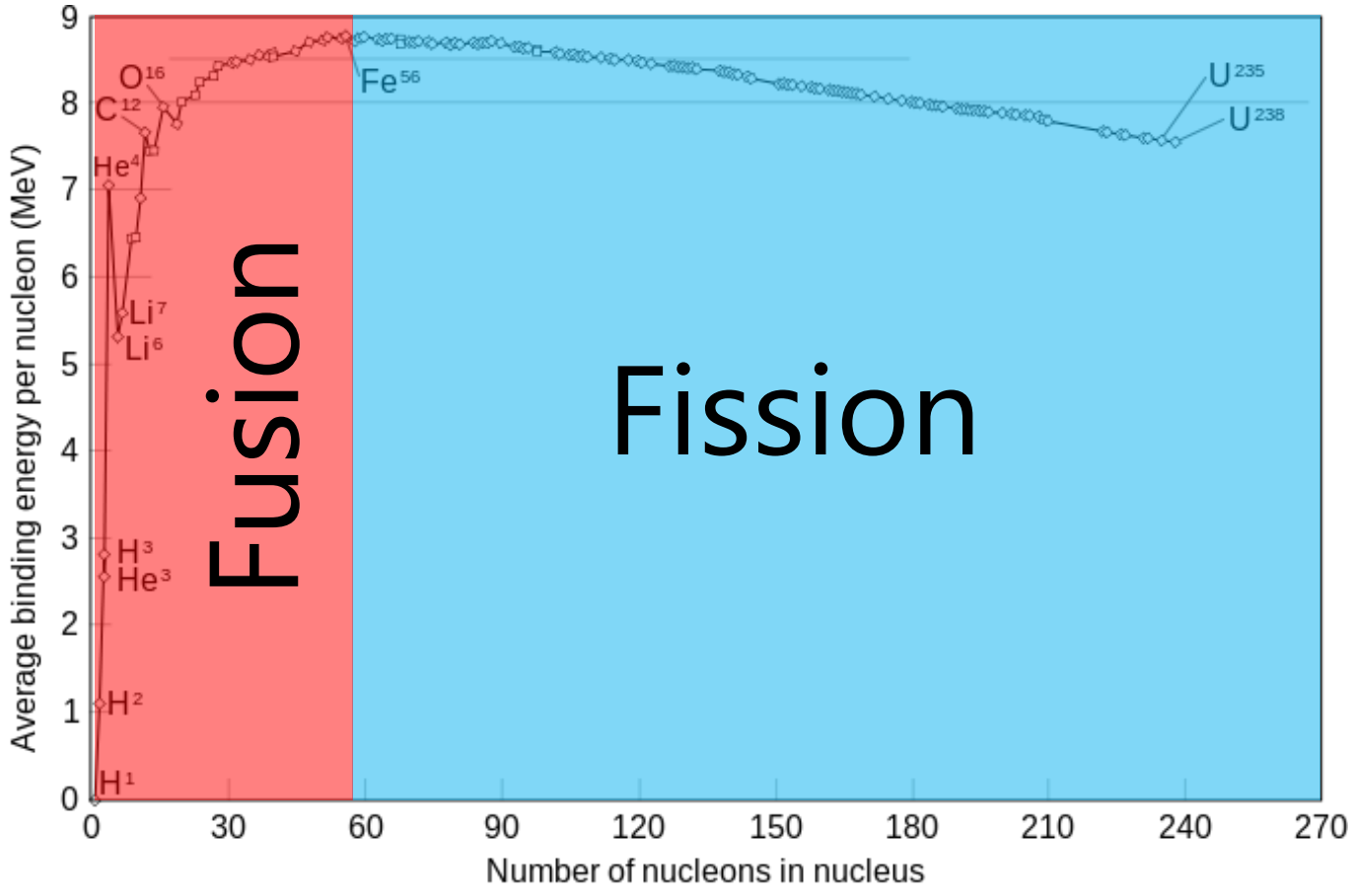
Conditions for Fusion

It's significantly more difficult to create fusion reactions here on earth

- High Pressure
- High Temperature

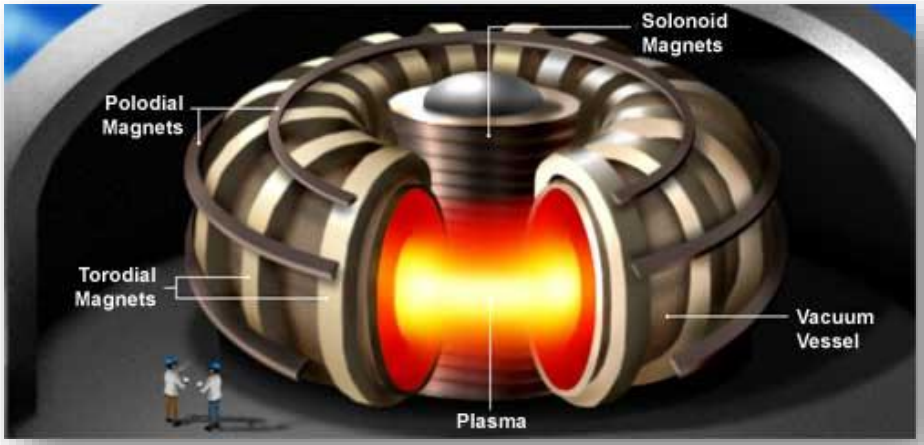


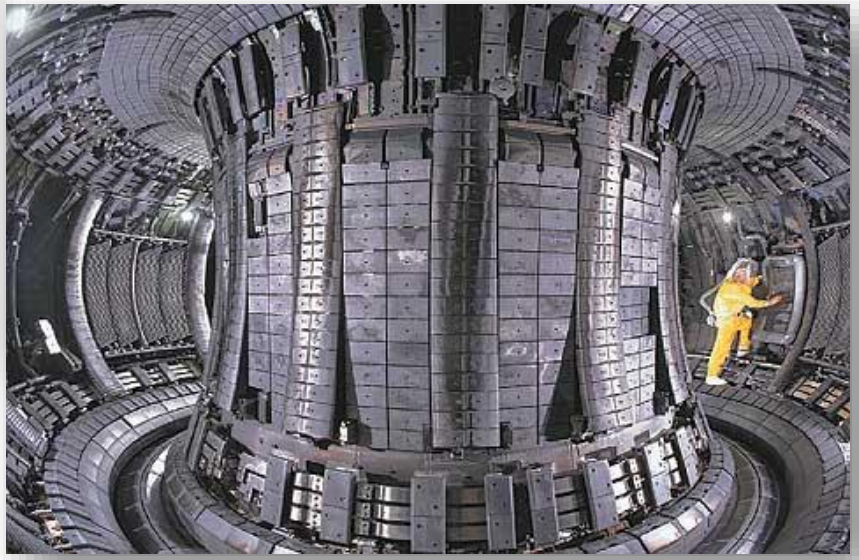
Fusion vs. Fission



Fusion as a Power Source

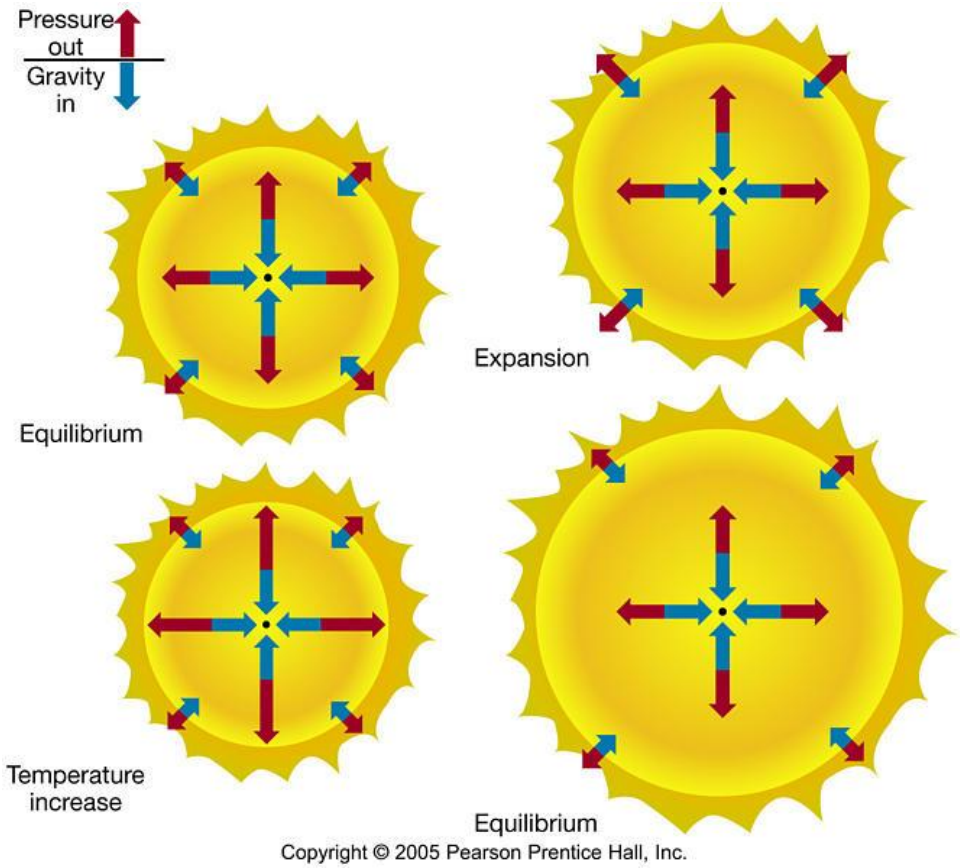
Fusion reactions have been successfully controlled using strong magnetic fields but the energy used to run the magnets exceeds the energy released in the reaction…

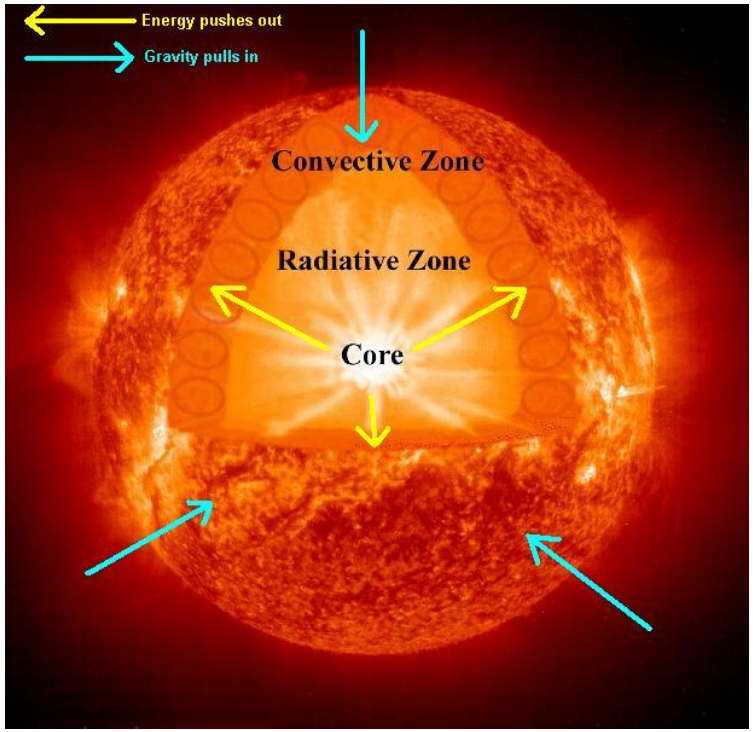




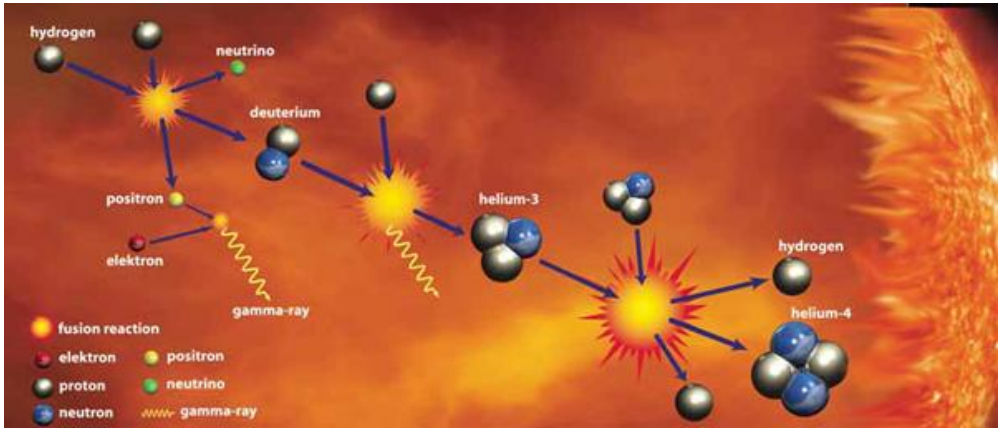
Stellar Equilibrium

Increasing temperature increases pressure and causes expansion





What happens as Stars Age??



Fusion in the core

H → He

1. Core runs out of Hydrogen
2. Hydrogen fusion outside of core and heats up star
3. More outward pressure / Star Expands [Red Giant]
4. Star runs out of Hydrogen and star collapses
5. High pressure/temp allow fusion of Helium → Carbon

What happens as Stars Age??

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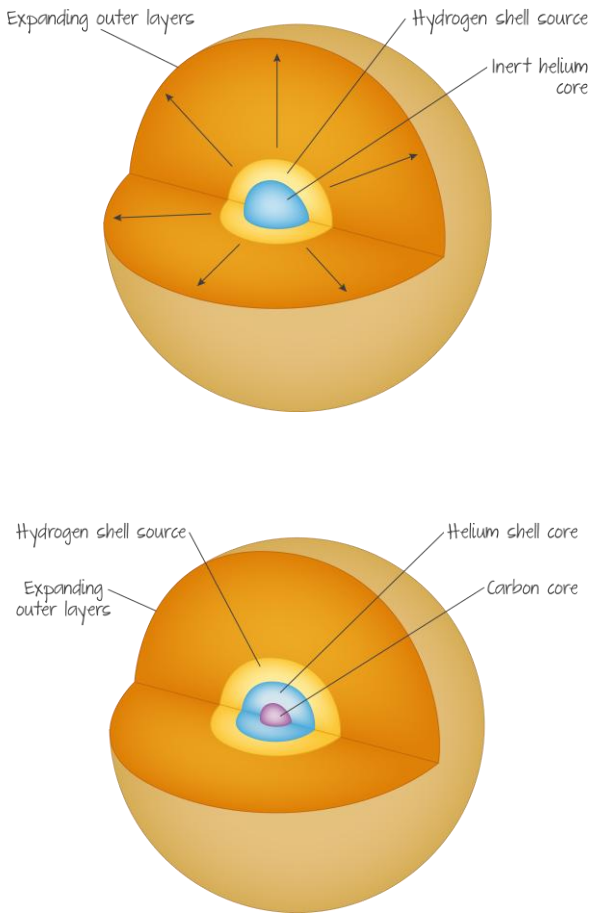
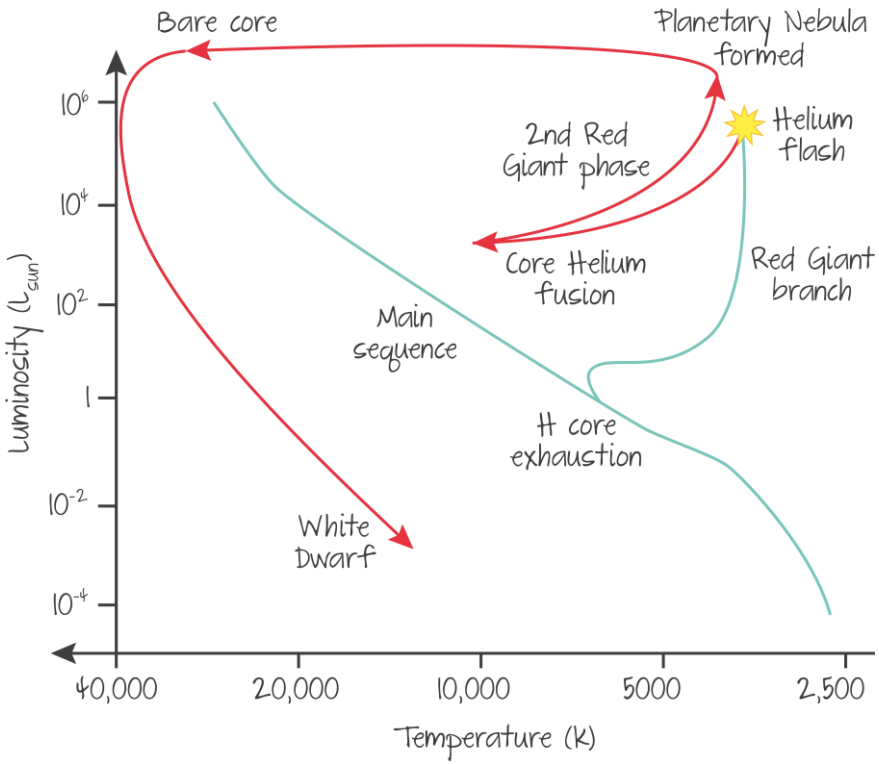


An average star can only fuse up to carbon before it dies



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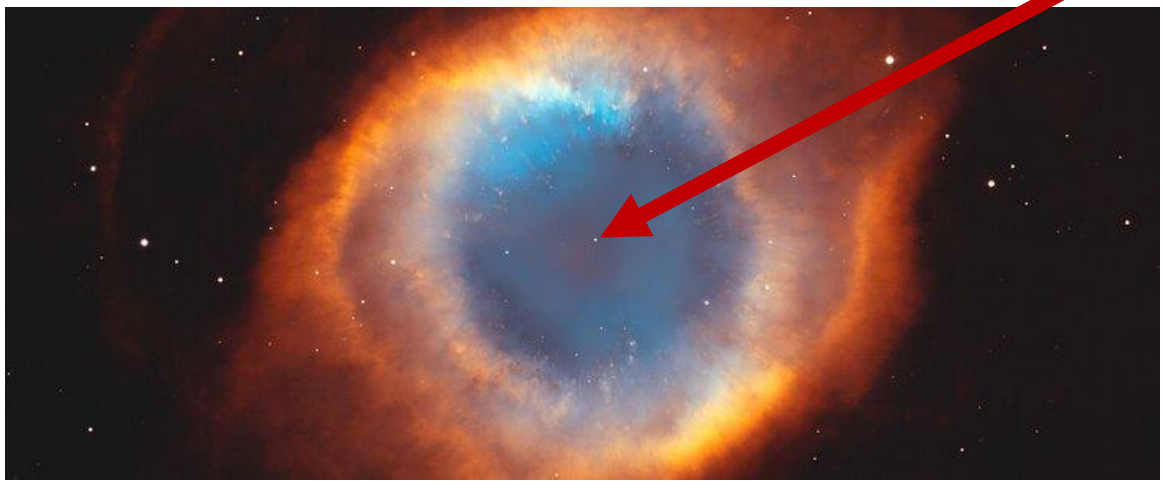
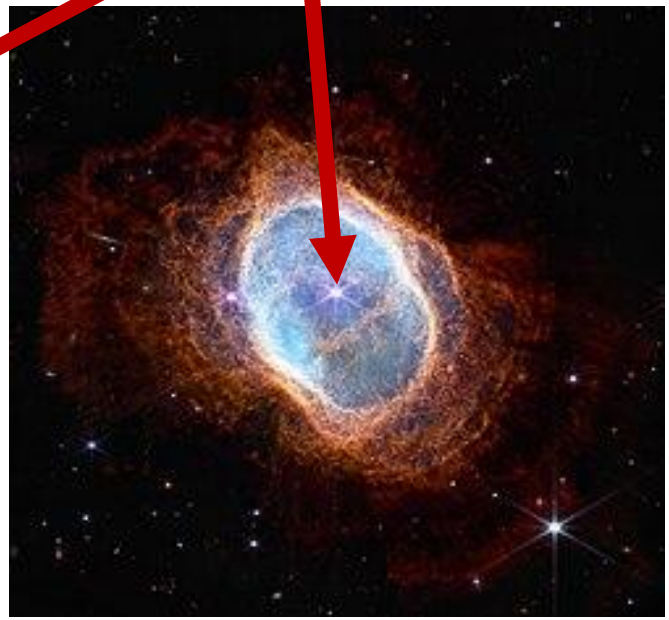
Planetary Nebula

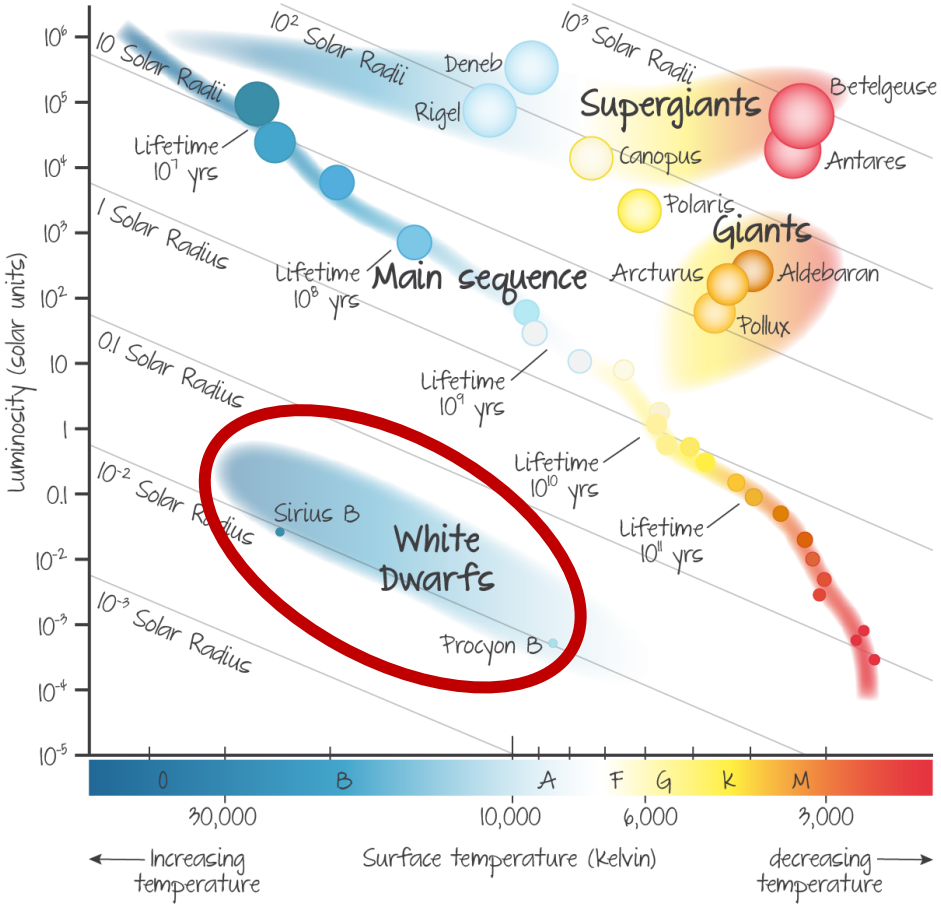
After the average star fuses its helium, the outer layers are ejected to form a planetary nebula

The hot dense core left behind is called a White Dwarf





White Dwarf Stars



SMALL
but
HOT

Life Cycle of Sun-Sized Star

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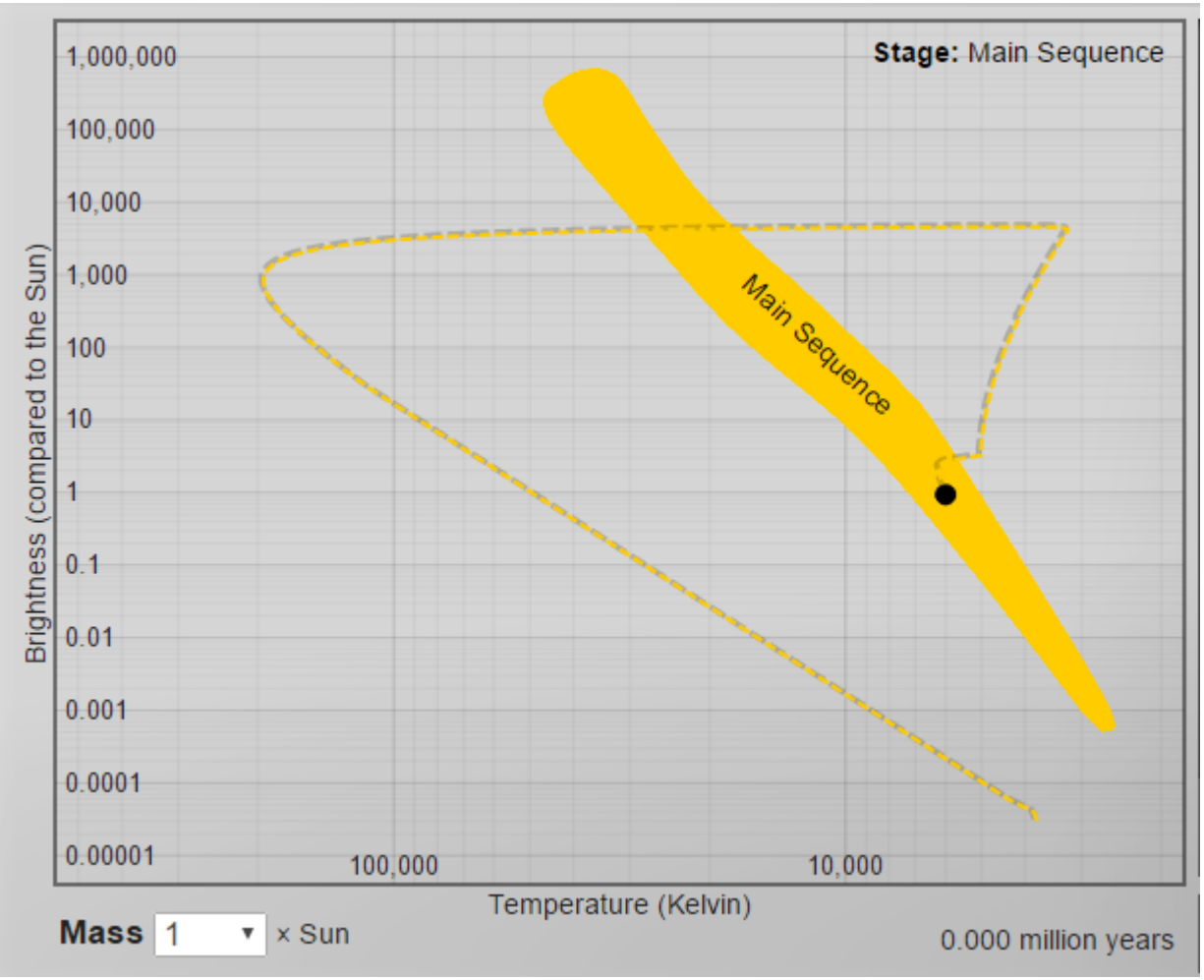

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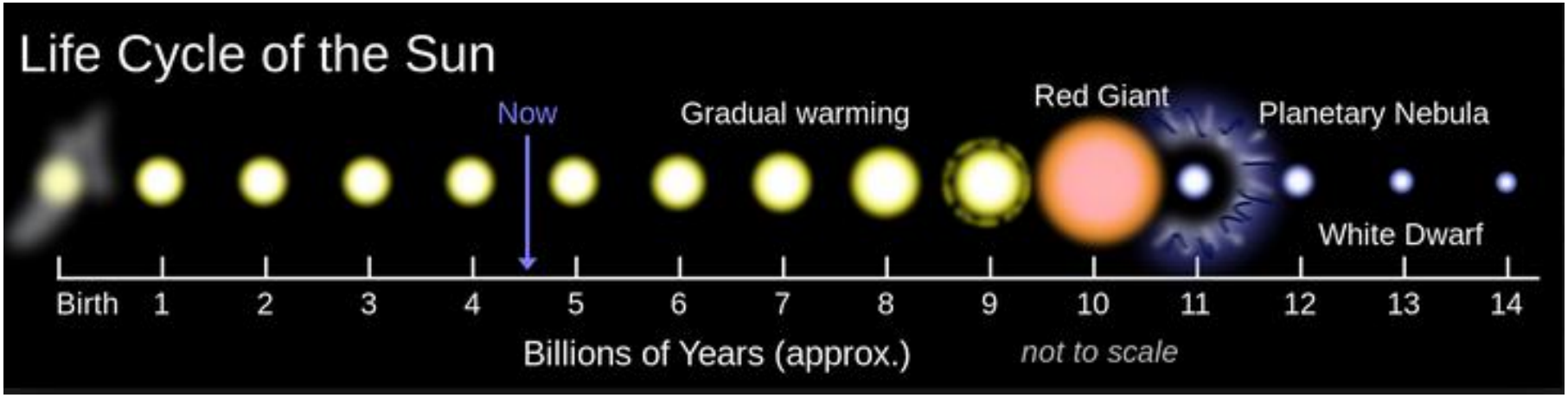
Life Cycle of our Sun



White Dwarf Stars

There is a maximum mass of a core that can become a white dwarf

Chandrasekhar Limit = 1.4 $M_\odot$ ← Sun's Mass

The core only makes up about 1/3 of the stars mass so a star with a total mass greater than about 4 $M_\odot$ will not form white dwarfs

If Star's Total Mass $< 4M_\odot$ It will become a White Dwarf

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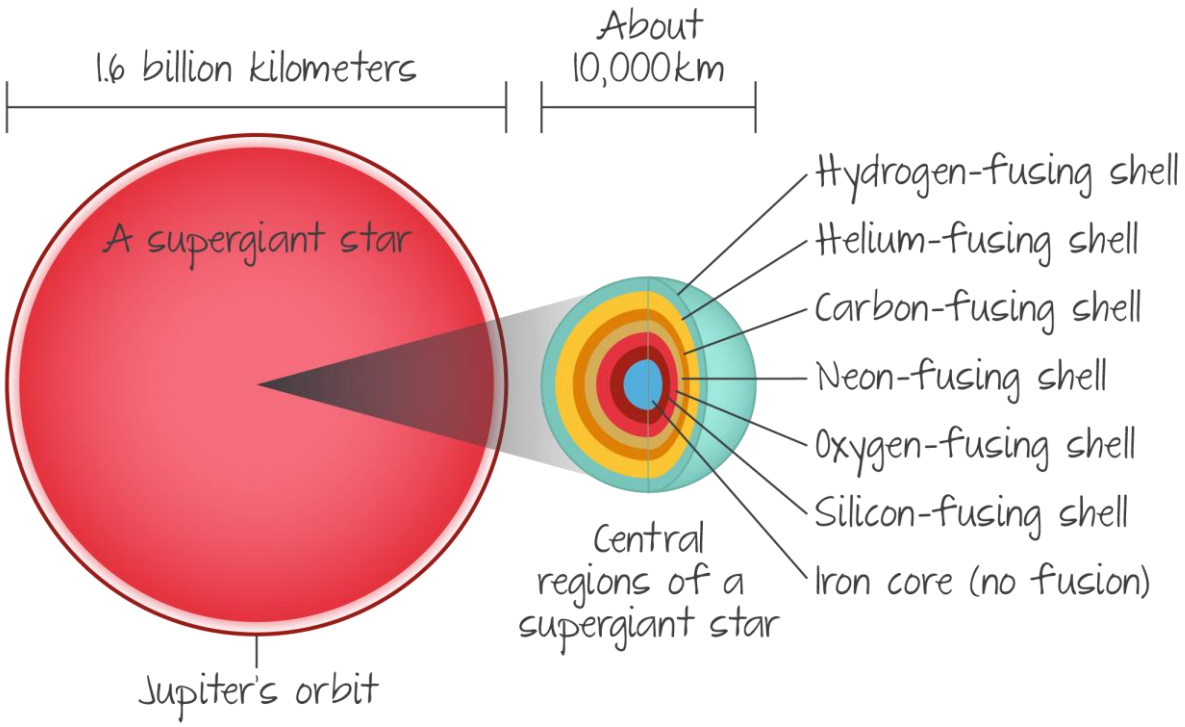
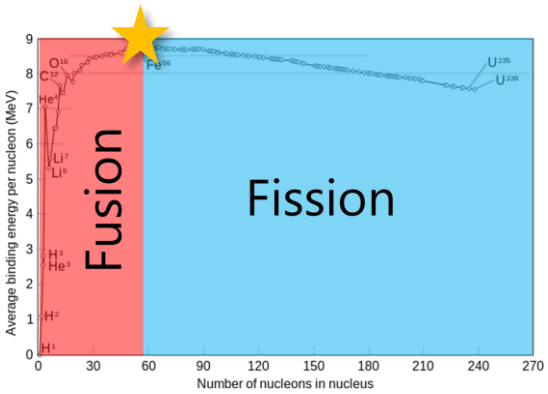
Life Cycle of Massive Star

Massive stars have enough gravity to keep fusing elements beyond carbon into shells of increasingly larger elements

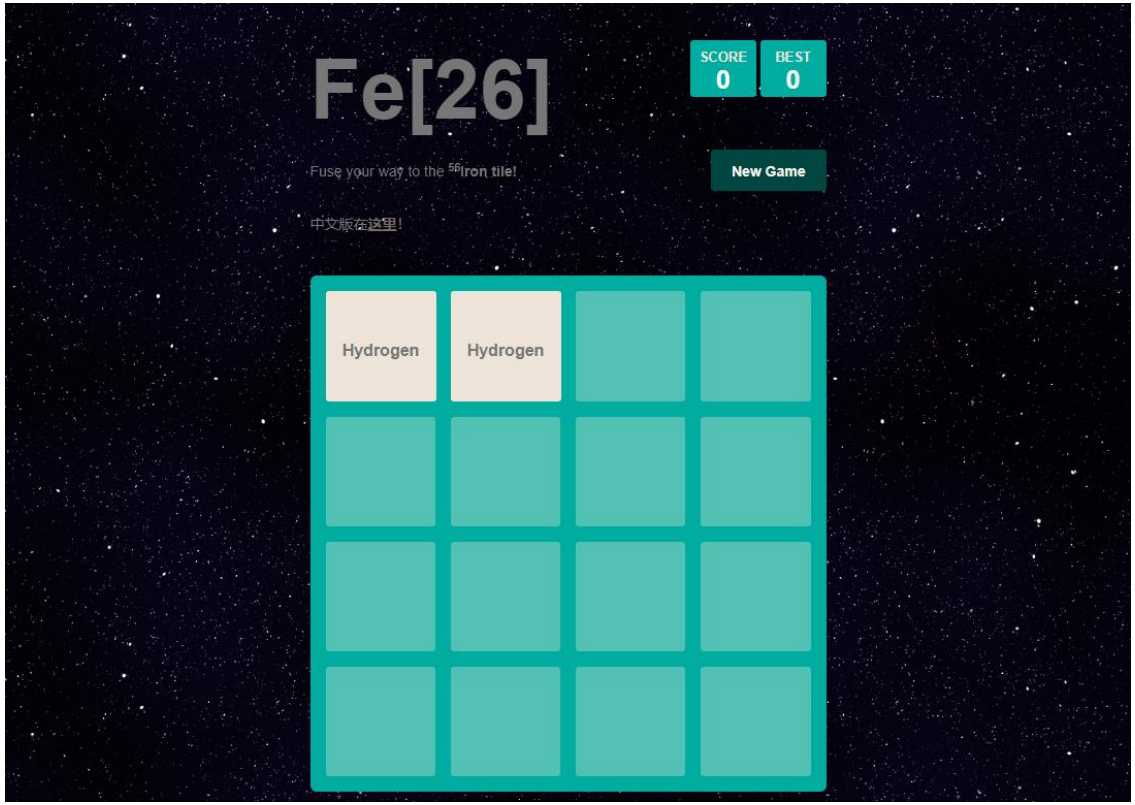


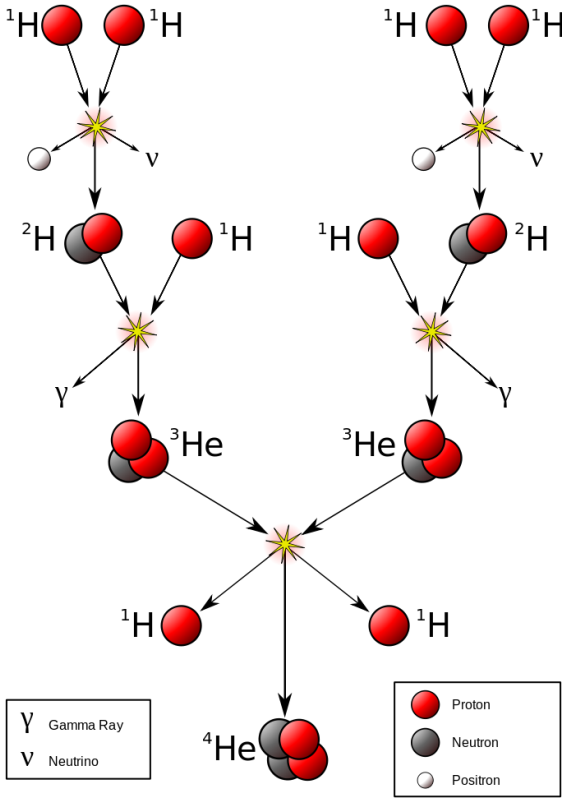


Remember the largest element in this "Fusion block"?

Iron

The Process Continues…





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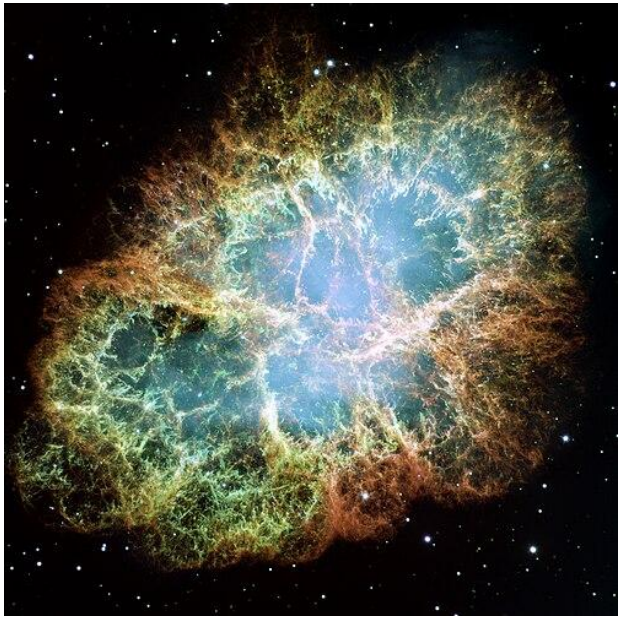
The Star Collapses

Once iron builds up, fusion can no longer produce energy, and the gravity overcomes the outward push causing the star to collapse in a violent event called a Supernova



Life Cycle of Massive Star

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The ultimate fate of a massive star depends on the mass of the final core after the outer layers are ejected

Oppenheimer-Volkhoff Limit = 3 $M_\odot$

A Neutron star above the Oppenheimer-Volkhoff Limit will collapse and form a Black Hole.

$< 3M_\odot \rightarrow$ Neutron Star

$> 3M_\odot \rightarrow$ Black Hole

Life Cycle of Massive Star

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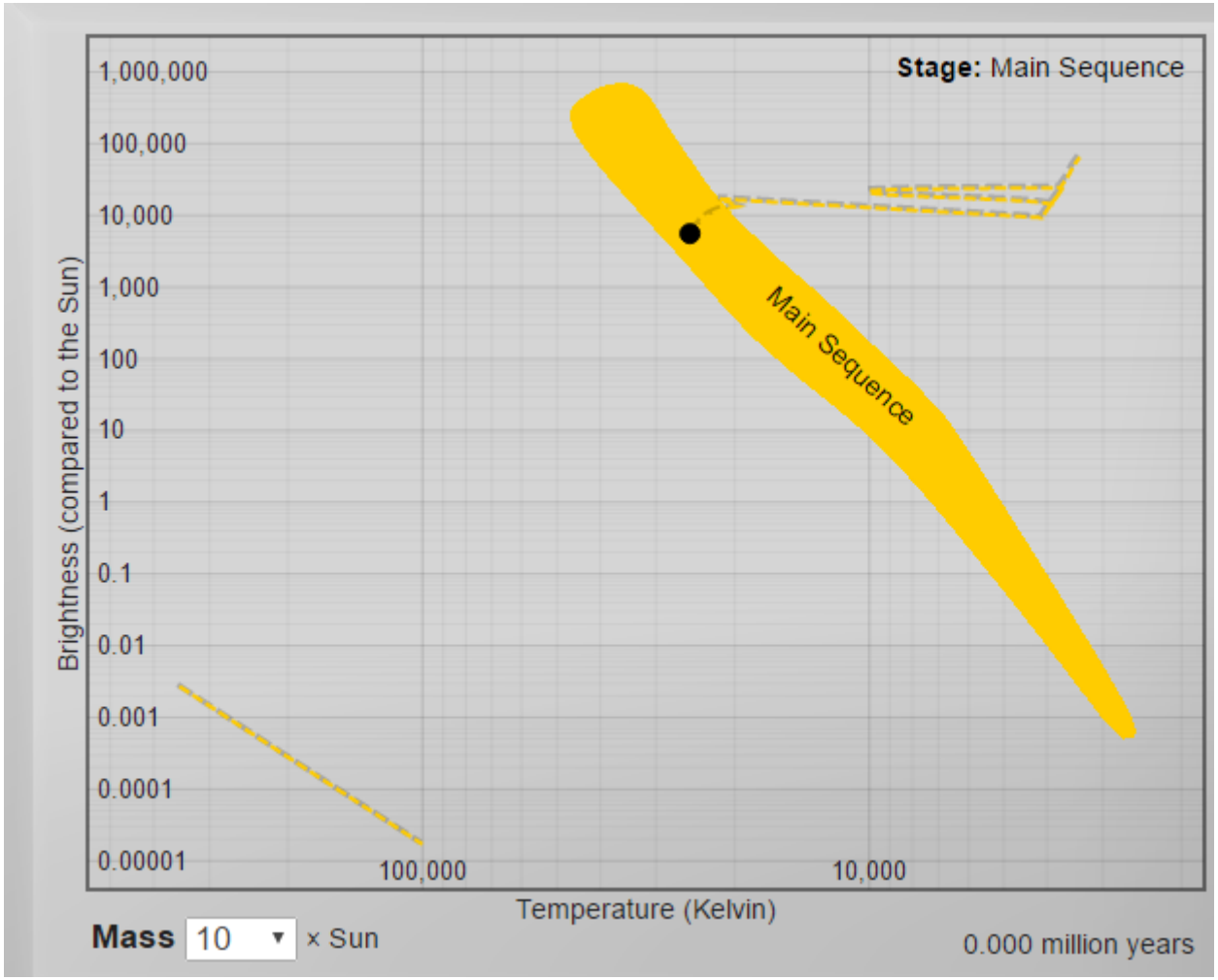

Black Holes?

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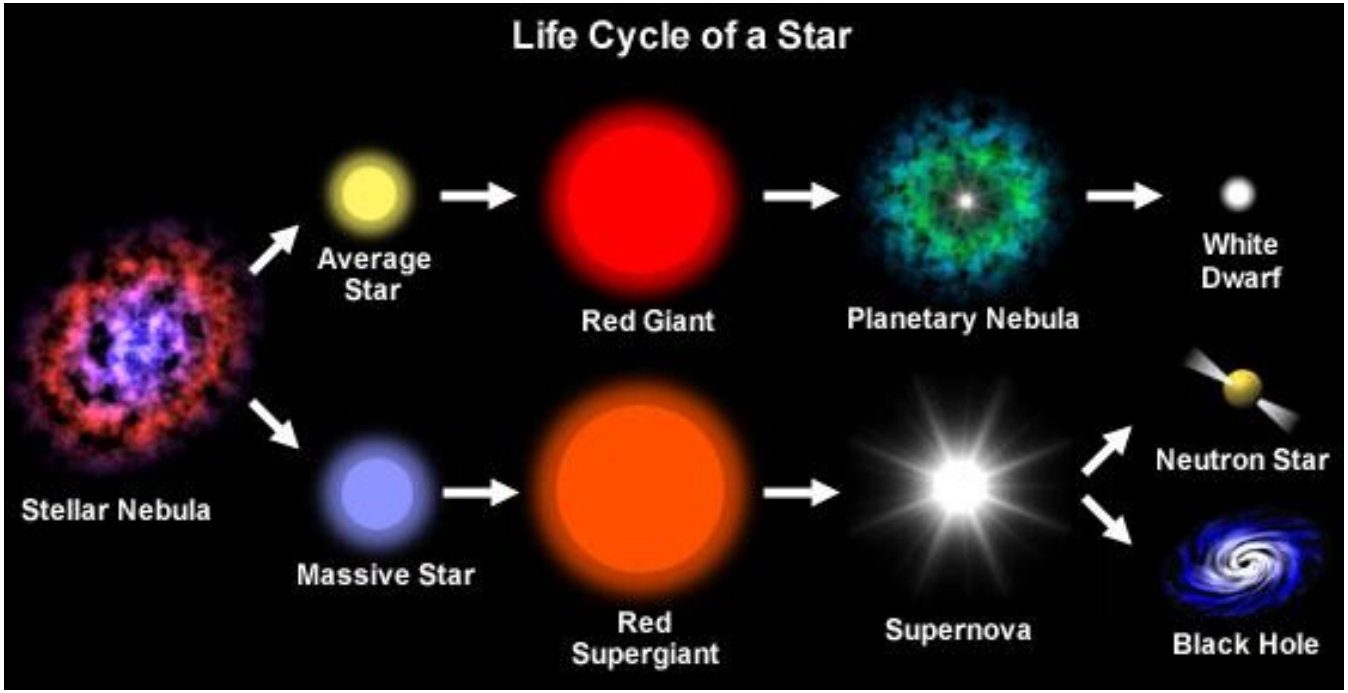
Life Cycle of a Star



$< 1.4M_{\odot}$

$> 3M_{\odot}$

Lesson Takeaways

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- ❑ I can describe the process of fusion and conditions required for it to happen
- ❑ I can calculate the energy released in a fusion reaction
- ❑ I can discuss the forces involved in stellar equilibrium
- ❑ I can describe the life cycle of a star
- ❑ I can describe the differences in fusion for an average and massive star
- ❑ I can predict the death outcome of a star based on the mass of its core at the end of life