Announcements

- **TA feedback forms are online!** find the link at the class website. Please take 5 minutes to tell your TAs your opinion.
- In case you did not notice, the Final is set for 03/21 from 12:00-3:00 pm. (This is posted on the class website)
  It will have about 80 questions, about 30 of them will be math problems.

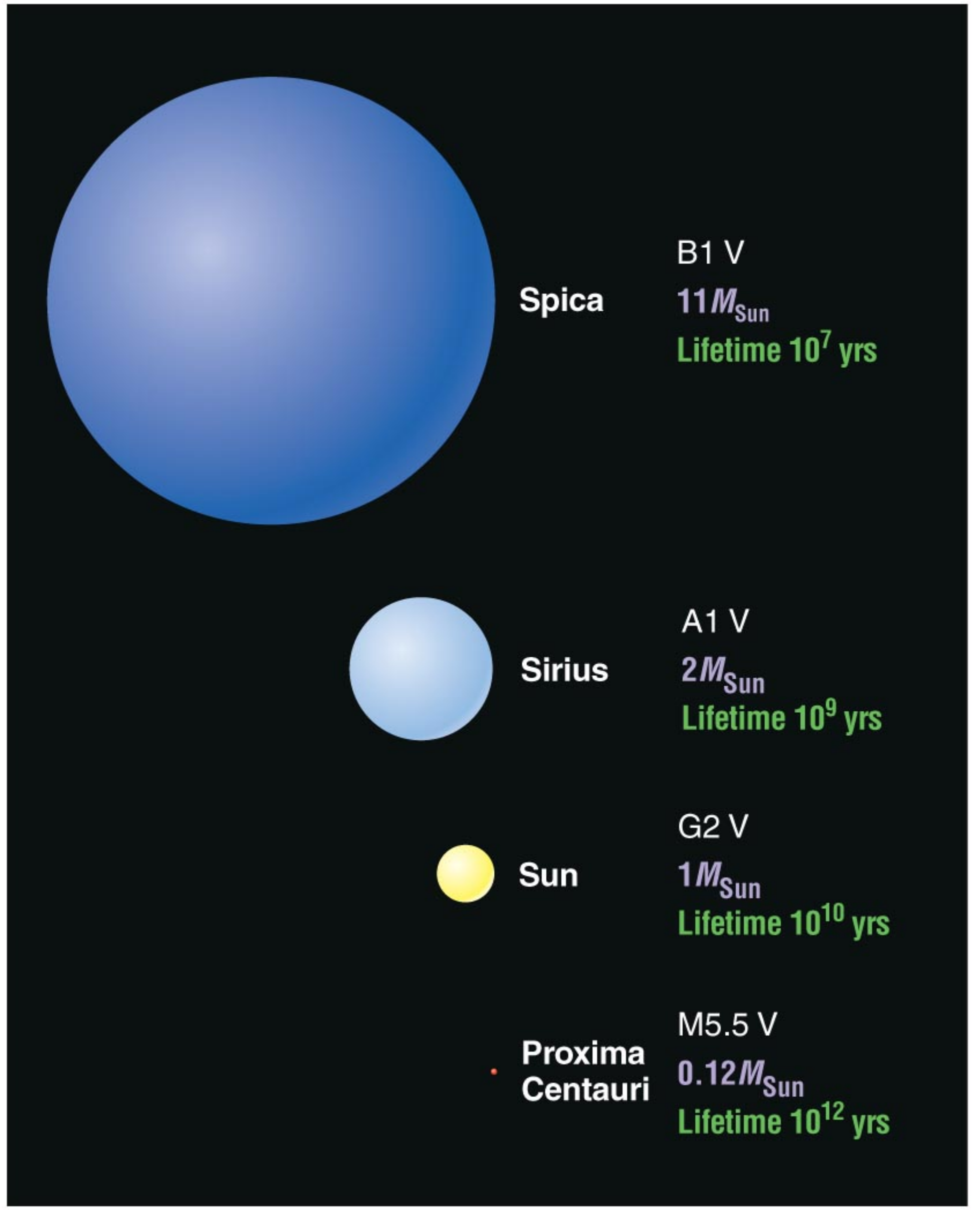
Main sequence stars

High mass stars:

Are more luminous
Have large radius
Are bluer (hotter)
Live shorter lives

Low mass stars:

Are dimmer
Are smaller
Are redder (cooler)
Live longer lives

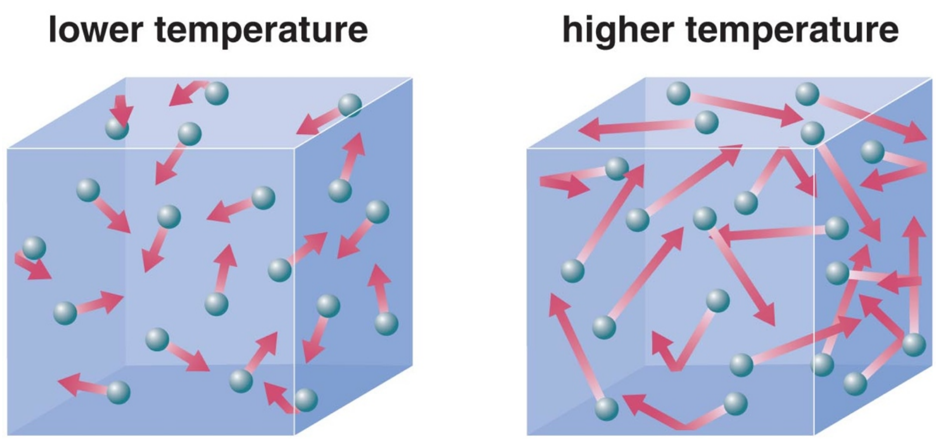


Chapter 16: Birth of Stars

What do we need to make a star?

Well... we need a big amount of mass

Cold mass? or hot mass?

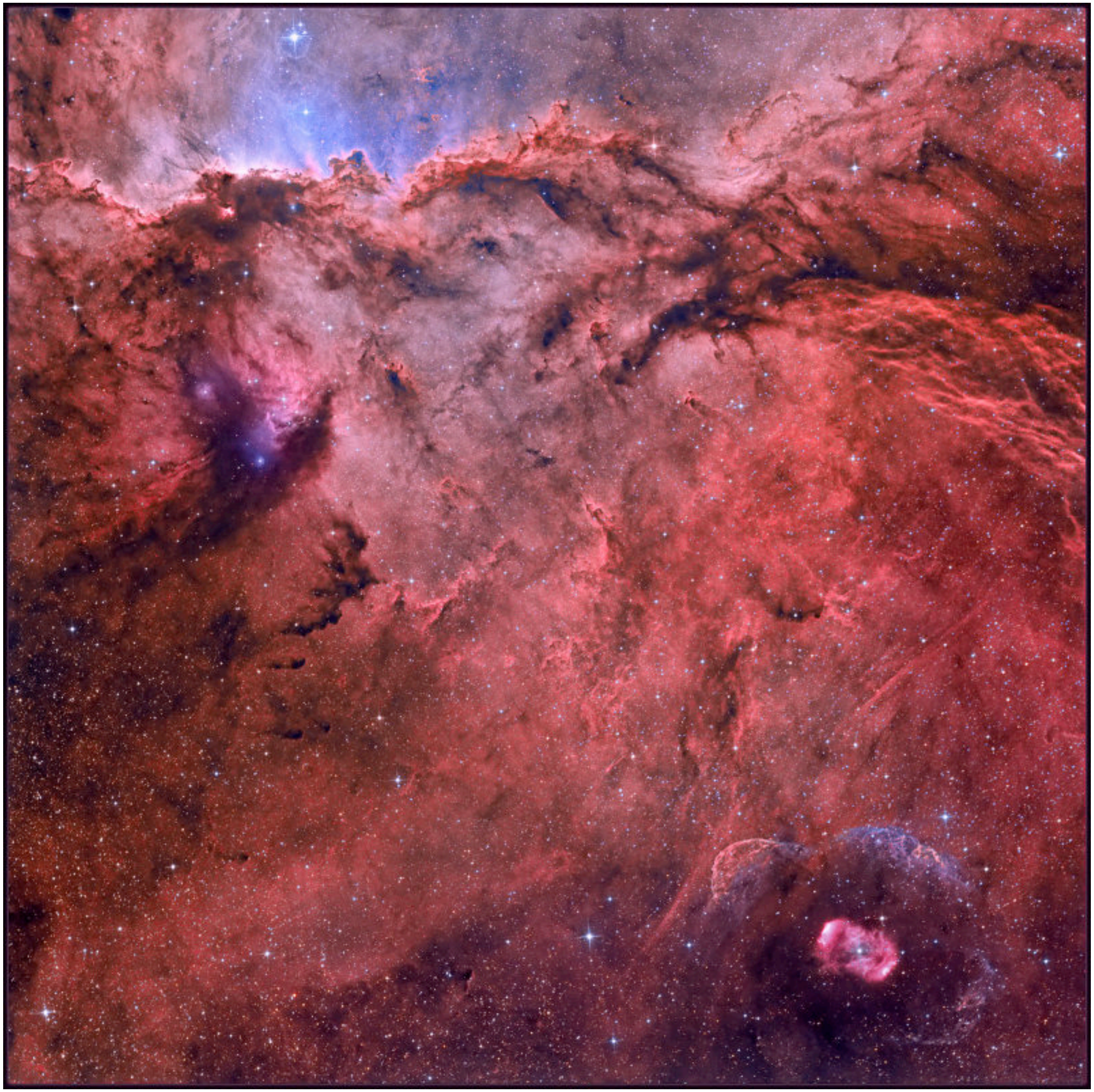


We need to *stick* the atoms together to form a star, that is a lot easier to do with colder material.

Chapter 16: Birth of Stars

We need a lot of cold material to form a star.

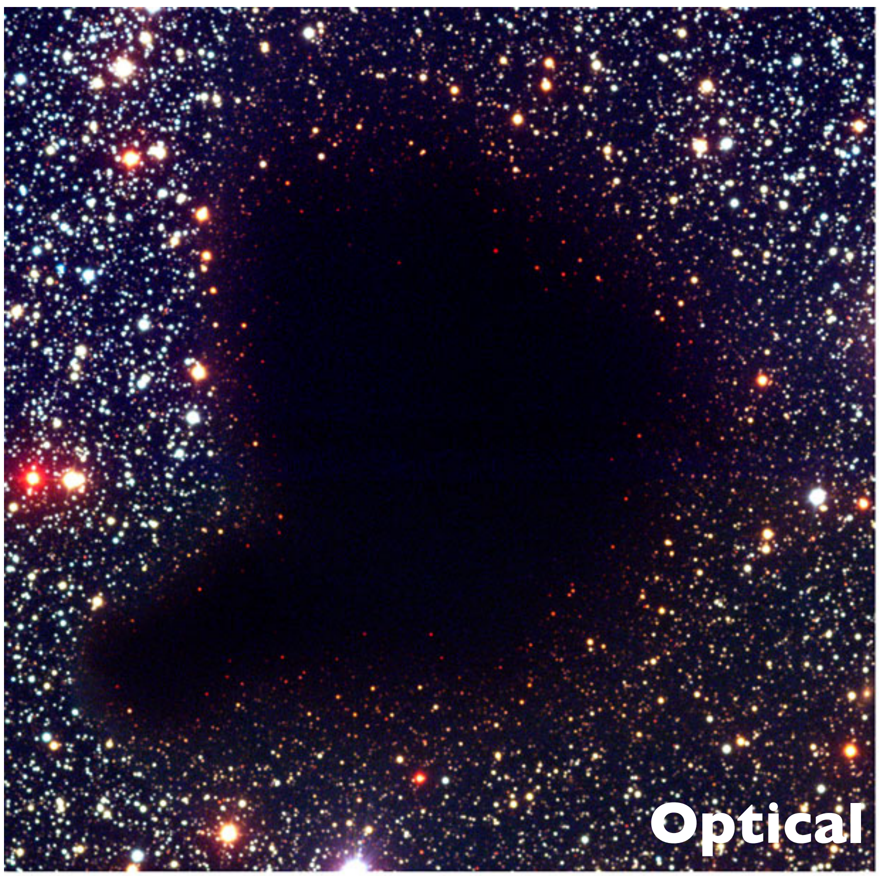
Where can we find it? **Molecular Clouds**



Chapter 16: Birth of Stars

Where can we find it? **Molecular Clouds**

They can be so dense that they can block all **optical** light from view.



Chapter 16: Birth of Stars

Where can we find it? **Molecular Clouds**

Once we have enough material, it actually needs to collapse (gravity will take care of that) into a star.

Density

Temperature

Formation of a cluster of stars

Credit: M. Krumholz (UCSC)

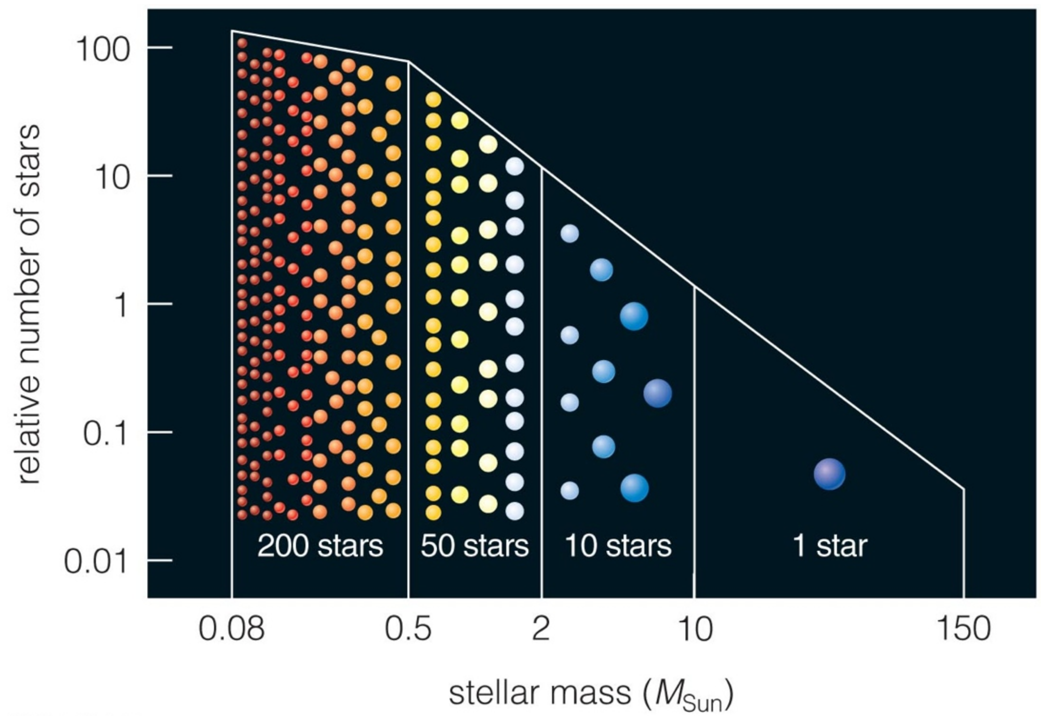
Chapter 16: Birth of Stars

Where can we find it? **Molecular Clouds**

Once we have enough material, it actually needs to collapse (gravity will take care of that) into a star.

Stars are *always* born in clusters, where the majority of stars are low-mass stars.

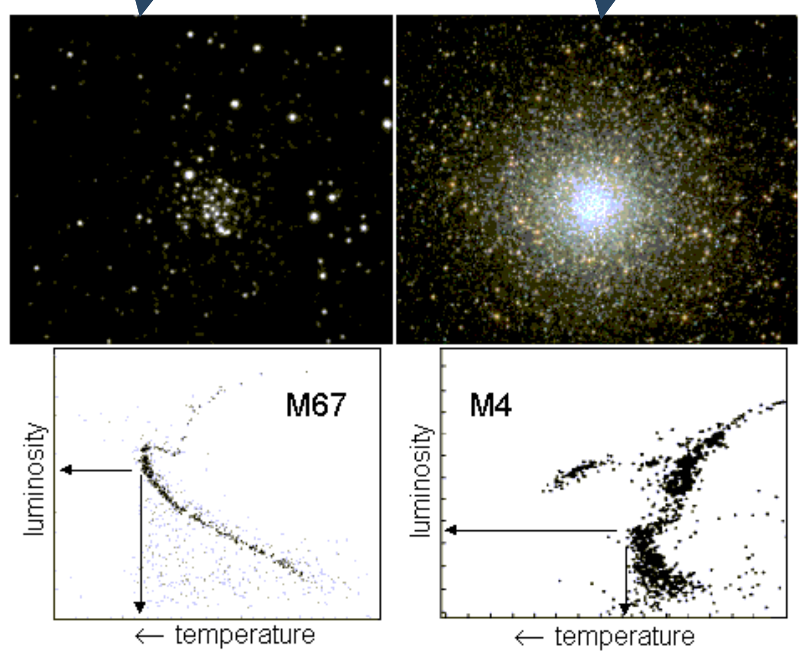
To determine the proportion of low-mass stars relative to high-mass stars is a field of active research.



Star Clusters

Stars are born in groups or clusters.
Clusters are gravitationally bound group of stars.
Every star in the cluster is born at roughly the same time (same age), and they are all at approximately the same distance from Earth.

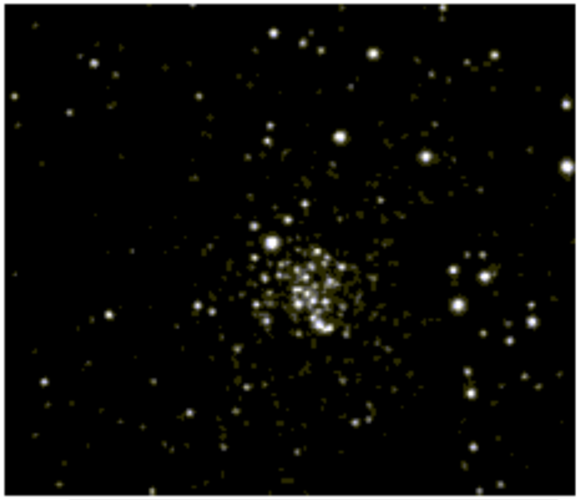
There are 2 kinds of clusters: Open clusters and Globular Clusters

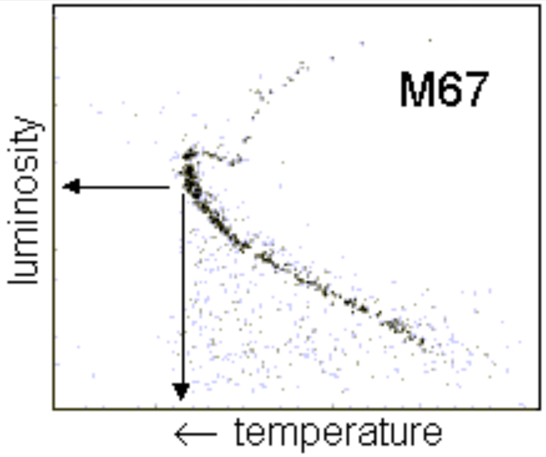


Open Clusters

"Open" because they look disorganized.
Younger clusters, they are located close to reservoirs of gas and molecules that can give birth to stars.

Can contain thousands of stars and have sizes of about 30 ly across.

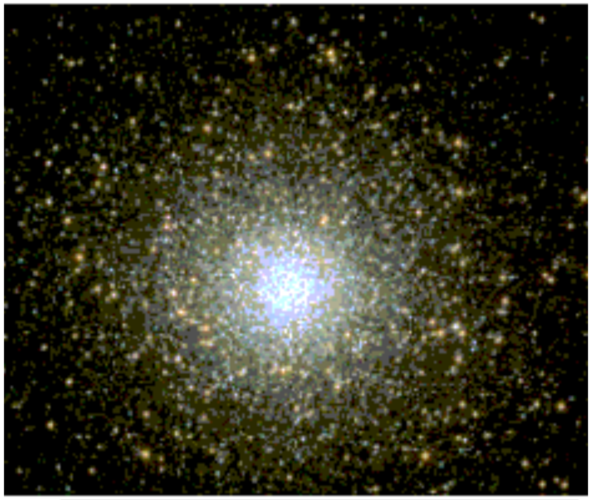




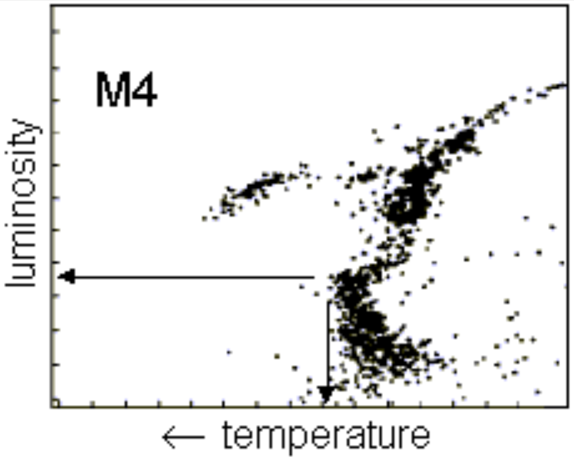
Young: because the hot blue stars are still present

Globular Clusters

"Globular" because they are dense and spherical
Older clusters, they are located in the haloes of galaxies, where there is not much material to form new generations of stars.



Can contain millions of stars and have sizes of about 100 ly across.



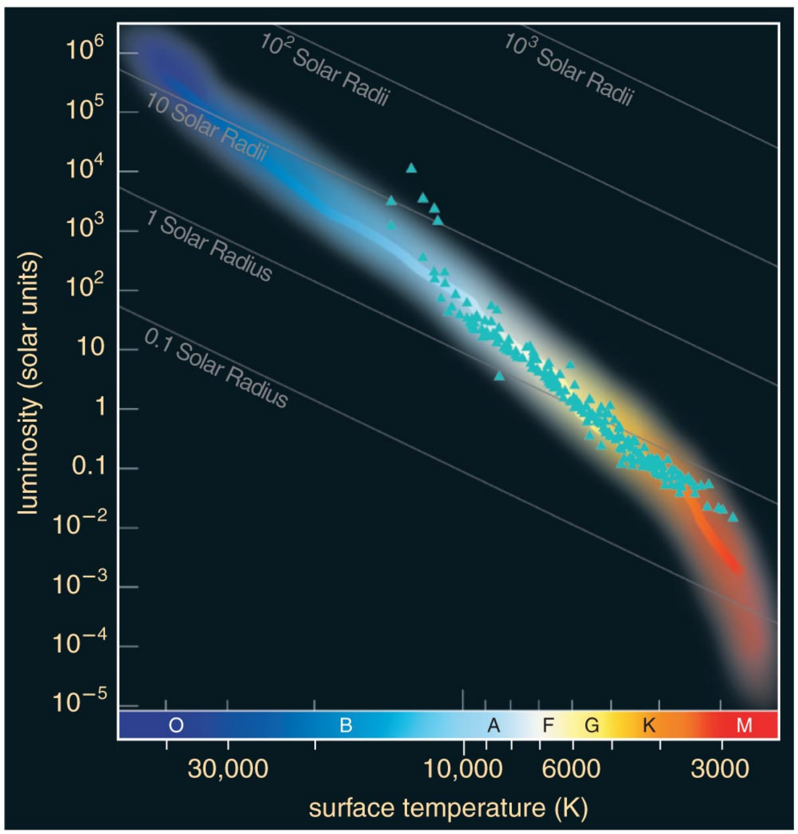
Old: because the hot blue stars are gone.

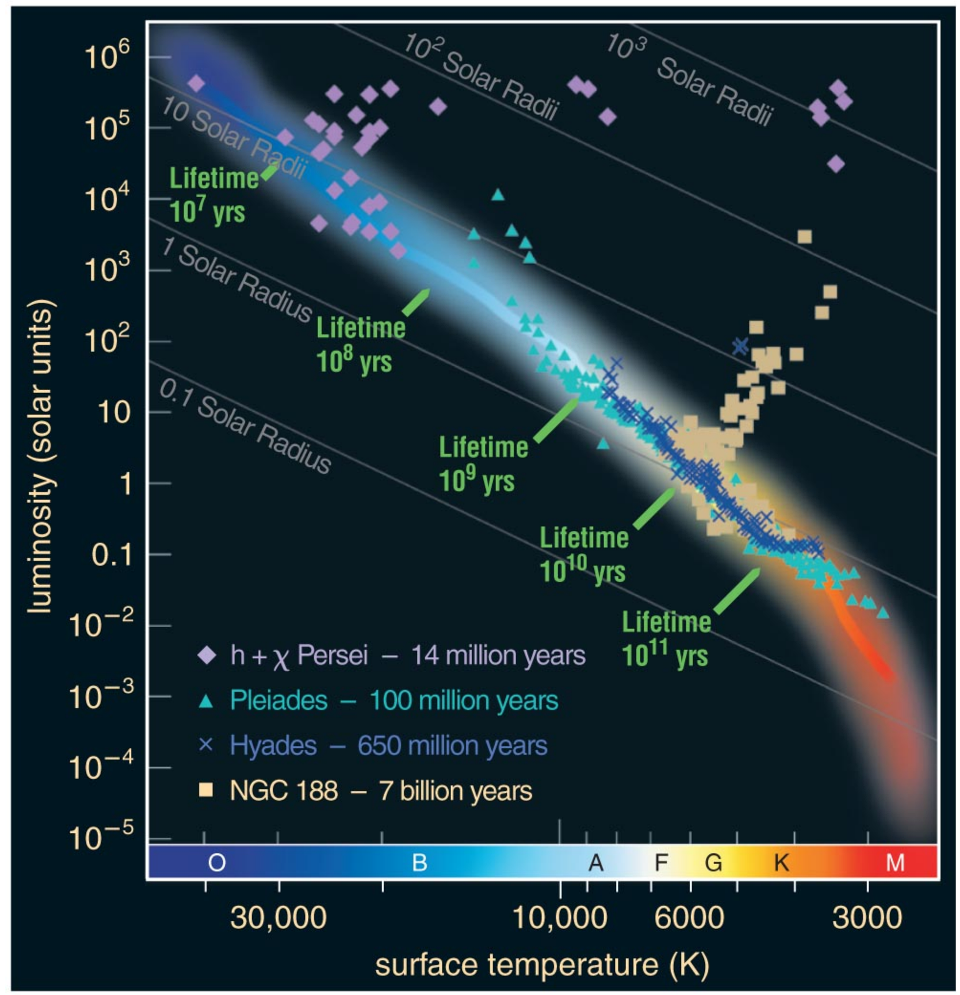
Age of a cluster?

Key points:

-All stars in the cluster have the same age (were born at the same time)

-Massive stars run out of fuel (leave the main sequence) sooner than less massive stars.

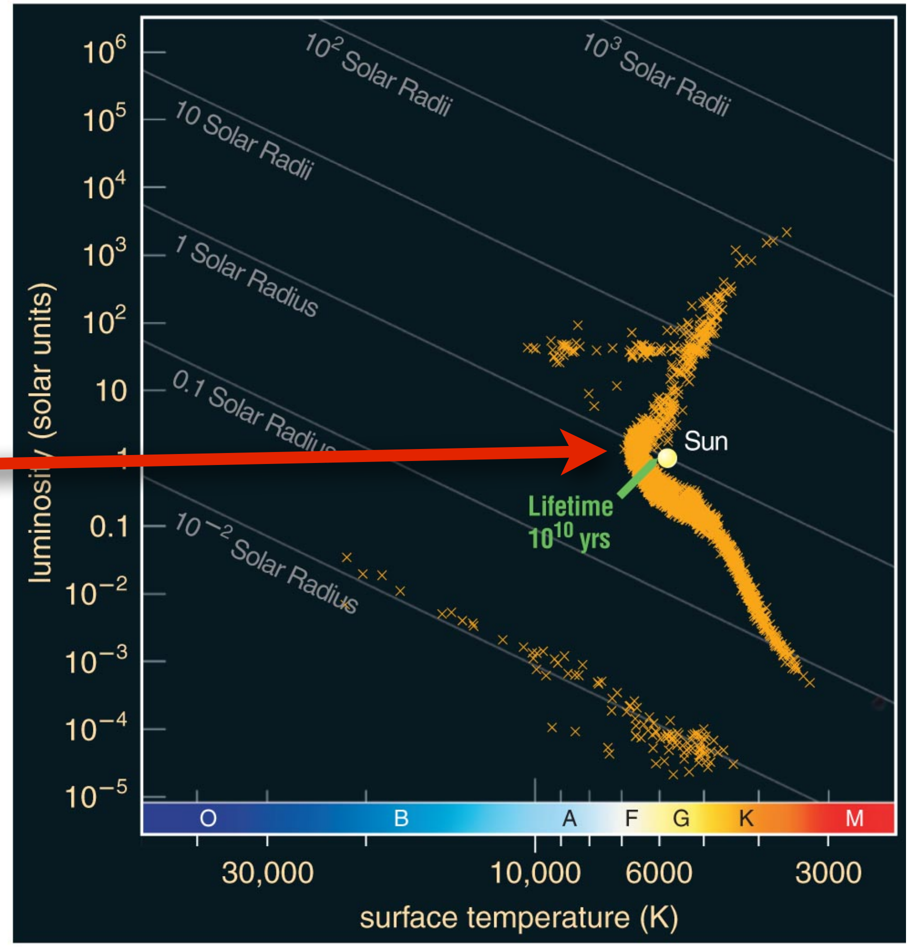




Age of a cluster?

Key points:
-All stars in the cluster have the same age (were born at the same time)
-Massive stars run out of fuel (leave the main sequence) sooner than less massive stars.

The position of the "turn off point" is what tells us the age of a cluster.
This is due to the fact that mass is related to the lifetime of a star.



How old is this cluster?

10 billion years!

Because stars that live only 10 billion years are just leaving the main sequence.

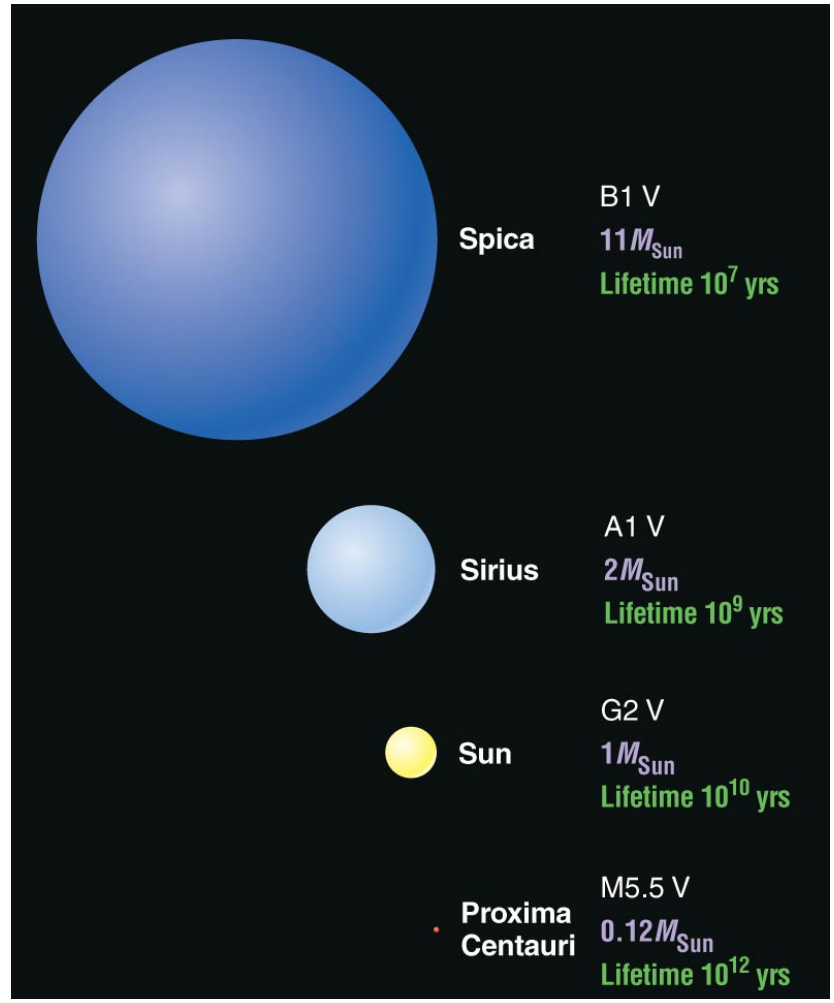
High vs Low mass stars

We know there is a range of masses for stars: $0.08M_{\odot} - 100M_{\odot}$

It is the **mass** what determines:
-The position a star will assume in the HR diagram
-When the star will run out of H
-How the star will end its life

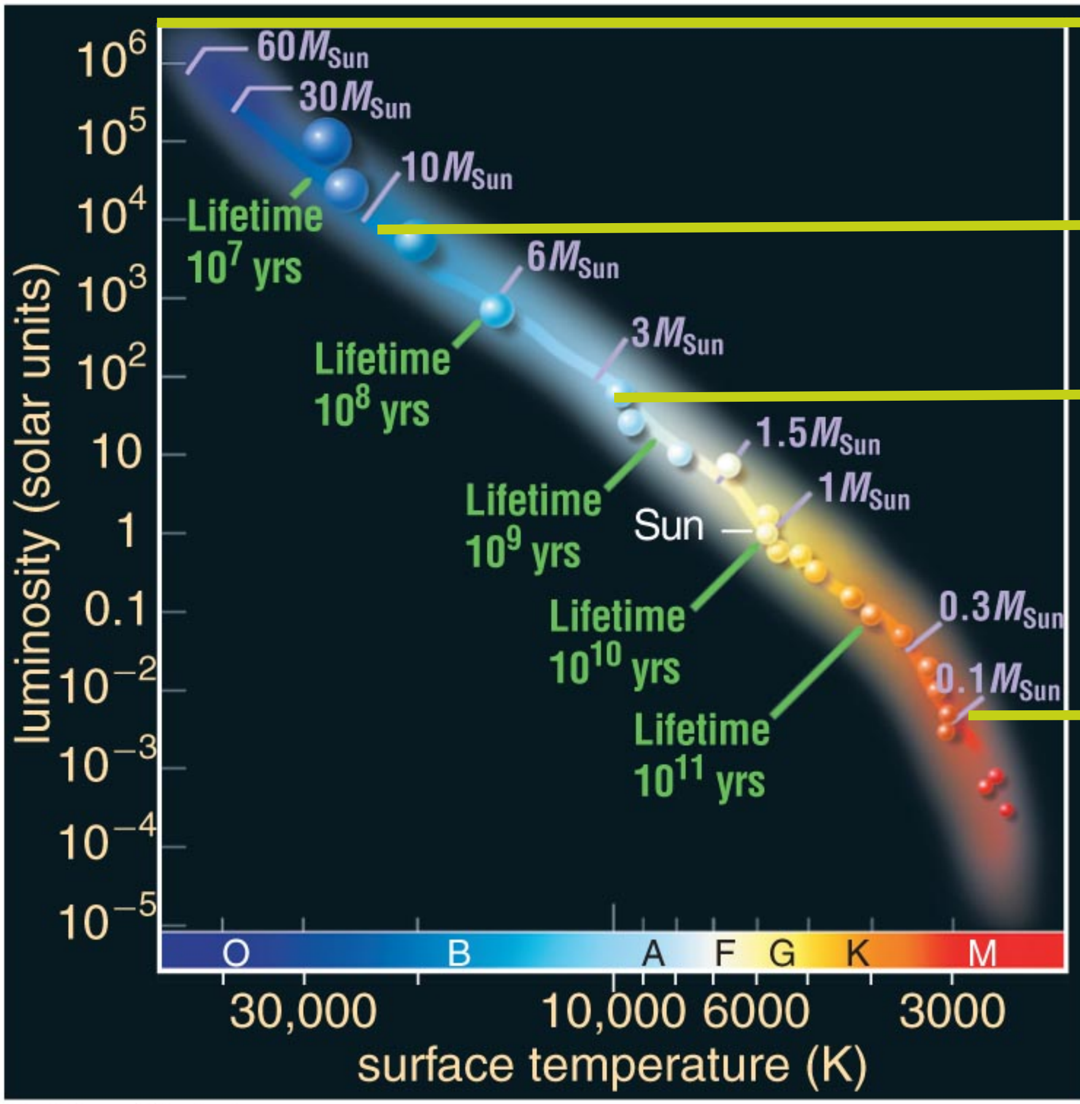
High mass stars:
higher core temperature
faster fusion
more luminous
shorter-lived

Lower mass stars:
lower core temperature
slower fusion
less luminous
longer-lived



High vs Low mass stars

Approximate Definitions:



High-Mass Stars
>8 M_{Sun}

Intermediate-Mass Stars

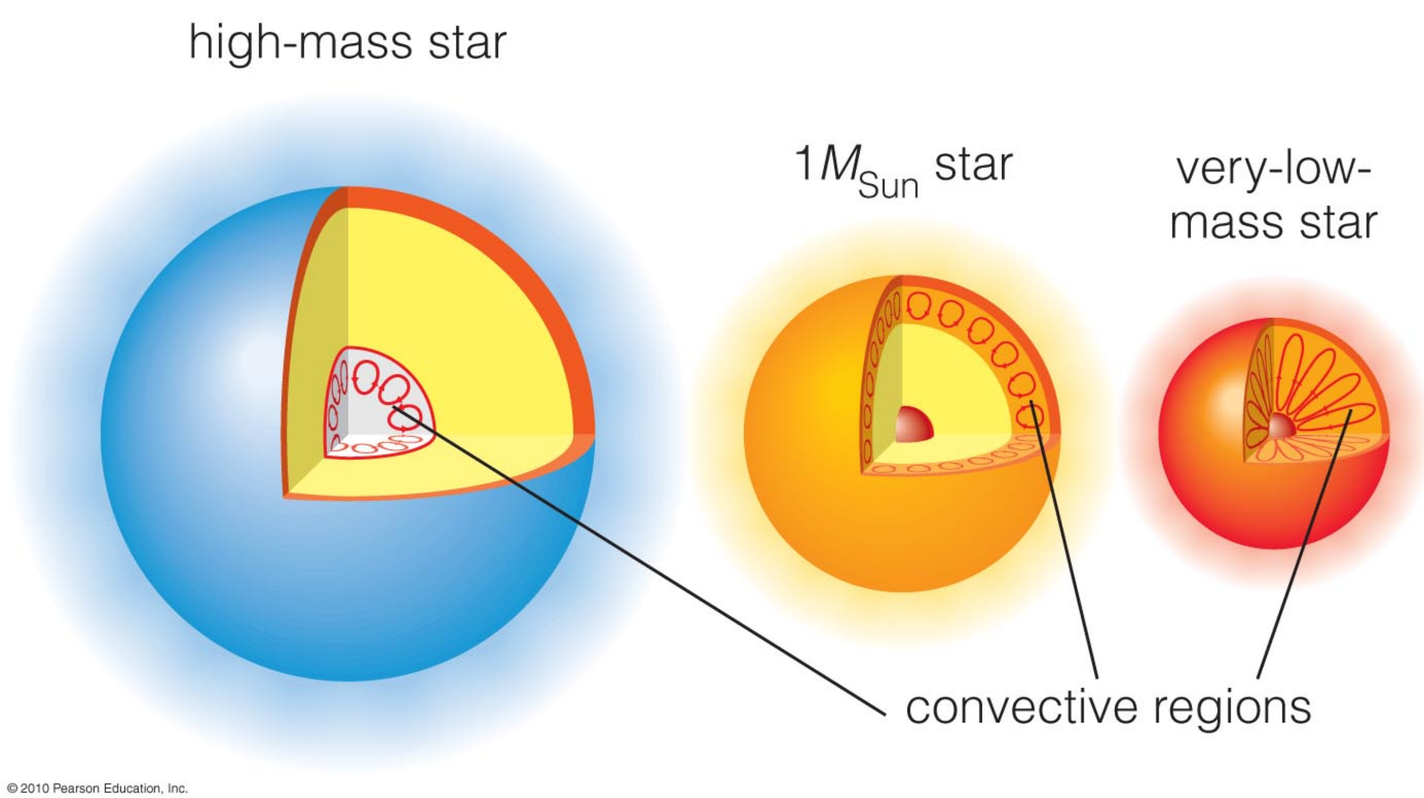
Low-Mass Stars
< 2 M_{Sun}

Brown Dwarfs

High vs Low mass stars

Structural differences:

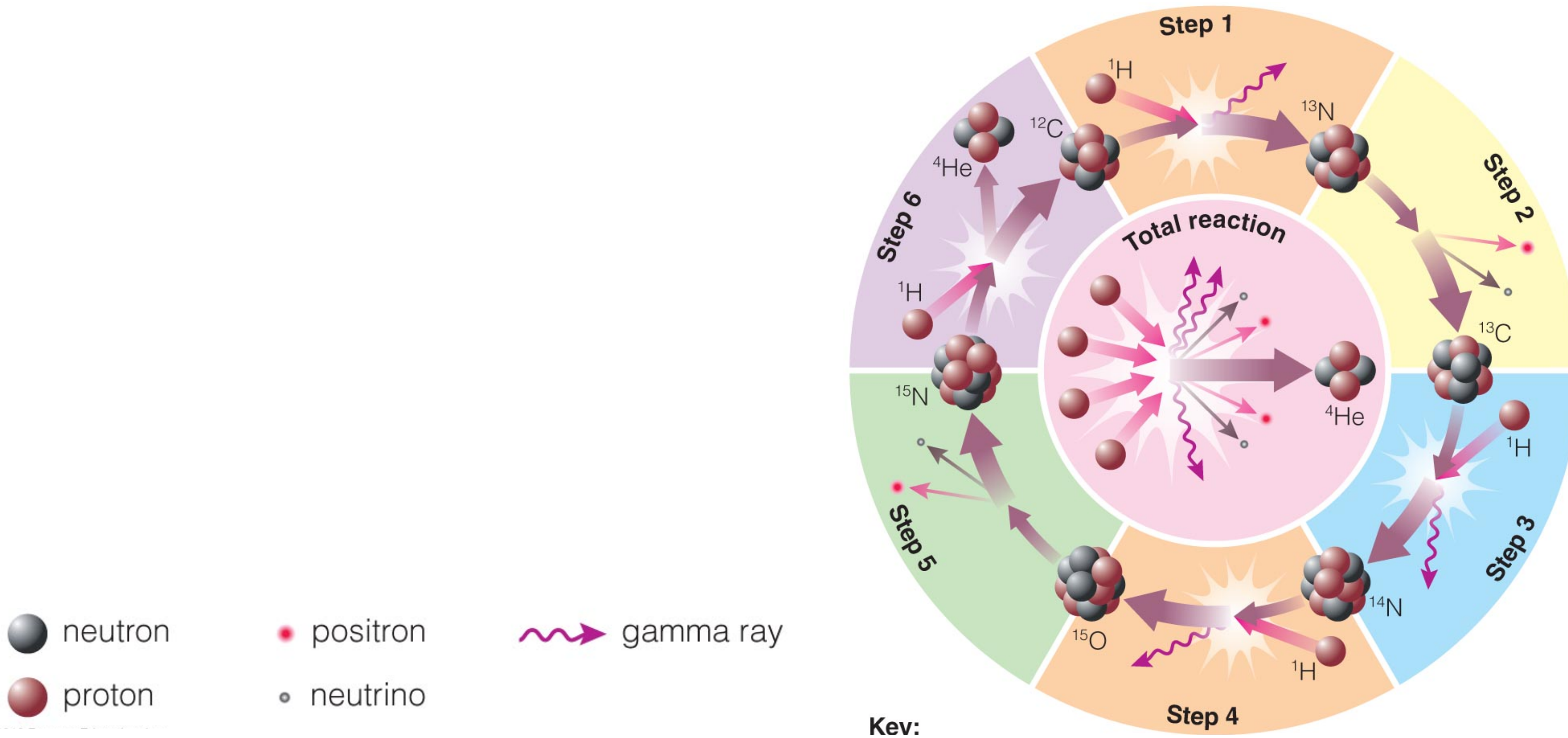
- Convective region:
  Lowest mass (dwarfs) are fully convective
  Typical low mass stars (Sun) are convective near the surface
  High mass stars are convective near the core



High vs Low mass stars

Differences in the fusion of H into He:

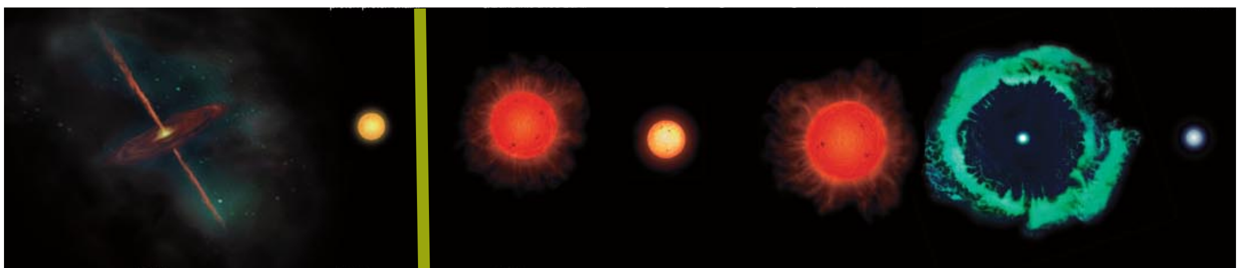
- Higher pressure means that there are more ways to fuse H.
  Low mass: proton-proton chain(as discussed for the Sun)
  High mass: Carbon-Nitrogen-Oxygen (CNO cycle)



High vs Low mass stars

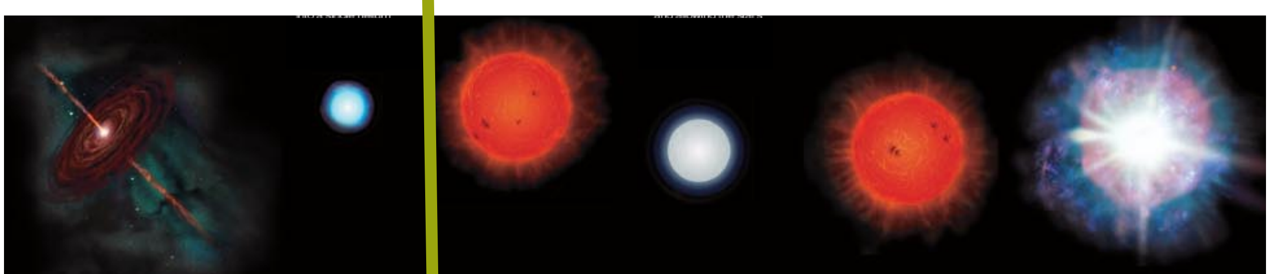
Differences in the evolutionary rates and paths

- Low mass: SLOW!
  orderly, distinct burning phases ⟶ will fade away



puf!

- High mass: RAPID!
  messy, multiple burning stages at once ⟶ will explode!



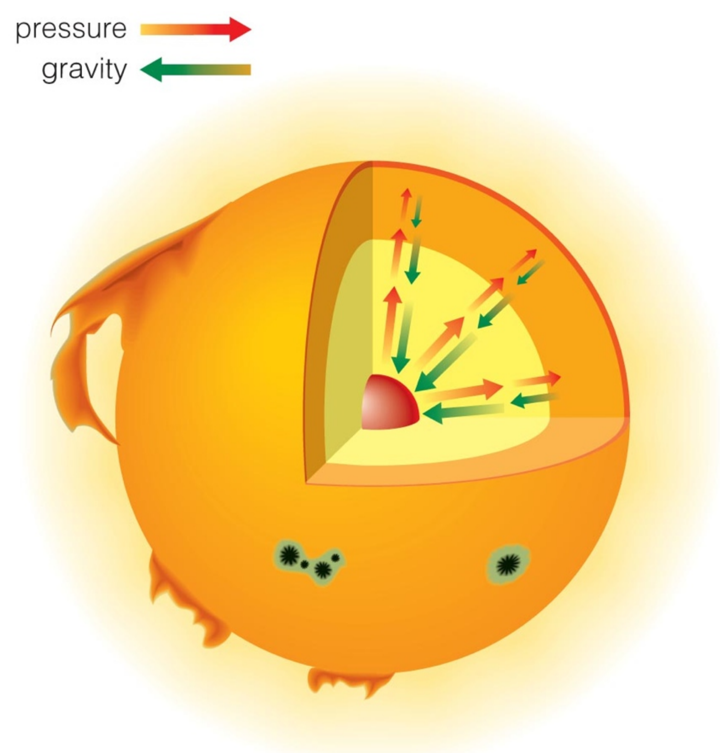
BANG!

Post main sequence evolution is quite different.

Post main sequence evolution: Low Mass

Post M.S.: Core hydrogen supply is gone

- Fusion of H into He ends
  Energy supply is gone
  Temperature drops, pressure drops
  (*red arrows get smaller, green arrows do not change*)



Core collapses!

http://www.youtube.com/watch?feature=player_detailpage&v=X6gBTT1VJgQ

Post main sequence evolution: Low Mass

Post M.S.: Core hydrogen supply is gone

- Fusion of H into He ends
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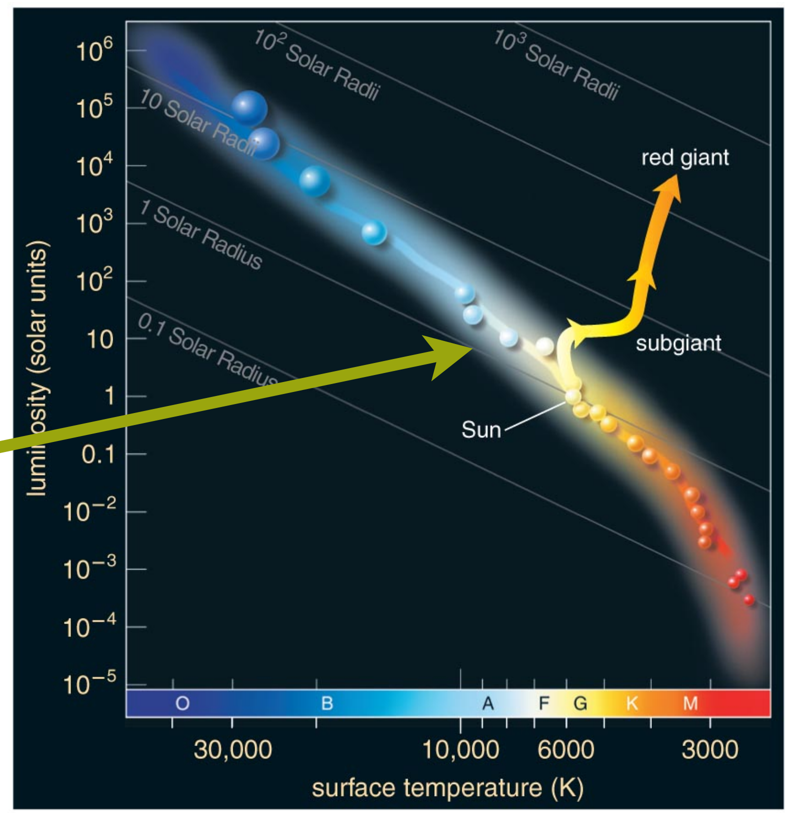
  (*red arrows get smaller, green arrows do not change*)

Core collapses!

Then, why...
what stops the core collapse?

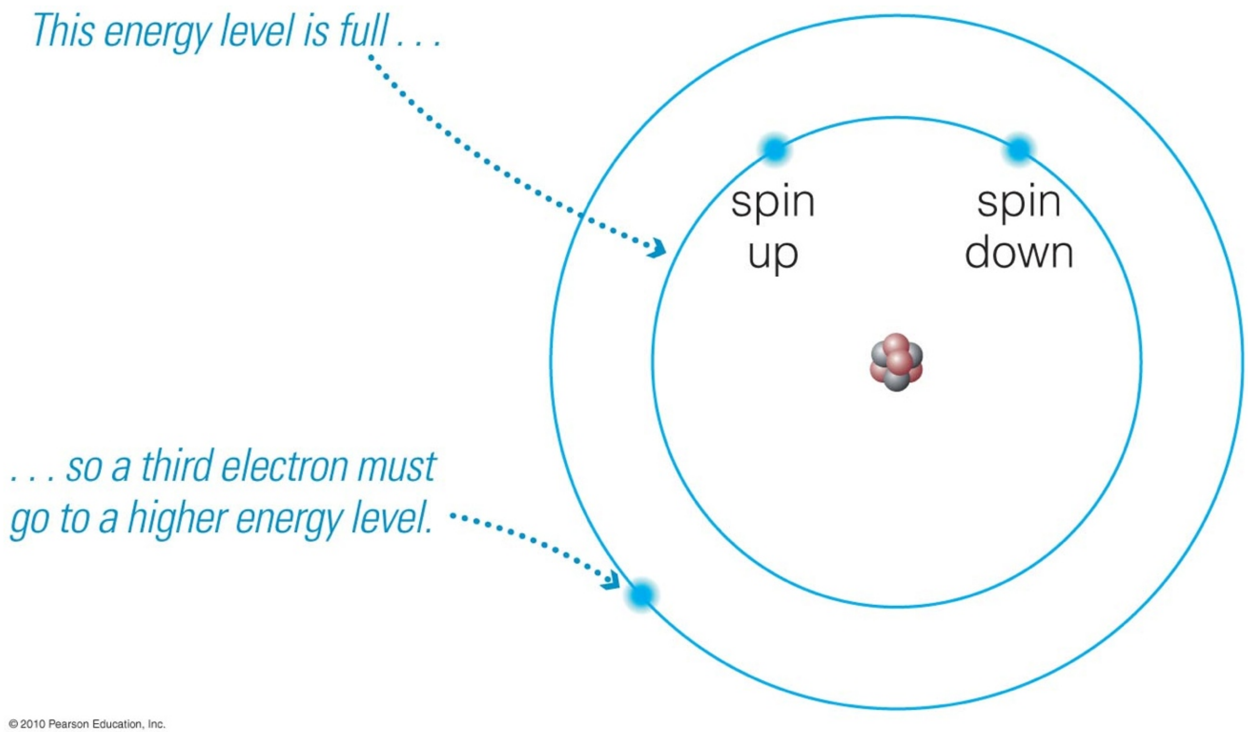


Post main sequence evolution: Low Mass

Degeneracy pressure

The density of matter is limited by two fundamental laws of quantum mechanics:

- Particles can't be in the same state (energy, spin) and place simultaneously.



Post main sequence evolution: Low Mass

Degeneracy pressure

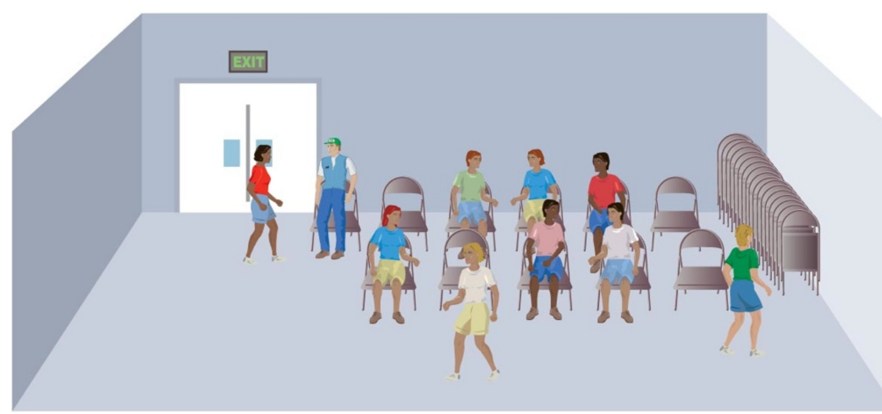
The density of matter is limited by two fundamental laws of quantum mechanics:

- Particles can't be in the same state (energy, spin) and place simultaneously.
- Heisenberg uncertainty principle
  (Uncertainty in location) x (uncertainty in momentum) > Planck's const.

$$\Delta x \times \Delta p > h$$

You can't squish too many particles into a very small place

When the star collapses, the available volume shrinks : fewer chairs



Post main sequence evolution: Low Mass

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- Heisenberg uncertainty principle
  (Uncertainty in location) x (uncertainty in momentum) > Planck's const.

$$\Delta x \times \Delta p > h$$

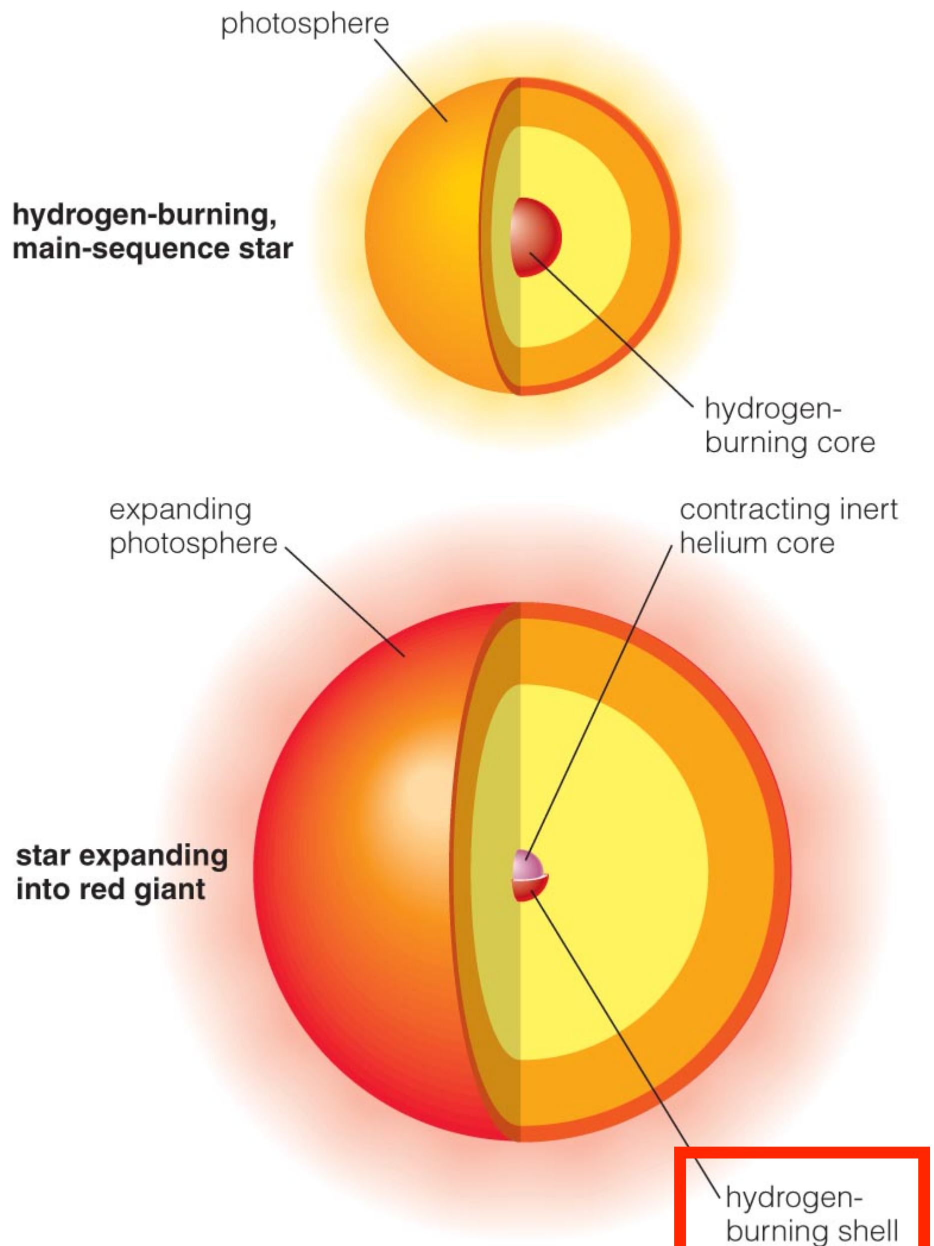
As Δx goes down (area is better defined),
Δp must go up (available momentum values must go up)

So the particles GAIN momentum (velocity), which provides pressure.
This pressure does not depend on temperature!

Post main sequence evolution: Low Mass

Post M.S.: Core hydrogen supply is gone

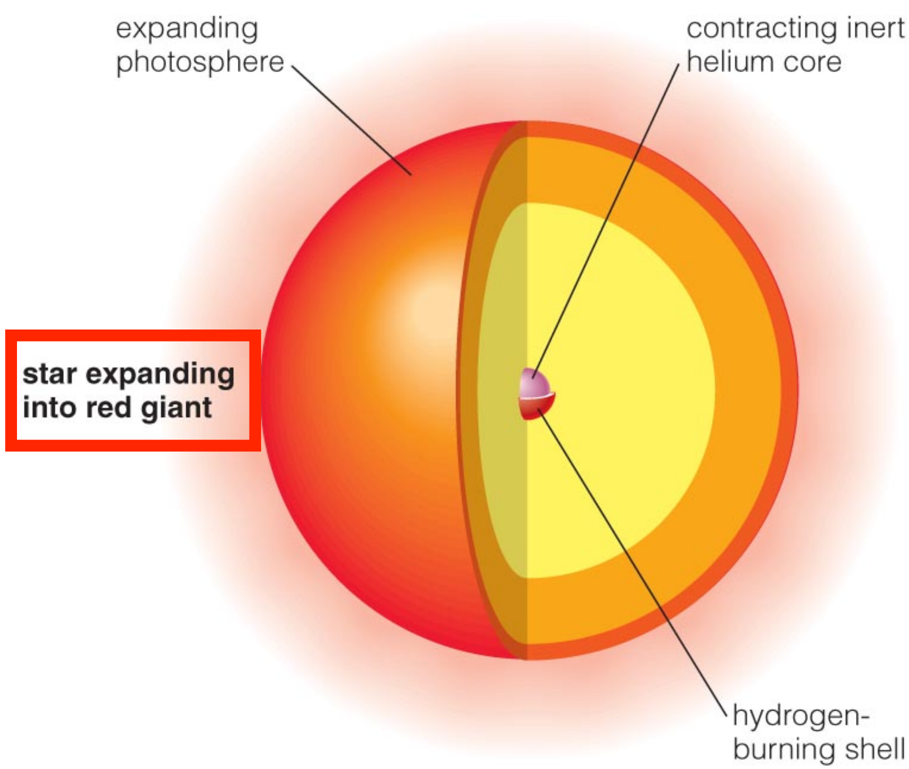
- The core collapses
- Shell burning
  Fusion of H into He is now possible outside the inert core



Post main sequence evolution: Low Mass

Post M.S.: Core hydrogen supply is gone

- The core collapses
- Shell burning:
  Fusion of H into He is now possible outside the inert core
- Luminosity increases
  -Fusion takes place in a larger volume of the star
  -Fusion is closer to the surface
  -The *thermostat* is broken:
  Increasing fusion rate in the shell does NOT stop the core from contracting
  -The core keeps collapsing, the shell keeps following it down

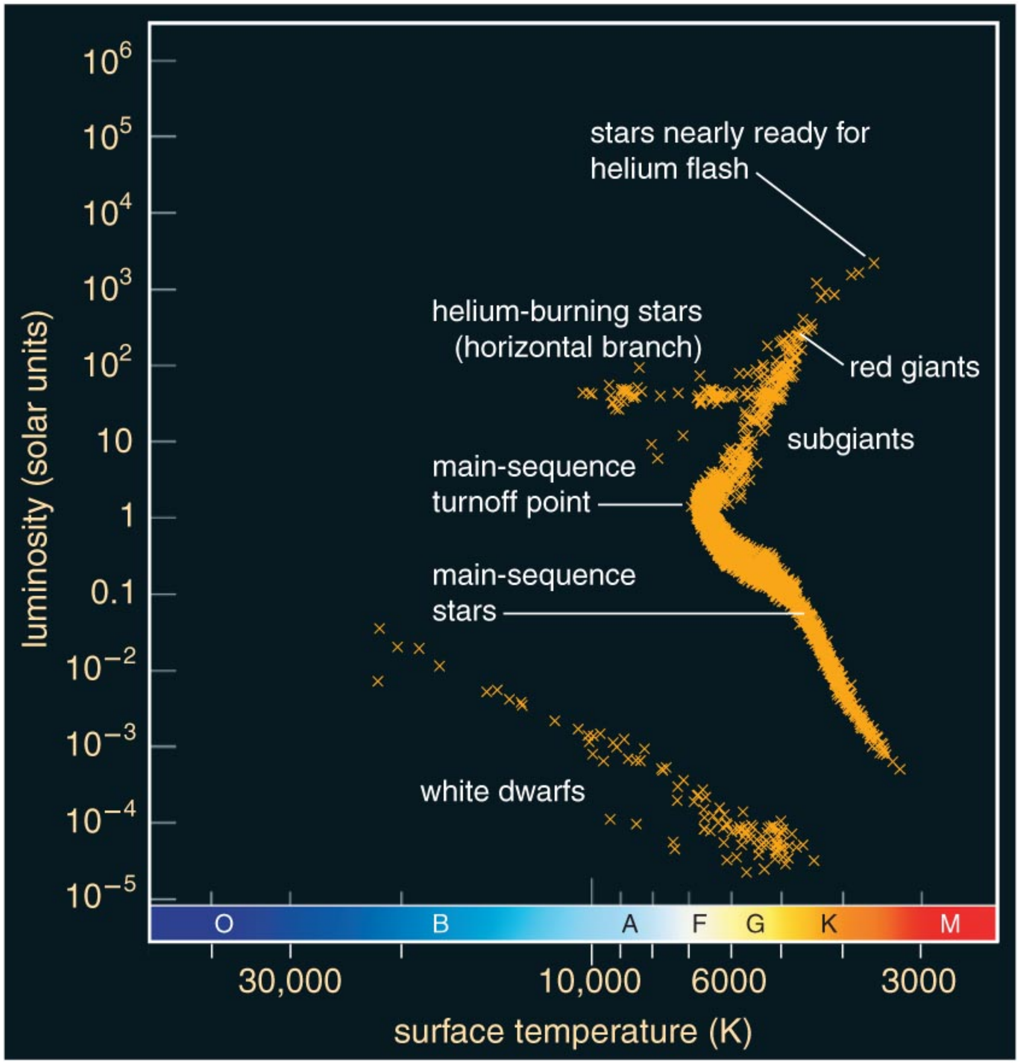


Post main sequence evolution: Low Mass

If the pressure never gets high enough, the core never re-ignites

- Outer envelope pushed out by thermal pressure until it escapes the star.
- Inert He core
- Degeneracy pressure support
- Fades away

Helium White Dwarf



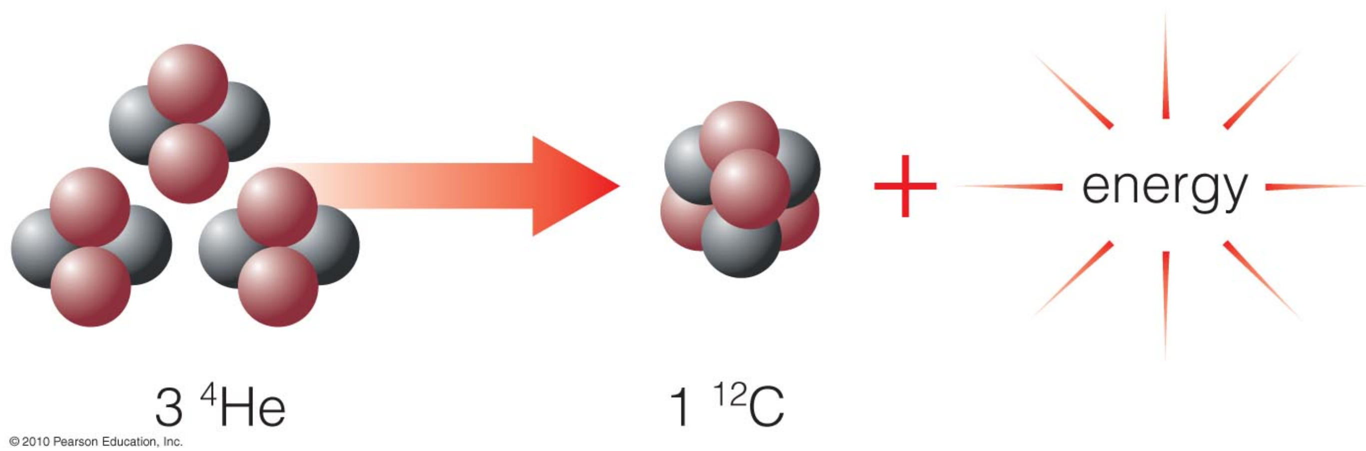
Post main sequence evolution: Low Mass

If the pressure DOES get high enough, core re-ignites

- **Helium Flash**
  In a degenerate core, He fusion can increase temperature without increasing pressure.
  He fusion rate rises quickly, nuclear fusion re-starts like an explosion.
  The energy created expands the core again.

Thermal pressure support is restored : Stable, controlled burning.

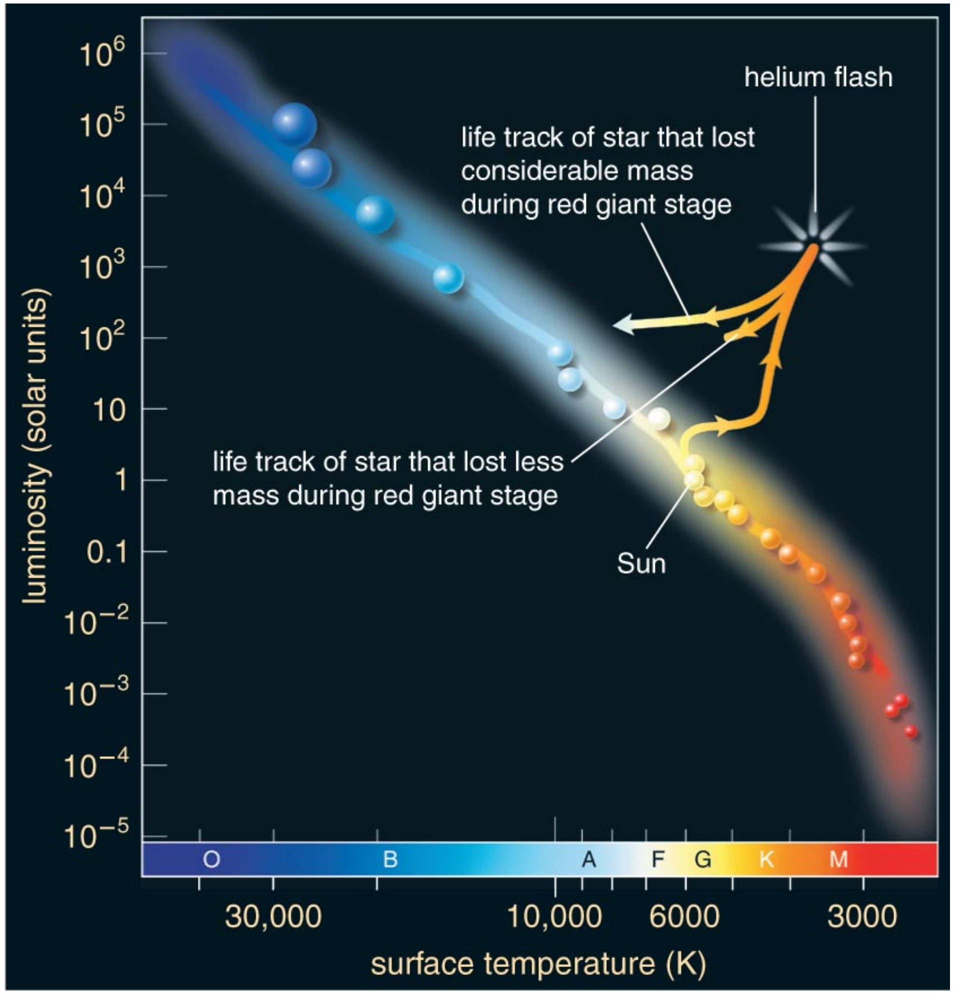
CORE FUSION = THERMAL PRESSURE SUPPORT



Post main sequence evolution: Low Mass

If the pressure DOES get high enough, core re-ignites

- **Helium Flash**
- Followed by stable core fusion of He into C.

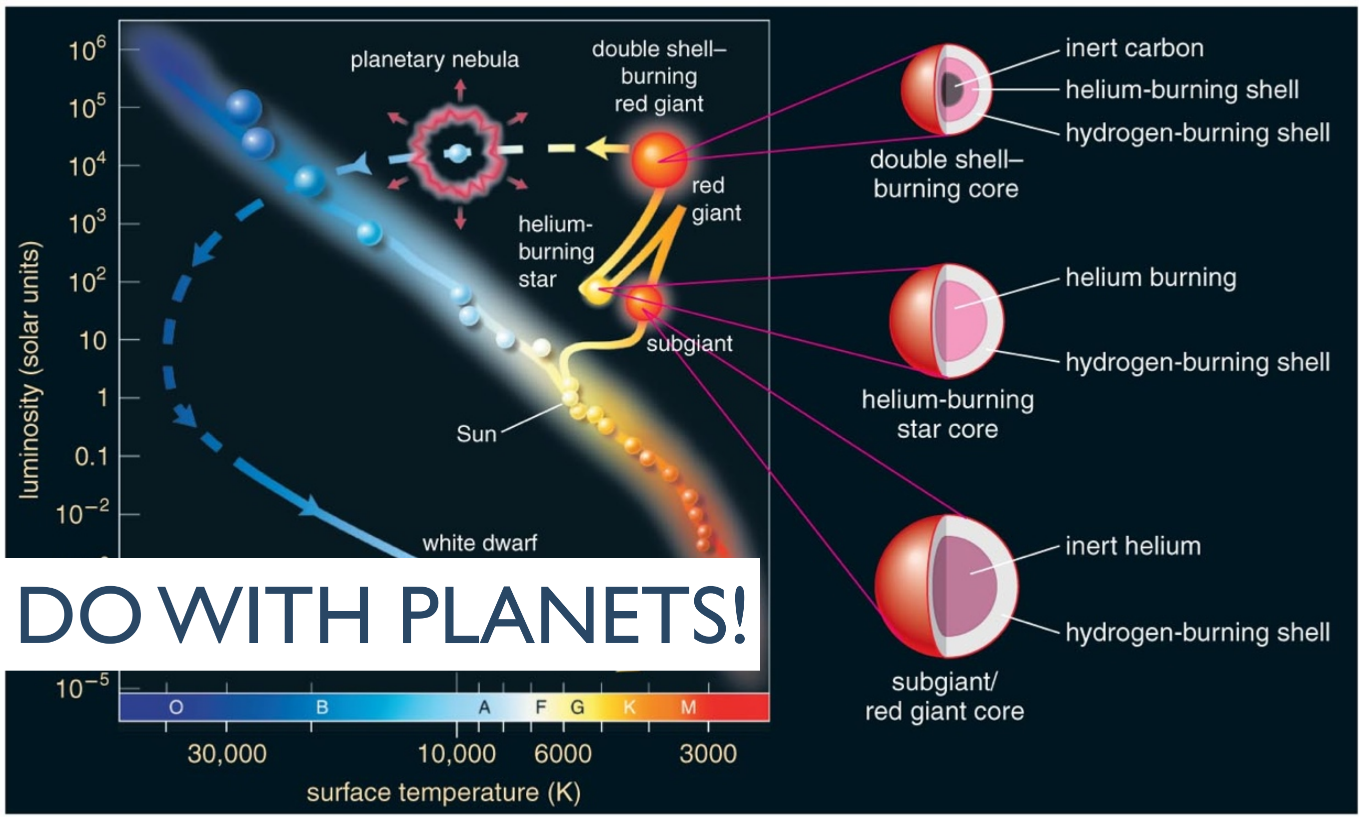


What happens next depends on Mass

Post main sequence evolution: Low Mass

If the pressure DOES get high enough, core re-ignites

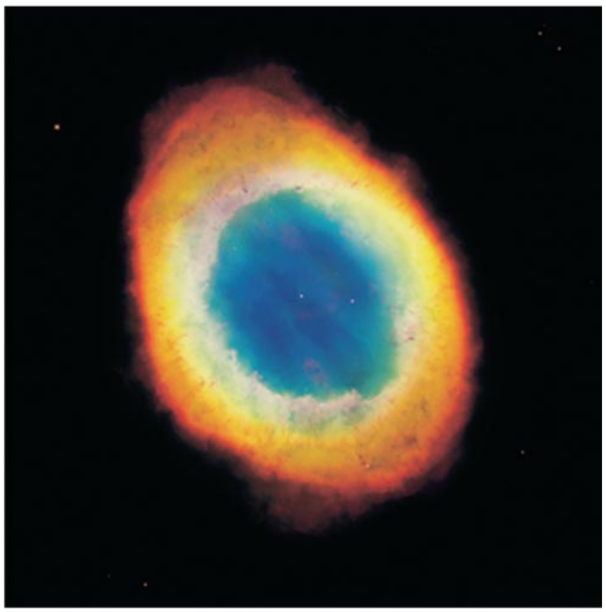
- Eventually, it will run out of Helium
- Core collapses again!
- Double shell burning: He-C outside of core, H-He above that.
- Brighter, redder, very unstable, looses mass through thermal pulses.
- Becomes a ***Planetary Nebula***

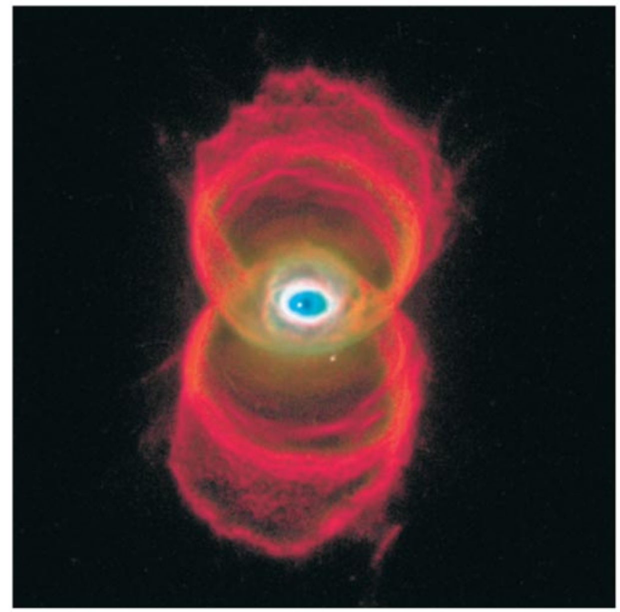


NOTHING TO DO WITH PLANETS!

Post main sequence evolution: Low Mass

Planetary nebulae: The *act of dying* of low mass stars
(not really related to planets)

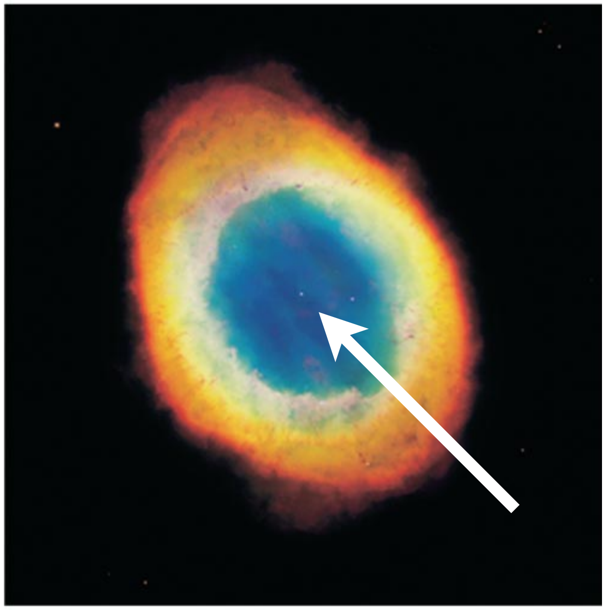


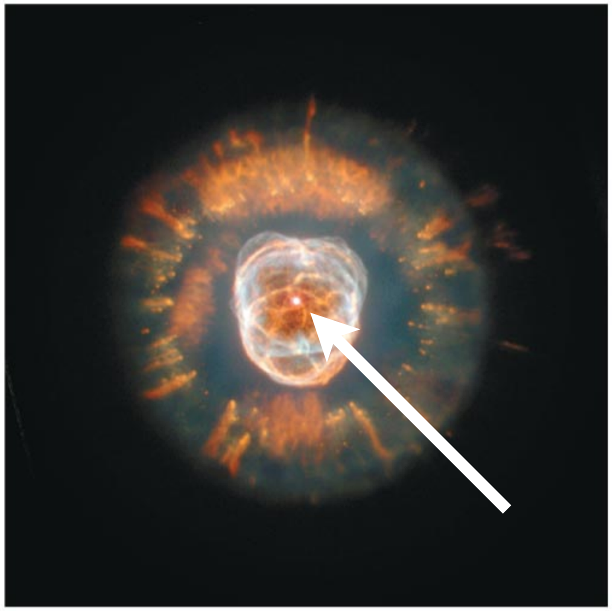


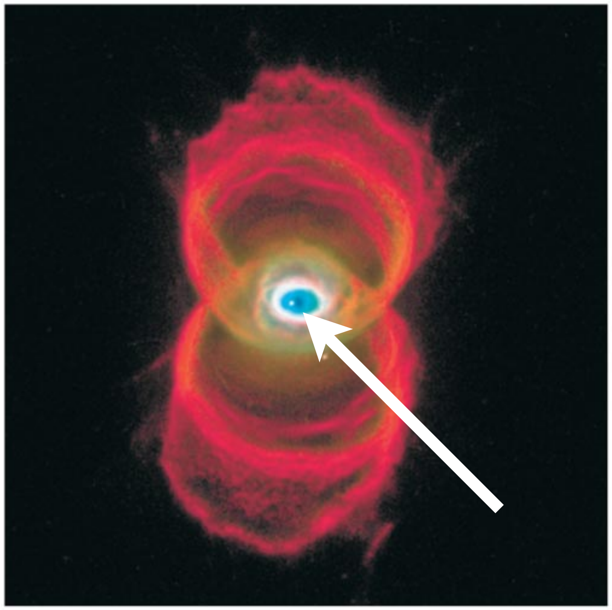
Post main sequence evolution: Low Mass

White Dwarf: The *corpse* left behind

- Supported by electron degeneracy pressure
- Inert Helium or Carbon core
- Cooling slowly, losing heat (energy) over time as it radiates it away
- If the planetary nebula is gone, just looks like a white pale dot.







Post main sequence evolution: Low Mass

White Dwarf: The *corpse* left behind