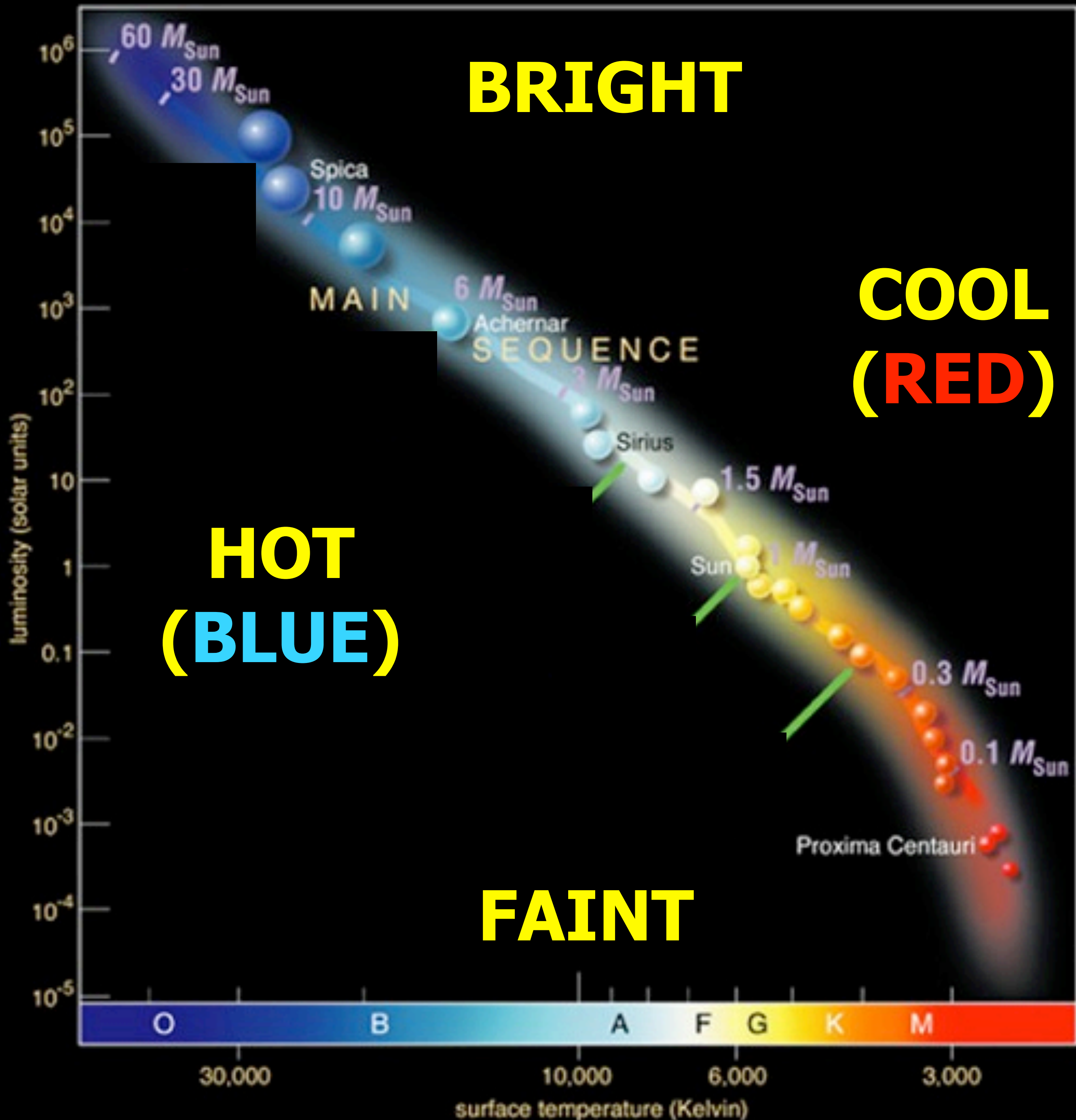
Astr 102

Lec 8: Stellar Birth and Evolution

- What is main sequence and what determines the position of a star on it?
- Why smaller stars live longer than bigger stars?
- How are stars born?
- What are non-main-sequence stars?

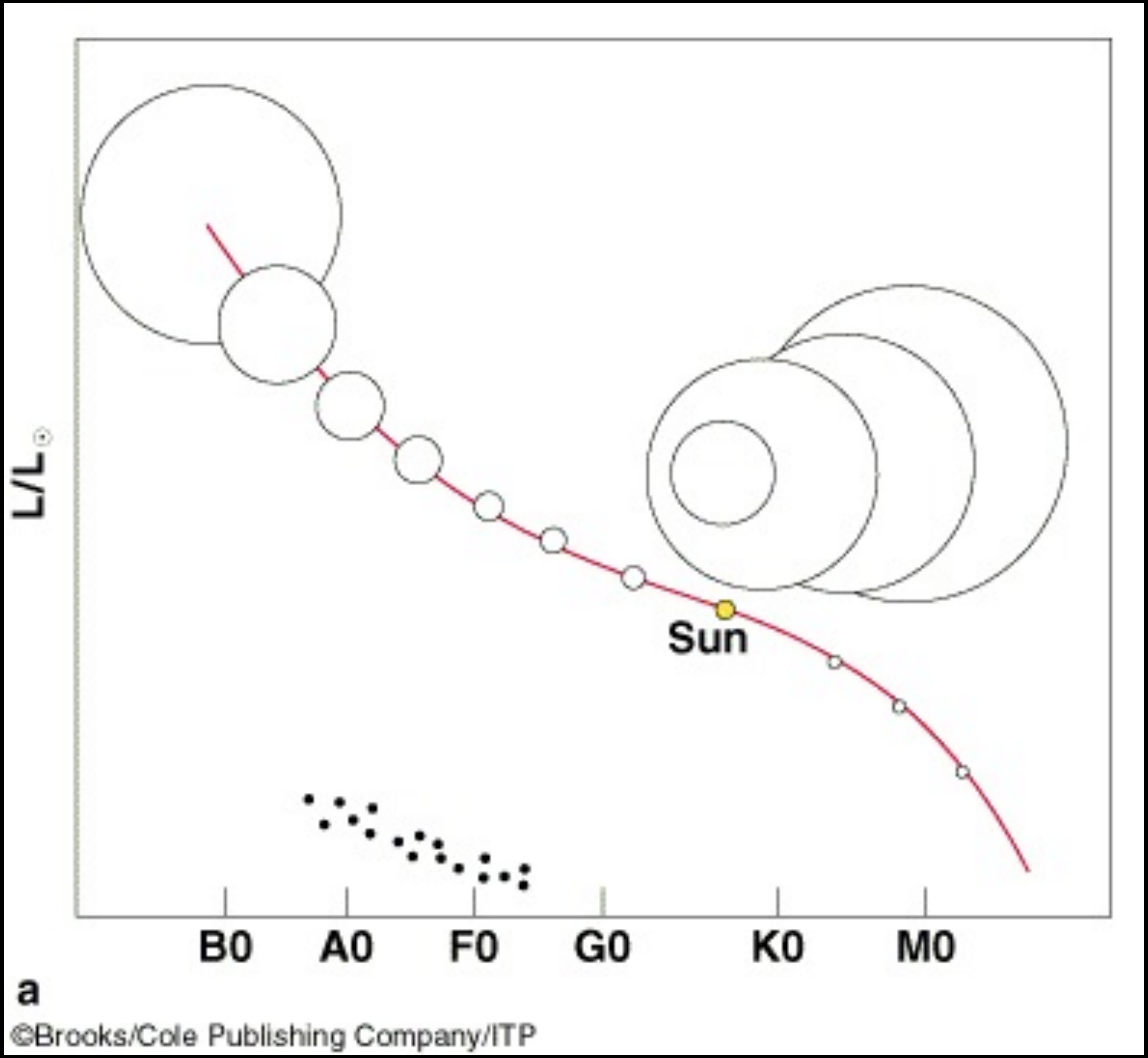
The Main Sequence



Stars can not have an arbitrary combination of luminosity and temperature (or radius)

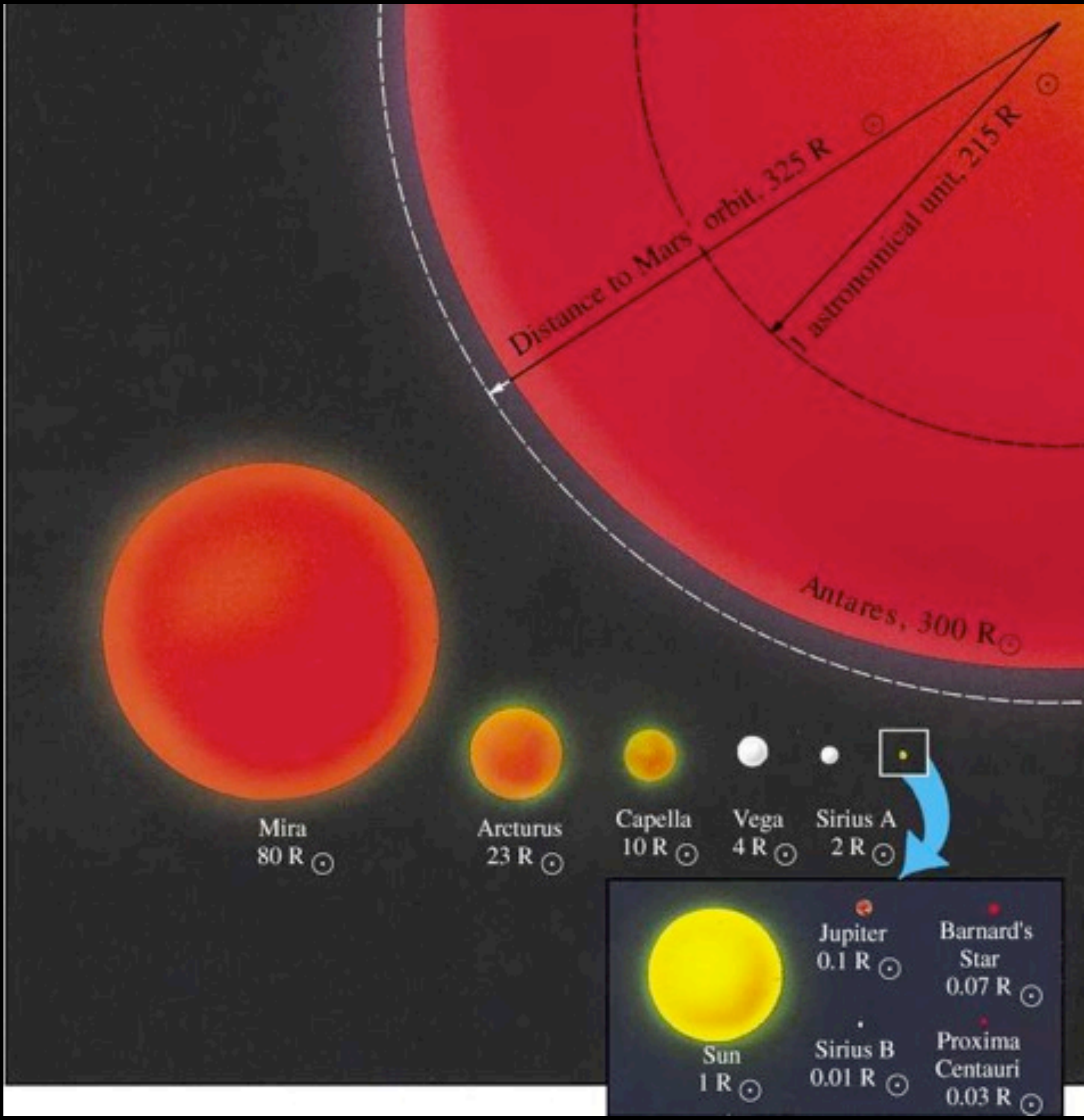
Some physical laws must be responsible for this sequence!

Stellar sizes on the HR diagram

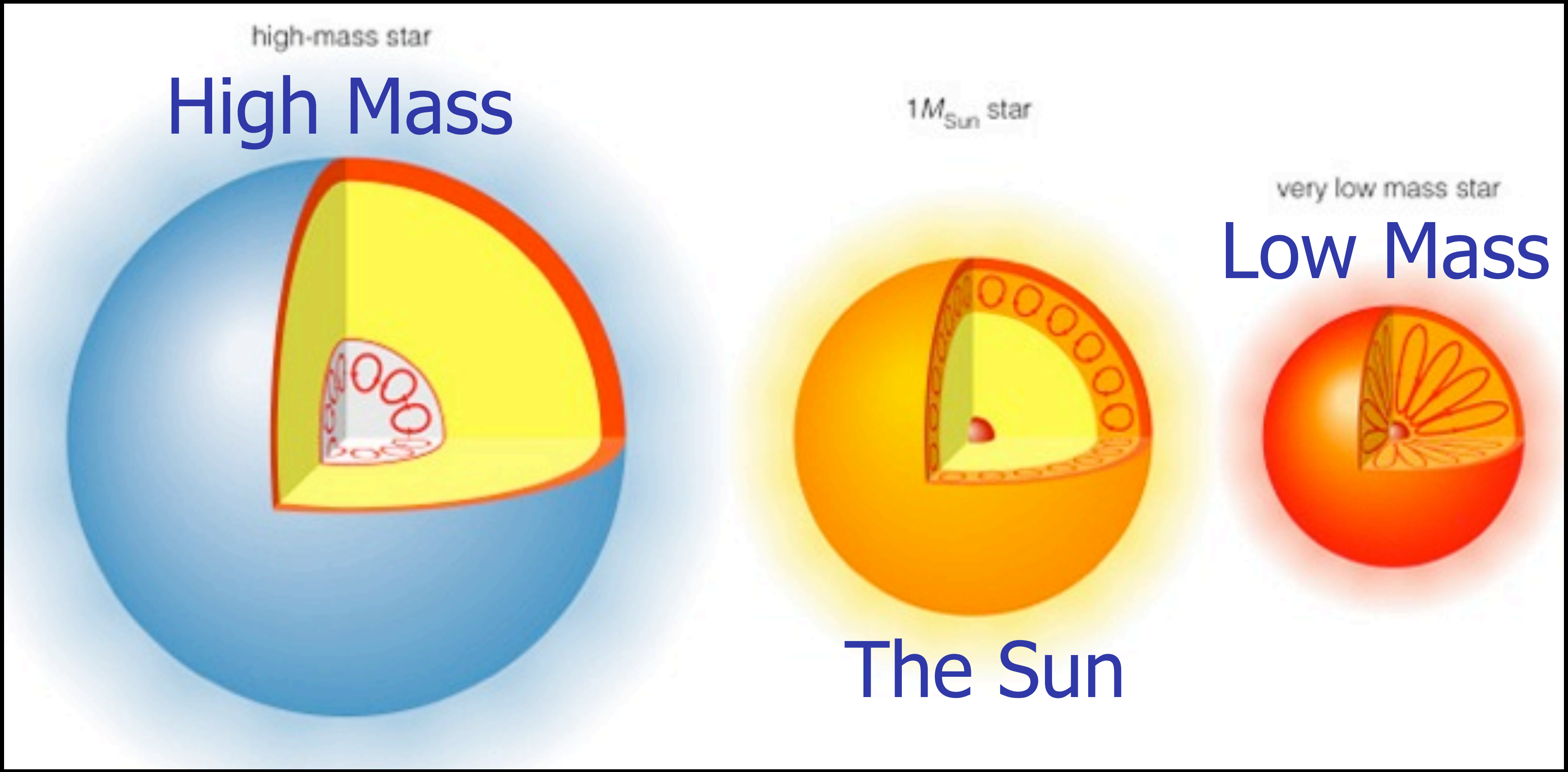


The range of sizes is huge.

Not so much along the main sequence, but non-Hydrogen burning stars get very, very big, or very, very small.

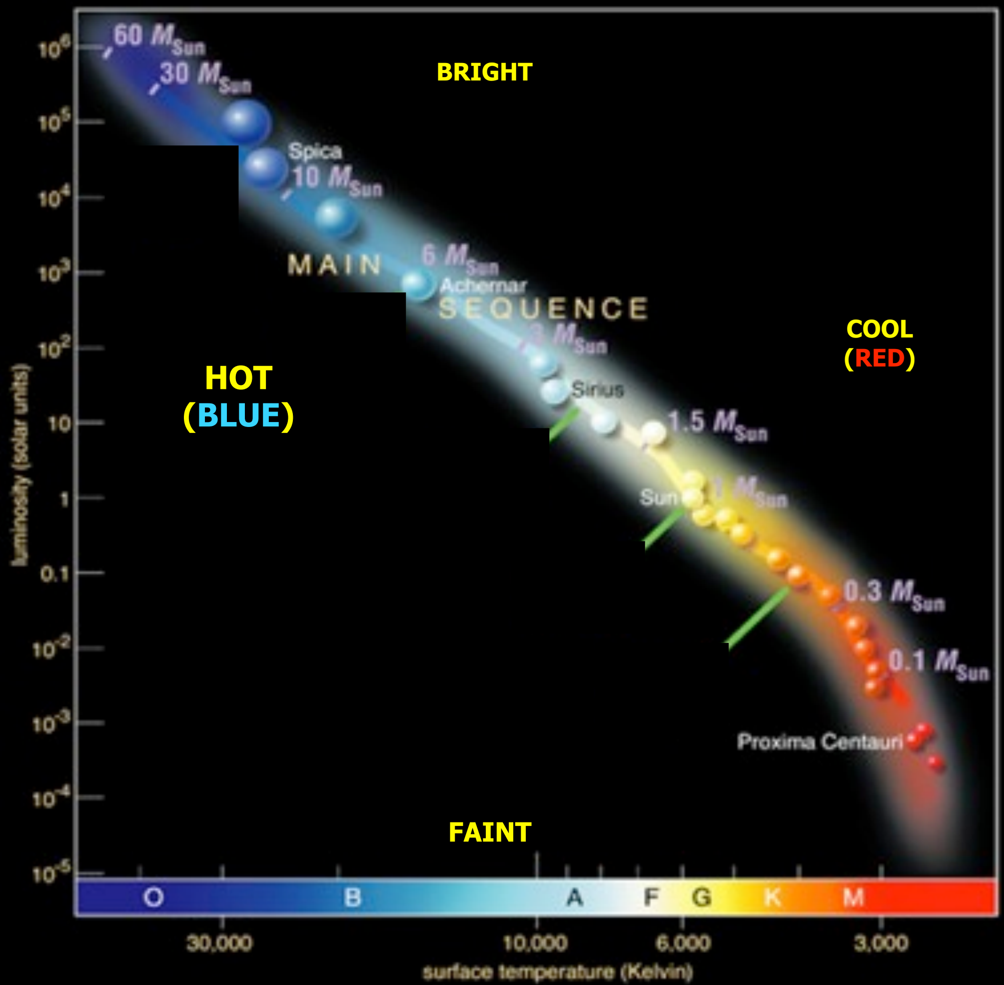


Stars of different masses have different internal structures.



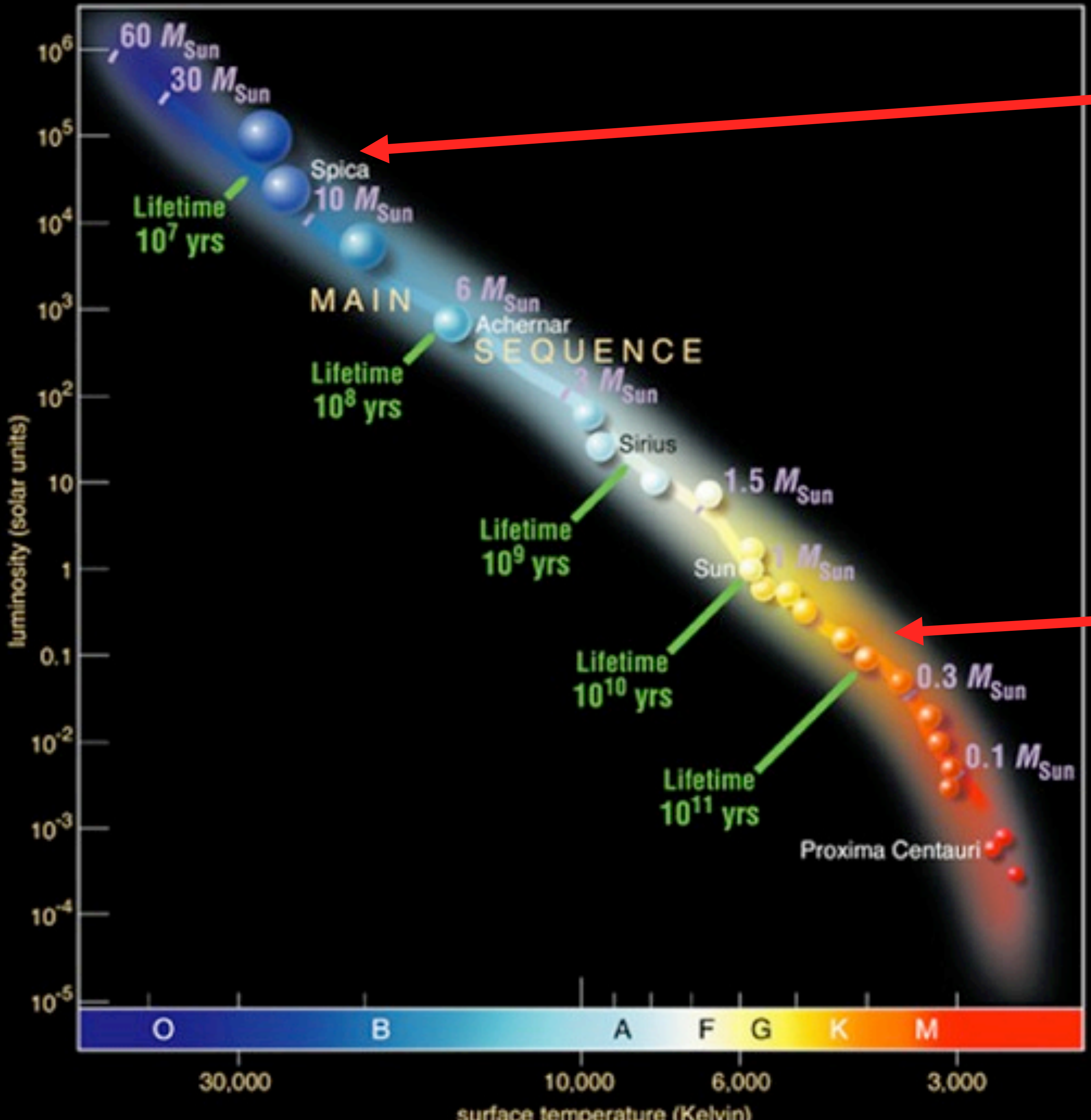
In fact, many other things are different too!

Massive stars are…



- Brighter
- Bigger
- Hotter
- Shorter lived

(…on the main sequence)



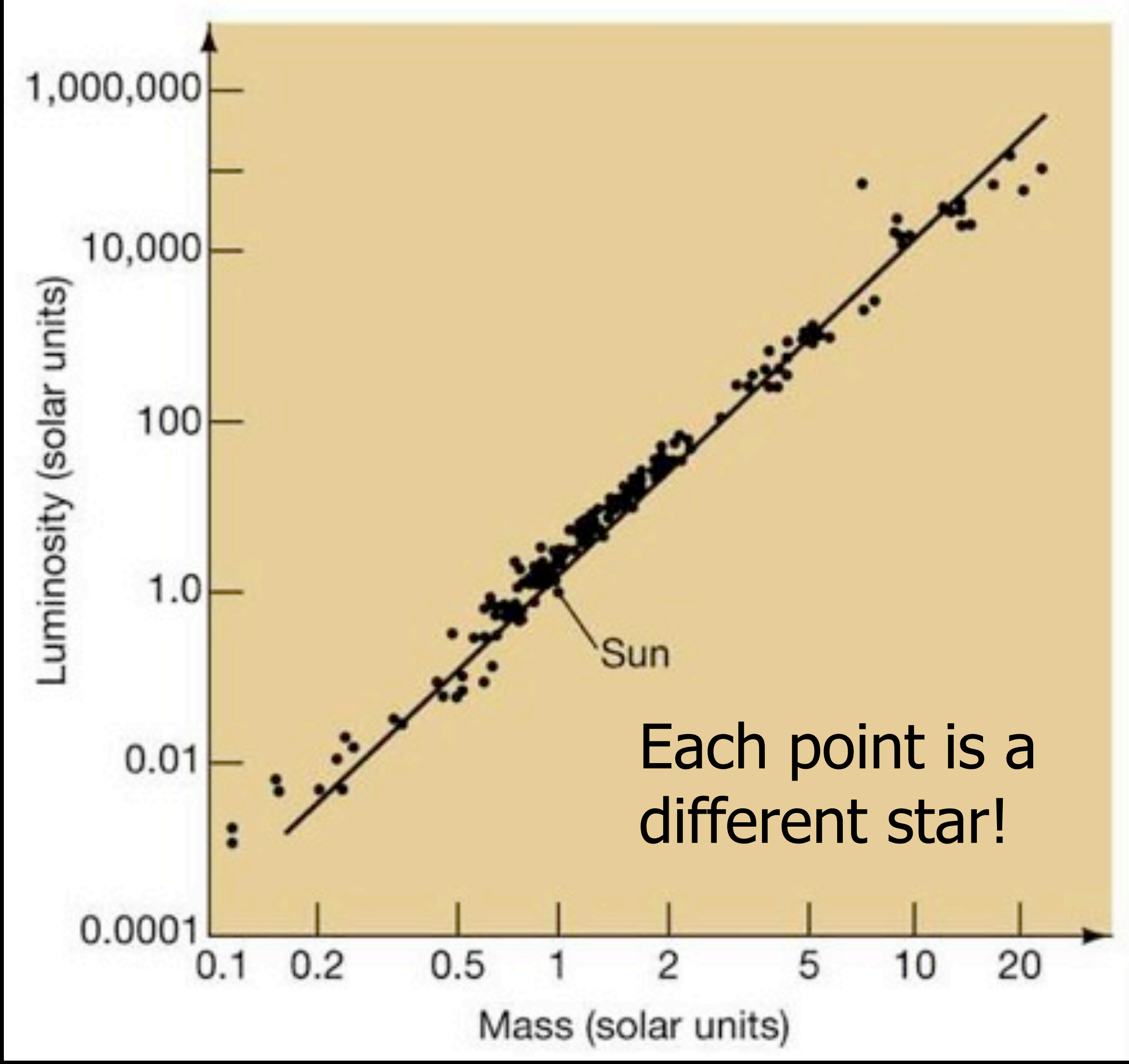
Die instantly
[$<10^7$ yrs]

Live Forever
[$>10^{10}$ yrs]

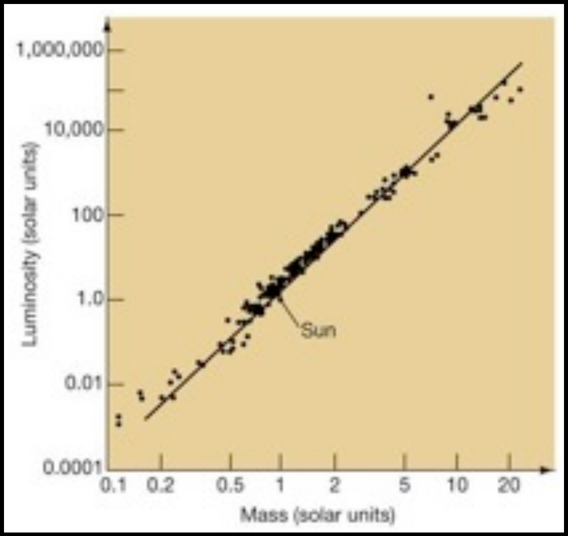
More Massive Star → Dramatically More Rapid Energy Output

$$L \propto M^{3.5}$$

If **mass** goes up by a factor of **10**, **luminosity** goes up by nearly **10,000**!



Why?

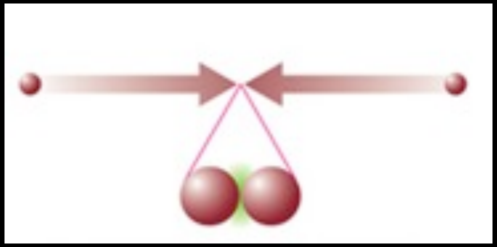


Rate of Fusion

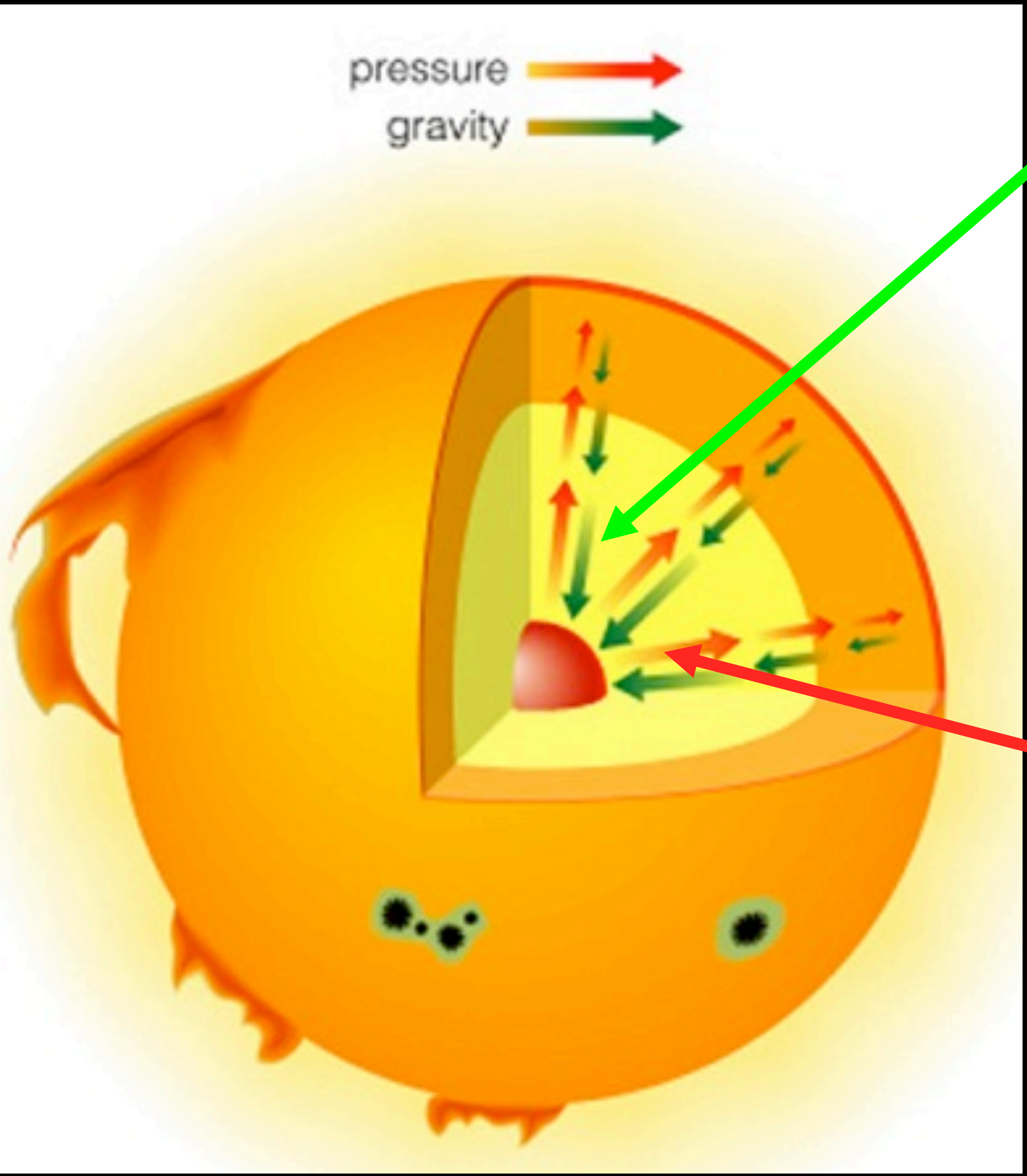
Depends on

Central Temperature & Density

Sets Luminosity!



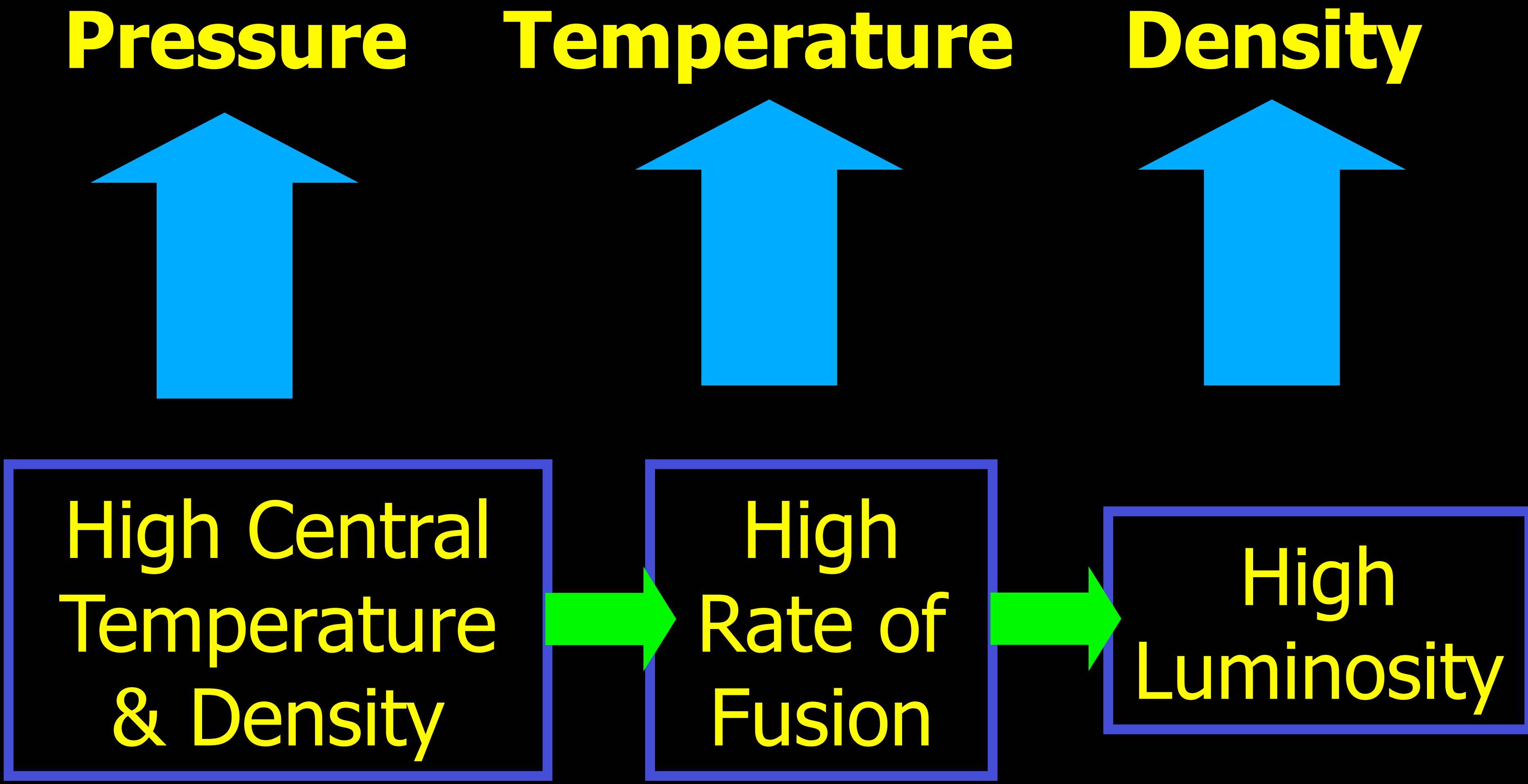
Massive stars have:



Larger gravitational forces…

…balanced by higher central pressures

High Mass = High **Central Pressure**



The Lifetime of a star is extremely sensitive to its mass.

Massive stars have more Hydrogen to burn

BUT

Massive stars burn their Hydrogen more quickly

The Lifetime of a star is extremely sensitive to its mass.

~ Amount of fuel

$$\text{Lifetime} \propto \frac{M}{L} \propto \frac{M}{M^{3.5}} \propto \frac{1}{M^{2.5}}$$

~ Rate at which fuel is used up!

Live Fast, Die Young!

- Sun ($1M_\odot$, $1L_\odot$)

  → 10^{10} years to use up its Hydrogen.

  Low mass stars live FOREVER!!!

- Heavy Star ($10M_\odot$, $\sim 10{,}000L_\odot$)

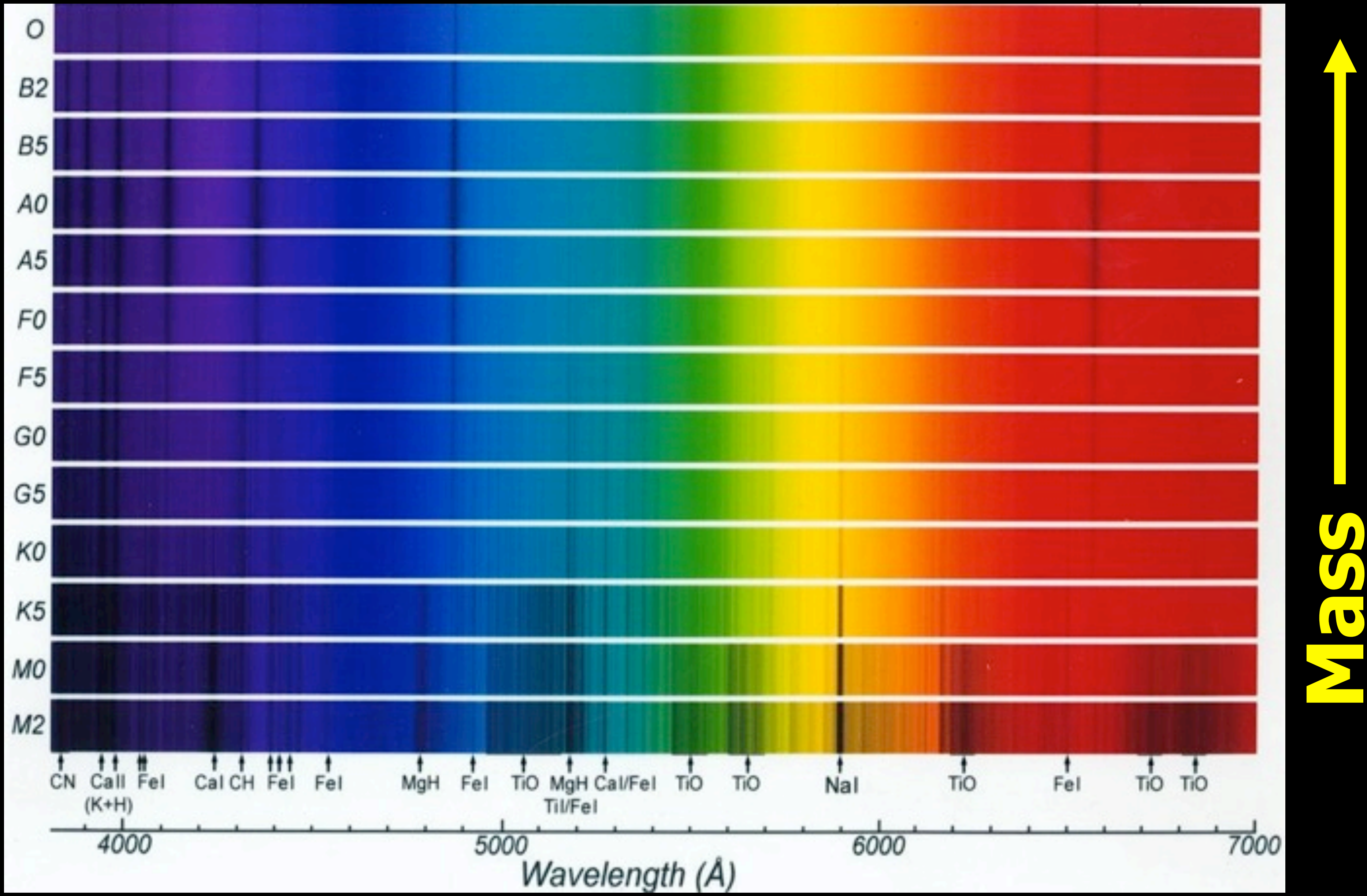
  → 10^7 years

High mass stars die IMMEDIATELY!

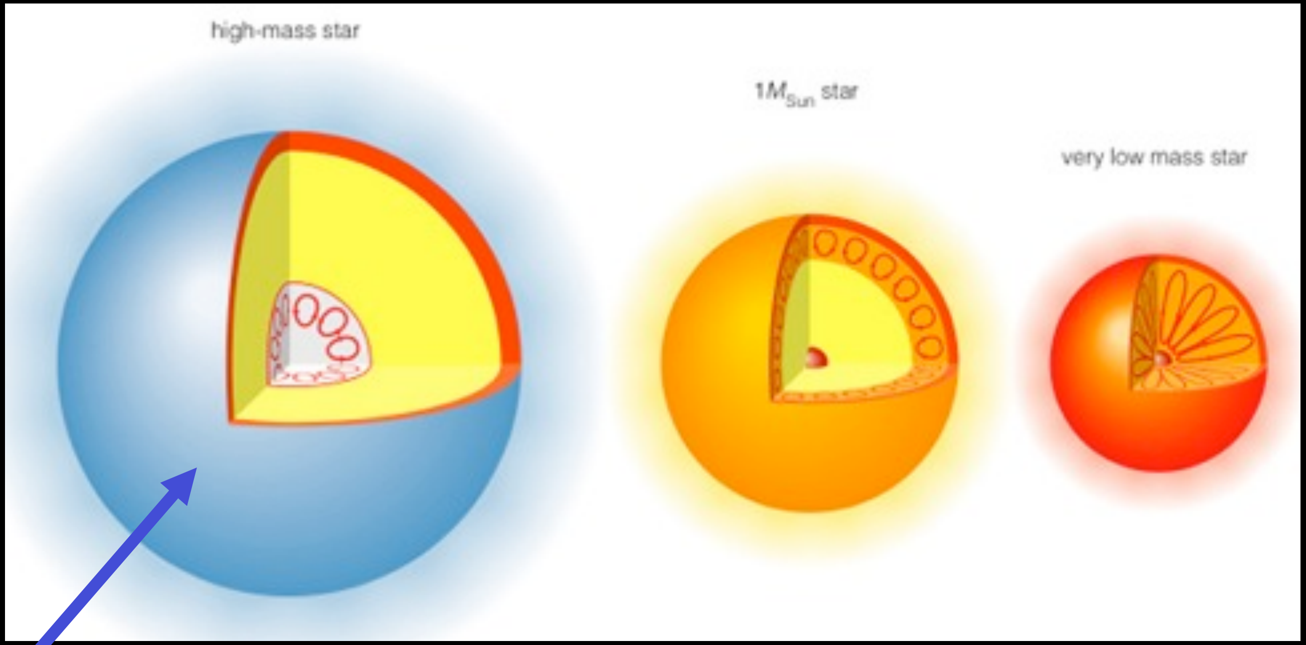
- Low mass stars are DIM and RED!
  - Red & Cool → M Stars, K Stars
- Massive stars are LUMINOUS and BLUE!
  - Blue & Hot → O Stars, B Stars, A Stars

(F & G stars like the Sun are in between)

Temperature sequence is a mass sequence!



THE MAIN POINT: The mass of a normal star sets all of its properties!!



Brighter, Bluer, Bigger

Big Implications!

- Stars do not live forever!

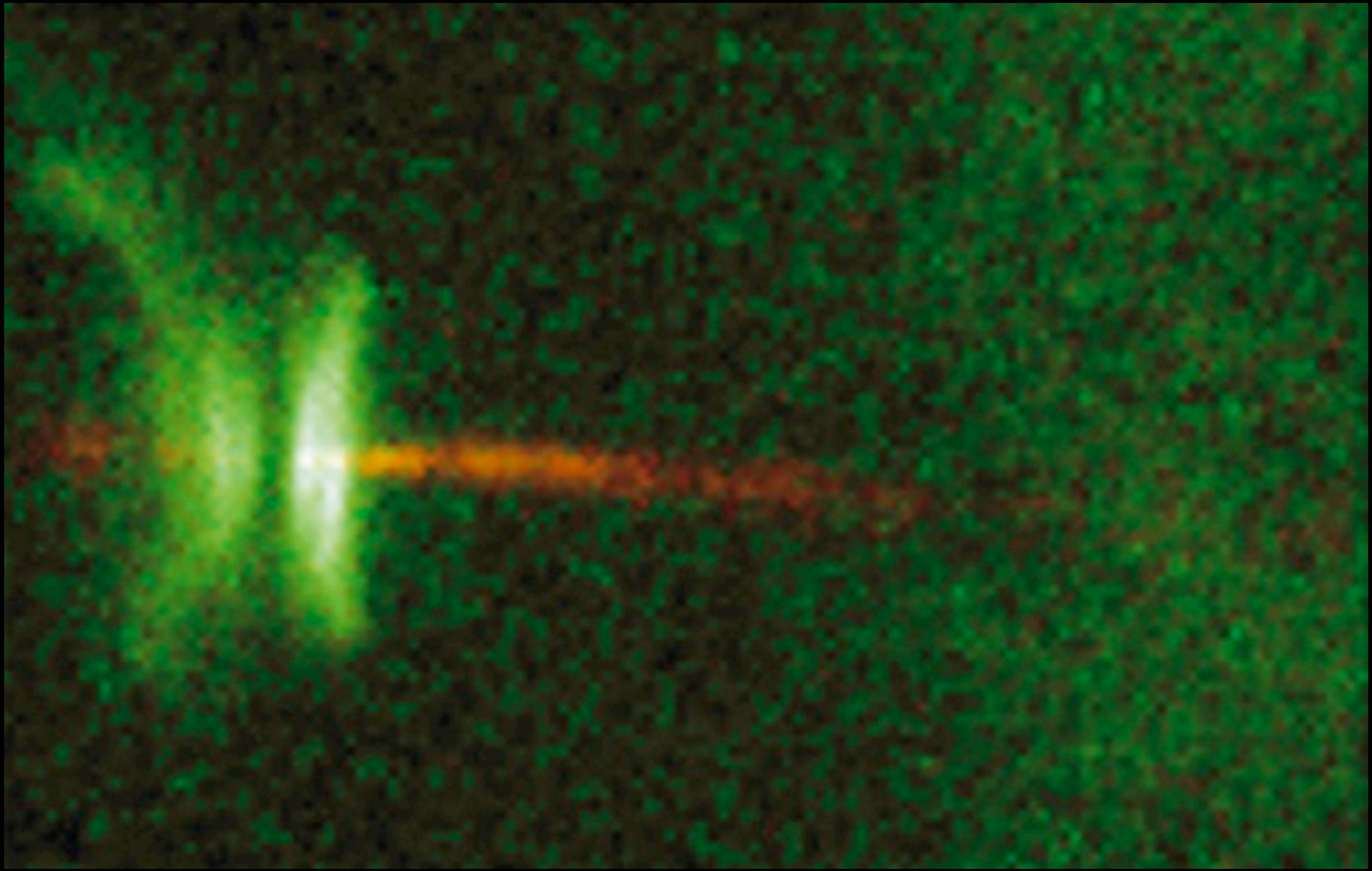
If you see a high mass star, it's not going to be around for long!

- Stars are continually created!

We see many high mass stars! Since they don't live forever, they must have been born in the last few million years!

Stars form from the gravitational collapse of dense gas

We actually see these “protostars”!



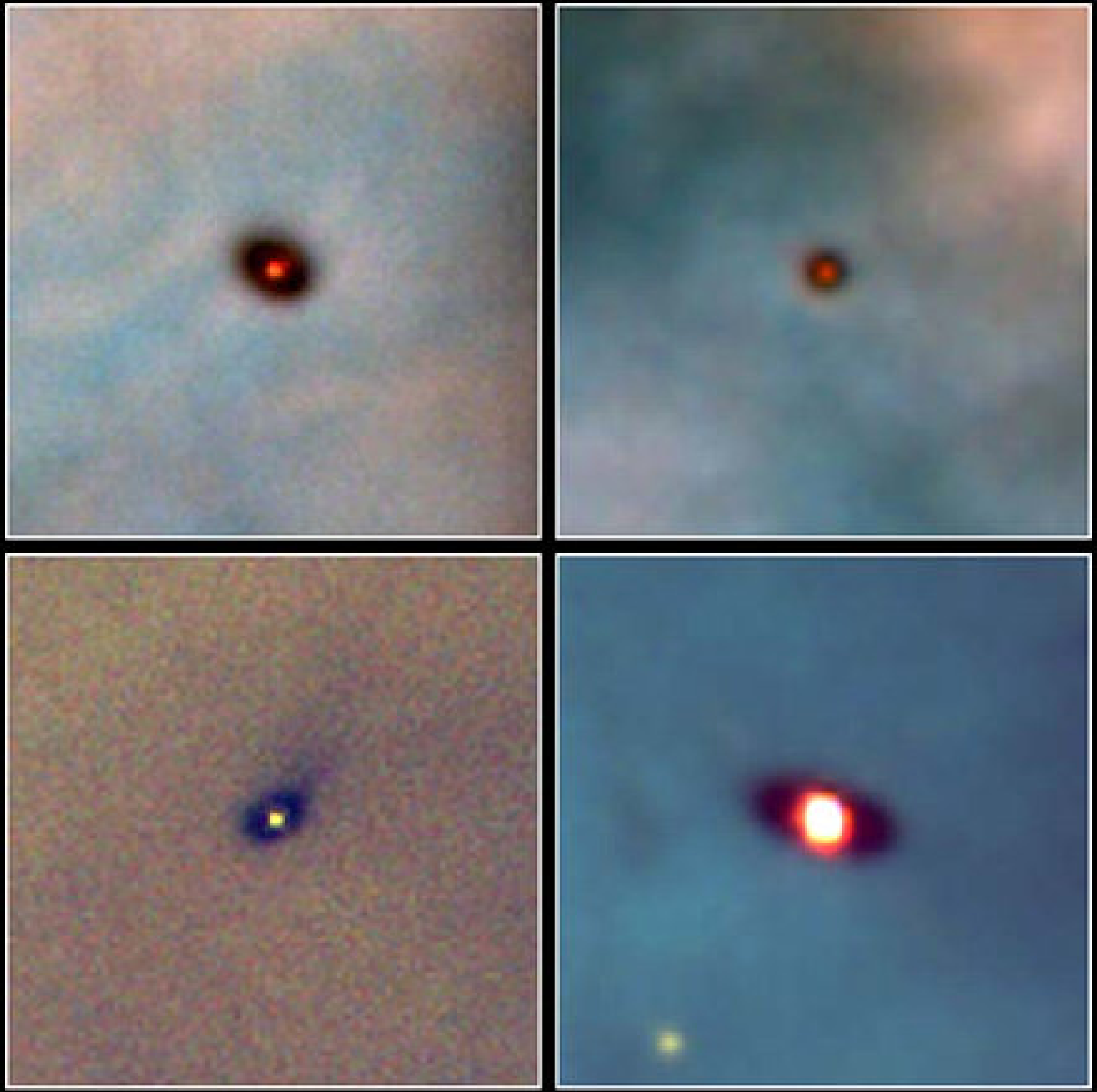
- Why the jet? We don’t exactly know!

We can also see the disks!

“Protoplanetary” disks

Seen in silhouette!

These may eventually form planetary systems like our own!



Stars form from the collapse of dense gas within galaxies.

Gas in galaxies = "Interstellar Medium"

This gas has a range of densities and temperatures:

Cold & Dense = Molecular! (H_2)

Warm = Atomic! (HI)

Hot & Diffuse = Ionized! (HII)

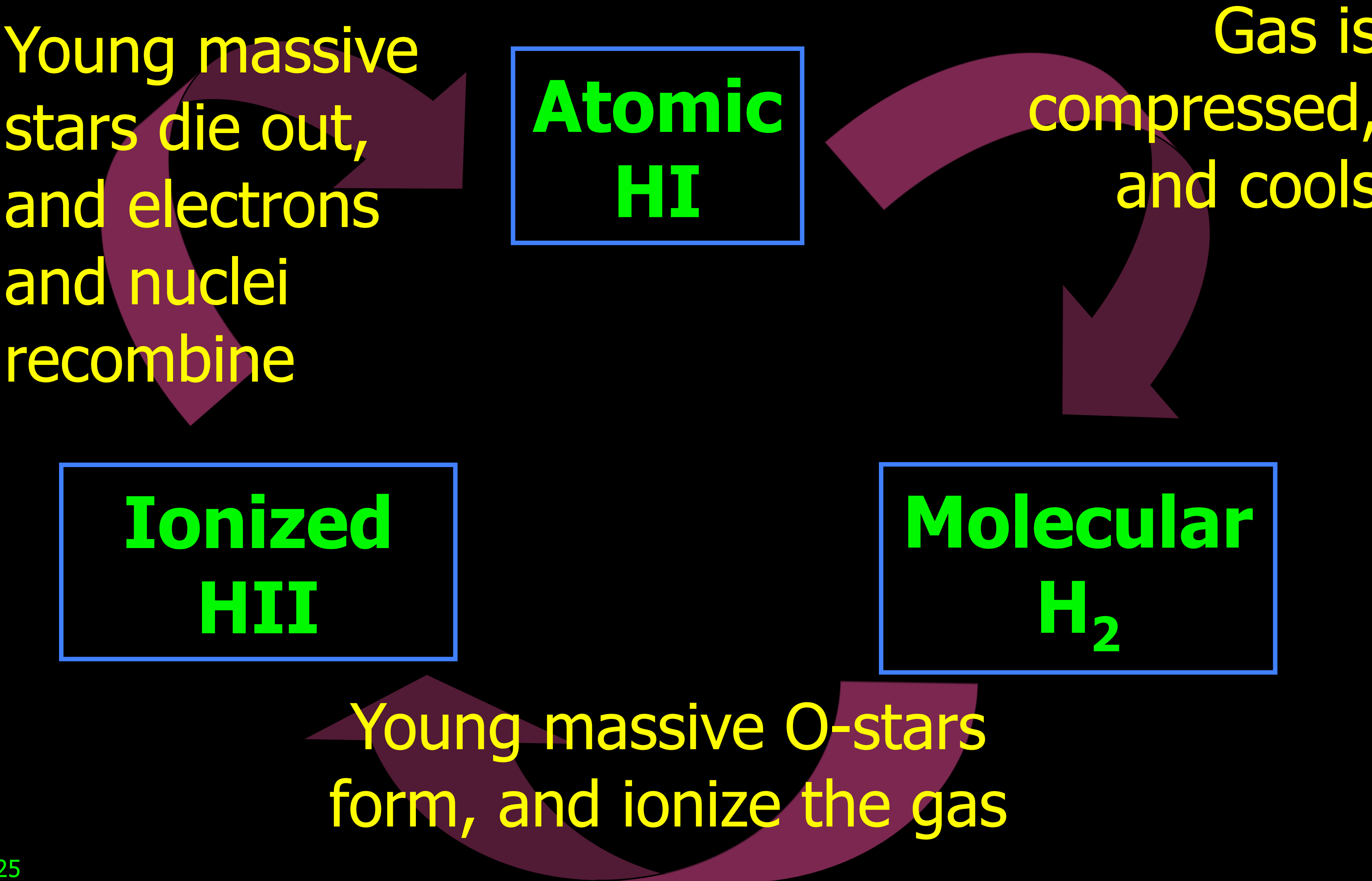
Stars form from the coldest densest gas → **Molecular**!

Stars, gas, and dust are tightly coupled!

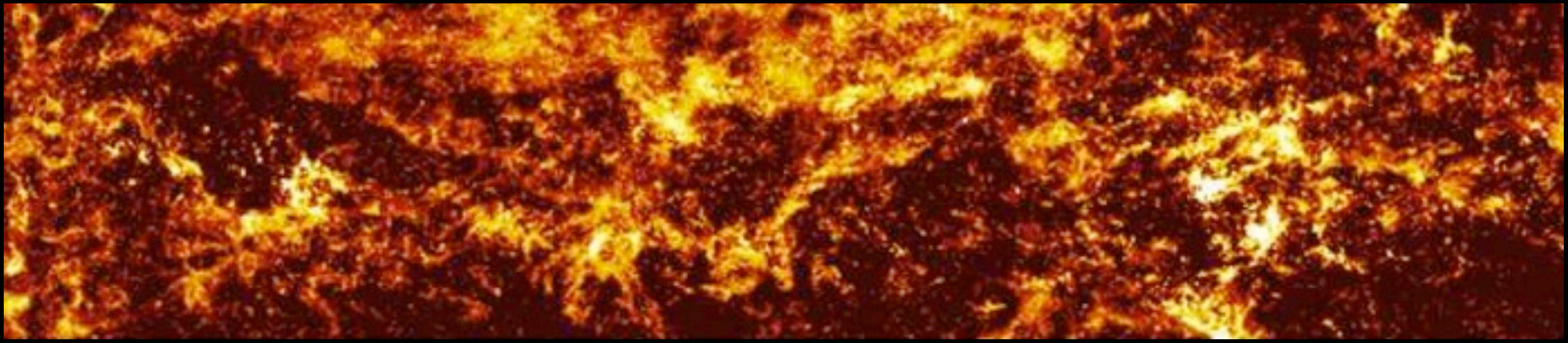
1. Stars form from cool gas…
2. Evolving stars release gas, and heat the surrounding gas.
3. Gas cools.
4. Back to Step 1.

Gas cycles between different "phases"…

How are the three phases of gas inter-related?



Molecular gas in the Milky Way…



(View of the outskirts, away from the center)

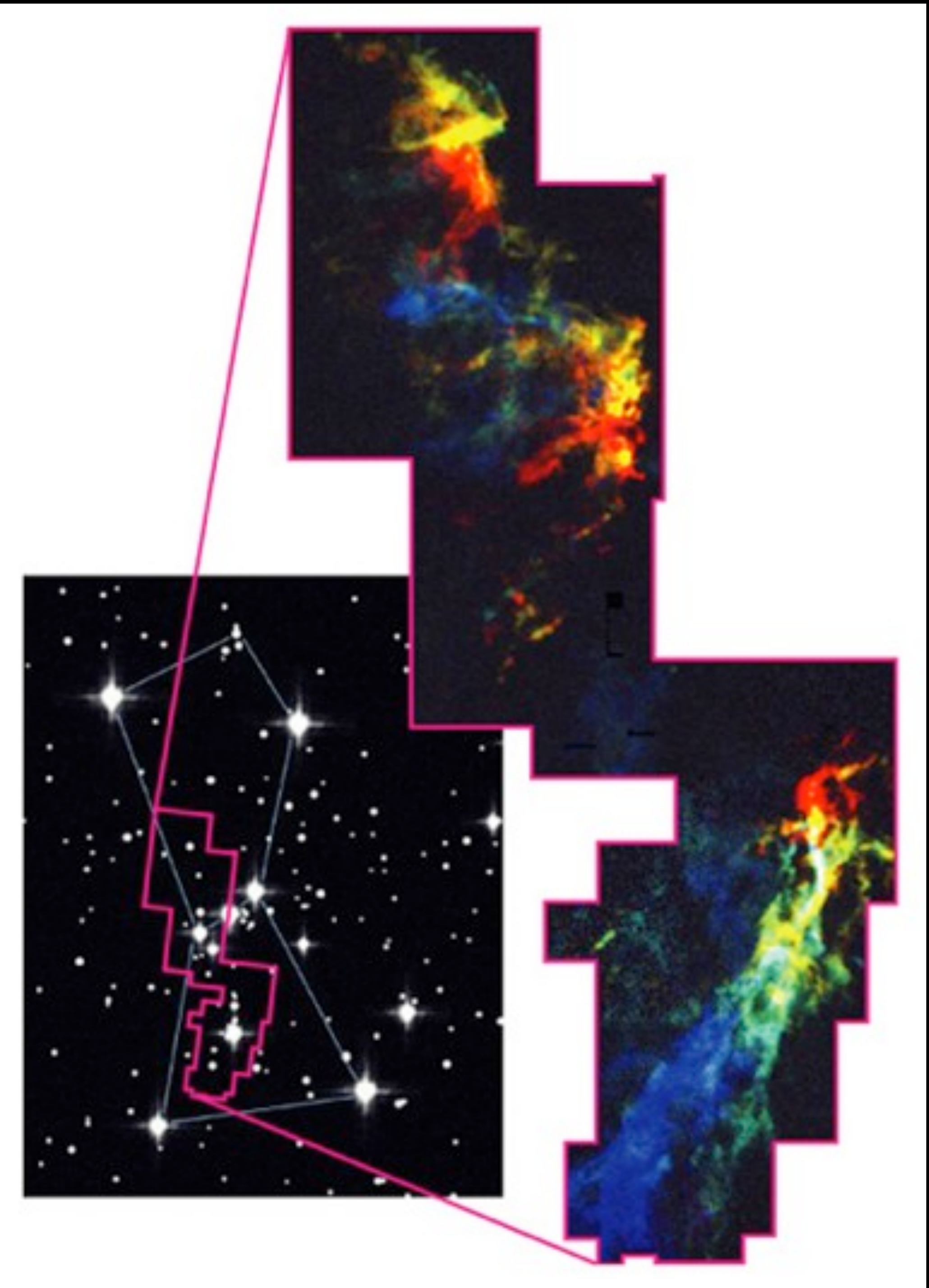
Clumpy!!! “Molecular Clouds”

This is why stars form in groups!

The Orion Nebula

Many new stars are forming in this dusty molecular cloud

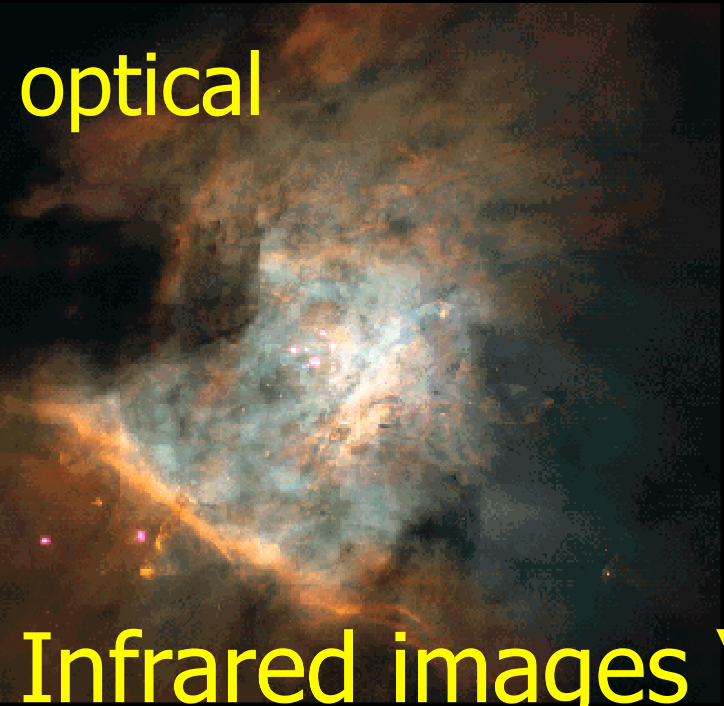
Molecular Clouds in Orion.



False color image is color coded by velocity! (red=receding, blue=approaching).

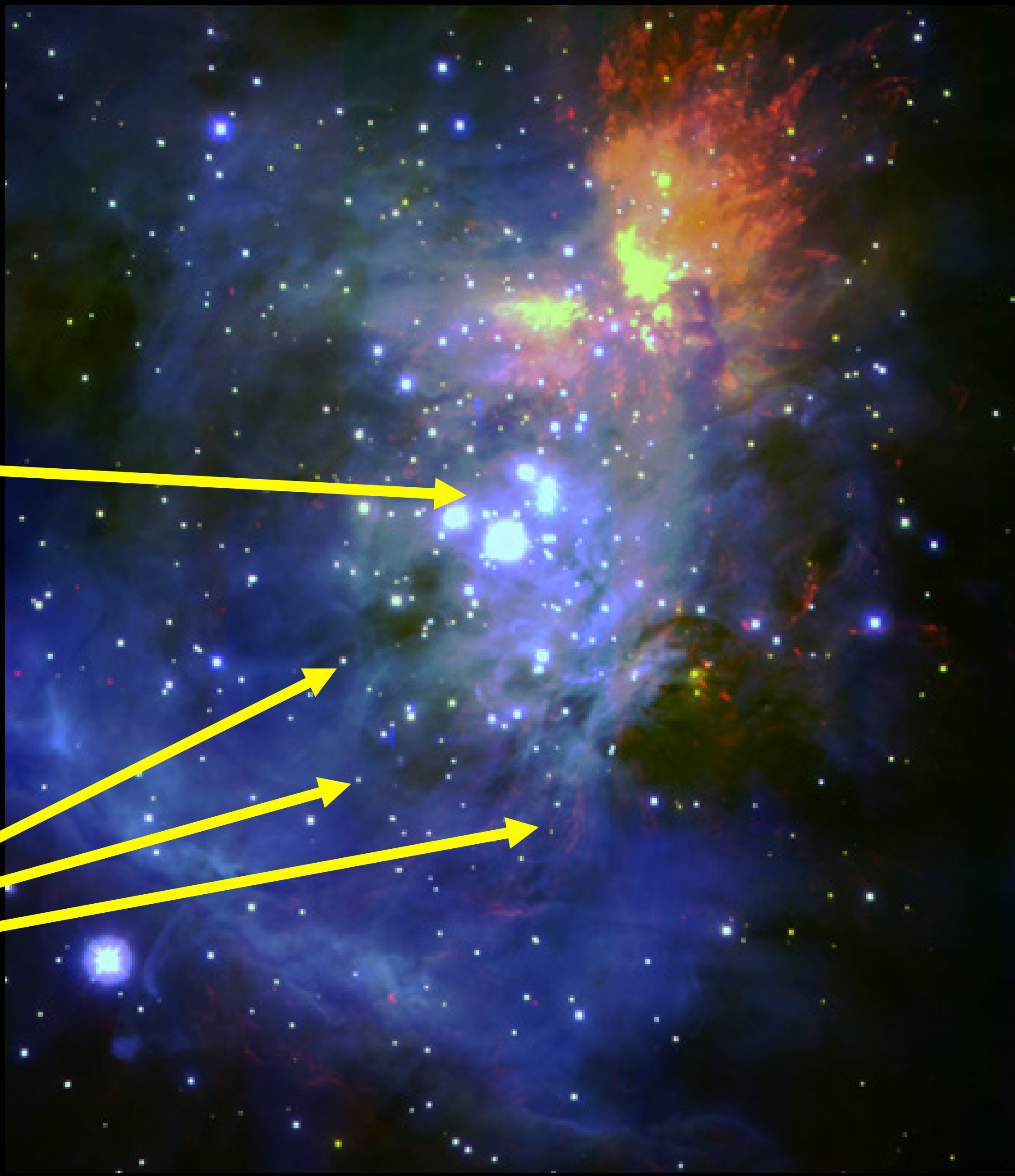
Cigarette smoke

The Orion Nebula in



Infrared images "see" through the surrounding dust of the molecular cloud, revealing newly formed stars.

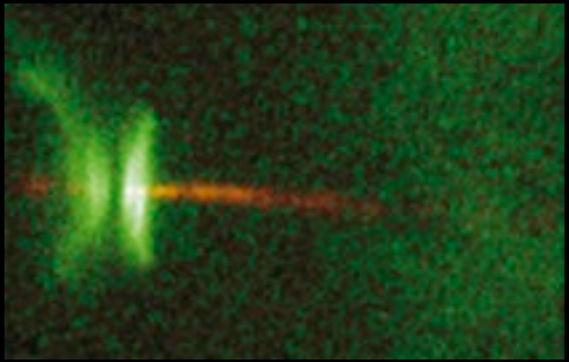
The Initial Mass Function in action



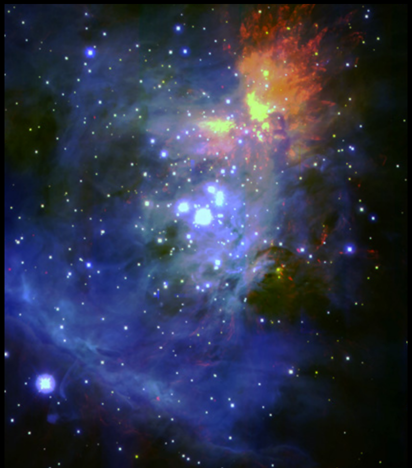
A few luminous high mass main sequence stars

Lots and lots of fainter low mass main sequence stars

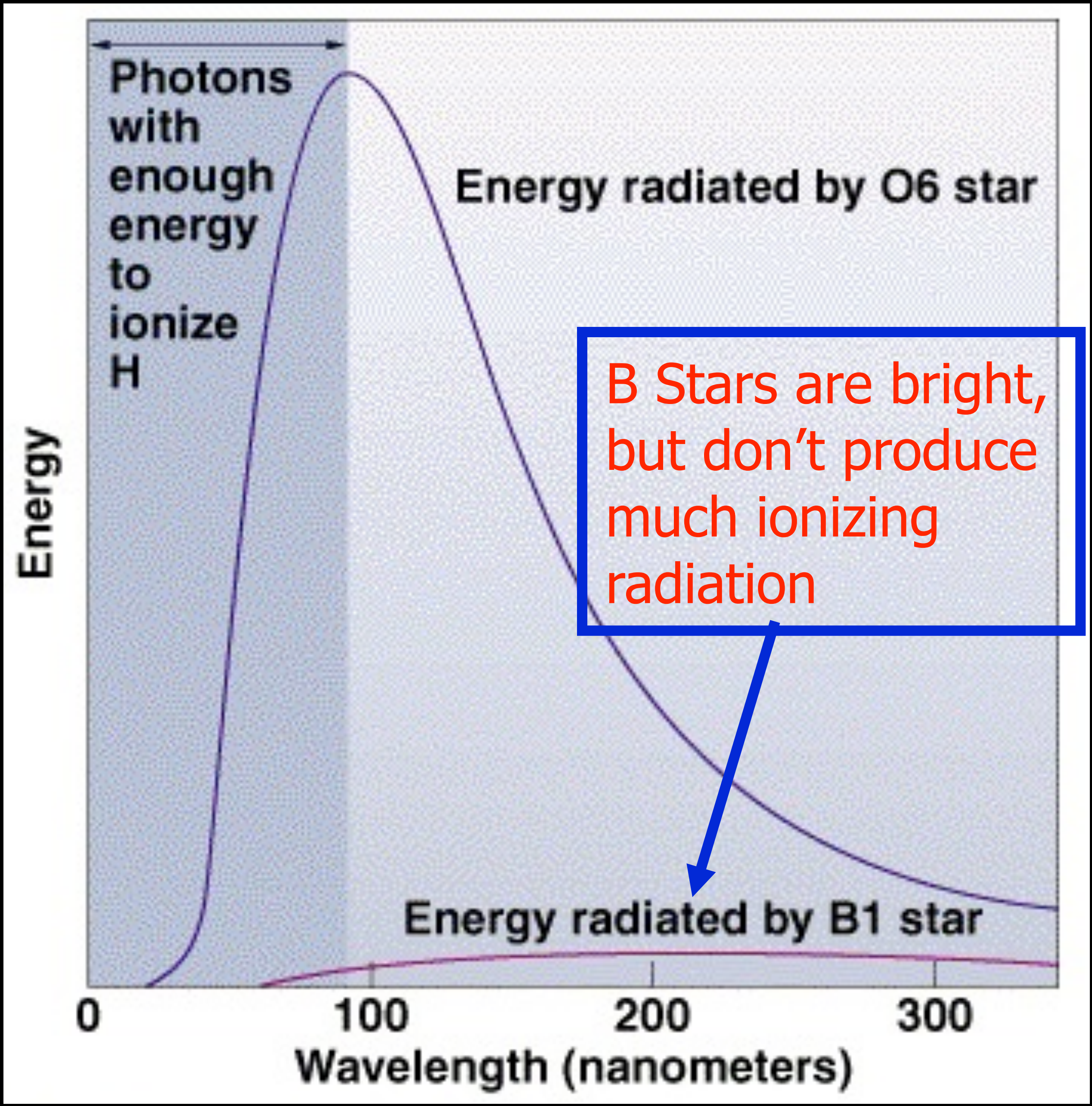
Star formation is very disruptive to the molecular cloud!



- Winds from jets!
- New stars = lots of **light**
- Young stars = lots of very **blue** O and B stars

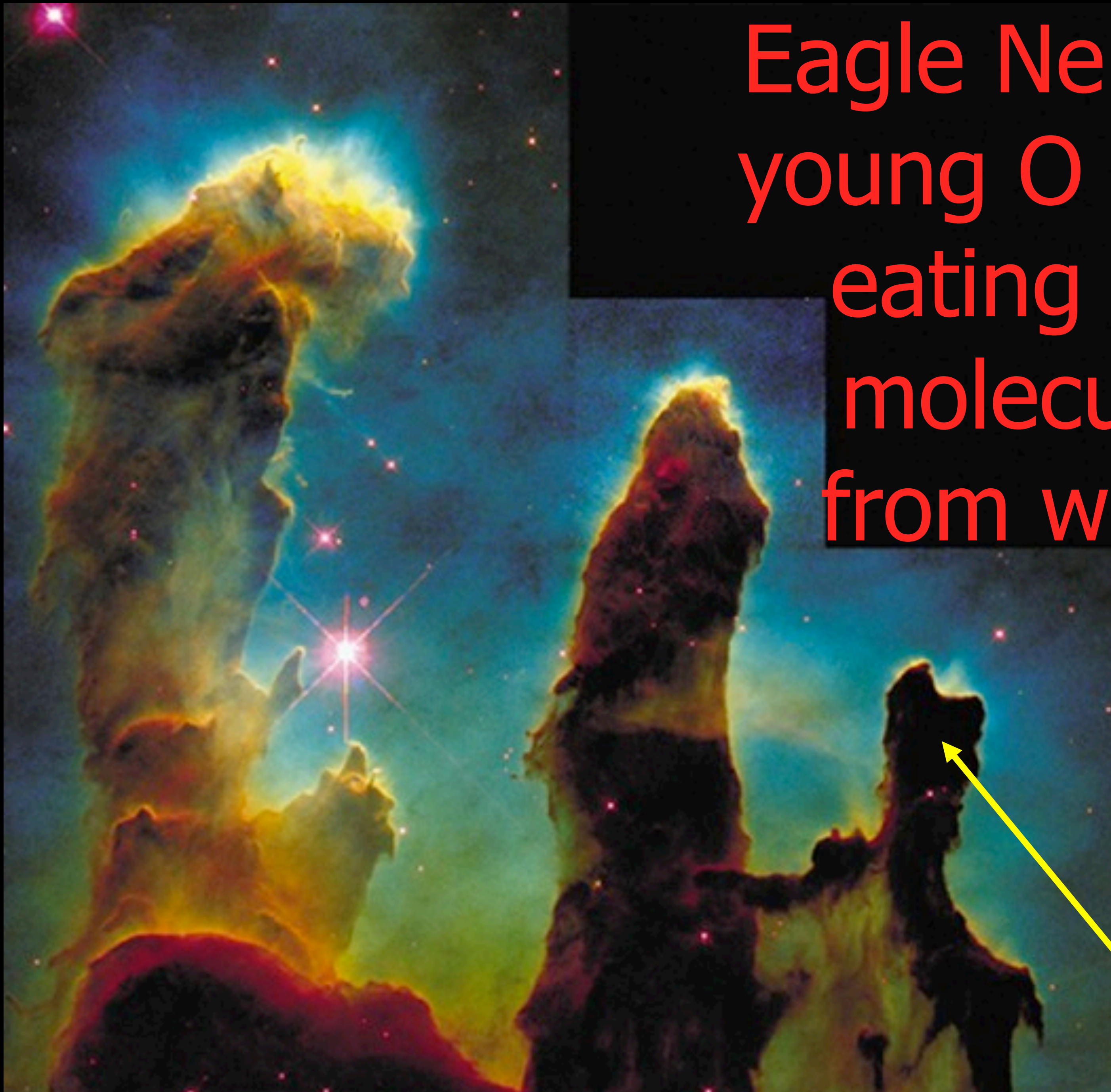


O Stars are bad!



B Stars are bright, but don't produce much ionizing radiation

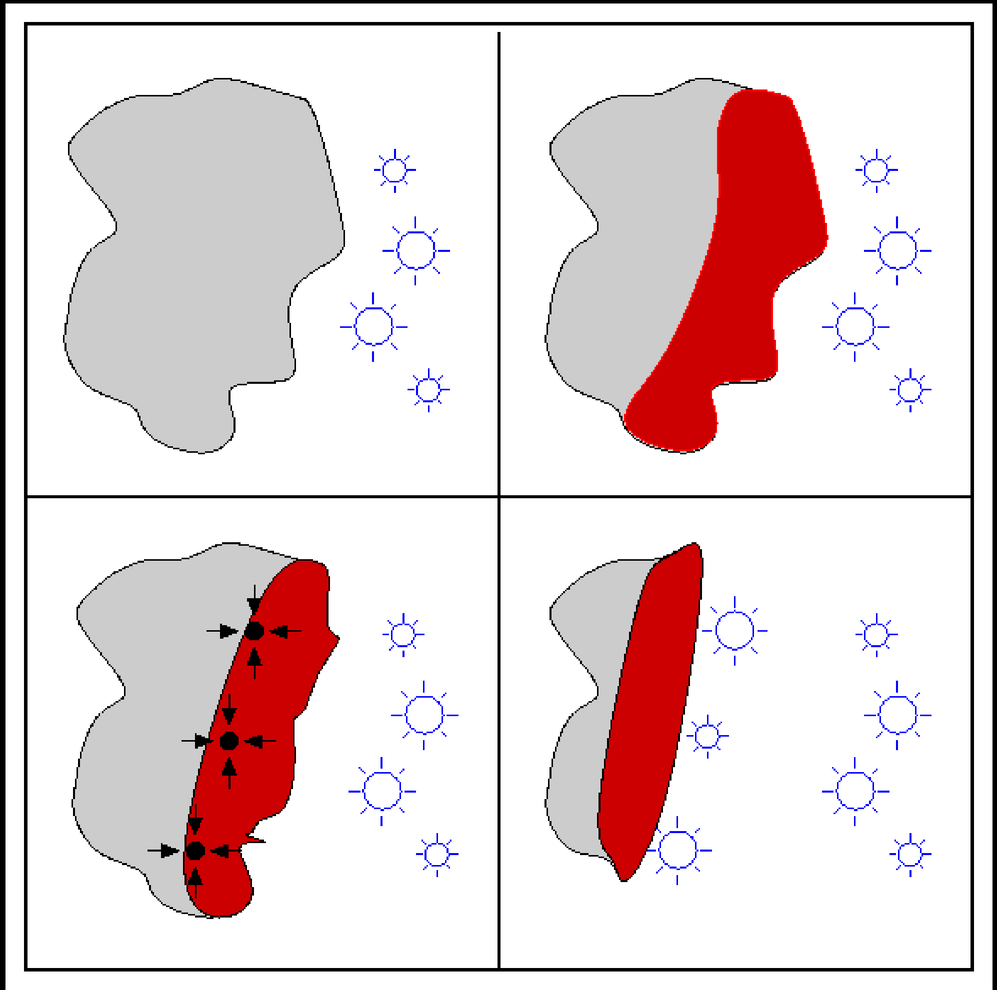
Eagle Nebula: Hot young O & B stars eating away the molecular cloud from which they formed!



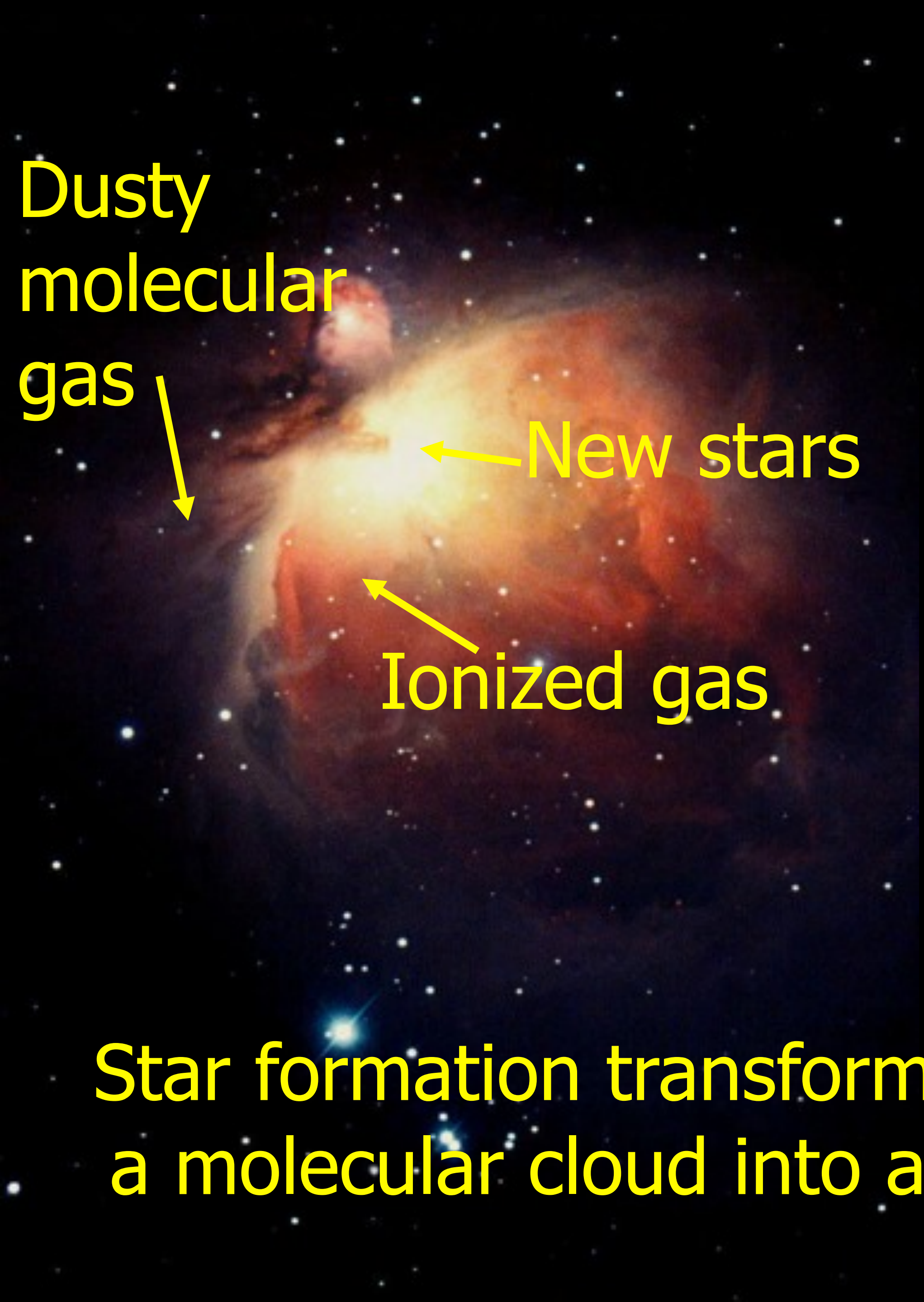
Gas is still molecular in the columns…

Star formation can entirely destroy the molecular cloud

As more stars are born, the molecular gas disappears, leaving only ionized gas



The Orion Nebula



- Hot young O & B stars heat the surrounding gas, ionizing it.

$$H_2 \rightarrow HII$$

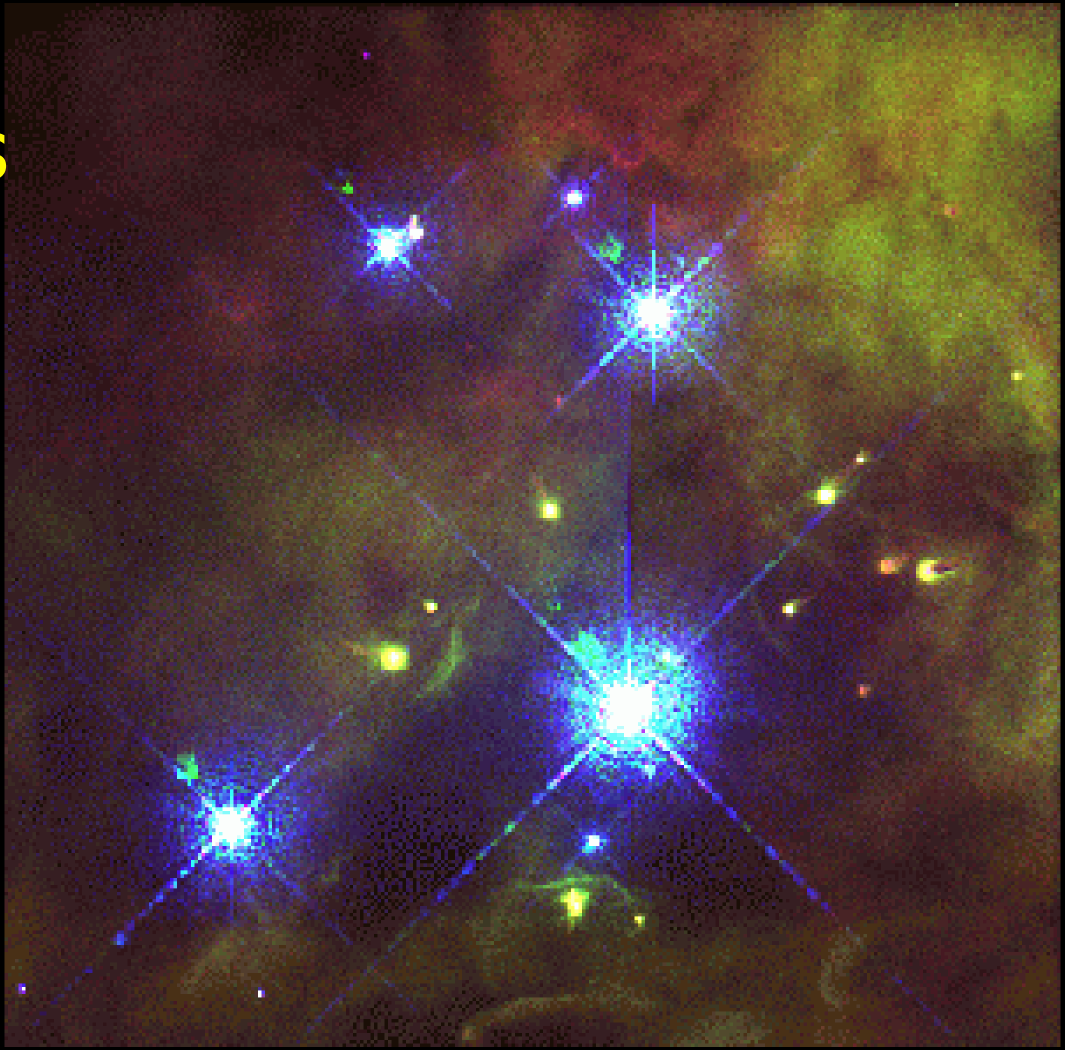
Molecular H → H_2; Ionized H → HII

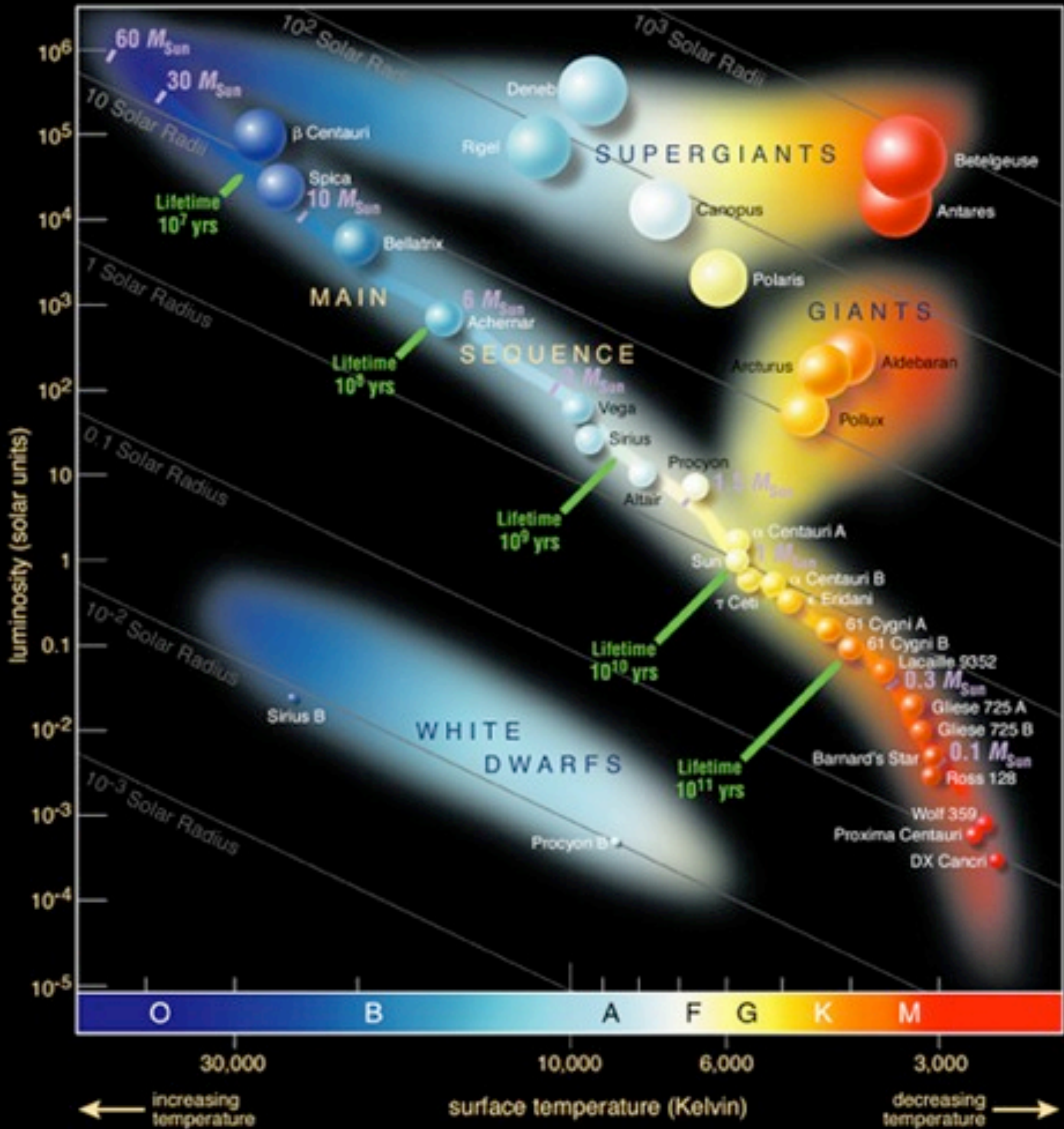
Star formation transforms a molecular cloud into an "HII Region"

New stars can also boil off some of the envelopes of lower mass

When high mass stars form, they can shut off the ability for any other stars to form.

This may be partially responsible for the exact form of the IMF





Upper Right:

“Red Giants”

“Supergiants”

Lower Left:

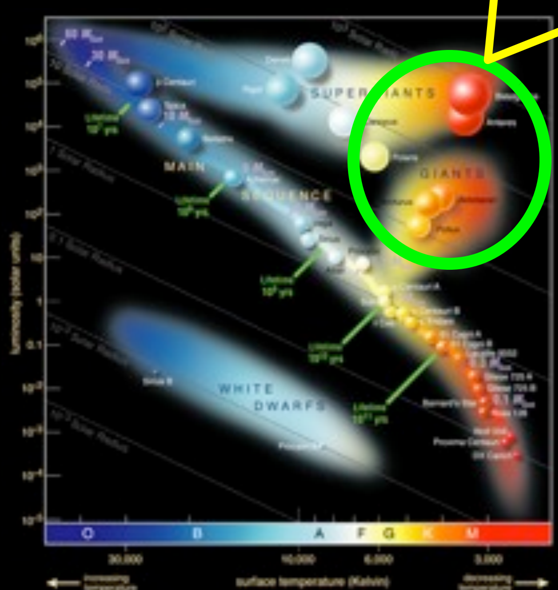
“White Dwarfs”

Hot.

Cool.

Cool, but big
→Luminous!

Hot, but tiny
→Faint.



"Red Giant"

Hot.

Cool.

Cool, but big
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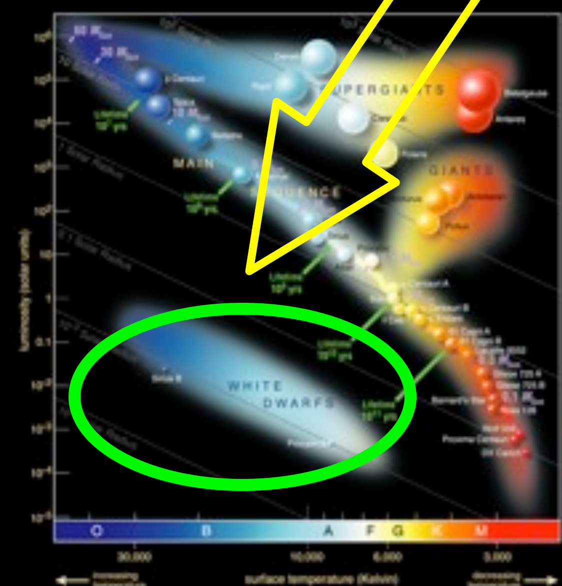
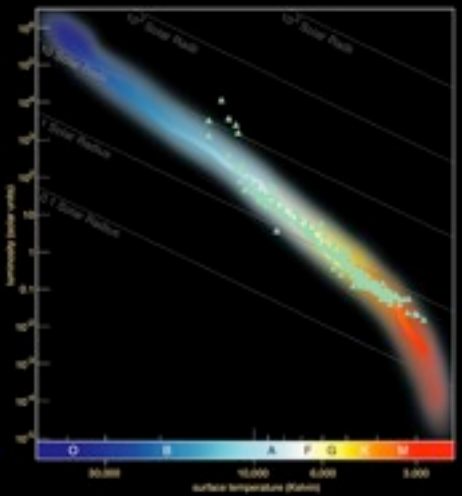
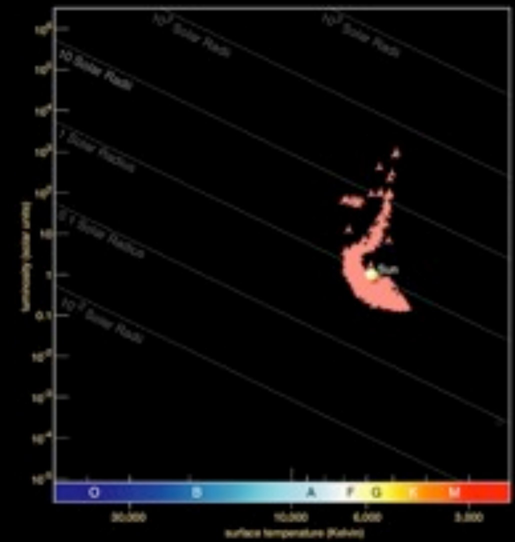


"White Dwarf"

The H-R diagram for a group of stars is not constant!





1. Massive stars use up the Hydrogen in their cores.
2. They evolve off the main sequence.
3. Evolving stars turn into red giants, red & blue supergiants, and white dwarfs.

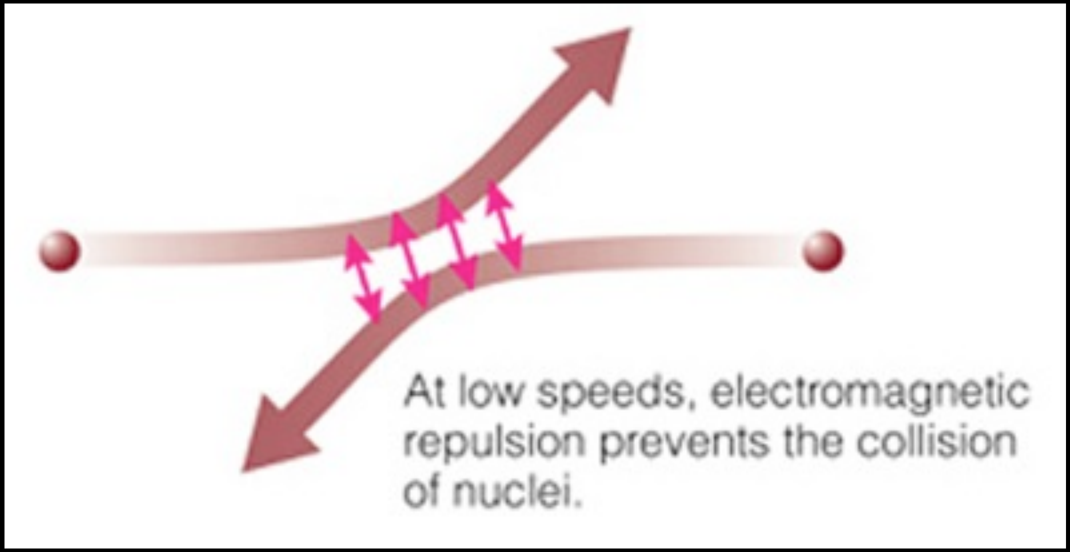
Life Rules for Stars:

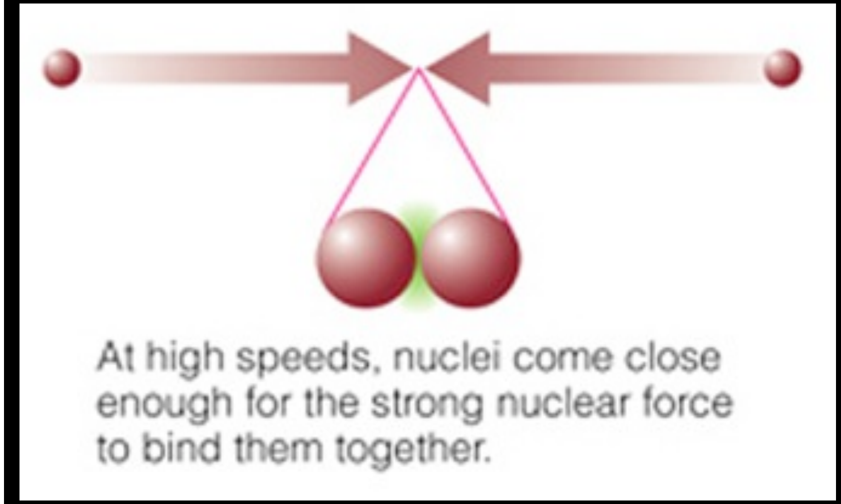
- When Stuff falls inwards, it heats up.

- When Stuff falls inwards, it gets denser too.

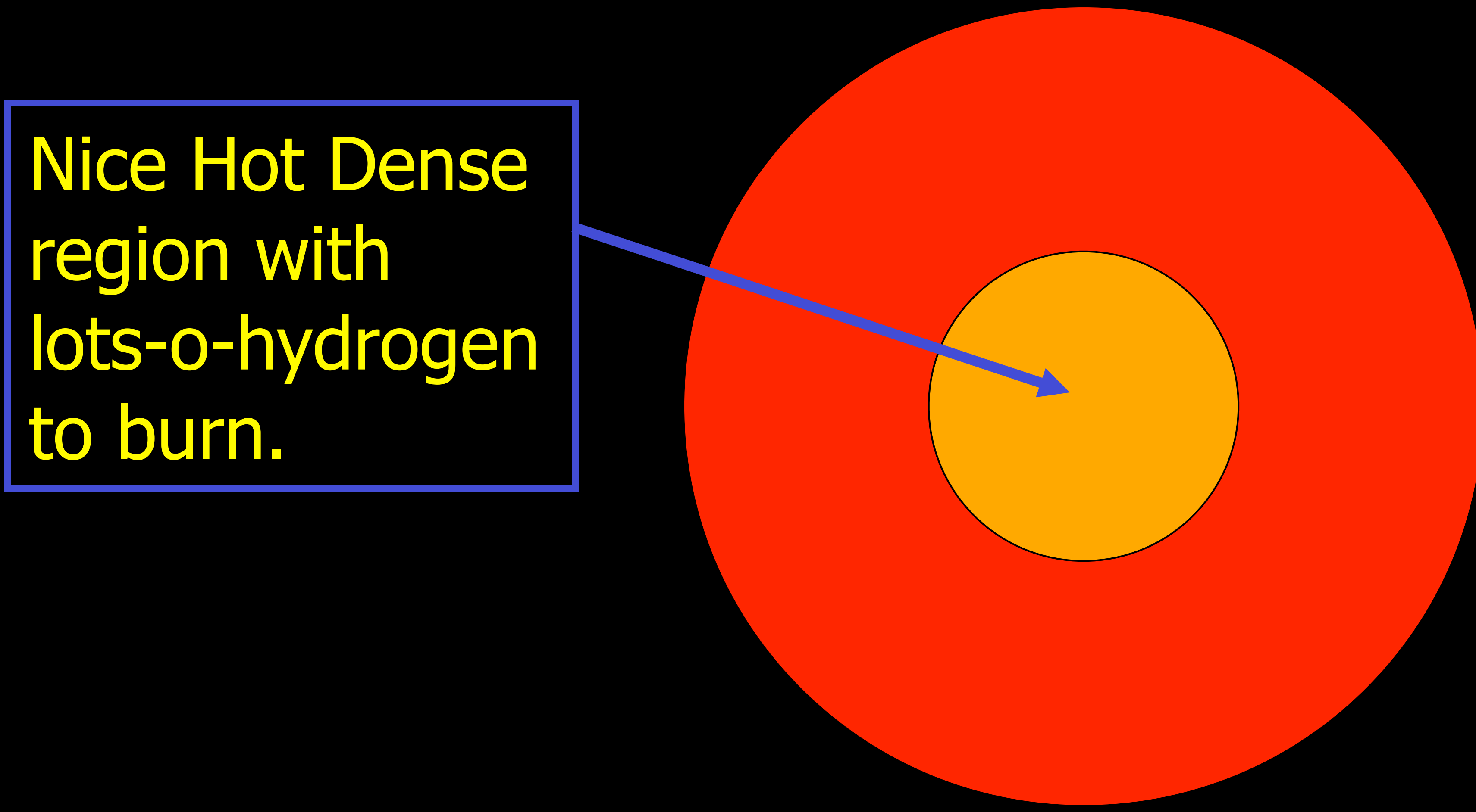
Life Rules for Stars

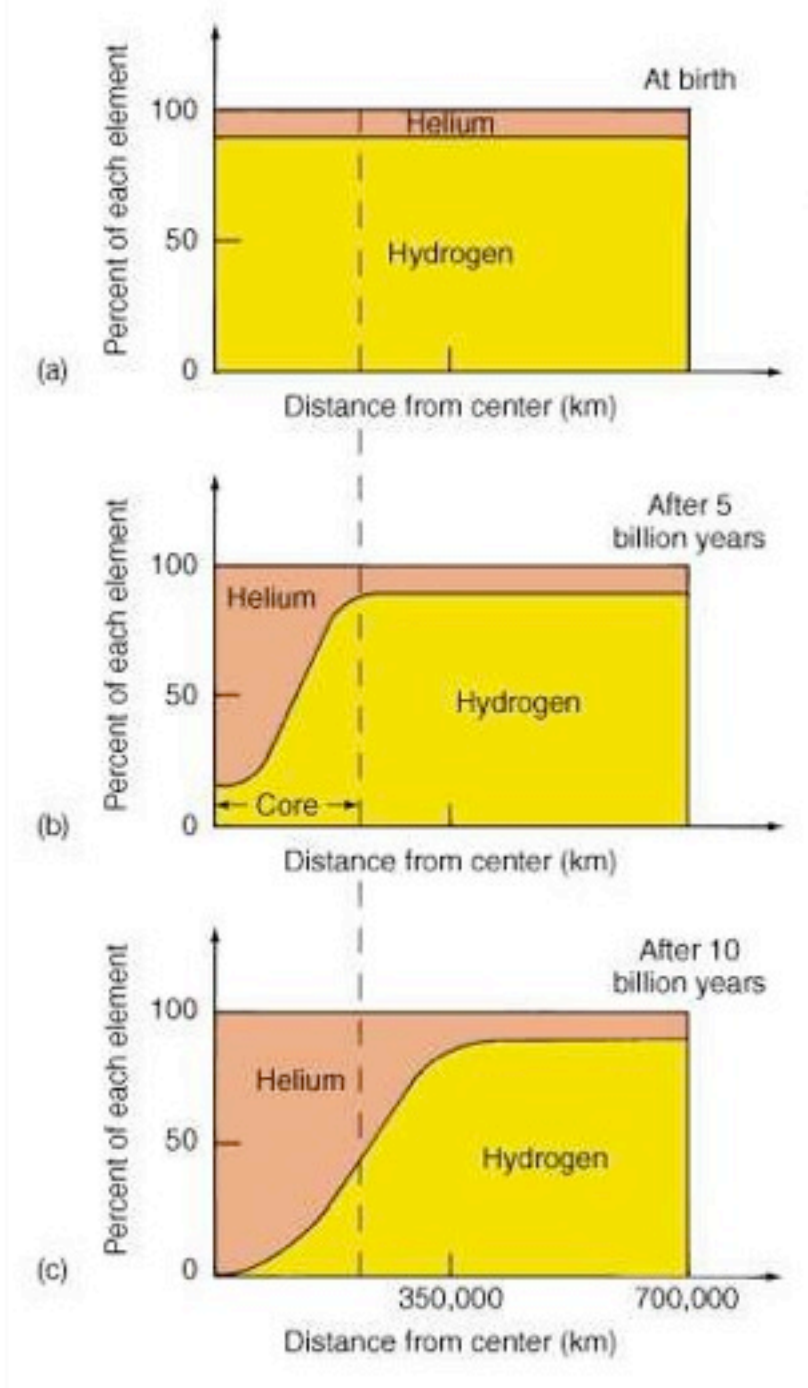
- When Stuff gets hotter and denser, heavier elements can fuse together.





Happy Star on the Main Sequence.



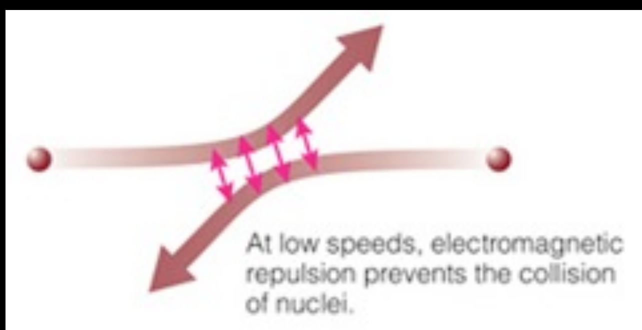


As time goes on, Hydrogen in the core gets used up!

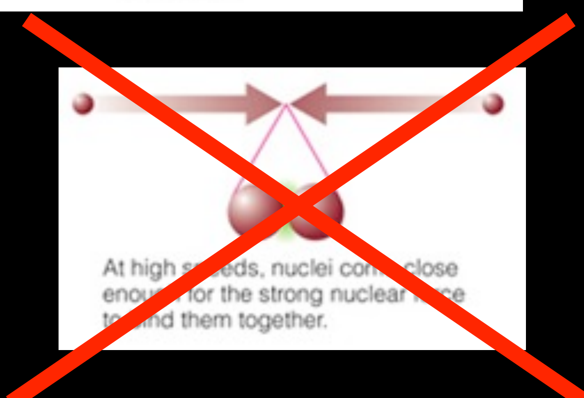
(PS. Keep in mind that the <u>mass</u> in the sun remains almost the same. It's just that the mass is in a form that it can't burn…for now!)

Stars can't burn Hydrogen <u>outside</u> the core!

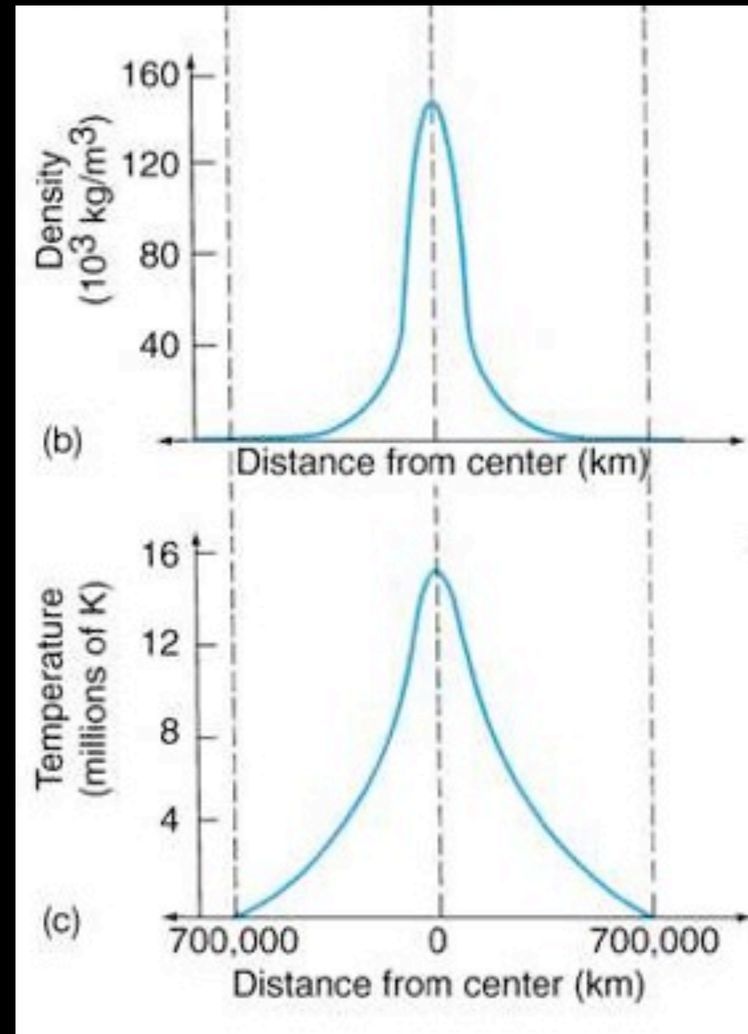
- Too cool!
- Too low density!



This.

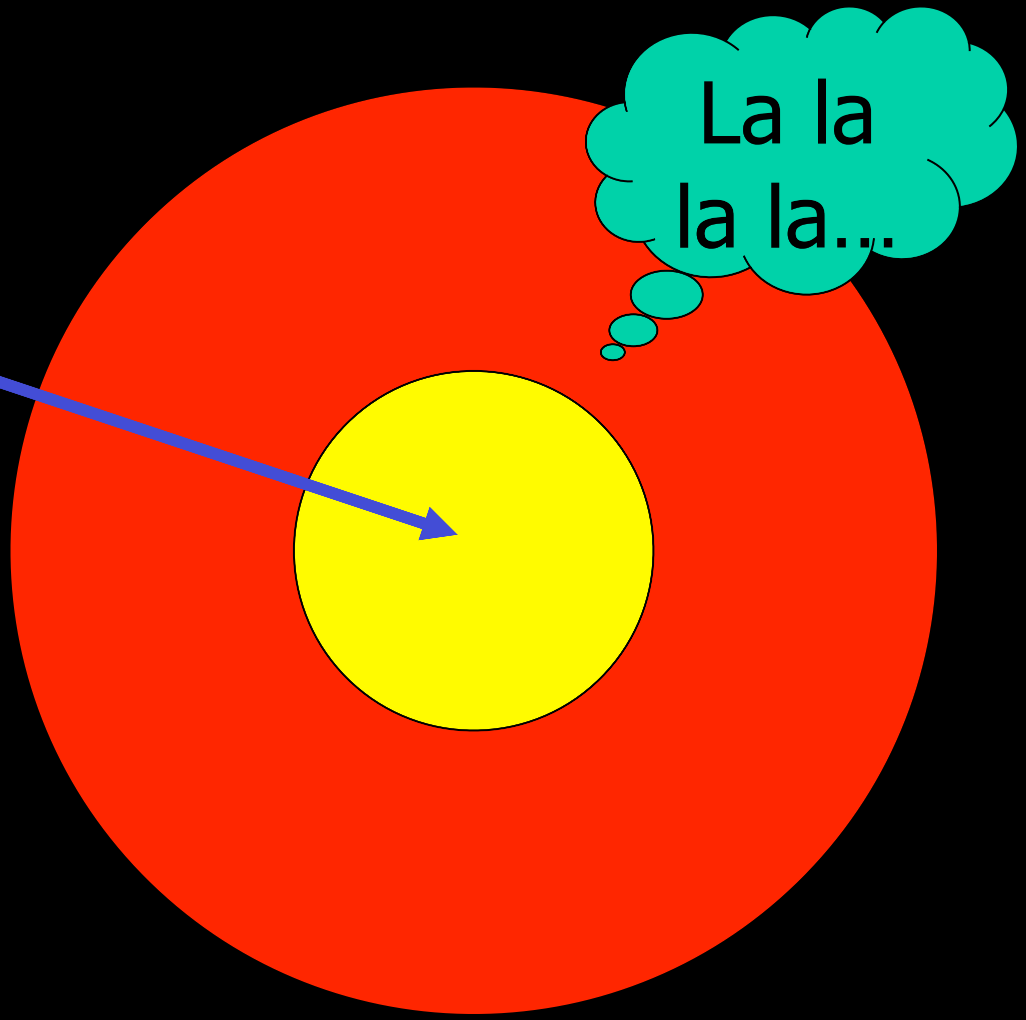


Not this.



Happy Star on the Main Sequence.

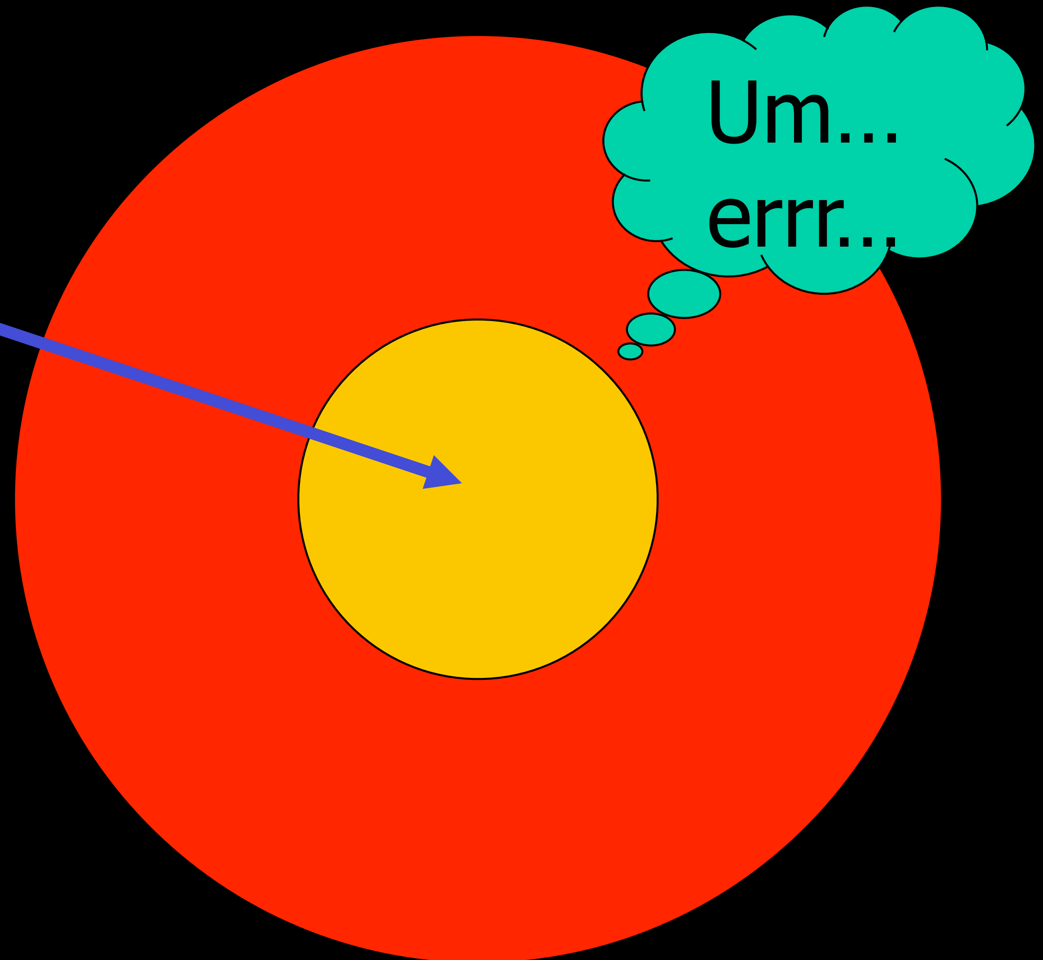
Nice Hot Dense region with lots-o-hydrogen to burn.



Becomes…

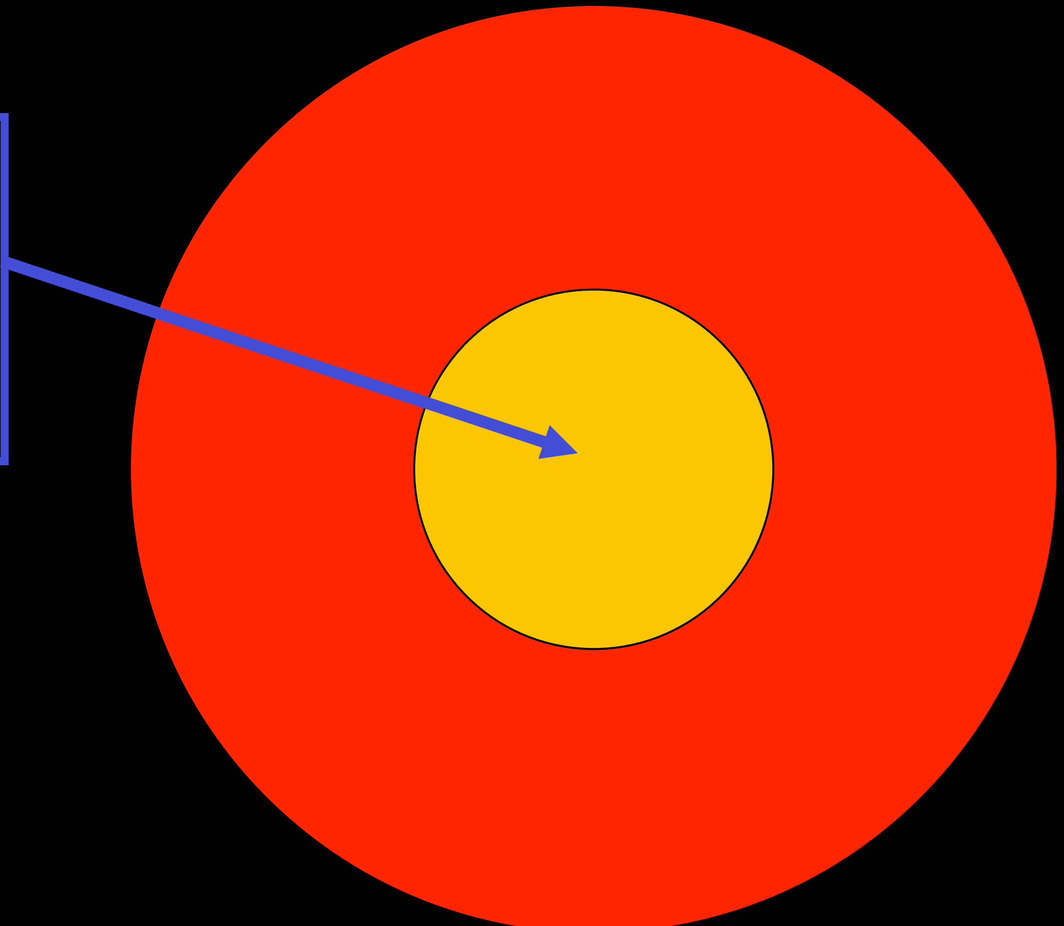
Nervous Star ending its time on the Main Sequence.

Running out of Hydrogen! Energy output is going down!



Nervous Star ending its time on the Main Sequence.

Without fusion, the temperature of the core will:



A. Cool down
B. Heat up

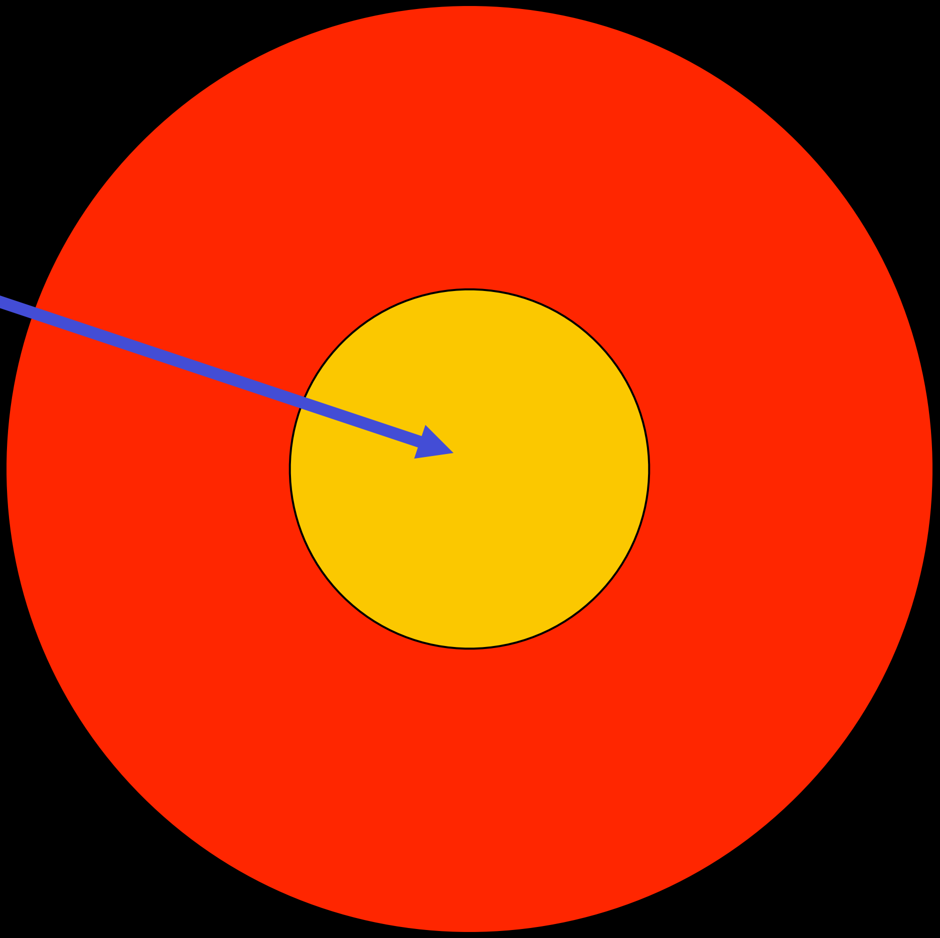
Nervous Star ending its time on the Main Sequence.

The pressure in the core will:

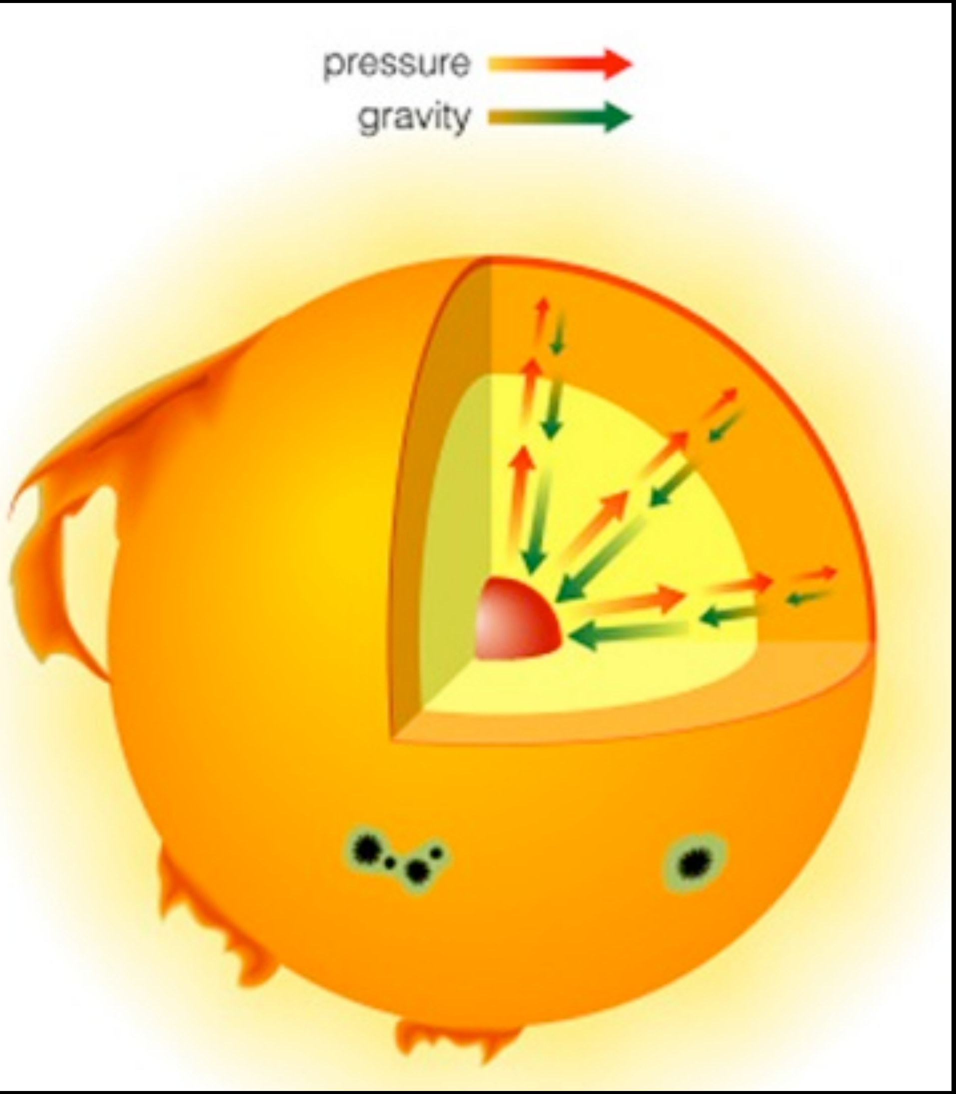
A. Decrease
B. Increase

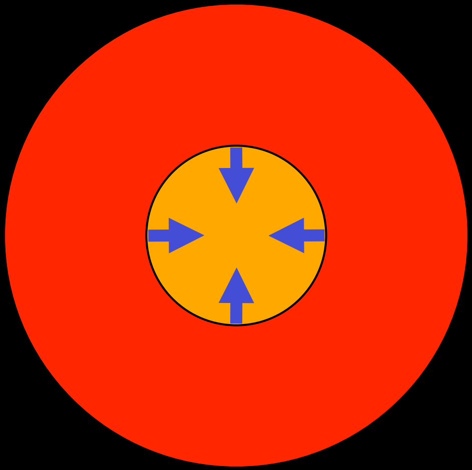
The core will:

A. Shrink
B. Expand



Core shrinks because it cools!

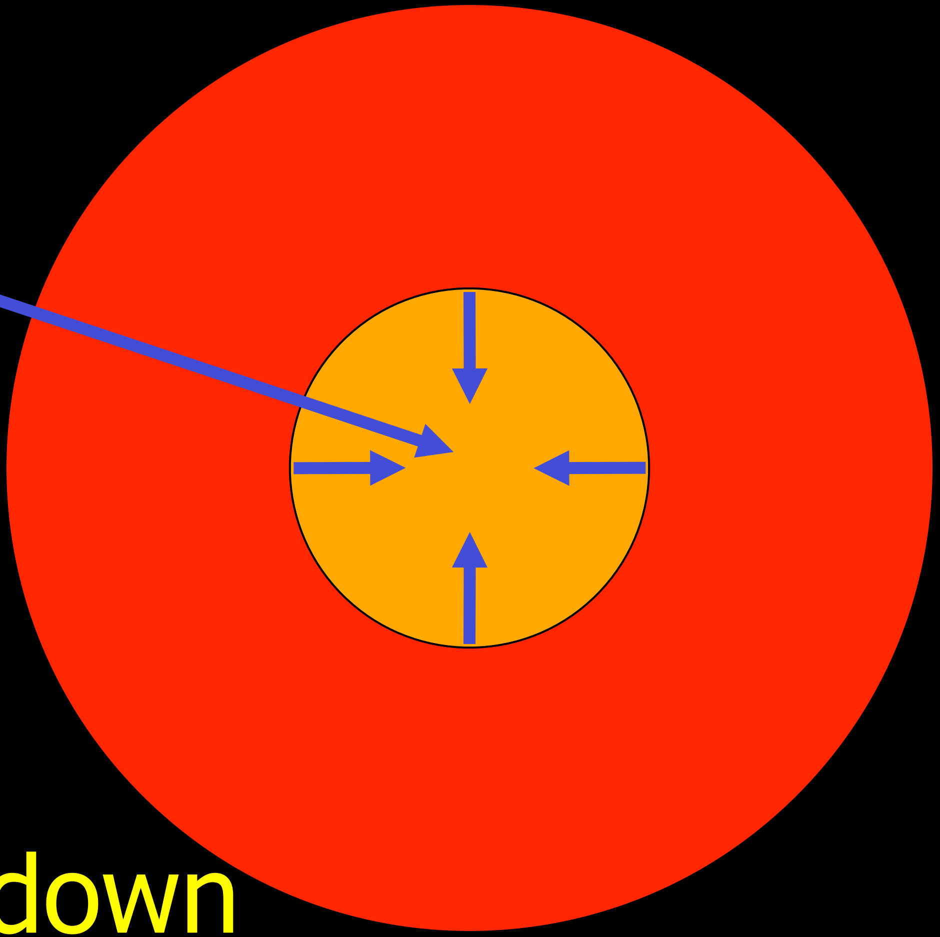




- Fusion Stops!
- Core Cools!
- Pressure Drops!
- Core Shrinks!

Temperature ↓ **Pressure** ↓

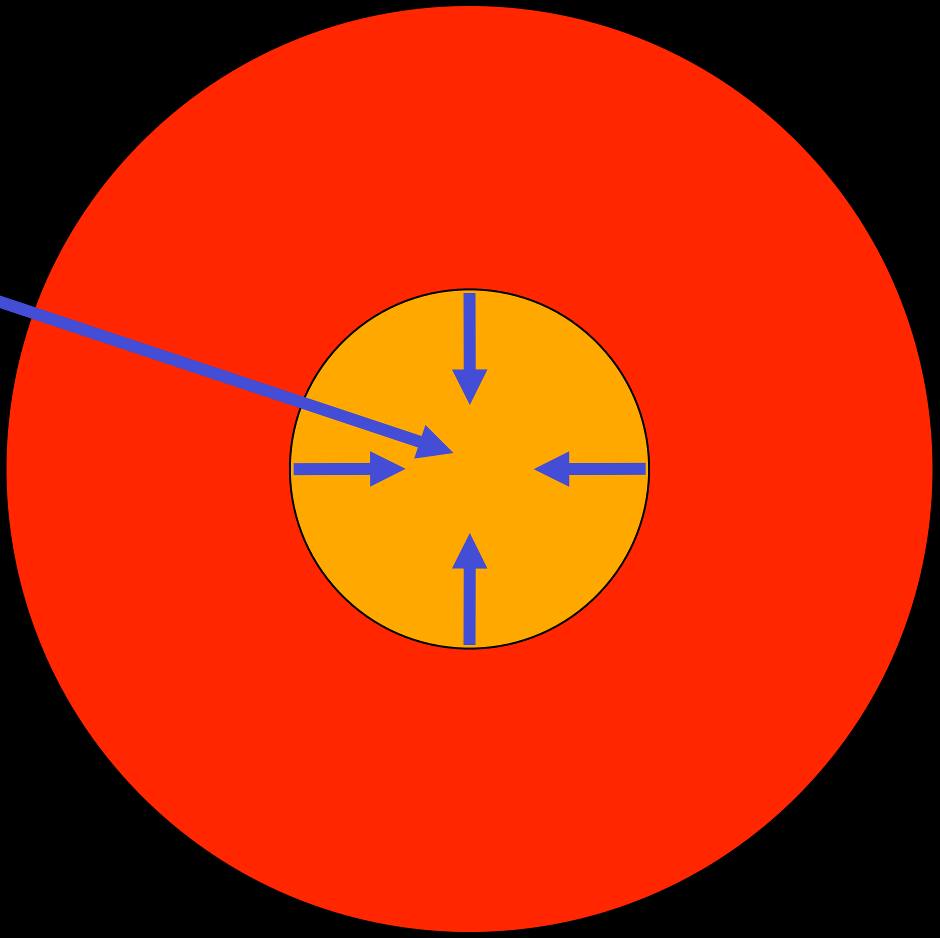
As the core starts to shrink and material falls in, the temperature in the center will:



A. Keep cooling down

B. Start heating back up

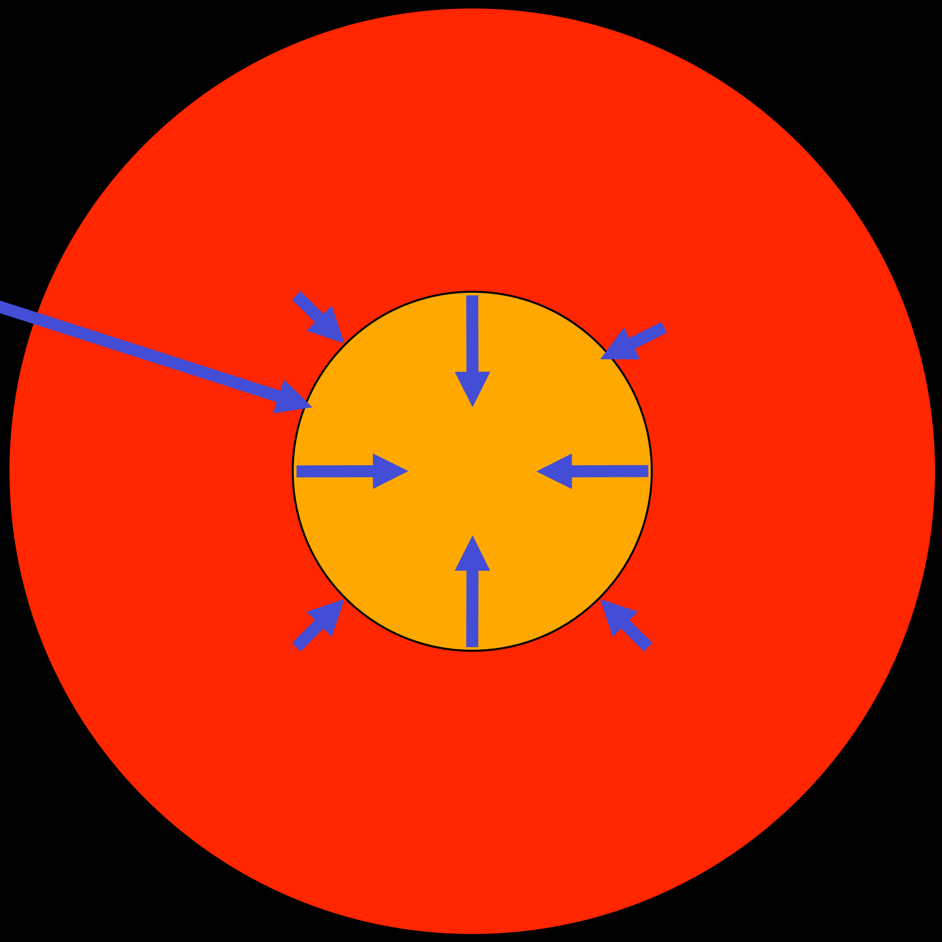
As the core starts to shrink and material falls in, the densities in the center will:



A. Decrease
B. Increase

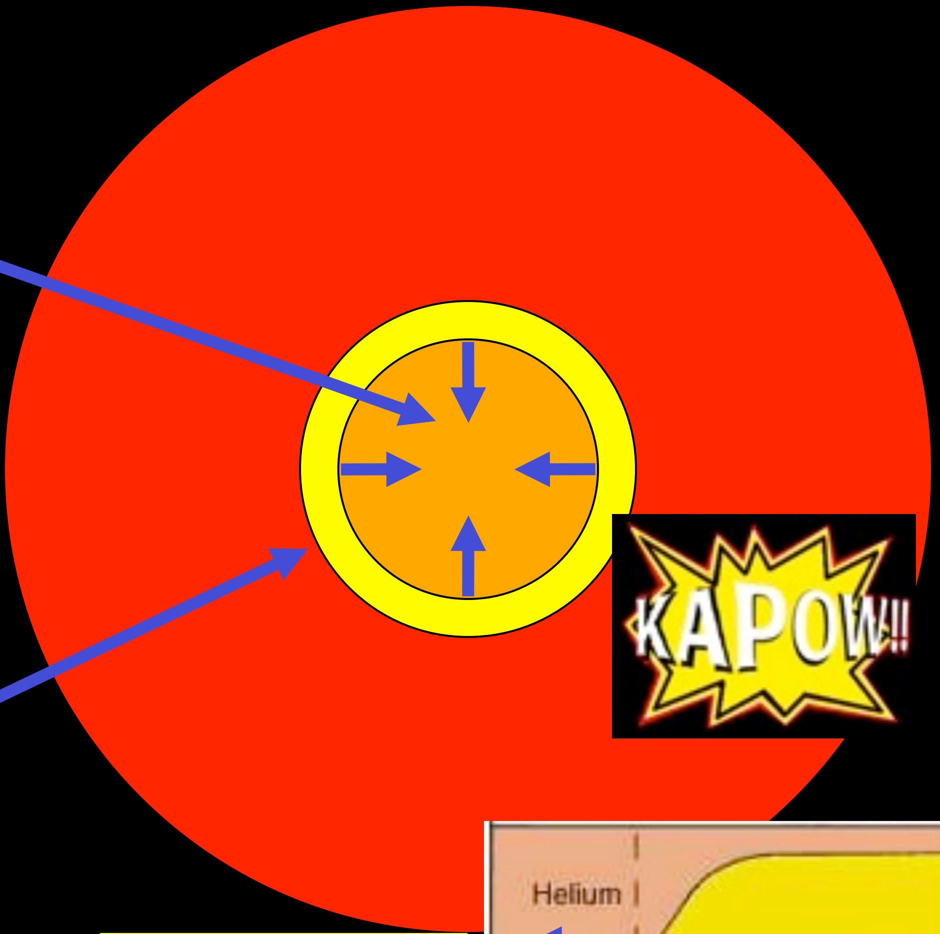
It shrinks, and heats up!

Layers above it fall in too! (nothing is pushing back)

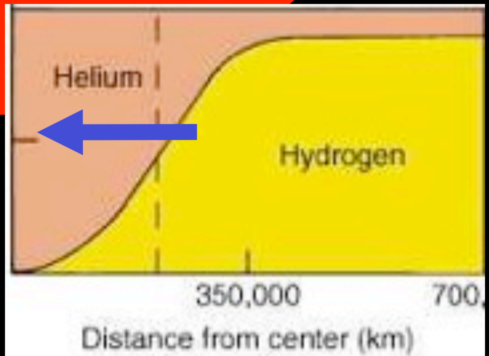


There's no Hydrogen left in the core, so it can't burn any.

But, the collapsing layers above are getting dense & hot! Starts burning H!



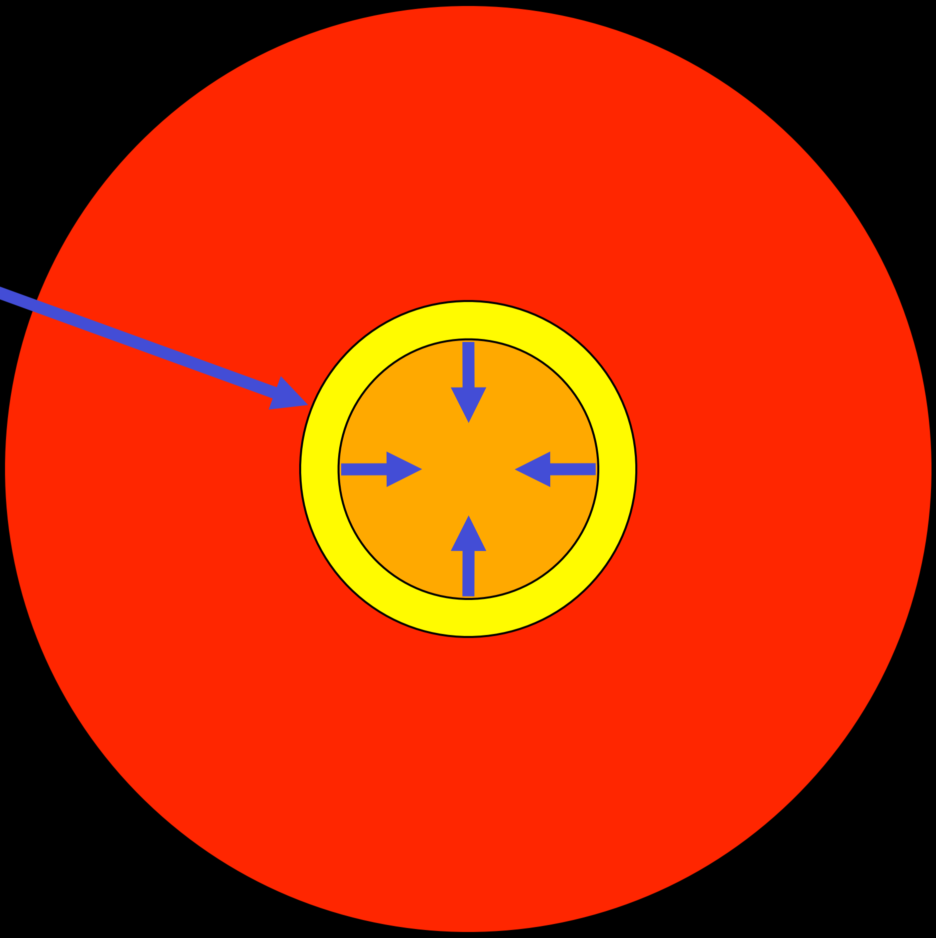
Plenty of fuel left outside the core



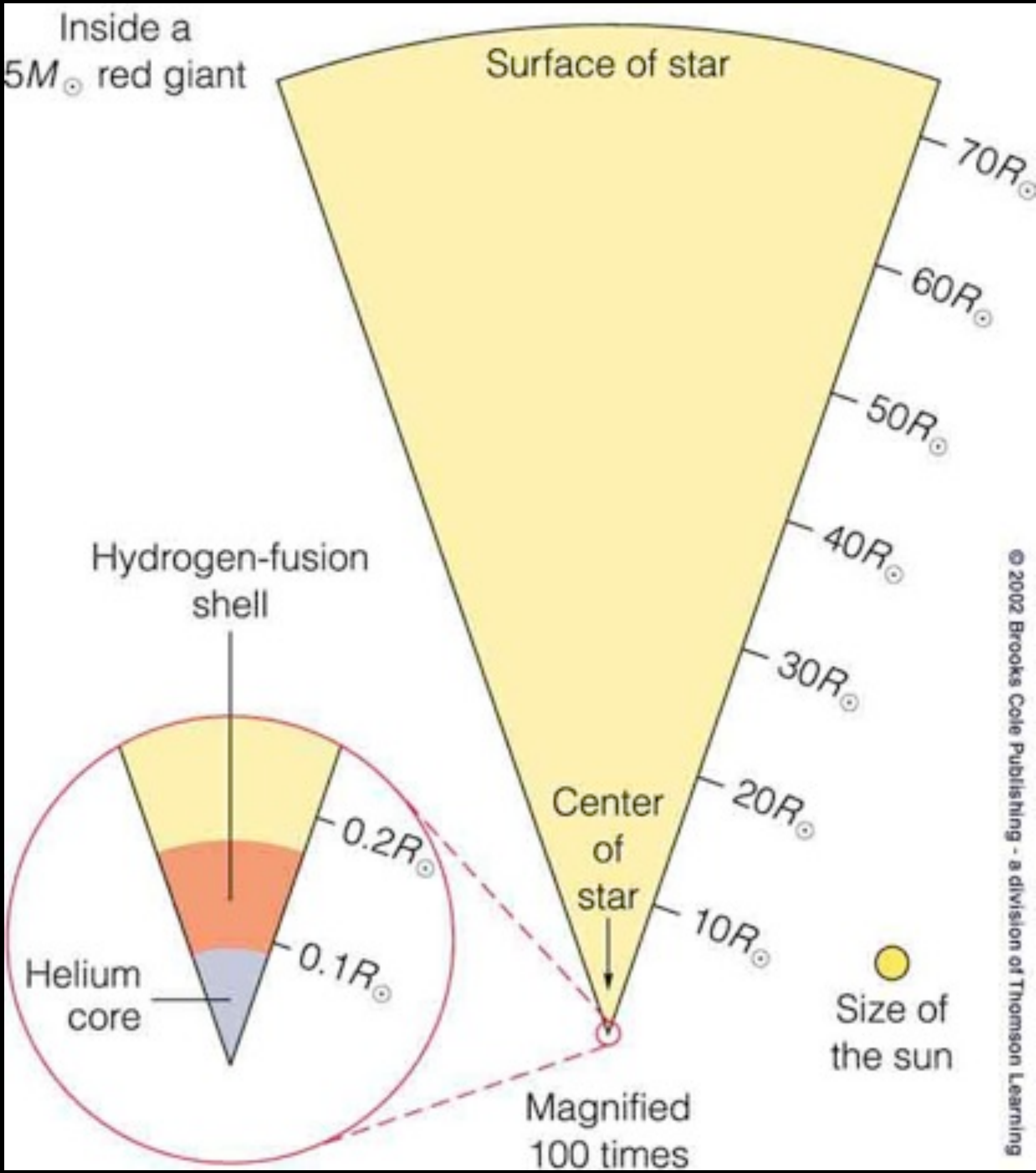
Shell is now even denser & hotter than original core!

Huge energy output!

Huge **LUMINOSITY**!

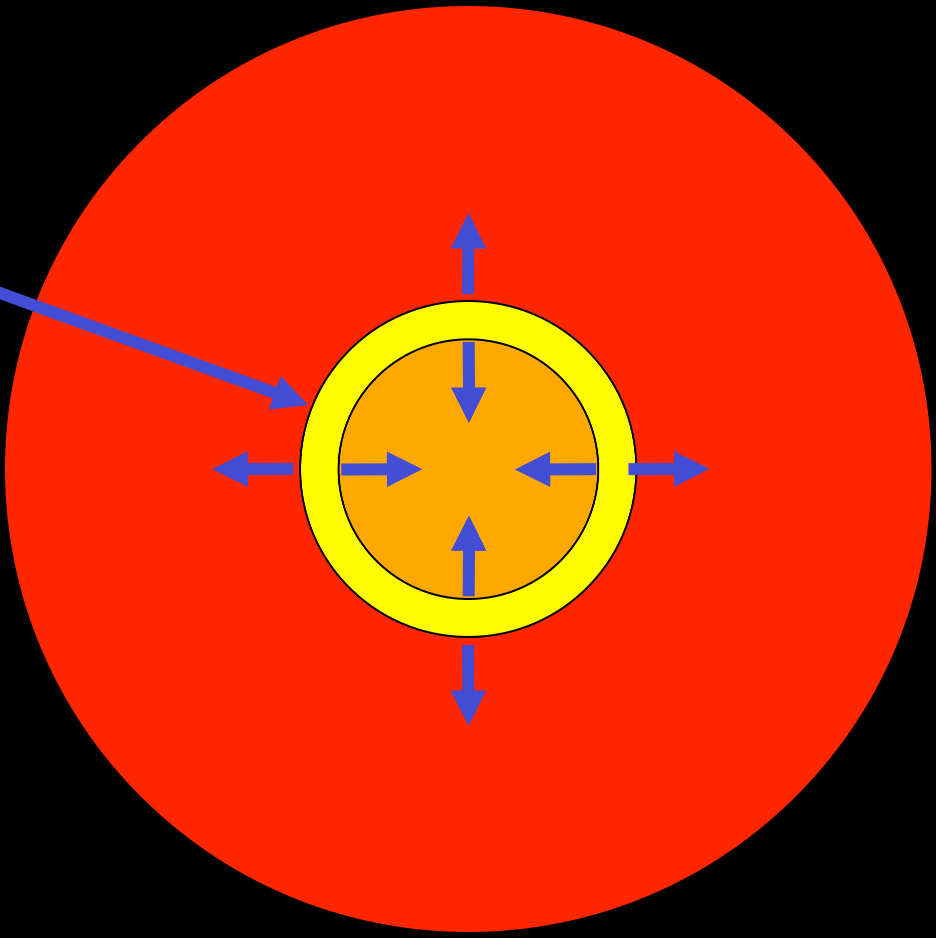


Where does the mass go??

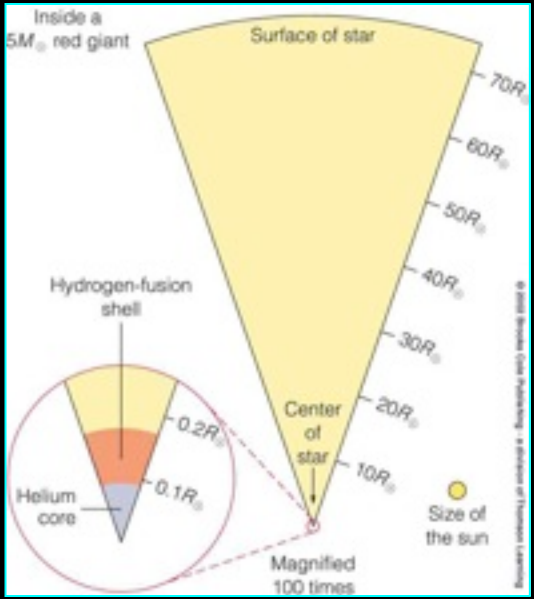


Luminous shell pushes up the stuff above it.

It’s still collapsing through!



Almost all the mass winds up in the center, inside the shell!



- Pressure only has to hold up a fraction of the mass it used to!
- More Energy Output + Less Mass to Hold Up =

HUMUNGOUS!!!

The star gets redder when it swells up!

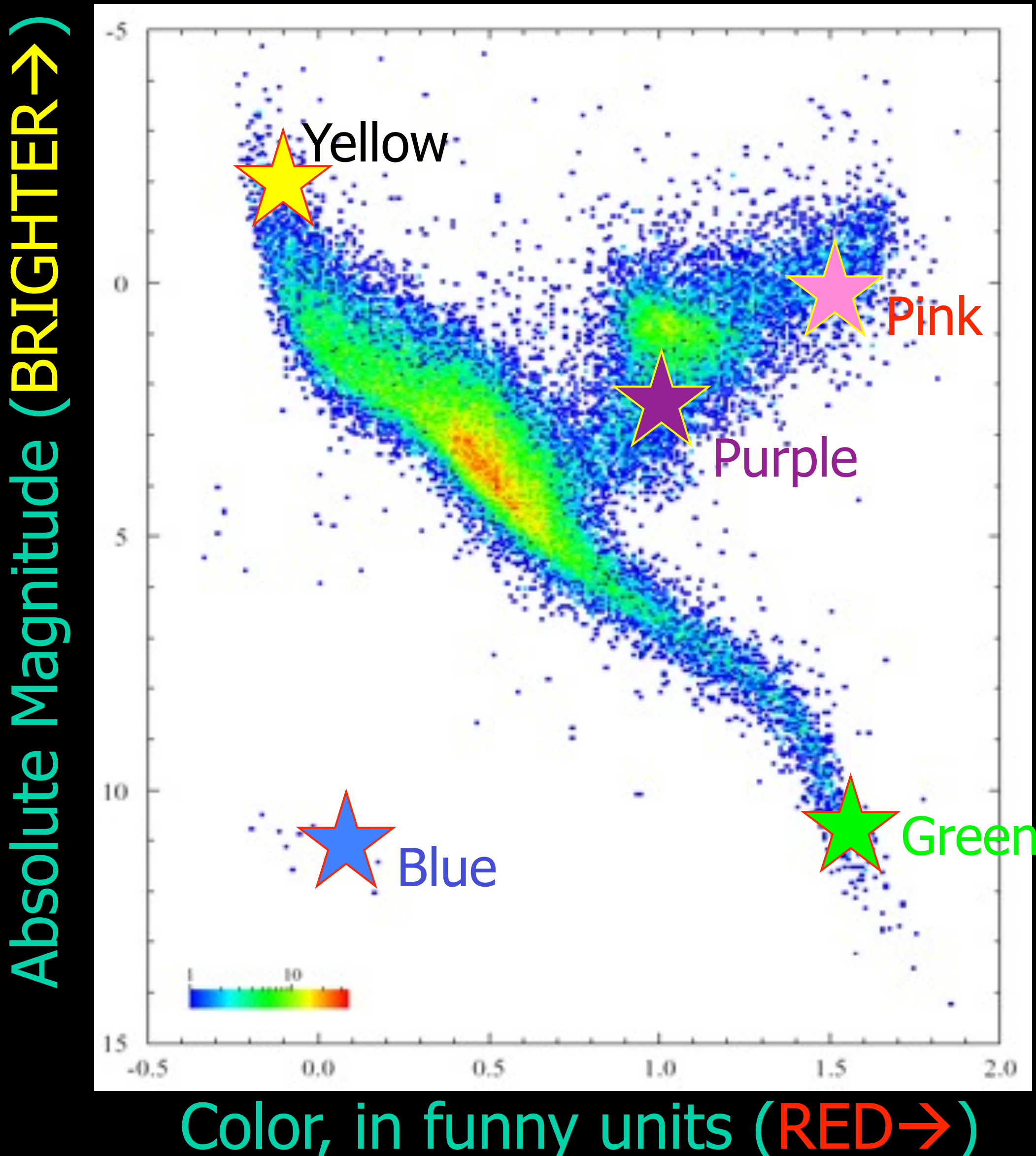
$$L = \sigma T^4 \times 4\pi R^2$$

Big!

Drops!
Gets Redder

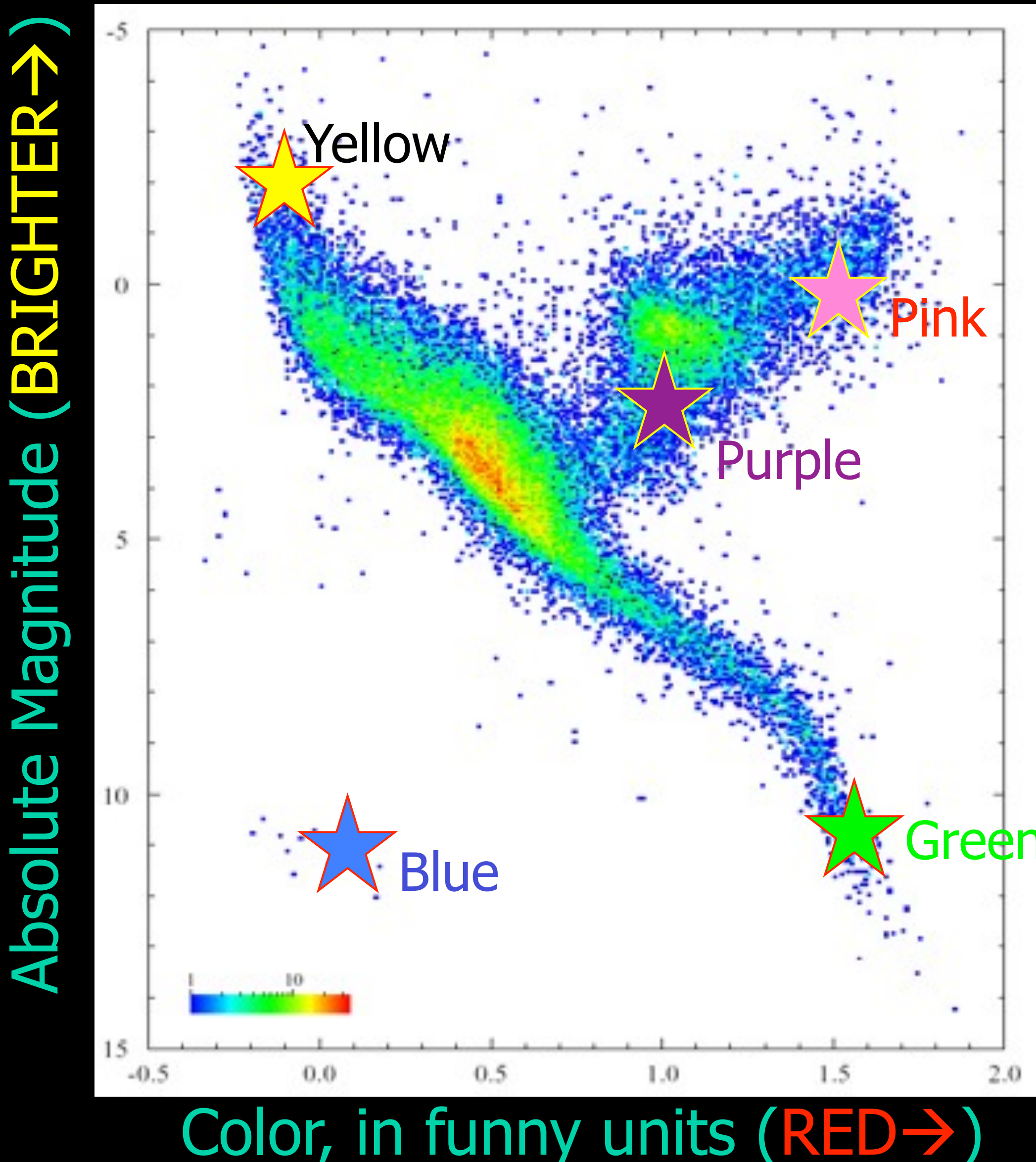
Really Big!

This turns the main sequence star into a red giant!



Which star(s):

1. Is the most massive?
2. Is the lowest mass main sequence star?
3. Is definitely young?
4. Are not experiencing Hydrogen fusion in their cores?



Which pairs of stars:

1. Have the same luminosity?
2. Have the same temperature?
3. Are likely to have the same size?