"Probability factor of one to one...we have normality, I repeat we have normality. Anything you still can't cope with is therefore your own problem."

The Hitchhiker's Guide to the Galaxy

Group Project is due on Monday, April 1.

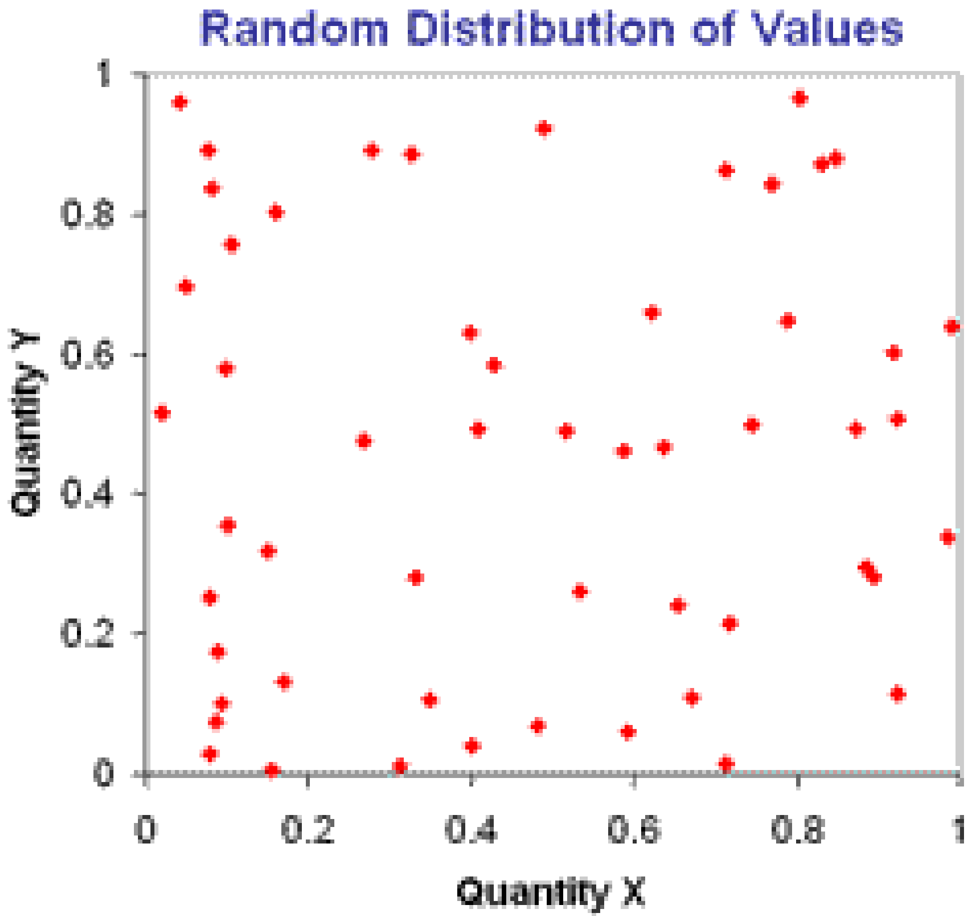
HW3 is due next Monday. On the course web page now.

We will have an in-class assignment on Wednesday.

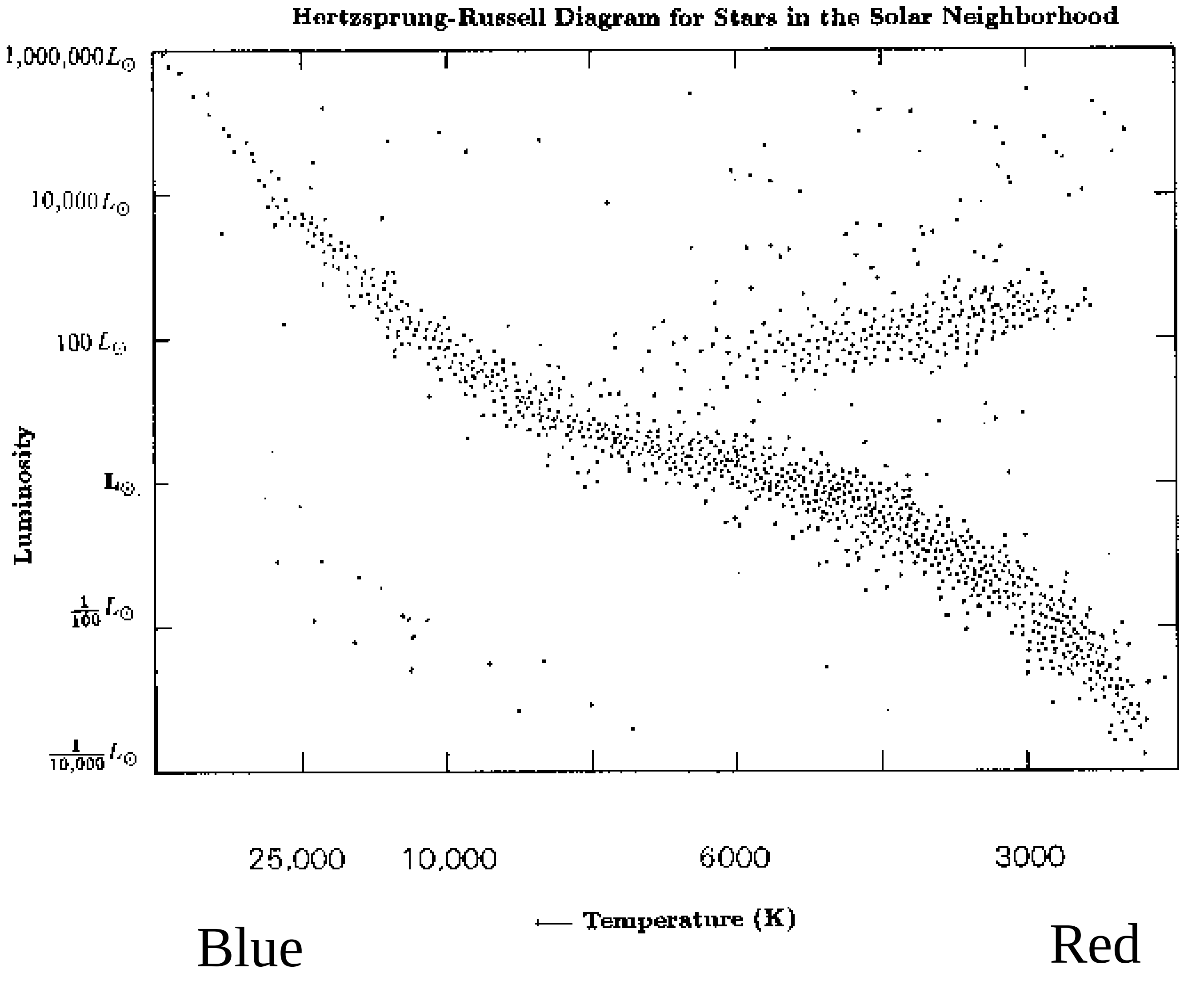
Reading updated for the entire section on stars.

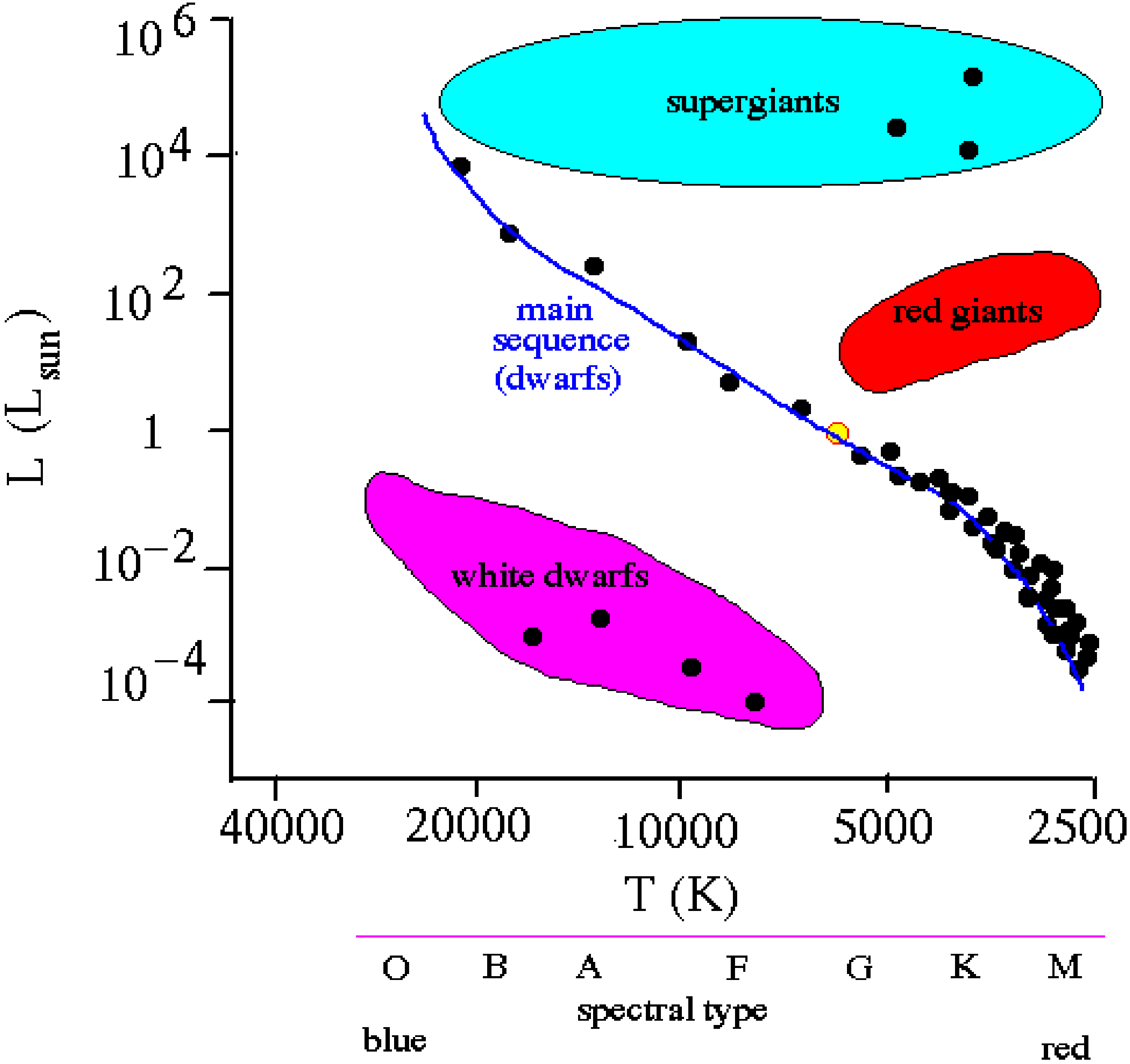
In science, if we can measure 2 things, we plot them against each other and look for relationships.

This is what random (unrelated) looks like



This is not random



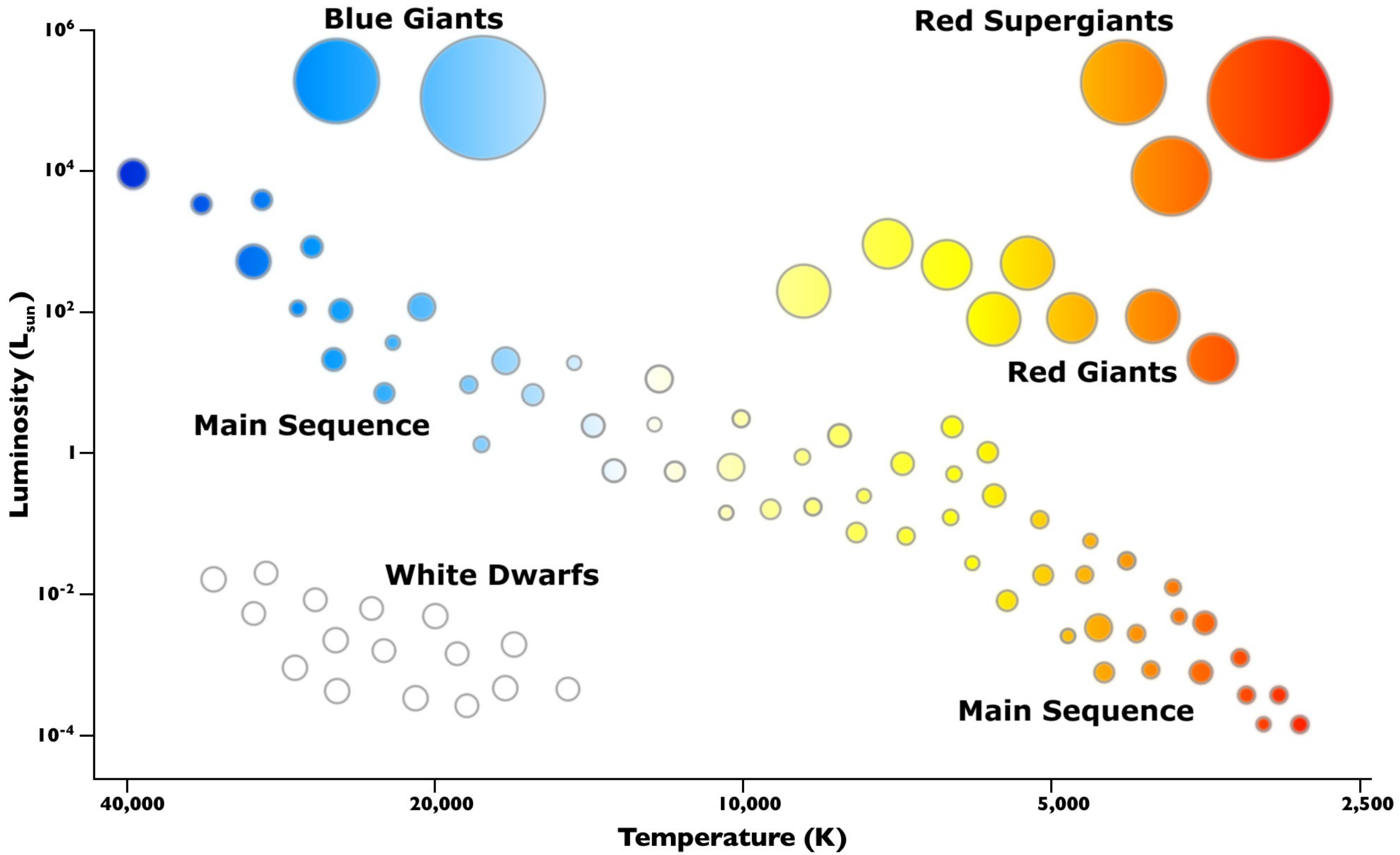


The stars fall into groups. The group where we see the most stars is called the Main Sequence. Stars of similar temperature, but brighter are called Red Giants, and smaller stars are called white dwarfs.

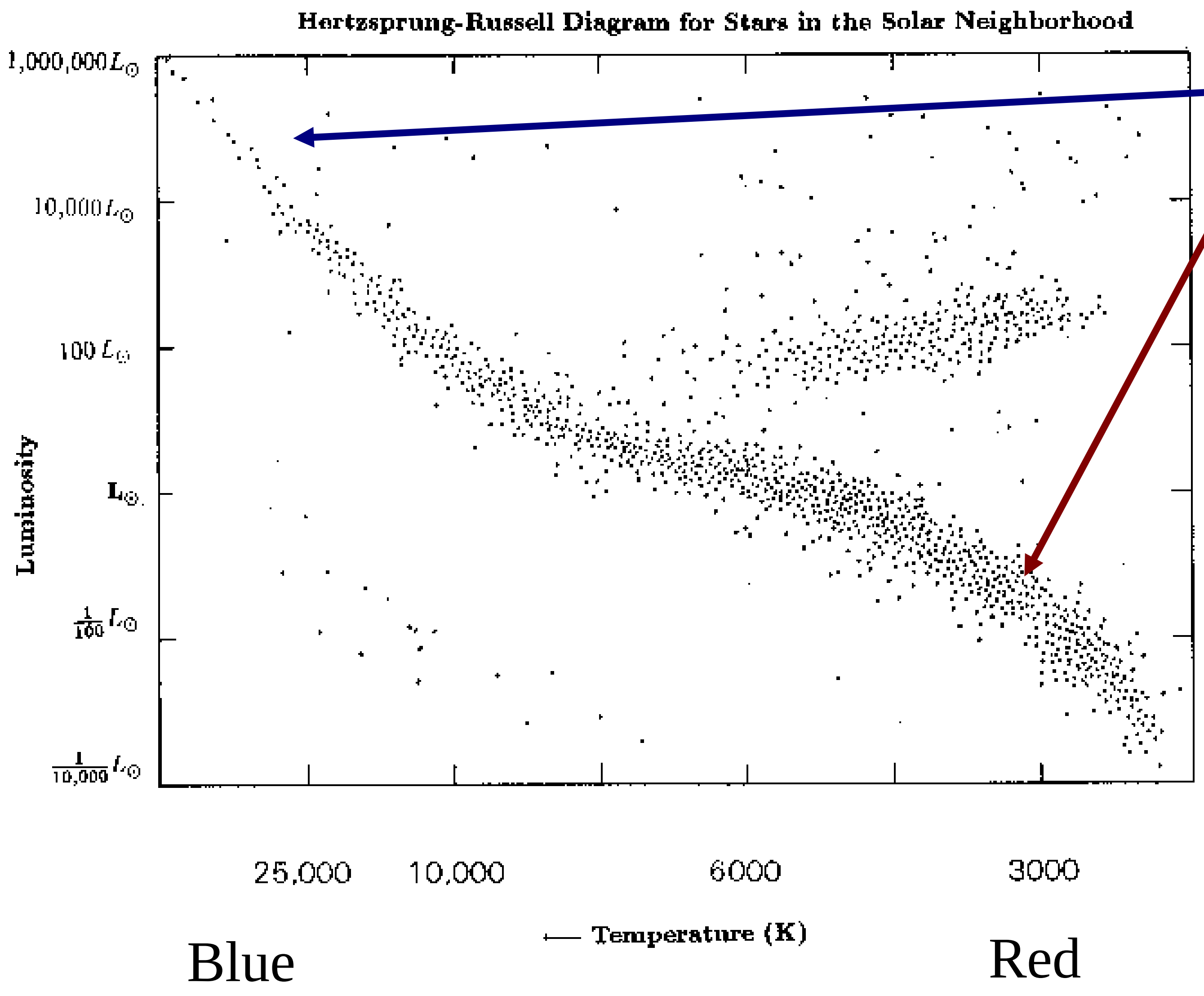
Russell-Vogt theorem:

A star's location on the HR diagram is determined by only 3 things:

its mass, age, and (barely) composition.



HR Diagram

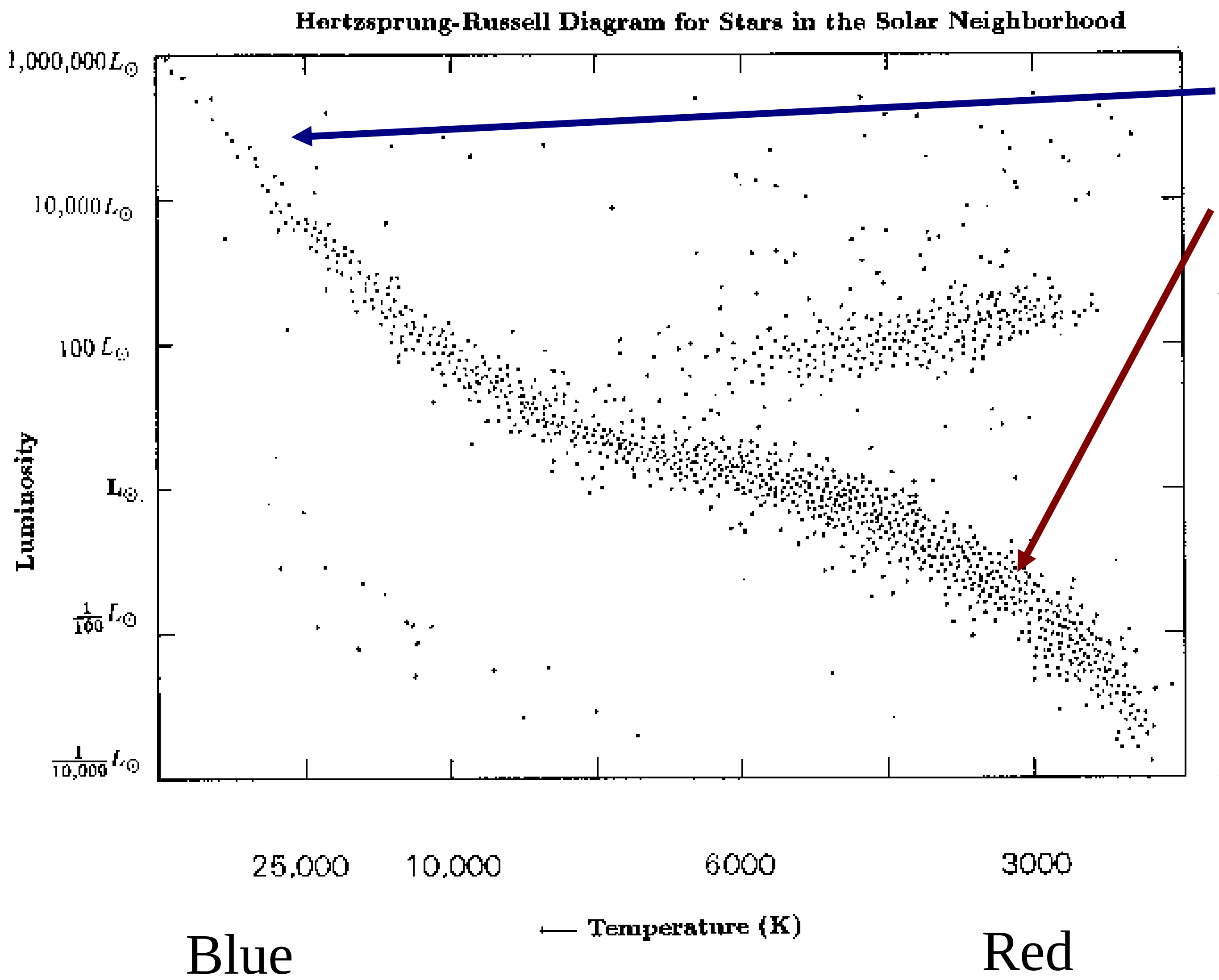


The difference between this star and this star is MASS

Main Sequence stars

- Are converting H to He in their cores.
- Our Sun is a main sequence star.

HR Diagram



100-200 M_{Sun} at the top

and

about

$0.02M_{Sun}$ at the bottom.

Relations on the main sequence.

How bright a star is on the main sequence depends on its mass.

$$L_{\mathrm{MS}} = M^{3.5} = \sqrt{M} \times M \times M \times M \times M$$

How long a star is on the main sequence depends on its mass.

$$t_{MS} = \frac{1 \times 10^{10}}{M^{2.5}} = \frac{1 \times 10^{10}}{\sqrt{M} \times M \times M} \,\mathrm{Yrs}$$

These equations use solar units (mass and luminosity)

On the main sequence, luminosity goes as mass to the 3.5 power.

That is $L=M^{3.5}=M x M x M x (M^{1/2})$

In solar units (the Sun=1).

Let's try one: How bright (compared to our Sun) is a 9 solar mass star?

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This MS star is 2187 times brighter than our Sun.

What about its main sequence lifetime?

In solar units (the Sun=1).

Let's try one: What is the H fusion lifetime of a 9 solar mass star?

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4.1×10^{7} or 41 million years

What is the temperature of a star with a peak in its continuous spectrum at 550nm?

- A) 550 K
- B) 3,400 K
- C) 5,300 K
- D) 8,200 K
- E) 82,000 K

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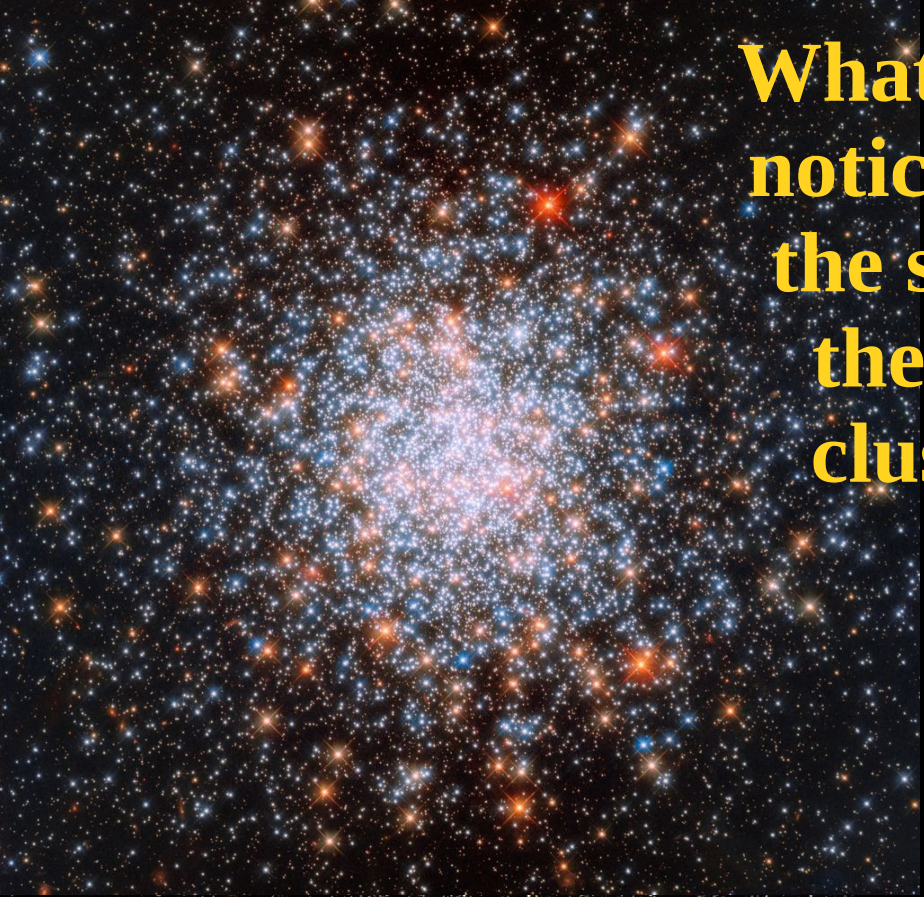
The Main Sequence is a mass sequence.

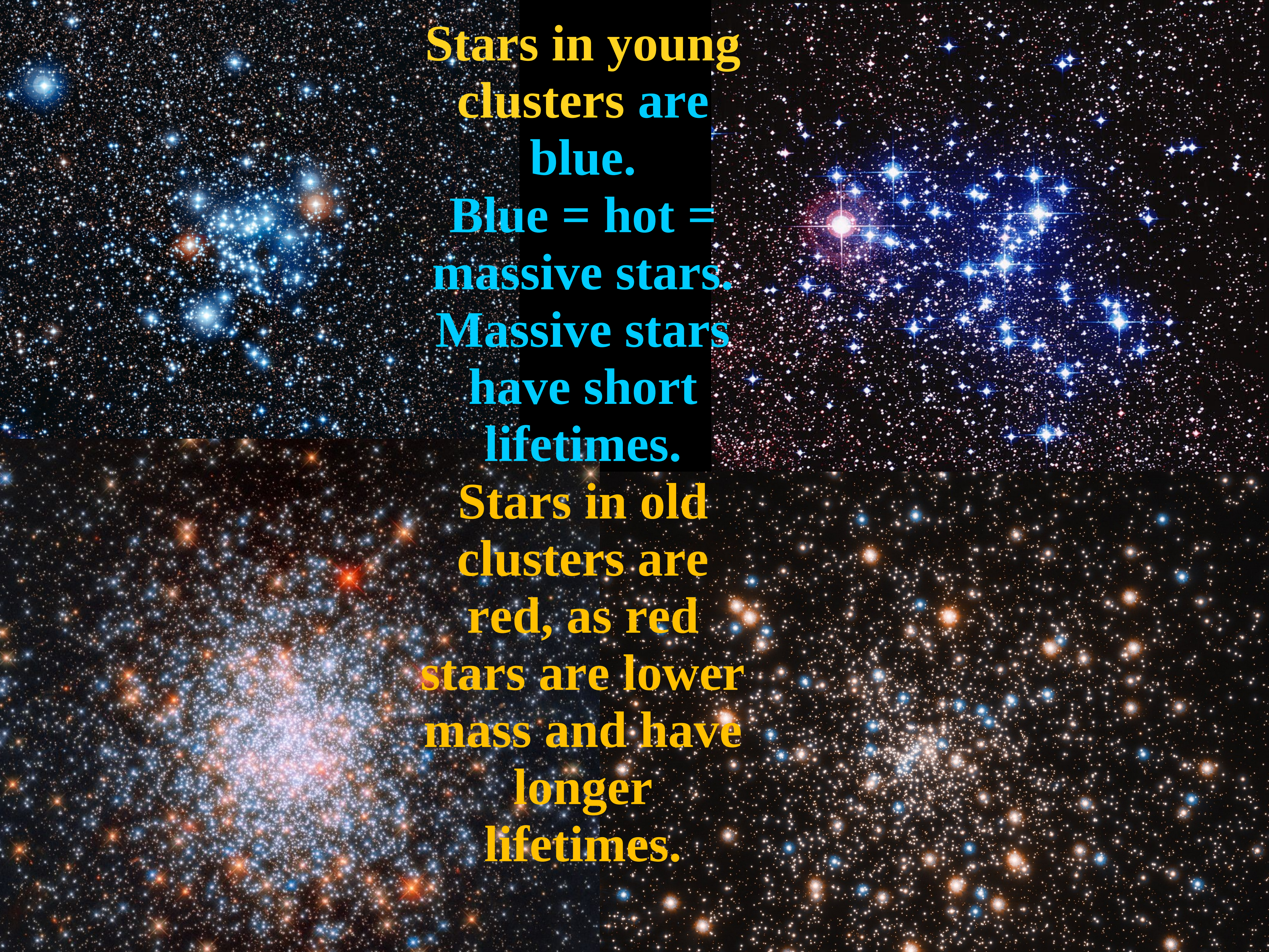
$$t_{MS} = \frac{1 \times 10^{10}}{M^{2.5}} = \frac{1 \times 10^{10}}{\sqrt{M} \times M \times M} \text{Yrs}$$

And more massive stars evolve faster. And stars forming from the same cloud roughly start their main sequence at the same time.

What do you notice about the stars in these young clusters?

What do you notice about the stars in these old clusters?

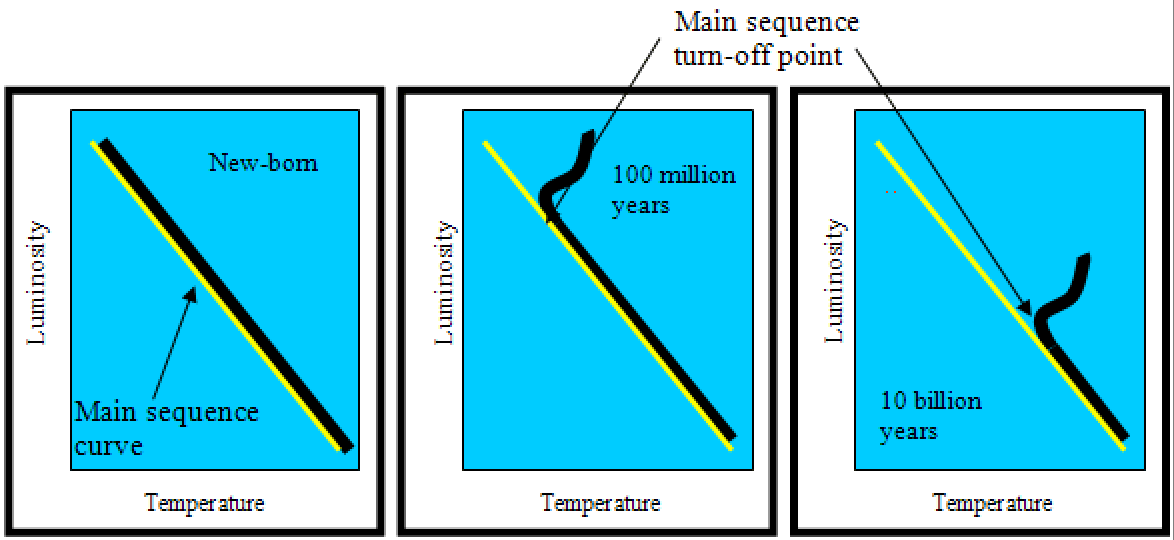


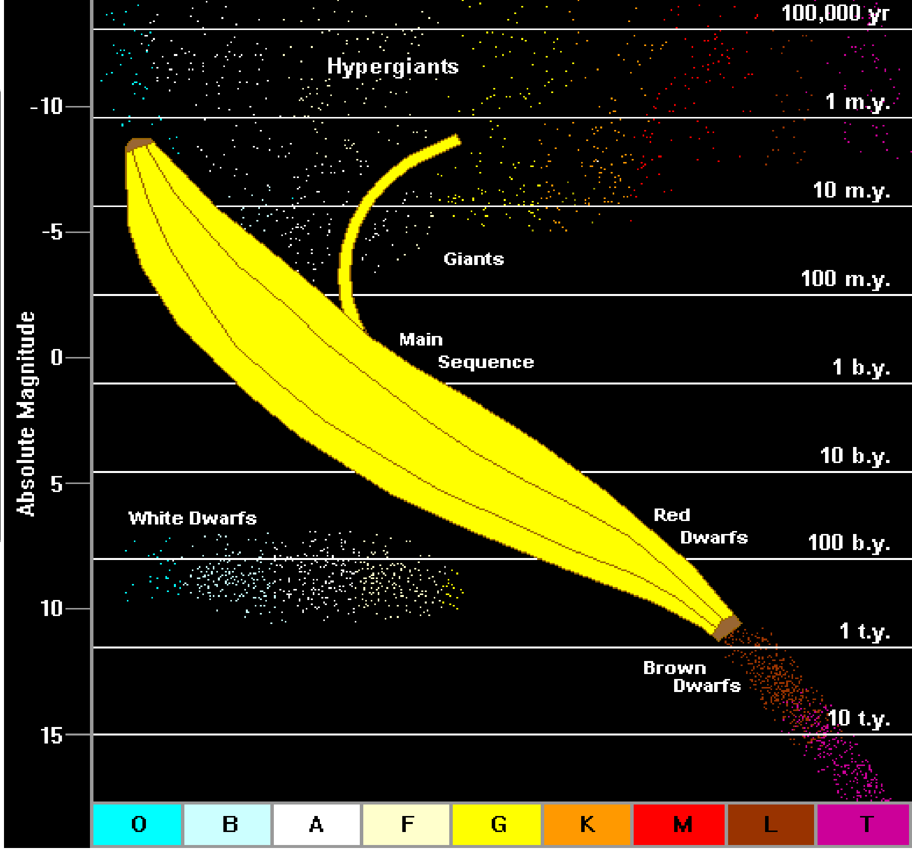

Stars in young clusters are blue.
Blue = hot = massive stars.
Massive stars have short lifetimes.
Stars in old clusters are red, as red stars are lower mass and have longer lifetimes.

Blue = hot = massive = young.

Red = older

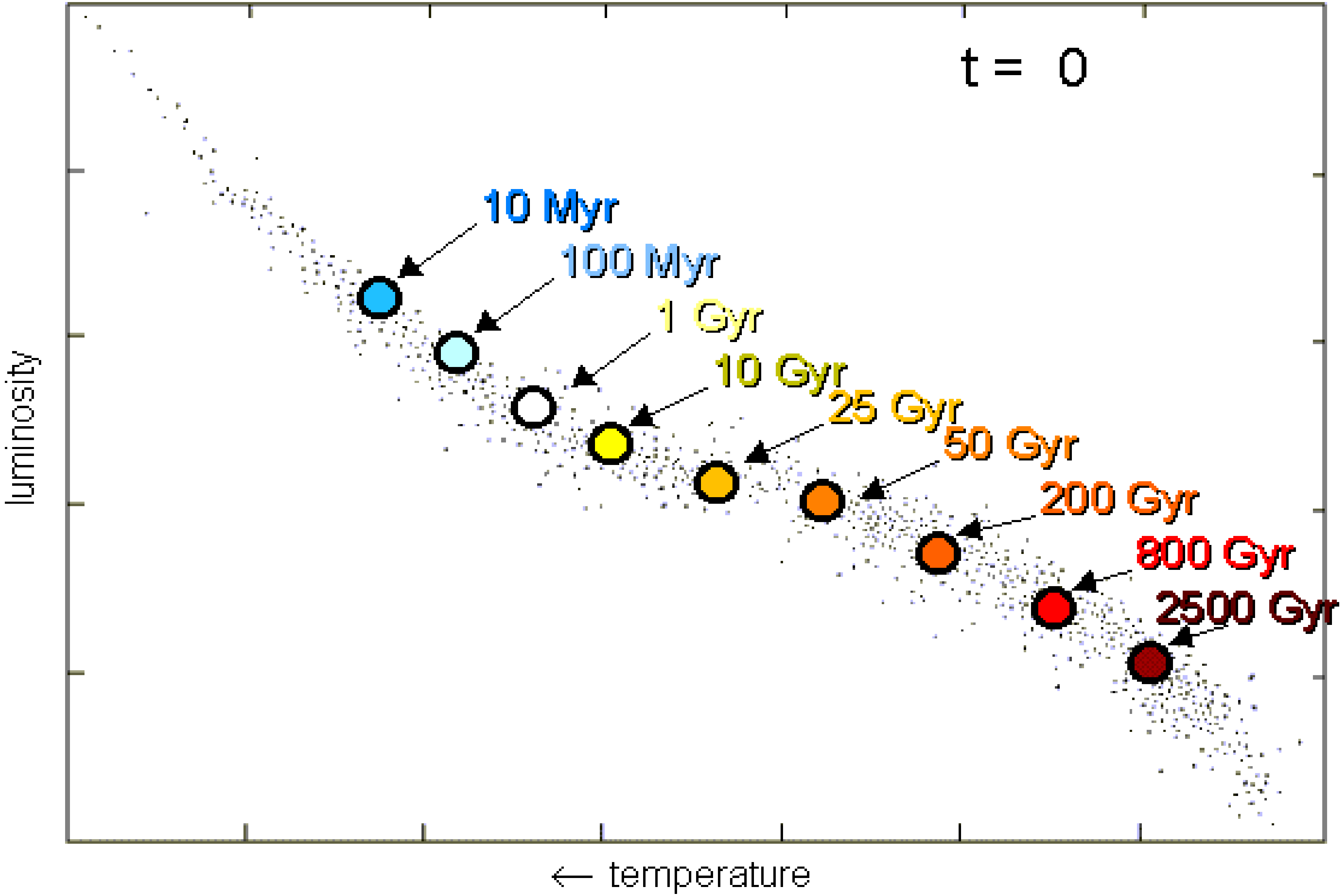
Color is related to age.



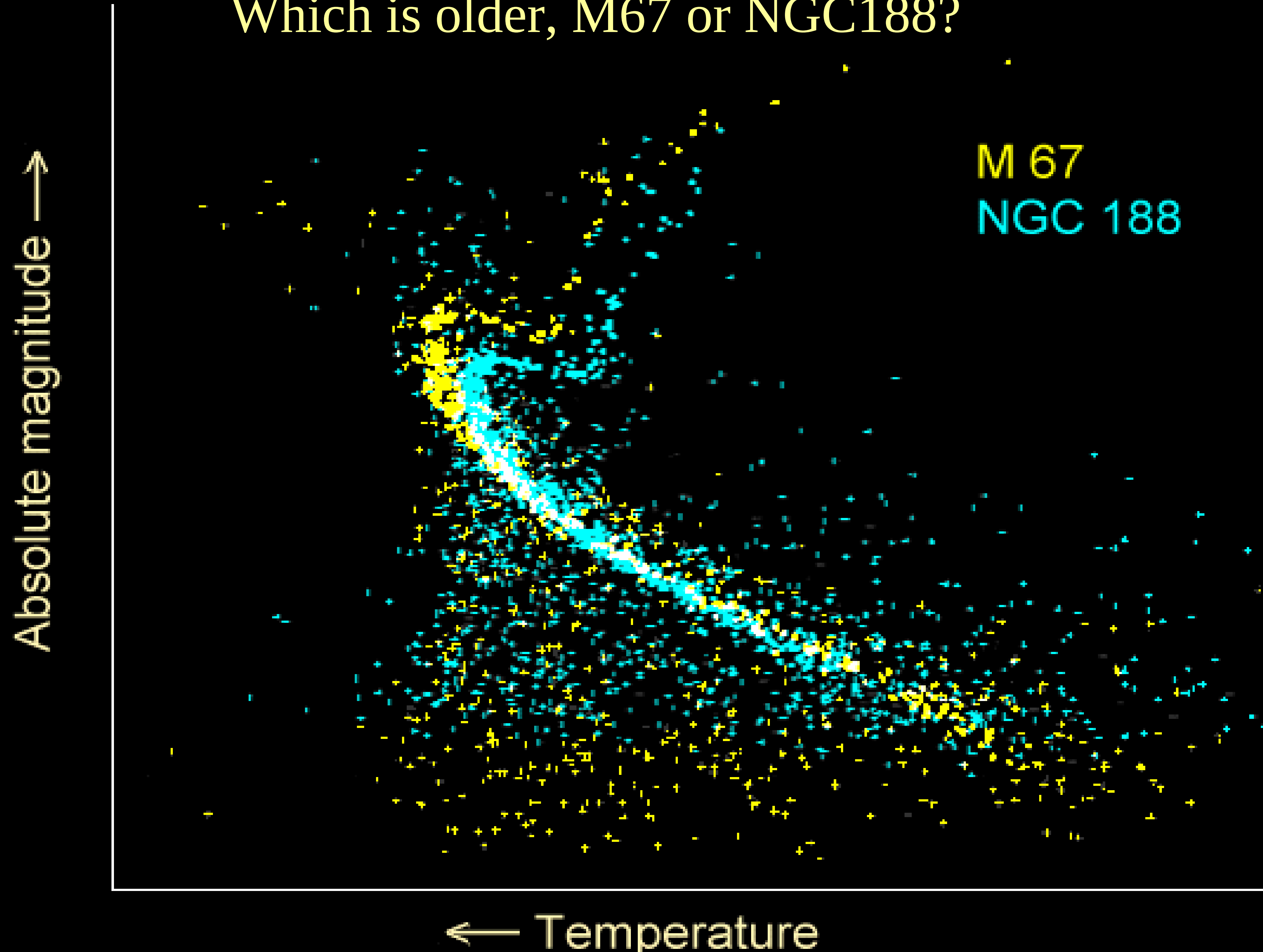


More massive stars evolve faster and leave the main sequence earlier.

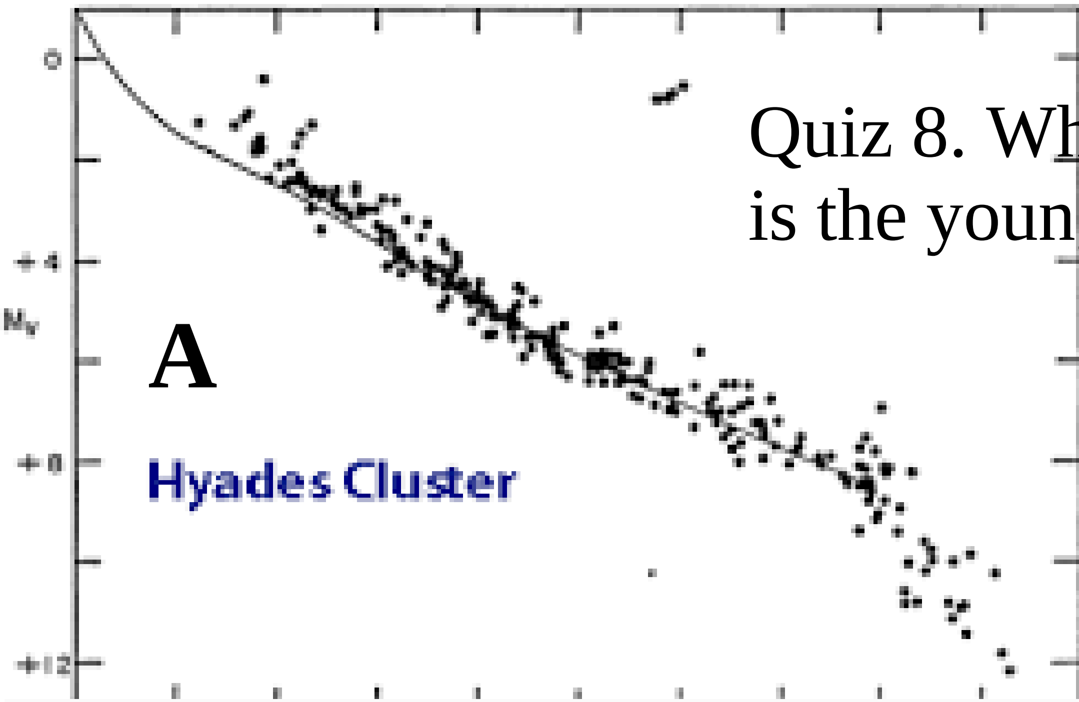
So for a group of stars, which began at roughly the same time, the length of the main sequence is an indicator of age.

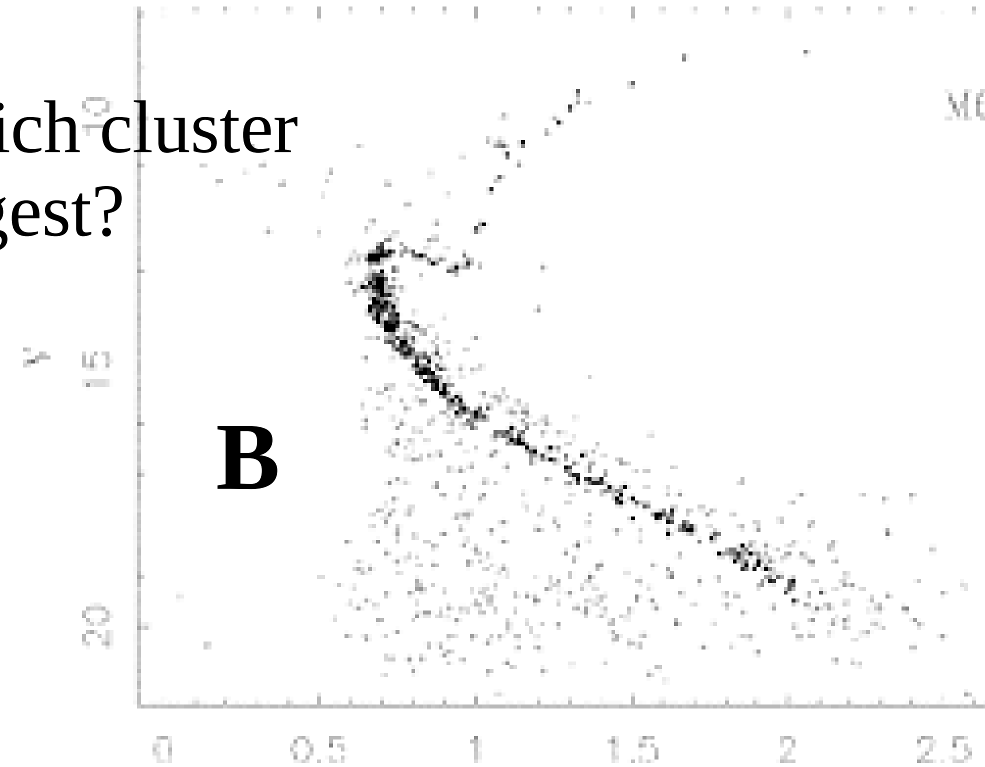

t = 0
10 Myr
100 Myr
1 Gyr
10 Gyr
25 Gyr
50 Gyr
200 Gyr
800 Gyr
2500 Gyr
luminosity
← temperature

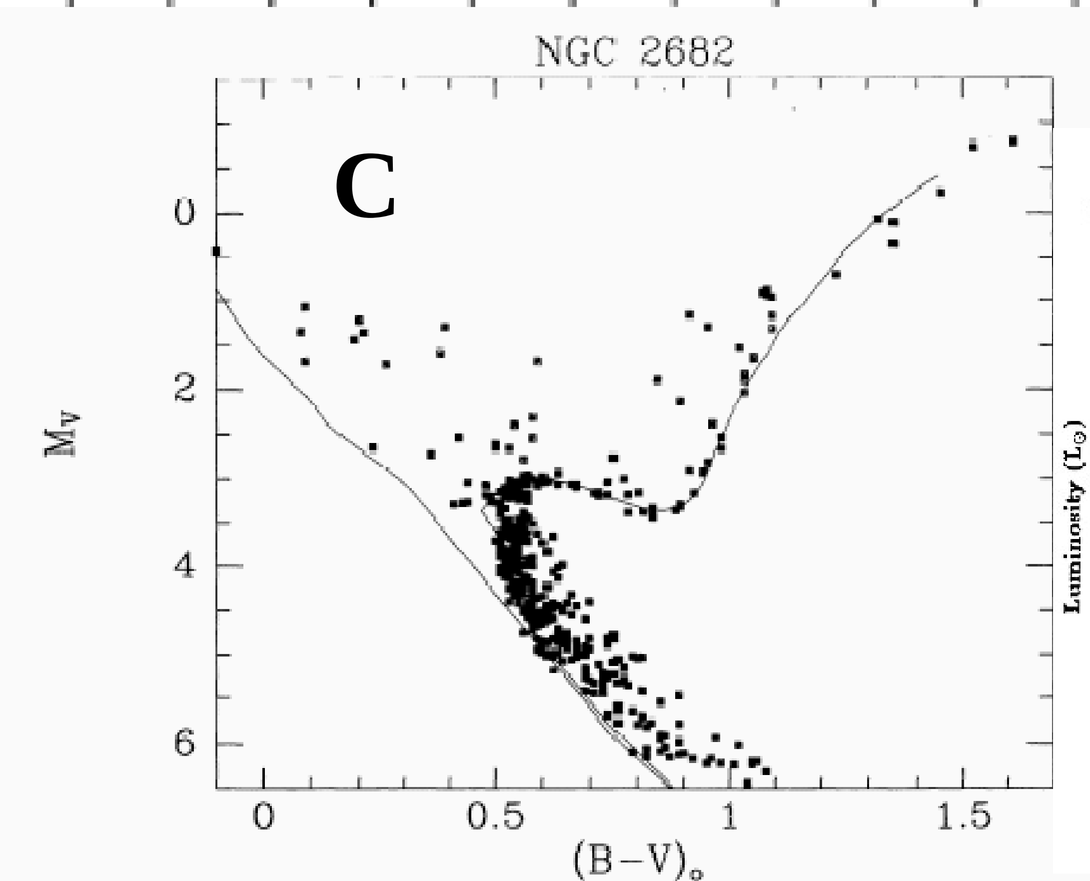
Which is older, M67 or NGC188?

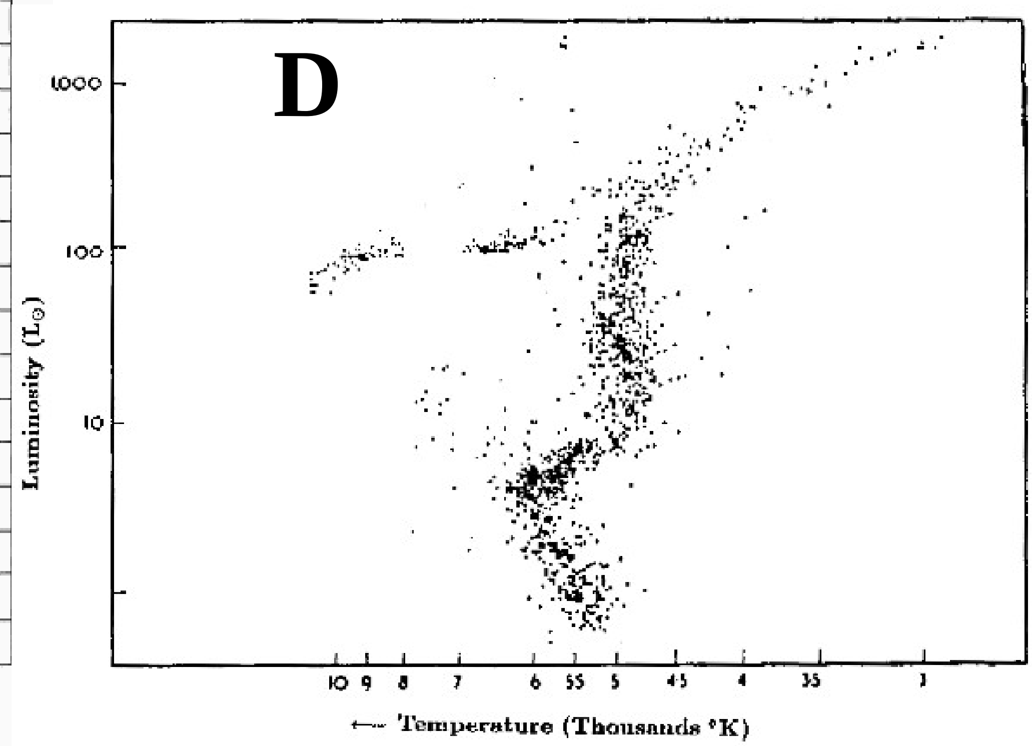


Quiz 8. Which cluster is the youngest?









This is a cluster.
Compared to how far away this is from us, the distance across the cluster is tiny.
The estimate that the stars in this cluster are all at the same distance from us is good.

What is the difference between star A and B? Assuming the dots are the same size.
(other than color & temperature.)

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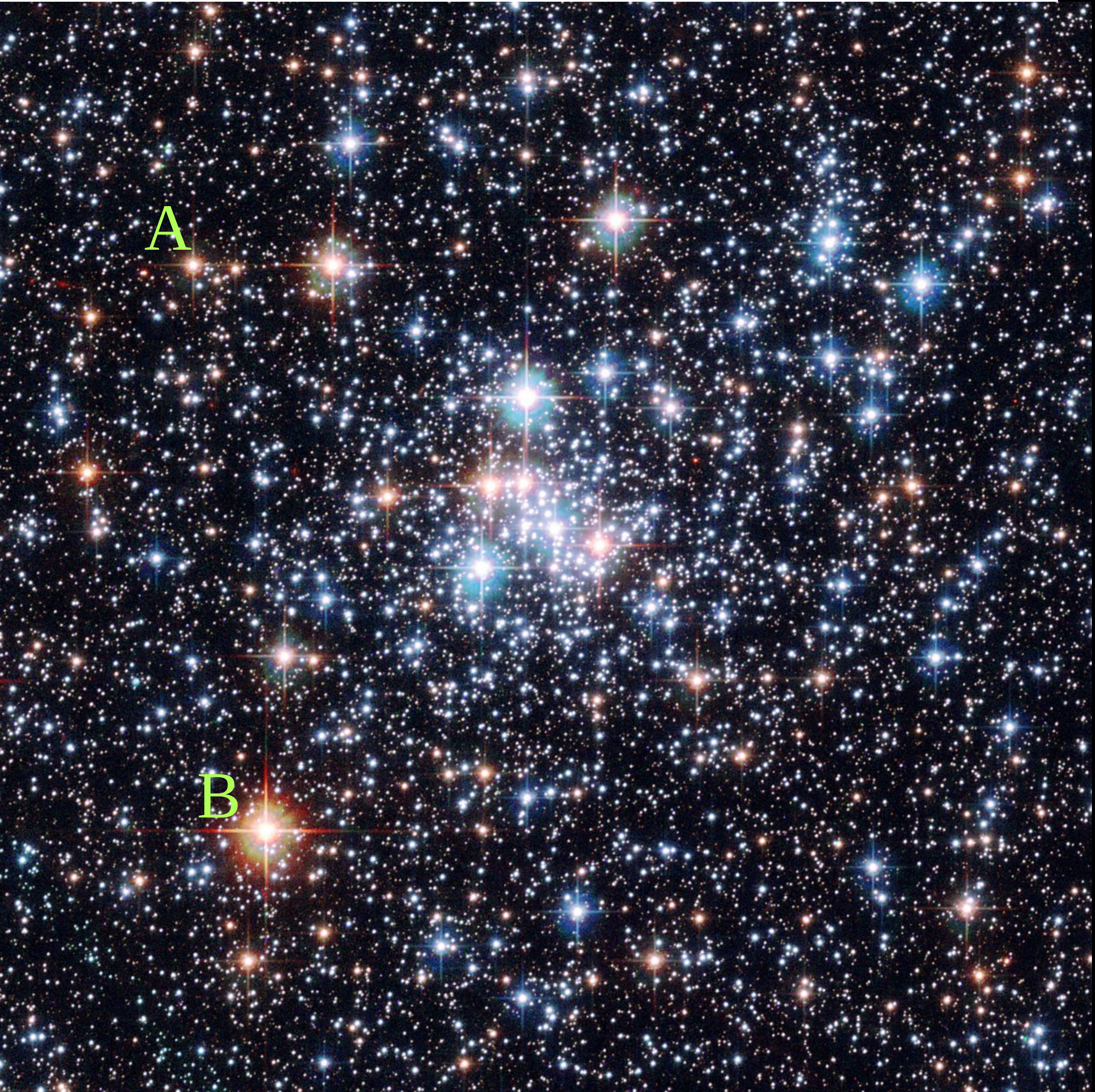
$L_{ap}=R^2T^4/d^2$

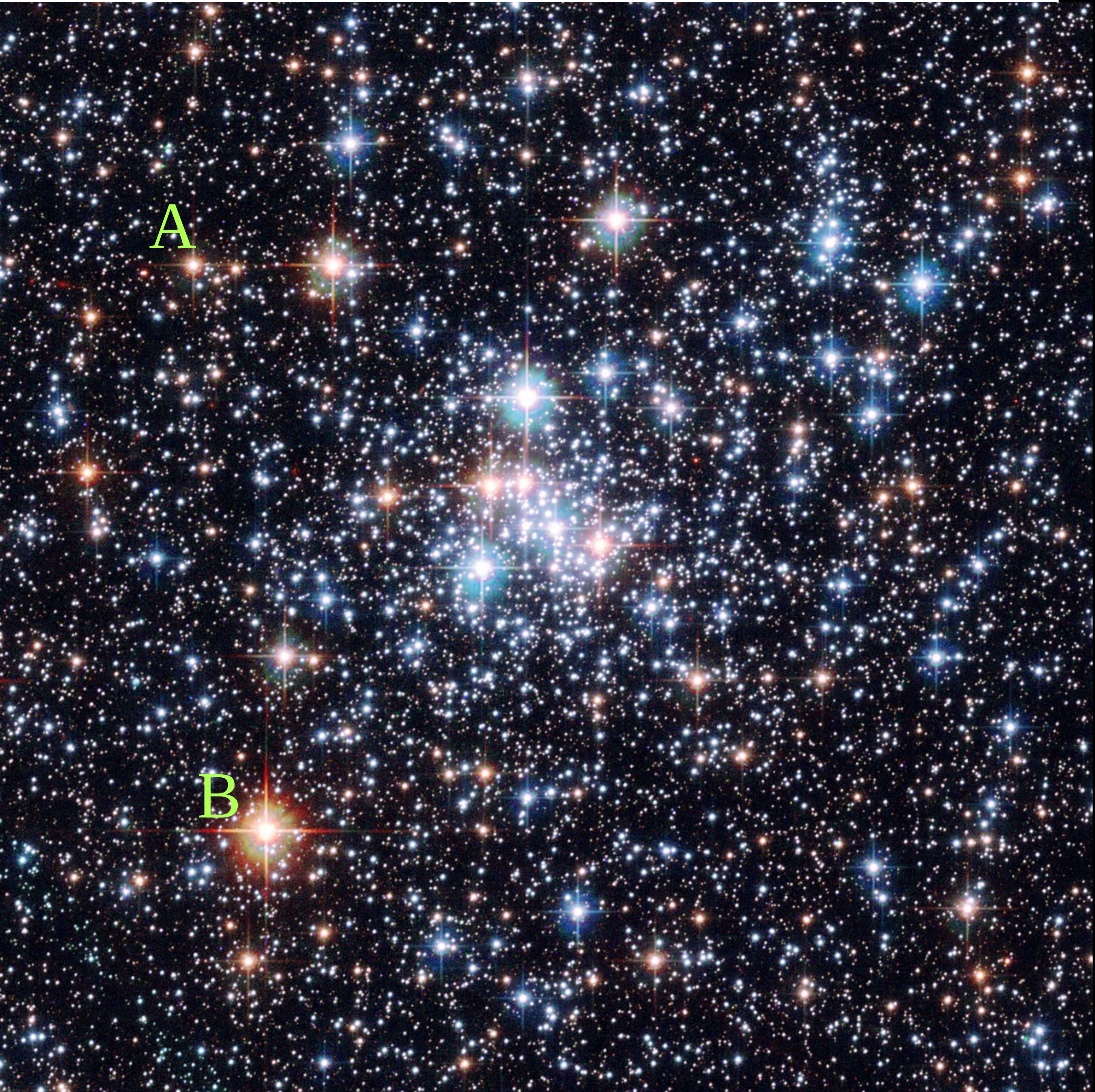
But d is the same.

So B must be larger than A

$R_B>R_A$



What is the difference between star A and B? Assuming the dots are the same color.



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$L_{ap}=R^2T^4/d^2$

But d is the same.

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This is a famous double-star Albireo.

Since they are in a binary, they are at the same distance from us.

So what do we know about the sizes (radii) of the blue and red star?

What do we know about the sizes (radii) of the blue and red star?

$L_{ap}=R^2T^4/d^2$

But d is the same.

So the red star must be larger than the blue star

So what?

So what's the big deal about the main sequence lifetime, or why are most stars we see on the main sequence?

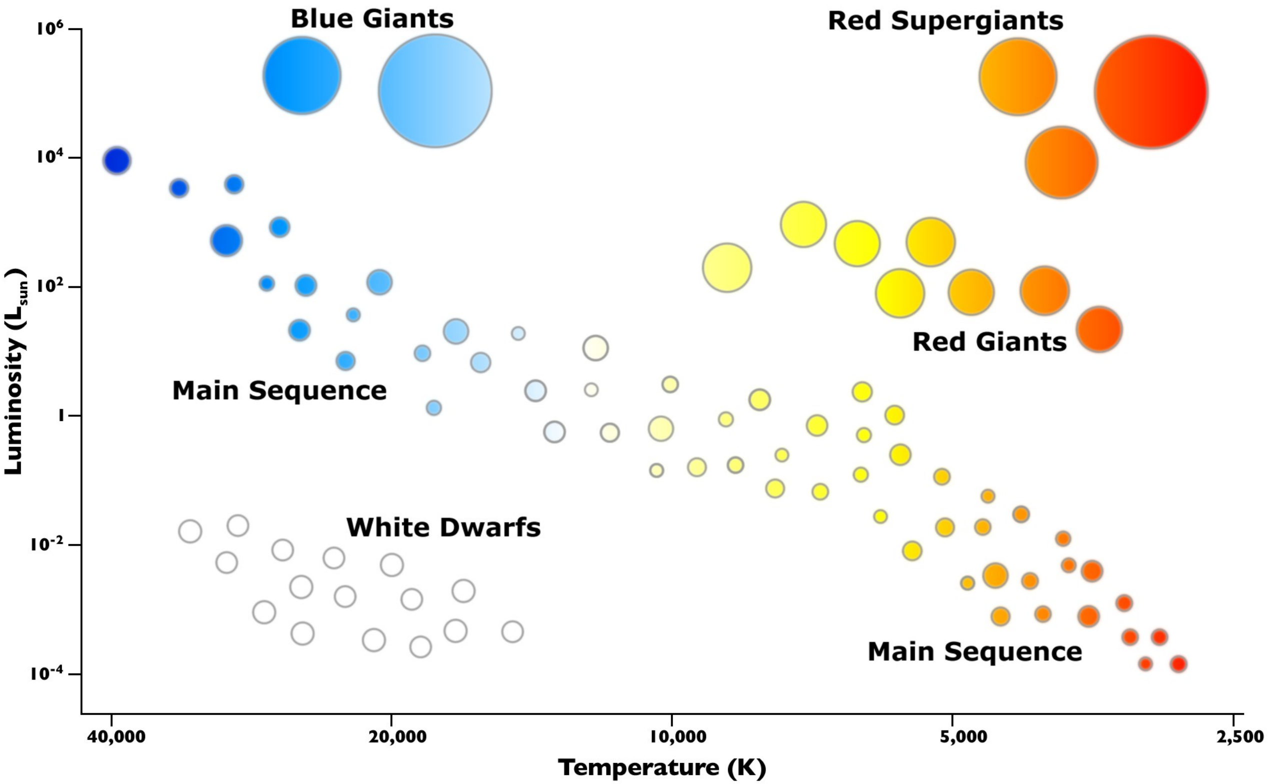
Stars spend 90% of their lifetime (some kind of energy generation) on the main sequence.

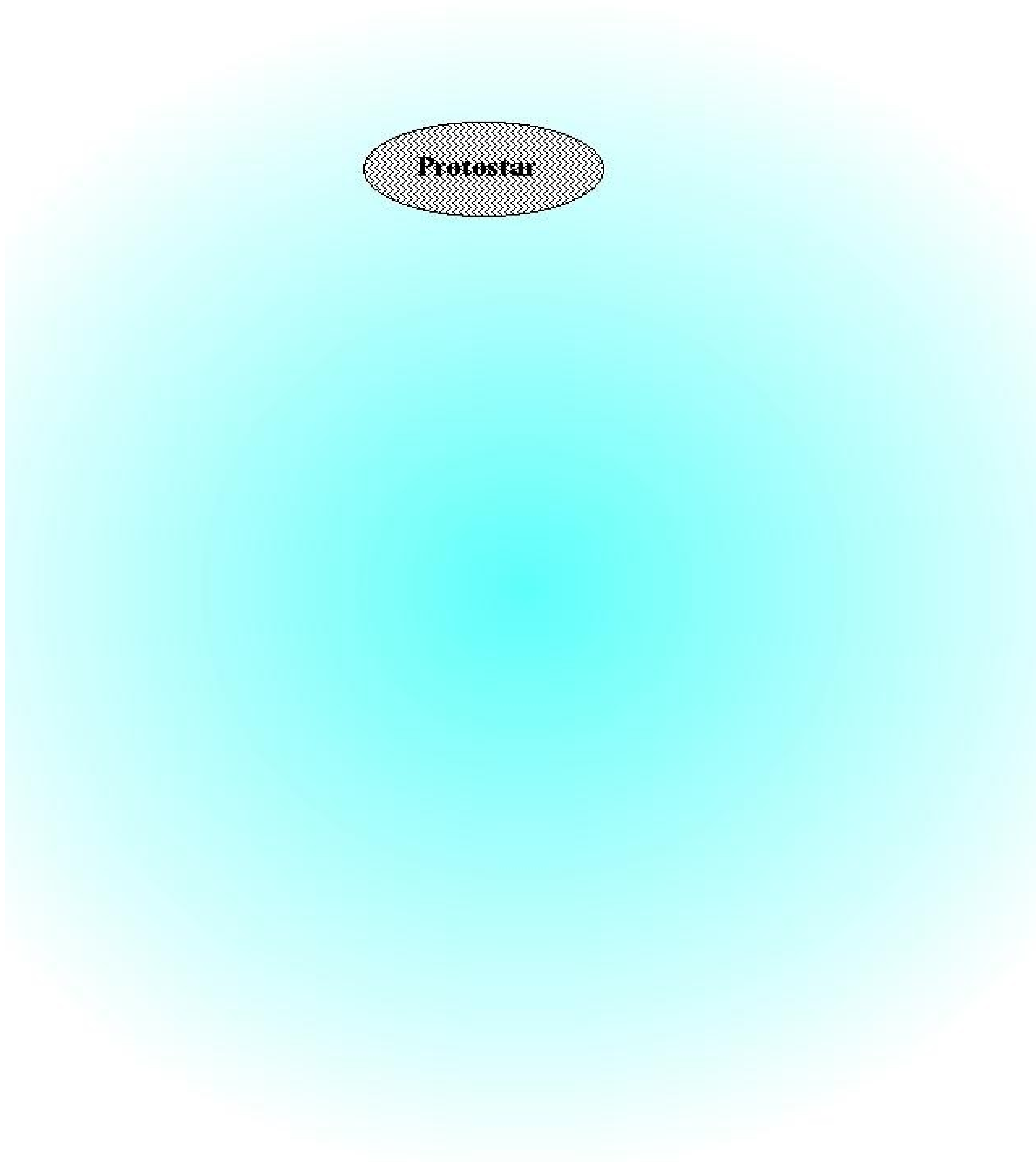
That brings us to stellar evolution!

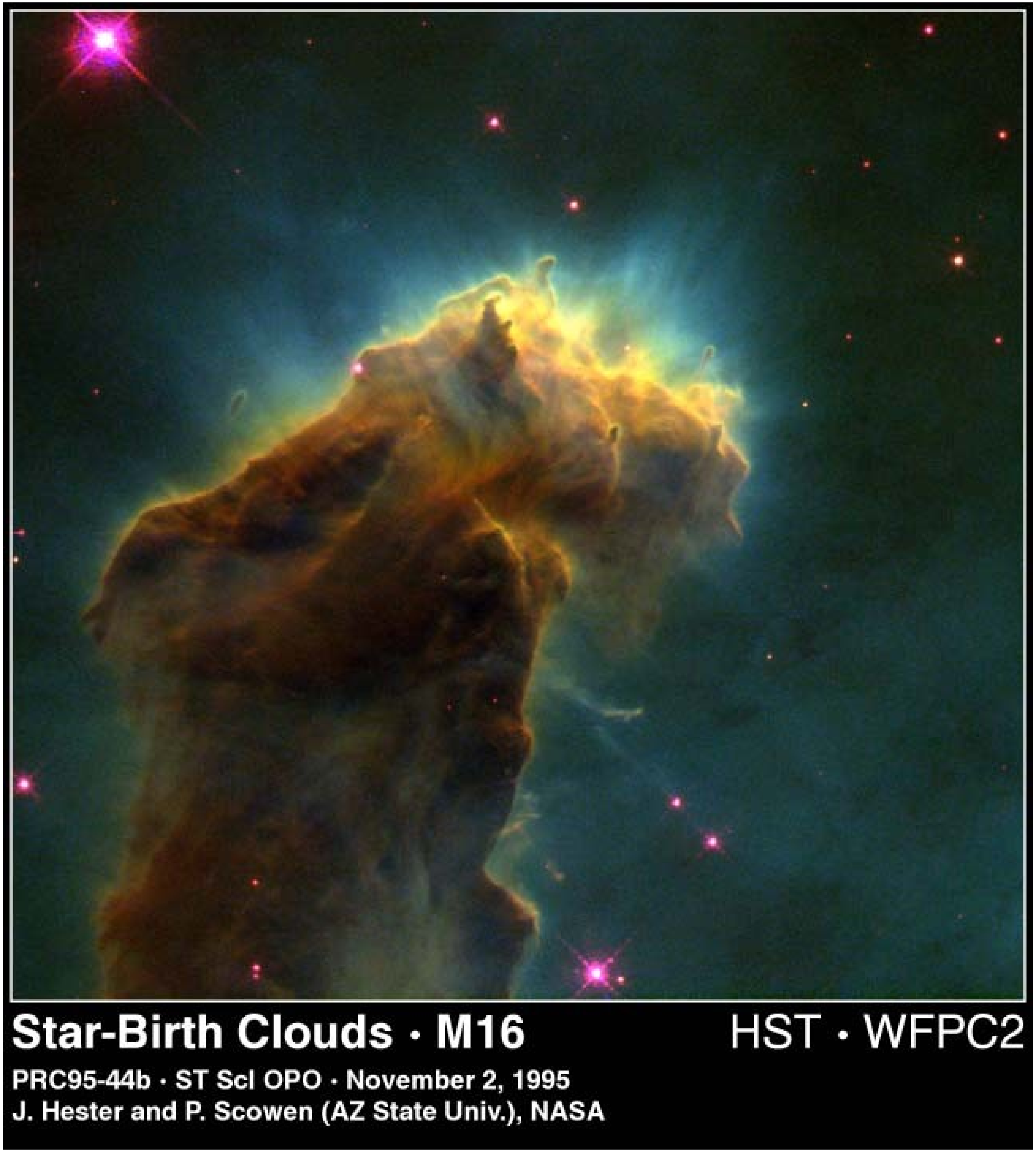
Or the third part of the Russell-Vogt theorem: Age.

We've already determined that massive stars have much shorter main sequence lifetimes than lower mass stars. So when the Russell-Vogt theorem says "age" we really mean "stage".

Stars have several "stages" of evolution.




Protostar

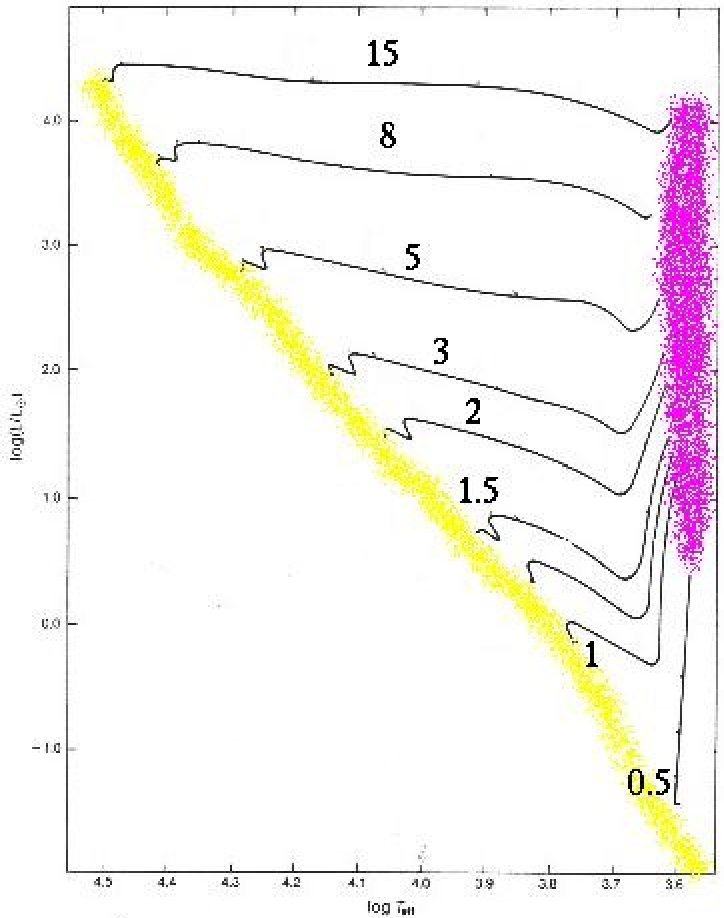


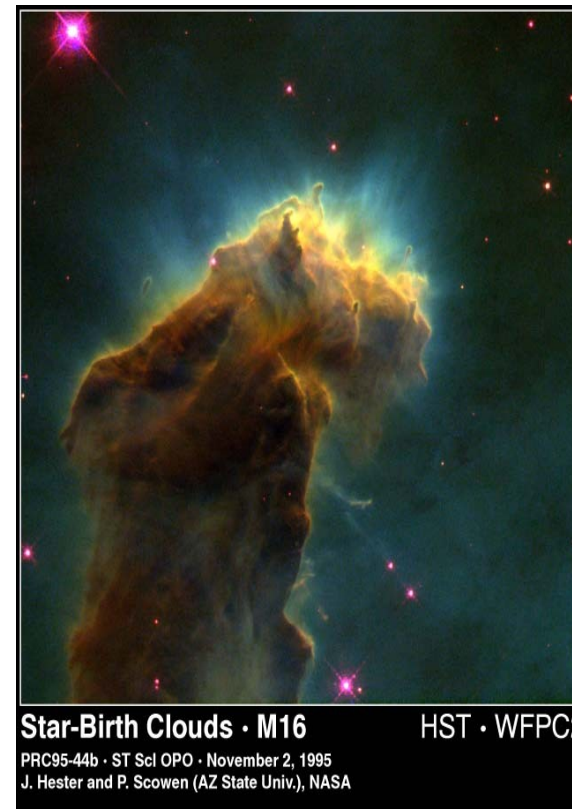
Stage 1: The birth of stars.

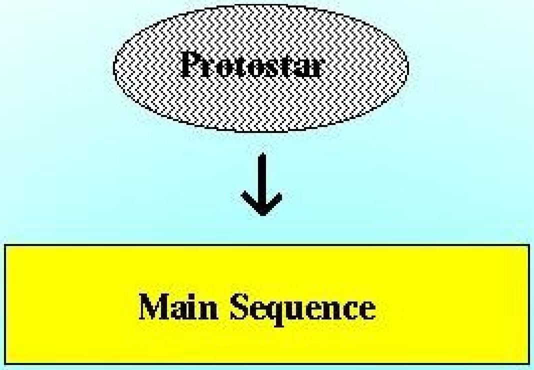
Stars are made from large molecular clouds of gas.

The clouds get slightly disturbed (by outside influences) and begin to collapse

The gas collapses under it's own weight. This converts gravitational energy to heat. (Just like in making our solar system.) As stars first become visible inside their collapsing gas cloud, they are called Protostars. Their energy source is gravity.



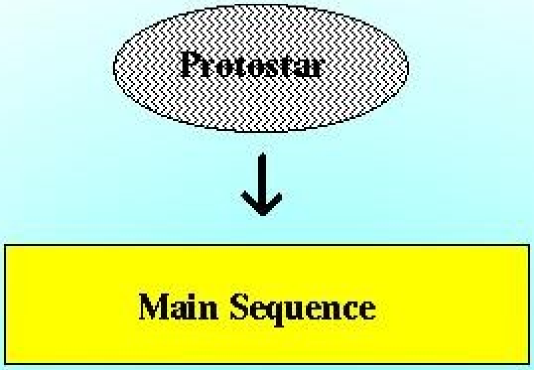




Stage 2: When stars are hot enough for nuclear fusion to occur in their core, they become Main Sequence stars.

This is where stars spend 90% of their lifetime fusing H to He.

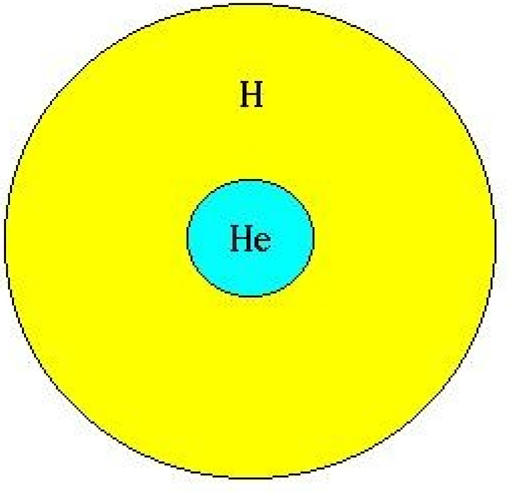
And 90% of main sequence stars are spectral class G or later (K, M)

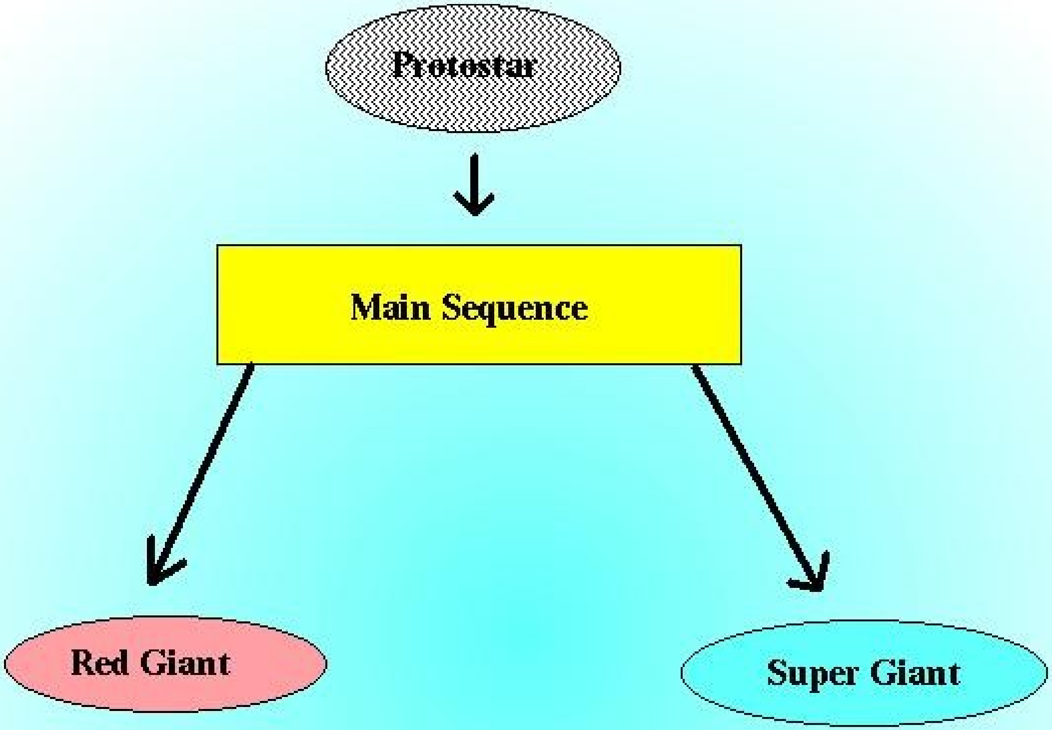


Stars leave the Main Sequence when they stop burning hydrogen in their core.

This happens when only 10% of their total hydrogen is converted to helium.

This is the structure of stars as they leave the Main Sequence.

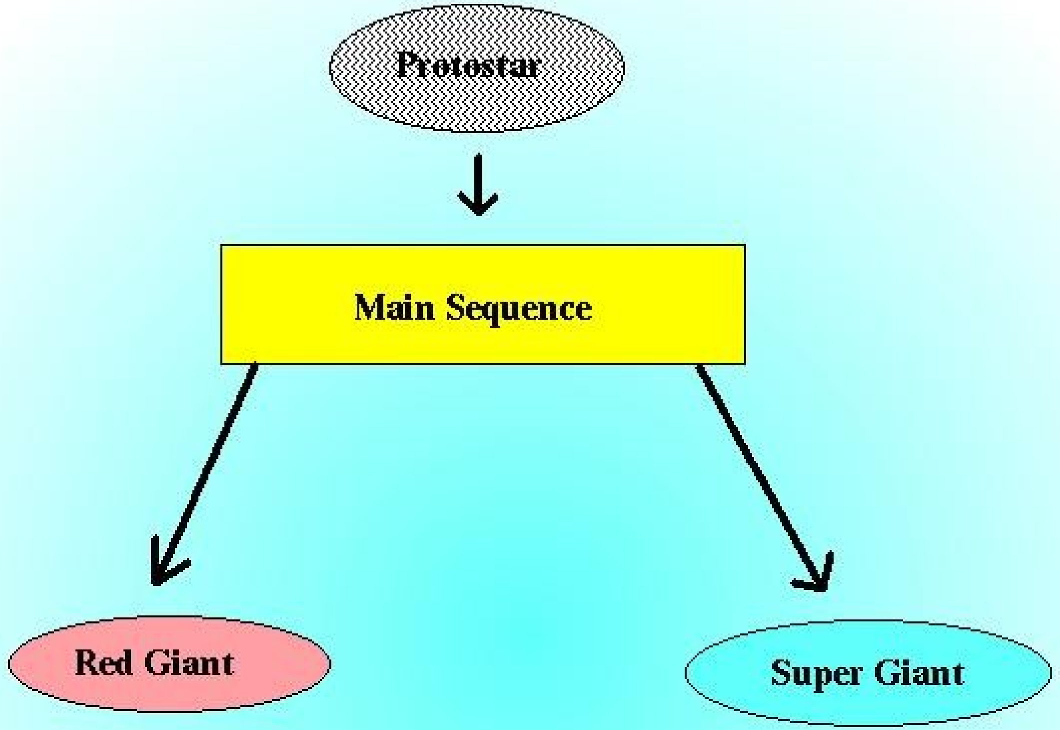




Stage 3: Evolution divides into 2 cases:

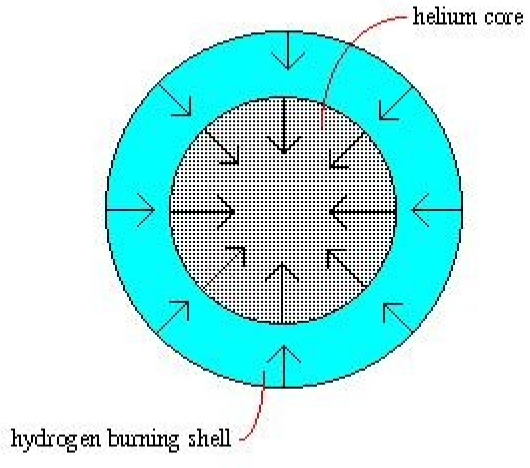
Stars less than $8M_{Sun}$ become Red Giants

Stars more than $8M_{Sun}$ become Supergiants



We will start with the Red Giants, and leave the Super Giants hanging for a while.

Just the core:



During the Red Giant phase, the core is shrinking (and getting hotter) and the shell surrounding the core is burning H and expanding.

Evolution so far:

Protostars: get energy from gravity (shinking)

Main Sequence: get energy from converting H to He in their cores

Red giants: get energy from shrinking core and shell H burning.
He core shrinks, H shell expands. The main energy source is gravity