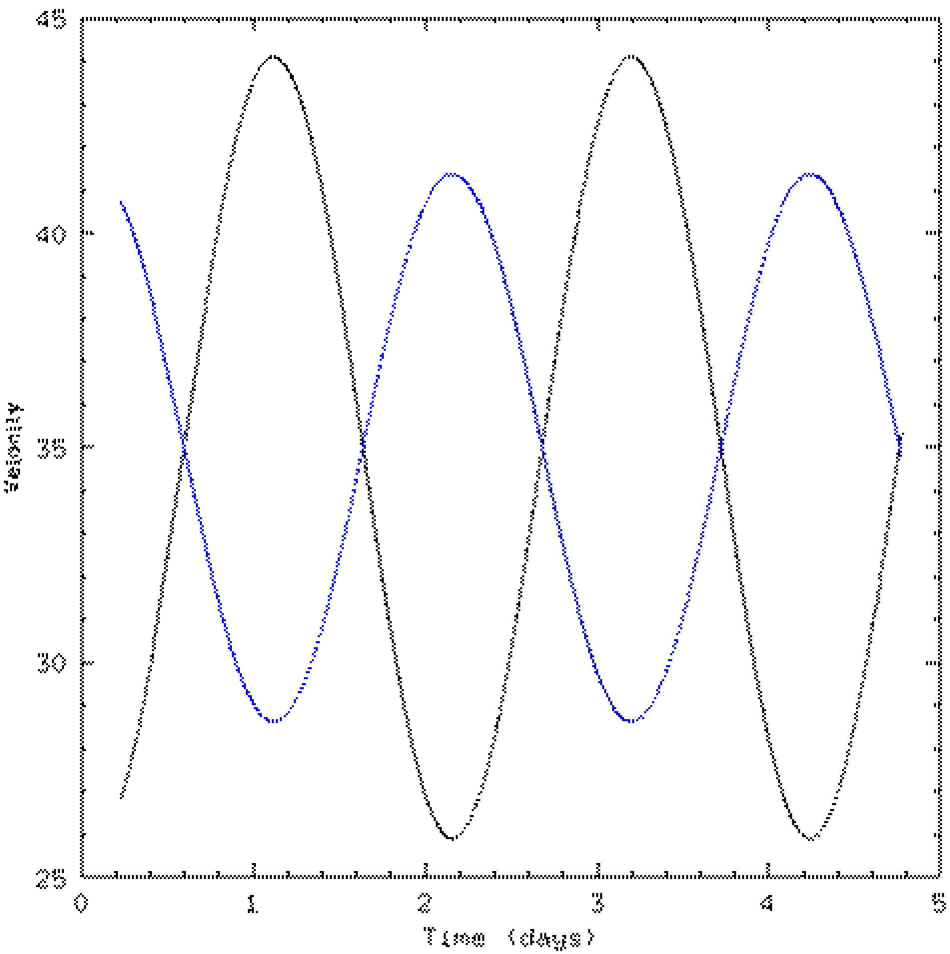
"Good people do not need laws to act responsibly, while bad people will find ways around the laws."

Plato

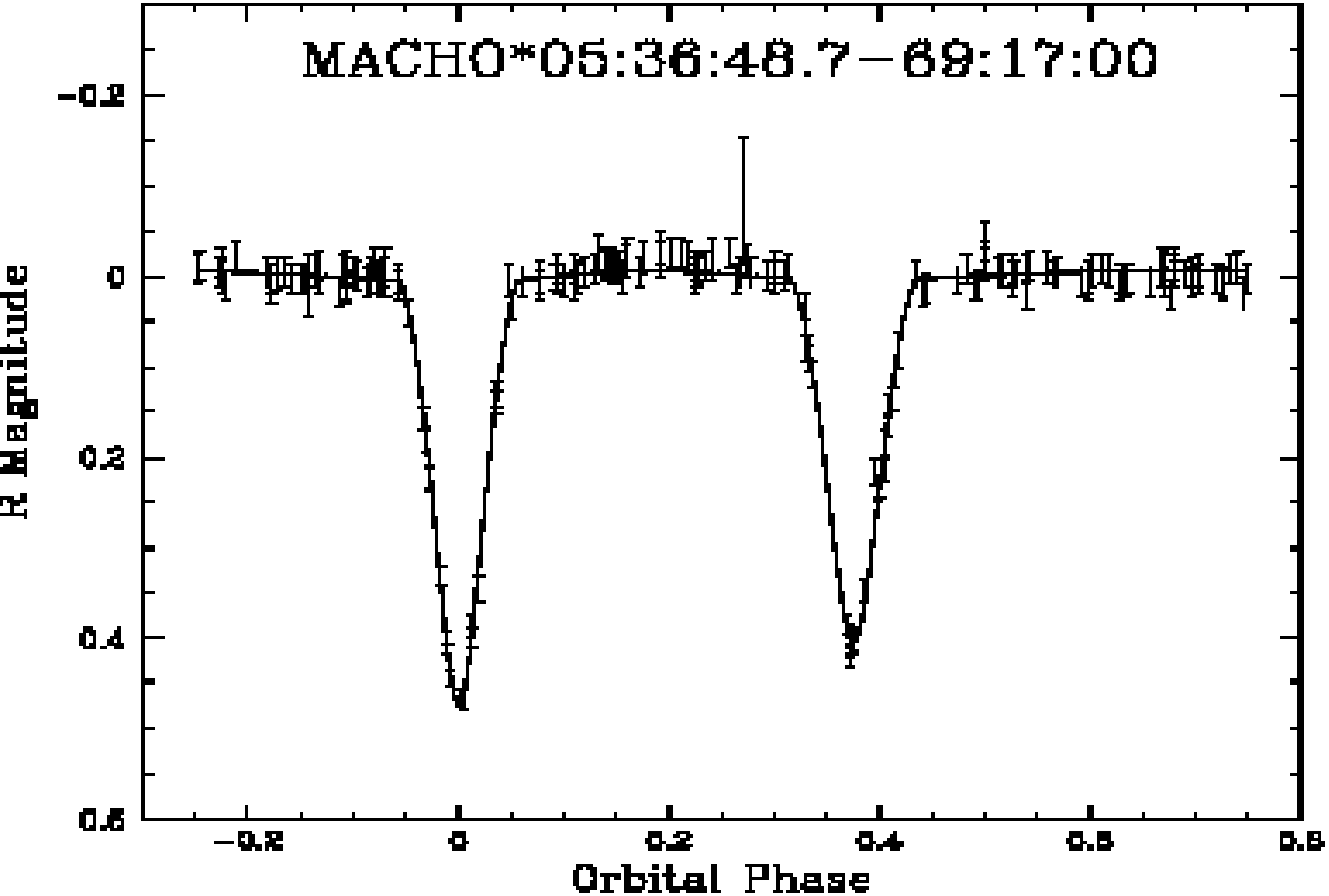
Because the blue track is for a star with slightly more mass than the black track. The star with the most mass moves the least.



Binary stars give us <u>mass</u>.

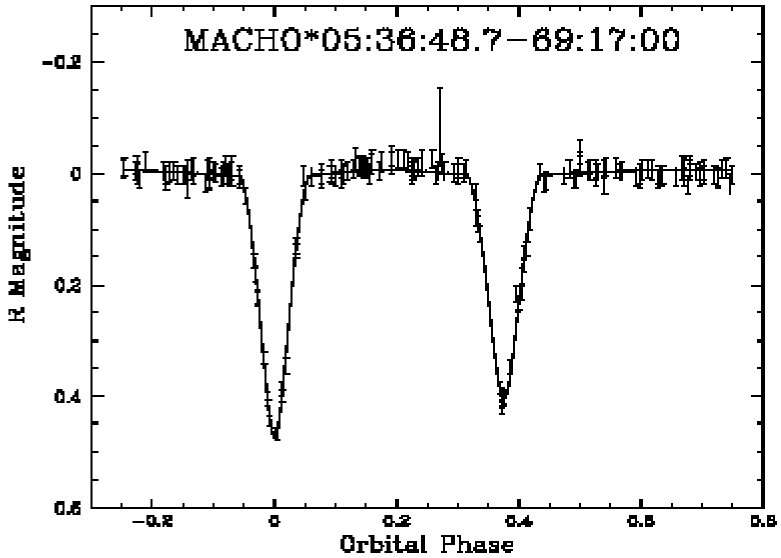
This is important! The *only* way we can determine masses of stars (besides our Sun) is from binaries!

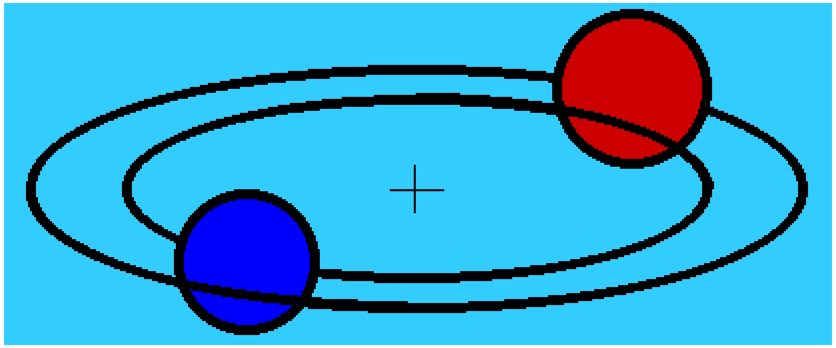
Binary stars can also give extra information.



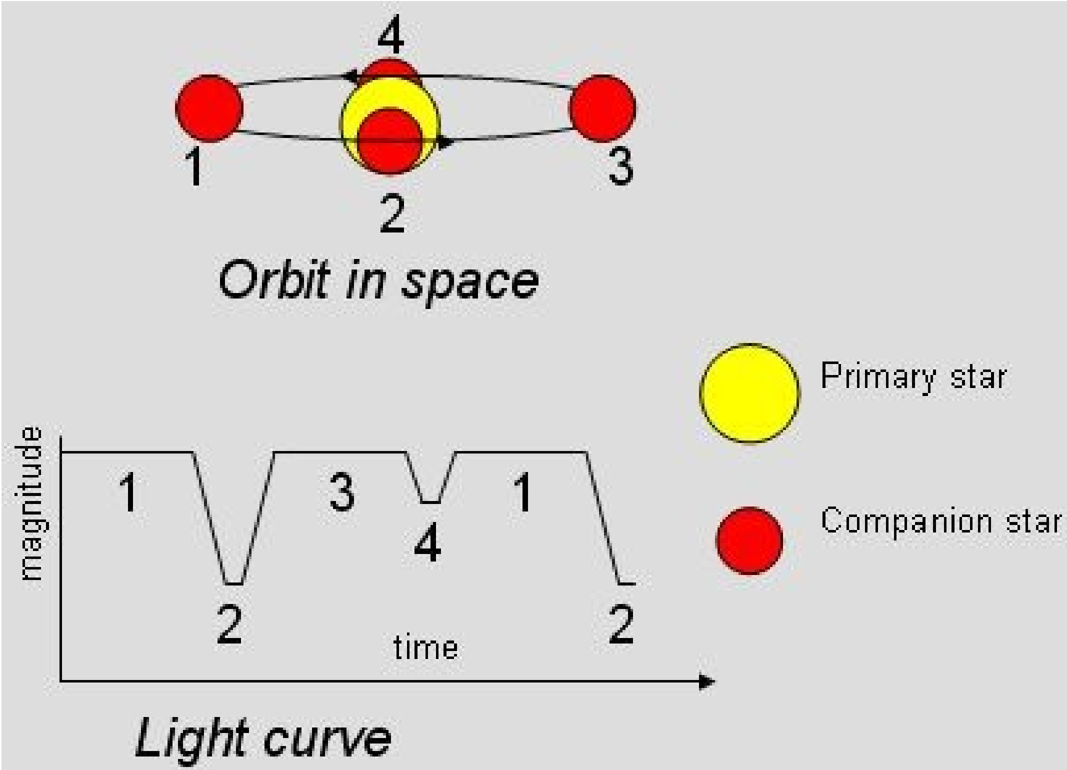
This is actual data. The y- axis is brightness and the x-axis is time through one orbit. Why is the brightness changing?

Because this is an eclipsing binary.





As one star passes in front of another star, the total light is reduced.



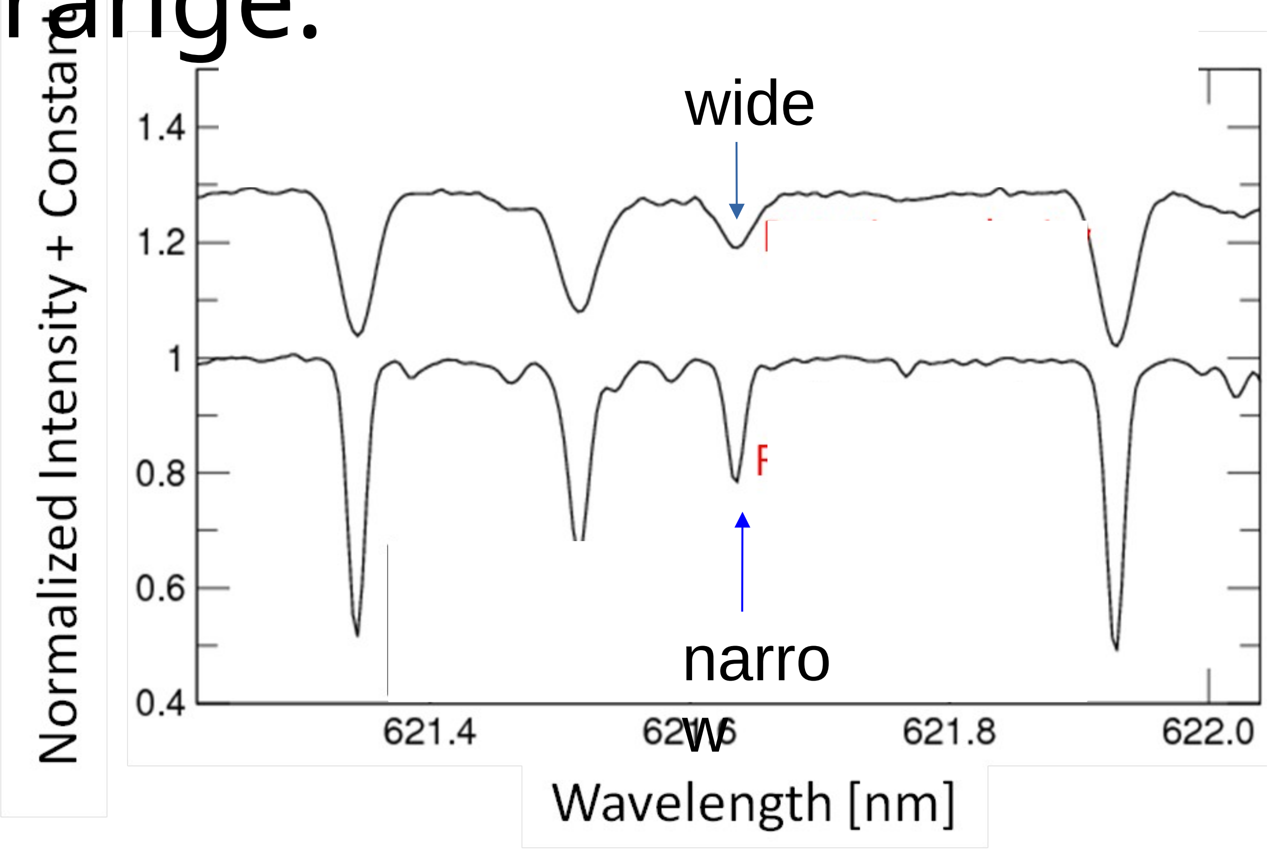
This is an eclipsing binary.

As one star passes in front of another star, the total light is reduced. For such cases, we get extra information: Not only

mass, but size and distance too.

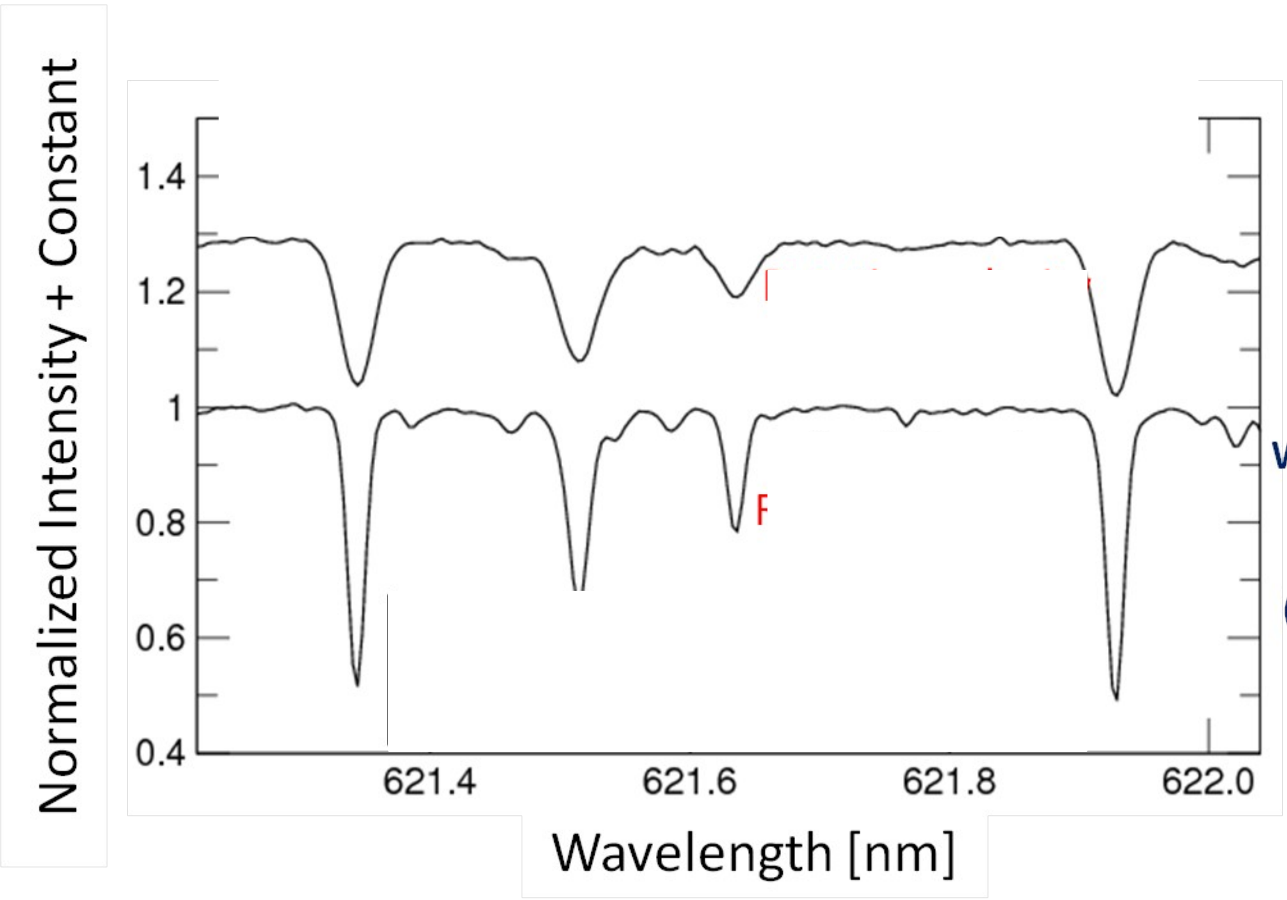
But there's more!

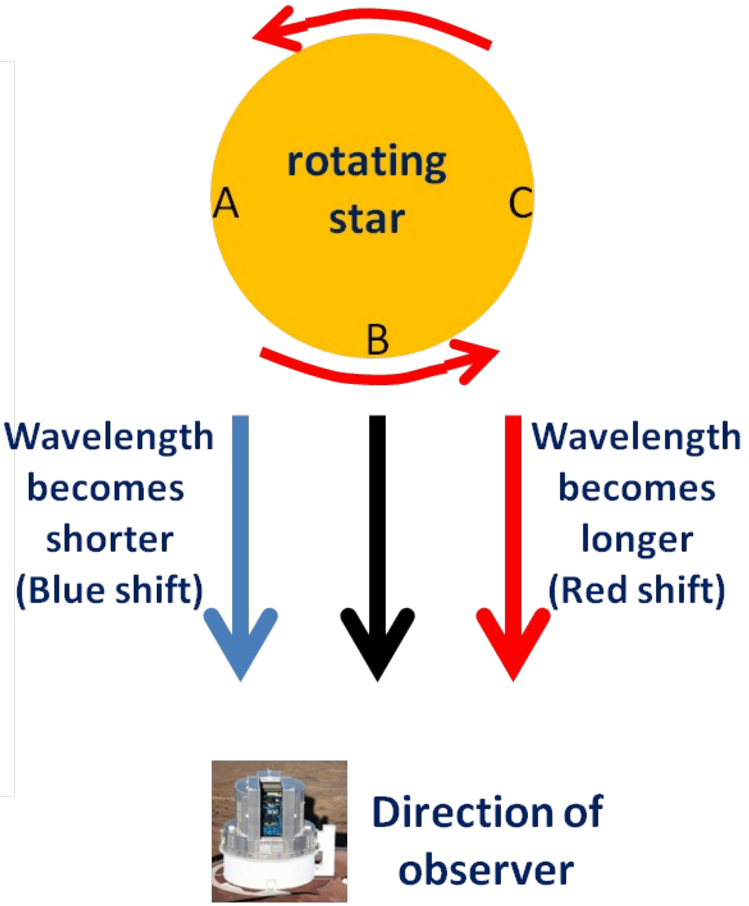
Two spectra covering the same range.



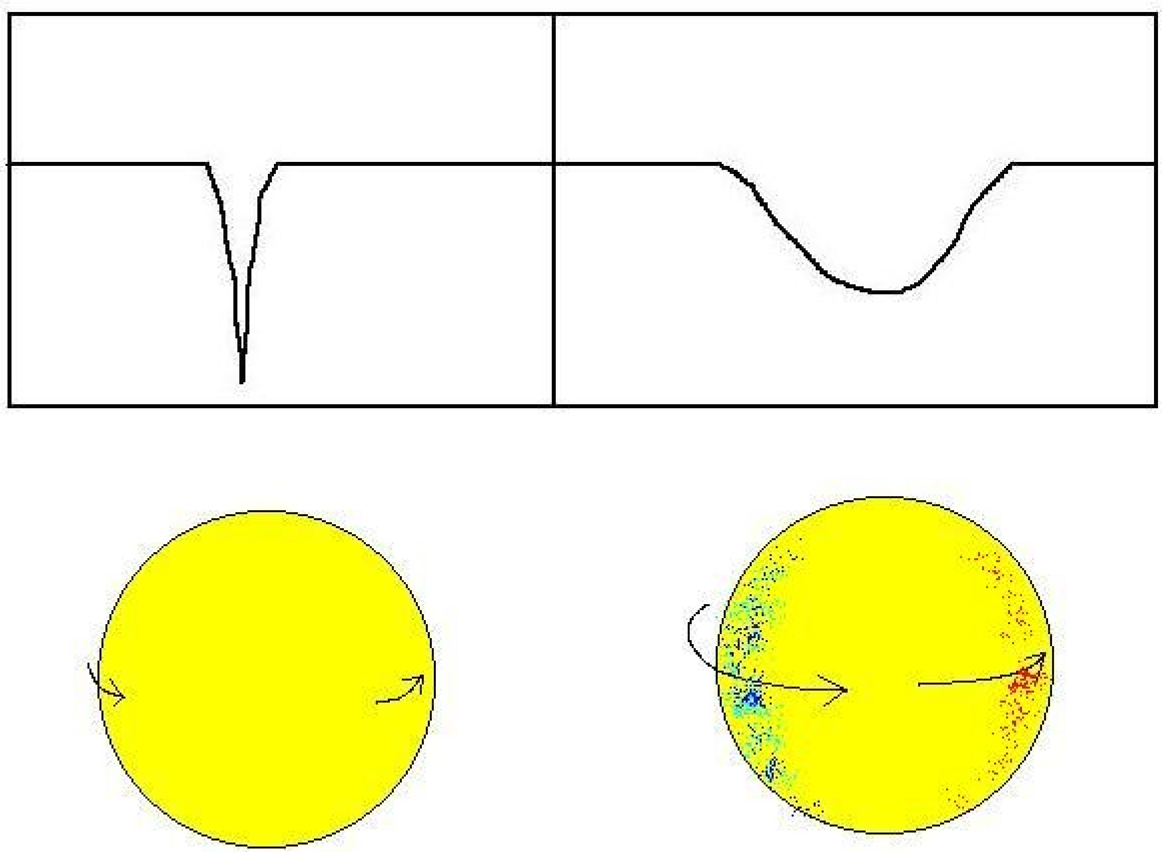
Why are the same lines in one star wider than in the other?

From the width of the lines we can get spin- again, just Doppler shift.





The star on the left is spinning slowly, so the line appears normal. The star on the right is rapidly rotating, so the left edge of the star is blueshifted, the right edge redshifted. This broadens (stretches) the lines.



We want to know:

- How hot are stars? ✓ $T = 2.9x10^6/\lambda$
- How BIG are stars (size)? ✓ Parallax, Eclipsing binaries
- How massive are stars? ✓ Binaries
- What are stars made of? ✓ Spectral lines: H, He
- How much energy do stars emit ✓ Luminosity
- Where does that energy come from? ✓ Fusion: $E=mc^2$
- How far away are stars? ✓ Parallax, eclipsing binaries.

Holy cow, that's everything!

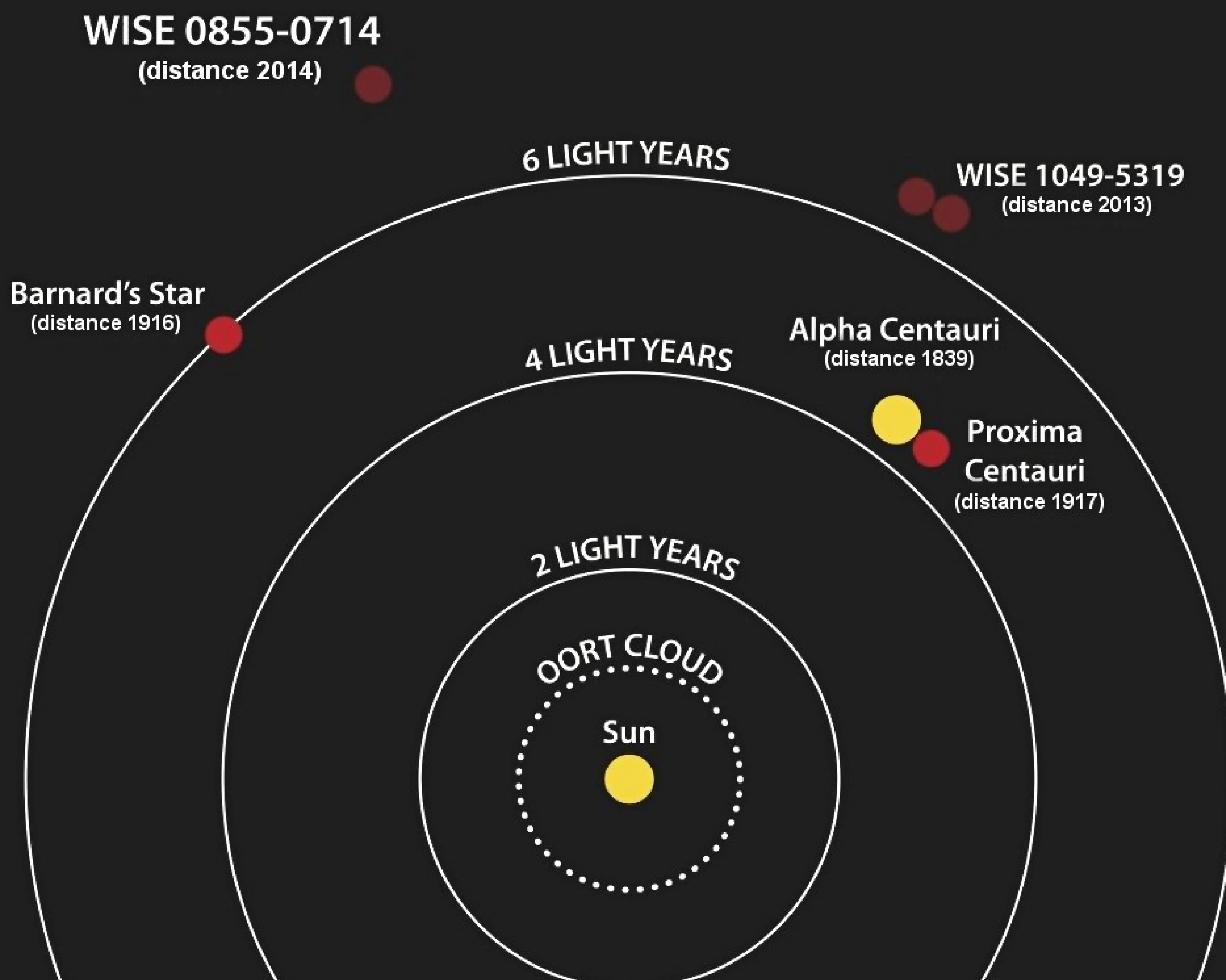
Plus spin, the structure of the Sun, neutrinos, etc.

Reminder: How to make a star brighter: $L_{ap}=R^2$📅T^4/d^2

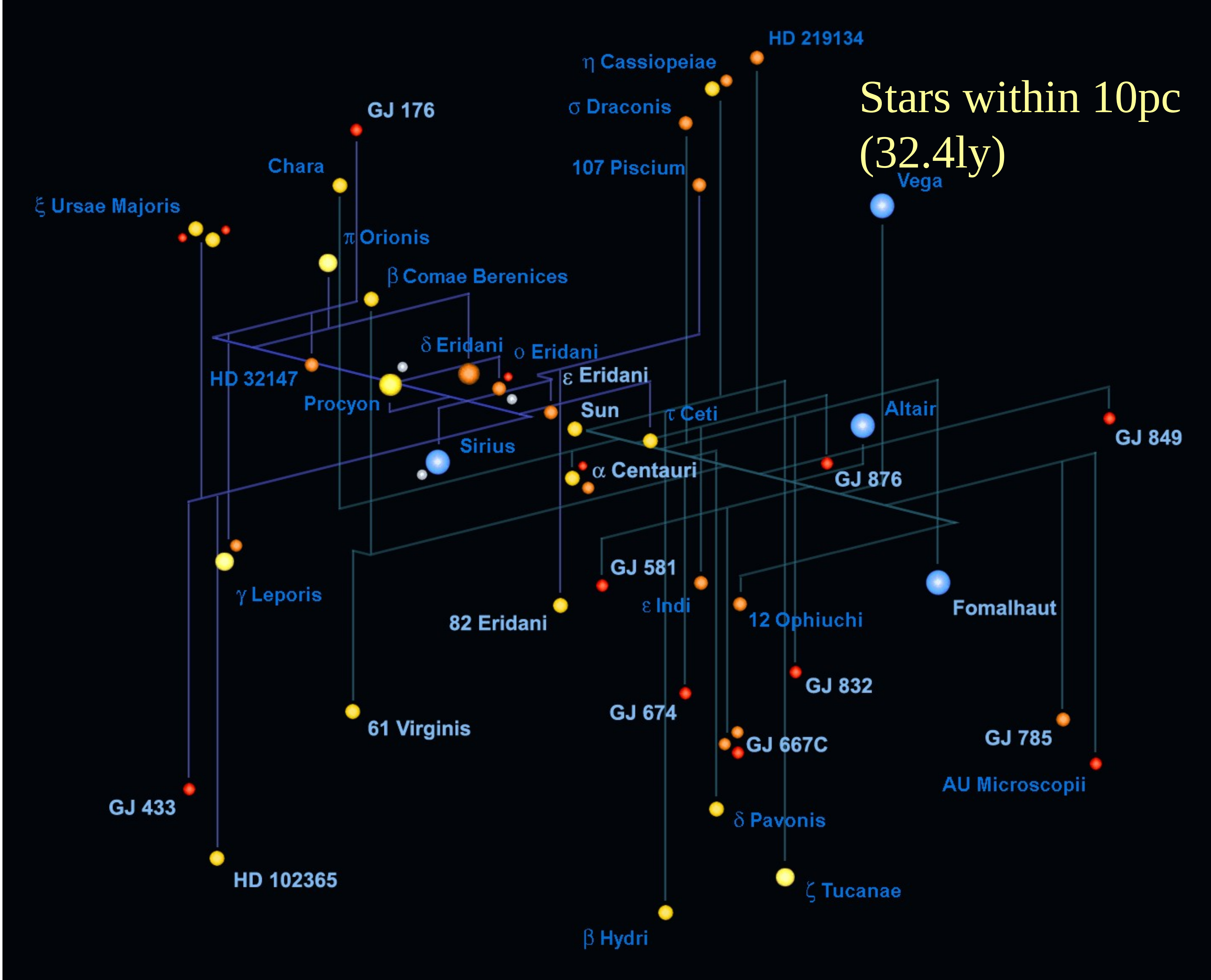
- Make it hotter: $E \sim T^4$
- Make it bigger: $E \sim R^2$
- Make it closer: $E \sim 1/d^2$

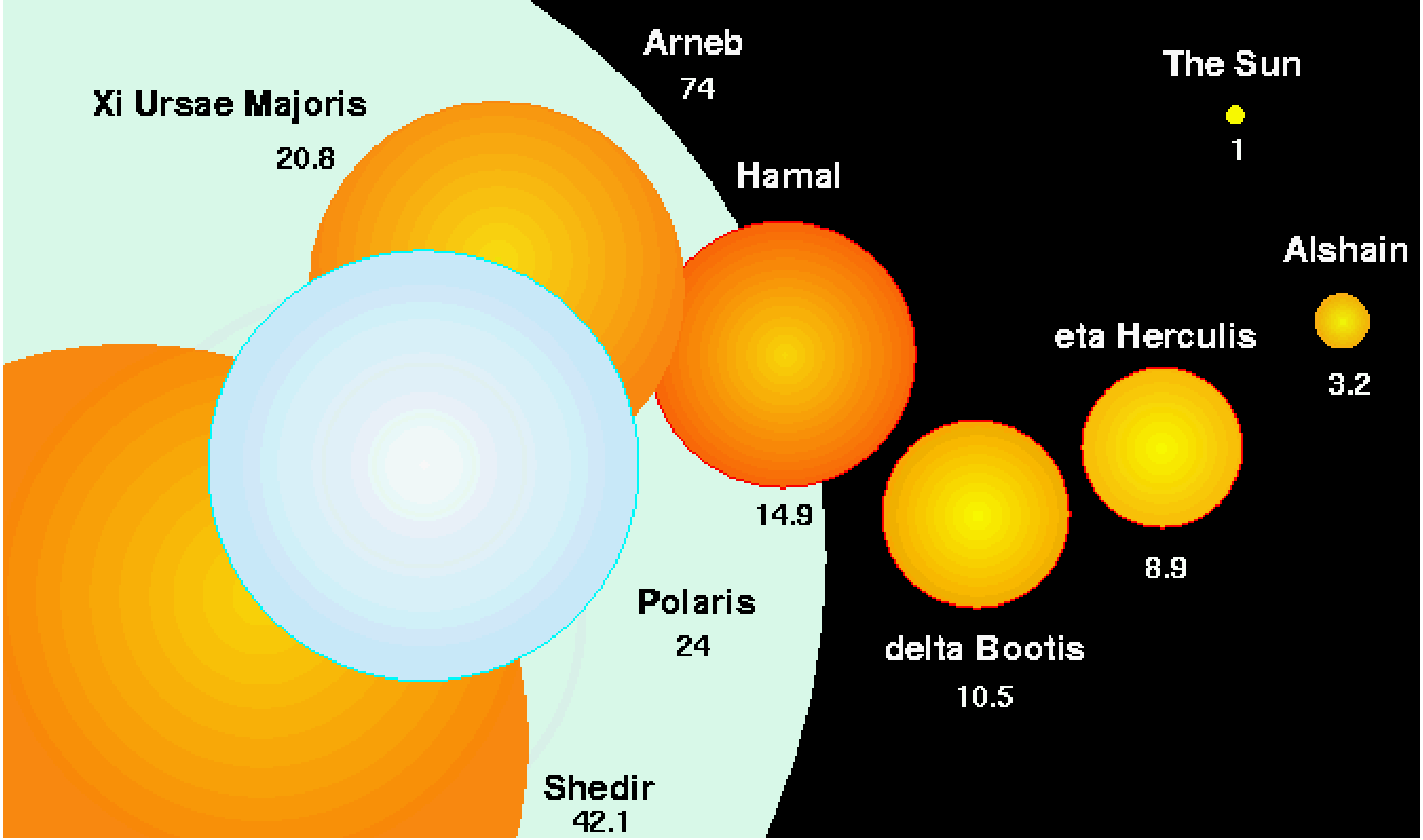
Hotter is most powerful.

THE SUN'S CLOSEST NEIGHBORS

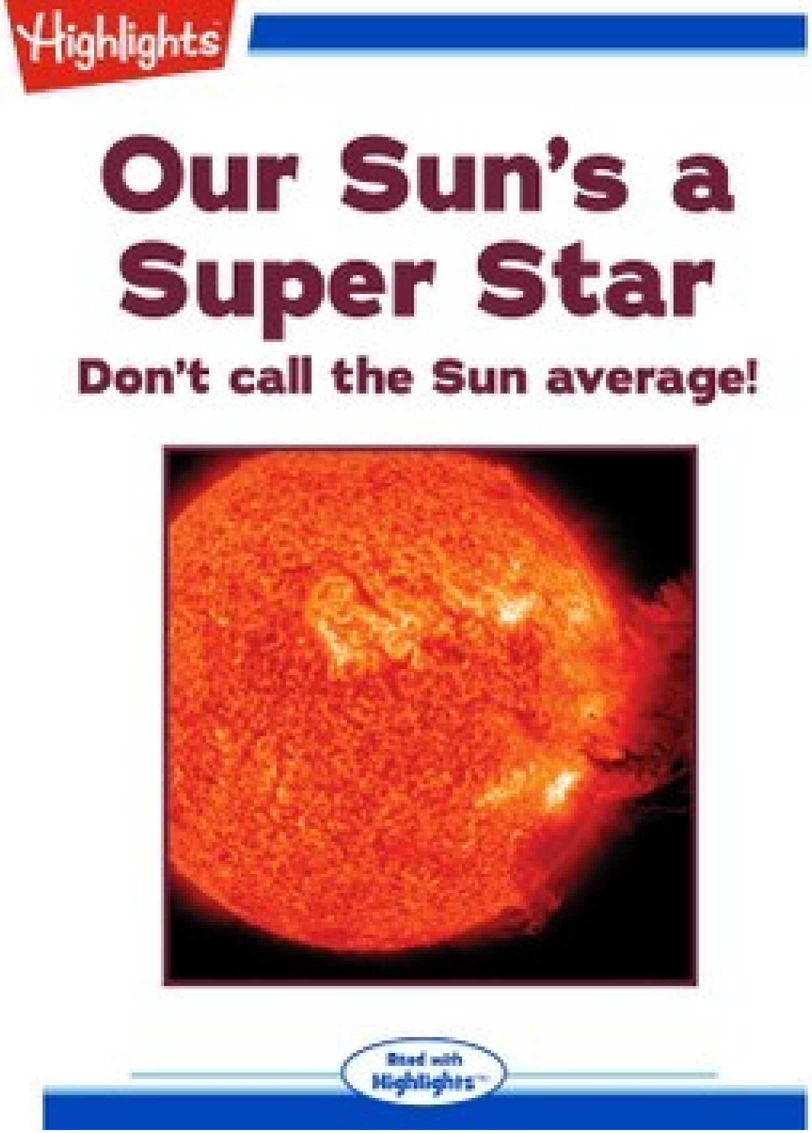


Stars within 10pc (32.4ly)





Stars come in a great variety of sizes and masses.



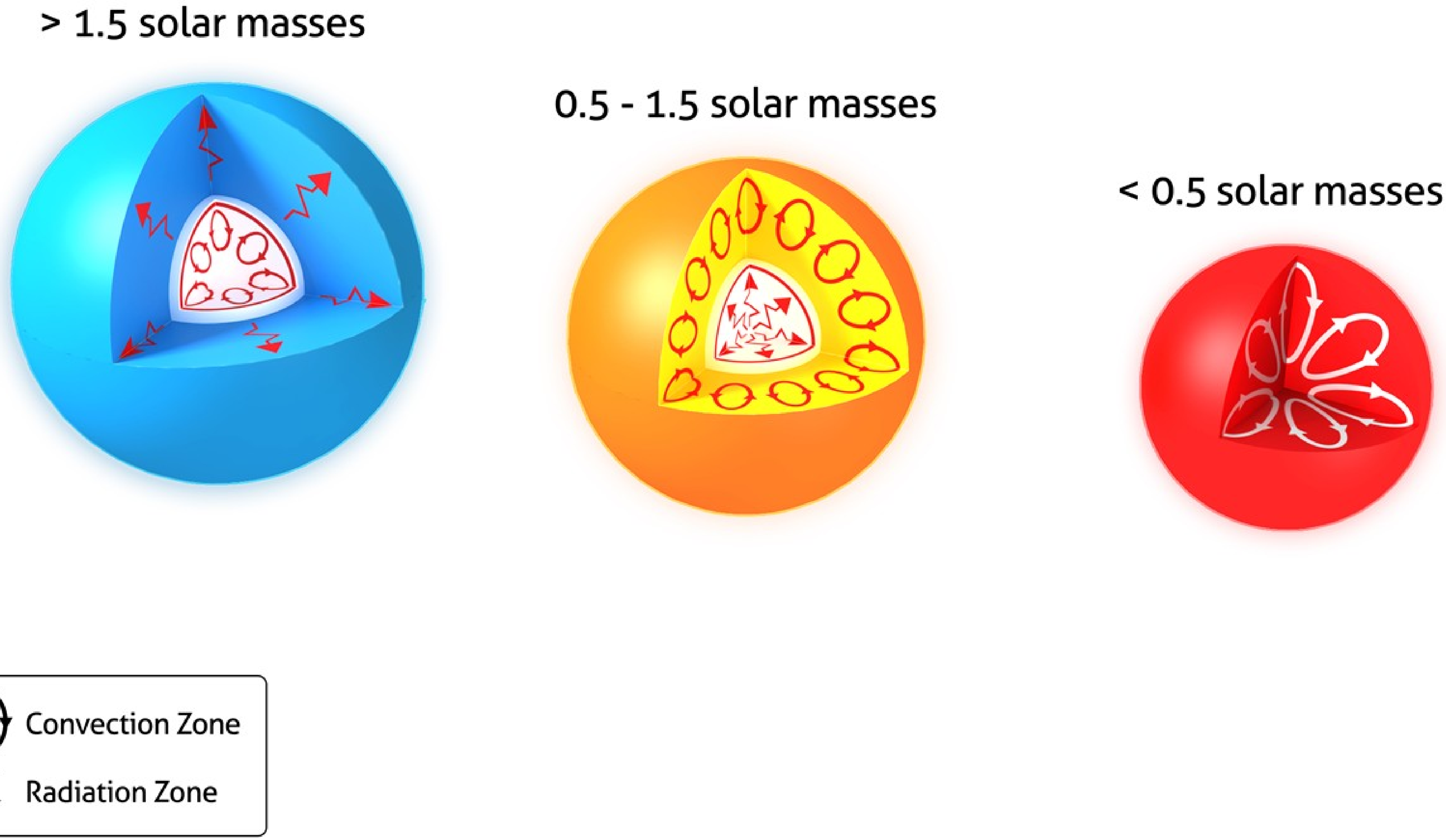
Most stars we see are larger and/or hotter (more massive) than our Sun.

But the most common stars have $0.0079L_{Sun}$, $T_{Surface}$=2,600K, $0.2M_{Sun}$, and $0.32R_{Sun}$

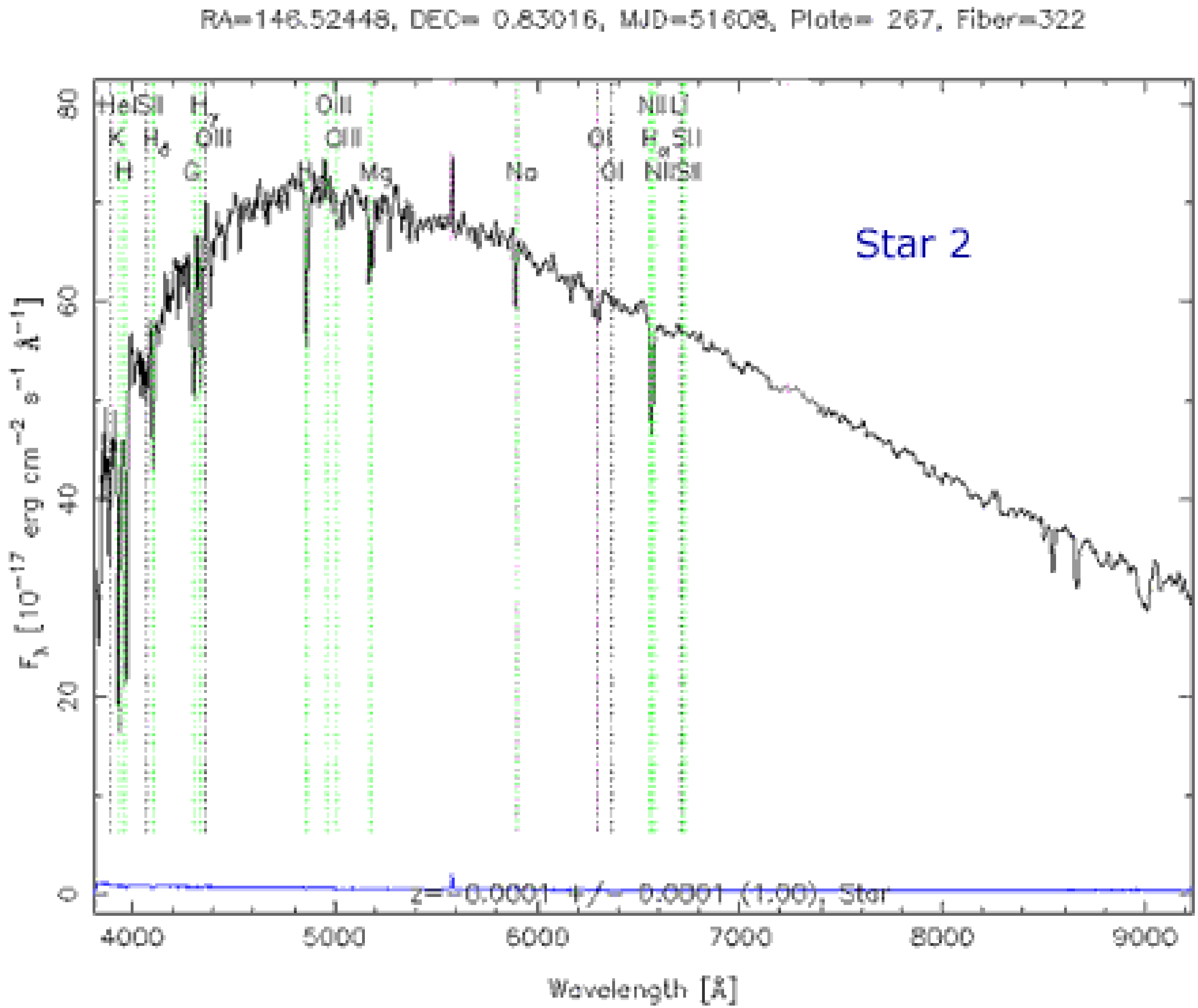
Stars within 10pc (33ly)

Objects	Systems	O	B	A	F	G	K	M	WD	BD	Planets
	Mass	40	17	2.5	1.5	0.9	0.7	0.3			
369	256	0	0	4	6	20	44	247	20	28	15
	$T_{surface}$(kK)	35	13.5	8.1	6.5	5.4	4.0	2.6			
	Radius	18	4.0	1.8	1.2	0.93	0.74	0.32			

Heat Transfer of Stars



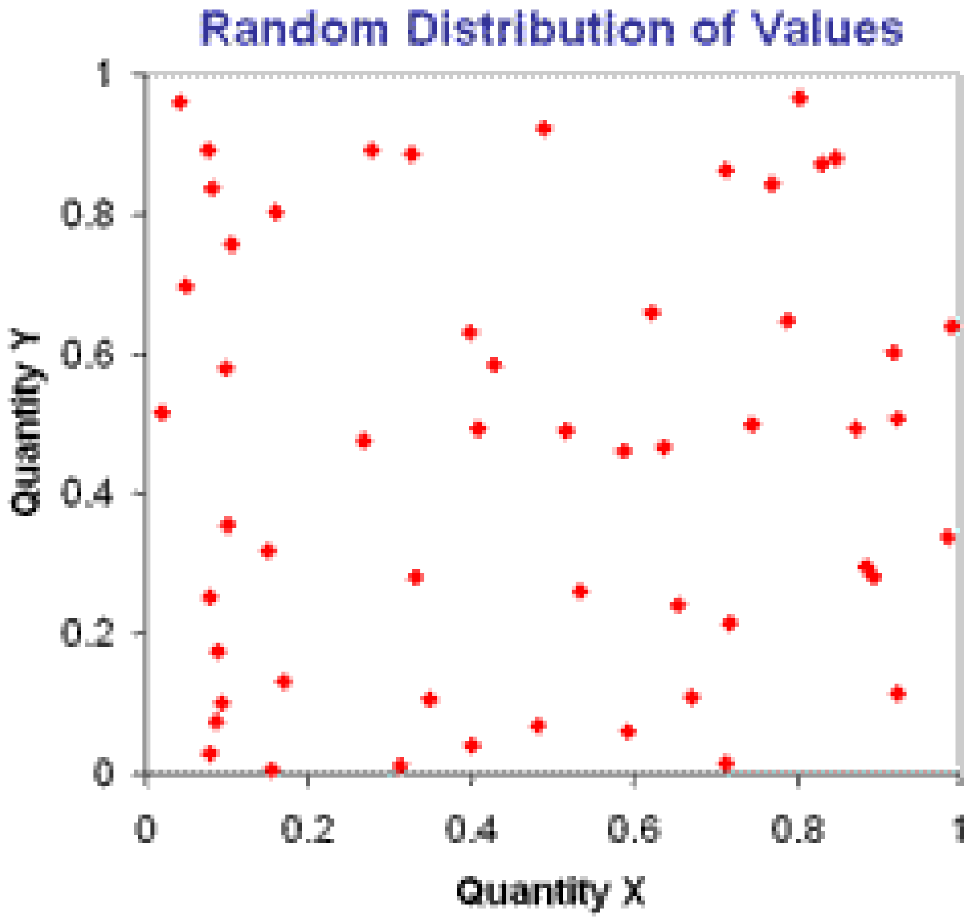
Stars have continuous spectra with absorption lines.



Classifying stars

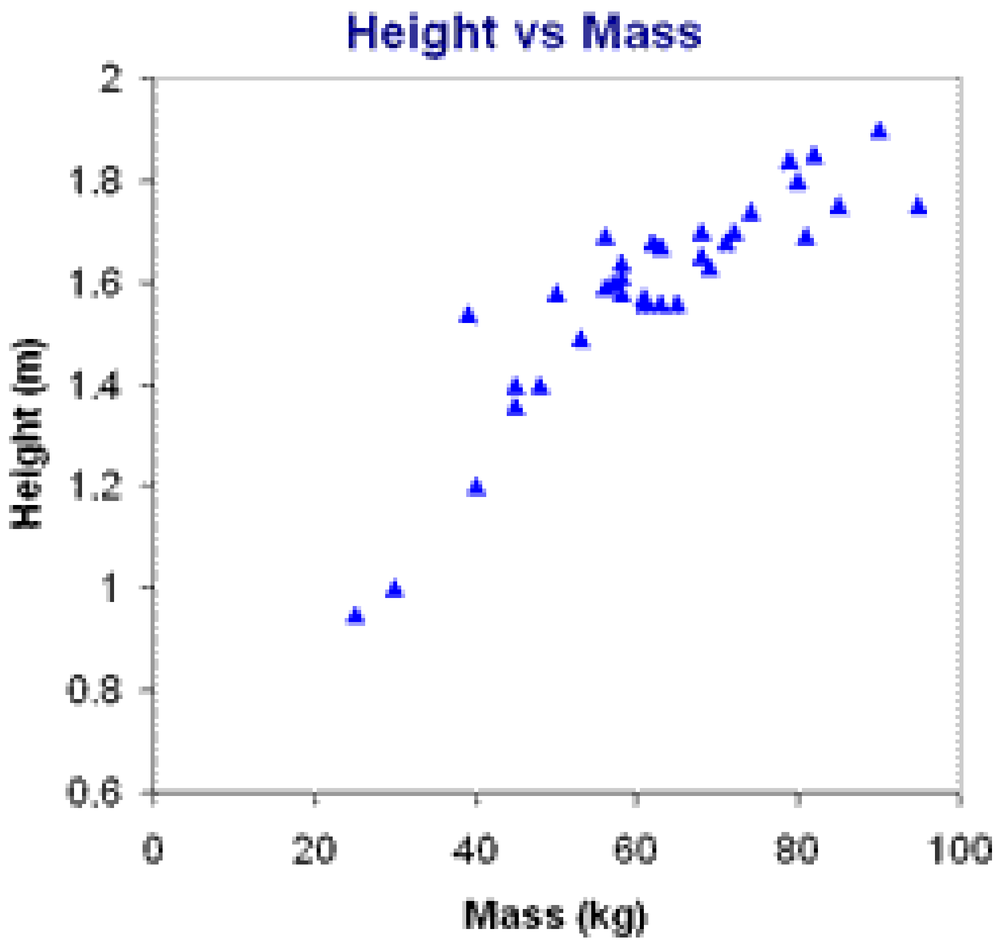
In science, if we can measure 2 things, we plot them against each other and look for relationships.

This is what random (unrelated) looks like



If we plot height versus mass (weight) of people, we get the graph below.

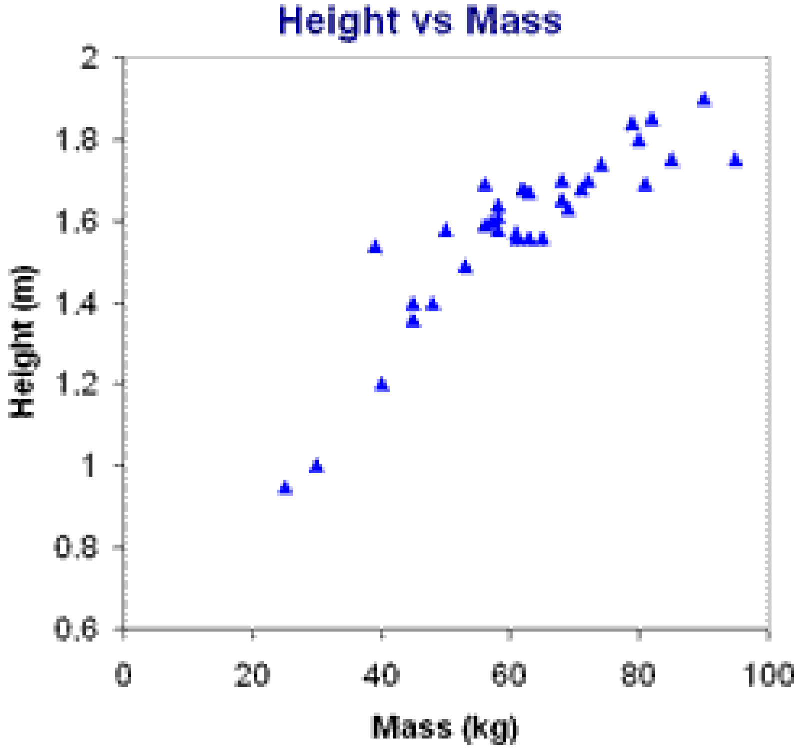
What's the underlying relationship



If we plot height versus mass (weight) of people, we get the graph below.

As people grow up (age), they gain weight. A child (shorter) weighs less than an adult.

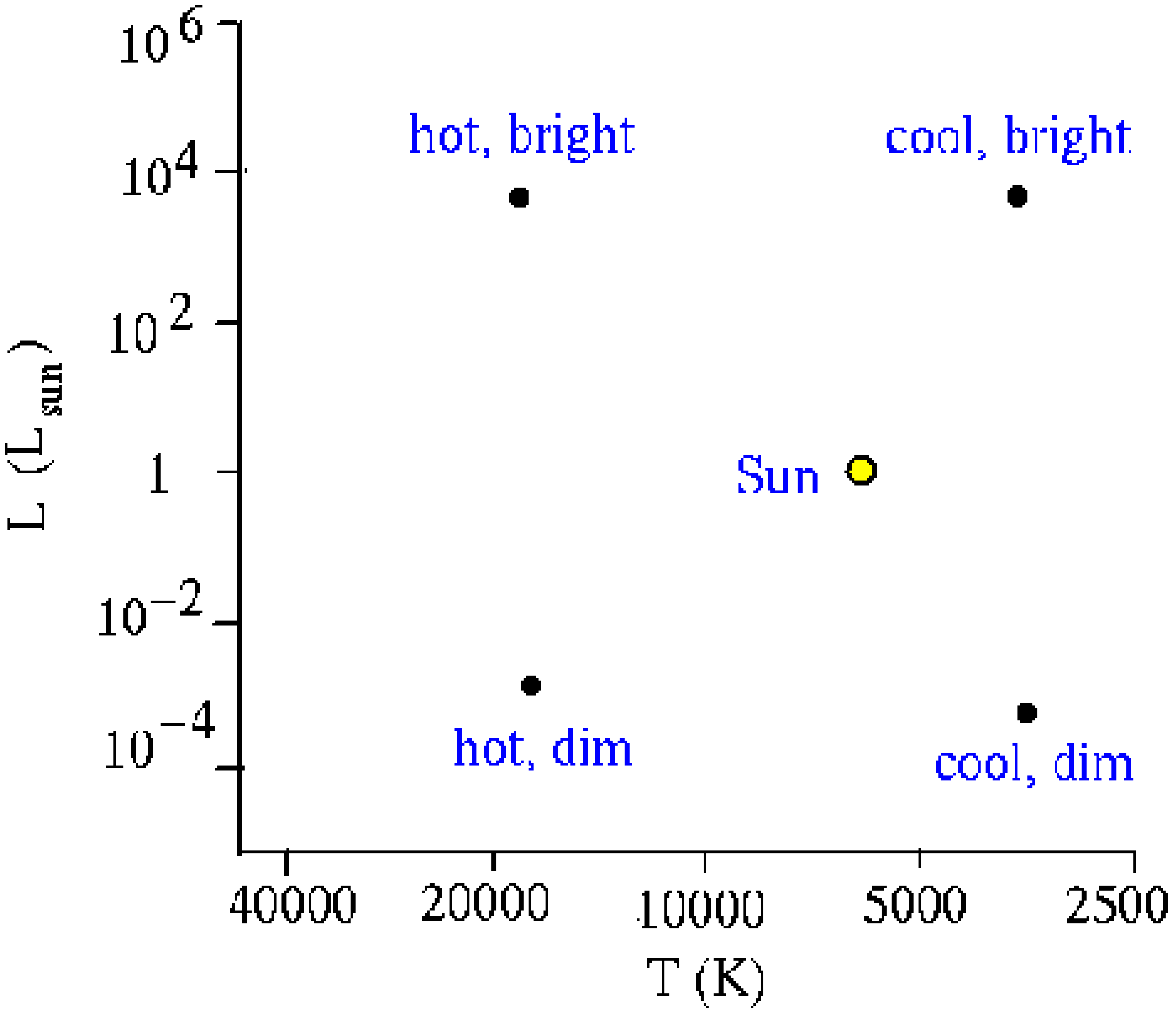
There is an underlying reason for the relationship.



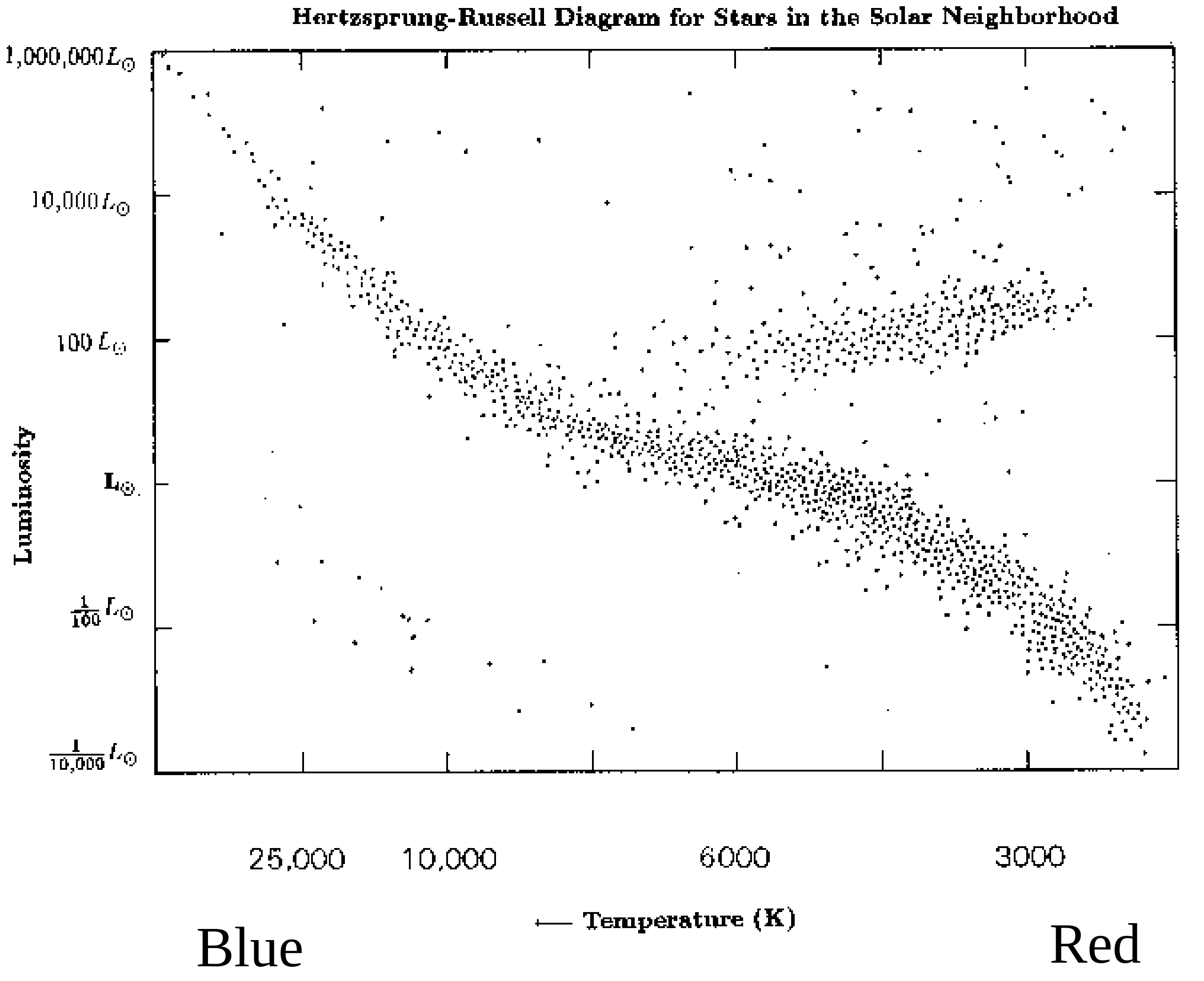
For stars, in an image we can measure 2 things: brightness and color.

So make a plot for that!

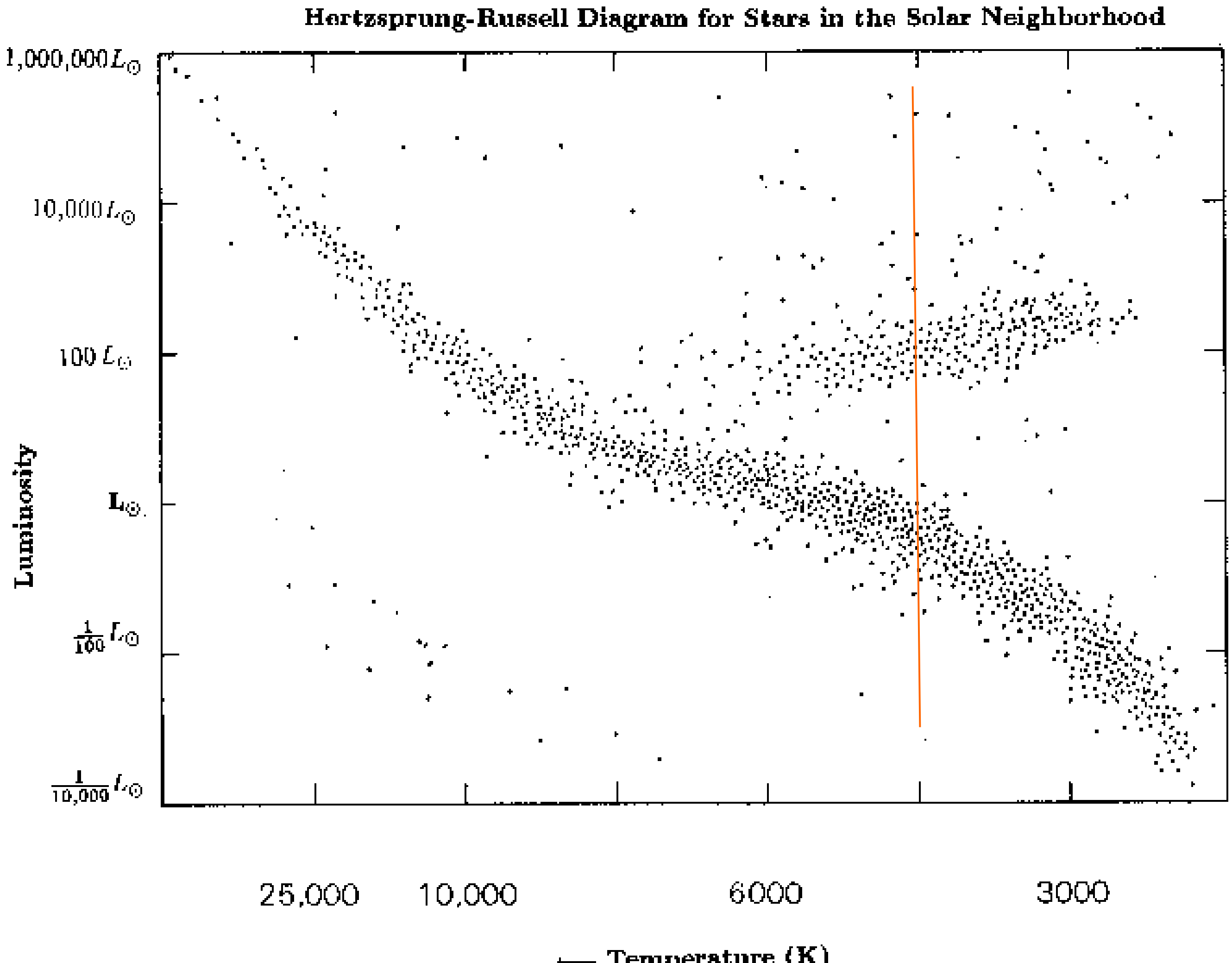
Regions in this diagram correspond to different kinds of stars.



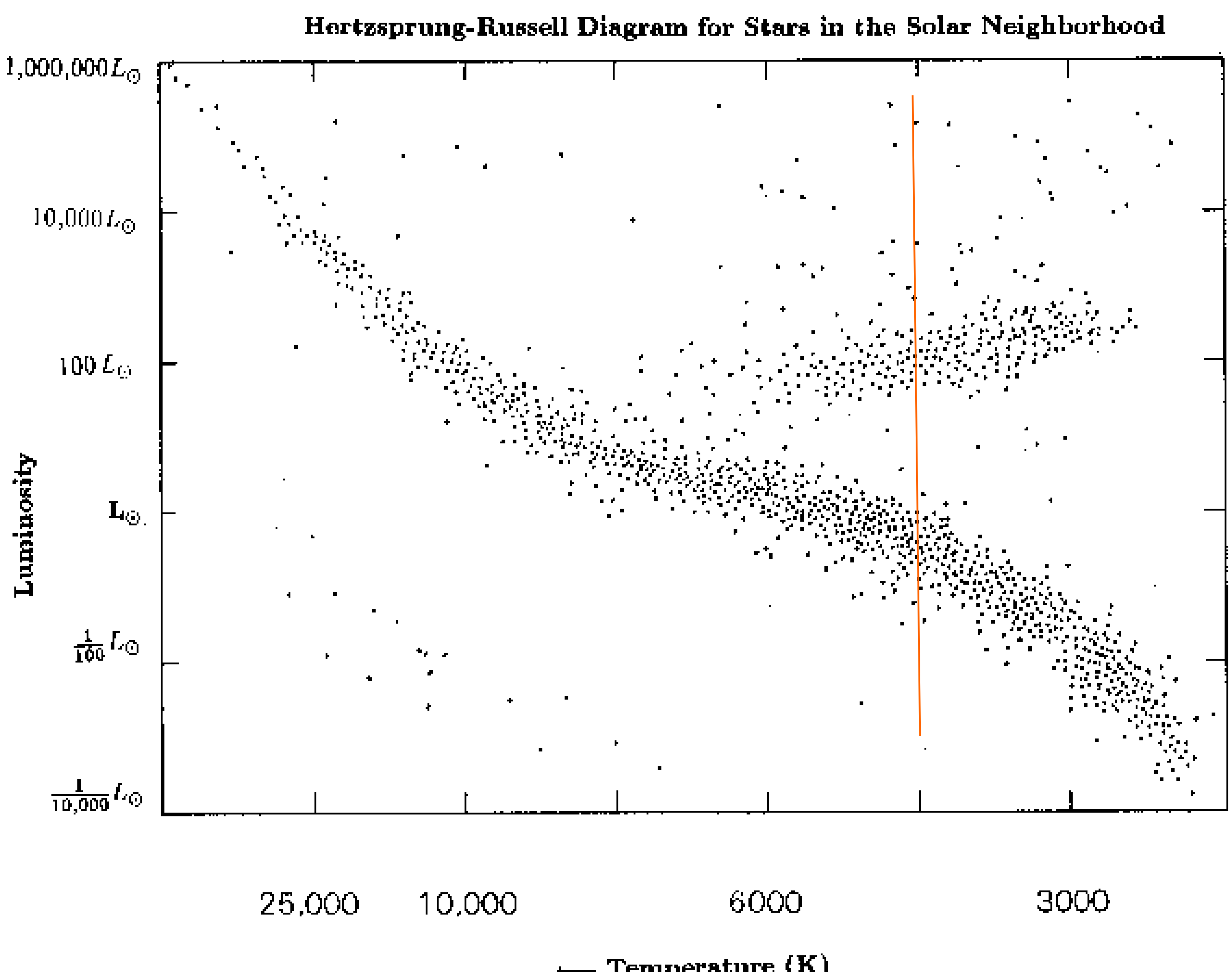
Hertzsprung-Russell Diagram of nearby stars. They had parallaxes for these stars.



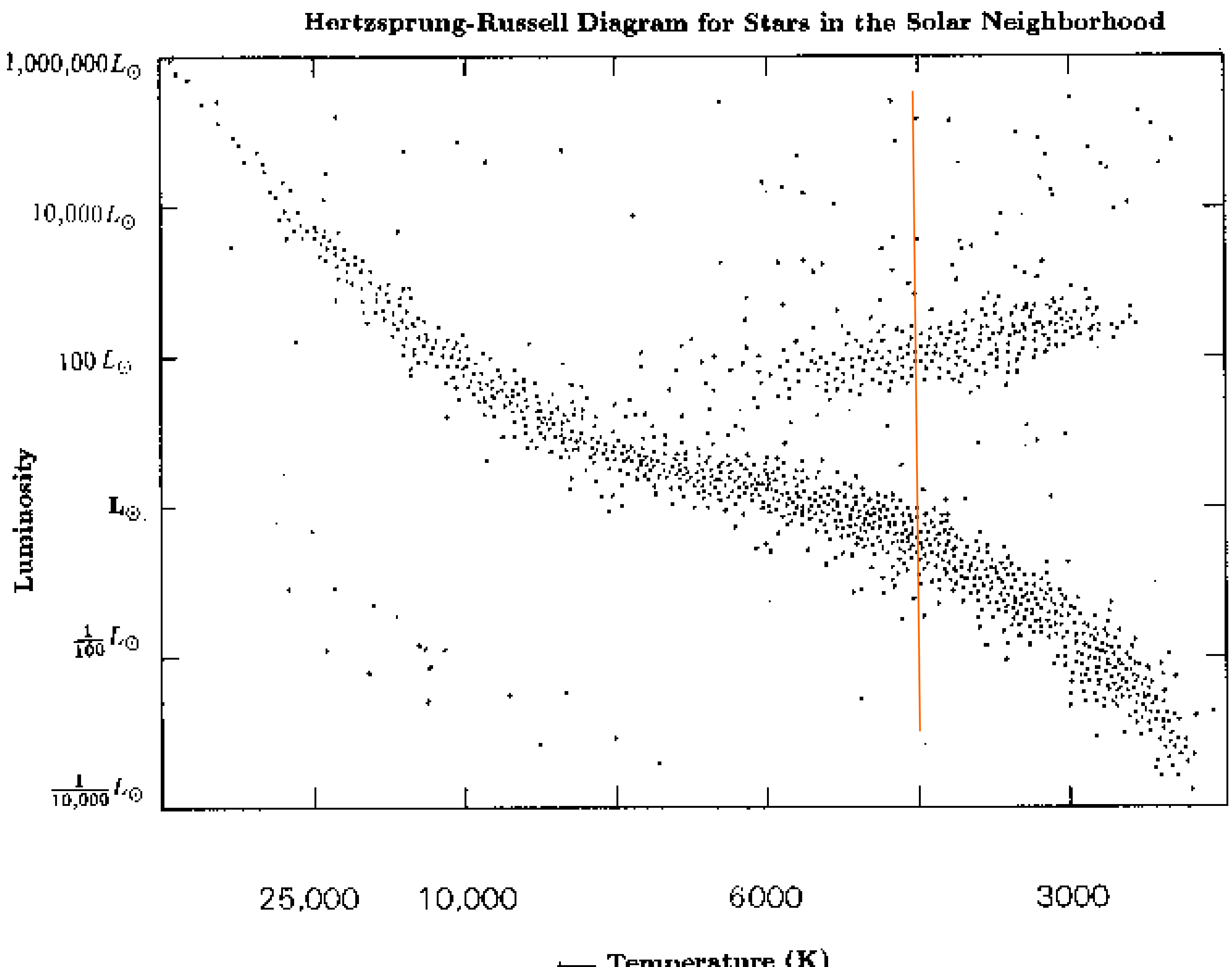
Consider the orange line I've drawn through the graph below. It is at 1 temperature (color) but passes through 3 regions of stars: the main sequence, red giants, and supergiants. Recall that (distance independent) brightness has an equation: $L=4\pi R^2T^4$.



Consider the orange line I've drawn through the graph below. It is at 1 temperature (color) but passes through 3 regions of stars: the main sequence, red giants, and supergiants. Recall that (distance independent) brightness has an equation: $L=4\pi R^2T^4$. If T is the same, but some stars are brighter, then they must be *larger*.

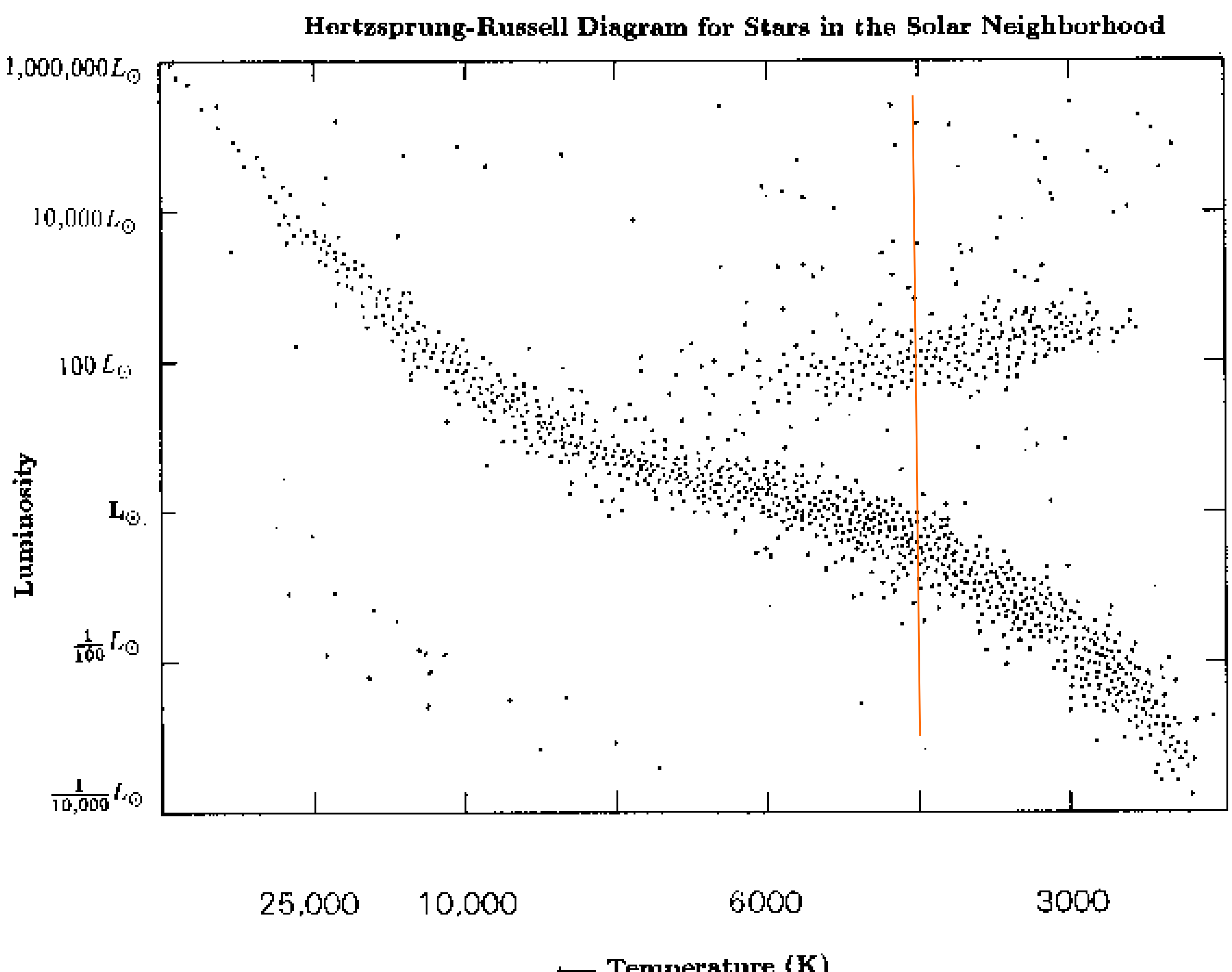


As the main sequence contains most stars, the stars on the main sequence are considered to be the '*normal*' size. The group of stars directly above them must therefore be larger, and these were called '*giants*'. Since they are only on the cooler side of the diagram, they are called *red giants*.

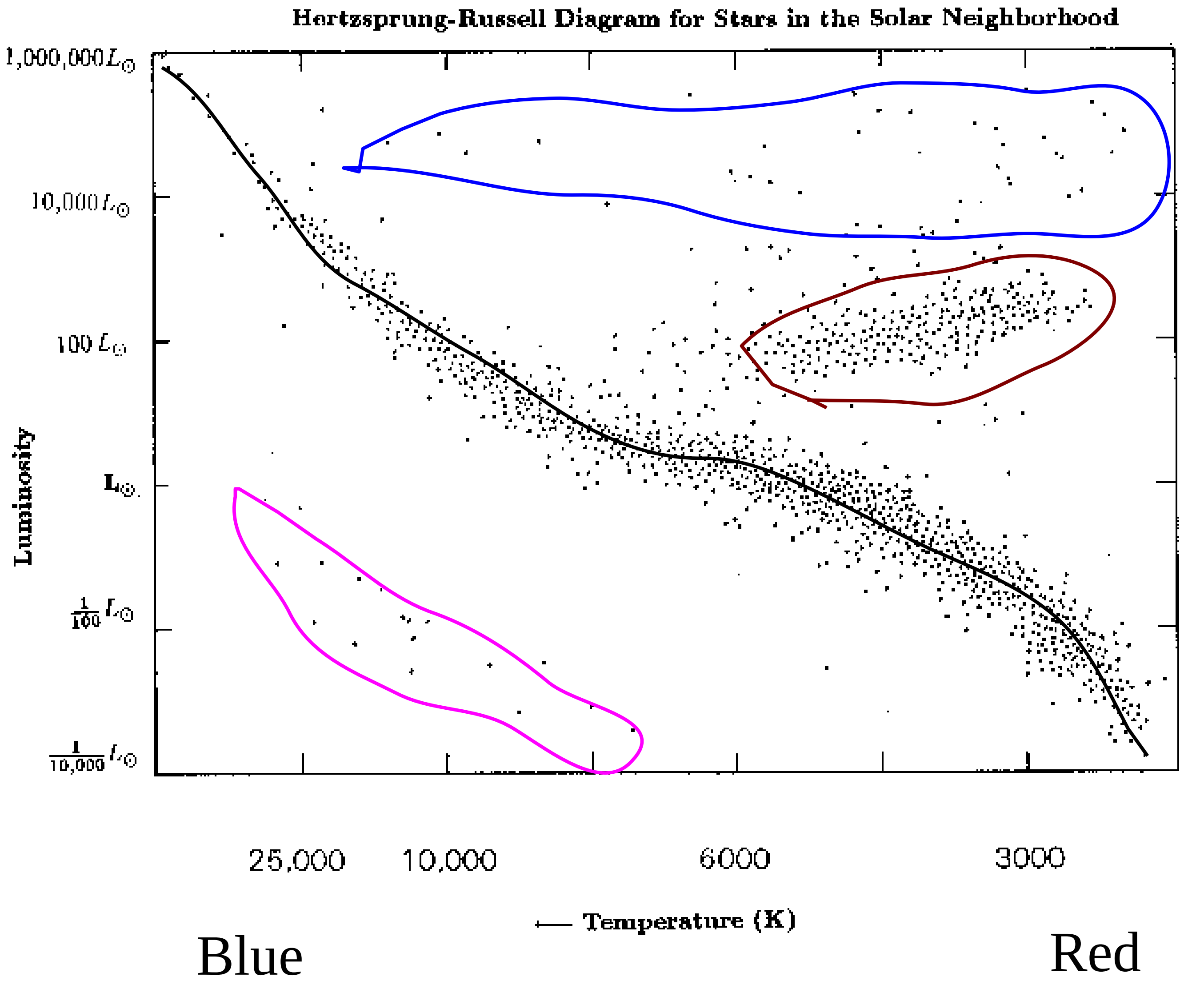


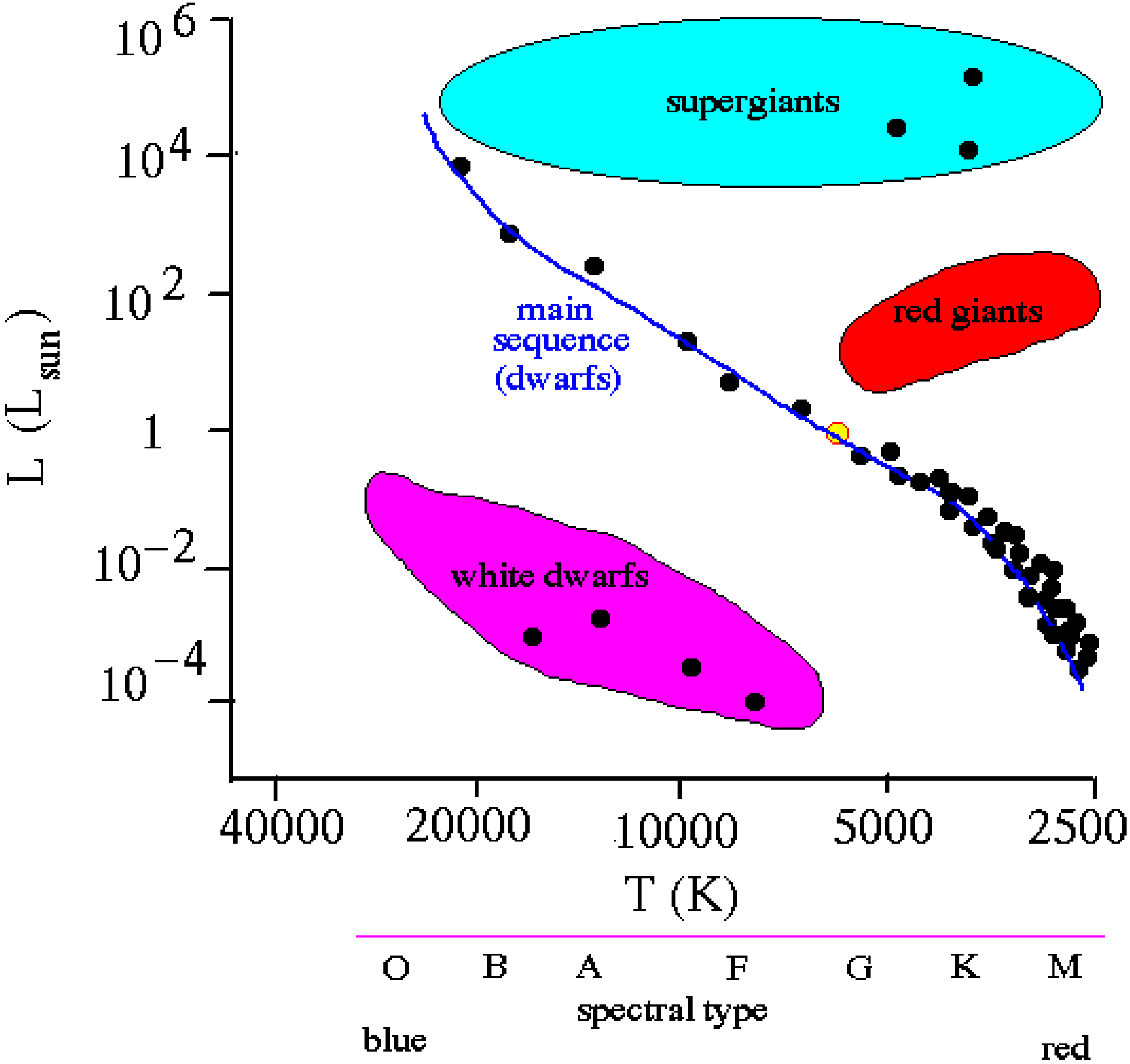
But there is another group even more luminous than the *red giants*.
Since these must be bigger, they are called *supergiants*.

Fortunately, no stars larger than supergiants have been discovered, so we don't need anything like super-duper-giants.

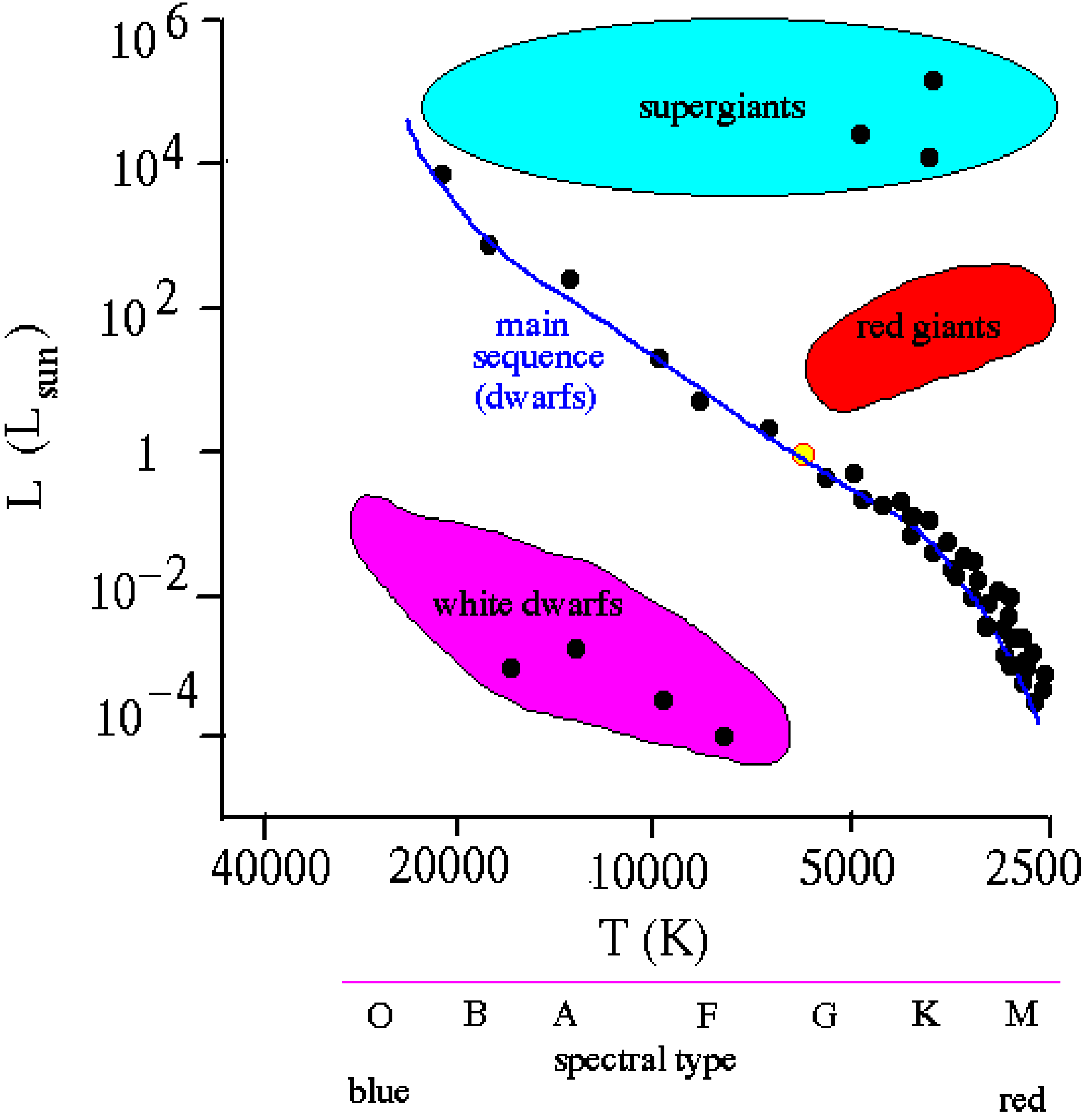


They noticed that stars do not appear randomly on this graph, but rather form groups. Why?





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.



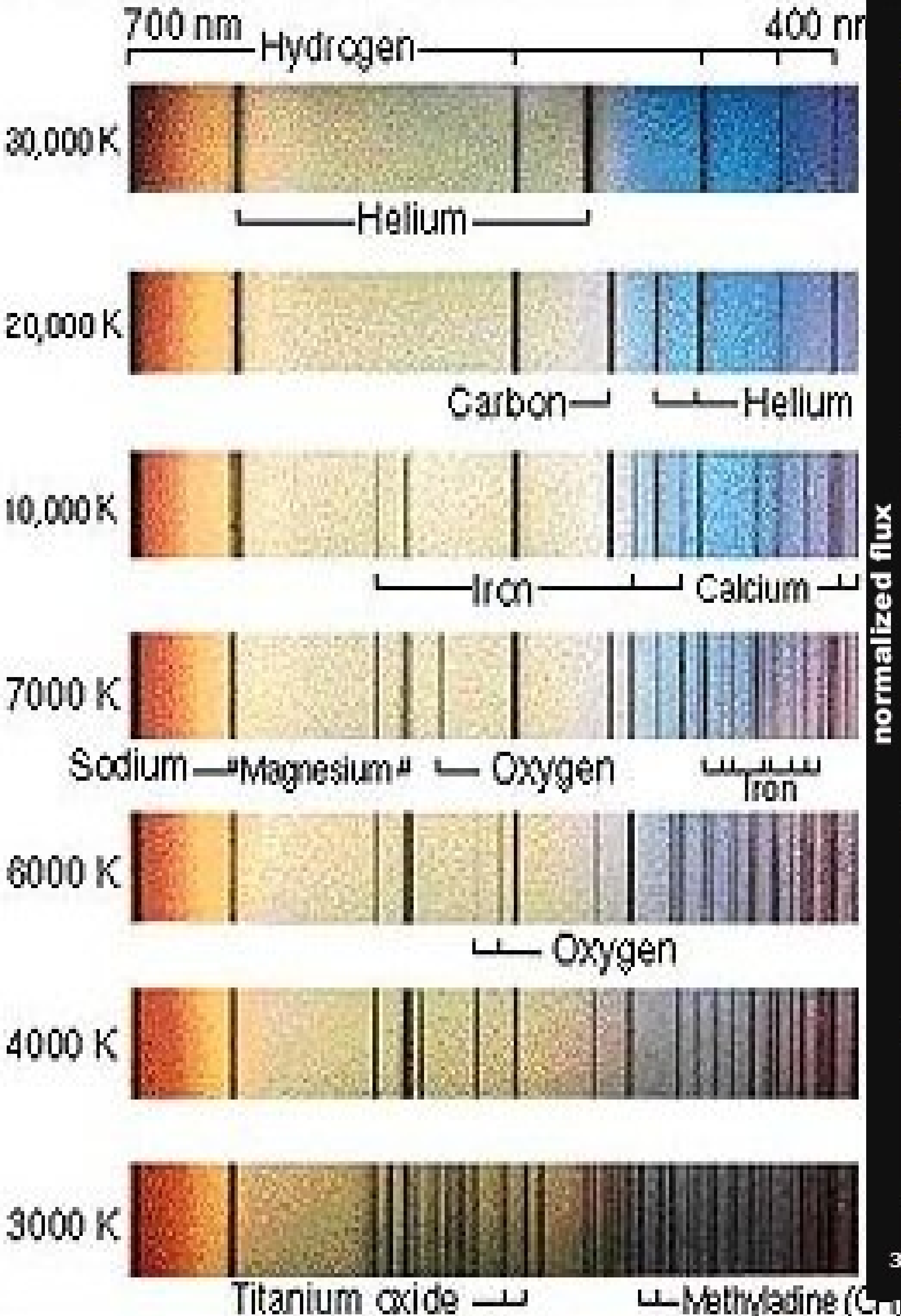
About this plot:

The X axis-

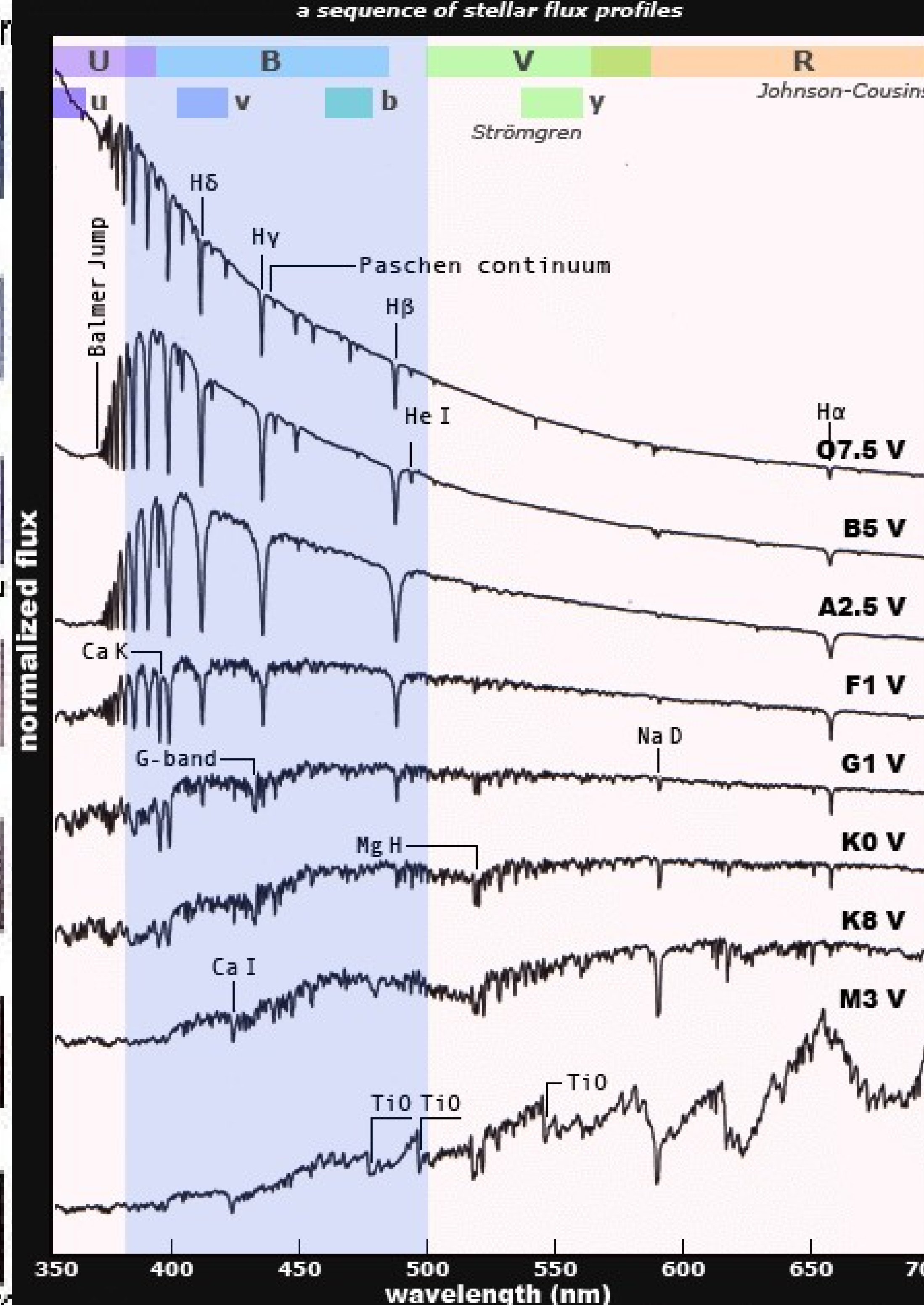
Temperature- hotter to the left, cooler to the right.

Color: blue is hot, red is cool

And spectral types



700 nm
Hydrogen
400 nm
30,000 K
Helium
20,000 K
Carbon
Helium
10,000 K
Iron
Calcium
7000 K
Sodium
Magnesium
Oxygen
Iron
6000 K
Oxygen
4000 K
3000 K
Titanium oxide
Methylidine (CH)



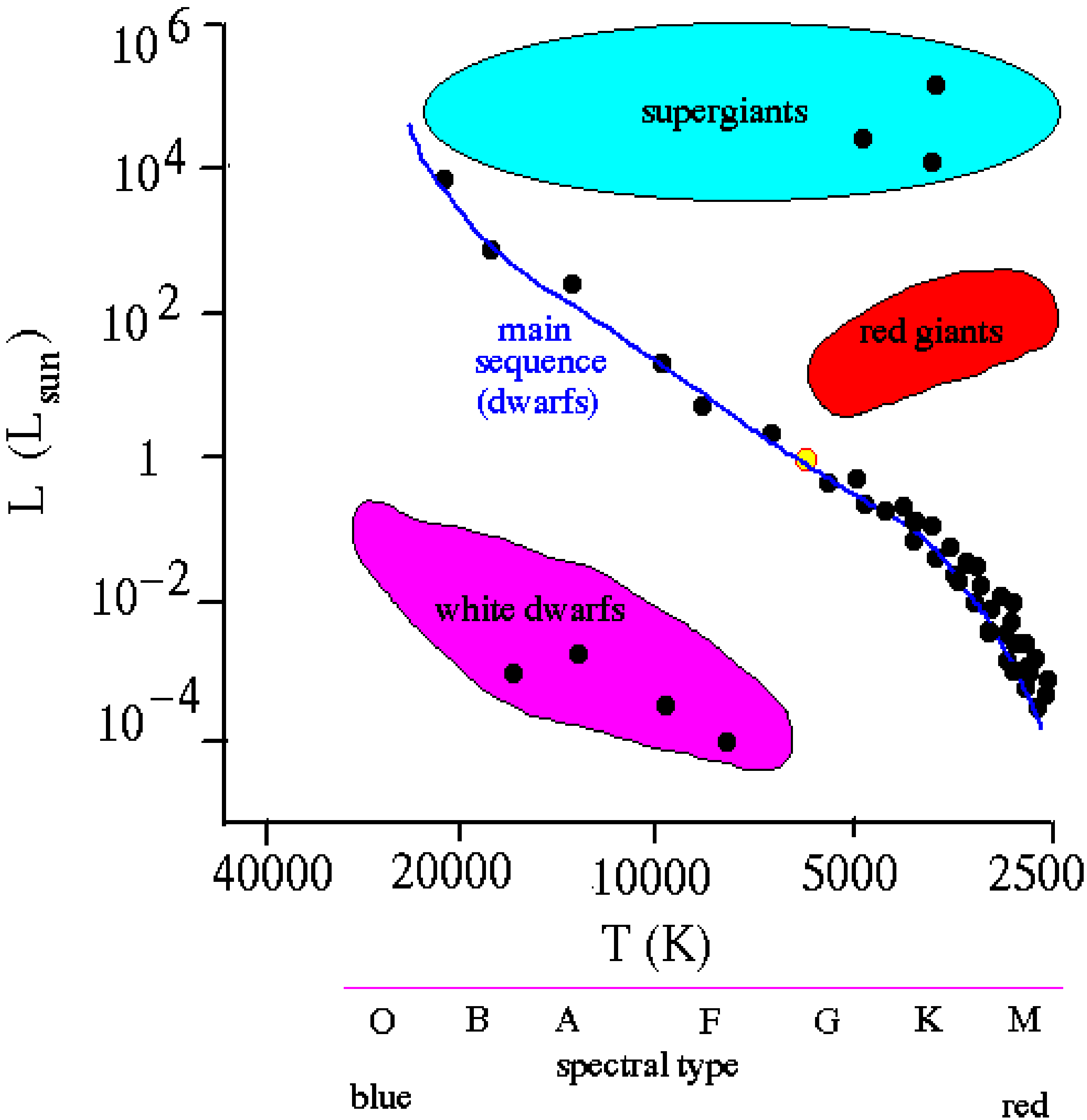
a sequence of stellar flux profiles
U
B
V
R
Johnson-Cousins
u
v
b
y
Strömgren
Hδ
Hγ
Paschen continuum
Hβ
Balmer Jump
He I
Hα
O7.5 V
B5 V
A2.5 V
Ca K
F1 V
Na D
G-band
G1 V
Mg H
K0 V
K8 V
Ca I
M3 V
TiO
TiO
TiO
normalized flux
350
400
450
500
550
600
650
wavelength (nm)

Spectral type mnemonic

Oh Be A Fine Girl/Guy Kiss Me

I like:

Oh Boy! Astronomy Faculty Get Killed Monday

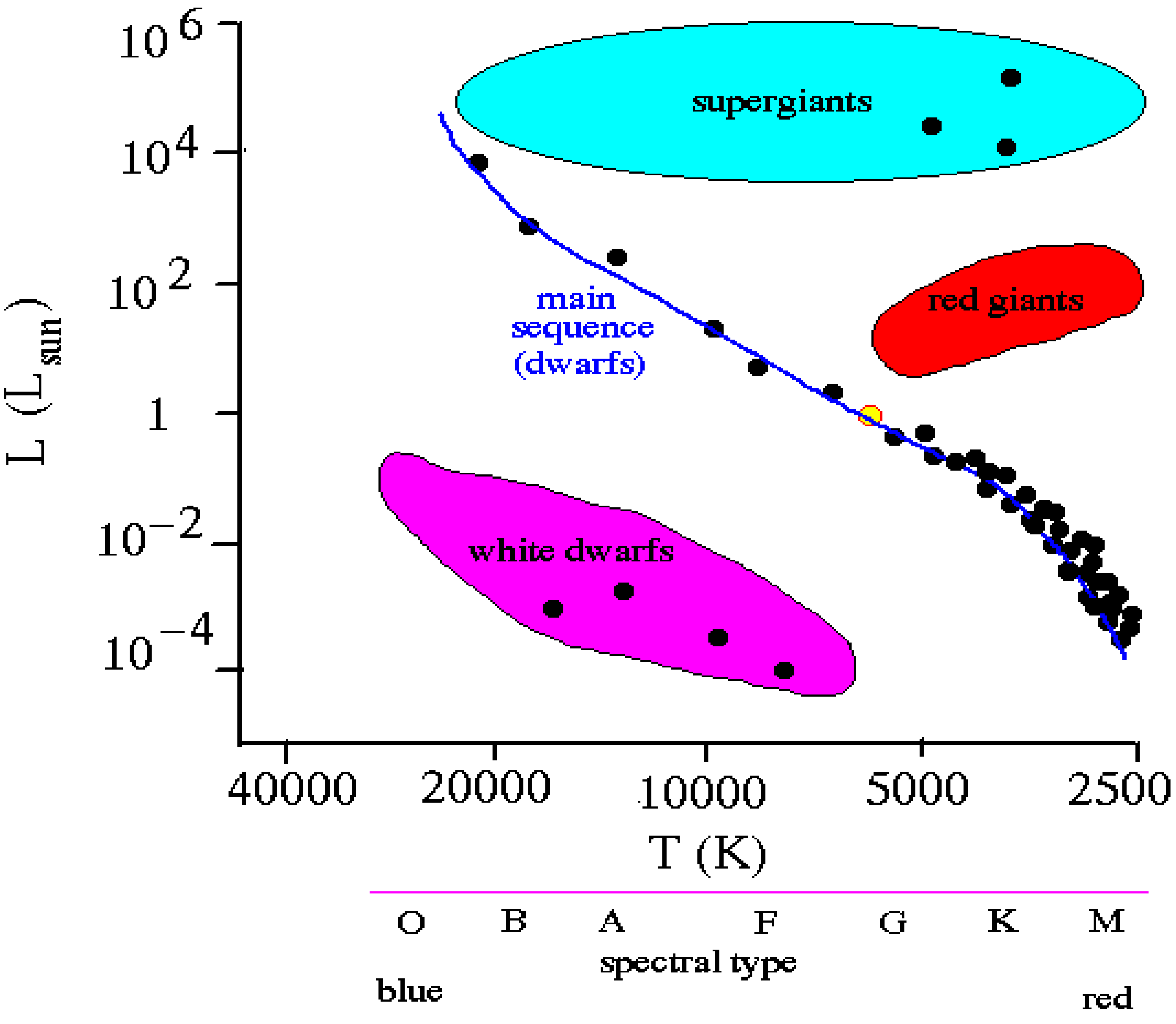


About this plot:

The Y axis-

Luminosity (in this case, in solar luminosities). Brighter towards the top.

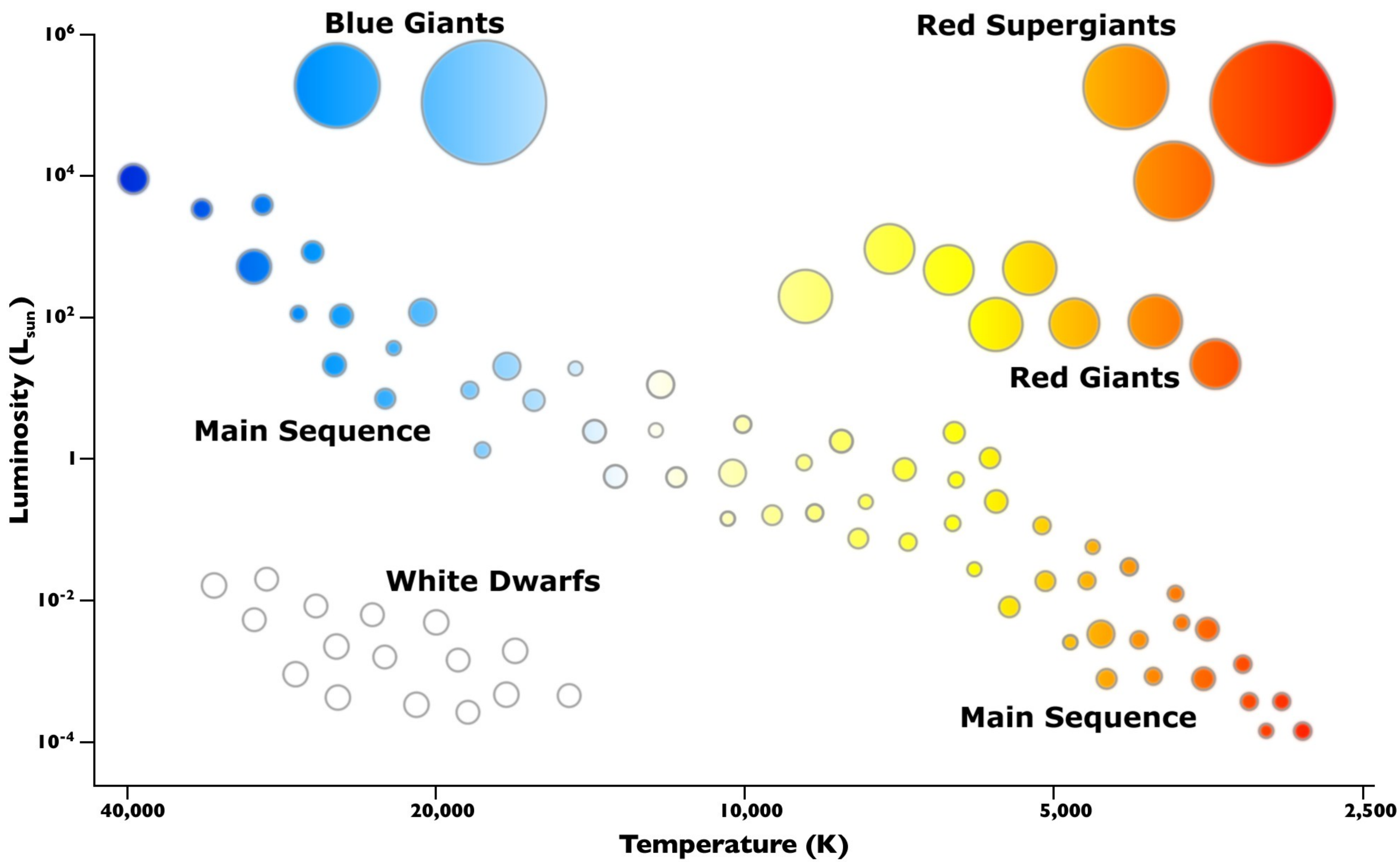
So what determines where a star is in the HR diagram?



Russell-Vogt theorem:

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

its mass, age, and (barely) composition.

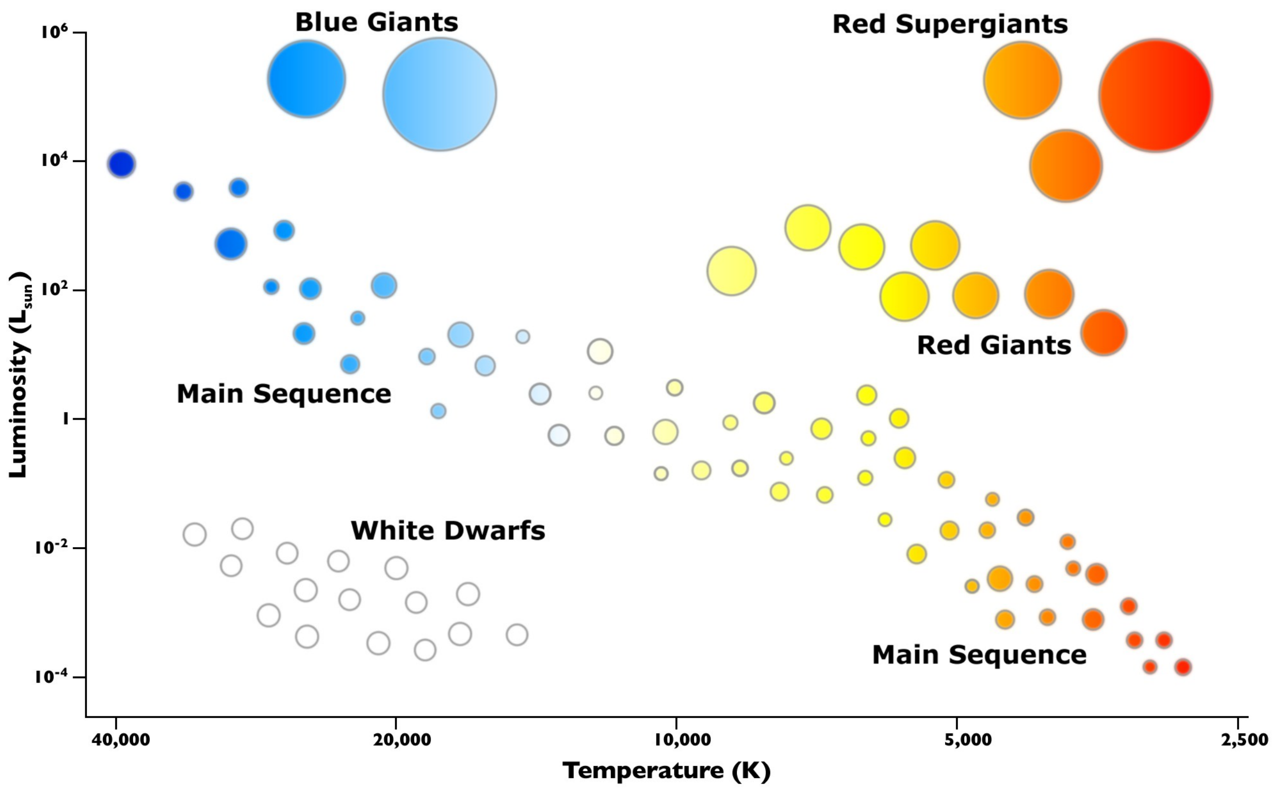


We will start with mass. Along the main sequence, luminosity goes as mass to the 3.5 power.

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

In solar units (the Sun=1).

$$L = M^{3.5} = \sqrt{M} \times M \times M \times M$$



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

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In solar units (the Sun=1).

Let's try one: How bright (compared to our Sun) is a 4 solar mass star?

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

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

In solar units (the Sun=1).

Let's try one: How bright (compared to our Sun) is a 4 solar mass star?

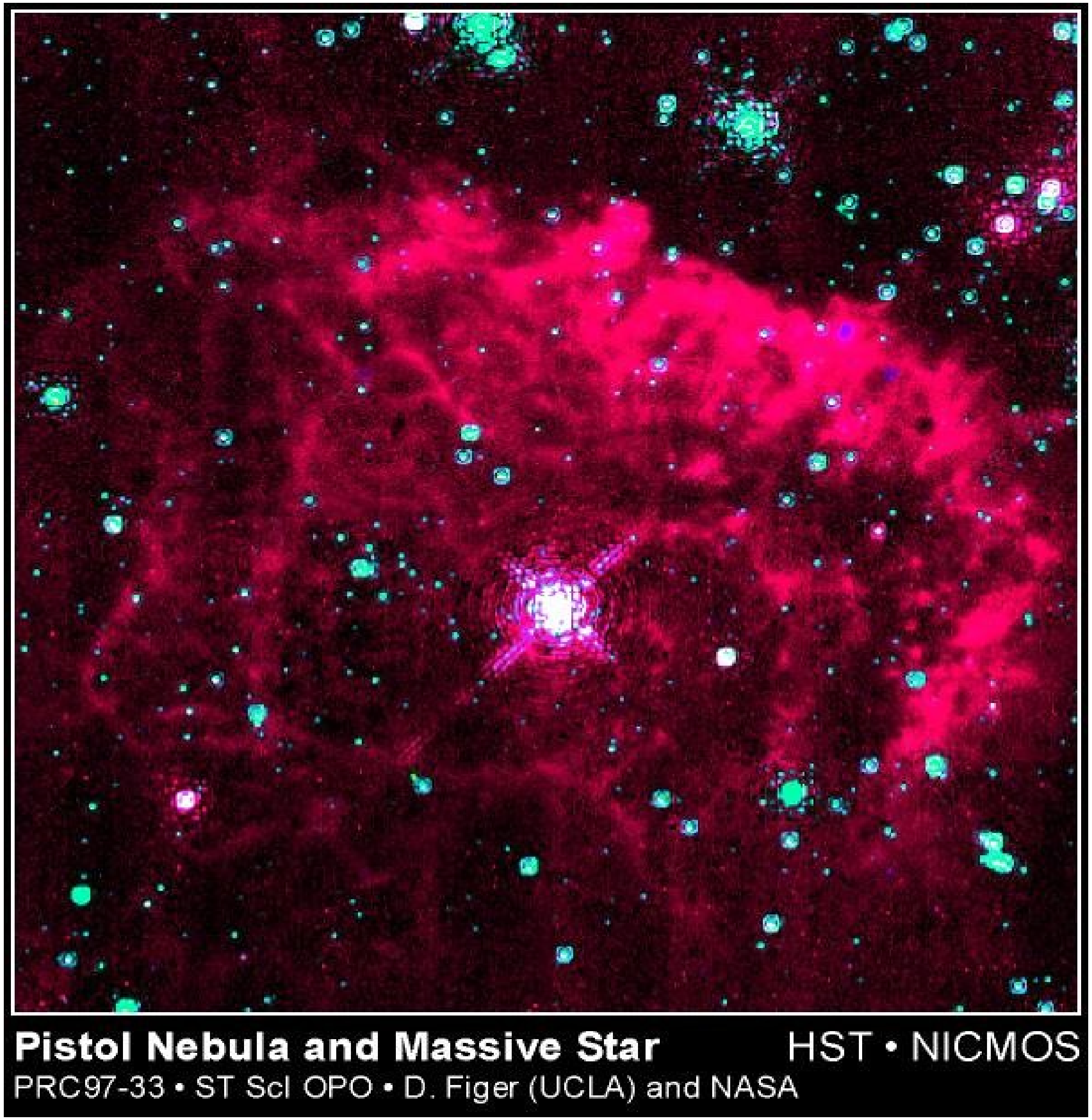
$$L = M^{3.5} = \sqrt{M} \times M \times M \times M$$

$$L = M^{3.5} = 2 \times 4 \times 4 \times 4 = 128$$

This MS star is 128 times brighter than our Sun.

Upper range for mass:

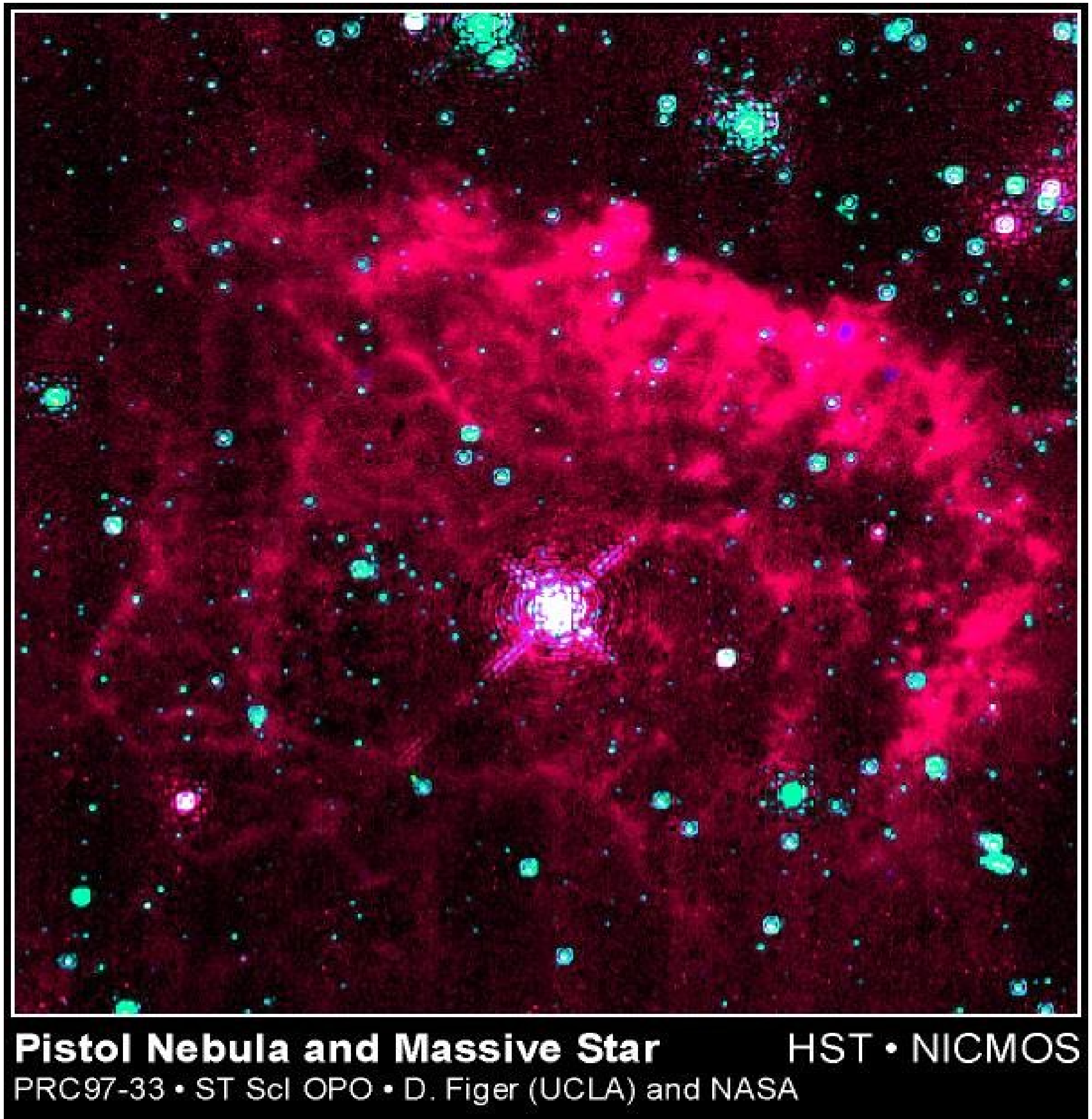
The Pistol star is about 100-200M_{Sun}



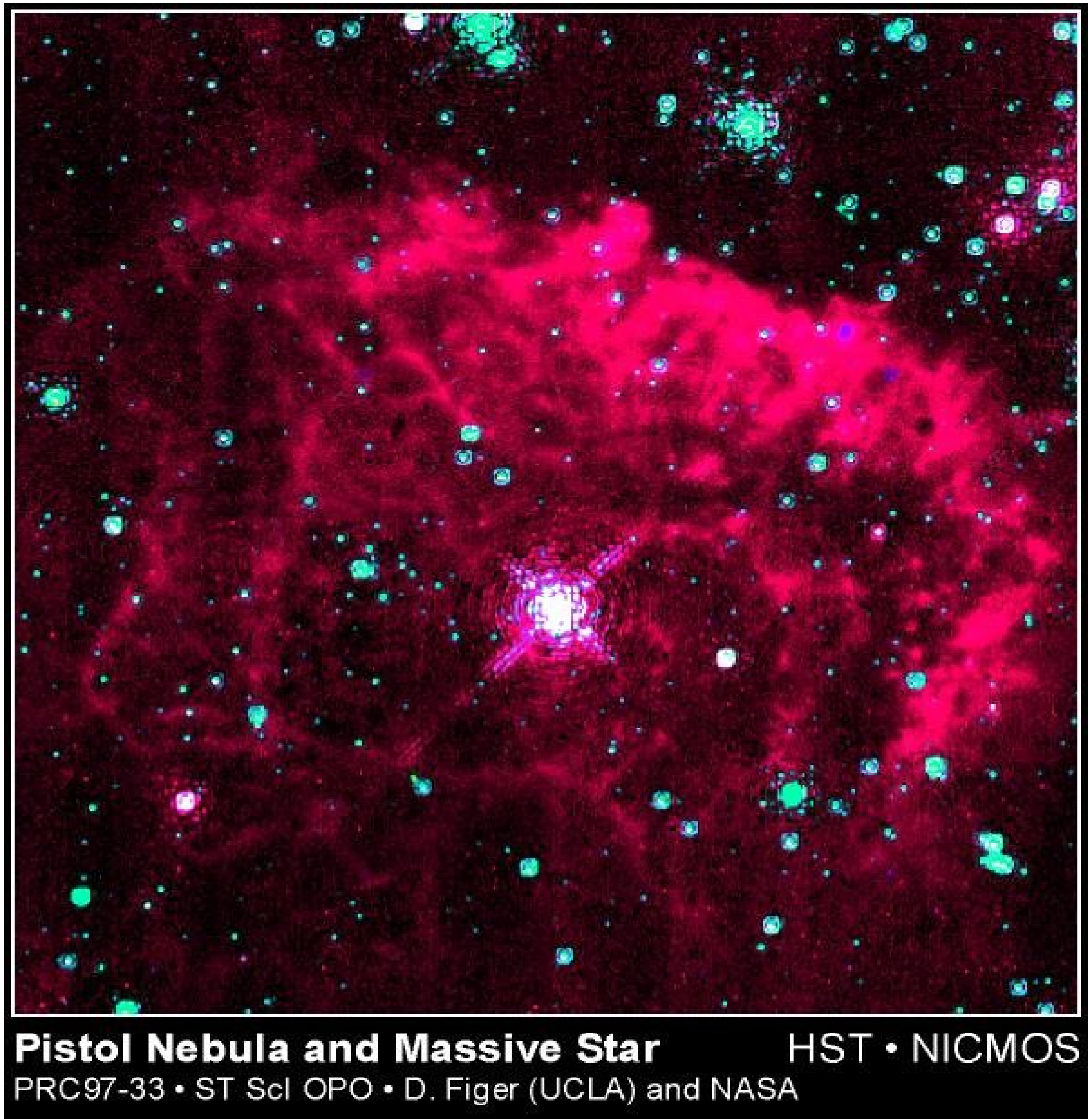
However, stars that big are extremely rare.

If the Pistol star is $100M_{Sun}$ how bright should it be using: $L = M^{3.5} = M^{1/2}xMxMxM$

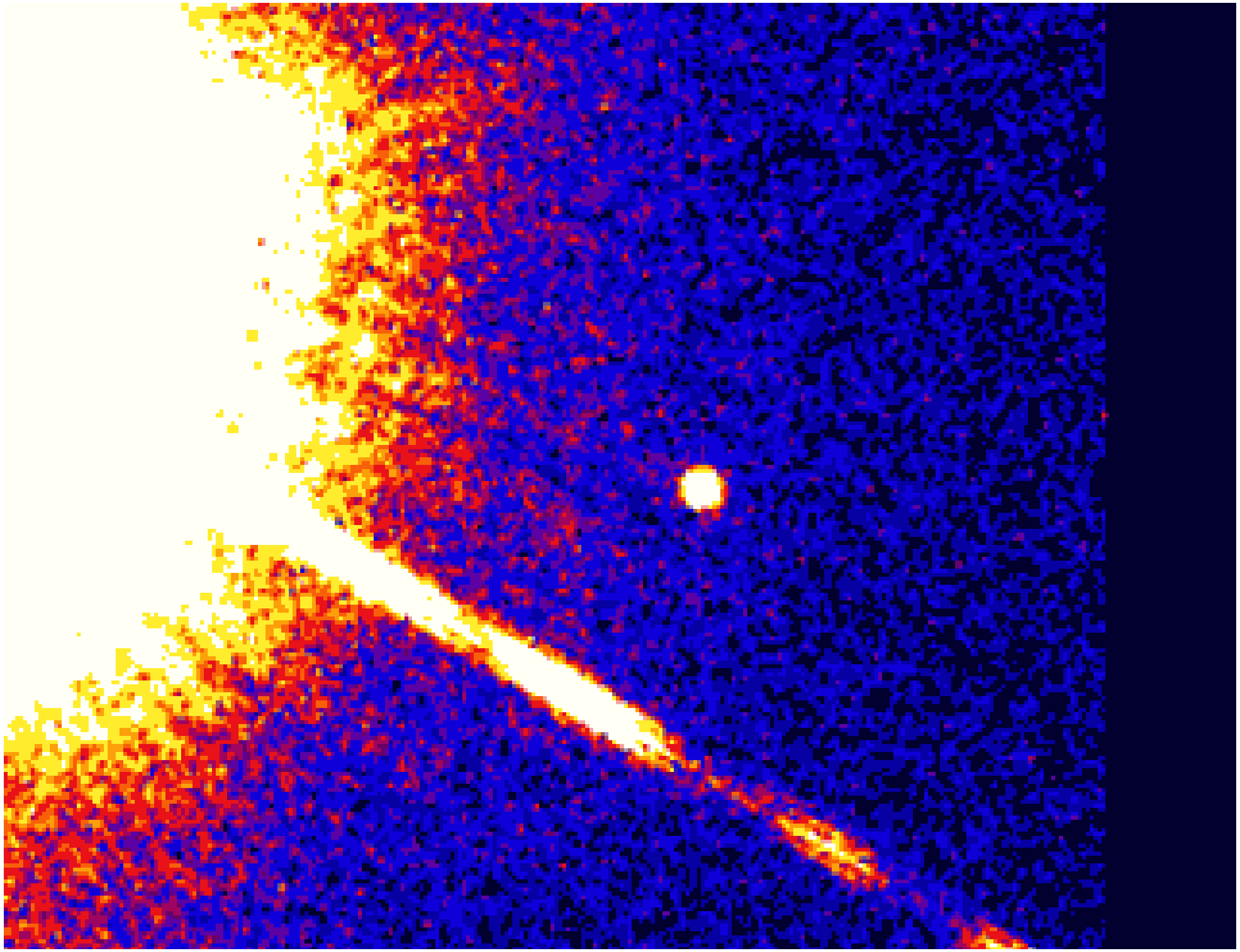
$$L = M^{3.5} = \sqrt{M} \times M \times M \times M$$



If the Pistol star is $100M_{Sun}$ how bright should it be using: $L = M^{3.5} = M^{1/2}xMxMxM = 10$ million!



Gliese 229B is in a binary with a Red Giant star. It is only 20-50 times more massive than Jupiter or $0.019M_{Sun}$. (How bright?)

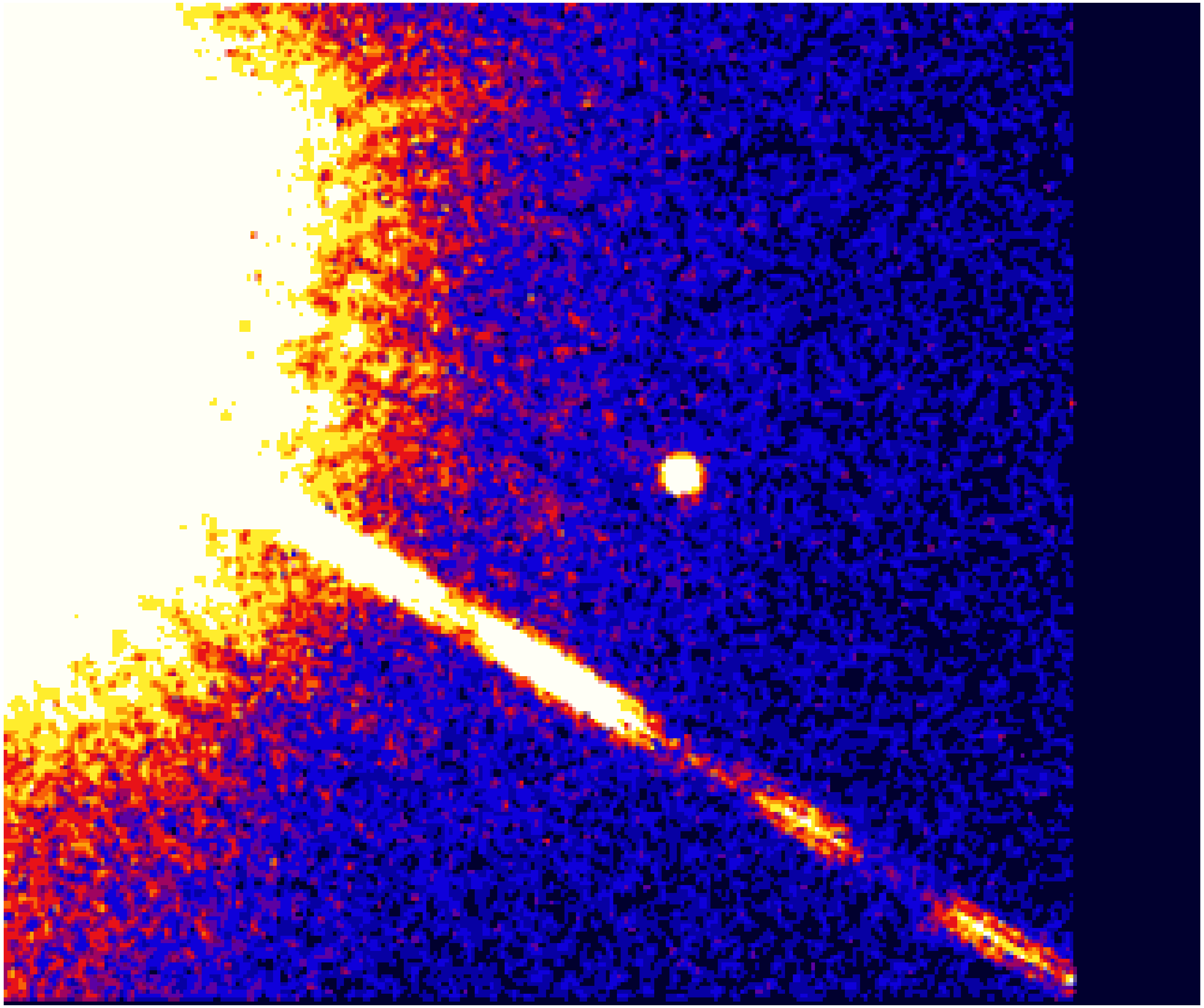


$$L = M^{3.5} = \sqrt{M} \times M \times M \times M$$

Gliese 229B is $0.019M_{Sun}$. How bright?

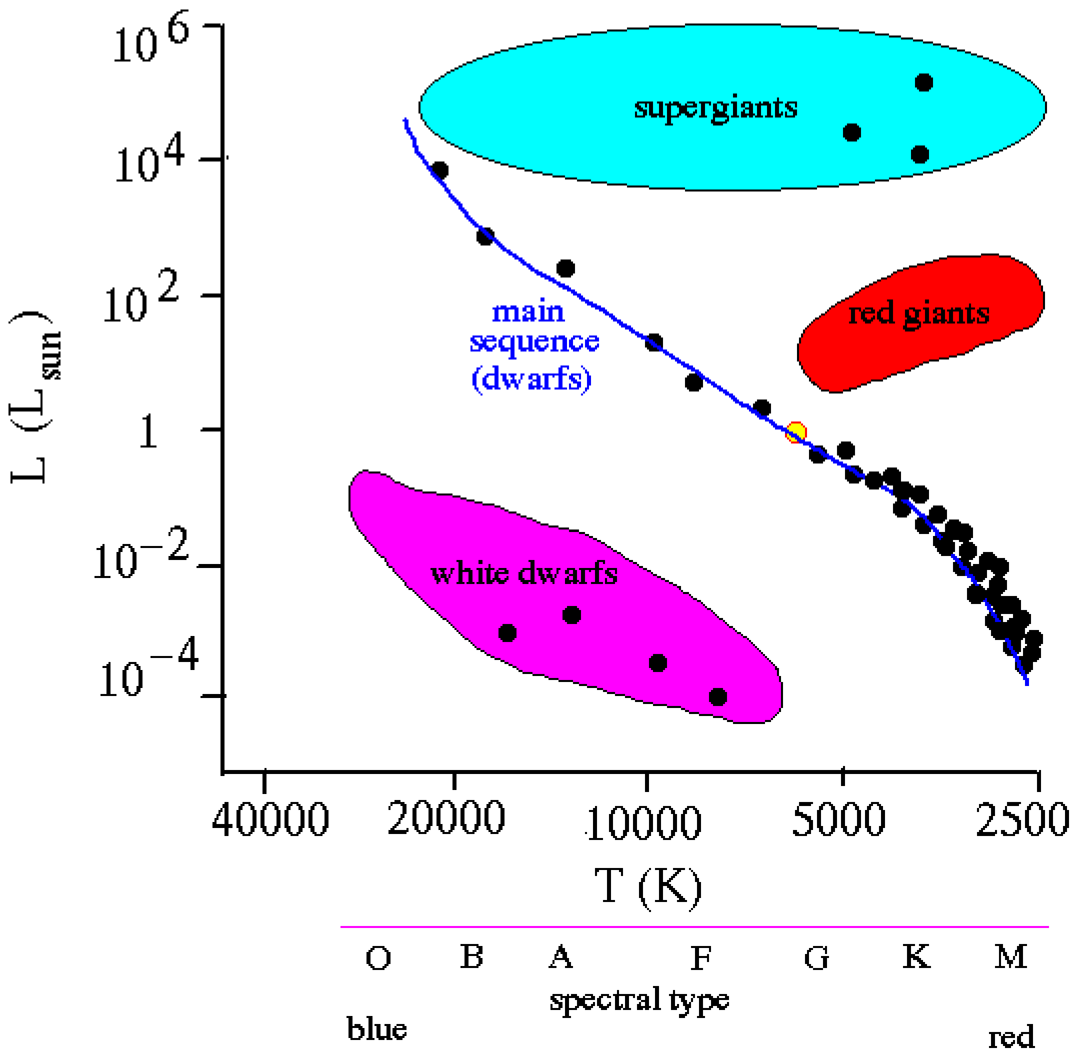
$L=(0.019)^{3.5} = 9.5x10^{-7} = 0.00000095$

9.5 ten-millionths!



So stars can get ~200 times the mass of the Sun, but millions of times brighter. What does that mean for fuel consumption?

Do stars with more mass live longer or shorter?



Massive stars have shorter main sequence lifetimes.

They have more mass, so more fuel to burn, but have to burn it quicker to support their massive weight.

$t_{MS}=1x10^{10}/M^{2.5}=1x10^{10}/(M_xM_xM^{1/2})$ in years.

If you put in mass in solar units.

So for M=1 (our sun), $t=1x10^{10}$=10 billion years.

Stellar lifetimes.

So our Sun will be on the main sequence for 10 billion years. What about a star with 100 solar masses?

$t_{MS}=1x10^{10}/(M_x M_x M^{1/2})$

Stellar lifetimes.

So our Sun will be on the main sequence for 10 billion years. What about a star with 100 solar masses?

t=1x10^{10}/100$^{2.5}$=1x10^{10}/(100x100x10)=1x10^{10}/10^{5}=10^{5}

Only 100,000 years!