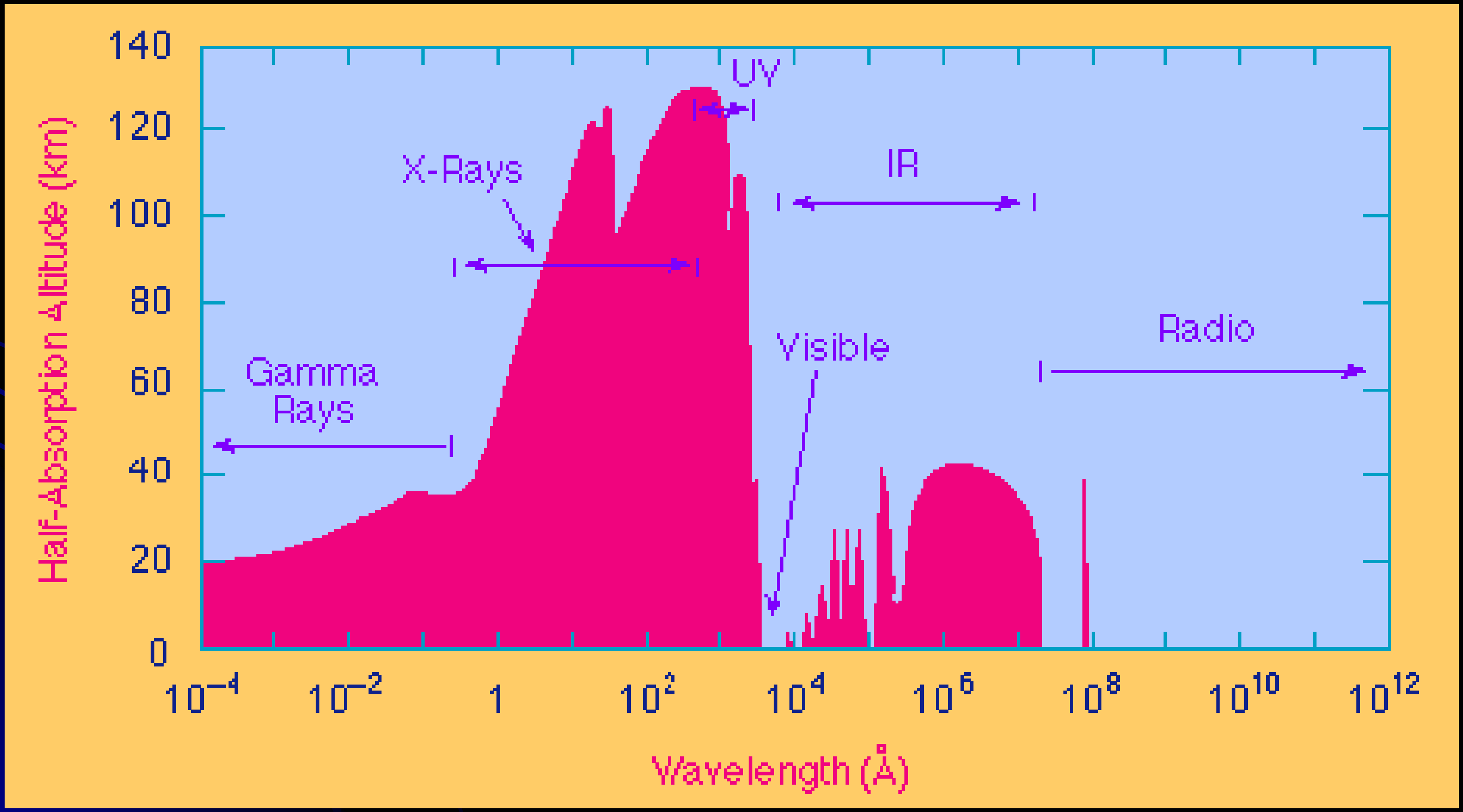
Relativistic Universe

Astronomy and stars

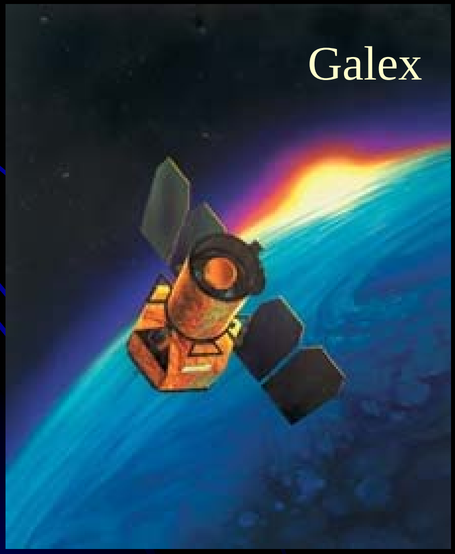
Atmospheric Windows

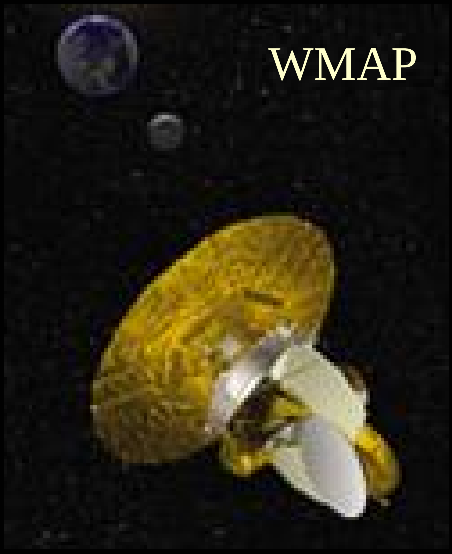
Not all light from space makes it through the earth's atmosphere. In fact, only visible light, radio waves, and some infrared light makes it to the ground. The rest of the electromagnetic spectrum can only be observed from space.



Observatories

Space Observatories





Ways of Creating Light

There are 3 ways to produce light.

- Through the blackbody process (thermal emission)
- Through line emission
- Through synchrotron emission

(This last way is only for a few peculiar objects with strong magnetic fields. We will be ignoring this mechanism in this class.)

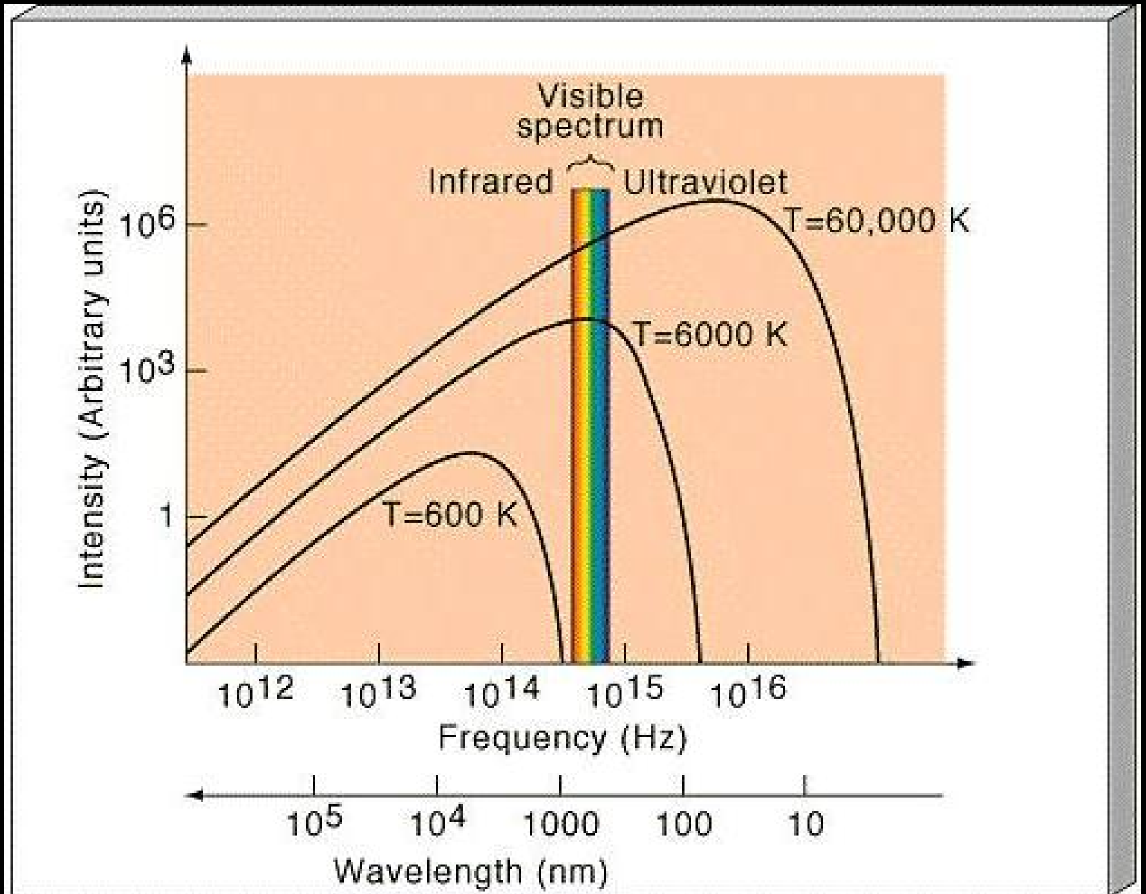
The Blackbody Process

Anything that is hot (*i.e.*, above absolute zero) produces light at all wavelengths – a continuous spectrum. But the amount of light given off at each wavelength is very sensitive to the object's temperature. Specifically,

The hotter the object:

- the more high-energy photons created
- the more light created (MUCH more)

$L \propto T^4$



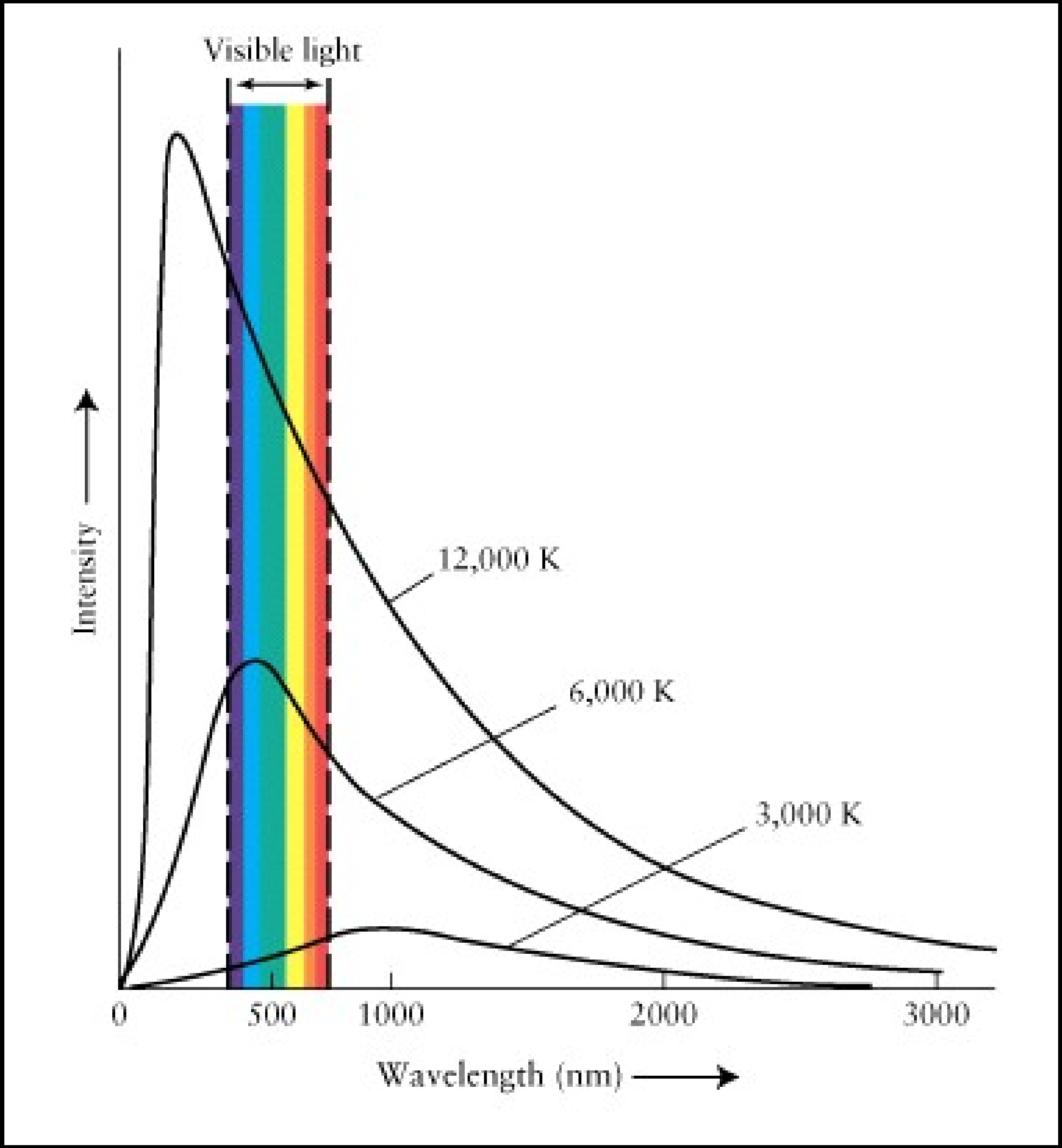
The Blackbody Temperatures

Temperatures

Sun: 6000 K (optical)

People: 300 K (IR)

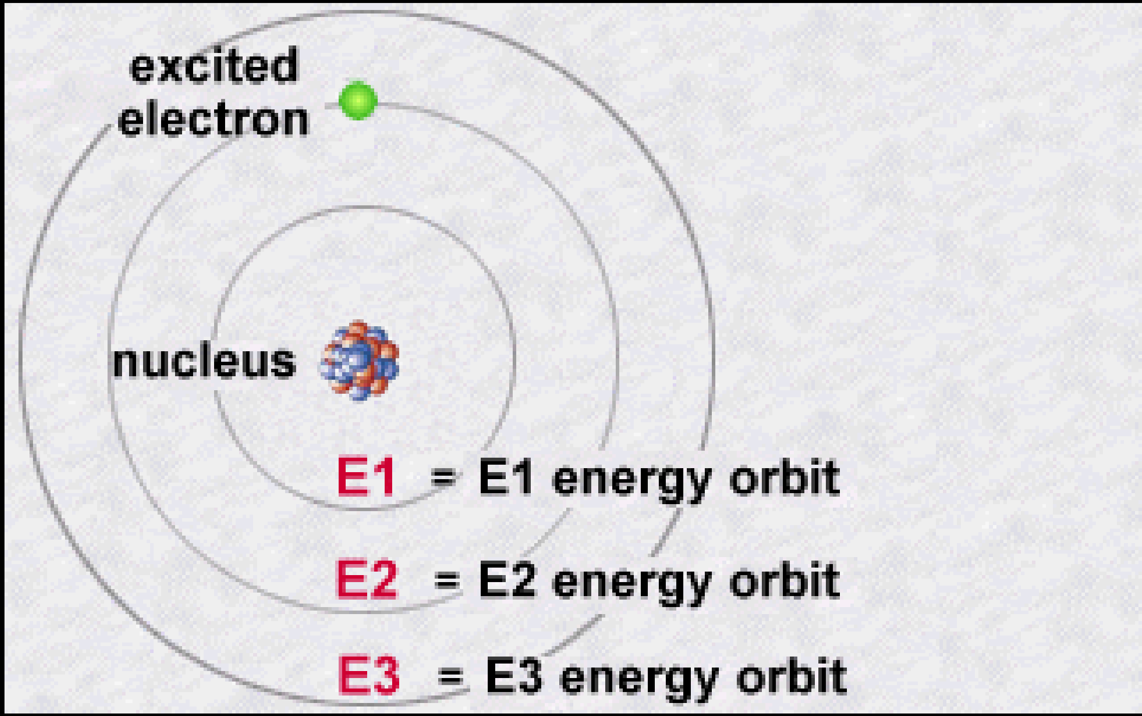
1,000,000 K gas: x-ray



Creating an Emission Line

Suppose something collided into a electron orbiting in the lowest energy level. Some of the energy of the collision could kick the electron up to a higher level. Eventually, when the electron falls back down, it has to give this energy back. It does so by giving off light.

Since each orbital has at a very specific level, electron transitions between the orbitals emit very specific amounts of energy. The spectrum from this process would ***not*** be continuous.



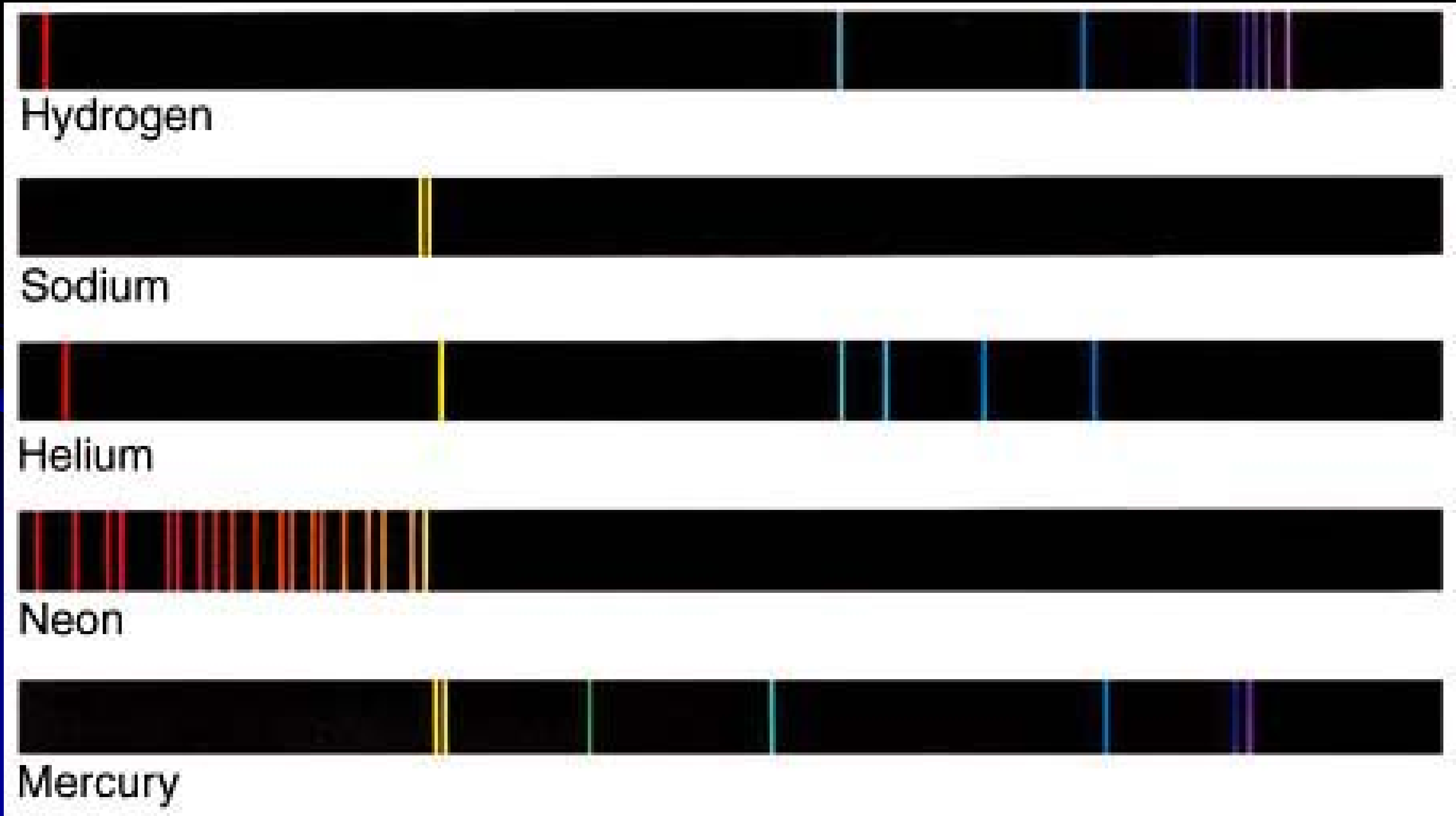
Ionization and Emission

Suppose a very high energy photon passes near an atom. If the photon has enough energy, it can kick the electron completely out of the atom, and create an ion. Eventually, the electron will recombine into (some level) of the ion, and cascade its way down to the lowest energy level. Each downward transition will produce a photon with the exact energy of the transition. This is not a continuous spectrum!

There is light only at very specific energies (*i.e.*, colors), which correspond to each transition.

Emission Line Spectra

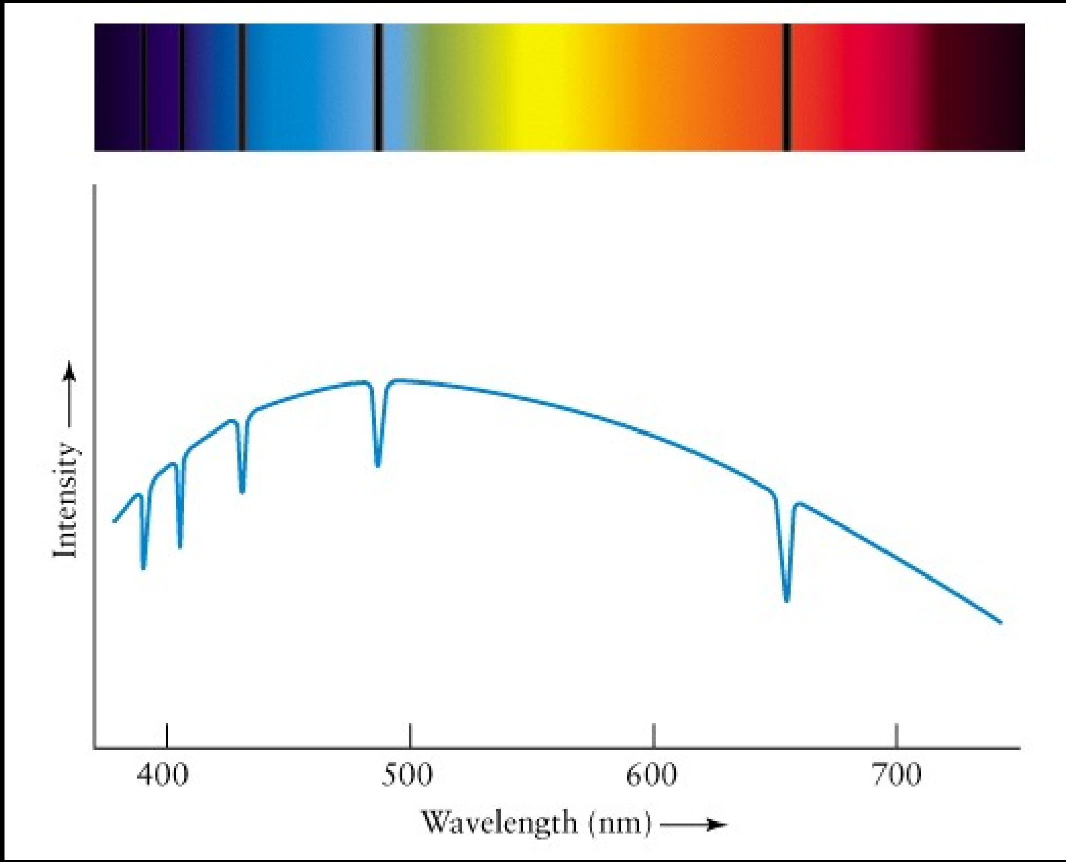
Since every element has a different set of atomic orbital energies, the emission line spectrum of every element is different. They are unique!



Absorption Line Spectra

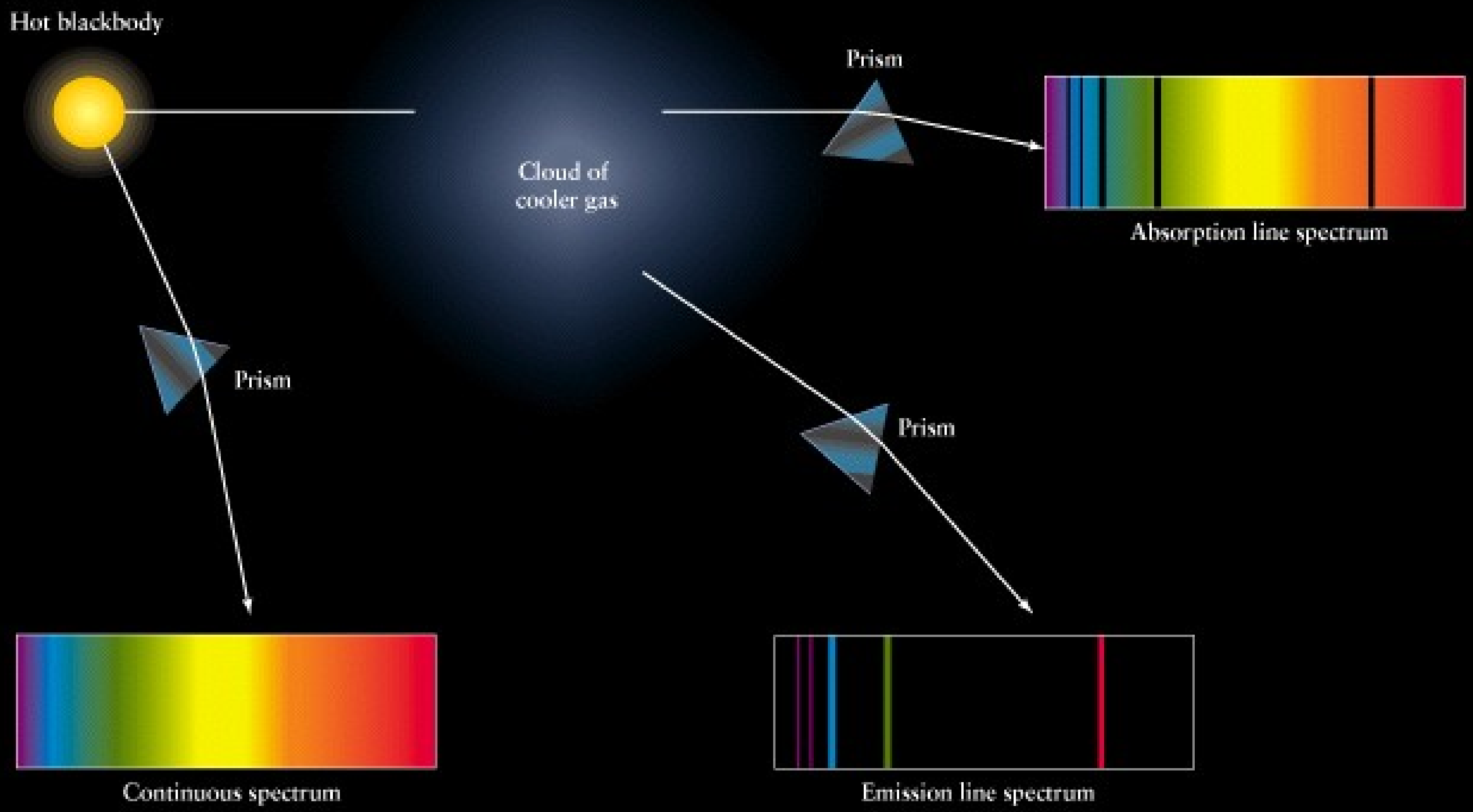
An object (like a star) emits a hot blackbody spectrum. Somewhere between you and the star (like on the outside of the star) is some cooler gas. That gas can absorb the photons which correspond to the atom's energy levels. The result is an absorption spectrum.

You observe the blackbody spectrum minus the energy that has been absorbed by the gas. (These photons have been re-emitted, but in other directions).

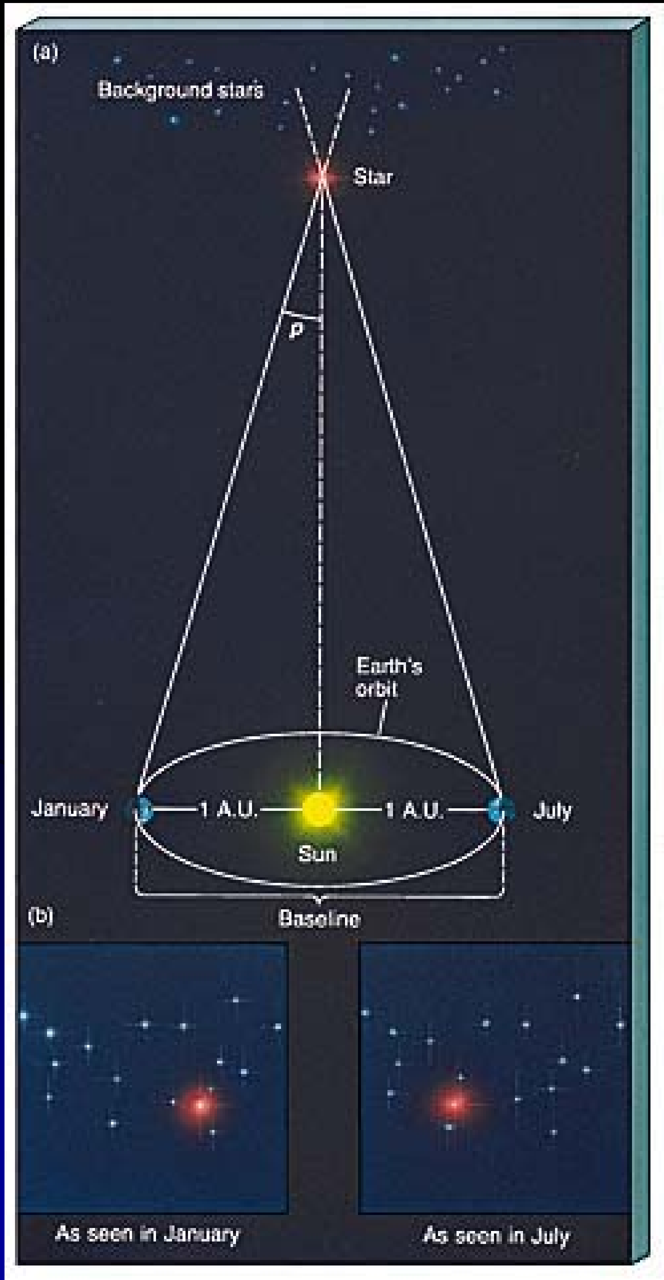


Emission versus Absorption

Atomic emission and absorption are really two sides of the same coin. Photons that are absorbed can be re-emitted to produce an emission line spectrum.



The Distances of Stars



Stellar distances can be determined via parallax – the larger the distance, the smaller the parallax angle (π)

The *nearest* stars have parallax angles of less than 1 arcsecond (1")!!

Astronomers define a parsec as the distance a star would have if its parallax angle were 1". From geometry

$$D(pc) = 1 / \pi$$

1 pc = 30,860,000,000,000 km

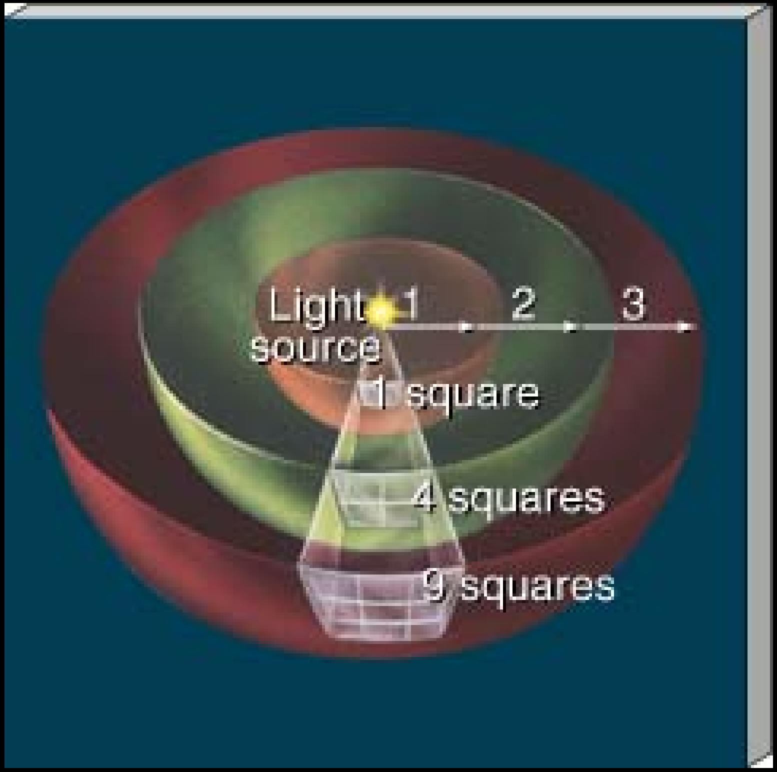
= 206,265 A.U.

= 3.26 light years

Measuring Stellar Luminosities

If you know the distance to a star (via parallax), then you know the star's luminosity from the inverse square law of light, *i.e.*, $l = L / r^2$, where

> ***l*** is the *apparent* luminosity,
> ***L*** is the *absolute* luminosity, and
> **r** is the distance.



Astronomers use either

- The solar luminosity (*i.e.*, a star that is equal in brightness to the Sun has $1\ L_{\odot}$), or
- An absolute magnitude system

The Magnitude System

Apparent magnitude is how bright a star appears in the sky. Each magnitude is 2.5 times fainter than the previous magnitude; a difference of 5 mag is 100 times in brightness!

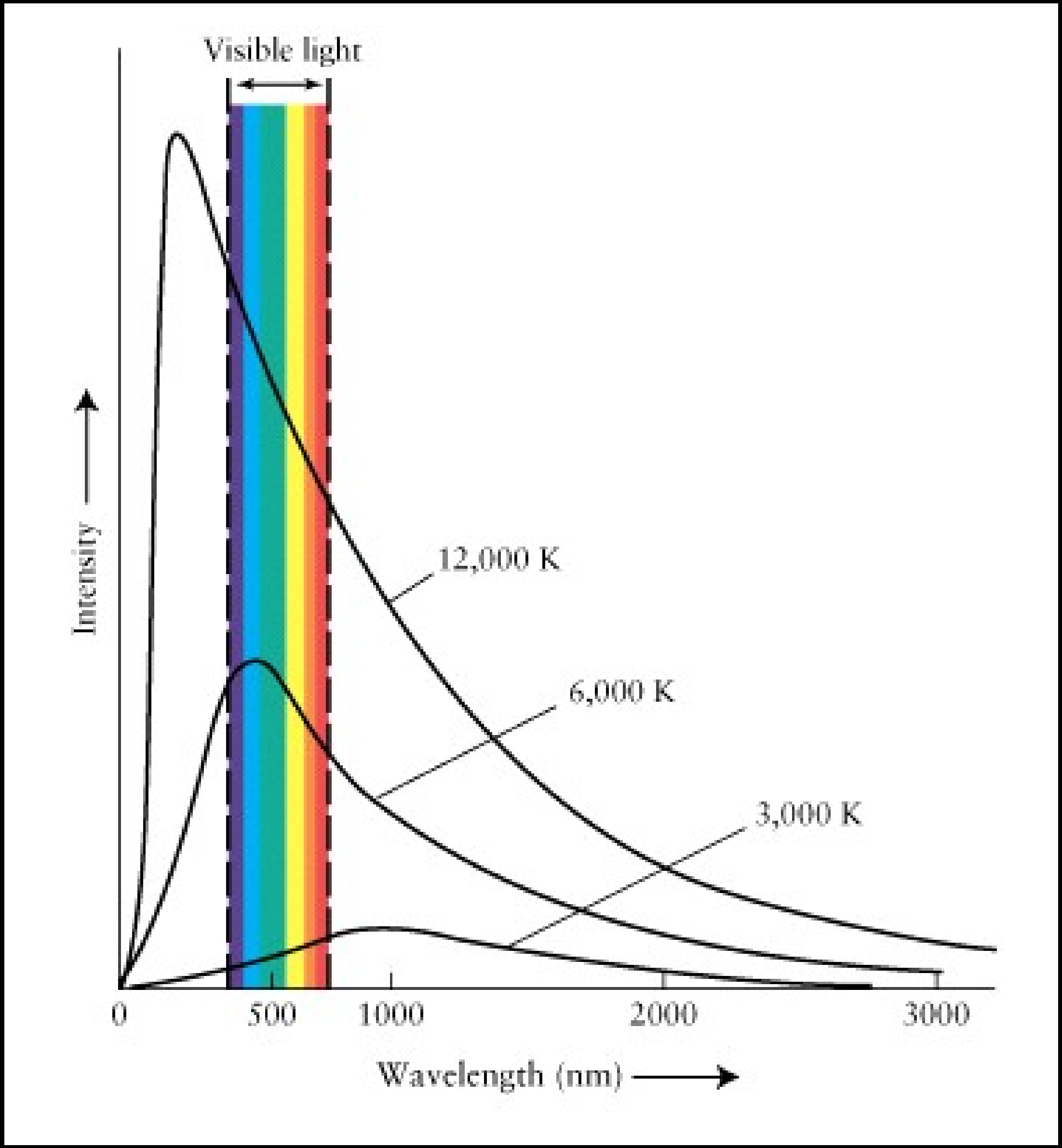
Absolute magnitude is how bright a star *would* appear *if* it were at a distance of 10 pc.

A 10 mag difference is 10,000 times in brightness!

Measuring Stellar Temperatures

One method of taking a star's temperature is to look at its color. Red stars are cool; blue stars are hot.

But watch out – dust may redden a star by scattering away the blue light.

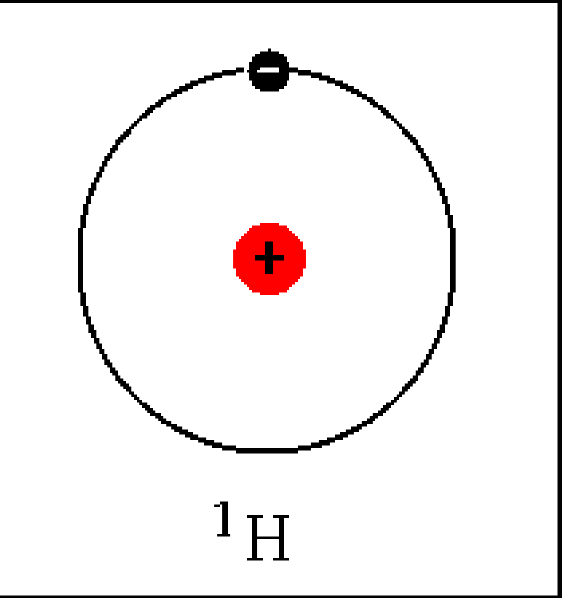


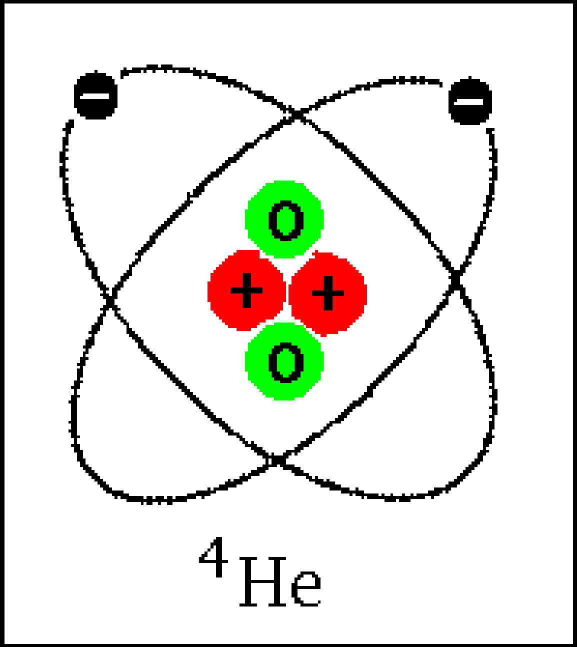
Measuring Stellar Temperatures

A better way of determining a star's temperature is to analyze the stellar absorption lines. Stars can display a wide variety of absorption lines: some show strong absorption due to hydrogen, some show strong helium, and some are dominated by metals.

But about 9 out of every 10 atoms in the universe is hydrogen, and about 9 out of 10 atoms of what is left is helium. So what's happening?

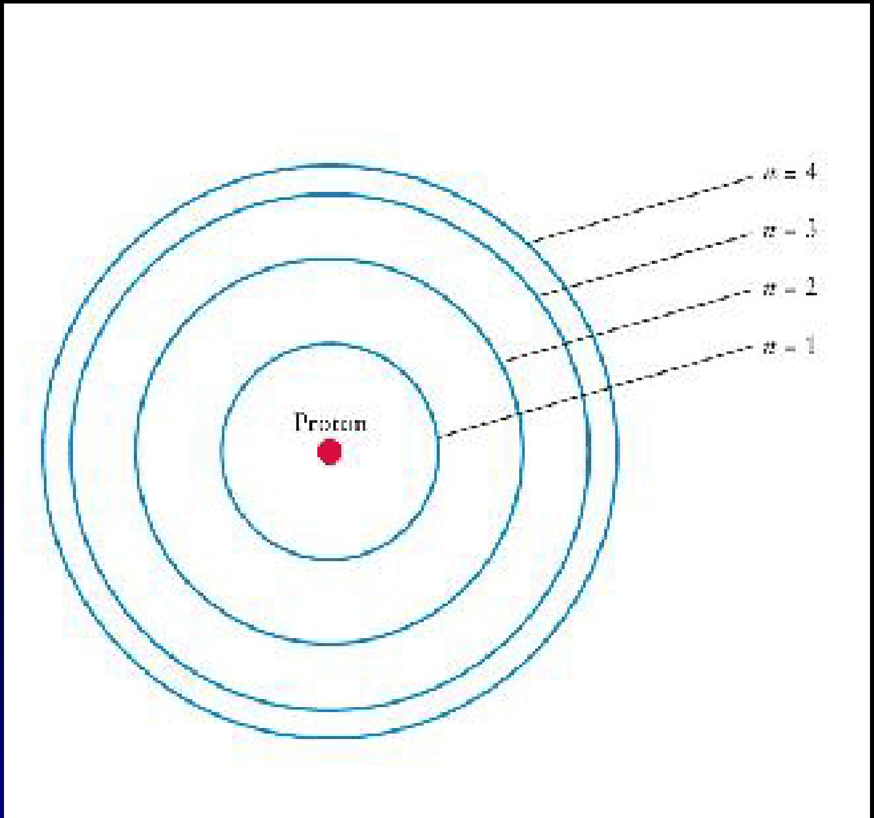
<u>It's a temperature effect!</u>

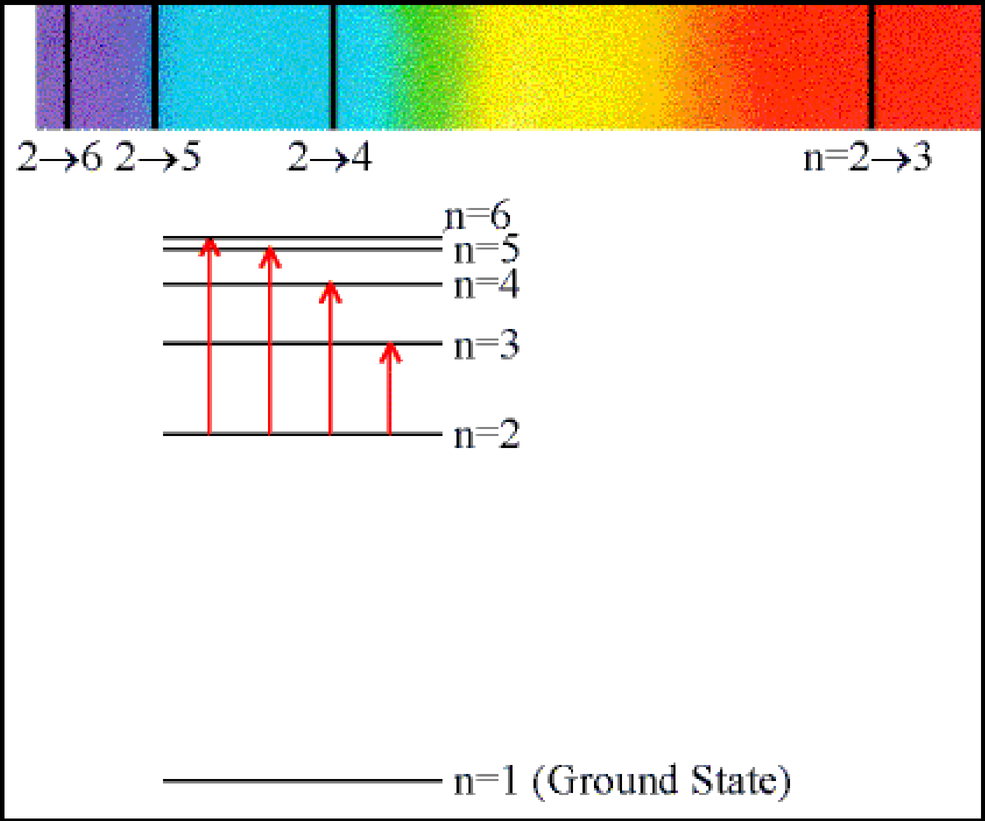




Example: the Hydrogen Atom

The hydrogen atom has a very big jump between the first and second energy levels, but a smaller jump between the second to the third.





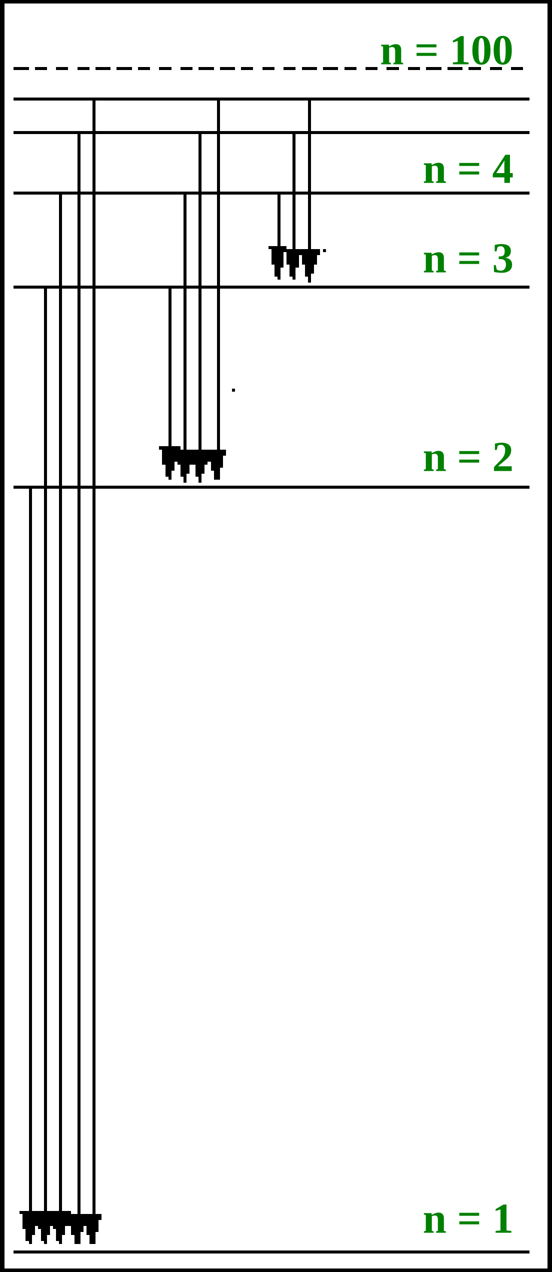
In hydrogen, all optical absorptions comes from the n=2 level.

Example: the Hydrogen Atom

If the star is too cool, there will be no electrons in the n = 2 level. (The atoms will be moving too slowly to collide anything up there.) If there are no electrons in n = 2 to start with, there will be no optical absorptions.

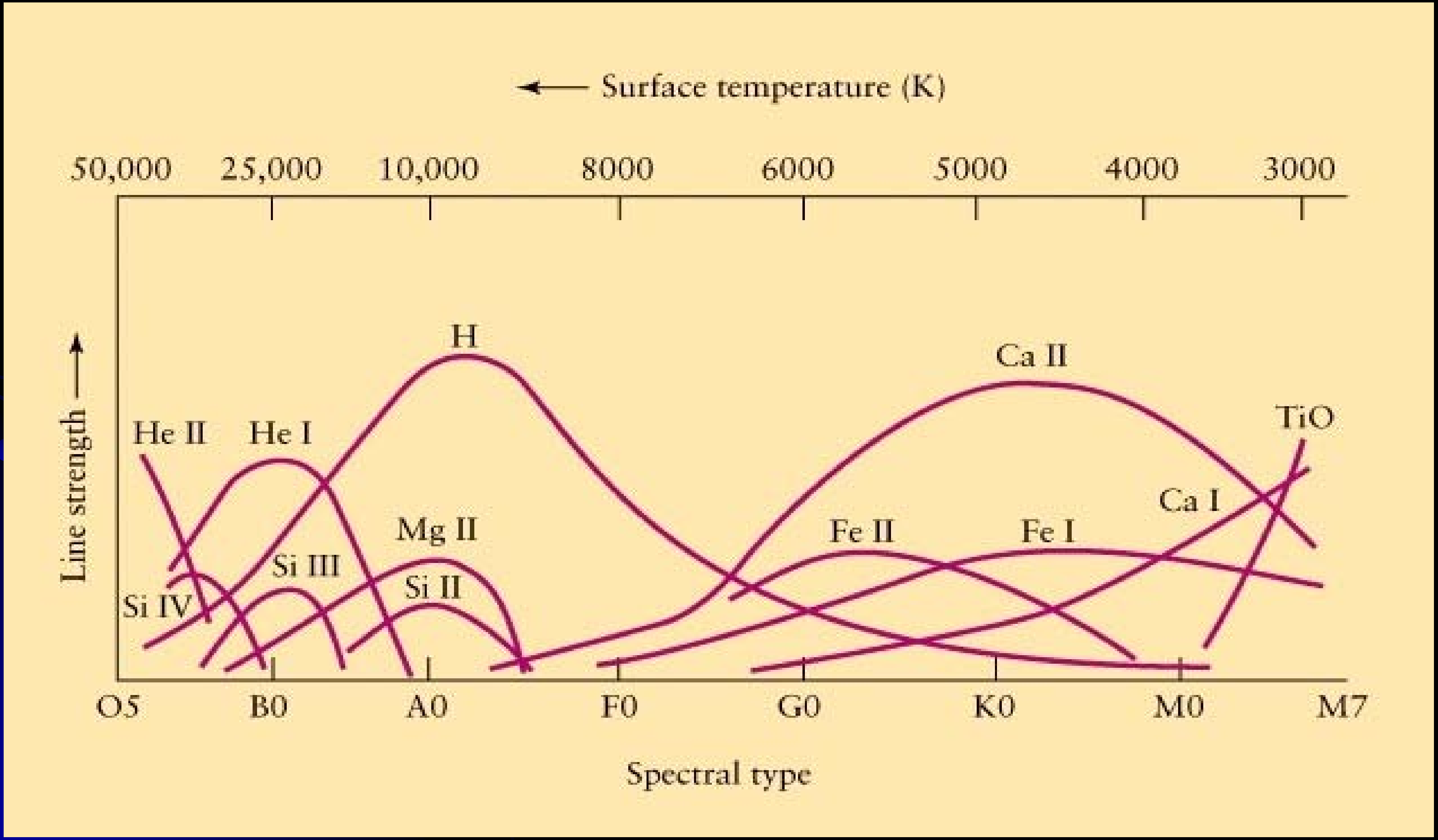
If the star is too hot, the ultraviolet photons coming from the star will ionize all the hydrogen atoms. If all the hydrogen atoms are ionized, there will be no electrons in the n = 2 level, and again, there will be no optical absorptions.

Consequently, hydrogen absorption (in the optical) is strongest at temperatures of about 10,000°. At higher (and lower) temperatures, hydrogen absorption is weaker.



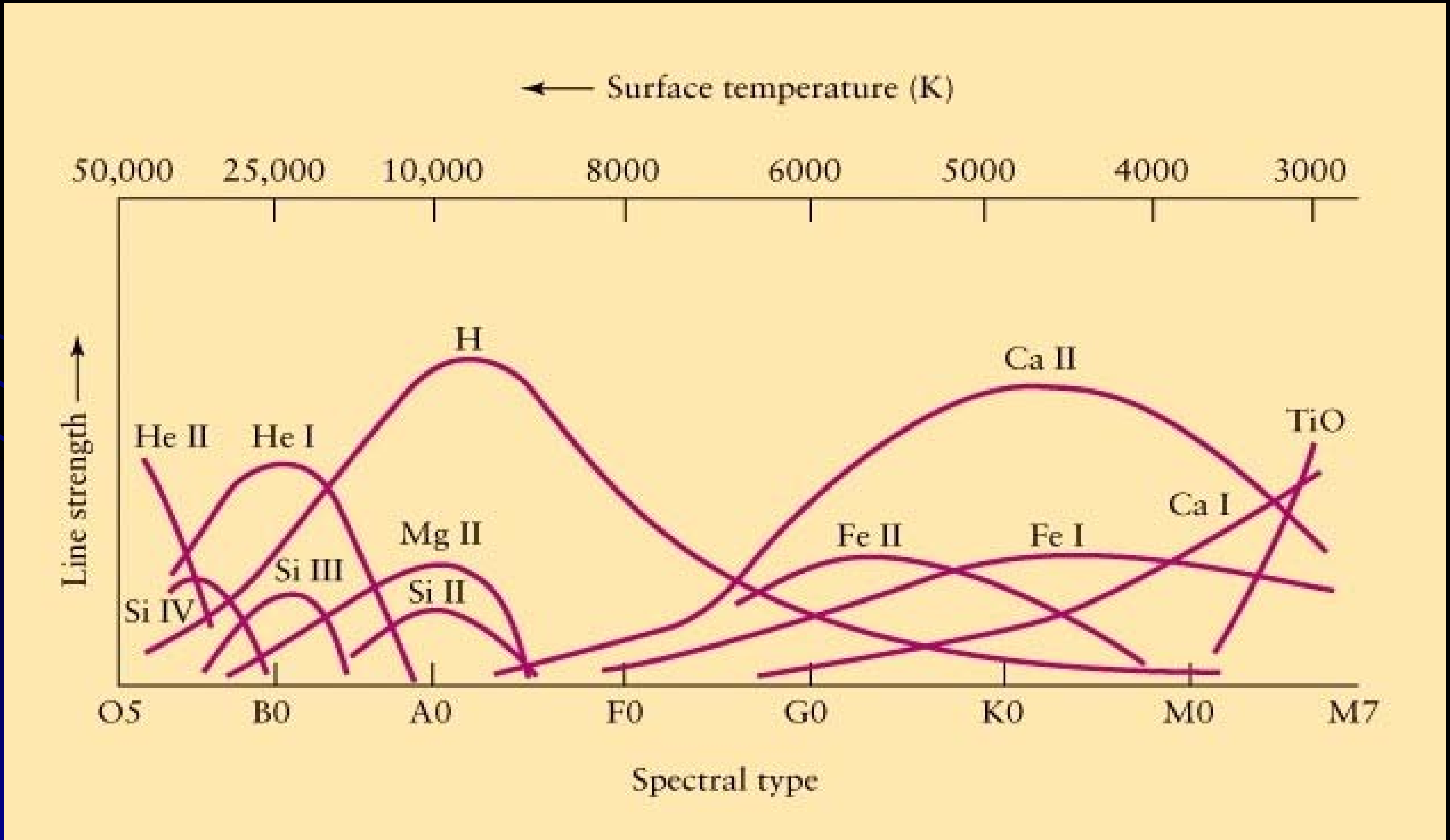
Measuring Stellar Temperatures

Each element works the same way; each has a “favorite” temperature range for absorption. By carefully identifying absorption lines, one can fix the temperature of a star precisely.

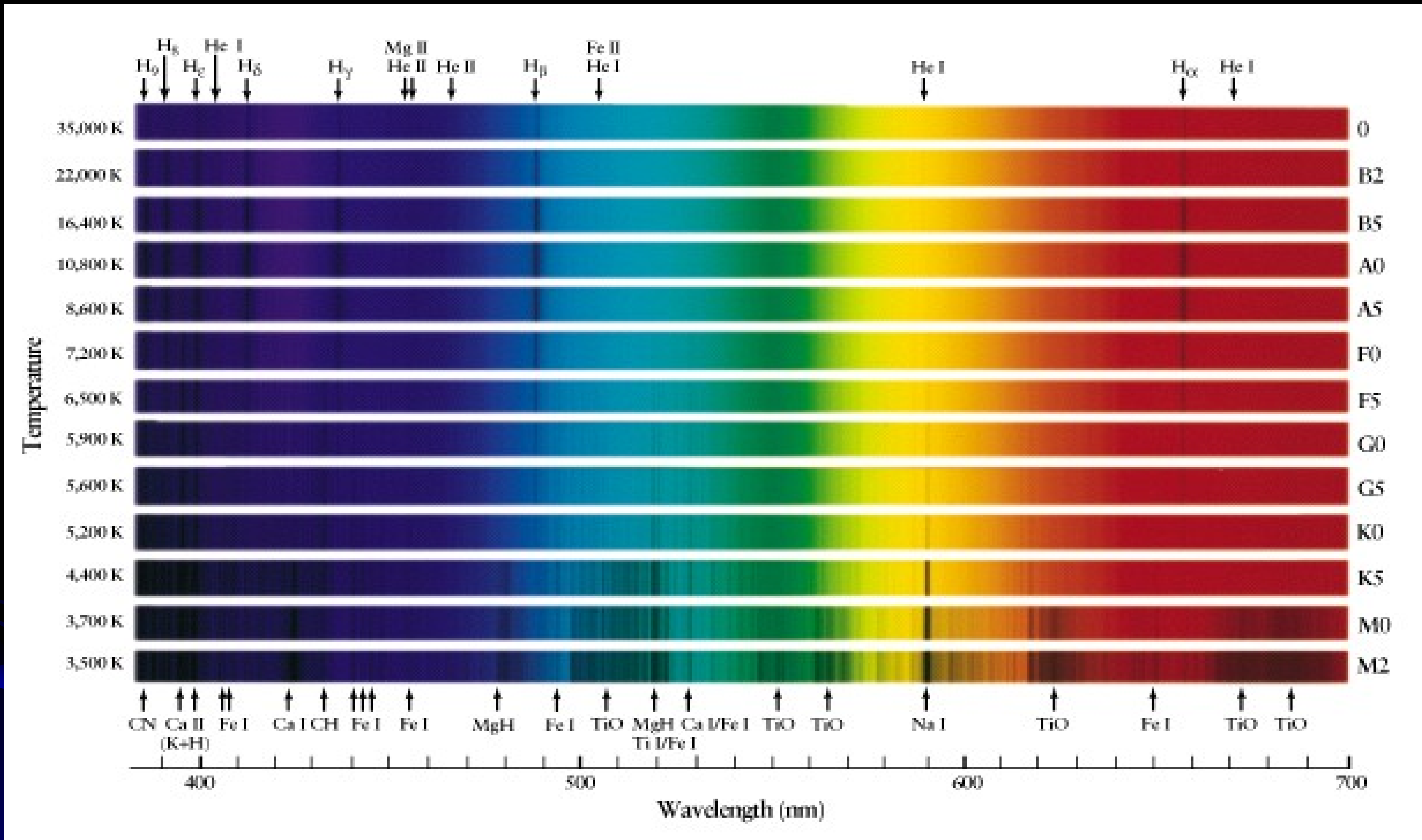


Examples of Strongest Stellar Absorptions

Hydrogen: T ~ 10,000°
Helium: T > 20,000°
Calcium: T ~ 5000°
Silicon: T ~ 15,000°
Molecules: T < 3000°

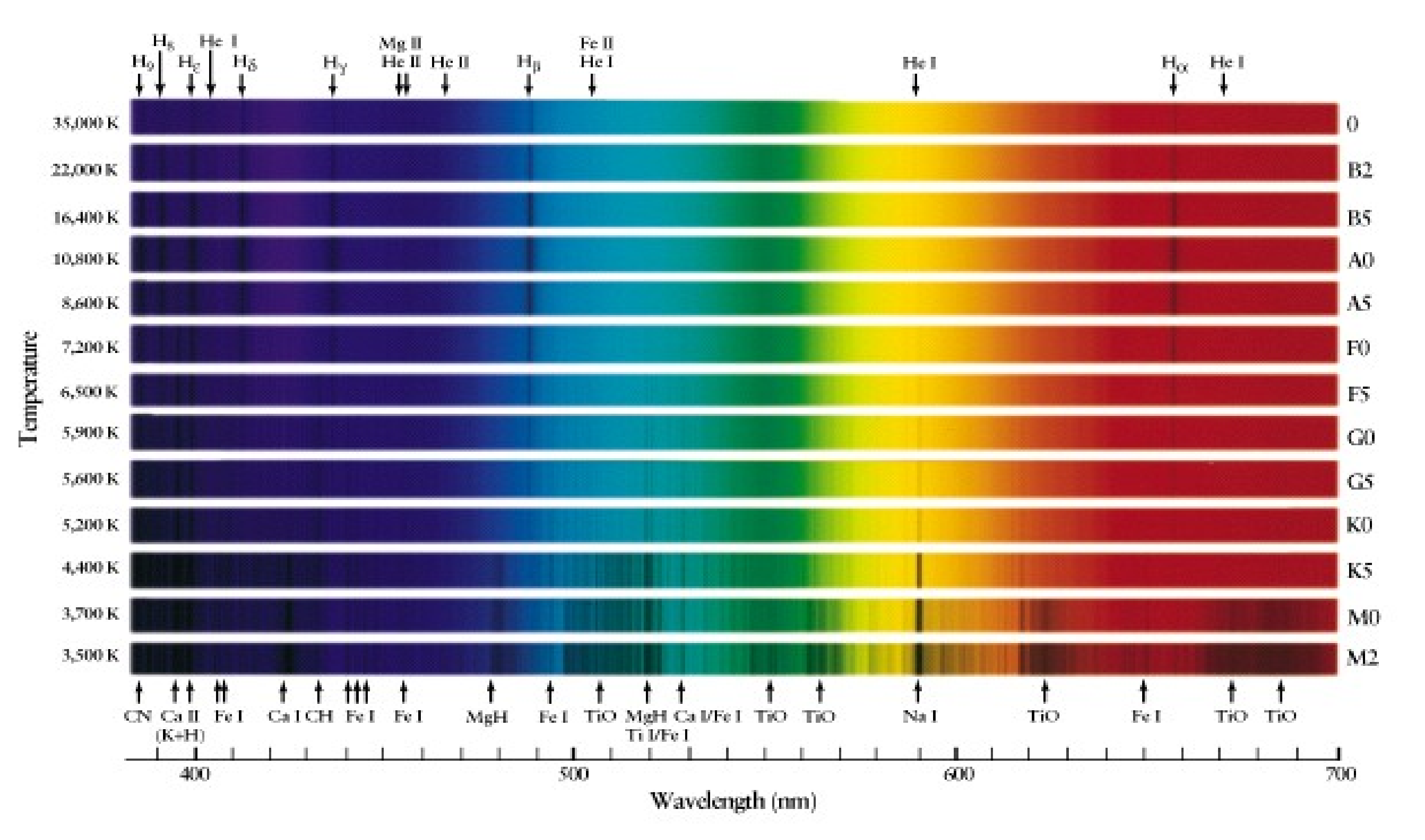


The Stellar Spectral Sequence



Astronomers originally classified the spectra of stars A through O based on the amount of hydrogen absorption. But since hydrogen absorbs most at intermediate temperatures, the spectral sequence is inside-out!

The Stellar Spectral Sequence

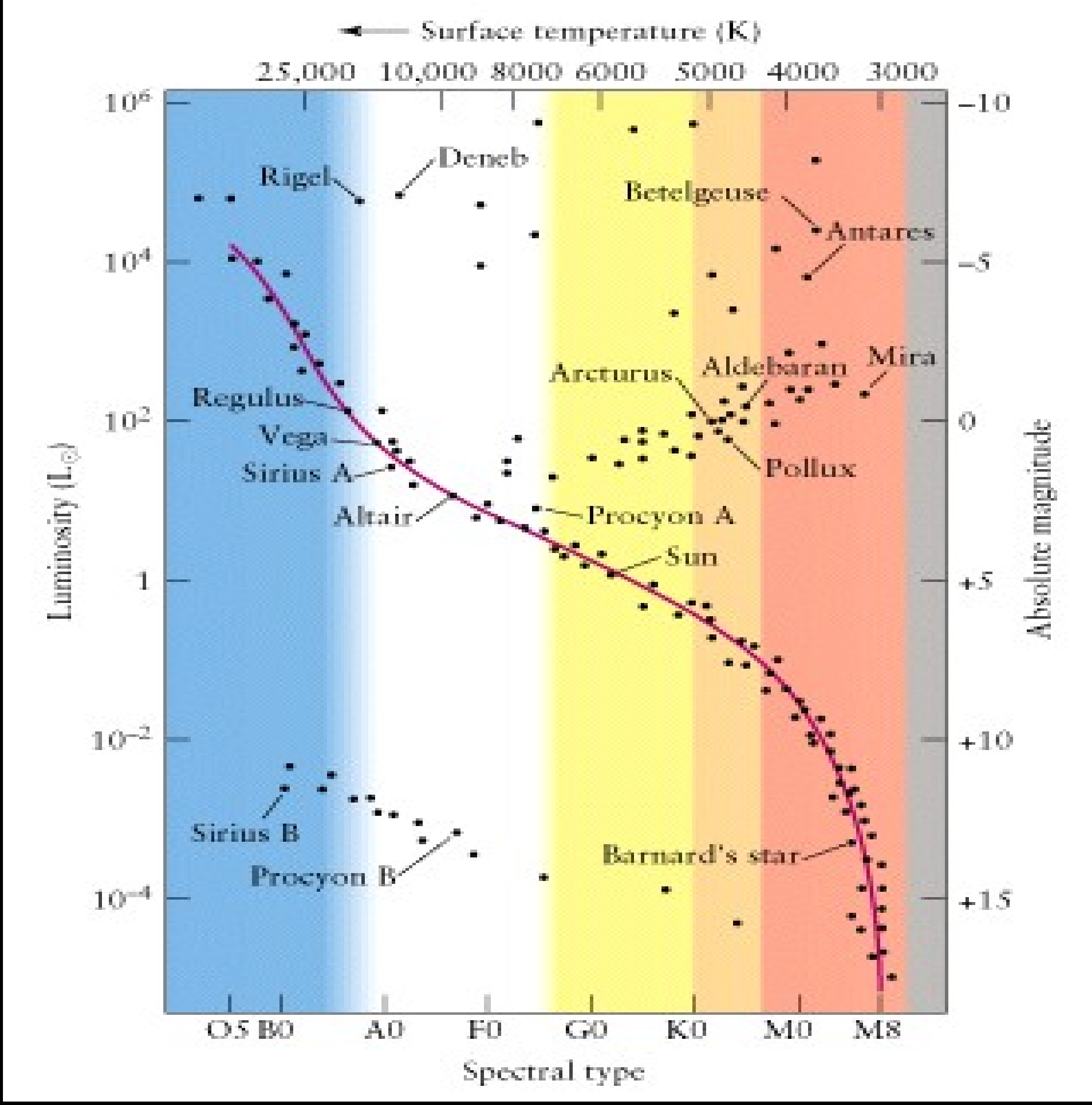


In order of temperature (hot to cool), the spectral sequence of stars is O-B-A-F-G-K-M. The traditional mnemonic is Oh Be A Fine Girl Kiss Me. (Recently, types L and T have been added to the cool end.)

The H-R Diagram

If a star's absolute luminosity and temperature are both known, they can be plotted against each other. This is called the Hertzprung-Russel (H-R) diagram.

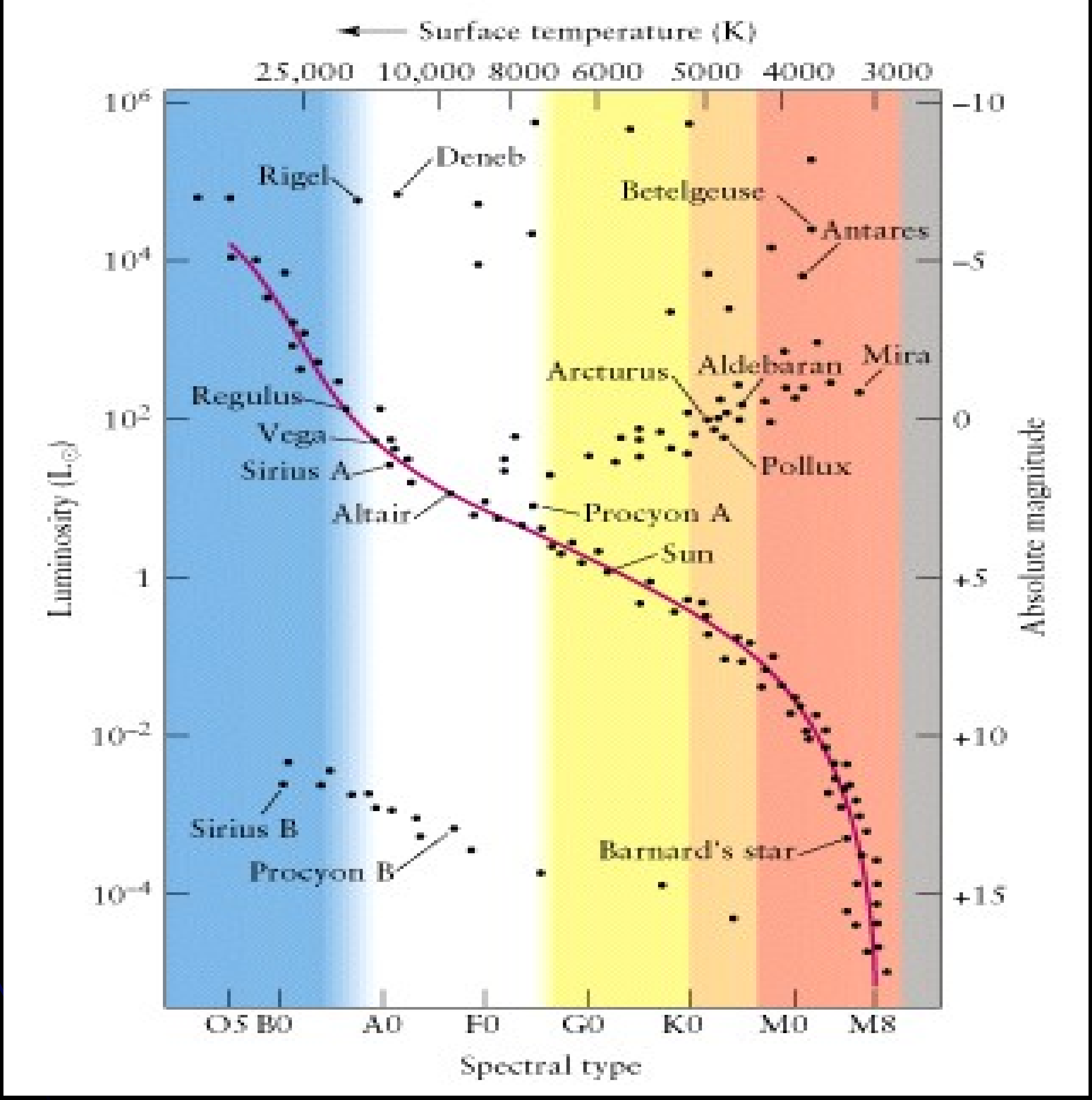
(As usual, the diagram is plotted somewhat backwards. Hot stars are plotted on the left, and cool stars on the right.)



The H-R Diagram

There are patterns in the H-R diagram. About 90% of the stars are located in a diagonal band, which goes from cool/faint to hot/bright. This is called the main sequence.

The Sun is a **G2** main sequence star.



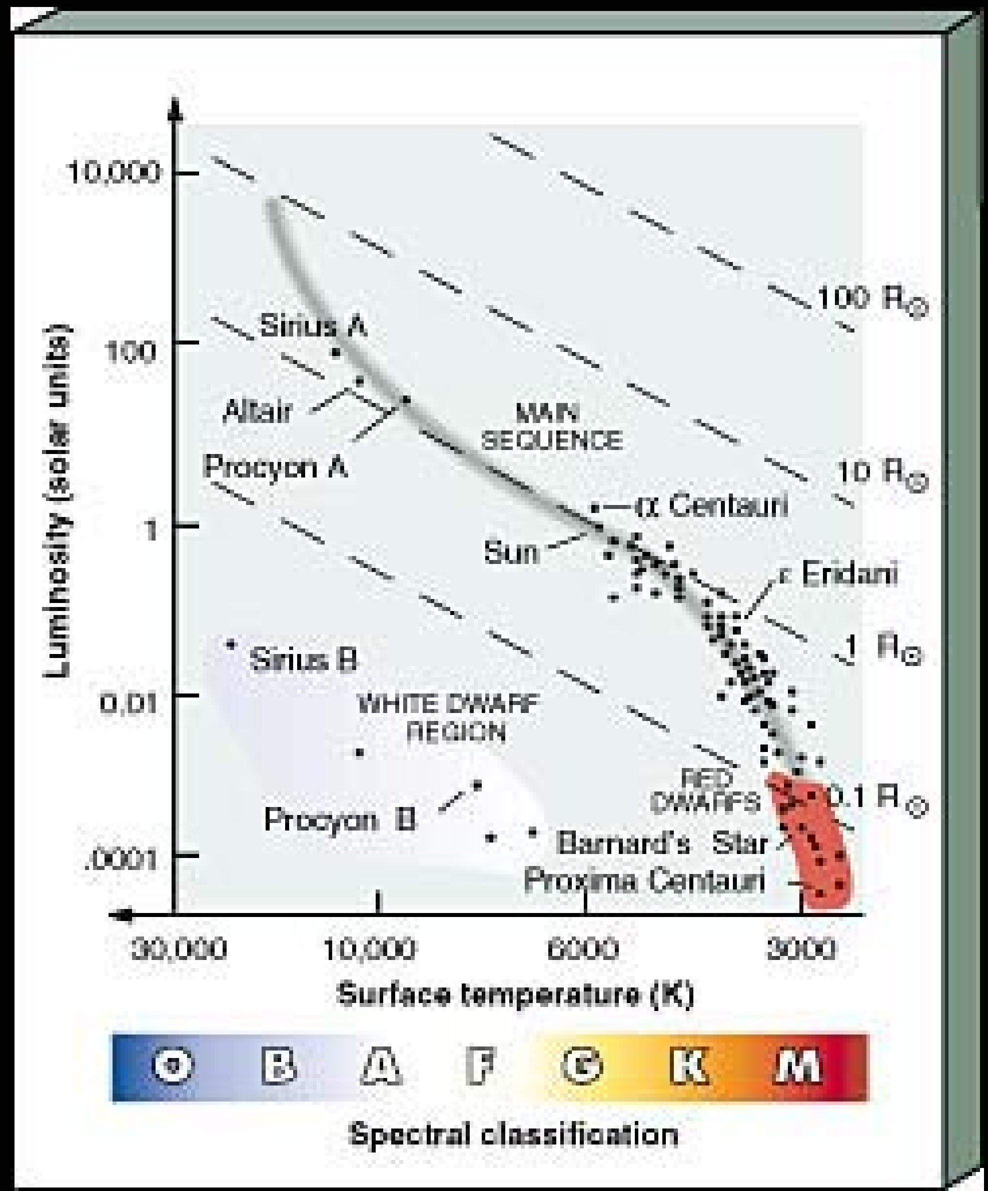
The Sizes of Stars

The main sequence makes sense. According to the blackbody law, hot things emit more light. But a star's brightness also depends on its size – the larger the area, the more light that is emitted.

The relationship between luminosity, radius, and temperature is

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

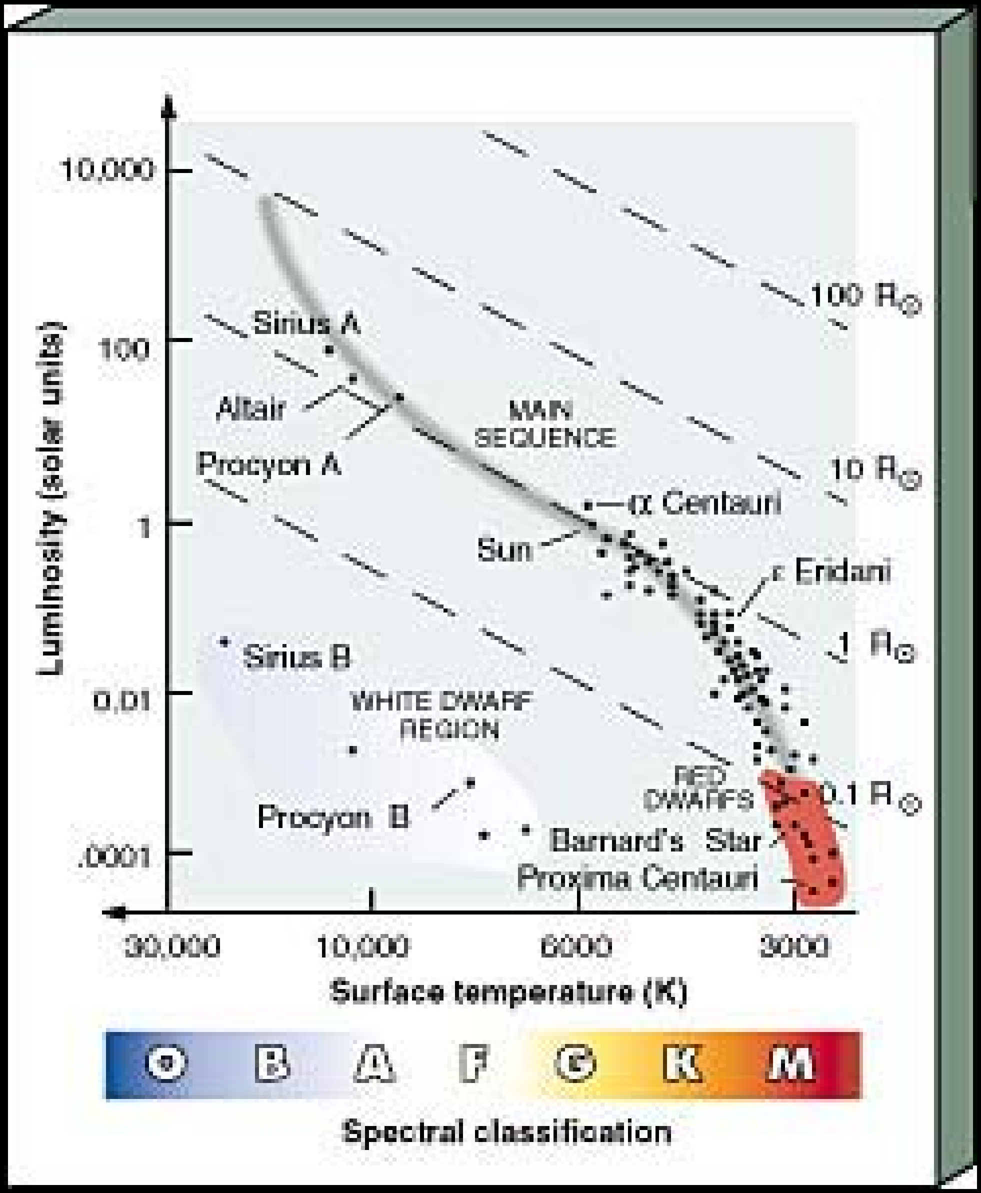
(π and σ are just numbers to make the units come out right)



The Sizes of Stars

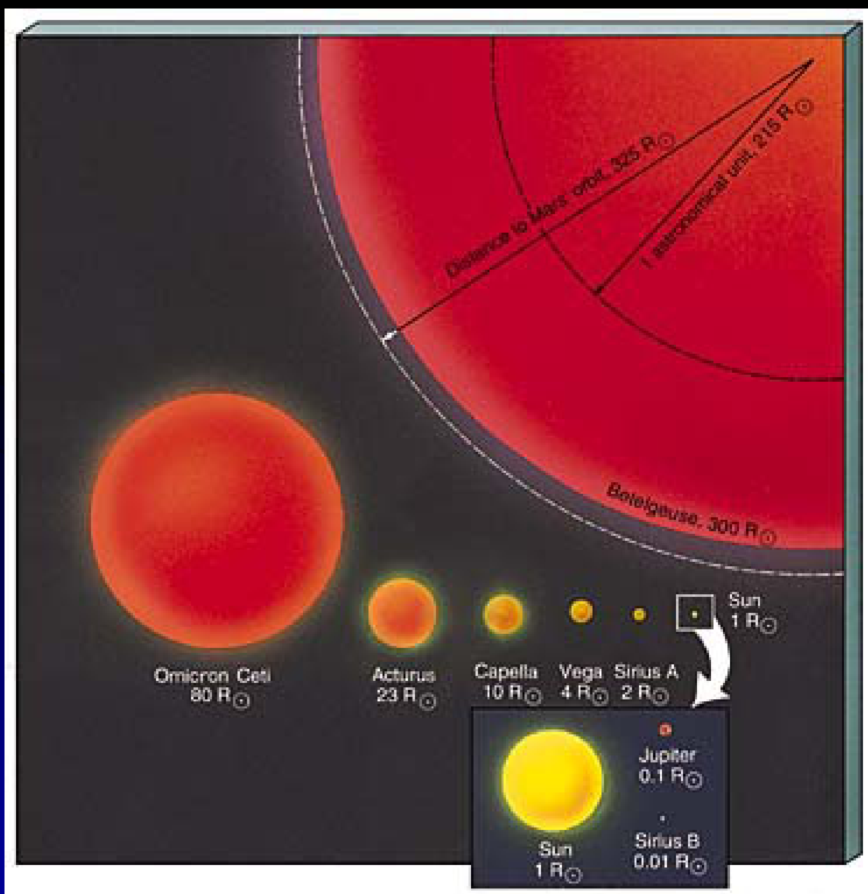
Some stars are not on the main sequence. Some are very cool, but also very bright. Since cool objects don't emit much light, these stars must be huge. They are red giants.

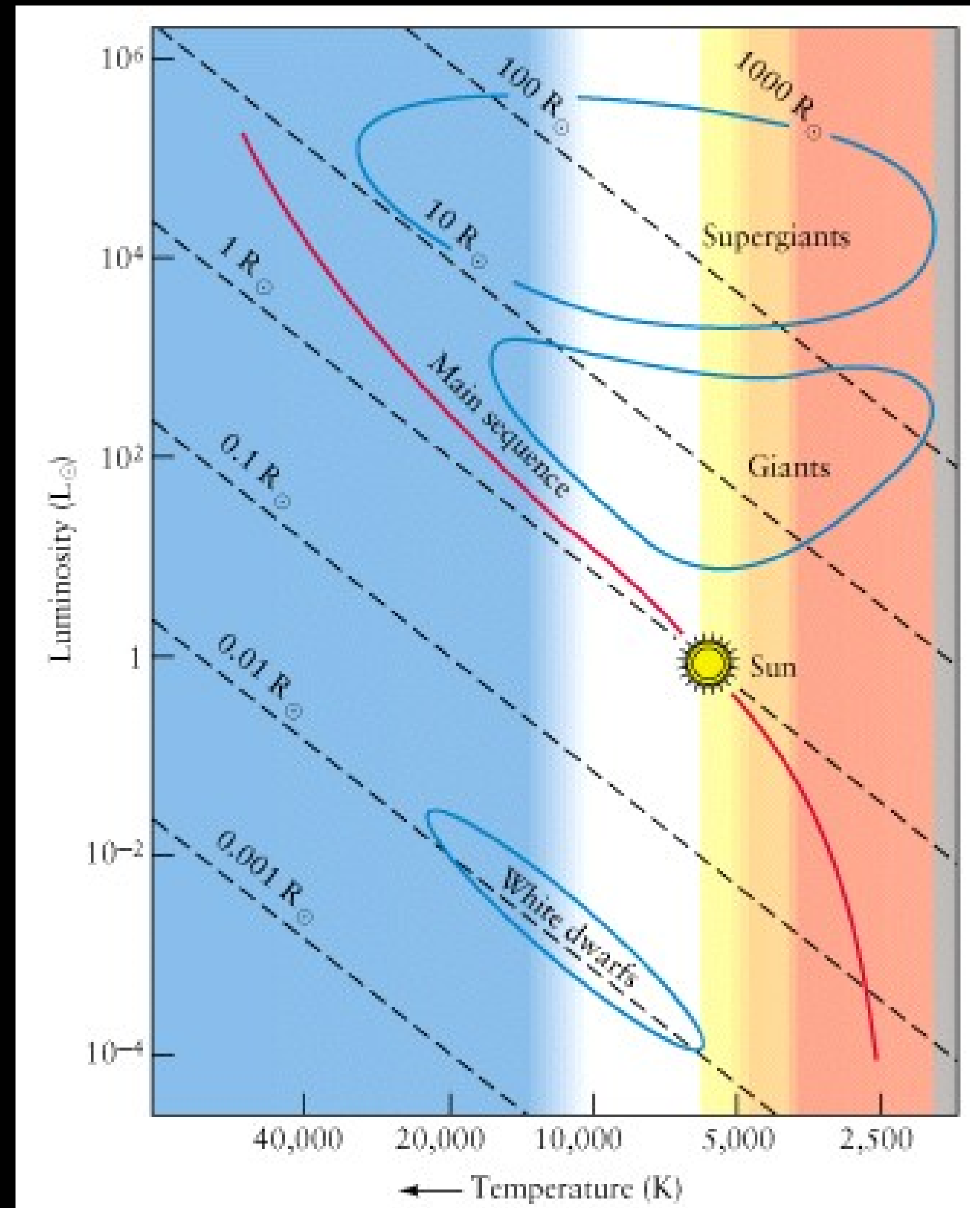
Some stars are faint, but very hot. These must therefore be very small – they are white dwarf stars.



The Sizes of Stars

The sizes of stars can be anywhere from 0.01 $R_\odot$ to 1000 $R_\odot$!





The Masses of Stars

- Stellar masses can only be determined via the application of Kepler's and Newton's laws, *i.e.*,

$$\boxed{(M_1 + M_2)\, P^2 = a^3}$$

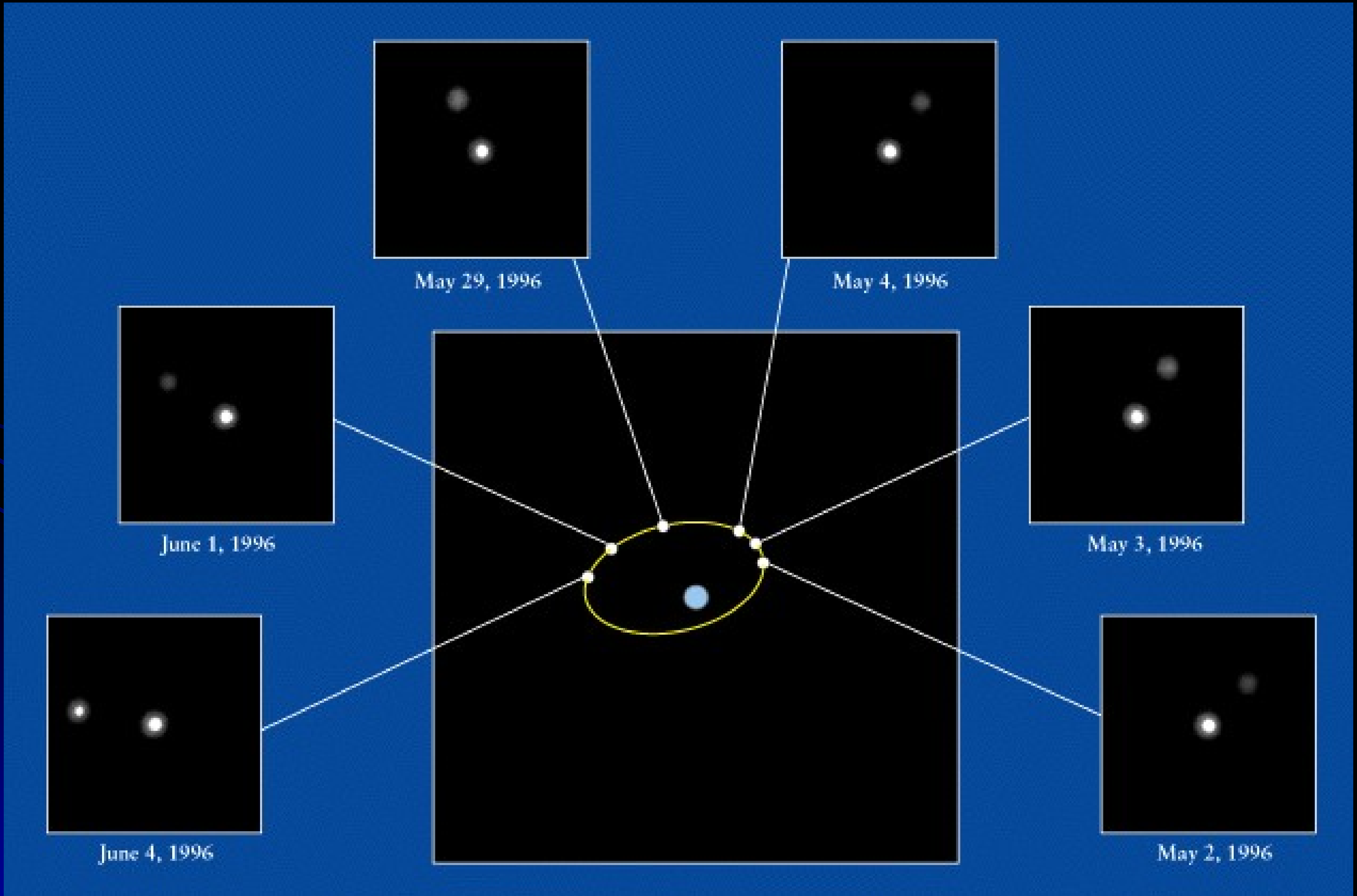
where

- **M_1** and **M_2** are the stellar masses (in solar units)
- **P** is the orbital period (in years)
- **a** is the semi-major axis of the orbit (in A.U.)

This requires *binary stars*!

Visual Binaries

When both stars can be seen, it's called a Visual Binary.

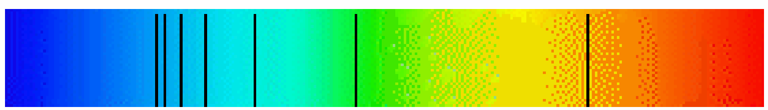


Spectrum Binaries

If the stars are too close together to be seen separately, it is possible to identify the object as a binary based on its spectrum

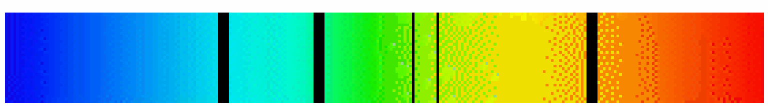
Spectrum Binary

Normally, each star as a unique spectrum (spectral class). For example, a hot star has a spectrum rich in hydrogen lines



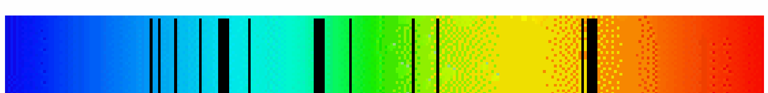
hot star

A cool star has thicker lines from metals, such as below



cool star

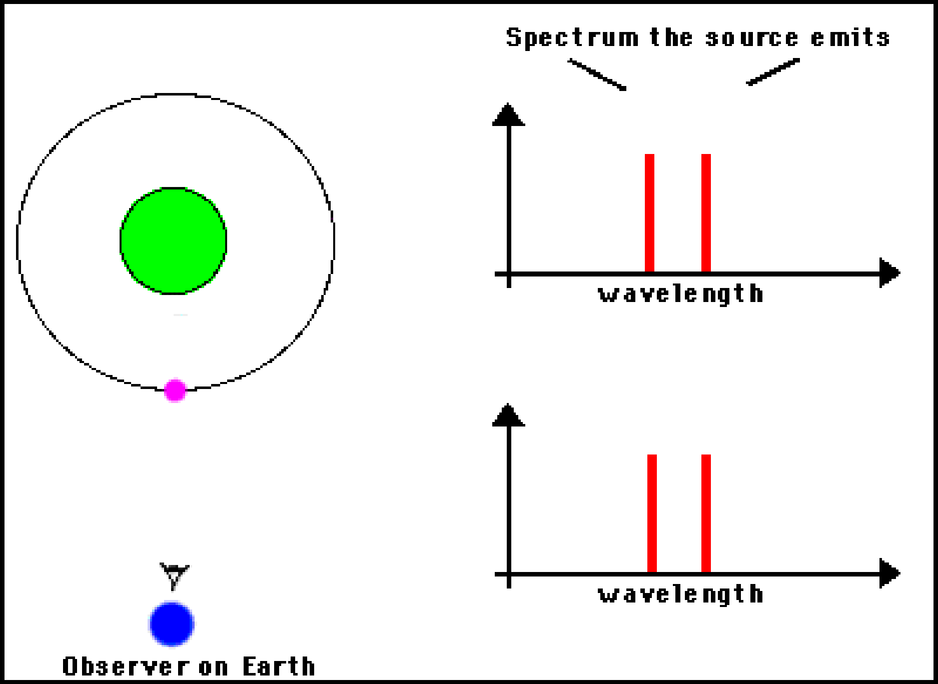
So, a spectrum binary is when you can not see two stars on the sky, but a spectrum of the object show two difference stellar classes, as below.



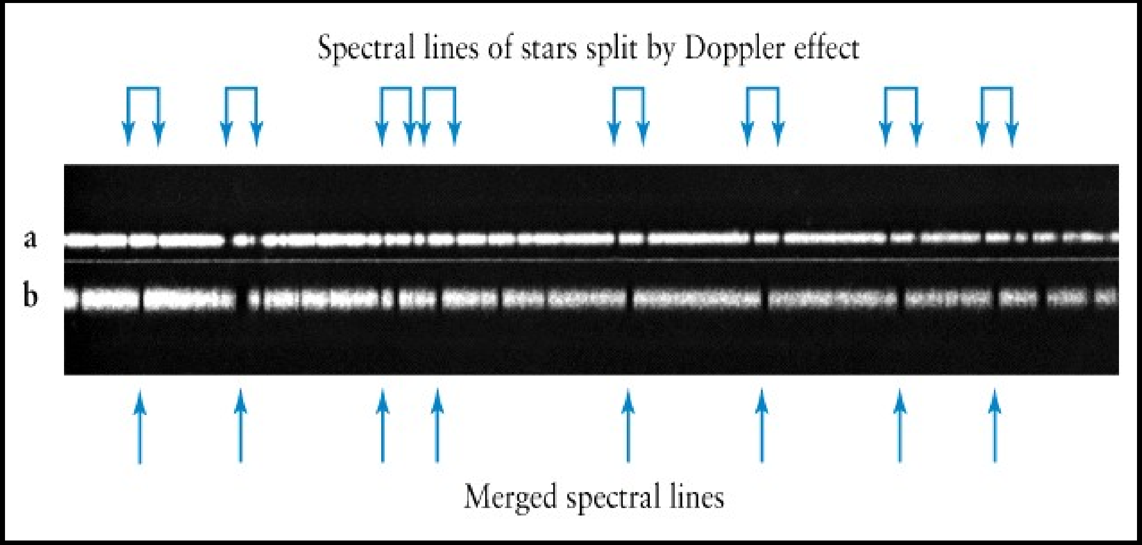
spectrum binary

Spectroscopic Binaries

If the Doppler shift of a star's absorption lines changes with time (redshift, then blueshift, then redshift, etc.), it's a spectroscopic binary.

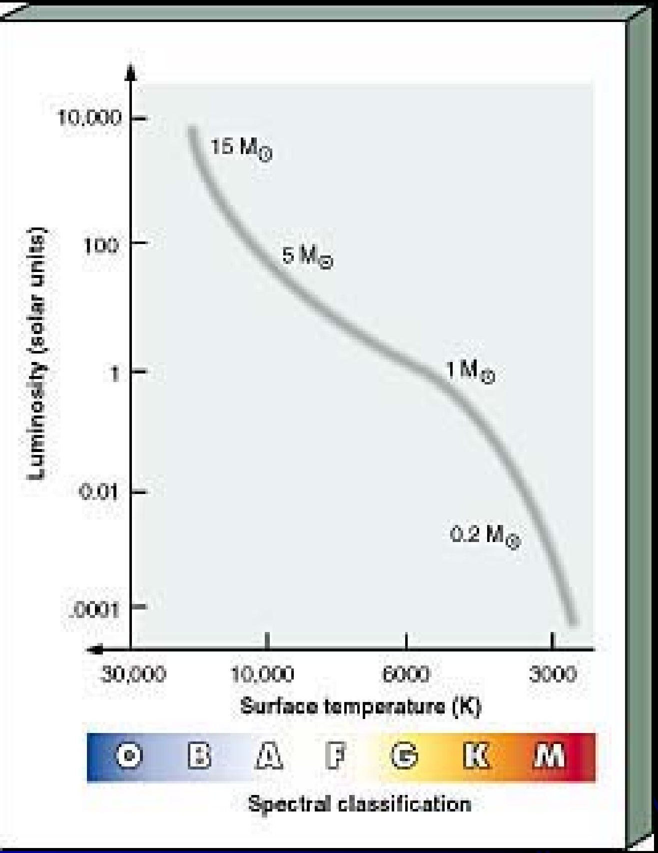


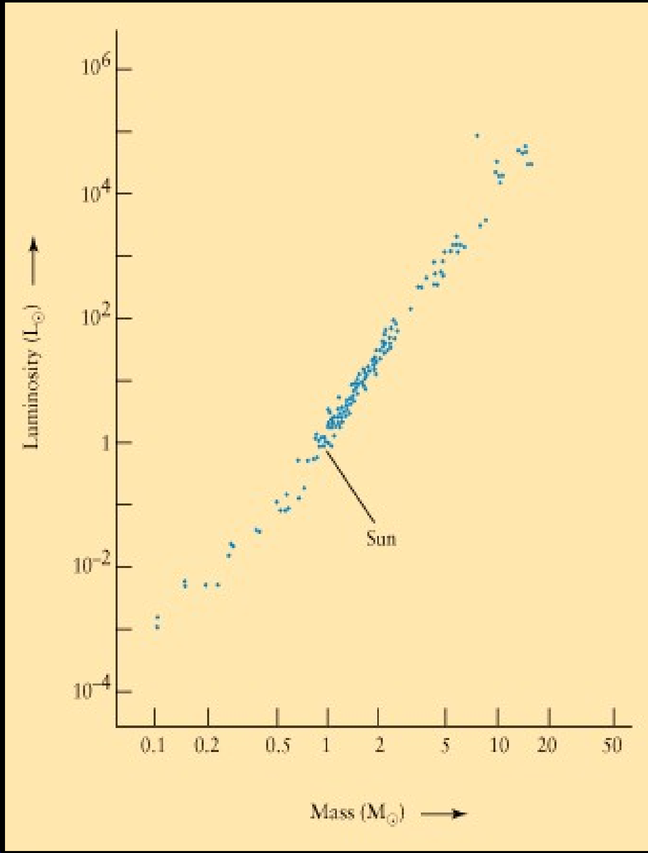
If one star is much fainter than the other, you may not see its lines. The object is then a single-line spectroscopic binary. If both sets of lines are seen, then it's called a double-line spectroscopic binary.

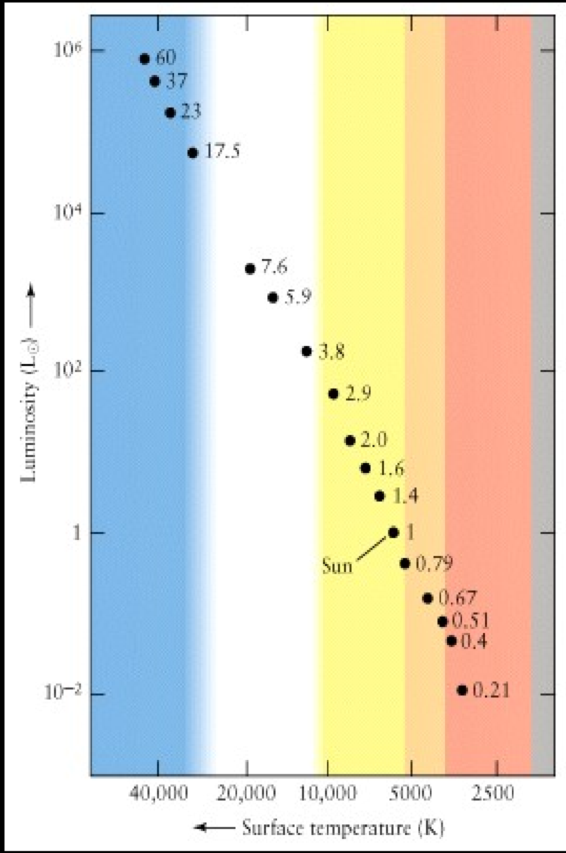


Results from Binary Stars Measurements

1) All stars have masses between 0.1 $M_\odot$ and 60 $M_\odot$
2) Main sequence stars obey a mass-luminosity relation: the brighter the star, the more massive the star.







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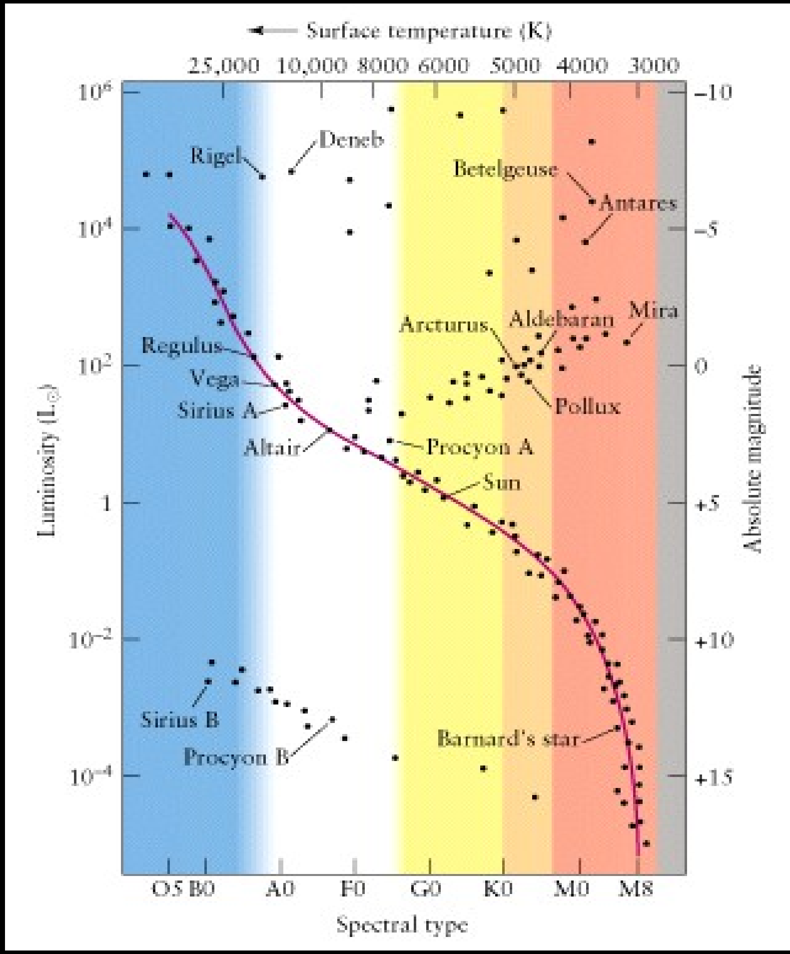

3) The white dwarf stars are all less than 1.4 $M_\odot$
4) There is no pattern to the masses of red giants.