Stellar Classification

What is a star?

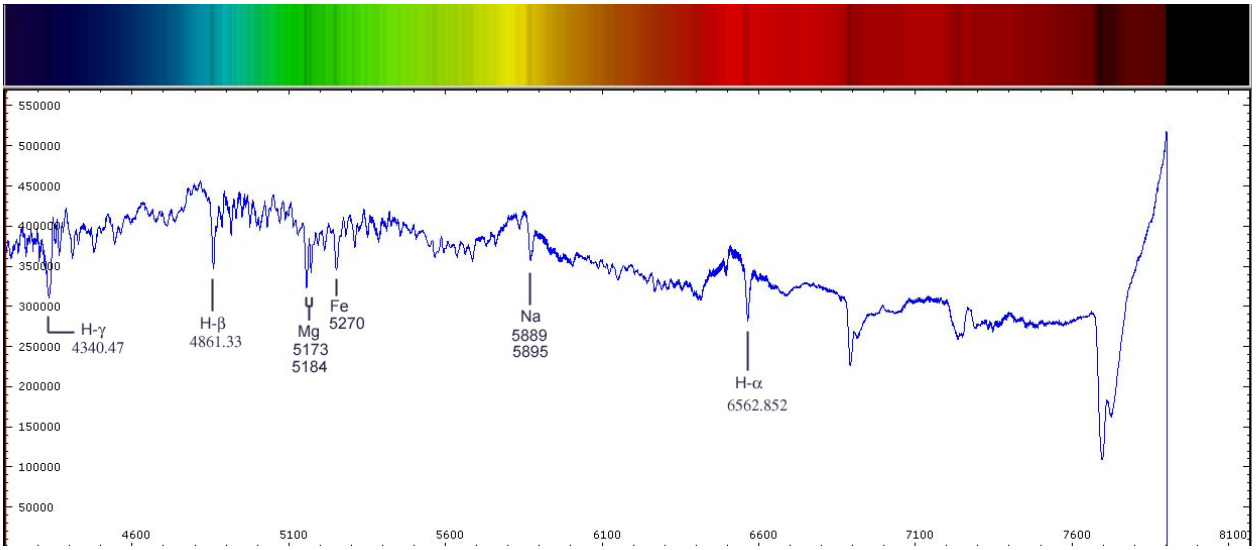
We have all looked to the night sky and seen the many stars illuminating the otherwise dark backdrop. If you haven't been amazed by this, you must not be seeing what everybody else is. But what is a star? Basically, it is just a big ball of "burning" gas. There are well over 100 billion stars in the Milky Way Galaxy alone, each with its own unique size, mass, temperature, and color. If stars have different colors, why do they all appear white in the night sky? The stars in the night sky are so far away, that the light given off by them is too dim for our eyes to see the different colors. If we were to look at the same stars with the help of a telescope, the different colors would become more apparent.

Side Note Experiment: There are actually two stars (Betelgeuse and Rigel) in the constellation of Orion that can be seen with the naked eye to have colors other than white. On a clear night, try to find these stars and determine what color they are.

Since the beginning of the human race on this planet, people have wondered about the stars and have tried to learn all they can about them. The first step in understanding stars is to observe them and classify them. One of the very first classifications of stars was made by ranking how brightly they shined in the night sky and grouping similarly bright stars together. Although there was no hard scientific evidence supporting the data at the time (the observations were made by simply looking at the sky with the naked eye), it was a way to organize stars which helped astronomers learn more information about them.

Looking at the spectrum of a star

Below is a picture of the spectrum of the Sun. We will be dealing with graphical representations of spectrums (the bottom half of the picture), but the above picture is a good example of showing all of the colors and the spots where color is missing. A spectrum is a graph of the amount of light something gives off (how bright the object is) at different wavelengths. In the spectra of stars, we frequently do not know the distances to the stars, so a star's spectrum shows how bright it appears from Earth. One easy way of splitting light, which can be used to see its spectrum, is with a glass prism.

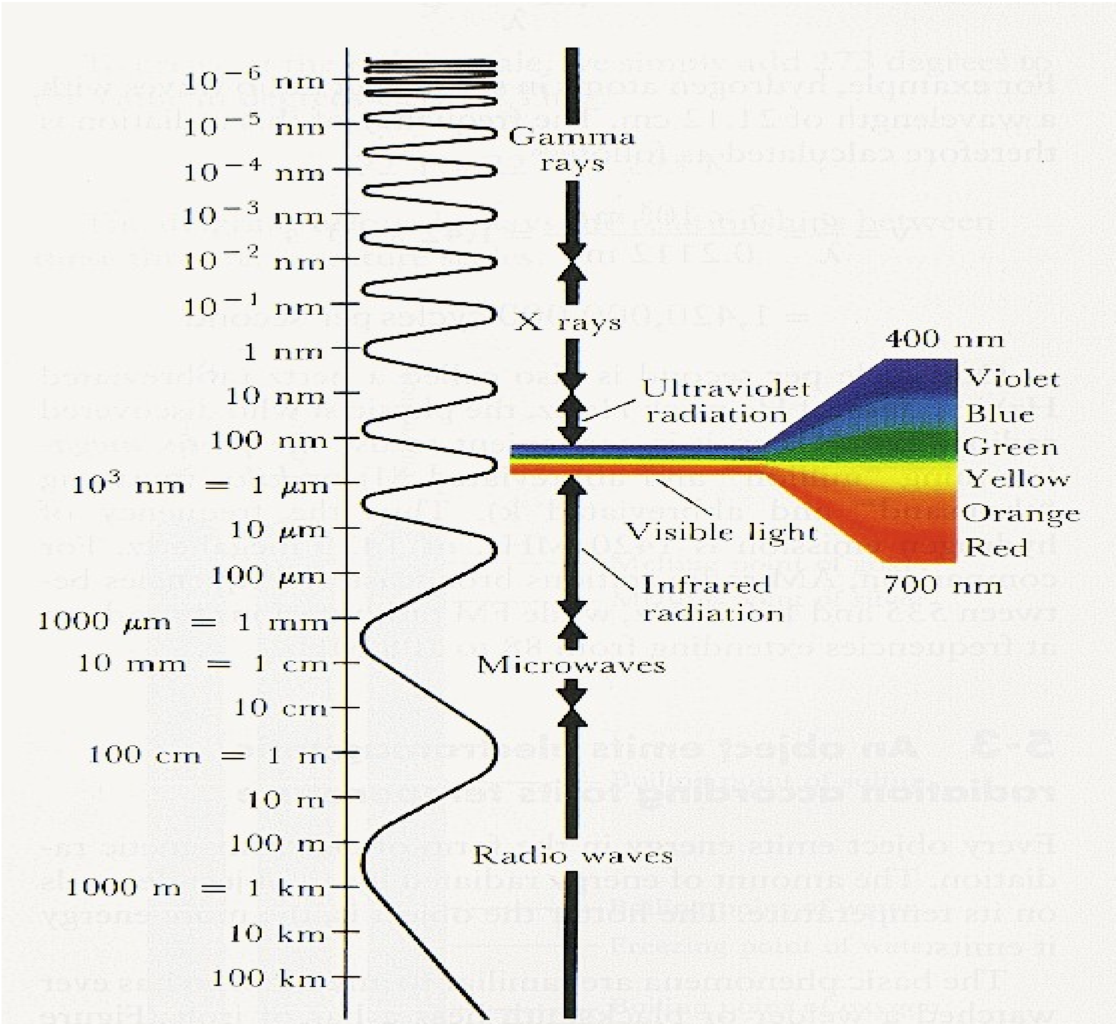


http://www.regulusastro.com/regulus/spectra/sol.html

Side Note Experiment: Try shining a flashlight through a glass prism onto a white backdrop (a piece of paper or a white wall would both work) and see what happens. Can you explain why?

******SDSS explanation******

Believe it or not, visible light is only a very small fraction of all the light in the world. Below is a picture showing the different types of light and at what frequencies they occur at. From largest wavelength to smallest wavelength, the different types of light are radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, x rays, and gamma rays. It is easily seen in the picture that all of the visible light, colors, and everything we see each day only consist of a tiny portion of all the light. It can also be seen in the picture that visible light spans from about 400 nanometers to 700 nanometers and as the wavelength changes, so does the color. Red has the longest wavelength, followed by orange, yellow, green, blue, indigo, and violet, hence the infamous ROY G BIV expression.



http://zebu.uoregon.edu/2003/ph122/lec04.html

All of the stars in the galaxy emit all of the colors in the light spectrum constantly. But wait, how then do stars appear to be different colors? This question will soon be answered.

Harvard Classification

In the late 1800s an astronomer at the Harvard College Observatory began to record stellar spectra, using a method similar to the glass prism described above. The first star looked at was noticed to have "gaps" or "breaks" in the spectrum at specific points, called absorption lines. This was not understood as well at the time as it is now, but nevertheless, the star was categorized as an "A". If the next star spectrum had similar absorption lines in the spectrum to the first, then it too would be classified as an "A". However, if the absorption lines were not similar to the first star, it was classified as a "B". This went on until all of the stars recorded were categorized with a letter between A and Q. In the beginning of the 1900s, a different astronomer used these same categorizing letters, but dropped all of them except for O, B, A, F, G, K, and M in that order. It was later realized that this classification was based on temperature, with O being the hottest and M being the coolest. Furthermore, the numbers 0-9 were added at the end of the letter to further divide the stars. For example, a B0 represents the hottest star in the B series, while a B9 represents the coolest star in the series. Our sun is classified as a G2 star. A way to remember the order of classifications is to use the mnemonic device, Oh Be A Fine Girl/Guy Kiss Me.

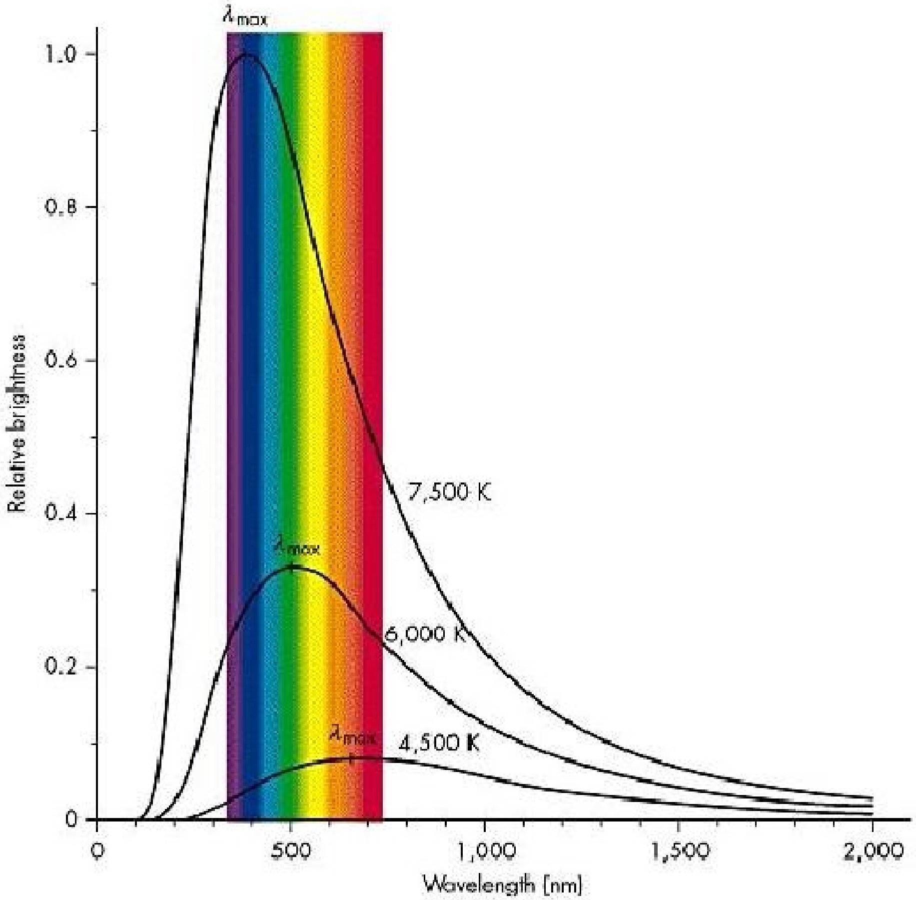
Exercise 1:

1. Which one of these four stars is the hottest? G2, A7, A1, B3

2. Which of these four stars is the coolest? O4, A4, K2, F8

The reason stars are different colors is directly related to them being different temperatures. The hotter stars look blue, the cooler stars look red, and stars like our sun (cooler than blue stars and hotter than red stars) look yellow. This is why physicists have trouble in the shower; the colors for hot and cold are mixed up. I know, bad physics joke. Of course there are different shades of the colors, meaning stars could be orange, bluish-white, or other shades of the above colors. The graph below shows a black body curve for three different stars with temperatures of 4,500 K, 6,000 K, and 7,500 K. A black body is an idealized object that absorbs all electromagnetic radiation (light) falling on it and re-emits that radiation in a spectrum. Yes, that is a lot of information. Basically, the black body curve is an ideal spectrum (no absorption lines or noise).

In the middle is the spectrum of visible light running vertically through the curves. What color do you think each star will be? The 7,500 K star is bluish, the 6,000 K star is yellowish, and the 4,500 K star is reddish. This is because the top of the curve in each different star is at a different color. So, this can be thought of as there being more or less of a certain color than the others. In the case of the 7,500 K star, the top of the curve is in the color blue. That color will shine brighter than the other colors and will appear blue to our eyes. All of the colors are still being emitted from the star, but blue is the dominant color, and this is what our eye will see most of, giving the star an overall shade of blue.



http://zebu.uoregon.edu/2003/ph122/lec04.html

A more scientific way of looking at this is to use the peak flux (flux can be thought of as brightness). With this we will be able to calculate the temperature of the star. The graph above has “wavelength” on the x-axis and “relative brightness” on the y-axis. The top of the curve is the peak flux. When you find the peak flux, use that point to find the wavelength, which will be the peak wavelength. There is an equation, known as Wein’s Law, that says the temperature of an object is inversely proportional to the peak wavelength. Expressed mathematically, this law is:

$$\lambda_{max} = \frac{b}{T}$$

Where is the peak wavelength, is 2.8977685×10^{-3} m·K (Wein’s displacement constant), and is temperature. When we talk about temperature, we really are talking about the effective temperature (T_{eff}). The effective temperature of a star is the temperature of a black body with the same luminosity per surface area as the star. Put simpler, the T_{eff} is the temperature we are measuring, being the atmosphere of the star. A chart relating the T_{eff} to the spectral type is below to be used for quick referencing.

Spectral Type	Temperature (Kelvin)
O	28,000 - 50,000
B	10,000 - 28,000
A	7500 - 10,000
F	6000 - 7500
G	5000 - 6000
K	3500 - 5000
M	2500 - 3500

Telephone Book

Each specific element has specific wavelengths of light that they like. If this specific wavelength of light hits that element, it will get absorbed by the element, leaving a gap in the spectrum at that wavelength. These absorption lines are very interesting and tell us what element is present, how much of it there is, and the gas pressure. Below is a "telephone book" listing the wavelengths of some important elements; Hydrogen has several different wavelengths called the Balmer series, which is very useful in stellar classification. We will use these wavelengths to determine what we can find in any given spectrum.

Wavelength (Å)	Label (what it is)
3934.777	Ionized Calcium (K)
3969.588	Ionized Calcium (H)
4102.89	Hydrogen-delta(H_δ)
4200	Neutral Helium (He)
4341.68	Hydrogen-gamma (H_γ)
4400	Ionized Helium (He^+)
4862.68	Hydrogen-beta (H_β)
4900-5200, 5400-5700, 6200-6300, 6700-6900	Titanium Oxide (TiO)
5176.7	Mg
5895.6	Sodium (Na)
6564.61	H-alpha (H_α)
8500.36, 8544.44, 8664.52	Ionized Calcium (CaII)

<u>Exercise 2:</u>

The data points for one specific spectrum are here. Put the points into Excel and make a scatter plot of the data. The wavelength should be on the x-axis and the flux should be on the y-axis.

1. Locate the Balmer series (H_δ, H_γ, H_β, H_α) on the spectrum.

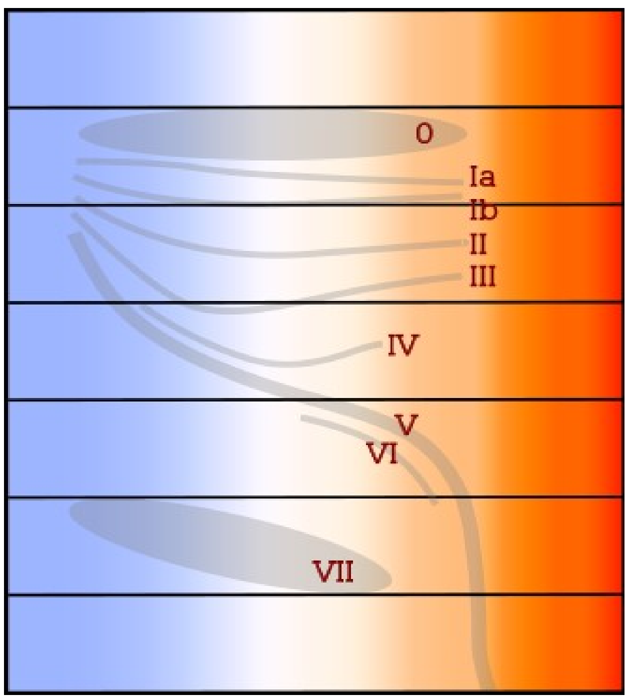
2. Using Wein's Law, what is the temperature of this star?

******Insert Excel "guessing black body curve temperature" application******

We have learned that by looking at how far along the x-axis an absorption line occurs at we can tell what it is. If we look at how big (the area) the absorption line is, we can find out how much of the element is present. Finally, the width of the absorption line tells us the gas pressure.

Yerkes Classification

We have already used letters (OBAFGKM) to classify the temperature of stars, now we will use roman numerals to classify their luminosities. The Yerkes classification system is a 2-Dimensional temperature and luminosity classification system based on spectral lines sensitive to stellar temperature and surface gravity which is related to luminosity. Each star fits into a luminosity class, denoted with roman numerals 0-VII as shown in the picture below.



Wikipedia

Higher pressure in a star leads to more collisions between atoms and broader, thicker lines. This is known as pressure broadening. To explain this, recall the equation for surface gravity of a spherical object:

$$g = \frac{GM}{R^2}$$

Where g is the surface gravity, G is the gravitational constant (6.673×10^{-11} N m^2 kg^{-2}), M is the mass, and R is the radius.

Exercise 3:

1. Calculate the surface gravity at the surface of the sun. ($R=6.955\times10^5$ km, $M=1.9891\times10^{30}$ kg)

2. Now, calculate the surface gravity at the surface of Star X. Star X has the same radius as the sun but only ¼ the mass.

3. Compare the difference. Can you explain in words what the difference is?

As seen with Exercise 3, even stars with the same radius but different mass will have a different surface gravity, meaning they will have different gas pressure, leading to different thickness in spectral lines. Similarly, stars with the same mass but different radii will have different amounts of pressure broadening.

0 stars are the most luminous and VII stars are the least luminous. Names have been given to these different classifications.

- **0** hypergiants (rarely used);
- **Ia** most luminous supergiants;
- **Ib** less luminous supergiants;
- **II** luminous giants;
- **III** normal giants;
- **IV** subgiants;
- **V** main sequence stars (dwarfs);
- **VI** subdwarfs (rarely used);
- **VII** white dwarfs (rarely used)

To further subdivide these classifications, lower case letters “a” and “b” can be used and “a” is brighter than “b”. For example, a Va star is brighter than a Vb star. Since 0, VI, and VII are rarely used, it is common to drop them and just use I-V. Width of the spectral lines will tell us which classification a star falls under. The stars with the thinnest spectral lines will be classified as I while the thickest lines will be classified as V. Since the line strength can vary greatly, the logarithmic of it, log(g), is taken to make the range more manageable.

Metallicity

Metallicity is another method that can be used to find the temperature of a star. Metallicity is the proportion of metals to non-metals in a star. Remember learning about the periodic table in chemistry class and having to memorize which element is where? Well, to astronomers, the periodic table is much simpler: there is Hydrogen and metals. Hydrogen is the only non-metal and all of the metals don't really need to be known. This is not true of course, as all elements are important, but it will help to remember that Hydrogen is the only non-metal.

The rate of ionization of different elements, meaning absorption lines in the spectrum, is determined by the temperature of the star and can be used to classify stars. We have also discussed that at certain wavelengths, an atom will absorb light which causes the absorption lines. The "Goldilocks temperature" will help you understand this.

Goldilocks Temperature: We all are familiar with the story of Goldilocks and the three bears. Goldilocks went into the home of the three bears and found three bowls of porridge on the table. She tried the first one and it was too hot. She tried the second one and it was too cold. She tried the third one and the temperature was just right, so she ate all of it. This is an analogy of how elements "choose" to absorb light. At specific temperatures, different elements will have greater absorption lines. For example, at about 9,000 K, hydrogen will have very strong absorption lines. So, by looking at a star's spectrum and seeing that it has strong hydrogen absorption lines, you can determine that the temperature of the star is somewhere around 9,000 K. A general table of classifications of stars and the types of spectral lines that you should see are below.

Spectral Type	**Temperature (Kelvin)**	**Spectral Lines**
O	28,000 - 50,000	Ionized helium
B	10,000 - 28,000	Helium, some hydrogen
A	7500 - 10,000	Strong hydrogen, some ionized metals
F	6000 - 7500	Hydrogen, ionized calcium (labeled H and K on spectra) and iron
G	5000 - 6000	Neutral and ionized metals, especially calcium; strong G band
K	3500 - 5000	Neutral metals, sodium
M	2500 - 3500	Strong titanium oxide, very strong sodium

<u>Exercise 4:</u>

If we were to look at an F5 star's spectrum, which elements would have strong absorption lines?