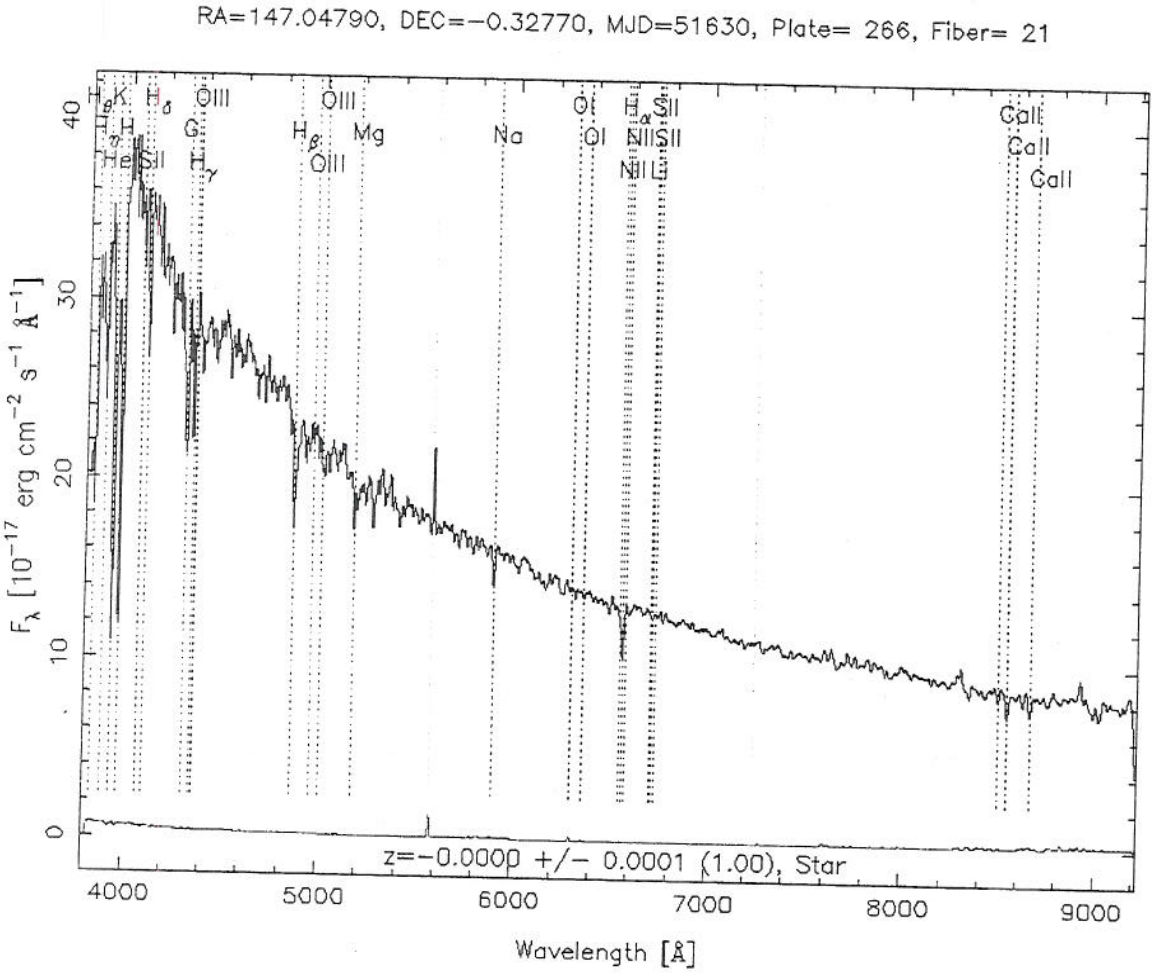
Harvard Classification

What is a spectrum?

In the late 1660's, Isaac Newton showed that "white light" is a mixture of light of different colors. He set up a prism in a dark room so a sliver of sunlight fell on it and projected the light on a screen across the room. The colors familiar to us in the rainbow – Red, Orange, Yellow, Green, Blue, Indigo, and Violet – showed up on the screen. We now know that these different colors of light have different wavelengths. Red light has a long wavelength; Blue light has a short wavelength. Astronomers do the same thing with light coming from objects in the night sky to measure the spectra of light coming from individual objects in the night sky. A spectrum is simply an x y plot, where the y (vertical axis) tells you the intensity of light, and the x (horizontal axis) tells you the wavelength of the light. Let's look at a spectrum taken by the SDSS of one star.



First, let's look at the axes. The vertical axis is F_{lambda}, in units of ergs per cm^2 per second per angstrom (an erg is a unit of energy and an angstrom is a unit of length). Note that it is multiplied by 10^{-17}, so we don't have to worry about decimal places, and the units are "nice" numbers like 10, 20, and 30. You know that ergs is a unit of energy, so this axis tells you how "bright" the star it. The horizontal axis is

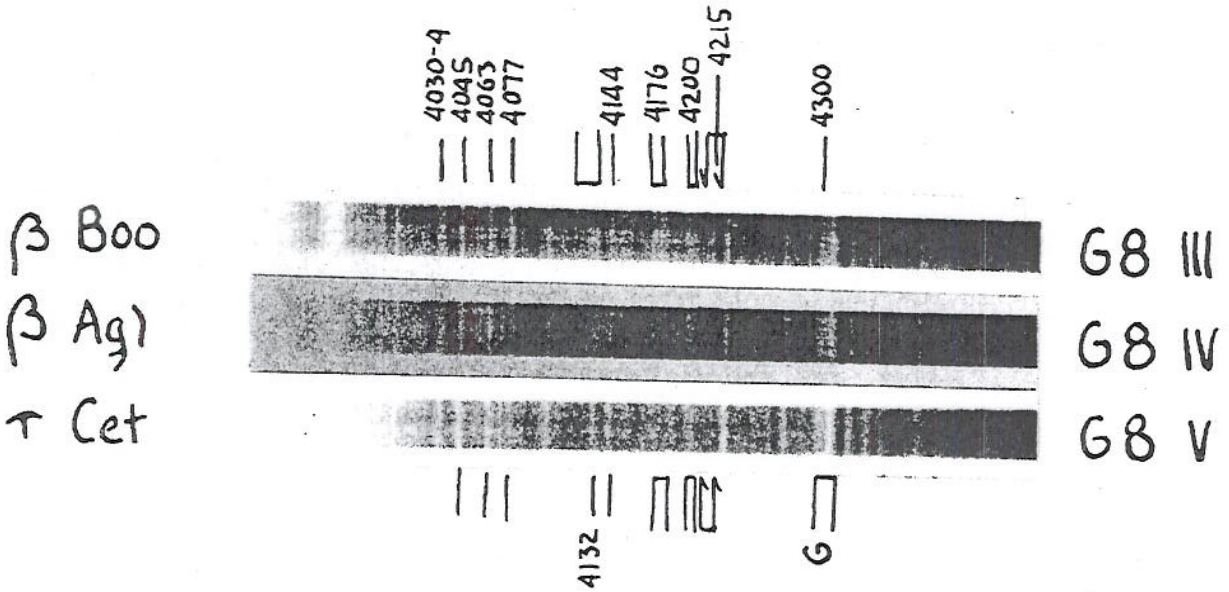
wavelength, measured in Angstroms. The blue light is on the left, around 4000 Angstroms, and red light is on the right, around 9000 Angstroms.

The basic characteristic of a stellar spectrum is that it is a continuous curve that starts at one brightness, goes up, and then comes back down. But, this smooth curve is "messed up" with dips. These are called absorption lines, and their location and size are very important clues about what that star is. This is what we'll be using to classify stars. Notice that on this plot, some of the absorption lines are marked – for example Mg and Na for Magnesium and Sodium. H is for Hydrogen, which has several lines: H_{alpha}, H_{beta}, and so on. After a while you'll be very familiar with all of these lines.

Stellar spectra contain a wealth of information. Two classification schemes – "Harvard" and "Yerkes" – use spectra to classify stars.

Harvard Classification

The initial work for classifying stars was done by inspecting photographic plates by eye. A prism was used to disperse the light onto the plate, creating a band of light. An example of one is shown here.



The light is dispersed from left to right, with shorter wavelengths (blue) on the left and longer wavelengths (red) on the right. There are three stellar spectra on the picture above. The names of the stars are written in on the left. Beta-Boo means the second brightest star (the alpha star is the brightes, beta second brightest, and so on) of the constellation Bootes. On the far right, the spectral classification of the star is given. (This is the classification we will be making for all of our stars.) The band of light running from left to right is the actual spectrum. Note that this is a photographic negative, so dark is light and light is dark. The vertical white lines then are absorption lines. The wavelengths are marked: 4030 angstroms on the far left (the -4 after that means that there are actually 4 lines close together

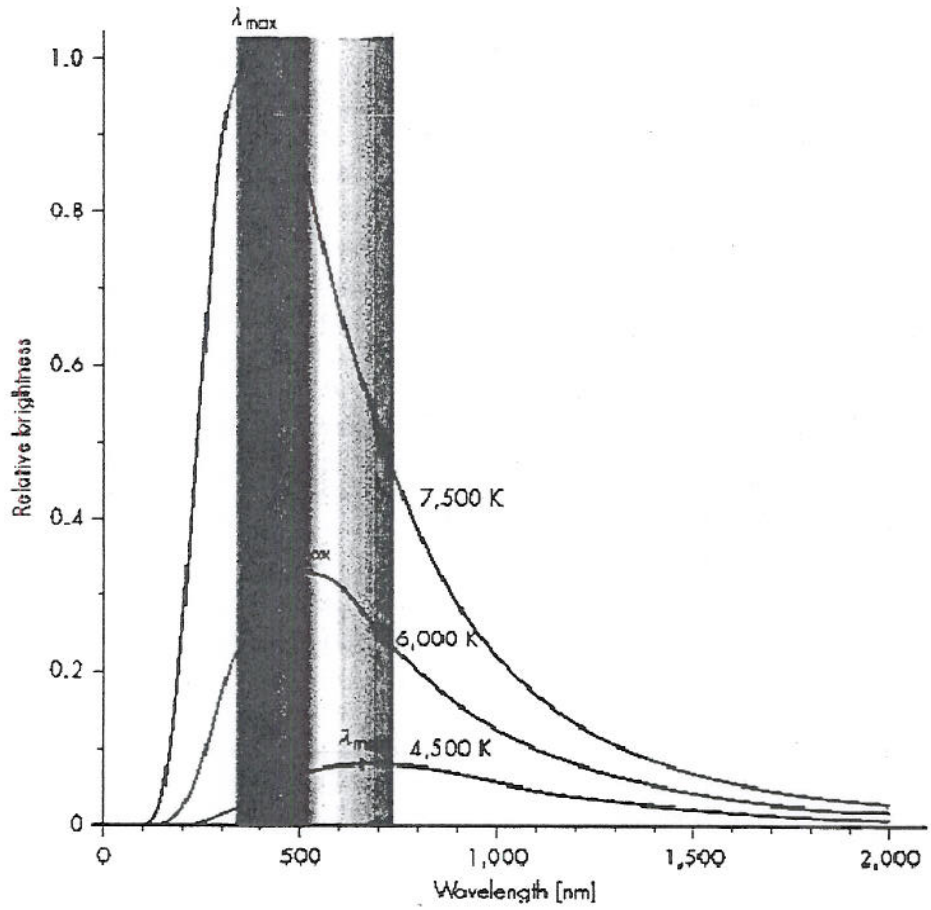
there). It takes considerable skill to set up the prism, telescope, and photographic plate to actually measure a spectrum.

All of these spectra were measured by eye. Their classification system started very simply. 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.

The reason stars are different colors is directly related to them being different temperatures. The hotter stars look blue, the cooler stars look red. This is why physicists have trouble in the shower; the colors for hot and cold are mixed up (insert laughter here).

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. The black body curve spectrum has no absorption lines or noise. One number – the temperature – defines the shape of the curve. This works for objects on earth and for stars.

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.



A more quantitative 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:

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

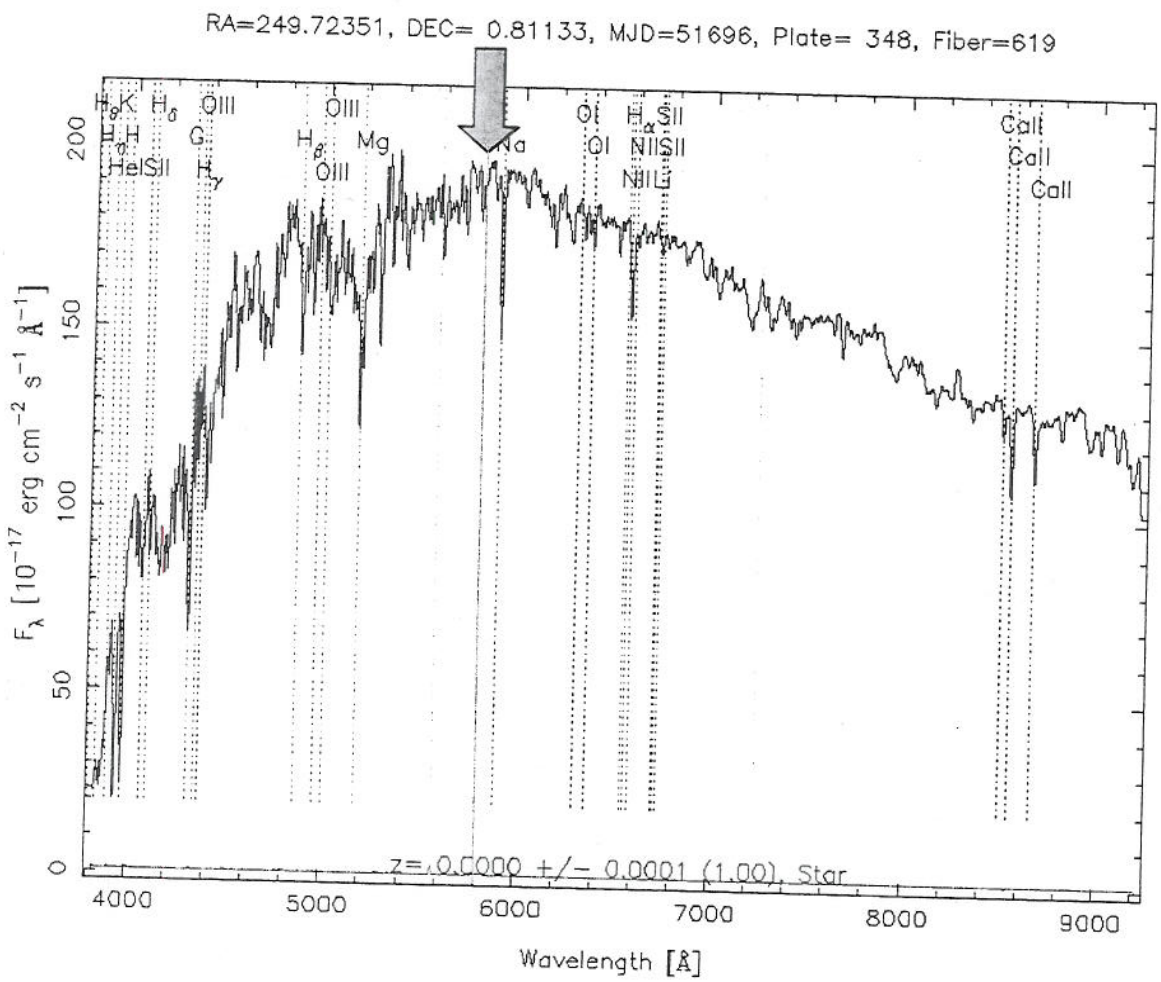
Where λ_{max} is the peak wavelength, b is 2.8977685×10^{-3} m·K (Wein's displacement constant), and T is temperature.

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 and can 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

Example Calculation:

Find the temperature of the star with the spectrum below.



1. Look at the graph and determine where the highest flux occurs at. The approximate location of the max flux is labeled on the spectrum with a red arrow.

2. Find the wavelength that corresponds to the max flux. A line is drawn on the spectrum to help find the max wavelength. λ_{max} is about 5800 angstroms (Å).

3. Using Wein's Law,

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

Rearrange the variables to solve for temperature:

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

4. Plug in the values and calculate the temperature. The units for *b* are meters*Kelvin, so our λ_{max} needs to be converted to meters. 1Å = 10^{-10}m. Our λ_{max} = 5800x10^{-10}m.

$$T = \frac{2.8977685x10^{-3}m \cdot K}{5800x10^{-10}m} = 4996.15K$$