Lab 5: Spectroscopy

Stellar Spectral Types

When astronomers look through their telescopes, they see billions of stars. How do they make sense of all these stars? How do they classify stars into types, and how do they tell which types are common and which are rare? Most importantly, how do they use the star types they see to learn useful information about stars? Stars with different colors have different temperatures. However, you might have wondered what happens when a star's peak wavelength is not visible on our spectrum. For a very hot star, the peak wavelength may be well into the ultraviolet wavelength range. For a very cool star, the peak wavelength may be well into the infrared. Do astronomers have other ways to find the temperature of a star from its spectrum, even if the star's peak wavelength is too short or too long to show up? Fortunately, they do.

If thermal radiation were the only source of light from a star, the star's spectrum would be a nice smooth curve. However, actual spectra observed from stars have a series of peaks and valleys as shown in Figure 1, meaning some of their light comes from "non-thermal" radiation - light emitted or absorbed by a process other than random jostling of atoms.

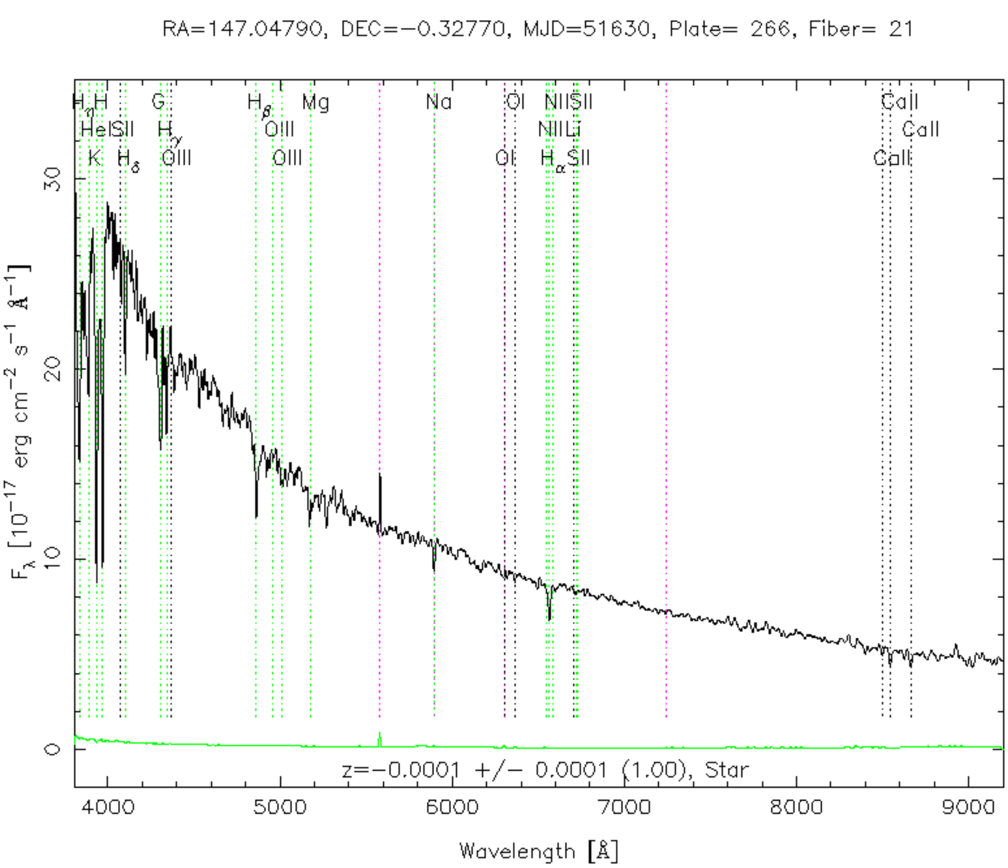

Figure 1: A typical example of the spectrum of a star

While the differences in spectra might seem to indicate different chemical compositions, in almost all instances, it actually reflects different surface temperatures. With some exceptions (e.g. the R, N, and S stellar types), material on the surface of stars is "primitive": there is no significant chemical or nuclear processing of the gaseous outer envelope of a star once it has formed. Fusion at the core of the star results in fundamental compositional changes, but material does not generally mix between the visible surface of the star and its core. Ordered from highest temperature to lowest, the seven main stellar types are O, B, A, F, G, K, and M. O, B, and A type stars are often referred to as *early* spectral types, while cool stars (G, K, and M) are known as *late* type stars. The spectral characteristics of these types are summarized in Table 1.

Table 1: The characteristics of each stellar spectral types

Type	Color	Approximate Surface Temperature	Main Characteristics	Examples
O	Blue	> 25,000 K	Singly ionized helium lines either in emission or absorption. Strong ultraviolet continuum.	10 Lacertra
B	Blue	11,000 - 25,000	Neutral helium lines in absorption.	Rigel Spica
A	Blue	7,500 - 11,000	Hydrogen lines at maximum strength for A0 stars, decreasing thereafter.	Sirius Vega
F	Blue to White	6,000 - 7,500	Metallic lines become noticeable.	Canopus Procyon
G	White to Yellow	5,000 - 6,000	Solar-type spectra. Absorption lines of neutral metallic atoms and ions (e.g. once-ionized calcium) grow in strength.	Sun Capella
K	Orange to Red	3,500 - 5,000	Metallic lines dominate. Weak blue continuum.	Arcturus Aldebaran
M	Red	< 3,500	Molecular bands of titanium oxide noticeable.	Betelgeuse Antares

Absorption and Emission Lines

Now we can start making the connection between the peaks and valleys we see in a star's spectrum and the energy levels of the star's atoms. Let's say that we shine a light with all the colors of the spectrum through a cloud of hydrogen gas. Not all of the light will make it through. All the photons that have exactly 10.2 eV of energy will not make it through the hydrogen, because they will be absorbed by hydrogen atoms jumping from the first energy level to the second energy level. Likewise, no light with an energy of 1.89 eV will make it through; those photons will be absorbed by hydrogen atoms jumping from the second energy level to the third energy level. The light that the hydrogen cloud absorbs shows up as dips in the cloud's spectrum. If the cloud were too hot, however, all its hydrogen atoms will crash into each other with enough force to free their electrons, and the gas will become ionized. The hot cloud's hydrogen ions have no electrons, so they cannot absorb light. When you look at the hot cloud's spectrum, you will not see any valleys from hydrogen absorption lines. Ionization occurs at about 10,000 K for

hydrogen. Therefore, if you do not see hydrogen lines in the hot cloud's spectrum, you can conclude it is hotter than 10,000 K. However, if the cloud were too cool, then the light would not have enough energy to boost its electrons into higher energy levels. In this case, you also would not see any hydrogen lines in the cloud's spectrum. You would see the strongest hydrogen lines for a cloud that is at about 9000 K. If you saw a cloud whose spectrum showed no hydrogen lines, how would you tell if it were hot or cool? For a cloud of pure hydrogen, you couldn't. But for real stars, which contain atoms of many elements besides hydrogen, you could look at the absorption and emission lines of other elements. For most elements, there is a certain temperature at which their emission and absorption lines are strongest. The lines you see in a star's spectrum act like thermometers. Some compounds, like titanium oxide, only appear in the spectra of very cool stars. Others, like helium, appear only in the spectra of very hot stars.
Therefore, the sequence of spectral types, OBAFGKM, is actually a temperature sequence with O representing the hottest stars and M representing the coolest stars.
Figure 2 summarizes the three types of spectra as discussed above.

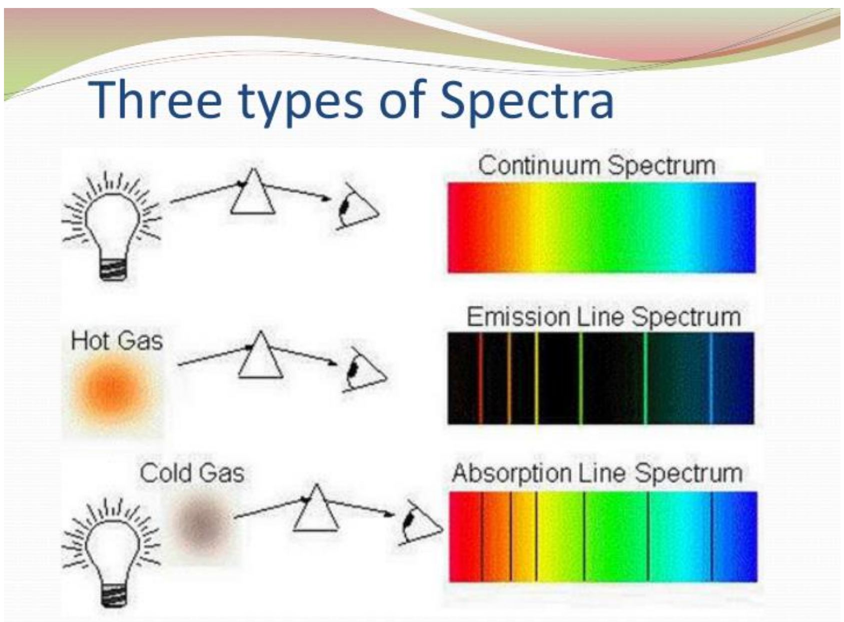

Figure 2: Three types of spectra.

In-Class Experiment

As an in-class experiment, you will learn to use a spectrograph and a detector (we will use a CCD camera). A basic spectrograph is described in Figure 3. A spectral source will be fed to the spectrograph through a fiber optic cable (Figure 4). We will use a hydrogen and helium lamps as spectral sources. The purpose of this experiment is to find emission lines in the spectrum so we can compare the lines with the spectrum of stars that we will be obtaining using the telescope. Make sure the slit side of the cable is connected to the spectrograph. The connector is not keyed so the connector needs to be rotated to make the slit properly oriented before the light hits the diffraction grating. Try to adjust the angle of the diffraction grating by rotating the knob on the side of the spectrograph to position the particular spectral lines within the FOV of the CCD camera. Once you see discernable spectral lines, record the reading on the knob. Note that there is no focusing mechanism for the camera. Thus, you will need to adjust the distance between the spectrograph and CCD manually. See Figure 5 for the spectrograph design. You will also need to obtain a wide range of spectral lines of each element so that after you take images of stars, you have a sufficient number of reference spectral lines to compare.

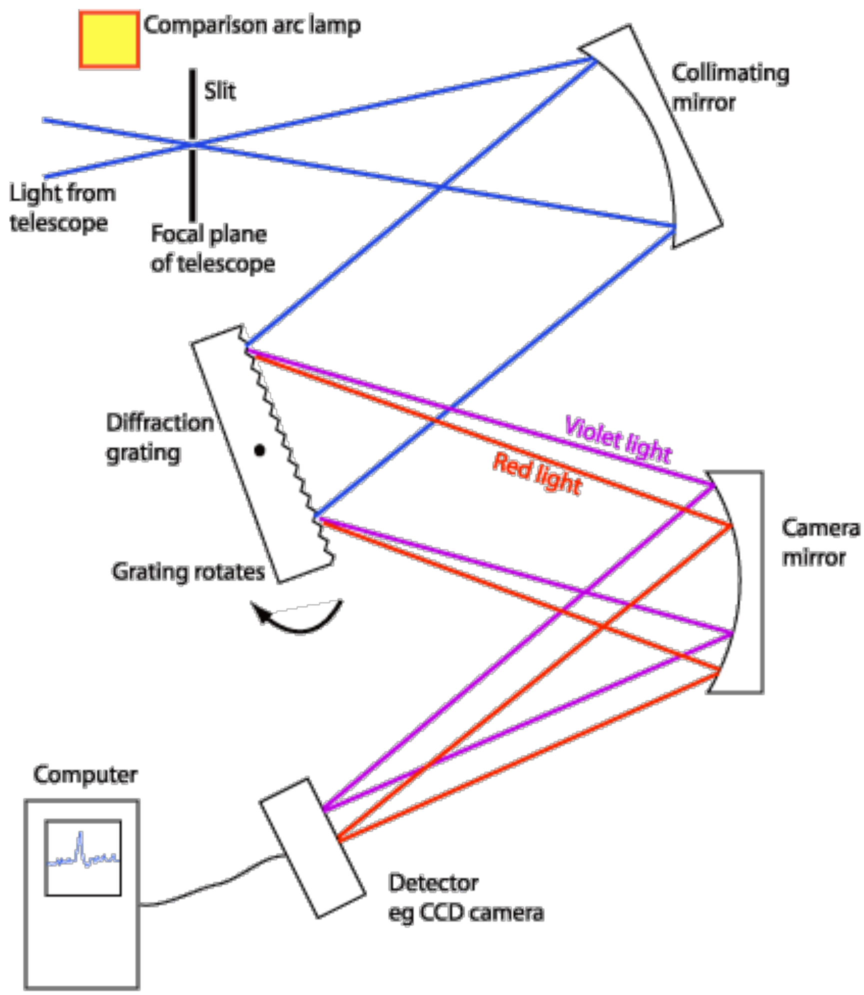

Figure 3. A schematic diagram of a slit spectrograph

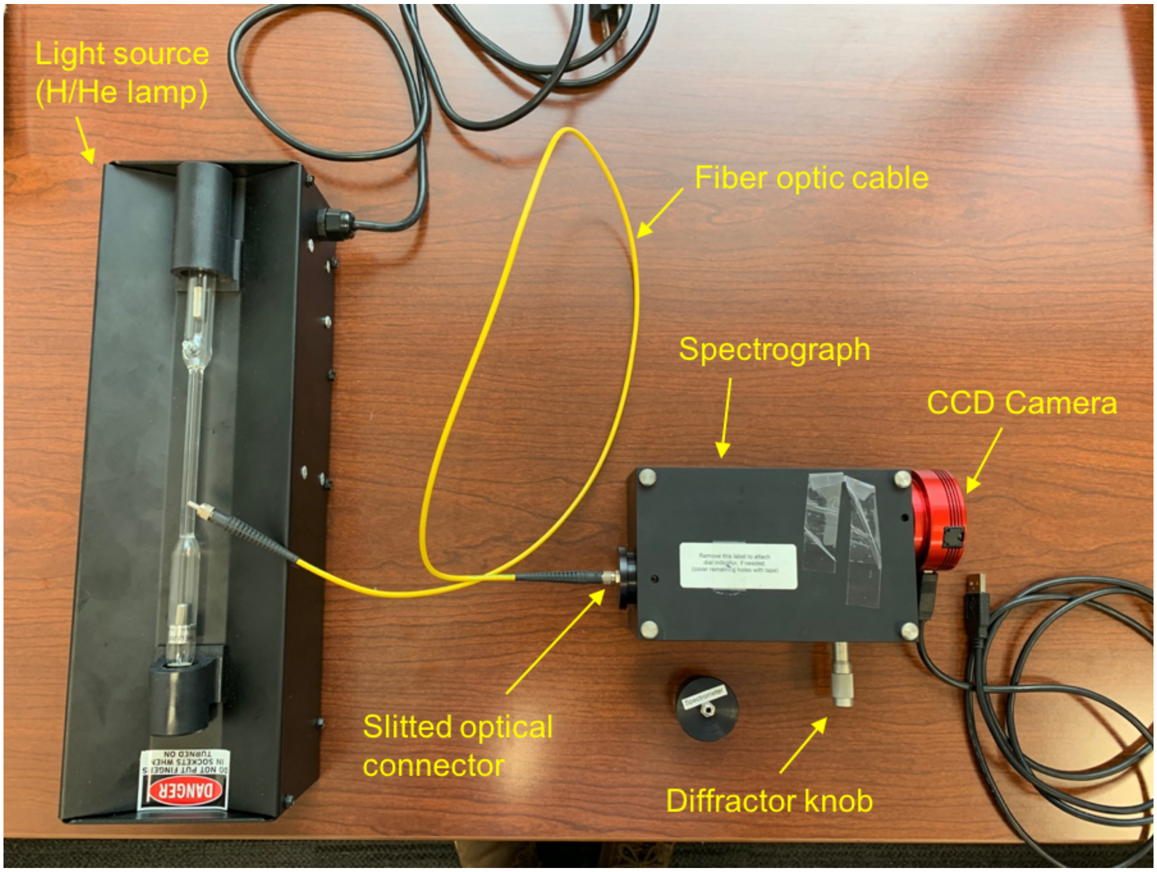

Figure 4. In-class experimental setup for hydrogen and helium spectral lines

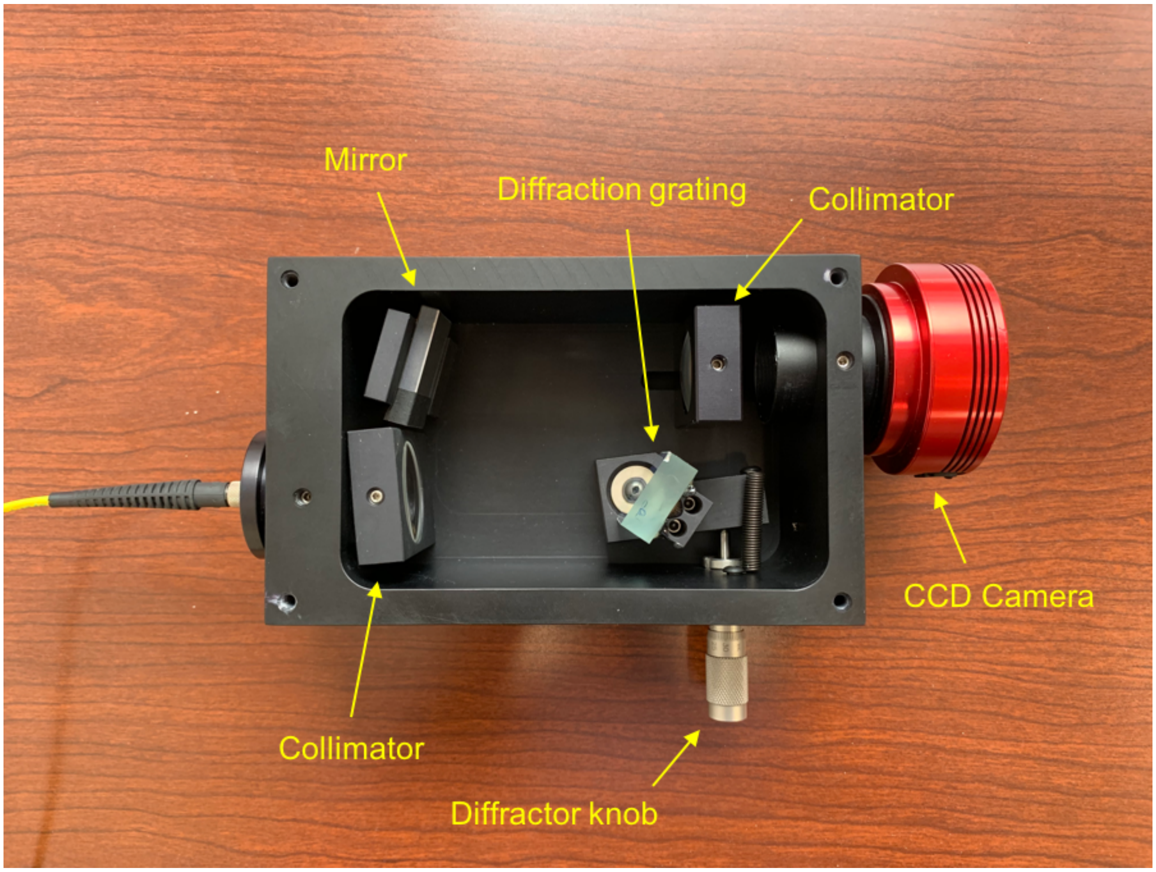

Figure 5. Design of spectrograph.

Telescope Observations

Now, replace the light source with the light coming from the telescope as shown in Figure 6. Since we have hydrogen and helium spectral lines we did in the above section, take images of stars whose spectral types are O, B, and A. However, take as many stars of various spectral types as possible to compare the reference spectral lines (from the lamps). Try to adjust the angle of the diffraction grating to position the particular spectral lines within the FOV of the CCD camera (have the spectral line images from the lamp experiment handy so that you can compare the lines while taking the images. Again, adjust the distance between the spectrograph and CCD manually to focus the image. In class, we will learn how to use the special gadget "ø-view" that sits between the telescope and the fiber optic cable.

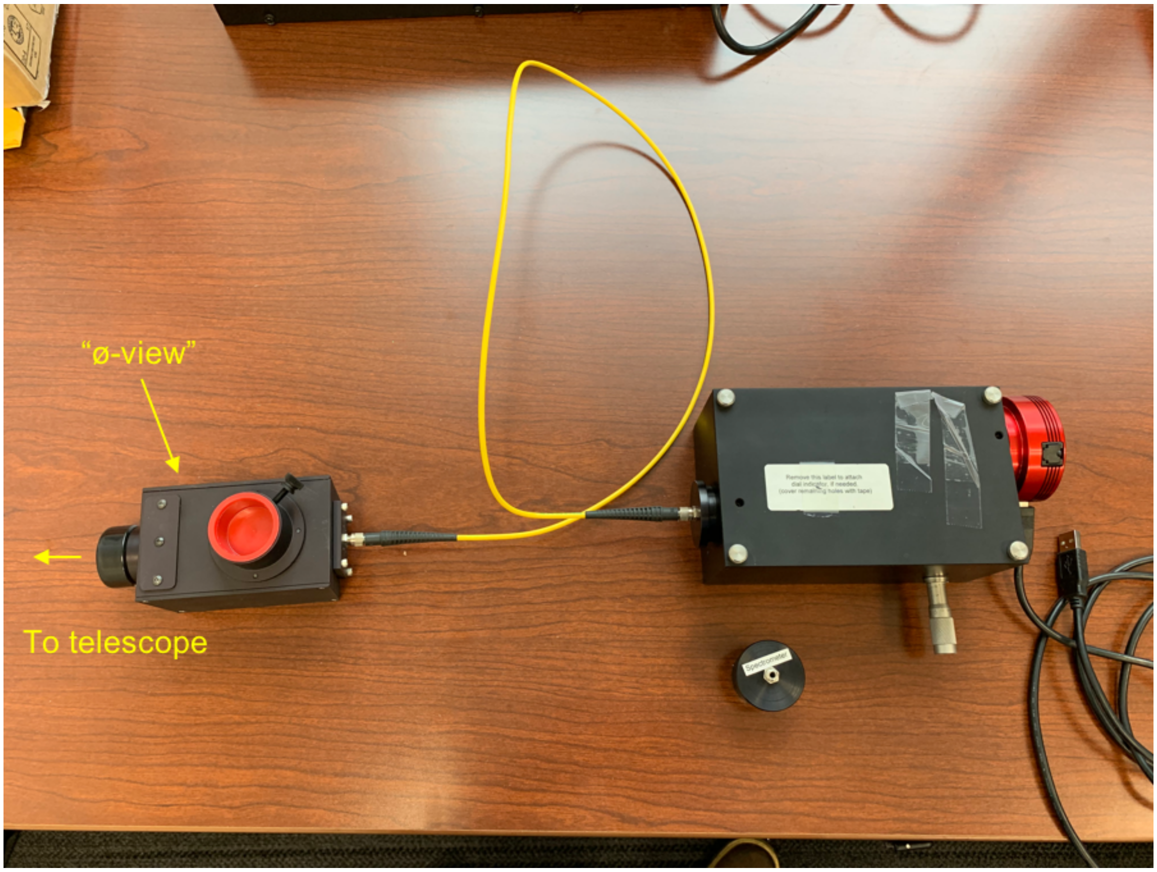

Figure 6. Spectrograph connected to "ø-view" for telescope observations.

Plotting the Results

Your lab report should contain spectral images that you obtained in class and from observations to compare. For your lab report, do the following:

1) Plot an X-Y graph to show emission lines of the H and He lamps. (X axis: wavelength, Y axis: intensity (arbitrary value), similar to Figure 1). Of course, knowing which emission line corresponds to what wavelength is challenging (need some type of well-calibrated light source with known wavelength(s)). For this lab, try to plot the emission lines and compare them to the wavelengths that you can find online ("H or He emission spectrum").
2) Plot an X-Y graph just like the one in 1) but for the observed star(s). Show the spectrum with the one in 1) to see if the spectral lines are aligned.
3) Discuss the spectral types of the stars that we observed and how they compare with the images that we obtained.