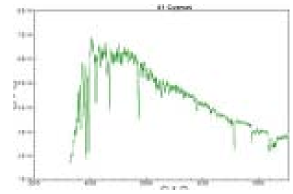
Name ____ Section ____________

Application Exercise: Spectral Classification of Stars



Objectives

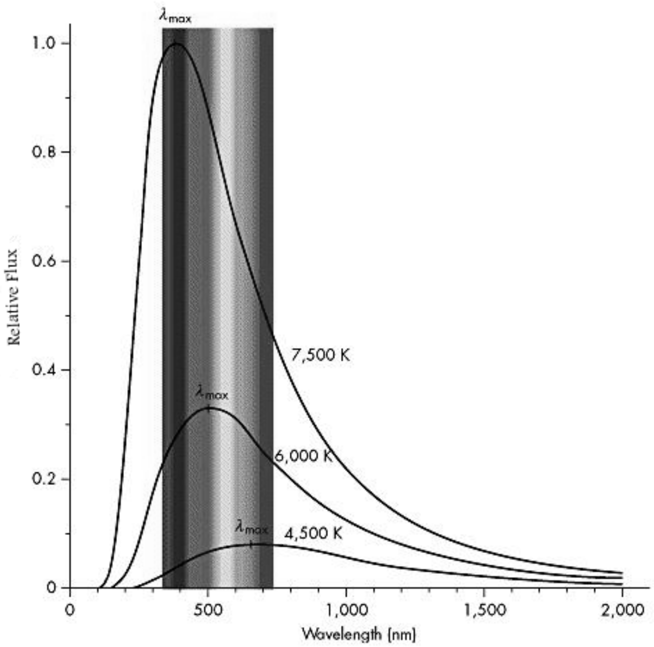
To learn the basic techniques and criteria of the spectral classification sequence by:

- examining and classifying spectra according to the strength of the hydrogen Balmer absorption lines
- examining and classifying spectra according to temperature using Wien's Law
- comparing the two schemes by identifying the temperature where the Balmer lines are strongest and recognizing the corresponding spectral class
- summarizing the physical reason why both very cool stars and very hot stars have weak Balmer lines.

Background and Theory

Classification lies at the foundation of nearly every science. Scientists develop classification systems based on *perceived* patterns and relationships. Biologists classify plants and animals into subgroups called genus and species. Geologists have an elaborate system of classification for rocks and minerals. Astronomers are no different. We classify planets according to their composition (terrestrial or Jovian), galaxies according to their shape (spiral, elliptical, or irregular), and stars according to their spectra.

In this exercise you will classify six stars by repeating the process that was developed by the women at Harvard around the turn of the 20th century. The resulting classification was a key step in elucidating the underlying physics that produces stellar spectra. Thus, in astronomy as well as biology, the relatively mundane step of classification eventually yields critical insights that allow us to understand our world.



The spectrum of a star is composed primarily of blackbody radiation--radiation that produces a *continuous spectrum* (**the continuum**). The star emits light over the entire electromagnetic spectrum, from the x-ray to the radio. However, stars do not emit the same amount of energy at all wavelengths. The peak emission of their blackbody radiation comes at a wavelength determined by their surface temperature, the relationship known as Wien's Law. Most stars put out the maximum amount of radiation in and around the optical part of the electromagnetic spectrum. The diagram at the left shows three blackbody curves for stars of different temperatures. As the temperature drops, the relative flux decreases, and the peak moves from the blue (hot) to the red (cool) wavelength regions of the spectrum.

In addition to the continuous spectrum, a star's spectrum will feature a number of either emission or absorption lines. *Emission lines* are produced by atoms when electrons drop from high energy levels to lower ones, emitting photons at specific frequencies in the process. This process adds radiation to the star's spectrum; emission lines are brighter than the region of the spectrum around them. *Absorption lines* are produced by atoms when their electrons absorb radiation at a specific frequency, thereby causing the electrons to move from a lower energy level to a higher one. This process removes some of the continuum being produced by the star and results in dark features in the spectrum. These lines are dimmer than the wavelength region around them.

Stars come in a wide range of temperatures. The hottest stars in the sky have temperatures in excess of 40,000 K, whereas the coolest stars that we can detect optically have temperatures on the order of 1000-1500 K. The characteristics of the spectrum of a star are strongly dependent on its temperature. *Differences in temperatures among stars change the energy output of the star, the wavelength where the continuous spectrum peaks, and the strength of the emission and absorption lines.* In this lab you will compare the strength of a hydrogen absorption line in the spectra of 6 stars and determine how the strength of that particular absorption line changes as a star's temperature changes.

Before we start classifying stars, let's take a close look at a hydrogen atom. The single electron of a hydrogen atom can occupy only certain *energy levels.* (Think of energy levels as unequally spaced steps of a ladder, with a huge 1st step and sequentially smaller steps thereafter. The higher up an electron is on the ladder, the more energy it has.) Astronomers use the letter 'n' and a number to designate each energy level. The lowest energy level is called the 'n = 1' level, the second lowest level 'n = 2', the third 'n = 3', etc.

Electrons are free to move from one level to another provided they conserve energy while doing so. If an electron moves down from the 2nd energy level to the 1st (n = 2 to n = 1) then the atom conserves energy by emitting a photon of light. The emitted photon has an energy (and corresponding wavelength) equal to the difference between the 2nd and 1st energy levels (i.e., we get an emission line.) An electron can only move up from the 1st to 2nd energy level if it gains the right amount of energy. The electron typically gains this energy if the atom absorbs a photon of light with the correct energy (or wavelength), giving us an absorption line. In this lab we will be dealing exclusively with absorption lines because they are much more common than emission lines in the spectra of stars.

Although hydrogen has only one electron, there are still many different energy-level transitions that electron can make; thus, hydrogen shows many different absorption lines. Physicists classify these lines based on the (low) energy level the electron begins on (before a photon is absorbed). Absorption lines caused by electrons starting in the $n = 1$ level and ending in any higher level are a part of the *Lyman series*. Absorption lines caused by electrons starting in the $n = 2$ level are a part of the *Balmer series*, and those caused by electrons starting in the $n = 3$ level are a part of the *Paschen series*. (Lyman, Balmer and Paschen were physicists who researched these transitions.)

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Spectral Classification-- Procedure and Worksheet

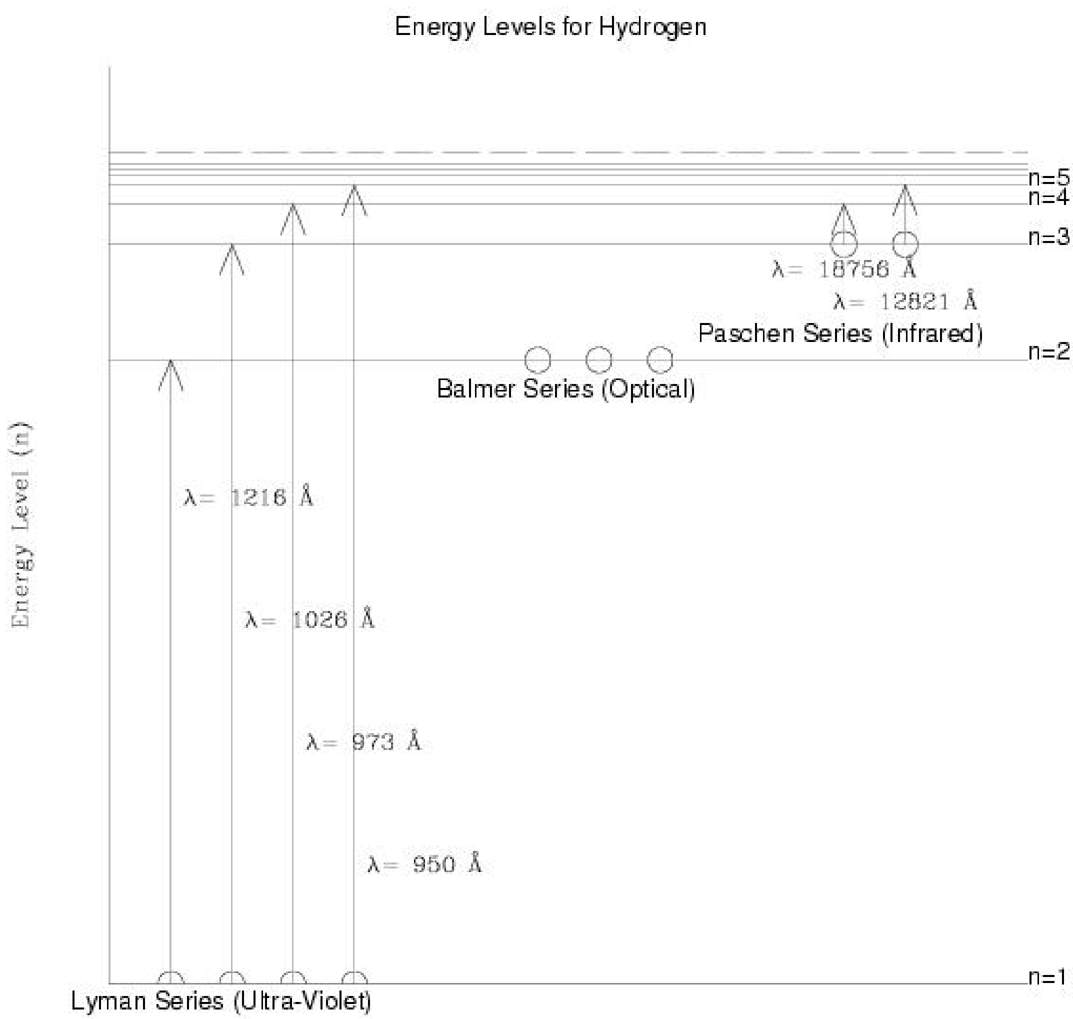
Note: In this lab all wavelengths are given in units of Ångstroms. 1 Ångstrom = 10^{-10} meters; 1nm = 10 Ångstroms.

Write all answers in the space below each question.

1. Look at the energy level diagram below. The open circles on the figure represent electrons. The electron transitions that correspond to the first four absorption lines of the Lyman series are drawn for you as well as their identifying wavelengths (i.e. the wavelength of the photons the atom must absorb to allow the electron to make each transition.) Also shown are the first 2 transitions of the Paschen series.

   a) Draw the first 3 transitions of the Balmer series on the energy level diagram below.

   b) Each Balmer series transition is associated with one of the following wavelengths: 4340, 6563 and 4861 Ångstroms. On the diagram, label which wavelength corresponds to each transition.



c) The dotted line in the energy level diagram represents hydrogen's highest energy level. What happens if an electron absorbs a photon with enough energy to place the electron above the dotted line?

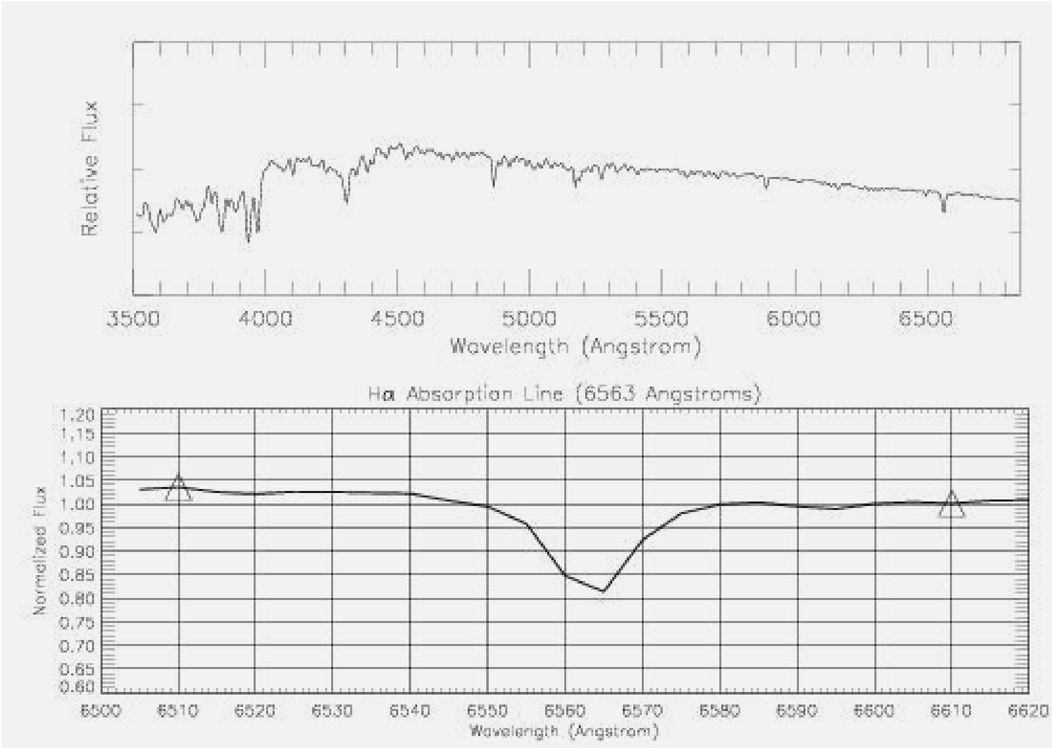
d) An atom must absorb an ultraviolet photon to produce a Lyman series absorption line, an optical photon for the Balmer series, and an infrared photon for the Paschen series. Explain why the Lyman series requires ultraviolet photons as opposed to optical or infrared. (Hint: Help yourself visualize the reason by looking at the energy level diagram.)

2. Look at the six panels of spectra on the following pages. Each panel shows the optical spectrum of six different stars. The top graph in each panel is the full spectrum; the bottom graph in each panel is a blowup of the Balmer series absorption line located at 6563 Ångstroms. Astronomers call this particular absorption line Hα (because it is the first line in the Balmer series and α is the first letter of the Greek alphabet), and it is created when an electron moves from the 2^{nd} to the 3^{rd} energy level. Note the difference between the scale on the wavelength axis for the top and bottom graphs.

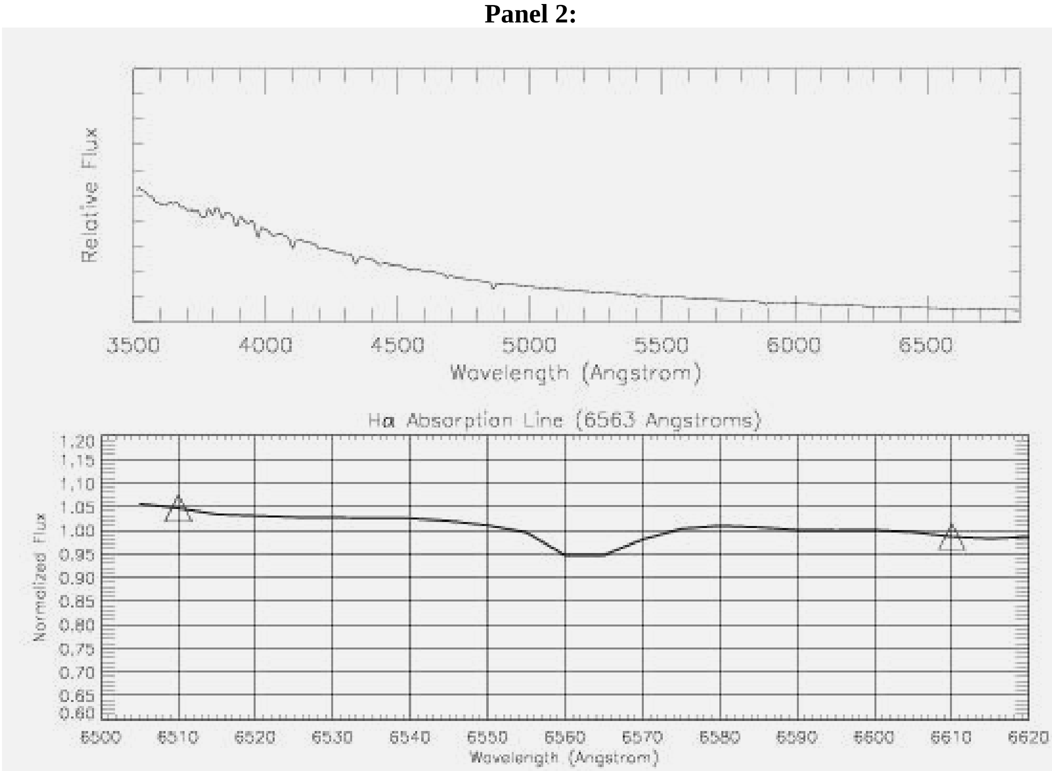
   a) In one well written sentence, explain why Lyman and Paschen series absorption lines are not seen in each panel's spectrum.

   b) In the top graph of each panel of spectra (starting on the next page), circle each of the 3 Balmer series absorption lines you drew on the energy level diagram in the first question.

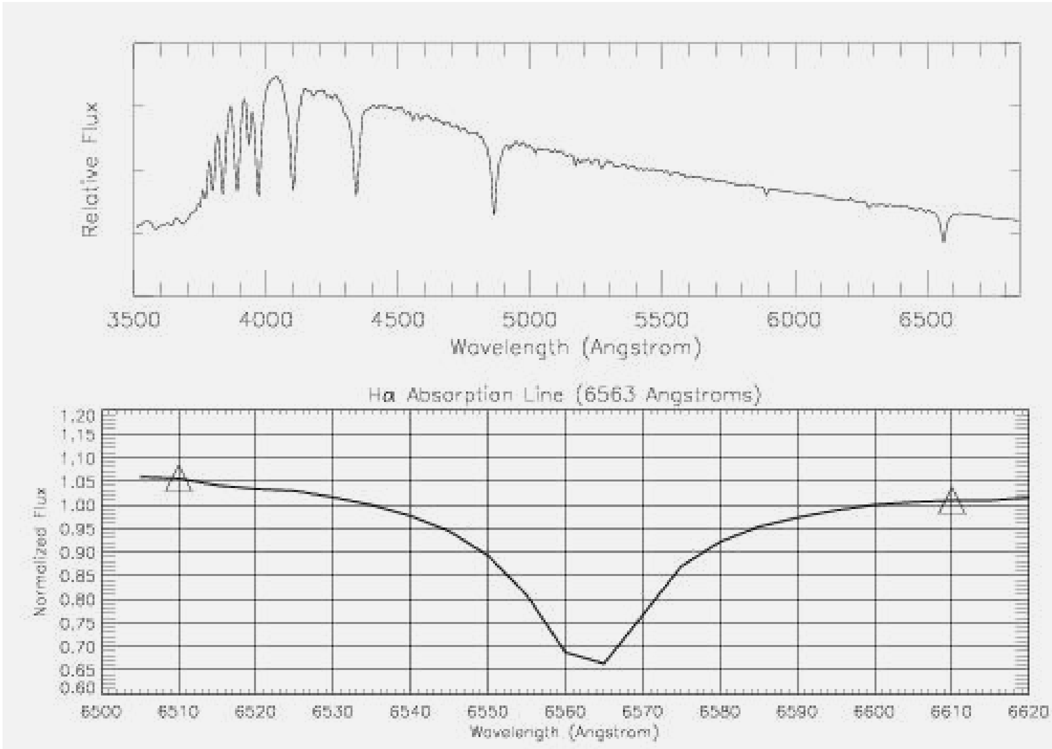
Panel 1:



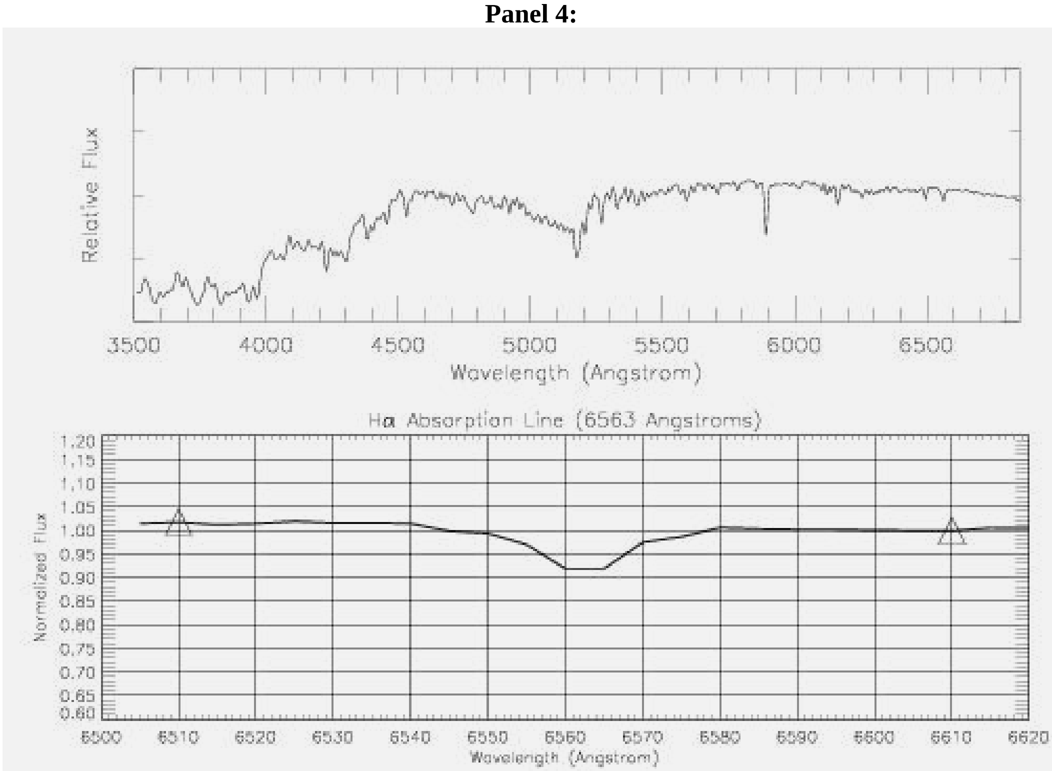
Panel 2:



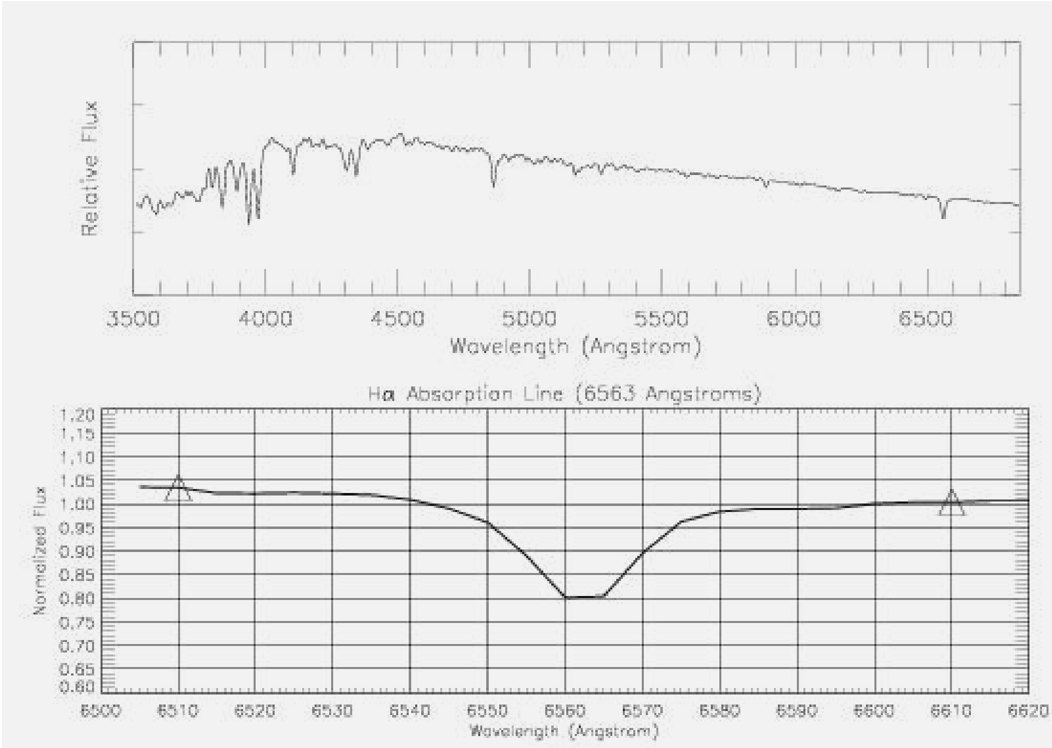
Panel 3:



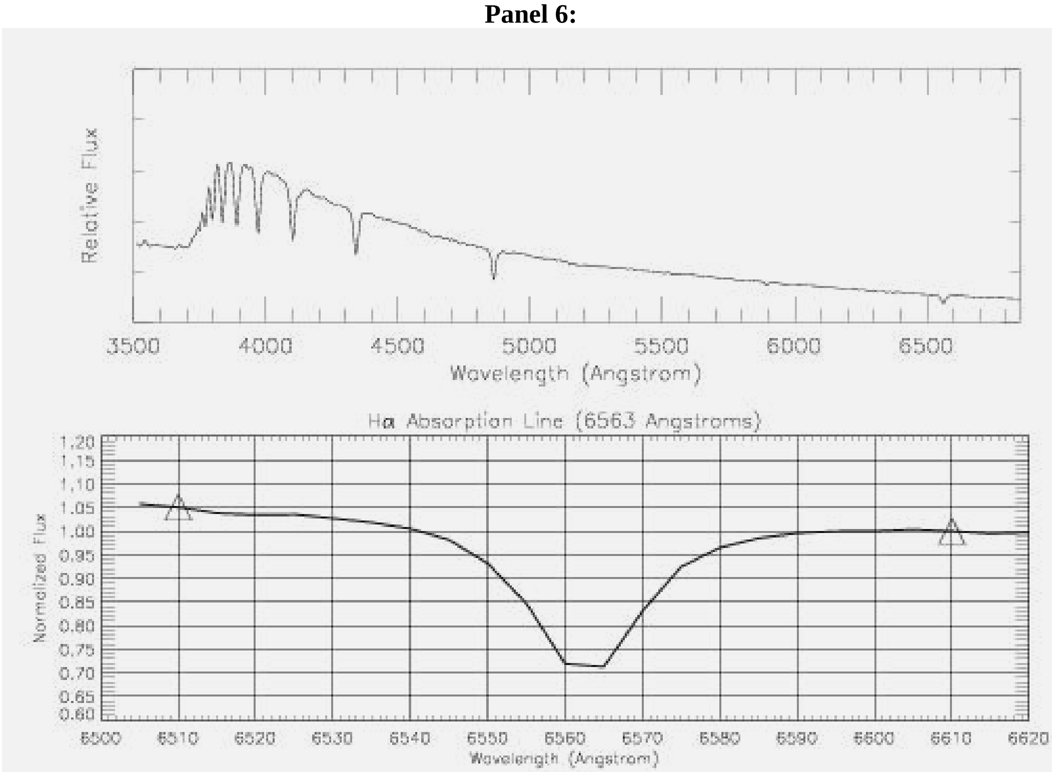
Panel 4:



Panel 5:



Panel 6:



3. To start, we are going to classify stars based on the 'strength' of their hydrogen absorption lines, specifically the Hα line. Look at the blowup of the Hα line in each panel. You will notice that each line dips down vertically and has a horizontal width associated with it. Absorption line 'strength' depends both on how much the line dips down and how wide it is. **Measure the strength of each Hα line in the bottom graph of each panel by following the procedure below**:

a) Draw a straight line in the bottom graph of each panel by connecting the triangles located at 6510 and 6610 Ångstroms. In doing so you are tracing the continuum near the absorption line.

b) Lightly shade in the absorption line now enclosed by the continuum.

c) The strength of an absorption line is the area enclosed by the absorption line. Measure the area by estimating the number of boxes contained inside of the absorption line. (This may be difficult to estimate as there will be “partial” boxes to consider; just do your best.) Record the strength (in number of boxes) of the absorption line in each panel in Table 1.

Table 1

Panel	Strength of Hα line (# of boxes)
1	
2	
3	
4	
5	
6	

4. Originally astronomers classified those stars with the strongest hydrogen lines as 'A' stars, stars with the next strongest lines as 'B' stars, the next strongest 'C' and so on. Eventually some letters were deemed unnecessary and dropped from the classification sequence. The letter assigned to a star is termed its ***spectral class***. **Assign a spectral class to each panel by following the procedure below:**

a) In the second column of Table 2, list the panel numbers from strongest Hα line at the top to weakest Hα line at the bottom.

b) Each panel corresponds to one of the following classes of stars: A,B,F,G,K and O. (We're skipping some letters here.) In the third column mark the letter that corresponds to each panel using the lettering scheme described above.

Table 2

Panel Number *strongest* Hα line to *weakest*		Spectral Class (Letter Designation)
strongest		A
↓		B
↓		F
↓		G
↓		K
weakest		O

5. One can determine the surface temperature of each star (i.e. the temperature of each star's photosphere) using the full spectrum in the top graph of each panel and Wien's Law:

$$T = \frac{2.9 \times 10^7}{\lambda_{peak}}$$

where ***T*** is temperature in Kelvin and λ_{peak} is the wavelength in Ångstroms where the blackbody curve peaks. **Determine the surface temperature of each star using the top graph of each panel by following the procedure below:**

a) Trace the underlying blackbody continuum in the top graph of each panel. (This is what the spectrum would look like with *no* absorption lines—i.e. a perfect blackbody.)

b) In the second column of Table 3 write down the wavelength (in Ångstroms) where the blackbody continuum in each panel peaks. If the peak is not shown on the graph, then write down a rough estimate of where you think the curve might peak.

c) Use Wien's Law (formula above) to calculate the surface temperature of each panel's star. Record your answer in column 3 of Table 3.

Table 3

Panel	Peak Wavelength (Angstroms)	Surface Temperature (K)
1		
2		
3		
4		
5		
6		

6. It was later realized that the strength of a star's absorption lines can be predicted if the star's surface temperature is known. This is because the heat of a star can excite electrons up to higher energy levels. For example, most hydrogen atoms in very hot stars are ionized (the electron leaves the atom completely,) and thus show very weak Balmer Series absorption lines. Cool stars keep most of their electrons in the 1st energy level. *The medium temperature stars show the strongest Balmer lines because most of their electrons start in the 2nd energy level.*

Therefore, it is more intuitive to classify stars based on their temperature rather than on their Balmer lines alone. Astronomers reordered the classification sequence such that the hottest stars came first, but they retained the letters originally assigned to each star based on their Balmer line strengths.

a) Reorder the classification sequence by listing the panel numbers from hottest star to coolest star in the first column of Table 4.

b) In the second column of Table 4, write down the letter you assigned each panel in Table 2. CONGRATULATIONS, YOU JUST OBTAINED THE (NON-ALPHABETICAL) STELLAR CLASSIFICATION SEQUENCE USED BY ASTRONOMERS.

Table 4

Panel Number *hottest* star to *coolest*		Corresponding Spectral Class (Letter Designation from Table 2)
hottest		
coolest		

7. What energy level must most hydrogen electrons start on to show Balmer absorption lines? What spectral class has the strongest Balmer lines? What Temperature does this correspond to?

Energy Level	**Spectral Class**	**Temperature**

8. Why do the hottest stars show weak Balmer lines? Why do the coolest stars show weak Balmer lines?

9. In addition to the 6 spectral types studied in this lab (A,B,F,G,K,O,) stars classified as L, M and T also exist. L, M and T stars are all cooler than K stars, with M stars being the hottest of the three and T stars the coolest. Rewrite the classification sequence you found in Table 4 to include L, M and T stars.

10. SUMMARY: In your own words, using good writing form, explain why the Stellar Classification Sequence is not in alphabetical order.