Spectroscopy

Background

Astronomers are in a very peculiar situation for scientists. They generally can't plan their own experiments. Instead, they must simply observe the experiments that nature provides for them. It is therefore critical to get as much information as possible from each drop of light that enters their telescopes. Today we'll look at several of the ways that astronomers extract information from the light that they receive.

Light is odd. Sometimes it behaves like a wave, sometimes it behaves like a particle, and it always travels at the same speed regardless of the speed of the object that emitted it. Because of its wave-like nature, we assign wavelike terms to it. The color of light is determined by the ***wavelength*** (the distance between one crest and the next) of the wave. If we count the number wave crests that pass us in one second, we will have measured the ***frequency*** of the wave. Wavelength and frequency are related by the velocity of the wave.

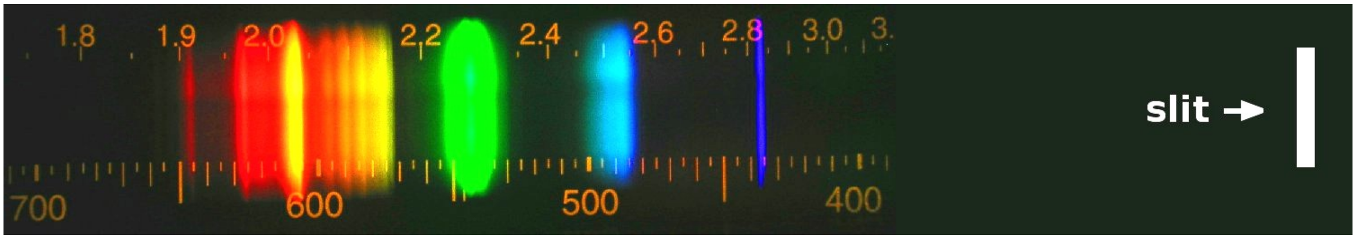
Light also behaves like a particle. It comes in discrete little packets known as ***photons***. Each photon has a distinct color (or frequency, or wavelength). Astronomers often use ***wavelength*** to refer to the color of a photon. The spectrograph that you'll use in lab measures the wavelength of the incoming light. It seems a little strange to assign a wave-like word like ***wavelength*** to something that behaves like a particle, but it's equally strange to assign particle like behavior to something that behaves like a wave. But, light is a just a little bit strange.

The particle-like nature of light is extremely useful for describing emission lines from a gas. Each element in a gas only absorb and emit photons of very particular colors (or wavelengths). By examining the emission lines, we can decipher the composition of the gas from far away. How handy!

Part 1: Lab Spectra

We'll begin by looking at several light sources in the lab with a spectrograph. Because we believe the laws of physics are universal, we assume that objects in space obey the same laws as objects in our laboratory. By comparing spectra of the lab sources with spectra of actual stars, astronomers can determine the star's chemical composition, temperature, and velocity.

1. Get used to using the spectroscope by looking at an incandescent light and the fluorescent lights. Spin the eyepiece until the lines are vertical and are spaced along the number line. It should look something like:



Point the SLIT at the light source!

2. Calibrate your spectrograph by looking at the hydrogen tube. Record the wavelengths of the emission lines that you see by drawing similarly colored lines in Table 1.

3. Find the same lines on the reference packet and record the actual wavelengths of those lines in Table 1.

4. Use the information from steps 2 and 3 to calibrate your spectroscope. Find a bright line, then move the plastic on the side away from the eyepiece to get the hydrogen lines aligned with the correct wavelengths.

Frequency is a measure of how many wave peaks per second are received by an observer. The wavelength and frequency are related by:

Wave speed = wavelength times frequency or $c = \lambda \nu$

where ***c*** is the speed of the waves, ν is the frequency in Hertz (cycles per second) and λ stands for the wavelength. (Remember $c = 3\times10^8$ m/s.)

5. Calculate the frequency of each color of light for Hydrogen and fill in Table 2.

Observe a **hot dense object**, like an incandescent light, with your spectroscope. This emits like a blackbody and you should see the entire visible spectrum.

6. In Table 3, record the wavelength ranges for Red, Orange, Yellow, Green, Blue, Violet for the incandescent light. (You will observe the fluorescent later.)

Now we will look at some emission line spectra. Emission lines arise from diffuse gases that are somehow excited. The Orion Nebula is one place where many hot young stars cause the surrounding gas to produce emission lines.

1. Look at the spectra of gas tubes supplied. For each one, carefully record the wavelengths of their emission lines in Table 4.

2. Using the spectrum charts in the lab, identify the mystery gas.

3. When everyone is done with the spectral tubes, observe the fluorescent lights again and record the spectrum in Table 3.

4. Answer the questions for Part 1 in the answer packet.

Part 2: Interpreting Spectra

Next we'll look at some simplified stellar spectra. These spectra can be used to measure the surface temperature of the star. A real stellar spectrum is a blackbody spectrum with absorption and emission lines superimposed. ***In this section, we are only concerned with the blackbody part of the spectrum.***

Wien's Law relates the wavelength (color) at the peak of the blackbody to the surface temperature of the emitter:

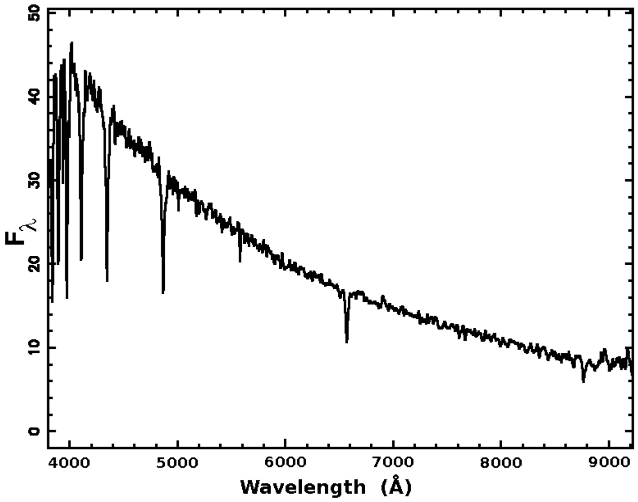
$$\lambda_{max} \times T_{surface} = 2.9\times10^6 \text{ K}\bullet\text{nm}$$

Here, λ_{max} is the wavelength (color) of the peak intensity and $T_{surface}$ is the temperature of the stellar surface. The number 2.9×10^6 is a constant. *(K and nm are the units of the right hand side, not variables)*

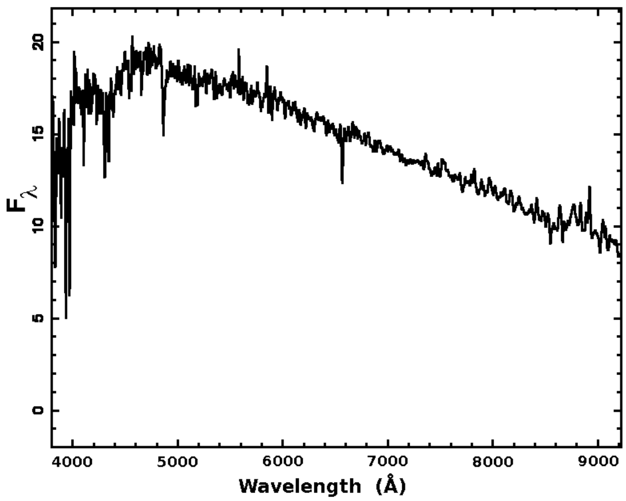
Astronomers use a historical classification system to identify stars known as the **Spectral Class**. Among other things, this system associates the surface temperature of a star with a letter in the sequence O B A F G K M. O stars have very high surface temperatures while M stars have very low surface temperatures. The table below gives the spectral class associated with a range of surface temperatures.

Spectral Class	Surface Temperatue
O	> 28,000 degrees
B	10,000 - 28,0000
A	7,400 - 10,000
F	6,000 - 7,400
G	4,900 - 6,000
K	3,500 - 4,900
M	< 3,500

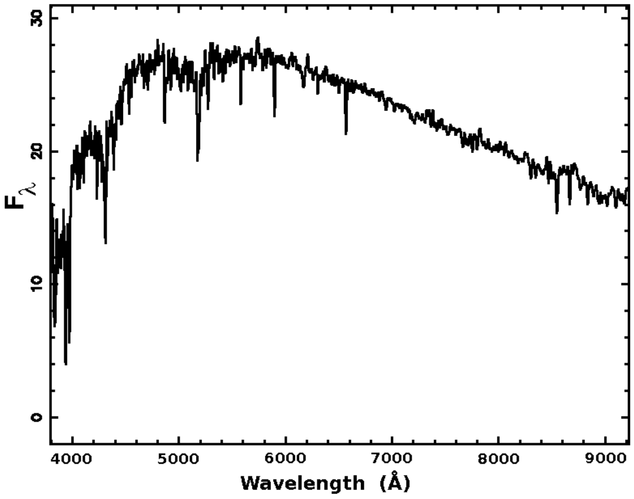
Star 1



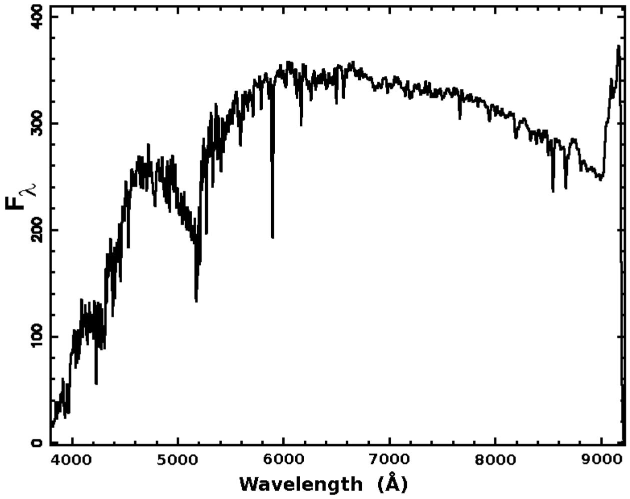
Star 2



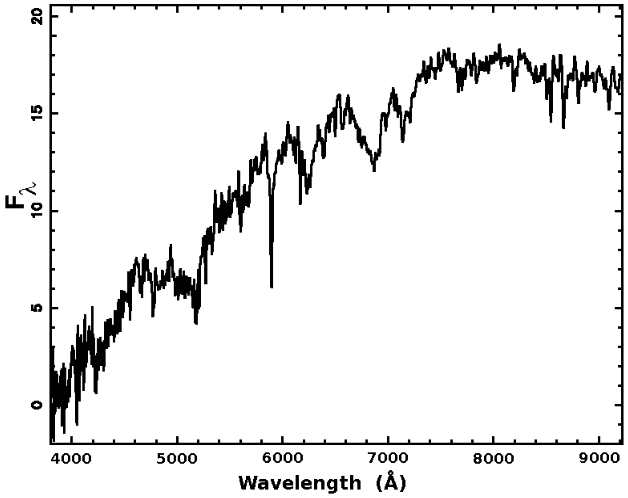
Star 3



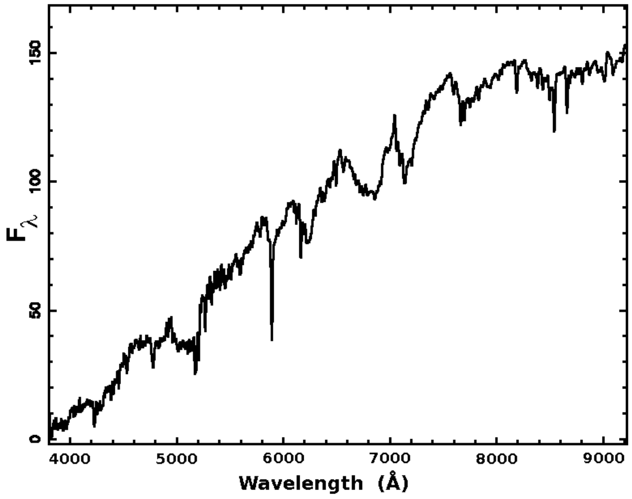
Star 4



Star 5



Star 6



1. Identify the *wavelength* at which the blackbody spectrum is the highest intensity. Be careful not to use an emission line! In some cases you will have to estimate, due to emission or absorption lines. This is real data!

2. Using Wien's Law, calculate the surface temperature of each of the six stars. Record your answers in the table on your data sheets.

2. Identify the spectral class for each of the six stars.

3. Find λ_{max} and the associated color for the Sun and Vega.

NOTE: The wavelength on the stellar spectra is in **Angstroms**. Remember to convert it to **nanometers** before applying the equation on page 4.

$$1 \text{ nm} = 1\text{x}10^{-9} \text{ m}$$

$$1 \text{ Angstrom} = 1\text{x}10^{-10} \text{ m}$$

(so you just need to divide the number in angstroms by 10 to get nm)

4. Answer the remaining questions.