# Measuring Temperature and Distance Remotely

With the exception of bouncing radar off an object and parallax, the primary way that astronomers determine distance is by somehow knowing the **Luminosity** of an object and then using its **apparent brightness** to calculate its distance. In **Part 1** of this lab, we will determine the distance to a light source by finding the relationship between distance and apparent brightness. We then can use that relationship to calculate a distance given a measured apparent brightness.

NGC 3766
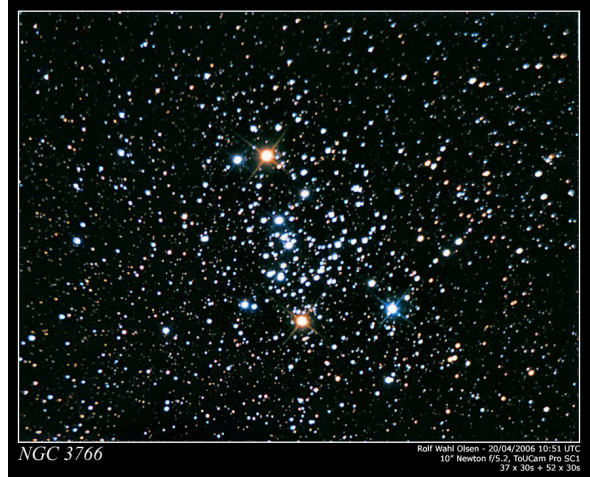
In order to use this relationship, we need to have some idea of what a true luminosity of an object is. Recall that for the H-R diagram, we have a relationship between the stellar temperature and an actual luminosity if the star is on the Main Sequence. However, if we want to use the H-R diagram, we need to have an idea of how to find the temperature of the star.

We already know that temperature is directly related to the peak wavelength of the blackbody spectrum. However, sometimes we want a faster and easier way to find temperature. In **Part 2** of this lab, we will find a relationship between the intensity (brightness) measured in two filters and the temperature.

Our goal is to be able to use these concepts in next week's lab to calculate distances to a cluster of stars.

<u>Part 1:</u> **Relating apparent brightness to distance**

First we will work on finding a relationship between apparent brightness and the distance of an object.

Experiment Setup:

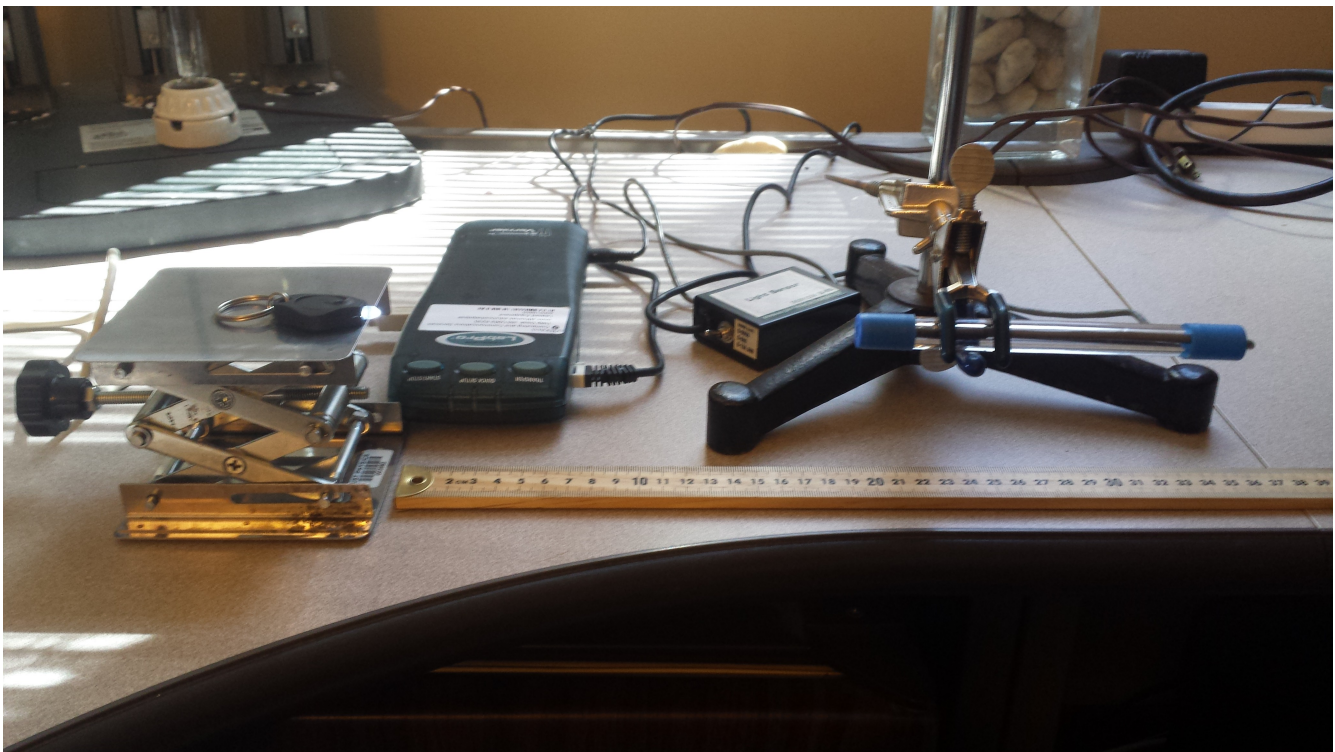Set up the experiment as in the picture below:

Figure 1

The LED should already be on. Place it on the lab jack so that it is aimed at the light sensor.

Match the height of the sensor as closely as possible to the height of the LED. **Important: Make sure the sensor is level & at the correct height!**

Start **Logger Pro** to display the reading from the light sensor.

Taking Data:

Start with the light sensor at 10cm from the LED. **Move the LED from side to side until you get the maximum signal from the sensor.** If you do not find the <u>maximum</u> signal you will not get good data.

Take readings with the sensor placed at five different distances from the LED. Leave 5 to 10 cm between each data point. **At each position, adjust the LED until you maximize the sensor reading**. Record your data in Table 1 in the answer packet.

Linearize and plot the data:

A powerful way to make predictions from a data set is by finding and using the relationships between the experimental variables. In this case, these variables are the distance and illumination.

By graphing our variables, we can easily make predictions. The easiest relationships to use in this way are linear, or those that fit a straight line. However, the relationship between illumination and distance isn't linear. Illumination decreases the square of the distance, just like gravity. Because we know this, we can _linearize_ the data and then fit a line to make predictions.

Calculate the _inverse square_ of your distance measurements and record the results in the center column of Table 1 in the answer packet. _Note: It may be helpful to write all of your numbers for $1/d^2$ in terms of 10^{-4} (for example, 0.01 will be 100×10^{-4})._

Plot your values of Illumination vs. $1/d^2$ on a piece of graph paper. Scale the axes of the plot so that your data fills the page. Using a ruler, draw the best fit line through your data.

Predict:

Have one of your lab members _secretly_ place the sensor at a random distance from the sensor and tell the rest of the group what the sensor reads without revealing the distance. Record the sensor reading in Table 2.

Using your plot and the sensor reading, determine the secret distance and verify with your lab partner whether you were correct. _(Hint: Recall what you graphed!)_

Part 2: Relating color to temperature.

We can use a spectrograph to measure the temperature of objects in space that emit like blackbodies by locating the wavelength of the peak emission (λ_{max}) and applying Wein's Law. However, we can also measure temperature using just the Vernier light sensor by taking illumination readings through two filters, one blue and one red.

The *ratio* of these two brightness readings is called the color index, and is correlated with temperature.
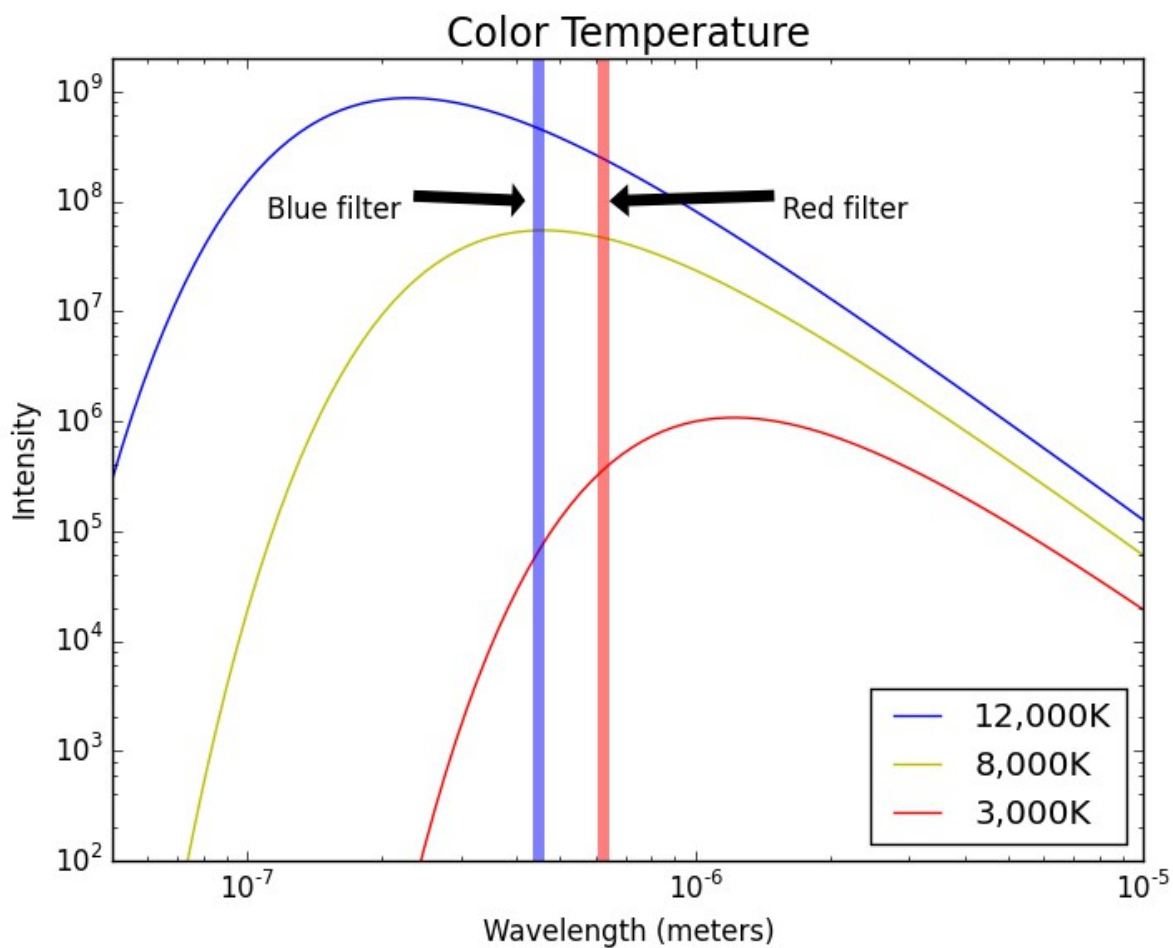

Figure 2

Sometimes, we want to use those filters with *magnitudes* instead of intensity. This is useful when we're trying to look at blackbodies like the ones in the above diagram. **Using magnitudes, the color index is a *subtraction* of Blue minus Red (B-R).** This is because magnitudes are logarithmic.

We will use *both* intensity and magnitudes in this section, so be sure to keep them straight!

Answer **Part 2, Questions 1 through 3** in your answer packet. The y-axis of the plot above shows intensity, which increases with brightness. Keep in mind that a high magnitude indicates a dim star and that a low magnitude indicates a bright star. It may be helpful to write magnitudes on the graph as well!

Experiment Setup:

Shut down Logger Pro. Set up the experiment as in the picture below:
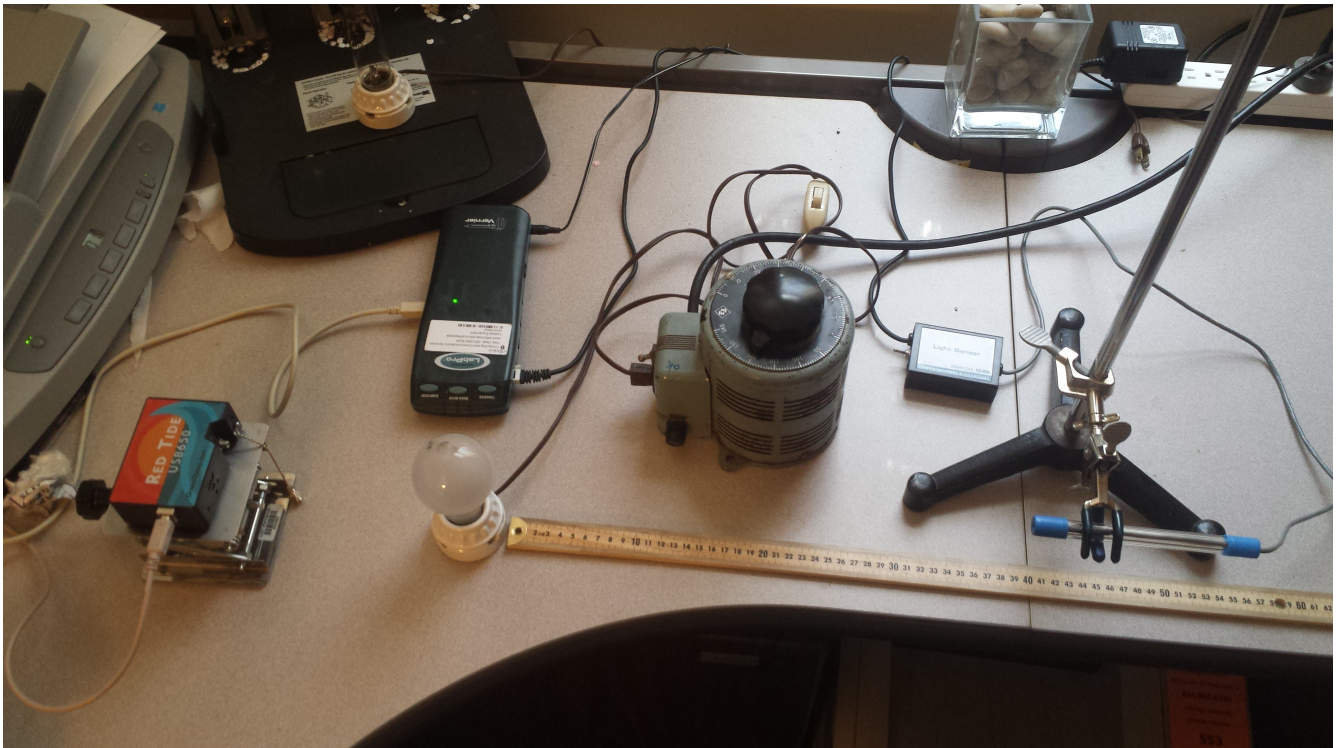

Figure 3

Plug the filament bulb into the variac. Adjust the variac to the first voltage setting in Table 3. Set the spectrometer on a lab jack and adjust the height so that it is pointed at the filament bulb. Attach the USB cable and start up the *Spectra Suite* software.

In *Spectra Suite*, set the integration time to 100 and the boxcar width to 50. (See Figure 4 below.)

If the spectrum is too high (cut off at the top) or too low, you can move your light closer or further away from the spectrometer or to the side to change the amount of light entering the aperture. You want to be able to see a good peak.

Your spectrum should look fairly smooth. If your spectrum still looks bumpy, talk to your lab instructor to see if you should increase the boxcar width further.
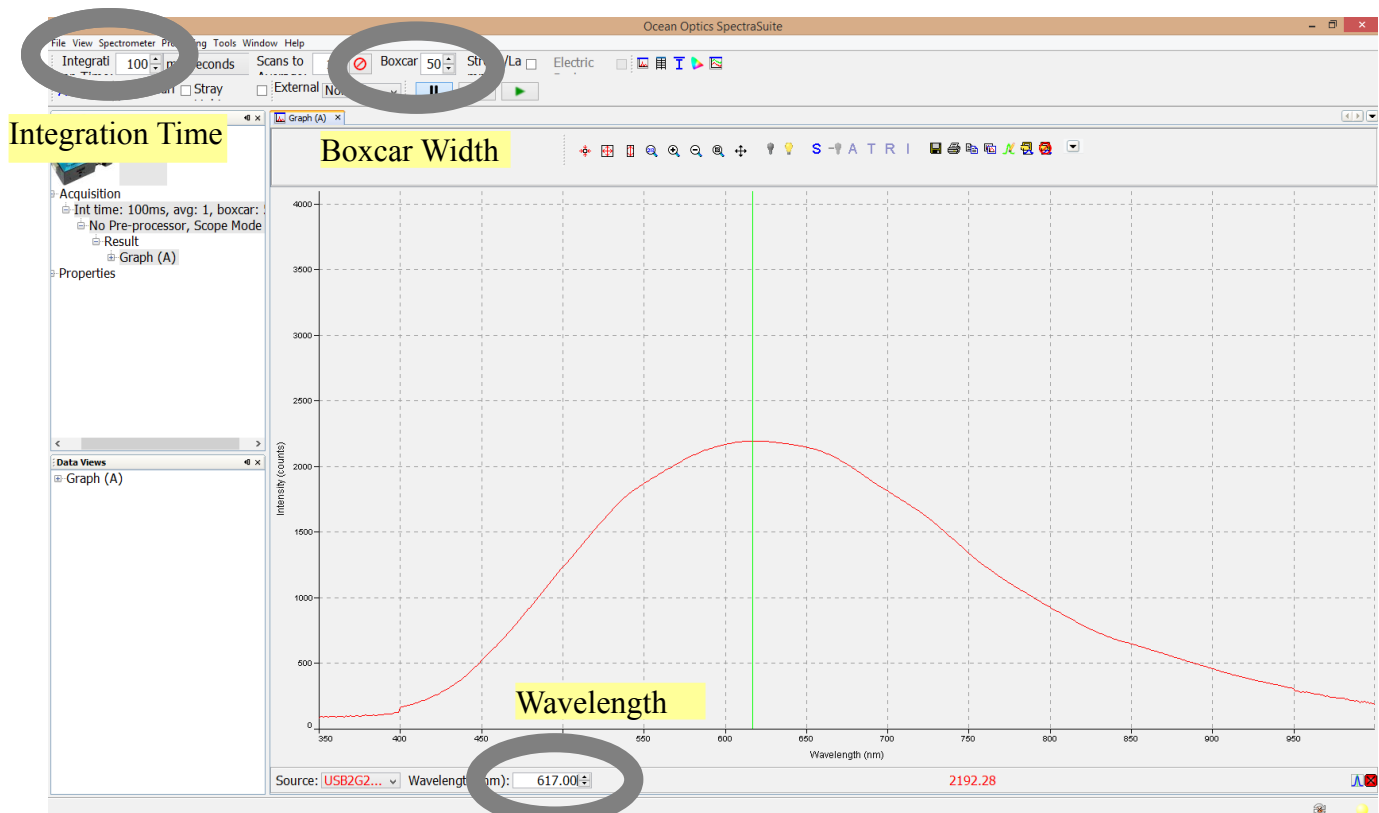

Figure 4

Click on the spectrum near the peak of the curve then use the arrow keys to find the maximum. Record the wavelength at the maximum in the lambda max column. This is in nanometers.

Calculate the temperature using Wein's Law and record it in the Wein Temperature column. In the equation below, T is in Kelvin and λ_{max} is in nanometers. Repeat for each voltage in Table 3.

$$\text{Wein's Law: } T = 2.9 \times 10^6 / \lambda_{max}$$

Now shut down **Spectra Suite** and start up **Logger Pro**. Point the Vernier Light at the filament bulb. For each voltage setting in Table 3, place the Blue filter against the Vernier light sensor and record the illumination. Do the same with the Red filter. Calculate the *ratio* of Blue to Red and record it in the last column (When using intensity rather than magnitude this should be a ratio).

Plot the data:

On a piece of graph paper, plot Color Index on the x-axis and Wein Temperature on the y-axis. Using a ruler, draw a best fit line on your graph.

Predict:

Set the variac to 120 volts.

Use the vernier light sensor to measure the Blue and Red illumination and record the results in Table 4.

Calculate the Color Index and record it in Table 4.

Use your best fit line to determine the filament temperature from the Color Index.

Now use the spectrometer to find λ_{max} and calculate the Wien Temperature. Verify that they match.

<u>Part 3:</u> **Determining the distance to a star.**

The main sequence on an HR Diagram displays a very useful correlation between stellar temperature and stellar luminosity. Our telescope is capable of taking images (and thus brightness measurements) in multiple color filters making it possible to calculate a **Color Index**.

Given what you have learned in this lab and what you know about Main Sequence Stars, describe in your answer packet a three step process that would allow you to measure the distance to a main sequence star using a telescope.