

Texas Tech University Department of Physics & Astronomy  
Astronomy 2401 Observational Astronomy  
Lab 8:- CCD Image Analysis:- Spectroscopy

### Objectives:

There are two principle objectives for this laboratory session.

- (a) To understand how to display a spectral image both as an image and graphically.
- (b) To understand how to use the VisualSpec software package to analyse spectra.

### Introduction:

Spectroscopy is by far the most important tool in astronomy! Using spectroscopy an incredible amount of information can be gleaned about celestial objects. However, until very recently, spectroscopy was the sole prerogative of the professional astronomer with their giant telescopes and massive spectroscopes. However, during the last decade, thanks to the development of CCD cameras and, more recently, low-cost and lightweight spectroscopes, spectroscopy is now available to amateurs with modest equipment.

Along with the development of affordable spectroscopes has been the development of software to analyse the spectra obtained. There are two freeware software packages available. One is by the SBIG company and is called “Spectra”. The other is by a group of amateur astronomers based in France and is called “VisualSpec”. In this exercise you will be using “VisualSpec”.

Your lab notebook write-up must include a Data Analyses section that includes all three of your spectra graphs, your RV calculation for Sirius and wavelength identifications for Betelgeuse and M42.

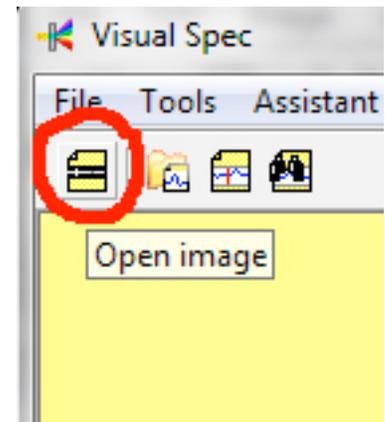
### Procedure:

Start by downloading the 3 .fit files from the course website. They have been calibrated for you.

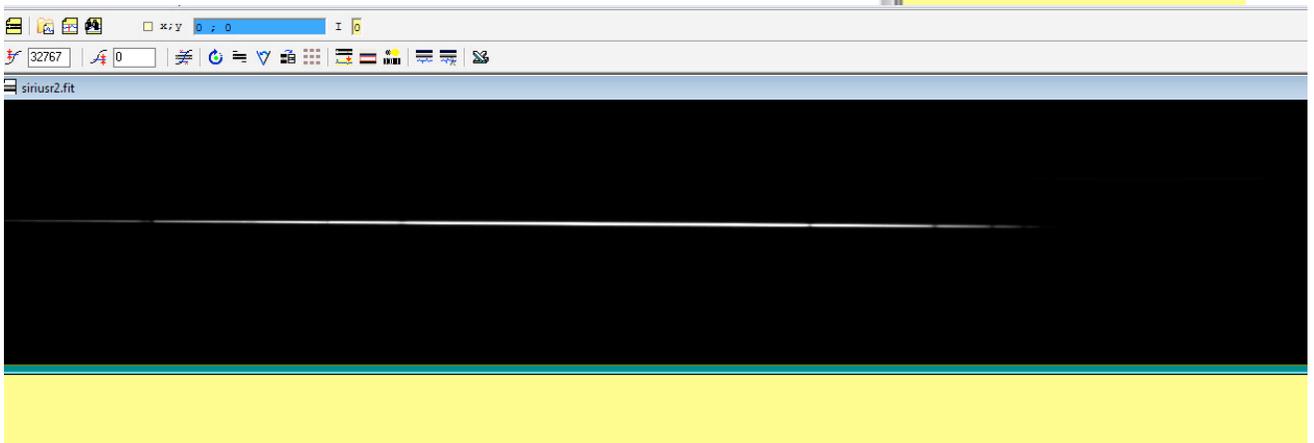
Now open the software “**VisualSpec**”. When the software opens, you will see the following:



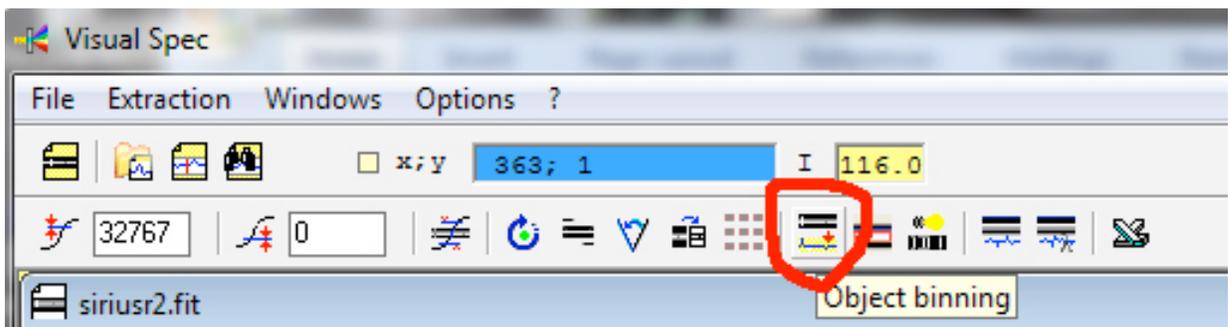
Click on the icon at the top left of the window and open your calibrated image of Sirius.



Once the image is opened, it should look something like the one below: (A nebula would appear as a series of bright lines)



The next step is to display the spectrum as a graph. While the photographic representation shown above shows some detail such as dark absorption lines, it is much easier to analyse the spectrum when it is displayed as a graph. To display the spectrum as a graph, click on the “Object Binning” icon as indicated below.



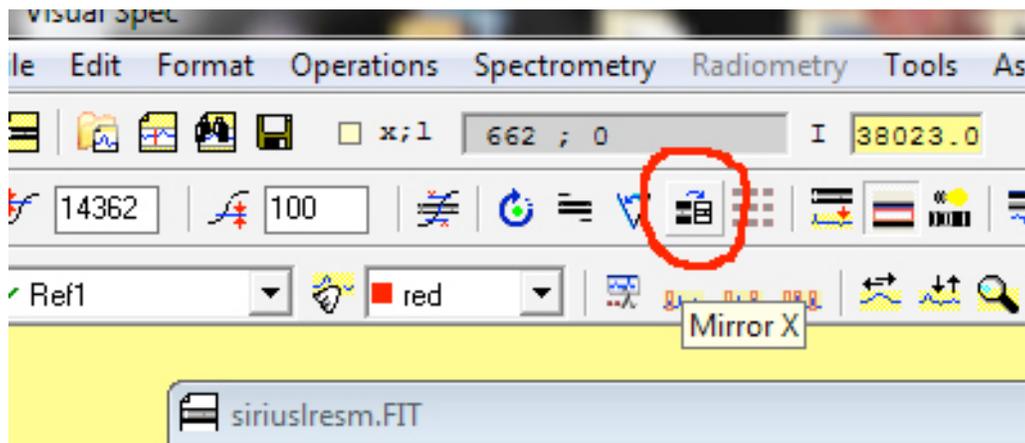
Now the software will display the spectrum as a graph. In the graph, intensity is plotted on the Y-axis and wavelength on the X-axis. In the graph of Sirius below, several dips in the graph are visible. Most of these are Hydrogen absorption lines, however the one furthest to the left is actually absorption caused by water in the Earth’s atmosphere.

These lines are important for identifying other lines in the spectrum and for determining the spectral classification of the star. Also note that the intensity of the background continuum is a curve. This is a result of the continuum light from the star and the sensitivity of the CCD across the visible spectrum.



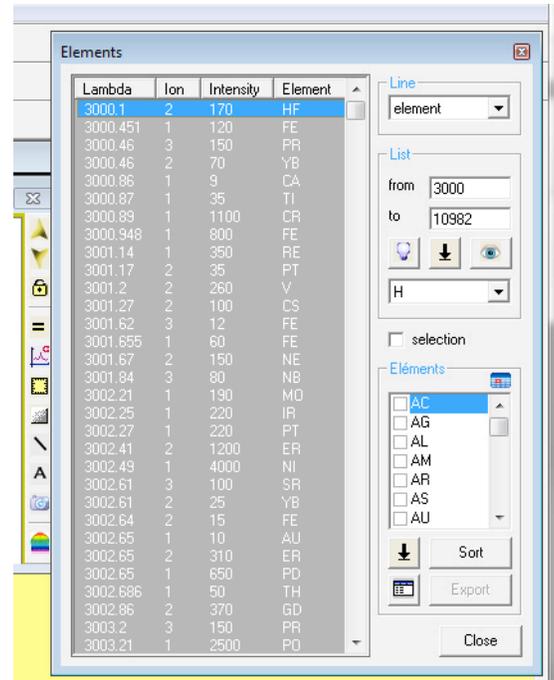
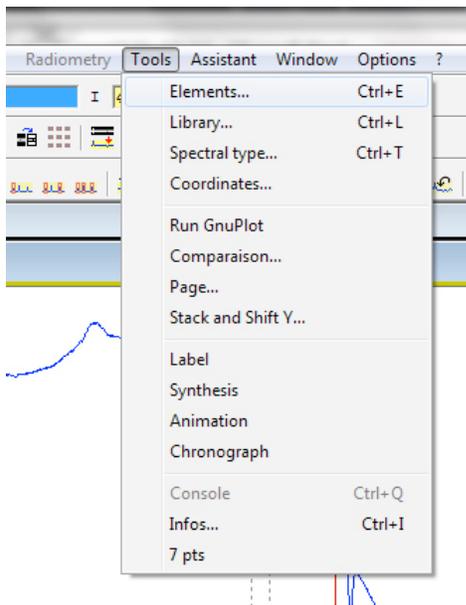
Before you go on however, it is important to make sure that you have the image and the spectrum the correct way around. For some reason, VSpec only works when the short wavelength end of the spectrum is to the right! The orientation of your image and spectrum will depend on how the spectrograph was attached to the telescope and which side of the pier the telescope was on. The way to check if you have the correct orientation is to look at the spectrum graph. Since it is showing the spectrum of an “A” star, the deepest lines are those of hydrogen. Most of the hydrogen lines are towards the blue end of the spectrum, and the further towards the blue you go, the weaker the lines become. In the graph above, notice that there are several lines on the left of the spectrum, that diminish, the further left you go. These are the hydrogen lines. While there are several lines to the right of the spectrum, notice how these are of similar intensity. So this graph is orientated correctly, with the blue end towards the left.

If your spectrum is not correctly orientated, you will need to close the spectrum graph and then reverse your image. You can do this by clicking on the “**Mirror X**” icon on the second row of icons.

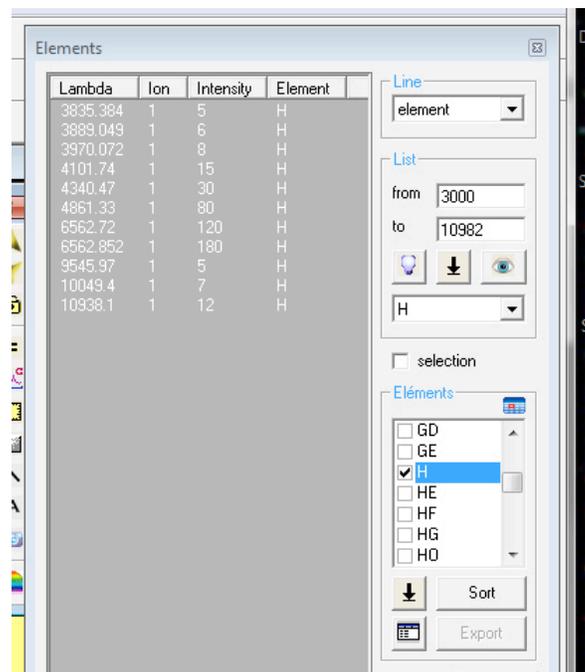


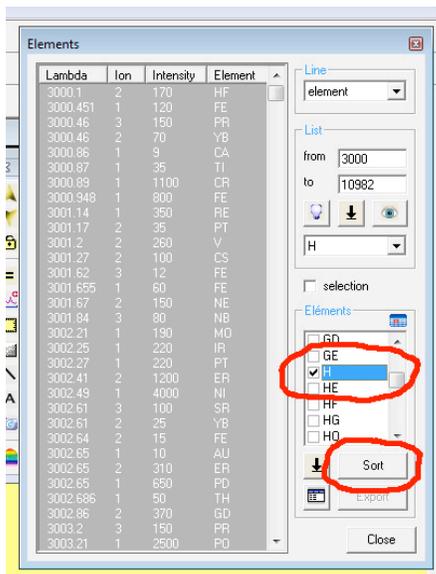
Once you have the image correctly orientated, re-display the spectrum graph. (Note: You'll have to flip ALL the spectra you have been given for this lab, you can do it first before you plot the graph after you open the image.)

Now that you have the spectrum graph correctly orientated, the next step is to identify the lines. To do this, go to the “Tools” menu and select “Elements”. This will open a new window which has all the elements listed along with their spectral lines as shown below.

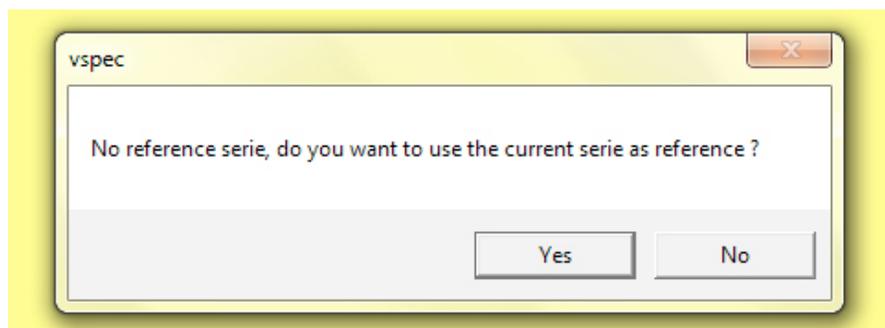
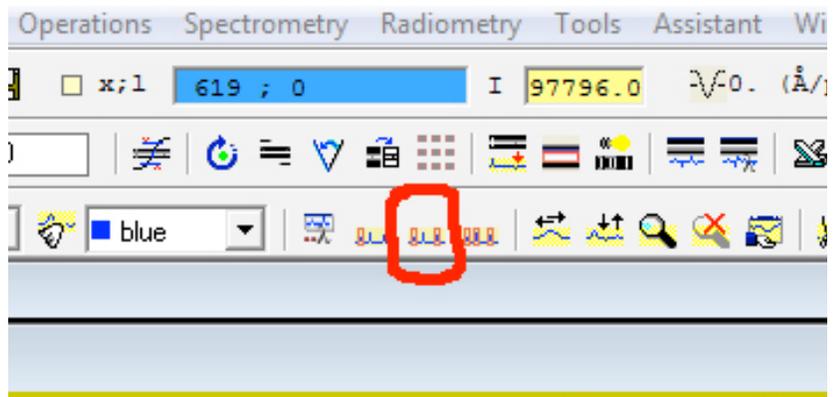


Having all the elements listed and their spectral lines makes life very complicated! Since we know that the star is an “A-type” and that the major lines are hydrogen, we can simplify things considerably by only displaying the hydrogen lines. To do this, go to the slider at the small window on the bottom right of the elements window. Drag the slider down until you see the “H” indicating hydrogen. Tick this box and then click “Sort”. Now the main “Elements” window only shows the hydrogen lines.



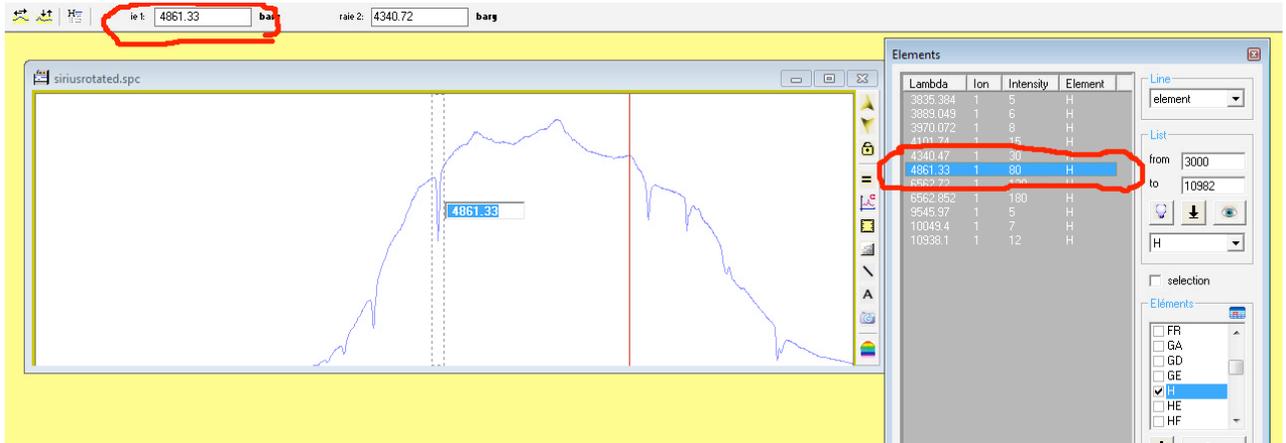


Next you have to choose the method of line identification. The best method is to use 2 lines as this will also calibrate the spectrum. To do this, click on the middle icon of the 3 in the bottom row of icons as highlighted in the image to the right. This will tell the software that you will be using 2 lines. Since you are not using a calibration spectrum, (we will come to that later) you will see the error message shown below. Just click “Yes”. Now you are ready to start identifying the lines.

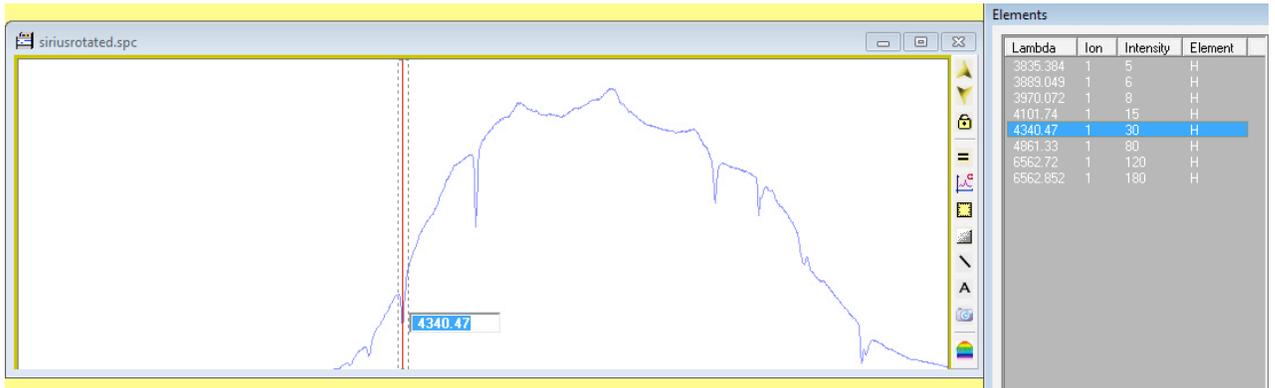


To do this, put the cursor on the left-hand edge of the deepest line. While doing this, you will notice that the red line follows the cursor. Then, holding down the left button on the mouse, drag the cursor to the other side of the line as shown below. Once you have done this, you will notice a small window appears next to the line with a number in it. This is where you need to enter the wavelength of the line you just selected. The line that you highlighted is the H $\beta$  line at 4861.33Å. To tell the software this, click on the H line at

4861.33Å in the “Elements” window. This will highlight it and also put the wavelength in the small window beside the line. It will also enter the wavelength in the small window above the graph, “ie 1”. The number in bold alongside this window is the x-axis pixel value of the deepest point of the line. Then double click the small window on the graph with the wavelength value.

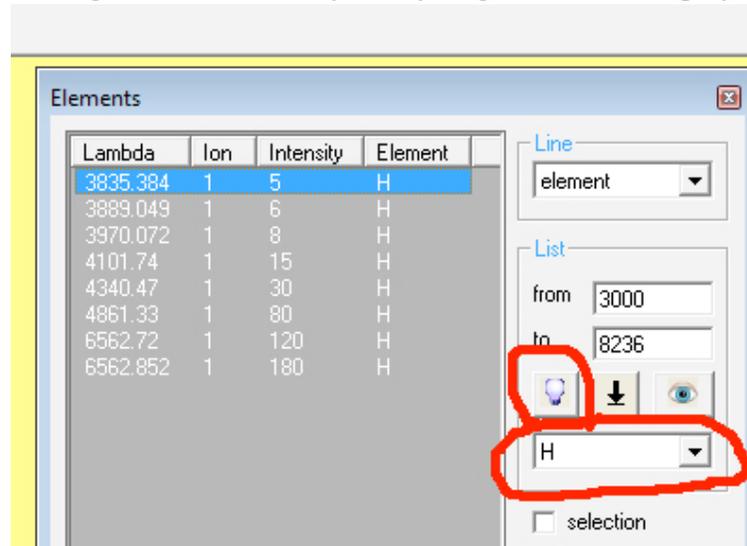


Now you need to select a second line. A good one would have been the H $\alpha$  line at 6562.72Å, which in the image above is to the right of the line you just identified. However there are 2 lines in this area and it is not clear which of these is the H $\alpha$  line. Therefore a better choice in this case would be the next line to the left, which is the H $\gamma$  line at 4340.47Å. Select this line as you did the previous one, and click on the corresponding line in the “Elements” window to enter that wavelength into the software.



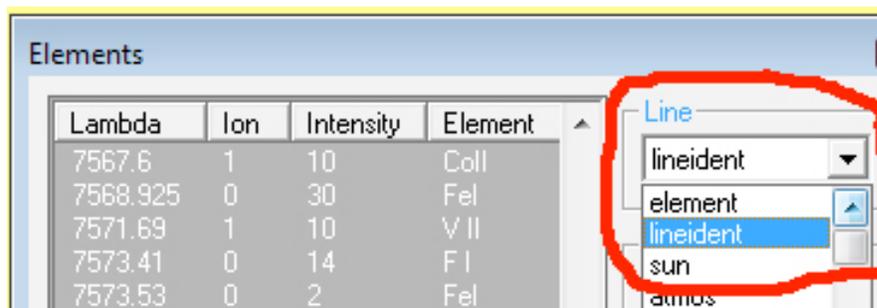
Now that the spectrum is calibrated, it is possible to identify the other lines. To do so, move the cursor to the next line on the left of the one you just identified and click on the deepest part of the line. Now the software tries to identify the line and highlights what it calculates as the wavelength and most probable element responsible for that wavelength. The element highlighted is most likely **not** going to be the correct one. This is because there are so many elements and their lines are so closely packed, that at the low resolution of the spectrum, the software has considerable trouble with the identification. However, since stars are mostly hydrogen, and since the spectrum of hot stars are dominated by the hydrogen lines, you can simplify things considerably. To do this, make

sure that “H” is selected in the small window about halfway down on the right of the “Elements” window, and then click on the icon just above it that looks like a light globe as indicated in the image below. Now only the hydrogen lines are displayed.



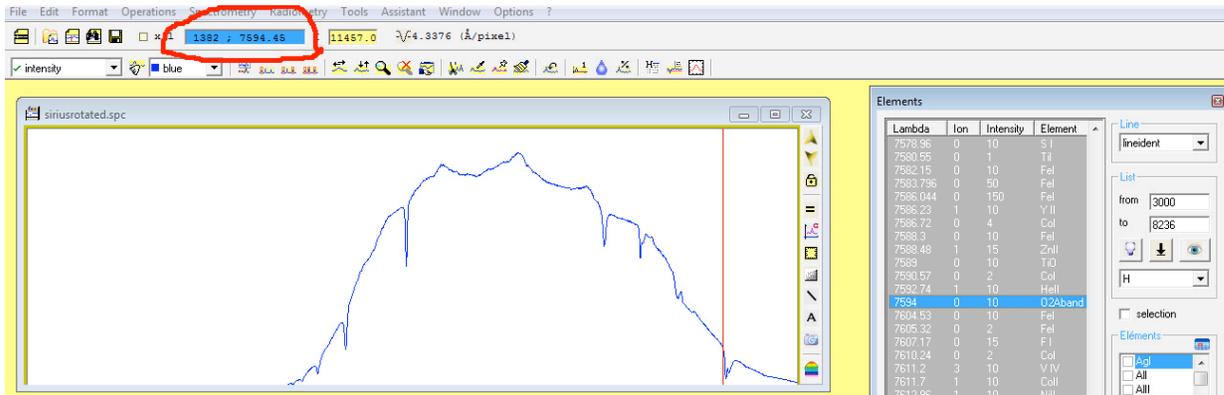
Now click again on the spectral line you just looked at and you will see that the hydrogen line at 4104.74Å is highlighted. Next, move to the lines at the right and see which of these is the H $\alpha$  line at 6567.72Å.

Once you have done this, look at the other lines on the right. As you click on those, you should notice that none of the wavelengths in the “Elements” window is highlighted. This indicates that these lines are not hydrogen. So what are they? To find out, go to the small window at the top left of the “Elements” window and click on the arrow at the right of it. From the drop-down menu select “**lineident**”.



Scroll down through the wavelengths displayed until you come to the “**O2Aband**” line at 7594Å. Click on this and you will notice that the red vertical line on the spectrum graph jumps to the furthest line on the right of the spectrum. That is because this line is caused by oxygen in the Earth’s atmosphere. Notice too that it does not correspond to the deepest part of the line! Why is this? The answer is that the spectrum was calibrated using the spectral lines in the star. These lines are doppler shifted by the radial motion of the star and by the motion of the Earth around the Sun. You can check this by scrolling up to the

“O2Bband” line at 6867Å and clicking on that wavelength. Now you will notice that the red vertical line on the spectrum jumps to the same edge of the line close to the H $\alpha$  line. Using this information it is possible to calculate the radial motion of the star. To do this, first click again on the “O2Aband” line at 7594Å. Then look at the blue window at the top left of the display. This window displays the intensity and wavelength of the spectrum at the point where the red vertical line is located. The difference between the listed wavelength and the wavelength displayed in the blue box is the doppler shift.



In the case of the spectrum of Sirius used here, the difference is 0.45Å.

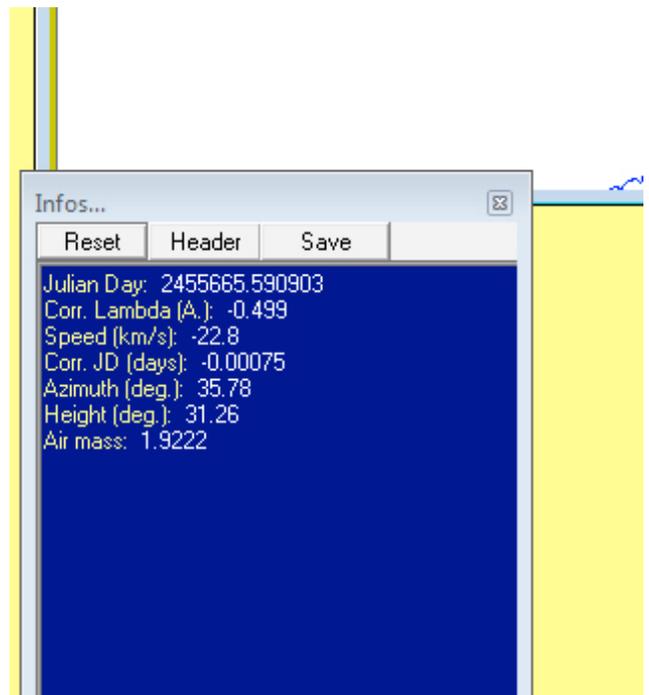
The formula for velocity from a doppler shift is:-  $v = \left( \frac{\Delta\lambda}{\lambda_0} \right) c$

where  $\Delta\lambda$  is the doppler shift,  $\lambda_0$  is the rest wavelength and c is the velocity of light.

Using the values above gives a radial velocity of:  $v = \left( \frac{0.45}{6867} \right) 300,000 km / s = 19.66 km / s$

Since the observed wavelength is longer than the rest wavelength, the star appears to be receding. However this is not the whole story. The motion of the Earth around the Sun has to be taken into account.

To do this, click on the menu “Spectrometry”, choose “Heliocentric Correction”. In the dialog box that opens, enter the longitude and latitude of Lubbock in decimals of a degree, (**Lat. 33.748 degrees; Lon. -101.959 degrees, make sure you include the negative sign in the longitude**) and then the RA and Dec of the star, then click compute. The software will then calculate the motion of the Earth with respect to the star and give this information in a small box.



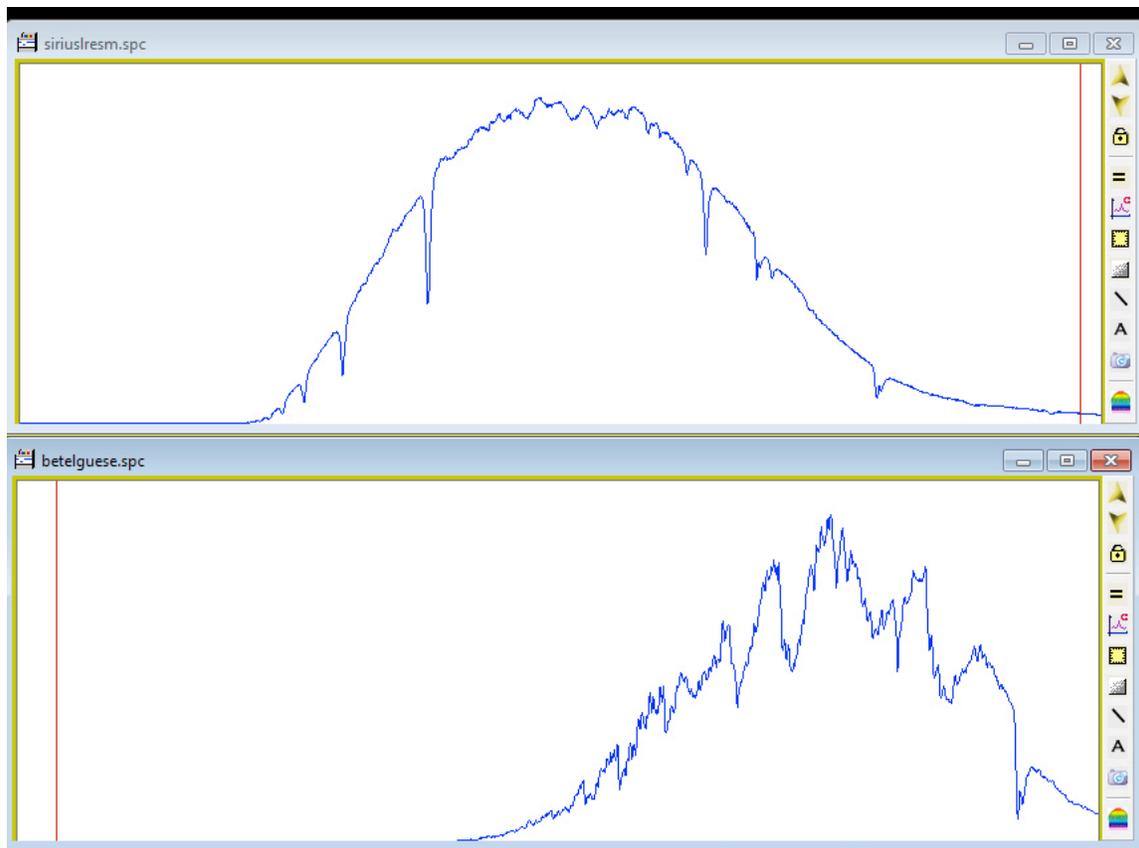
The speed given for the Earth can then be added to the earlier calculated speed of the star.

$$19.66 + (-22.8) = -3.1 \text{ km/s.}$$

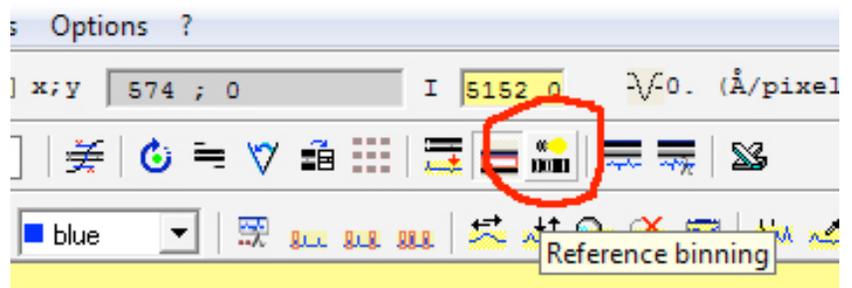
This agrees quite well with the catalogue value of  $-4.1 \text{ km/s}$ . What result do you get for Sirius?

**Now is a good time to save your Sirius spectra. Be sure to record your radial velocity calculation in your lab book.**

Now open your image of Betelgeuse. (leave your image of Sirius open for the moment)  
Now display the spectrum graph. When the software asks if you want to replace the current series with the new binning result, click **NO**. That way you can see the spectrum of both stars.

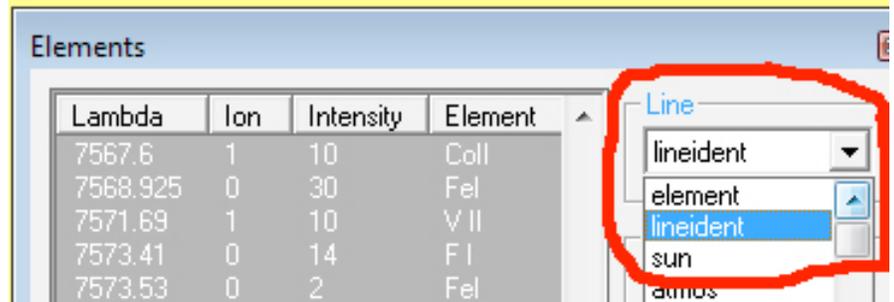


Looking at the 2 spectra, you can see that there are considerable differences between them. This is because Betelgeuse is a cool, red-giant star, too cool to display any hydrogen lines. Also since it is cool, it emits very little blue light, but a lot of infra-red light. The spectrum also shows a considerable number of deep absorption lines. Most of these lines are due to metals, particularly Iron and Calcium. To identify some of these lines, **first close the graph of Sirius**, then



click on your Sirius image and then click on the “**Reference Binning**” icon. This will add the spectrum of Sirius to the spectrum of Betelgeuse. Using the hydrogen lines in the Sirius’ spectrum as a guide, you can calibrate the Betelgeuse spectrum. Calibrate the spectrum just like you did earlier. (As you start the calibration, you will notice that the spectrum of Betelgeuse will disappear. The software does this to make it easier for you. Once you have the calibration done, the spectrum of Sirius will disappear and that of Betelgeuse will be displayed.)

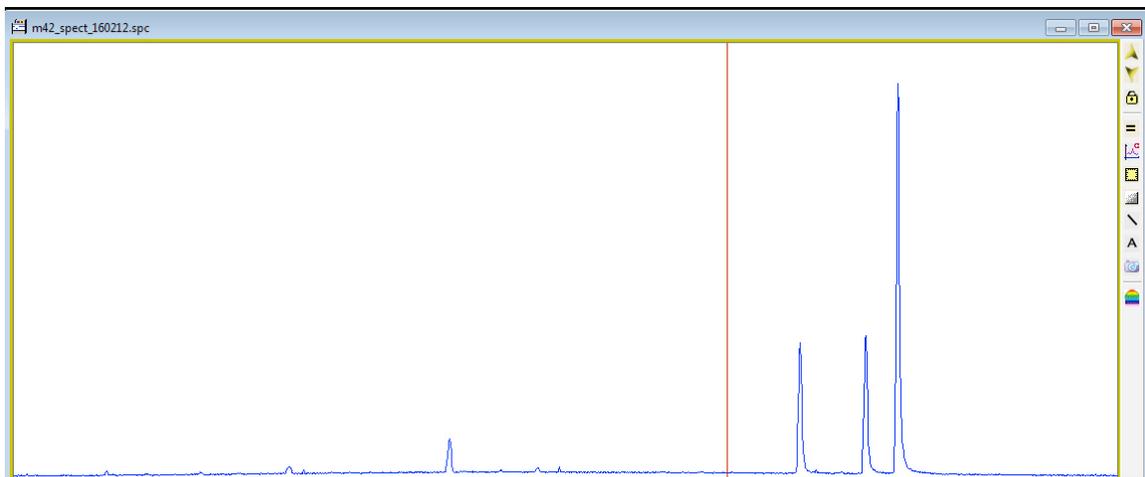
Once you have the spectrum calibrated, click on the “lineident” as before, and this time, choose the FeI set of lines. Then try and see if any of the lines in your spectrum match any of these.



Did you get any matches? If so, what were the wavelengths?

**Record these values and save your Betelgeuse spectra.**

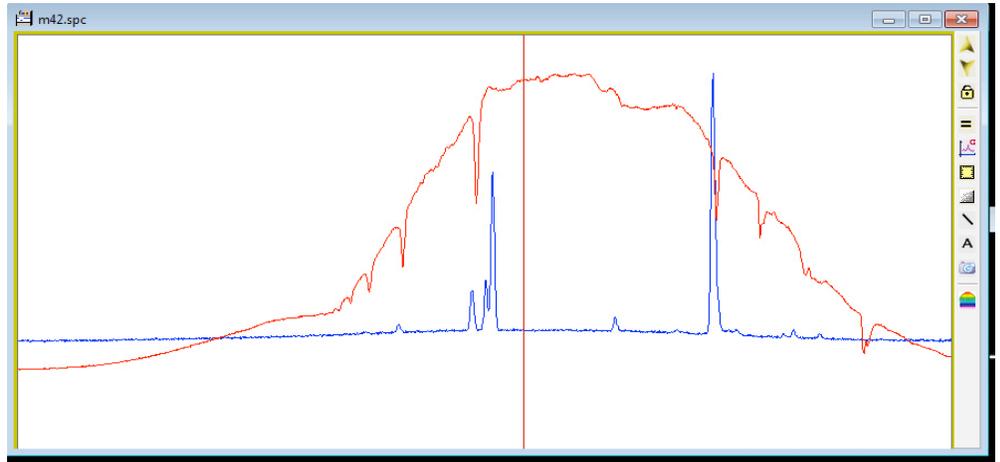
Now that you have learned how to calibrate a stellar spectrum and identify some of the lines, it is time to have a look at your M42 nebula spectrum. Close your stellar spectra and images. Now open your image of M42 and display the spectrum as a graph as you did earlier. You should see something like that below.



Notice how instead of absorption lines, the spectrum consists of emission lines. Also open the image you made using the Hydrogen lamp. You will use this for calibration.

To see which of the lines are hydrogen, open the star image again. Then click on the “**Reference Binning**” icon.

This will display its spectrum superimposed on the nebula image. Using the hydrogen lines in the star's spectrum as a guide, you can calibrate the nebula spectrum.



Calibrate the nebula spectrum and then start trying to identify some of the other emission lines. This can be tricky as the number of possible lines is huge. You can make life a little simpler by realising that the most common elements in a nebula with strong lines in the visible portion of the spectrum are  $H\alpha$ ,  $H\beta$ ,  $H\gamma$ ,  $H\delta$ , HeI, OIII, NII and SII. To choose just these elements, go to the “Elements” window and in the lower right is a small window of elements with a slider. Slide down and each time you come to one of the above elements, tick the box beside it. Once you have selected all of the elements above, click “Sort”. Now you can try to identify the lines. To help you, the strongest line apart from the  $H\alpha$  line is the OIII line at  $5006\text{\AA}$ . What are the other lines caused by?

Lambda	Ion	Intensity	Element
3645.981	0	10	H
8203.572	0	10	H
8255.153	0	10	H

Line: lineincident

List: from 3000 to 8257

selection: H

Eléments:

- H (H9)
- H (H9)
- H (Hbet)
- H (Hdel)
- H (Heps)
- H (Hgam)
- H2Oa-band

**Record your results and save your spectra of M42.**