


About the software

This exercise is designed for Graphical Analysis 3.0 by Vernier Software. An “” icon appears when analysis of the data with the computer is necessary. This manual uses images from the Macintosh version of Graphical Analysis to illustrate the examples, but the Windows version is essentially identical. The data is available on the CD-ROM. To order Graphical Analysis, Vernier Software can be reached at the following address:

Vernier Software, Inc.
8565 S.W. Beaverton-Hillsdale Hwy.
Portland, Oregon 97225-2429
Phone: (503) 297-5317, Fax: (503) 297-1760
email: dvernier@vernier.com
WWW: <http://www.vernier.com/>

Summary of Commands

File/Open... (-O)

Opens the spectrum. Use this command if the spectrum file is in GA 3.0 format. Unfortunately GA 3.0 is unable to open files in GA 2.0 format.

File/Import from Text File...

Use this command to load a spectrum that is in text format. For this command to work properly the spectral data must be comma-delimited.

File/Close

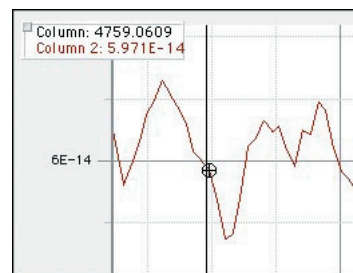
Use this command to close the current spectrum.


Analyze/Examine (-E)

Activates the examine tool (the magnifying glass) which gives the wavelength (the X value) and the flux per unit wavelength (the Y value) of the datapoint closest to the cursor.

Graph/Scaling...

Allows the X- and Y-axes to be rescaled either by inputting ranges manually or automatically by using the data values.



Use the examine tool (using **Analyze/Examine** or -E) to determine the wavelength (the X value) of absorption and emission lines in the spectrum. In this example the wavelength of the datapoint in the same column as the cursor is 4759 Angstroms (Å). The flux density per unit wavelength (the Y value) is 5.971×10^{-14} erg cm⁻² s⁻¹ Å⁻¹.

Stellar Spectroscopy

The Message of Starlight

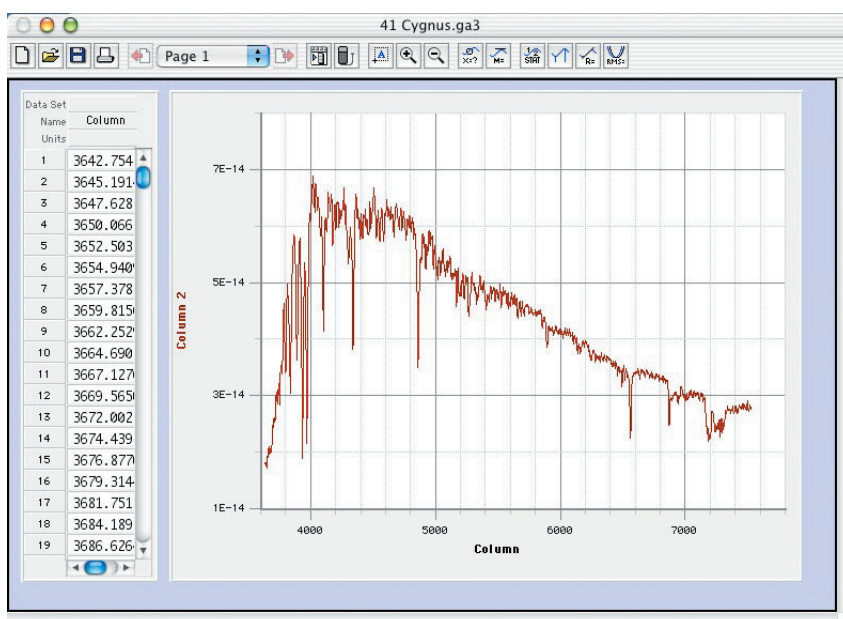


An Example: The Spectrum of 41 Cygnus

Description of the spectrum

“41 Cygnus” is a bright, variable star in the Constellation of Cygnus, the Swan. A spectrum of this star was obtained with the Kitt Peak National Observatory 2.1-meter telescope on July 27th, 2000.

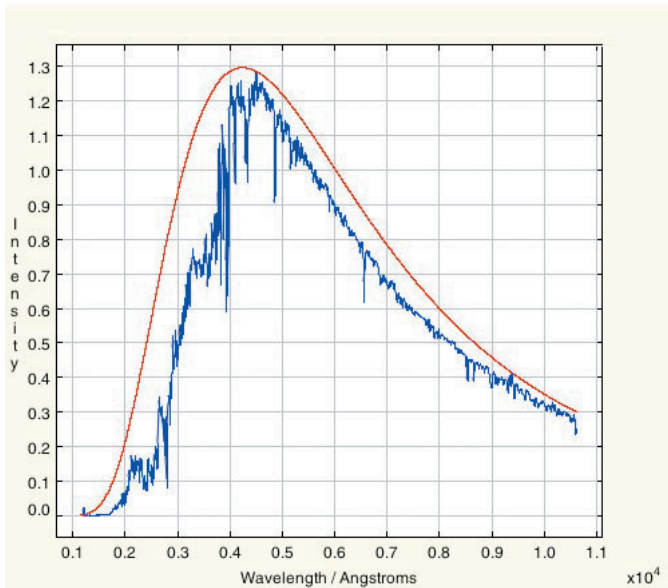
Load the spectrum using the **File/Open...** command. It should look similar to the illustration below:



This spectrum measures light from 3600Å to 7500Å (the X-axis). For comparison, the human eye can see from 4900Å to 7000Å. The Y-axis is the flux density per unit of wavelength and is given in units of $\text{ergs/sec/cm}^2/\text{\AA}$. You will notice that the spectrum contains many bumps and wiggles, which correspond to many absorption lines. First we will study the shape of the continuous spectrum and estimate the location of the peak. This is not easy to do because the many absorption lines present have significantly changed the shape of the continuum.

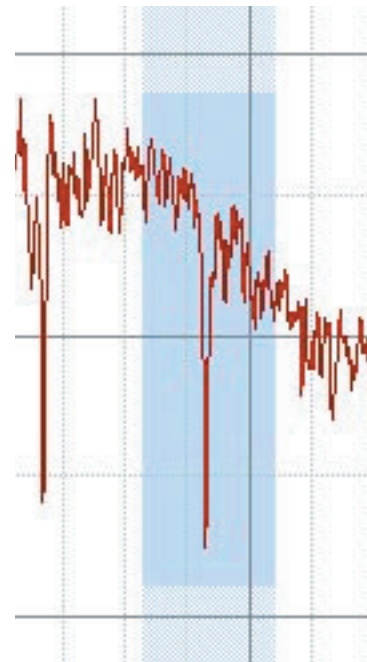
The diagram below shows a plot of what the spectrum might look like without absorption lines. Note that this plot was not generated with Graphical Analysis, or for 41 Cygnus itself, but for a similar star. Also note that the line is always above the data because absorptions remove light from the spectrum. This line is therefore a model of what the continuum looks like without any absorption lines. This plot was generated with a Java applet at:

<http://www.jb.man.ac.uk/distance/life/sample/java/spectype/specplot.htm>

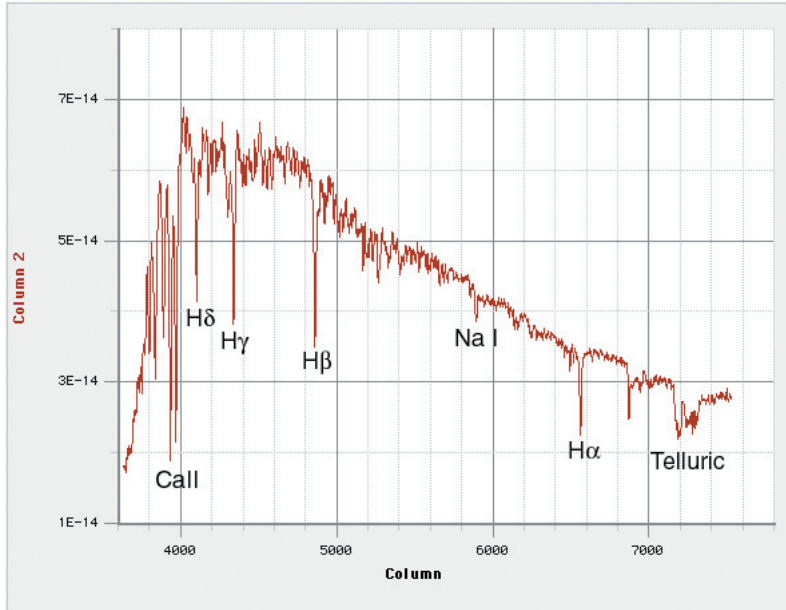


The line is not a precise fit, but we see that the peak of the spectrum occurs around 4200\AA . Using Wien's Law we estimate the temperature of the star to be about 6900 K . Based upon this estimate we tentatively classify it as an *F* class star, although with the uncertainty in our measurement of the peak wavelength it could also be an *A* class star.

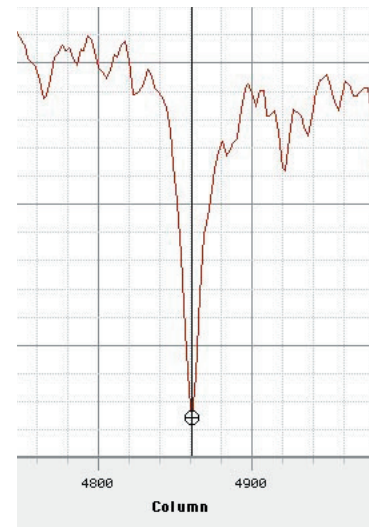
Next we will study the absorption lines. To study the absorption lines more closely you may zoom in on portions of the spectrum and use the examine tool to measure their wavelengths (see right). The Balmer series of Hydrogen lines is strong in this object, as are the CaII $\lambda\lambda 3933, 3968$ lines (labeled below).



To zoom in on a portion of the spectrum click and drag a rectangle around a region and then select **Zoom Graph In** from the **Analyze** menu.



Many other metal lines are also present. They are too numerous to mention, however G-band $\lambda 4300$ and FeII $\lambda 4175$ are clearly present. The strong Balmer lines indicate that this must be an *A*, *B* or *F* class star. Metal lines are not very strong in *B* class stars; and in general metal lines are increasingly common in cooler stars. We conclude that this is an *F* class star because the CaII lines are stronger than the Balmer lines. This is in agreement with our spectral classification based upon the temperature of the star; and indeed astronomers have classified this star as an *F5*.



Once zoomed in turn on the examine tool and place the cursor at the bottom of the absorption line. The wavelength (X) of this absorption line is 4861\AA , which is H β .

Stellar Spectroscopy

The Message of Starlight



Procedure

For each spectrum you will analyze the continuum, absorption lines and emission lines (if present). To better learn how to analyze a star you are encouraged to first work through the example.

Determining the Temperature from the Continuum

First you will study the continuum of each star to determine its temperature. You will use the examine tool to estimate the peak wavelength for the continuum of each star as best as you can. Note that this is not necessarily the highest datapoint in the spectrum, as emission and absorption lines are also present. Determining the peak of the continuum is not easy for stars with many absorption lines because the lines can significantly alter the shape of the continuum, so do the best you can.

To measure the location of the continuum peak in the spectrum do the following:

- ☐ Open the spectrum and measure the peak of the continuum:
 - **File/Open...** (⌘-O) the spectrum to be studied.
 - If the graph shows only a bunch of dots make sure the graph options are set correctly. To do this select the graph by clicking on it once and then selecting **Options/Graph Options...** from the menu. Make certain the “connect lines” option is selected.
 - Activate the examine tool (**Analyze/Examine** or ⌘-E). The information box gives the wavelength (the X value) and flux per wavelength (the Y value) of the datapoint in the same column the cursor. Position the cursor over the region you which you think is the peak of the spectrum and record its wavelength (the X value).

For some of these stars, the peak of their continuum spectrum occurs outside of the limits of the spectrum (off the left or right side). For these objects our spectrum is insufficient to determine the peak of the continuum.

1. For each star for which you can see the peak in the continuum spectrum, use Wien's Law to calculate its temperature.
2. Sort the stars based upon their temperature, from the coolest to the hottest. For the objects for which the spectrum is insufficient to see the peak of the spectrum just give it your best guess; later you will use other diagnostics to determine which stars are hotter than the others.

Absorption and Emission Lines

Now you will measure the wavelength of the absorption lines in each star to identify the spectral class of the star. Some stars have emission lines as well, and the wavelengths of these lines should be measured too.

☐ Measure the positions of strong spectral lines:

- Use the examine tool (**Analyze/Examine** or $\frac{\text{H}}{\text{E}}-\text{E}$) to measure the wavelengths of at least four of the strongest absorption and/or emission lines in the spectrum of each star. Identify these lines with the table of common spectral lines given to the right.

A few notes: This is not a complete list of all the spectral lines seen in these stars. Most of the lines given are between 4000 and 5000Å, because historically this is the portion of the spectrum astronomers have studied most closely. Also note that some lines overlap, e.g., H ϵ and CaII λ 3968. The molecular bands can be quite wide, 50Å or more. For the molecular bands you should estimate the location of the center of the band and measure its wavelength as best as you can.

The goal is not to identify each and every absorption line in the spectrum, but rather to gain enough information to identify the class of star; e.g., only the hottest stars have helium lines, so the presence of several of the helium lines is an important indicator. Similarly, metal lines are stronger in the cooler stars. If an observed line has a wavelength that is close to two lines in the table, you may be able to differentiate by studying other lines. For example, if you see an absorption line at 3970 it could be either H ϵ and CaII λ 3968. If you see the other hydrogen Balmer lines it is likely H ϵ . If you see the other CaII line at λ 3933 it is likely CaII λ 3968. If you see CaII and Hydrogen lines it is likely a blend of both lines.

Note that stars these stars are moving slowly, such that their spectra will not be noticeably red or blueshifted. Their spectral lines should therefore appear roughly in the positions listed in the table. Because this is real data there is some error in measuring the wavelength, although your measured positions should match the values in the table to within about 3Å.

The Earth's atmosphere causes strong absorption features which are known as *telluric* absorption lines, which are also listed in the table. Sodium in the Earth's atmosphere also tends to cause the NaI absorption line to appear at 5890Å.

3. Based upon the emission and absorption lines you identified and the information in the classification table, assign a spectral class to each star. For each star describe upon what evidence you have based your decision, and how confident you are in your classification (e.g., how certain are you a star is a *B* star and not an *A* star?)
4. Using your results from question #3 again list the stars from coolest to hottest. How well does this agree with the list you generated based upon the continuum and Wien's Law?
5. These are real stars and, like people, each star is special and unique in its own ways. Some of these stars have characteristics which make them deviate from the classifications given. For the stars which deviate describe how they do not match the description of their spectral class. Do any of the stars not match *any* of the spectral classes?
6. *Advanced:* We know that the absorption lines in a star's spectrum are caused by its cooler atmosphere, but some of these stars also have emission lines. Describe a physical scenario in which a star's spectrum will contain emission lines. Note that it doesn't have to be the right explanation for the stars in question here.
7. Why should astronomers have all the fun? Create your own mnemonic for the spectral classification sequence.

Common Spectral Lines (given in Å):

Hydrogen (the "Balmer Series"):

H α	6563
H β	4861
H γ	4340
H δ	4101
H ϵ	3970
H8	3889
H9	3835
H10	3798
H11	3771
H12	3750

Helium:

He I	4026, 4388, 4471, 4713, 5015, 5048, 5875, 6678
He II	4339, 4542, 4686, 5412

Metals:

C II	4267
C III	4649, 5696
C IV	4658, 5805
N III	4097, 4634
N IV	4058, 7100
N V	4605
O V	5592
Na I	5890, 5896
Mg I	5167, 5173, 5183
Mg II	4481
Si III	4552
Si IV	4089
Ca I	4226
Ca II	3933, 3968
Sc II	4246
Ti II	4300, 4444
Mn I	4032
Fe I	4045, 4325
Fe II	4175, 4233
Sr II	4077, 4215
Hg	4358, 5461, 5770, 5791

Molecular Bands:

CH "G band"	4300
CN	3880, 4217, 7699
C ₂ "Swan"	4380, 4738, 5165, 5635, 6122
C ₃	4065
MgH	4780
TiO	4584, 4625, 4670, 4760

Telluric absorption bands:

5860-5990
6270-6370
6850-7400
7570-7700