

Physics 344 Lab 7 Stellar Spectral Classification

Due: Thursday, December 14

Text Reference: Chapters 12 & 13

Purpose: Spectroscopy is the most powerful tool of modern astronomy. By breaking the light from celestial objects into its component colors and measuring the intensity of each color, we can determine many of the important physical characteristics of these objects. Classification is a fundamental technique used throughout science, and astronomers used it to organize and guide their studies of stars. Willamina Flemming, Annie Jump Cannon and Antonia Maury, working at the Harvard College Observatory at the turn of the 20th century, grouped stars into classes according to their spectral characteristics. The resulting classification was a key step in developing our physical understanding of stars.

The spectrum of a star is very similar to that of a blackbody: a continuous distribution of energy over the entire spectrum, with a characteristic shape. The wavelength of the peak of the continuous spectrum is determined by the star's surface temperature, as expressed in Wein's Law. The temperatures of most stars put their peak emission in or near the visible portion of the spectrum. Superimposed upon the continuous spectrum is a pattern of absorption features that arise from the atoms and ions in the star's atmosphere. These absorption features are the basis for the stellar classification sequence.

In this lab we will use a fiber-fed spectrograph to obtain spectra of a number of stars. We will calibrate the wavelength scale of the spectra and rectify the fluxes. We will estimate the star's temperature from the peak of its continuous spectrum. We will identify the stellar absorption features and correlate their strengths with the star's temperature, to explore the atomic processes that produce these features.

Observations:

Turn on the spectrograph CCD controller, located under the desk, and let the system reach equilibrium temperature (about 15 minutes). Start the Spectrograph CCD software (**NOT** the Direct CCD software) from the desktop icon on the telescope control computer. Select high gain for all the observations of this lab. The spectrograph is sensitive to light leaks, so take all exposures with all the dome lights off. There is a periscope to view the fibers in the telescope focal plane. To use it, move the beamsplitter knob to the "align" position, and unfold the periscope arm. The eyepiece of the periscope focuses by twisting. To observe, flip the beamsplitter back to the "observe" position and cap the periscope eyepiece. There is a blinking green LED (switch on the Spectrograph CCD controller) to aid in finding the fibers. (If you can see the fibers clearly enough, it is not necessary to use the blinking LED.) A knob located in the lower front of the spectrograph sets the grating tilt, which selects the wavelength region recorded. Set this knob to 520.0 nm for all observations.

1. Focus

- a. Point the telescope to Vega, and center it in the finder. Synch the telescope if necessary.
- b. Use the telescope motion controls (in The Sky/Telescope menu) to move the star onto the fiber. Jog the telescope 15 minutes East. If the telescope is pointing west of the meridian (as you will be for Vega), jog 15 minutes North also. If pointing east, jog 15 minutes South instead (because the telescope flips over the pole when moving to the other side of the sky). The star should be visible in the periscope now. Position it near the central 100-micron (larger) fiber, and synch the telescope again.
- c. Focus the telescope by eye, viewing Vega through the periscope.

2. Comparison Spectrum

- a. Set the spectrograph central wavelength to 520.0 nm, using the knob on the lower front of the spectrograph. Always remember to record this setting on the Spectrograph CCD GUI.
- b. Make sure that the beamsplitter is in the “align” position, and shine the neon calibration lamp into the periscope eyepiece. Hold the lamp about 6 inches below the eyepiece. Take a 15-second “object” exposure. Check it with the *ruatv* program to make sure that none of the bright lines are saturated – if so, hold the lamp further below the periscope eyepiece and repeat the exposure. If the exposure is too weak, try holding the lamp closer to the eyepiece.

3. Standard Star

- a. Keep the spectrograph central wavelength at 520.0 nm for all spectra in this lab. Make sure to record this setting on the Spectrograph CCD GUI.
- b. Turn on the blinking green LED (switch on the Spectrograph CCD controller) to aid in finding the fibers. (If you can see the fibers clearly enough, it is not necessary to use the blinking LED.)
- c. Position Vega on the central 100-micron fiber. Most of the starlight should disappear down the fiber when it is properly centered.
- d. Make sure the blinking LED is turned off.
- e. Flip the beamsplitter back to the “observe” position and immediately take a 30 second exposure.
- f. Use the *ruatv* program to inspect the spectrum – the “e” key will extract and plot the fiber nearest the cursor. There should be a well-exposed spectrum of the star. If not, you probably don’t have the star centered on the fiber – realign the star and try again. If the spectrum is saturated anywhere, reduce the exposure time and take another spectrum.

4. Stars

Slew the telescope to each of the stars in the following table. The “order” column is the suggested order in which to do the stars – those around Orion will not be available at the beginning of the night. Position the star on the central 100-micron fiber and take spectra centered at 520.0 nm. Adjust the exposure times so that no part of the spectrum is saturated (>4000 ADU). You will probably need to adjust the pointing before each exposure to keep the star on the fiber. Remember to rotate the beamsplitter back to the “observe” position

before each exposure. Approximate exposure times are 30 seconds for the magnitude 0 stars, and 100 seconds for the magnitude 1 stars. (The exposure is highly dependant on how well you center the star on the fiber.) Remember to offset the telescope 30 minutes South and re-synch when you reverse from west to east.

Order	Star	SAO	Type	Mag
7	Alnitak	132444	O9 I	1.74
6	Rigel	131907	B8 I	0.18
1	Altair	125122	A7 IV-V	0.76
2	Mirfak	38787	F5 I	1.79
4	Capella	40186	G8+G0 III	0.08
3	Aldebaran	94027	K5 III	0.87
5	Betelgeuse	113271	M2 I	0.45

5. Moon

If the moon is available, take a 20-second exposure spectrum (shorter around full moon). The moon reflects sunlight, and so its spectrum is that of a G0 V star.

Data Reduction:

- Copy your data to a working directory in your “My Documents” area, and only work on the copies, not the original images. **If you did not obtain spectra of all the program stars in the green (wavelength setting 520 nm), you can use the data from Nov 30 (files spec012 to spec048) to complete the lab. Please note that the header of the comparison spectra in files spec012 through spec014 is wrong – it lists the central wavelength as 440.0 nm, but the setting was actually 520.0 nm. This should not cause any problems with the data reductions. Since the Moon was not available for most of the observations, there is no need to analyze the lunar spectra (Capella will serve as our example of a G star).**
- In IDL, use the *cd* command to change to the directory where you have made copies of your images.
- Run the IDL routine *ruatv* and display your comparison spectrum. Locate the bright neon lines at wavelength 5400.562 Å (near x=392) and 5330.778 Å (near x=461, the right-most of the two lines in that region). Use the “f” key to fit each of these lines with a Gaussian function, and record the fitted center positions (x). Fit a linear function to these two spectral lines and record the coefficients (A and B) of the fit for use in the next step:

$$\lambda = A + B x$$

- The CCD system is very occasionally inserting some additional columns at the beginning of each row of the spectroscopic images. The reduction programs will ask you for the “offset” for each image that you process. Normally this will be 0. The table below lists the images for which the offset is non-zero, and the proper value to enter. The software will properly align the images for all the later steps of the analysis.

Directory	Filename	Offset
Nov29TW	spec001.fit	5
Nov29TW	spec002.fit	5
Nov29TW	spec003.fit	5
Nov30	spec034.fit	5
Nov30	spec035.fit	5
Nov30	spec036.fit	5
Dec4MC	calib003.fit	3
Dec4MC	vega009.fit	3
Dec6	vega003.fit	1
Dec6	vega004.fit	1
Dec6	vega005.fit	1
Dec6	vega006.fit	1
Dec6	vega007.fit	1
Dec6	vega008.fit	1
Dec6	vega009.fit	1
Dec6	aldebaran019.fit	2
Dec6	aldebaran020.fit	2

- Use the IDL program *neoncomp* to analyze your comparison spectrum. Run *neoncomp* (with no parameters). The program will ask you for the filename of the image that you want to analyze. Provide the offset (0 unless the file is in the table above). Then answer the next two questions with your approximate wavelength zeropoint and dispersion (A and B) from step 3 above. Answer the “Which fiber” question with the number 100 (if you are interested in the effect of fiber size on resolution, you could repeat this step, answering 50 to this question, but make sure that the last time you run *neoncomp* you analyze the 100 micron spectrum). The program first displays the extracted spectrum to make sure that there are no terrible mistakes – press the “enter” key to continue. The program then displays each of 16 neon spectral lines from your spectrum and a fitted Gaussian function – press “y” to accept the line or “n” to reject it (you may want to reject some of the weak lines if the spectrum is under-exposed). After you have examined each line, the program does a linear fit to wavelength as a function of position for the lines that you accepted, and displays the residuals about that fit. Information about the fit is displayed in the IDL message window. You can try other fit orders to see the effects: orders 2 (quadratic) and 3 (cubic) are interesting. When you are satisfied with the fit, enter a 0 to end the program. Record the fit order, the fit coefficients, the RMS fit error, and the line FWHM (in Å) for

your report. Discuss the effects of using the higher order terms in your report. The program records the fit coefficients of the last fit that you ran in the file *wavecal.dat* for later use.

6. Process your Vega spectra with the IDL program *vegaproc*. This program will expect to find the file *wavecal.dat* produced in step 4. The program uses the known fluxes of Vega to calculate the sensitivity of the system as a function of wavelength, and records the relative correction coefficients in a file named *fluxcal.dat*.
7. Now process your spectra using the program *sproc*. The program uses the calibration files *wavecal.dat* and *fluxcal.dat* produced in the previous steps. The program can combine multiple spectra of the same star taken at the same wavelength settings – it will ask how many spectra you want to combine, and then asks for the filename of each spectrum. You should combine spectra with reasonable signals on the star, but not ones that were hopelessly underexposed – these will just add noise to the combined spectrum. For the first spectrum, the correction for the Earth's motion about the Sun is calculated and output – record this number and include it in your report. The program then extracts the spectrum from the central 100-micron fiber position in each image, corrects for the bias and dark (using unexposed nearby portions of the image), calibrates it based on your comparison spectrum analysis and the Vega fluxes, and corrects the wavelengths to heliocentric wavelengths. All of the processed spectra are summed, and the resulting total spectrum is plotted. **You are asked for a filename in which to save the results; enter star's name (one of vega, altair, mirfak, capella, aldebaran, betelgeuse, rigel, or alnitak). You must use one of these names for the later programs to work properly.** The program creates a file *xxx.spec* (where *xxx* is the name you specify), containing the wavelength, flux, and flux uncertainty of each point in the spectrum. It also creates a postscript image of the plot in a file named *xxx.ps*. You can view this file with the *ghostview* program, and use this program to convert it to other formats (pdf, jpeg, etc.).

Data Analysis:

1. Use the routine *scomb* to combine your green spectrum with the red and blue spectra (which are in the //JodrellBank/Ph344/Lab 7 directory). The program will ask you for the star name (one of vega, altair, mirfak, capella, aldebaran, betelgeuse, rigel, or alnitak), and will then combine the three spectra, plot the total spectrum, and save the data in a file names *xxx_c.spec*, with the plot in *xxx_c.ps*. Process all 7 stars in this way (you can also do Vega).
2. Compare the combined spectra, and try to organize them in a temperature order, based on the shape of their continuum spectrum. It may be helpful to plot the spectra on individual sheets and compare them. Identify some of the strong spectral features in each spectrum. See any introductory astronomy text for a discussion of the absorption lines in various spectral type stars.
3. Use the program *linefit* to measure a few spectral lines in each spectrum. See the table below for some lines to consider measuring. (Note that as the spectral type changes, some of the lines will disappear.) Record the wavelength and equivalent width of each line fitted.

4. Use the fitted wavelengths of the lines to calculate the star's heliocentric radial velocity, using the Doppler formula:

$$\frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} = \frac{v}{c}$$

5. Plot the equivalent widths of a few representative lines as a function of spectral type (as a proxy for temperature).

Atom	Wavelength
H I	6562.80
H I	4861.36
H I	4340.46
H I	4101.74
H I	3970.07
Ca I	4226.73
Ca II	3968.47
Ca II	3933.66
Mg I	5167.32
Mg I	5172.68
Mg I	5183.60
Na I	5889.95
Na I	5895.92
He I	3888.65
He I	4471.48
He I	5015.68
He II	4685.70