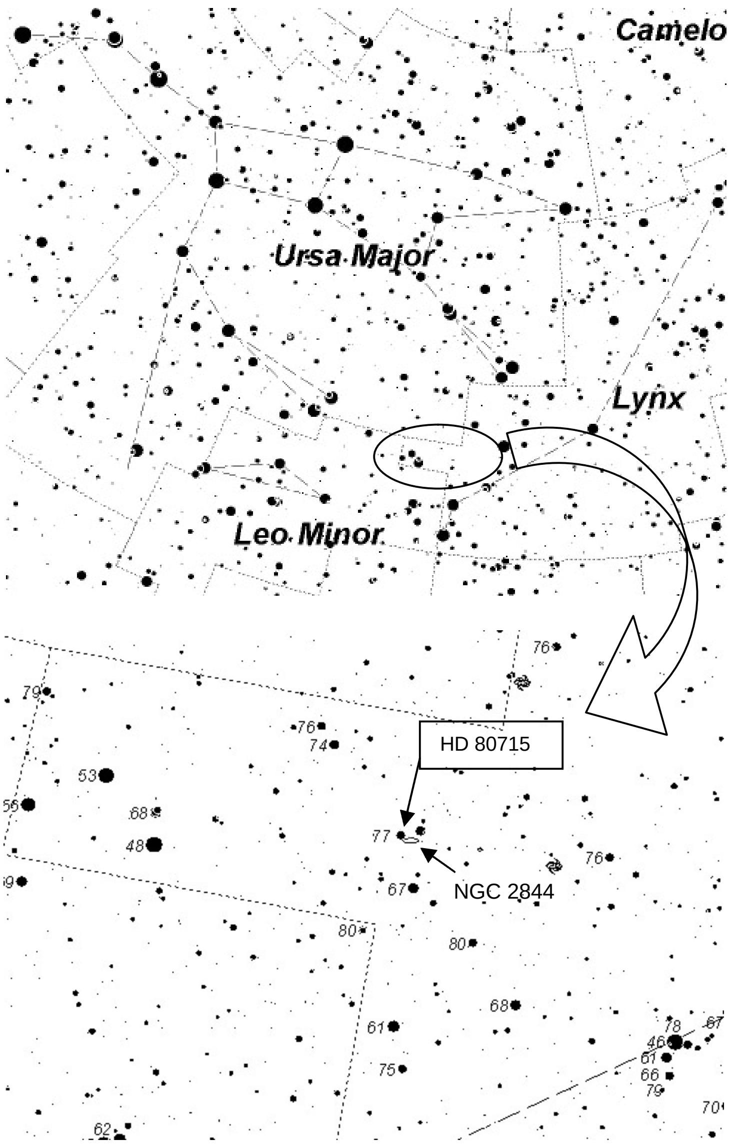
Astronomy I
Lab 6
Mr. James

A Detailed Study of a Spectroscopic Binary

In this Lab, we will use a series of spectra and other published data to derive the main physical properties of the spectroscopic binary star system HD 80715. Our sources of observational data are the set of spectra depicted on page 188 of our text (reproduced on the second page of this packet) and the properties cited in the introduction that follows.

Image of HD 80715 (NGC 2488 is to its right) obtained from the Digitized Sky Survey, Hubble Space Science Institute using digitized plates from the Palomar All Sky Survey originally commissioned by the National Geographic Society.



Charts produced using TheSky Astronomy Software, op. cit.

Introduction. HD 80715 is spectroscopic binary in the constellation Lynx. Published observed parameters set m_v = 7.63 (combined magnitude for both stars), spectral and luminosity classes at K2V for both stars (Nahide Craig, et al, Center for EUV Astrophysics, UC Berkeley, reported in *The Astrophysical Journal Supplement Series*, 113:131–193, November 1997). The Hipparcos Catalog gives the parallax as 0.04119 seconds of arc. The coordinates of the star are RA $09^h\ 22^m\ 55^s$, Decl. +40° 10’ 11” (Hipparcos Data recorded in *TheSky Astronomy Software*, Software Bisque, Inc. 2001). The star is in the same field of view as the 14^{th} magnitude galaxy NGC 2844.

Procedures.

1. We will be making measurements of each of the spectra shown on the next page. Before doing these measurements, set the scale of your measurements. That is, you will need to know how many nm of Doppler line shift corresponds to one millimeter of measurement. We will call this number, whose units are nm/mm, *k*.

2. Prepare a table for your measurements. The table will need to show the spectral shift for each star on each spectrum. You will also need room for the velocity calculation that results from each measurement. Including headings, we need to prepare a table having 5 columns and 15 rows. Your table will have the structure shown on the next page.

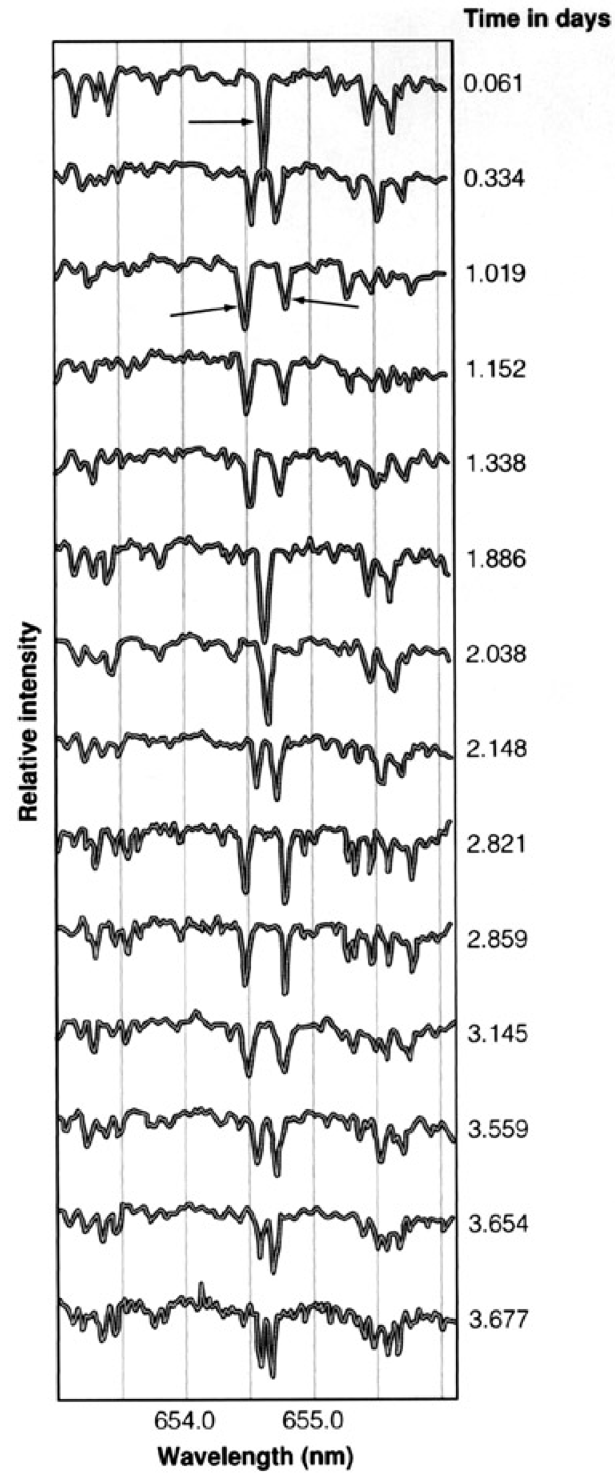
3. Carefully, using a sharp pencil, draw a vertical line the entire length of the graph at the wavelength where the spectral lines from both stars coincide (0.061, 1.886, and 2038 days). This line will be treated as the relative rest wavelength for the spectra. Shifts to the left (blue-ward) will indicate that a star is moving toward us and shifts to the right (red-ward) will indicate that a star is moving away from us.

4. Carefully measure the number of millimeters of shift for both stars on each spectrum. Record your measurements in the appropriate cells in your table in the appropriate column labeled x_A or x_B.

5. Each measurement corresponds to a Doppler shift which in turn corresponds to a radial velocity for the star whose light produced the shifted line. Rather than make a Doppler calculation for each measurement, make a custom formula for this experiment:

   a. The Doppler Formula is $\frac{v}{c} = \frac{\Delta\lambda}{\lambda}$. Solving for the velocity, we have $v = \frac{c\Delta\lambda}{\lambda}$. Since $\Delta\lambda = kx$, our customized velocity formula is $v = \frac{ckx}{\lambda}$.

   b. Carefully determine the value of λ from the line drawn in number 3 above. Since $c = 3 \times 10^5$ km/sec, we can combine our values of c, k,



Fourteen spectra of the star HD 80715 are shown here as graphs of intensity versus wavelength. A single spectral line (arrow in top spectrum) splits into a pair of spectral lines (arrows in third spectrum), which then merge and split again. These changing Doppler shifts reveal that HD 80715 is a spectroscopic binary. Diagram and text obtained from *Seeds, Michael,* Horizons, Exploring the Universe, 9th edition, 2006, Brooks/Cole Publishers.

and λ to give a single linear equation for calculating *v* for each spectral measurement. This formula is *customized* for this star system at this wavelength. If we were to study another star, we would derive a new formula just for that star.

c. Use your derived formula to calculate the velocity represented by each shift. Record your results in you table in the appropriate cells.

Time (days)	x_A(mm)	v_A(km/sec)	x_B(mm)	v_B(km/sec)

Sample Table

6. On a sheet of graph paper, plot the radial velocities of both stars. This is best done by orienting your paper sideways with the horizontal axis running through the *middle* of the graph. The vertical axis will be on the left side. Since the spectra cover a period of about 4 days, make 4 days the full scale of your graph. The maximum radial velocities occur when the spectral lines from each star have the widest separation. Use the values in your table to determine the best scales for both axes.

   Notes about the graph: Consider the first spectrum to be when the relative velocities are zero. The spectra are not uniformly spaced in time; therefore your data points should not be uniformly spaced in the horizontal direction. The sign of the velocity is important.

7. Draw <u>smooth</u> *sinusoidal* curves through your graphed data.

8. Find the period in days as closely as you can read. Convert your value for the period into both seconds and years. Record all three values.

9. Assume that the orbits of the two stars are circular and viewed edge on (this assumption is good with regard to circularity for close binaries; edge-on -- called orbital inclination -- requires additional data which we will assume exists for this star). Based on your maximum orbital velocities and your value of P, find r_A and r_B in km. Convert these to au. Then calculate *a* in au.

10. Find the total mass in solar units using the modified form of Kepler's Third Law.

11. Find the mass ratio for the stars.

12. Find the stars' individual masses in solar units and kg.

13. Use the Mass-Luminosity relation to estimate the luminosity of the two stars in solar units and in J/sec.

14. Spectra indicate that our stars are main sequence stars. Estimate their temperatures based on the information given in the introduction.

15. Find the radius of each star in solar units and km.

Evaluation and further investigation.

16. The system parallax is given in the introduction. How far away is the system?

17. If we could see the individual stars, what would be their absolute magnitudes? How can you determine, or estimate these values?

18. What would be their apparent magnitudes? Are your answers consistent with the apparent magnitude given in the introduction?

19. The spectral line used in this lab is the Hydrogen α line (656.3 nm). Use this to determine the system radial velocity and whether the system is approaching or receding from us.

20. Draw a diagram of the system. Is a scale diagram feasible?

A summary table to keep track of your results:

Star	Spect. type	Temp. (K)	Luminosity		Radius		Mass		M_v
			L_O	J/sec	R_O	km	M_O	kg	
HD 80715 A									
HD 80715 B									
System:	Distance:		Radial velocity:						
	Rest wavelength								
	Period:		sec			days			years

You will prepare a lab write up using the guidelines discussed in class. Make sure that you adequately discuss each item in this handout and the scoring rubric.

HD 80715 Lab Write Up Name ______________________

Item to be Assessed	**Score***
1. The problem to be solved/investigated: to derive the orbital and physical characteristics of both members of the HD 80715 system using observational data.	
2. Methods/procedures:	
a. Establish the scale of the spectra to be measured.	
b. Determine the rest wavelength for the observed spectral line.	
c. Measure the Doppler shifts in mm of each star for each of the fourteen spectra.	
d. Tabulate the results.	
3. Analysis:	
a. Design a custom Doppler formula for the HD 80715 system.	
b. Calculate the radial velocities corresponding to each Doppler shift measured.	
c. Plot a graph showing both stars' velocity curves.	
4. Discussion	
a. Determine the orbital period for the HD 80715 system in seconds, days, and years.	
b. Calculate the radius of each star's orbit in au.	
c. Calculate the average distance between the stars in au.	
d. Calculate the total mass of the system.	
e. Determine the mass ratio for the two stars.	
f. Determine the individual masses for the two stars.	
g. Determine the luminosity, temperature, and size of each star.	
5. Evaluation	
a. Calculate the distance to the system and the system radial velocity.	
b. Estimate the absolute magnitudes of the two stars.	
c. Determine the apparent magnitudes of the two stars and compare to the published *combined* apparent magnitude of HD 80715.	
d. Draw a diagram of the system.	
e. Sources of error are limited to the errors in measurement of the spectra.	
6. Presentation quality and aesthetics	
a. Word processed	
b. Neatness of plot and diagram	
c. Quality and competence of writing	
Total (out of 40)	

*Scoring is on a 5 point basis per item. For example, 5 indicates a complete and superior treatment of the item; 3 indicates a substantially complete and accurate treatment of the item; 1 indicates a partial or confused treatment of the item; and 0 indicates that the item was omitted.