Physics 344 Lab 6
Variable Stars

Due: Thursday, November 8
Text Reference: Chapters 5 & 10

Purpose: Certain types of stars are unstable to radial pulsations, and thus periodically change their size, temperature, and brightness. Some types of variable stars, called RR Lyrae and Cepheid variables, obey a period – luminosity relationship, and thus are very useful distance indicators for relatively nearby galaxies. In this lab we will measure the light curve of a Cepheid and an RR Lyrae variable star in our Galaxy. Some interesting URLs for variable stars are: http://www.aavso.org/vstar/vsots/0900.shtml and http://antwrp.gsfc.nasa.gov/apod/ap041012.html

We will take B and V images of a field that contains both the variable star that we are interested in, and also another non-variable star of comparable brightness. By determining the ratio of the brightness of the program star to the brightness of the other star, we can map the variation of the program star's brightness independent of complicating effects such as changing extinction due to airmass and transparency variations. This technique is called "differential photometry". Since data are required over an extended period to determine the light curves and periods, we will pool the observations and each student will analyze the full data set. It will be important to observe the stars on every available clear night. Students who do not sign up for and carry out their fair share of observations will receive lower grades on the lab, and will be brought to the attention of the Vogons.

Data Acquisition:

1. Just before sunset, turn on the CCD and its cooler, and allow at least 15 minutes for the CCD temperature to stabilize. Set the zoom to 210 and the focus to +8.000 (look for updated notes on the focus setting in the dome or on the class web page).
2. Create a folder in //JodrellBank/Ph344/Lab6. Name the folder with the date and your initials (e.g. Oct5TW).
3. Set the image root name to *flat* and the exposure type to *Flat*. Set the gain to *Low* and put in the B filter (position 1). After the Sun has set, take images (without saving them) of the eastern twilight sky until the CCD is not saturated in a ~1 second exposure. Then check the *Save Image* box and take five flats. Change to the V filter, verify that the CCD is not saturating, and take five V flats
4. Set the image root name to *zero* and the exposure type to *Zero*; keep the gain *Low;* the filter setting is irrelevant. Take 25 zero exposures (use the *Multiple Exposure* control).
5. Set the image root name to *dark* and the exposure type to *Dark*; keep the gain *Low;* the filter setting is irrelevant. Make sure that all lights are off. Take three dark images with exposure times 120 seconds each.

6. Point the telescope to Delta Cepheii (SAO34508). Determine the best focus for the telescope in each of the B and V filters by taking images at a series of focus settings and measuring the image FWHM using the *ruatv* tool *p* key routine. Record these settings for future use.
7. When the sky is fully dark, take B and V images of Delta Cepheii. Use exposures that produce a strong but not saturated signal (~1 second in V and 2-3 seconds in B). Remember to reset the focus (if necessary) when changing filter.
8. Point the telescope to GSC 3929:1811 and center the star in the CCD. Verify that XZ Cyg (SAO 31761) and GSC 3929:1703 are both in the field of view. Take a pair of B and V images, approximate exposure 30 seconds in V, 60 seconds in B.
9. Repeat step 8 every 15 minutes or so, until the end of your assigned time slot. Between observations, examine your images (with *ruatv*) and make sure that there were no problems with telescope pointing and tracking, exposure time, focus, etc.
10. Finish by repeating step 6 once.

Data Processing (in IDL):

1. **IMPORTANT!** Copy all your Lab 6 CCD images from the folder //JodrellBank/Ph344/Lab 6/… to a folder in your "My Documents" area. Make sure that you always work on these copies, not the original images! Copy the flats and zeros for your night also, even if you did not take these data yourself. Make sure that the zeros are all named "zeroxxx.fit" where xxx is a 3-digit sequence number, the darks are all named "darkxxx.fit", and the flats are all named "flatxxx.fit". NO OTHER FILE NAME SCHEME WILL WORK PROPERLY! Rename the images if necessary.

2. Start IDL running, and move to the folder where your stored your data copies with the *cd* command:

   cd, 'username/pathname'

   (here "username" is your login name and "pathname" is the path in "My Documents" to the folder where you have put the data).
3. Run the IDL command *mkdibias*. This will compute and subtract the overscan value from each zero image, and then combine all your zeros together using the biweight to reject any discrepant data points (cosmic rays, mostly). The resultant image is written in a new file named "Zero.fit" in the same directory. Examine this image (in *ruatv*) and compare it to one or more of the individual zero images. Comment on anything that seems significant to you.

4. Run the IDL command *mkdidark*. This will compute and subtract the overscan value from each dark image, subtract the combined zero image made in step 3 above, divide the image by its dark accumulation time, and then combine all the darks together using the biweight. The resultant combined image is written in a new file named "Dark.fit" in the same directory. Examine this image and compare it to one or more of the individual dark images. Comment on anything that seems significant to you.

5. Now use the IDL command *mkdiflat* to make the combined flat images. This command will compute and subtract the overscan value from each flat image, subtract the combined zero image made in step 3 above, subtract the combined dark image of step 4 above multiplied by the dark accumulation time of the flat image, scale the flat by the mean of a central region, and then biweight combine all the flats of the specified filter. The resultant image is divided by its mean value (so that later division by this scaled flat will not, on average, change the values of an image), and written in a new file named "FlatX.fit" where "X" is the filter name (B or V). Run this command twice times, once for each filter:

   mkdiflat, 'B'

   mkdiflat, 'V'

6. Now process your star images using the IDL command *diproc*. This command will compute and subtract the overscan value from the image, subtract the combined zero image made in step 3 above, subtract the combined dark image of step 4 above multiplied by the dark accumulation time of the current image, and divide by the appropriate flat field image. The resultant image is written to a new image named "Pxxx.fit" where "xxx.fit" was the original filename. Process each of your images, one at a time, using the command:

   diproc, 'xxx.fit'

   Use *ruatv* to compare a processed image to the original image, and comment on what effects the processing has on the image.

7. Examine your processed images using *ruatv*. Use the *p* command in *ruatv* and select the *show radial profile* option. Determine the FWHM of a few stars in each image – you should find values around 3 to 4 pixels. If so, set the aperture radius to 10 pixels, the inner sky radius to 15 pixels, and the outer sky radius to 20 pixels. Then measure both the program star and the reference star in each image. Record the x and y object centroid, the FWHM, the sky level, and the object counts. Record these results in the spreadsheets in the //JodrellBank/Ph344/Lab 6 folder. Please try to complete this stage of the processing of your data as soon as possible, since your classmates will need your results (and you theirs) to complete the rest of the lab.

8. Use the coordinates of the stars presented in *The Sky* to calculate the image scale for your observations. Express the image scale in arc seconds per pixel. (Remember that when converting right ascension in temporal units (hours, minutes, seconds) to angular units (degrees, arcminutes, arcseconds) there is a factor 15 cos(δ) where δ is the declination.) Measure the scale in both the B image and the V image.

Data Analysis:

1. When a sufficient number of images have been processed and saved in the spreadsheets on JodrellBank (about two weeks of observing), a notice will be posted on the class web site. Copy the spreadsheets to your "My Documents" folder. (It will probably be easiest to use Excel to carry out the data analysis and prepare the plots discussed below, but you can use any system you prefer.)

2. Calculate the instrumental magnitude for each measurement:

   $$m_{inst} = -2.5 \log_{10}(\text{counts})$$

   Then use the known magnitude of the reference star to calculate the magnitude of the program star:

   $$m_{prog} = m_{prog,inst} - m_{ref,inst} + m_{ref}$$

3. Plot a light curve for each of the two program stars: the V magnitude as a function of time. Also plot a color curve: the B – V color as a function of time. Estimate the period from these plots.

4. Prepare a "phase" column in the spreadsheets: put your period estimate in a cell, and then calculate:

   phase = MOD(time,period) / period

   (MOD is an Excel function to calculate the modulus function. An Excel hint: for the period cell reference in the above formula, use the absolute location notation colrow. Then you can easily copy the formula into a range of cells.) Plot the V magnitude as a function of this phase. Vary the period estimate until the plot is smooth – this is the best estimate of the period. Try to estimate the uncertainty of the period by changing the period estimate by small amounts until you feel the plot is unacceptable. Report the period and its uncertainty. How could you achieve a more accurate measure of the period?

5. The color of the star is proportional to its temperature, and the magnitude is related to its luminosity. Hence we can calculate (up to a scale factor) the radius of the star at each observation:

   $$B - V = (7000\text{ K} / T_{eff}) - 0.56$$
   $$L \propto 10^{-0.4\,V}$$
   $$L = 4\,\pi\,R^2\,\sigma\,T^4$$

   So:

   $$R \propto 10^{-0.2\,V}\,(B - V + 0.56)^2$$

   (To calculate the radius in physical units requires also knowing the distance to the star.) Calculate the radius of the star for each observation, scale them so that the maximum radius is 1.0, and plot the pulsation curve of the star (radius versus phase). By what fraction does the star's radius change over its period?

6. Compare the three plots (light curve, color curve, and pulsation curve) and discuss the phase relations of the variations. You may find it best to plot the three curves on the same graph, one above the other, all with the same X (phase) axis.)