FRI Astronomy Lab #3

Goal: You will analyze a sequence of images using aperture photometry to produce a light curve of a variable white dwarf star. To prepare these images, you will perform the necessary bias, dark, and flat field corrections in an effort to remove instrumental effects. You will then do relative photometry of the target and one or more comparison stars in an effort to remove observational effects such as transparency variations and/or clouds. You will also consider the optimal aperture size to use for the photometry. Your final result will be a plot of the properly extracted light curve of this star.

Instructions

1. There will be a few questions throughout this lab. Be sure to type up your answers and submit them on Canvas with your final plots.

2. You will begin by copying some IRAF files over from rocky. These are bundled together in a file called "hsp.tar.gz" and are located in the directory "/home/rocky/fri/FRI/lab3files/". Once you have that on your local machine, `gunzip` and un-`tar` the file (pro tip: these actions can be combined by typing `tar -xzvf`).

3. Next, scp over, gunzip and un-tar the data file "phot_lab.tar.gz" – from the same place – in your home directory. This contains the data that you will be working with in this lab.

4. You will use IRAF to properly reduce and analyze the provided data. You will use the login.cl file provided in the `hsp/ccd_hsp` directory for this lab that has been modified to let you access some custom data reduction tasks. `cd` into that directory and open login.cl with your favorite text editor to tell IRAF where and who you are. Aquamacs is a text editor that offers an intuitive graphical interface and may be called upon by typing `amacs login.cl &` in the `ccdhsp` directory, but any text editor will do. Set the `home` parameter to your **p**resent **w**orking **d**irectory, and the `userid` field to your username. **Important:** make sure that there is a trailing `/` in the `home` field.

5. Open `xgterm` and `ds9`, and start IRAF like you did in the last lab. Move to the data directory by typing `cd ../../phot_lab`

6. The goal of data reduction is to remove unwanted noise from the data, while retaining as much actual science signal as possible. This is done using three different types of calibration images that are taken every observing night. These bias, dark, and flat frames are distinguished from stellar images by filenames beginning with "b," "d," and "f," respectively. Type `ls` to identify them.

   Q: Why do you think it's useful for there to be 30 of each of these image types rather than just one?

7. First you will create a master bias image with the task "zerocombine". A bias image is taken as a zero-length exposure used to *subtract* readout noise and bias offset from our other images. Readout noise and bias offset are types of noise that are added onto every CCD image when the pixel values are being recorded at the end of an exposure. A *master* bias is created by averaging many individual bias frames. To do this, you must first create a list of all the individual bias images, one per line. The biases are named "b5*.fits", so type `ls -1 b5*.fits > blist` to store this list to a file "blist". Note: `-1` is "minus one" not "minus ell."

8. "zerocombine" can create a single master bias from the images in this list. Type `epar zerocombine` to set the parameters of this task to their appropriate values. Set input to `@blist` and the output to `Zero`. Notice that the combine method is set to "median." This causes the output file to consist of an image with pixel values equal to the median values of the corresponding pixels in the images that are being combined.

   Q: Why is a median combination more useful than a straight average (mean)?

   The other parameters will hopefully not need to be changed. Type `:go` to run the task, which will create the master bias image `Zero.fits`. View this file in the `DS9` window by typing `display Zero 1` and use your cursor to explore the pixel values.

9. Similarly, you will now need to create a master dark image with the task "darkcombine". Dark images are taken with the shutter closed for the same length of time as the science image exposures. These are used to subtract thermal noise from the science images caused by the warmth of the detector and electronics. Type
   `ls -1 d5*.fits > dlist` to save a list of dark images as the file "dlist"

   Q: Why is it important that dark images are made with the same exposure times as the science images?

10. Now type `epar darkcombine`. Set input to `@dlist` and the output to `Dark`. The other parameters will hopefully not need to be set. When this is done type `:go` to create the master dark file `Dark.fits`. Examine this calibration image by typing `display Dark 1`

    Q: Do dark frames also capture the type of noise that bias frames are used to calibrate or are their pixel values completely independent of this noise? Are there any distinct features in the master dark that weren't in the bias? Why might this be?

11. The final master calibration image you need to create is the master flatfield image, which you get from the individual flats with the task "flatcombine". Flats record the pixel-to-pixel variation in sensitivity across the CCD by measuring a uniformally-illuminated chip. This is a multiplicative type of noise, and will need to be divided out of the science images. The flats are named "f5*.fits". Save a list of these files (one per line) in a file "flist".

12. Now type `epar flatcombine`. Set input to `@flist` and the output to `Flat`. The other parameters will hopefully not need to be set. When this is done type `:go` which will create

the master flat file `Flat.fits`. View this image.

13. Now go to the non-IRAF window and `cd` into directory `phot_lab`. From this location type the command `./filelist.sh`
    This creates the master list of raw data images (`ilist`) and the list of filenames for the to-be-processed output images (`olist`).

14. Go back to the IRAF window and type `epar ccdproc` and set images to `@ilist` and output to `@olist`. Also, make sure that `zero`, `dark`, and `flat` are set to `Zero`, `Dark`, and `Flat`, respectively. The other parameters can be left untouched. Type `:go` to perform the calibrations of all the science frames using the master bias, dark, and flatfield images you created earlier. This may take a few minutes. The science images are having bias and dark noise subtracted from them, and their pixel values are being divided by the relative brightness variations of the master flat frame.

    Q: While bias frames are treated as containing "additive" noise, flat fields characterize "multiplicative" noise. What is the distinction?

15. Now that you have reduced the science images, it is time to measure the brightness of stars in these images by performing aperture photometry. First, you need to identify the target star and the comparison stars. The target you are monitoring is named `GD66`. Search the SIMBAD astronomical database at `http://simbad.u-strasbg.fr/simbad/` for this object to obtain a finder chart that will aid your identification.

    Type `epar mark` and set "fname" to be the name of the first calibrated image, `A1143c.0001`. Now type `:go` and *closely* follow the instructions in the terminal window to mark the stars of interest. Mark the target star first, and make sure that the `ds9` window stays highlighted after each invocation of the `r` command. After reviewing the list of the stars that you selected, type `:wq` to exit the list and type "yes" in response to the next prompt to indicate that you are happy with your selections (or "no" to try again!).

    Q: There are certain stars in these images that would make better comparison stars than others. Why might you want to avoid using particular stars in these observations?

16. Aperture photometry is performed by summing the values of a number of pixels surrounding a star's central position in the reduced images and subtracting a measured "sky brightness." The distance (in pixels) out from the star's center that you sum the light within is called the aperture size. It is important that you select an aperture size that captures the most stellar signal without introducting too much sky noise. This is best done by eye—performing the light curve extraction using many aperture sizes and comparing the quality of the results—and we will take this approach in the next lab. As a good rule of thumb, 4-5 times the full-width at half-maximum (FWHM; the distance from the center of the star image in pixels to where the light intensity decreases to half the peak value) of the radial profile of the stellar image will capture most of the star signal without an extreme amount of avoidable noise.

Run `imexamine` on a few of the reduced frames throughout the image set and use the "r" command to inspect the radial profiles of a few stars in the images. The last three numbers displayed along the top of the plot are measurements of the FWHM (using slightly different calculations).

Q: What is the typical FWHM value of a stellar profile in these images? Does this depend much on which star you are examining? Do the values vary much over the course of these observations? What size aperture would you recommend based on the rule of thumb given above?

17. The final step in this process is to actually run the aperture photometry package. We will explore the effect that changing your aperture size has on the signal strength in your light curve in the next lab; for today we will just uniformally adopt an aperture size of 16 pixels.

    Start by typing `epar hsp_nd`. Set `list_fil` to `olist` and `base_out` to `a1143pr`. For each light curve extraction, set `diaf_beg`, `diaf_end`, and `annulus` should already be set to the desired aperture size of `16`. Then type `:go`. This will measure the brightness of the stars you selected that falls within the defined aperture in all 139 science images. A new file called `a1143pr16.` will be created that contains the light curve corresponding to aperture size `16`.

18. To plot the resulting light curve, in the non-IRAF window type '`lcplot.py a1143pr16.`'. This will create a pdf of the plot in your current directory. Open this plot plot and make sure it looks ok. Then submit the plot along with the answers to the questions from the previous parts of this lab on Canvas.

19. Congratulations, you've just reduced data! Type `lo` into the `xgterm` to log out of IRAF and bask in the glory of a job well done...