Observational Astronomy
ASTR 310
Fall 2009

Lab 3

Open Cluster Photometry: Part II

1 Introduction

The objective of this project is to learn how to produce color-magnitude diagrams of star clusters using CCD images obtained with the CCD system at our observatory. The technique involves getting images of the cluster through two filters, V and R in our case, reducing the data and plotting V versus (V−R). The usual color-magnitude diagram is a plot of V versus (B−V) but since the CCD is relatively insensitive in the blue but is very sensitive in the near infrared R-band, we use V−R instead. Both B−V and V−R are good temperature indicators, and that is all that is needed.

- **Part I.** Reduce images of the galactic cluster M67 and produce a color-magnitude (C-M) diagram . These images were obtained a number of years ago with our 20-inch telescope and the Photometrics Series 200 CCD system. They are similar to the ones you will be taking yourselves, whenever weather permits.

- **Part II.** Obtain your own observations of a galactic (open) cluster, and, as far as possible, reduce them in the same way as the M67 data. Here you will hopefully use the 20-inch telescope with the Apogee CCD in the west bay. The 14" with the SBIG ST-8 CCD in the east bay is the back-up plan.

2 Observation of an Open Cluster

For this second part of the lab, you will need to select a galactic ("open") cluster that is observable at this time of year, obtain your observations through the V and R filters, and carry out the same sort of reduction as you did with M67. (A list of clusters is given in the appendix, but your TA will probably make you use NGC 7243.)

What you need in order to get a good result is:

1) Images of over 50 stars in the cluster through two filters. You may need to take overlapping images of the cluster to get enough stars, but only if the cluster is sparse (the Apogee CCD field of view is usually large enough). Crowding can be a problem, and you may have to take some short exposures to avoid saturating the brightest stars.

2) Good flat field frames for both filters.

2.1 Observations with the telescope

Due to equipment constraints, you may need to postpone the flat field until after you do the cluster. Be careful to prevent stray light from scattering into the camera. In particular keep the monitors pointing away from the telescope because we have found that they can put in considerable non-uniform background light.

1) Get the computer and connect it to the telescope. Activate the CCD software. (Likely, this will already be done for you by the TA.)

2) Take flat field frames (this can be done before or after you observe your clusters):
a) Place the standing lamps so that the target screen is illuminated uniformly. The idea is to get the lamp fairly close, so the target will be bright, without compromising the uniformity of the illumination.
b) Find the exposure time needed to give a maximum of 16,000 ADU's. Take several frames; you will later average them.
c) You need to do this for both filters. The filters are changed by hand in this setup, and so the TA will change them for you.

3) Open the roof, locate a known bright star, and re-calibrate the pointing. Find some stars which are bright enough to produce good images in a few seconds, without being so bright as to go over 16,000 ADU. Use these stars to set the focus. The stars should be in the same part of the sky as your cluster (maybe the cluster itself, if any of the stars are bright enough). Well focused images are of great importance for the success of this project. Focus the telescope very carefully, for each filter separately, recording the setting for best focus. On the 20", the focus is changed by the button on the telescope's hand-paddle.

4) Go to the cluster and plan out how many frames you will need to get over 50 stars. Be generous here because you are going to throw out up to half of the stars because of crowding in the field. Take each field through both filters before changing fields. Figure out a good nomenclature for the fields, e.g., NGC7243R1m for a 1 min exposure in the R-filter.

Long exposure times will probably overexpose the brightest stars, so you will have to take another pair of short exposures - perhaps 15 or 30 seconds - that does not overexpose them.

5) When you are done, copy your frames from the hard drive C to your USB disks to take back for analysis.

The tracking on the 20" tends to wander in Right Ascension (East-West) for exposures of over about a minute. The motion is not regular, so it has proven hard to remove. The telescope will lurch suddenly a few arcsec, which will produce elongated images. To deal with this, take a series of shorter exposures (say, 18 exposures of 60 seconds each, through each filter), and then examine them back in the computer lab, discarding any in which a rapid movement has elongated or doubled the images. Typically, you might throw away 3-5 images in each filter. Then you will stack the images as described later in the lab to build up the long exposure.

3 Data Reduction

There are several steps to the data reduction. The procedures are essentially the same as what you did with M67, except some differences with the calibration frames:

1) Start MATLAB and read in your .fts image files. Average each set of dark frames (i.e. average all of the 60 second darks into one averaged 60 second dark frame, and so on for any other exposure times you have). Subtract the appropriate averaged dark frames from all of your images, including the flat fields. Remember, writing a .m file to do this saves a lot of repetition later, especially if you have to stop for some reason and come back to working on the lab later.

2) Flat-fielding: Take all the dark-subtracted flat-field images taken with the same filter, add them together and divide the sum by the mean value of the sum. This will give an averaged flat-field whose mean is unity (i.e., it is normalized). Divide the dark-corrected science images by the normalized flat-field of the corresponding filter to correct them. After you have done this, save each corrected image into a matlab file. For example, if the array containing your corrected image is named "im1", to save it into a file use **save image1.mat im1**. That will create a MATLAB data file in disk named "image1.mat" that contains the data corresponding to the image. Make sure you use the **.mat** extension in the name

3) Pick one image (in each filter), and shift the others in the same filter to overlap it, using **imshift(im,ny,nx)** (just as you did in Lab 2), where **nx** is the number of rows to shift by and **ny** is the number of columns to shift by. Then you can add up all of the shifted images and get the final images you will analyze. Remember that the exposure time for this summed image is **not** 60 seconds, but rather $n * 60$ seconds, where n is the number of 60 second images you have summed together. If you include the short exposure in your sum, remember to account for the different exposure time for that one image. I have written the task **im=imaver('im.list')** to help you automate this process. This function takes as a parameter a file ("im.list" in the example, be sure there are no blank lines) containing a line for each image you want to average. Its format is

```
image1.mat   320.3   277.1   60.0
image2.mat   325.5   280.3   60.0
```

that is, the name of the image file, the X and Y coordinates measured for the *same* star in each image, and the integration time. IMAVER will run through each image and shift them accordingly to have them properly aligned, then average then weighted by the exposure time. You may want to use **findstars** in each image to get the precise coordinates for the location of the stars (the algorithm goes by brightness, so the brightest star will be first in all lists, unless there are two stars that are very similar in flux).

4) Rotate your images if necessary using the MATLAB function

im = imrotate(im,angle)

to bring them close to the standard orientation of north at the top, and east to the left (the way things look in the sky). See help imrotate for more information on the angle option. NOTE: The rotation is likely necessary for these images, as they're taken with a different CCD than the M67 images. To determine the proper rotation angle, look up the star cluster at SIMBAD

http://simbad.u-strasbg.fr/simbad/sim-fid

and from the cluster's page, scroll down to the "Plots and Images" section, where you will find a link to the "Aladin applet". Make sure you use the applet and not the previewer! Open the applet, and it will load an image of the cluster with the known objects in the SIMBAD database overplotted. These images are oriented properly (N up, E left), and so you can match the star patterns in your images to the patterns in these images to determine E and N in your data. You will be using this page in step 7, too.

5) Follow the procedures in Part I to measure the magnitudes of all the stars in all of the images. Run the **all_aper** routine to get the magnitudes of the stars (on both the summed images AND on a short exposure, so you get the brightest stars too). Be mindful that the value of "Kccd", electrons/ADU, which was 15-16 for the Photometrics CCD used in Part I, is not the same for these images (you will need to edit your copy of **all_aper** to change "Kccd"). Both the Apogee CCD on the 20" and the SBIG ST-8 CCD on the 14" have a gain value of 2.3 electrons per ADU.

6) Next, you need to run **pmerge** to combine the photometry of the different images. Also, if you took a short exposure to get the brightest stars without saturation, you will have to scale the stellar fluxes by the ratio of the exposure times. For example, if the long (i.e. summed) exposure was 200 sec and you also took a 15 sec exposure, the ratio of exposure times is (200/15) = 13.333. You would need to multiply the measurements made on the 15 sec images by this factor, to bring them onto the same scale as those on 200 sec images.

To simplify this process, **pmerge** takes a third number along with the coordinates of the same star in each frame (refer to the explanation for part 1 of this lab). Use the third place in the coordinate array to specify the exposure times of the two images; the fluxes of both images are then scaled to a common exposure time of 100 sec. You would run **pmerge** as follows:

pmerge('vmerge','vshort',[250,195,15.0],'vlong',[244,202,200.0])

In this example, the short exposure is 15s and the long exposure 200s. (Make sure the files you merge contain no blank lines.)

Finally, you will run the "color" routine to get the (V-R) color, and plot up the color-magnitude diagram, (V-R) vs. V.

7) Convert your V and (V-R) to the standard V and (B-V) system. This will involve finding published values of V and (B-V) for some of the stars in your cluster and also a finding chart so that the stars with published values can be identified on your images. Go back to the Aladin applet at SIMBAD. If you click on the stars that have red circles, some information for the star will appear in the box at the bottom of the screen. Click on the information to open the page for that star. You may have to authorize the program to pop up a window the first time. The page will open in a new tab, and will display the coordinates and other information of the star. Look to see if it has a B and V magnitude, and also look at the spectral type. You need to find two stars that have very different spectral types, so that the two stars have a significantly different value of B-V. Something in the O/B/A range and something in the F/G/K range would be good (but preferably not a combination of A and F). The luminosity class (the Roman numerals, indicating if the star is a supergiant, a giant, or a dwarf) does not matter, as we are only interested in temperature.

8) Plot up the H-R diagram using your data transformed to the standard (B-V) system. Compare your results to published H-R diagrams.

4 Report

You should submit the following items:

- Abstract - a few sentences summarizing what you did and what your results were.
- Observations - A text summarizing your experience collecting the data for the lab, any problems you encountered, and how you dealt with them. Mention are the reasons for the exposure times you chose.
- A table of your observations, giving the object observed, date and time of the observation, filter used, integration time, file-name and any comments that seem important.
- Analysis - a description of what process you followed to get from the raw data to the final results. At least mention the commands you used and what those commands did.
- Discussion - answer any questions asked in the lab. Comment on the C-M diagram, e.g., point out the red giants, if any, the blue giants, if any, the main sequence, etc. What stars, if any, probably do not belong to the cluster and why? Is the scatter in the main-sequence, say, due to inherent scatter or is it due to observational errors? Back up your opinion with a bit of error analysis.
- A tabulation of all numerical parameters used in your analysis. This should include things like:
  - the parameters you used in FINDSTARS to locate the stars,
  - the parameters you used in ALL_APER to measure the brightnesses of the stars,
  - the transformation coefficients to the standard B, V system,
  - and so on.
- A printout of the final, derived magnitudes and coordinates of all the stars.
- A color-magnitude diagram of the cluster, obtained by plotting from MATLAB).

Your write-up should be accompanied by the name of an ursa directory which has all of the original .fts files plus the other output files such as the .fap, etc files.

5 Appendix I

Cluster lists can be found in the **Astronomical Almanac** (pp H49-H55) and in the **Observers Handbook** (pp 206-219).

Here is a list of **cluster candidates**.

NGC 2099 (M37) good
NGC 1039 (M34) ok (sparse)
NGC 7039 ok (sparse)
NGC 7044 ok (sparse)
NGC 7062 ok
NGC 7063 ok
NGC 7067 good
NGC 7082 good
NGC 7092 (M39) OK, but sparse, without faint stars
NGC 7209 sparse, poor choice
NGC 7243 v. good
NGC 7686 ok
NGC 7654 (M52) good

The field of view of the Apogee CCD on the 20” is $11.1' \times 11.1'$, and the field of view of the SBIG ST-8 CCD on the Celestron 14-inch is $12.1' \times 8.1'$.

Due: 10 December 2009