CCD Image Processing of M15 Images – Estimated time: 4 hours

For this part of the astronomy lab, you will use the astronomy software package IRAF (Image Reduction and Analysis Facility) to perform the basic image processing on the CCD images from the telescope that you learned about in the pre-lab assignment. Then you will produce final images in two wavebands – V and R – for the globular cluster M15. For the lab report, you will need to describe the procedure you followed, so take notes as you work. Blank tables and space are provided as a guide for some of the measurements you will make throughout the lab. Include any notes in your lab notebook.

The basic steps for image processing were described in the lab. manuscript, and good descriptions are given in the reference *Handbook of CCD Astronomy* (Howell). For the lab report, you will need to explain the data reduction steps in analyzing the CCD images, so take notes while you work. The main steps you will follow are:

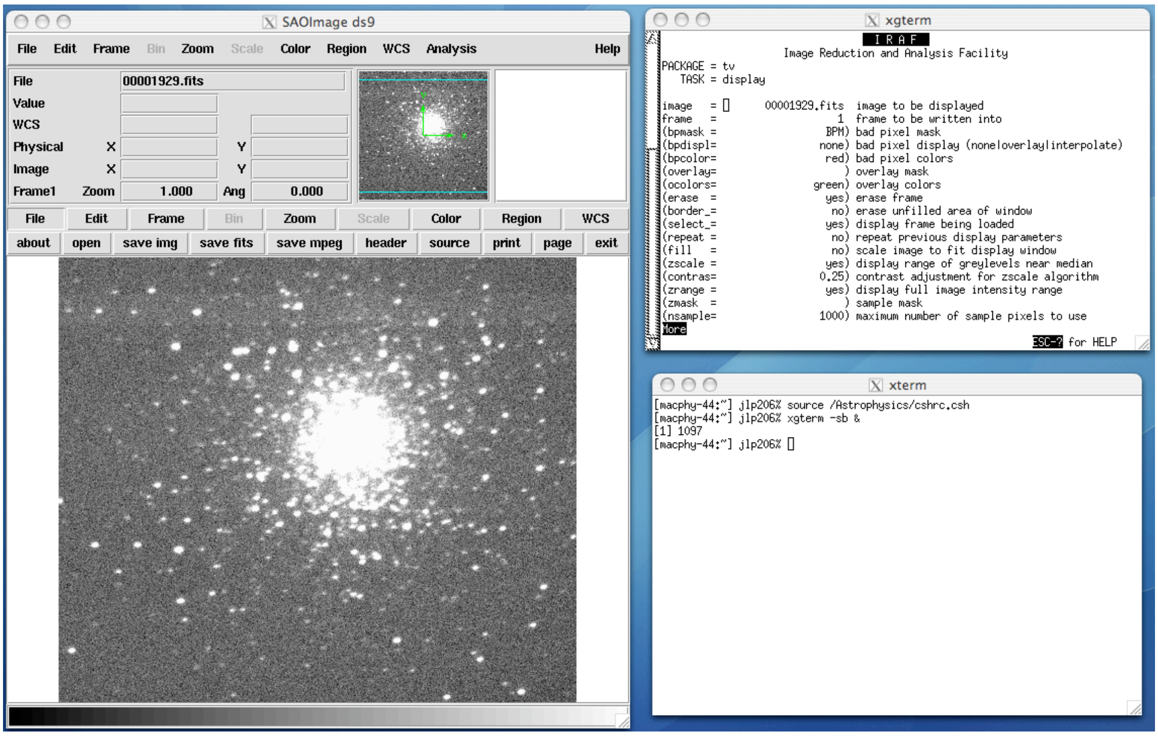
(0) Copy the image files and set up the software IRAF and DS9
(1) Learn how to display images
(2) Construct a flat field calibration image and understand its purpose
(3) Understand the purpose of the sky background image for each target and wavelength
(4) Use the sky and flat field images to perform image reduction
(5) Align and combine individual images to produce a final V and R image
(6) Align the final V and R images.

(0) Copy the image files and set up the software IRAF and DS9

See separate handout, "Astro lab software setup on the PHY/309 Macs".

(1) Display Images in IRAF / DS9

To display one of the files in DS9, click **file** and **open** to bring up a file browser. Select one of the '.fits' files, such as the M15 image **`00001929.fits`**.



To adjust the scaling of the image to see brighter or fainter features, in DS9 select the scale button and then try out the choices on the bottom row - **min max**, **zscale, linear** and **log** - to see the effects on the number of stars visible.

Selecting the **color** button and then one of the choices on the bar below will give a false color image and selecting the **zoom** button and then one of the choices in the bar below will change the part of the image displayed.

Images can also be sent to the DS9 display from within IRAF. We will use this capability later when we are measuring stellar positions and magnitudes. Use the Unix list command **ls** at the IRAF prompt to see the data files that are available. To display a different M15 file, type

ecl> display 00001930.fits 1

where **00001930.fits** is the CCD image file. The image should appear in the large ds9 window.
It is possible to display several images at one time; to do so, additional **display** commands would be entered and the last number increased to **2, 3, 4, etc**.

IRAF is an astronomy data reduction package that consists of a series of routines called tasks. The tasks you will use for this part of the lab are: **display, imstat, imcombine, imarith, imshift, and imexam**. To obtain information on any task, type '**help taskname**' at the IRAF prompt; it is a good idea to read the documentation on these tasks. Each task has an associated list of parameters. To change the values of the parameters, type '**epar taskname**' from within IRAF. Editing parameters does not execute the task; to run the task, type '**taskname**' from within IRAF including any filenames needed. IRAF can accept lists of files, but does not create file lists – you need to make lists of filenames for IRAF to use.

To adjust the parameters for display directly from IRAF, type

ecl> epar display

and investigate the effects of **zscale=no, zrange=yes** and **zscale=yes, zrange=no** on the display. You can also compare **ztrans=log** and **ztrans=linear** to see the impact on the number of stars visible. To save your change, type **:wq** which will write and then quit the task editor. If you make a mistake and need to quit without saving, type **:q!**.

(2) Generate V and R Flat Fields

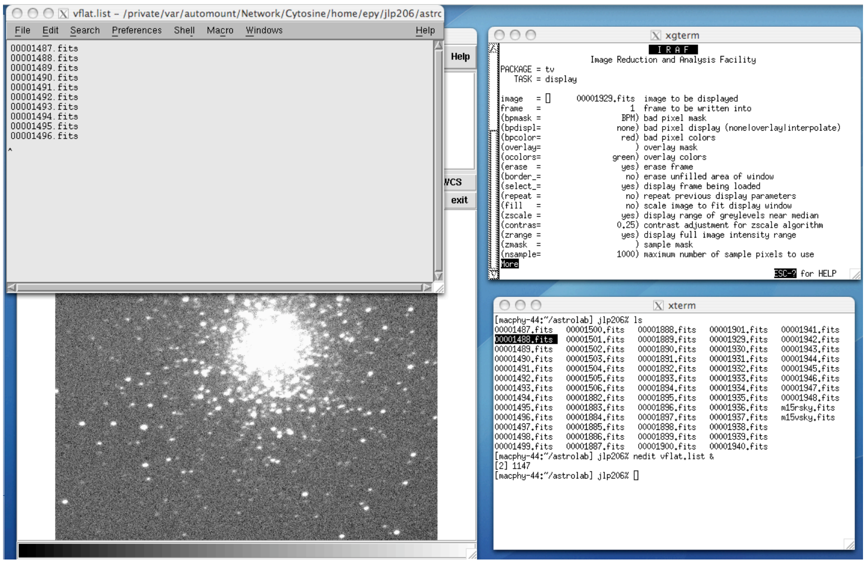
The first task is to create a flatfield to correct for varying pixel sensitivity across the array. This is needed later for the cluster data reduction (section 4).

Check the log sheet for the after-sunset blank sky images and find the set of images for V and for R that are not saturated, but have high signal. In IRAF, display an image from the beginning and end of the set for each filter.

• Note what features are present in the blank sky images and give an explanation (it is possible to print the images from ds9). Note the difference between the image at the start and the end of the stack and give an explanation. Record observations in your notebook.

Next you will need to combine the stack of images into a final image with the IRAF task **imcombine**. You will also need to use the **imstat** task to find the statistics of the image pixel values. First, make a list of all the V images that you will use – **vflat.list** – and a separate list of all the R images – **rflat.list**. The list needs to be a **plain text list, not a Word or RTF file**. Use a plain text editor such as TextEdit with Format-> Make Plain Text**.** To select the files you need, type:

% cd astrolab (or the name of your directory)
% ls



The sample note sheets given in the instructions have a space for you to keep track of the names of the lists you create.

Use **imstat** to find the statistics of the images using your list. For the V images, run:

ecl> imstat @vflat.list

and you should see a list with columns IMAGE, NPIX, MEAN, MIDPT, STDEV, MIN, MAX. Make sure you understand the general trend. If any of these columns are missing, type

ecl> epar imstat

to enter the editor of **imstat** and then type return until you get to the fields option and type all the above entries, separated by a comma, but no space. To save your change, type **:wq** which will write and then quit the task editor. If you make a mistake and need to quit without saving, type **:q!**.

To combine the list of sky flats for a given filter, use the **imcombine** task. Use the IRAF command

ecl> help imcombine

to get information about the options of **imcombine**.

• Select the most appropriate options for the parameters combine and scale to make a combined flat for each of V and R. Explain your choices and explain the difference between an average (mean) and a median. Record your choices/notes in your notebook.

The combined image now needs to be normalized by the median value of the image. This is to ensure that pixels with the median sensitivity level retain their values and pixels with lower quantum efficiency have their counts increased. The **imarith** task is used to perform addition, subtraction, multiplication and division with images. Two images or an image and a constant are given as input to imarith and an output image name needs to be given. The general format is

ecl> imarith *image1.fits* [+,-,/,*] *image2.fits outputimage.fits*

or, for arithmetic with one image and a constant value *x*

ecl> imarith *image1.fits* [+,-,/,*] *x outputimage.fits*

where only one operator **+,-,/,** or ***** is selected. If lists of images are used rather than individual images, then the format is

ecl> imarith @*input.list* [+,-,/,*] *image2.fits* @*output.list*

where **input.list** and **output.list** are lists of fits files; the two lists must be equal in the number of file names. You will need to use lists with **imarith** later in the lab. DO NOT TYPE THIS COMMAND AS WRITTEN – ***image1.fits***, etc ARE VARIABLES AND YOU NEED TO USE THE APPROPRIATE FILE NAMES IN THE LOG OR NAMES YOU DECIDE.

• Produce a final, normalized flat for the V and R filter data and note the name of your file in your notebook. Understand why the flats are normalized and how they are used. What is the median value of the final flat?

(3) Understand the V and R Sky Images

You have been provided with the sky files

m15vsky.fits
m15rsky.fits

These are produced in a similar way to the flatfields, by coadding the sky observations.

• Display the sky files and use IRAF to measure the medians. Record the median values in your notebook.

(4) Perform Image Reduction

From the log sheet, identify the M15 images. There should be two exposure times for each filter; use the 30s exposure time files.

• Make lists of each type of M15 image (V and R) and use imstat to check the background level and compare the background with the sky value taken through the same filter.

You will need to use **imarith** to perform the sky correction on each raw image, so you will create an output list of image names. Choose a simple naming scheme like 00001000.sky.fits or 00001000.ss.fits to correspond to the sky-subtracted file of raw image 00001000.fits. The output list from the sky processing will be the input list for the flat fielding step. A third list will contain the names of the output of the flat fielding.

• Use imarith to perform the calibrations on the raw images to account for the sky background and non-uniform response of the pixels in the array (flat-field correction). If you are unsure how to do this, first re-read the lab manuscript. Record the steps you followed in your notebook.

The sky and flat field corrections need to be done in two separate steps

(5) Align and Combine V and R Image Sets

Because the telescope tracking is not perfect, the positions of the stars drift from image to image. You will need to measure the x,y pixel position of a star in each image and shift all the images so that they are aligned and then combine the aligned images. Choose a bright star in a less crowded area, but not at the edge of the field. To measure the x,y positions, you will use the task **imexam** and then **imshift**. First, display the image, and then start **imexam** with

```
ecl> imexam
```

You may need to click on the ds9 display window and then you should be able to move the cursor to the star to be measured and type '**a**' and then '**q**' to quit. In the terminal window you should see the pixel locations of the center of the star calculated from a centroid routine in IRAF. Repeat this process for all the good quality images. Make sure that you understand what the plot displays.

• Record the x,y positions of the same star in all the images rated 'good' on your data reduction summary sheet. Choose a star in the middle of the list as the reference image and calculate the Xshift and Yshift value from the reference image. <u>Read the documentation of imshift to understand the sign convention.</u>

With the shift known for each image, make a text file containing the shifts, with one pair of shifts per line. This shifts file is an input parameter for the task **imshift**. Read the information about the **imshift** task and use it to align all the images. Use

```
ecl> epar imshift
```

to set the **input**, **output**, and **shifts_file** parameters for **imshift** and then run the routine on the list of images.

• Combine the shifted images with imcombine to make a V and R image. You should notice more stars in this image since the total integration time is much larger. Display a single image next to the combined image for comparison.

<u>(6) Align Final V and R Images</u>

Because you need to calculate the magnitude of each star for both V and R, it is important to be able to identify each star from the position in the image, therefore, the last data reduction step is aligning the V and R images you just made. As was the case previously, you will need to choose a reference image, measure the shifts of the second image, and make a shifts file (two lines in this case). Since there are only two images, it is not necessary to make an input and output list, the files names can be separated by a comma in the parameters for **imshift**.

• Use imshift to create the final, combined and aligned images for the V and R filters. Congratulations – you are now ready to measure the magnitudes of the targets.

Target: M15
Filter: V
Exposure: 30s

File Number	Quality (Good/Bad)	Median	x (pixel)	y (pixels)	Xshift	Yshift

Target: M15
Filter: R
Exposure: 30s

File Number	Quality (Good/Bad)	Median	x (pixel)	y (pixels)	Xshift	Yshift

Names of lists and images for V band data

List of images used to make V flat: __**`vflat.list`**____(suggested name)_______
Combined V flat image: ___**`vflat_combo.fits`**_____(suggested name)________
Normalized V flat image: __**`vflat_norm.fits`** ______(suggested name)________

V sky image: ___**`m15vsky.fits`**_____(given this file)__ __

List of raw M15 V images: ______________________
List of sky calibrated images: ______________________
List of flat-fielded images: ______________________

Reference image: ______________________
List of shifts from reference image: ______________________
List of shifted images: ______________________
Combined image: ______________________

Final image aligned with R band image: ______________________

Names of lists and images for R band data

List of images used to make R flat: __**`rflat.list`**____(suggested name)_______
Combined R flat image: ___**`rflat_combo.fits`**_____(suggested name)________
Normalized R flat image: __**`rflat_norm.fits`** ______(suggested name)________

R sky image: ___**`m15rsky.fits`**_____(given this file)__ __

List of raw M15 R images: ______________________
List of sky calibrated images: ______________________
List of flat-fielded images: ______________________

Reference image: ______________________
List of shifts from reference image: ______________________
List of shifted images: ______________________
Combined image: ______________________

Final image aligned with V band image: ______________________