Department of Physics and Astronomy
University of Iowa
29:137 Astronomical Laboratory
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Lab 5: Advanced CCD Photometry and Imagery

1 Introduction

In previous projects, we have gotten the idea of taking data with the CCD camera. We have acquired both imagery and photometry data (measuring stellar magnitudes). In doing this, however, we have not full explored the capability of the ST-402XME camera, and not fully taken account of some of the limitations of the instrument corrected for systematic errors. Now's the time to set things straight.

We will also take advantage of the experience we have gained in the first set of observations in Lab 2. Now we know what can be done and what some of the pitfalls are.

This lab will concentrate on the following CCD properties.

1. Operating the Peltier coolers, and reducing the thermal noise.
2. Examining the dark frame correction
3. Making color measurements through use of color filters to make measurements like the U, B, V magnitudes
4. Making "flat field" corrections, which account for the change in sensitivity over the front of the CCD chip

A description of these corrections/instrument operation modes is given in the ST-402XME manual.

This lab activity has two portions. The first is in the lab, and will involve simply operating the camera in the various modes and seeing the resultant test data on the bench. The basic philosophy here is that it easier to operate an instrument on a bench in a well-lighted room than it is on a cold, windy night on a roof top. However, this is an astronomy class, and we have to use these instrument capabilities on stars and other astronomical objects. The astronomical observations will subsequently be done with our Celestron 8 telescopes in a clear night session.

The equipment is the same we have used in the previous labs, and you-all are familiar with them. Many of the operational modes are also those with which we are familiar. For completeness, these are repeated below.

2 Equipment to be used

The following are the pieces of equipment that you will use in this project. We have equipment for two setups.

- An SBIG ST-402XME camera, with power adaptor and USB cable.
- A computer running the CCDOPS software package and Maxim DL for image analysis
- 3 neutral density filters to cut down the brightness of the light levels for the laboratory measurements. Astronomical CCD cameras are sensitive
- Pieces of opaque cloth to block light to the camera, or alternatively, the SCFG light screen[1]
- Celestron 8 telescope (or similar telescope) with finder telescope.
- Adapter, C8 → ST-402XME camera

3 Powering up the Camera and Establishing a Link with the Computer

You have done this before; here it is again for completeness.

1. Connect the camera to the computer, and establish communication between them. Connect power to the camera, and run the USB cable from the camera to one of the *back USB ports* of the computer. Bring up CCDOPS on the computer.

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[1] An acronym for "Shower Cap For Gorillas"

2. You now need to have the computer and the camera talk to each other. You do this by clicking on the “camera” button in the menu bar of CCDOPS, then click on “Establish COM link”. The camera should make a number of clicking sounds and flash a red pilot light to show its contentment if the link is successful.

4 Part 1: “Finger Exercises” on the Bench

All of the operations and camera operation modes that will be used in the astronomical observations will be gone through in the lab. Be sure and have the SBIG manual ready at hand during these measurements.

4.1 Activating the coolers

The noise level in the CCD can decrease significantly if the chip and readout electronics are cooled. The ST-402XME has thermoelectric coolers that can be turned on and operated. First, check out the operation of these coolers.

Look in the lower right corner of the CCDOPS screen. You will see the camera temperature indicated. To check on the status of the coolers, pick CAMERA in the option menu, and choose SETUP,
CAMERA → SETUP
Pick a Set Temperature is between 25 to 50 degrees Centigrade below ambient. It would be good to start perhaps 10 degrees below ambient, see how the camera responds, then lower it further. Then activate the coolers.

You can check on the operation of the coolers in the CCDOPS screen. It will display the device temperature and the percentage of cooler capacity being utilized. In the initial cooling phase, it will read 100 % as the coolers go all out. When it has reached the set temperature, the percent of capacity should settle down to a maximum of 75 - 85 % of capacity. If the value persistently exceeds this, you are working them too hard, and it is necessary to raise the set temperature.

4.2 Observing with Filters

The rest of the experiment will involve grabbing frames with the camera. Start out by turning out the room lights and shutting the blinds. See if that gets the room dark enough so that the CCD is not saturated with an exposure of the shortest time (0.04 sec).

4.2.1 Operations with the Filter Wheel

It is not necessary to make measurements or take images with the full visual spectral range. The camera can operate with filters inserted in the light path. This also allows measurements of the color and thus temperature of stars.

First of all, note that the filter status is also displayed in a data box in the lower right corner of the CCDOPS control screen. It probably lists a "-" meaning no filter in the optical path.

To examine the status of the filter wheel (a device which rotates different filters into the optical path) and to select a filter, click on FILTER in the menu bar. It will show that Red, Green, Blue, and Clear filters are available.

Take short exposures with each of the filters. Look at the images, and measure the highest pixel count in the brightest part of the image. Write down these numbers and report them in your lab report. You will notice that the raw reading is substantially lower when one of the colored filters is included.

4.2.2 Checking the Filter Wheel

Check out that the filter wheel is operating as advertised. Cover the camera with the opaque cloth or the SCFG to cut down the background light. Hold one of the tunable light boxes under the SCFG and turn it on. Shine a light which is R,G, or B on the camera and cycle the filter wheel through R, G, and B. Make sure you see a bright image when the right color light is turned on.

4.3 Checking out the Dark Frame Operation

When an exposure is made, some of the raw pixel count is due to light coming in the camera (say from stars), and some is thermal noise generated in the camera. This latter, unwanted signal is called the dark count or dark current, and is corrected by taking dark frames.

This should be taken care of in the GRAB button. It produces a dialog box, with one of the choices being "Dark Frame". In previous astronomical observations, we have made the choice “Also”, meaning a dark frame is taken and subtracted from the “sky frame” before display. Let’s check and make sure it works.

1. Use one of the filters and take an image of the darkened room. The image should be of a blurry glow. That’s OK for our purposes. First of all, take it in the standard way, with Dark Frame=Also chosen. Save the image to your Working Team folder for analysis in Maxim DL.

2. Now let’s verify that the preceding procedure really worked. GRAB an image with the same exposure time, but with Dark Frame=none. This will only take the “sky frame”.

3. Take a third exposure which is only the dark frame, by choosing Dark frame=Only.

At the end of the data-taking portion of this exercise, take all three images to Maxim DL. Measure the image intensity at several positions in the image, and make sure that method #1 gives the same answer as an analysis in which you manually subtract the dark frame from the sky-only frame. Report your measurements and results in your lab report.

This exercise is important for the following reason. In our astronomical observations in Lab 2, we found that the astronomical images had a finite background which had to be subtracted from any stellar brightness measurements. If the dark frame subtraction is working properly (through the Dark frame=Also option), this indicates that the background is due to sky background light, probably arising from light pollution.

4.4 Flat Field Measurement

Measurements of “flat fields” means taking images of uniformly illuminated fields, and then measuring the variation in the raw pixel value over the chip. Read the description of this process in the document “CCD Calibration I: System Corrections”, by Professor Robert Mutel in the “Textbooks” section of the course web page.

In our lab, we will use a uniform, white piece of cardboard held in front of the camera. Orient the whole system so that the light from the shuttered windows uniformly illuminates the white cardboard. GRAB an image. It should appear uniform and unsaturated. Save the file for future analysis in Maxim DL. Change the orientation of the cardboard screen (to compensate for nonuniformities in the cardboard) and take another image.

After the data-taking phase, analyse these flat fields in Maxim DL. Determine the variation in the raw pixel value, both on the large scale from one side of the chip to the other, and also on smaller scales of 5-50 pixels. Report your measurements and results.

5 Part 2: Astronomical Observations

In this part of the project, we will set up the equipment on our Celestron 8 telescopes and make astronomical observations. The setup will be identical to that of Lab 2. One modification to the procedure is to set up the equipment while there is still daylight. This makes everything easier, *but it also permits the crucial step of checking the alignment of the finder scope before trying to find the stars.*. In addition, one of the telescopes should be mounted on the permanent pier at the east end of Van Allen Hall.

The objects which we will observe are Vega (obvious), γ Lyrae, β Lyrae, ϵ_1 and ϵ_2 Lyrae, β Cygni (Albireo) and M57, the Ring Nebula in Lyra. Be sure you know how to find these objects in the night sky. Consult published star charts or use Starry Night Pro.

- Be sure the Peltier coolers are turned on and the camera has cooled down and stabilized before astronomical observations are made.
- Be sure that all frames are taken with Dark frame=also.

We will take images in R-G-B filters for all observations. When you save the files, give them names that reflect this. It would also be good to have one of the working team members act as scribe and write all of this down.

Here is the sequence of observations to be undertaken.

1. Let's begin with Vega. You will recall that it was saturated in the images in Lab2, but the filters act like "attenuators" to but down the brightness of the light. If we can use Vega, it will be a real bonus, since it is a major photometric calibrator. Take 0.04 second exposures in R, G, and B. Immediately check them. If the peak brightness is less than

the saturation value of 65,000, we can use Vega as our calibrator. If Vega saturates, then we cannot use it, and need to go to γ Lyrae as our calibrator. The U, B, and V magnitudes of Vega are 0.02, 0.03, and 0.03, respectively.

2. Take images of γ Lyrae, β Lyrae, and ϵ_1 and ϵ_2 Lyrae in R, G, and B. Save them in your Working Group folder.

3. Take R, G, and B images of the famous double star β Cygni.

4. Take R, G, and B images of the Ring Nebula, M57. Take a long enough exposure so that you can see detail in your image. A hint is to use the clear filter when trying to find this nebula.

6 Data Analysis with Maxim DL

Import your images to Maxim DL. Make and report the following measurements.

1. Assume that the R filter corresponds to V, and B filter corresponds to B in the U,B, V system (so-called Johnson magnitude system). Measure the B and V magnitudes of all stars observed. Compare your results with the accepted magnitudes. Present your results in the form of a table and a graph.

2. Comment on any particularly blue or red stars.

3. Measure the project separation (in astronomical units) of the two components of Albireo. You will have to do some extra work in researching properties of this star, as well as determining some features of our equipment.

4. Study and present your images of M57. Is it particularly bright in one or the other color? Can you think of why this might be the case?

7 Appendix: Measuring Stellar Magnitudes

The model we use for the response of the camera to a star is as follows. Let Q be the raw count on a pixel of the CCD. Then

$$Q = AFt \tag{1}$$

where F is the flux of radiation from the star (Watts/m^2), t is the time of integration or exposure, and A is the coefficient describing the instrumental response. Given fluxes F_1 and F_2 from two stars, the difference in their magnitudes is then

$$m_1 - m_2 = 2.50 \log \left(\frac{F_2}{F_1} \right) \tag{2}$$

So if we have observations of two stars, characterized by measureables Q_1 and t_1 and Q_2 and t_2, respectively, the difference in magnitudes is

$$m_1 - m_2 = 2.50 \log \left(\frac{Q_2 t_1}{Q_1 t_2} \right) \tag{3}$$

Obviously, the camera must be unsaturated for these equations to be valid. In addition, there is a noise floor that must be corrected for. Even in the total absence of light, the pixels will develop a charge. This must be corrected for. In standard operation, the camera takes a dark frame and subtracts it. However, at least as a check that this has been done properly, you need to measure the background far from any star and determine the background that needs to be subtracted from the raw measurement to yield a value of Q that is used in the above formula.