Department of Physics and Astronomy
University of Iowa
29:137 Astronomical Laboratory
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Lab 2: Imagery and Photometry with a CCD Camera

1 Introduction

In this lab, we will use the ST-402XME CCD camera to make astronomical observations and measurements. The camera will be attached to a Celestron 8 telescope and used to make images, and measure magnitudes. The Celestron C8 is inferior to the Rigel telescope, which will be used later in the semester, but this setup will allow us to see all components of a telescope and CCD camera in operation. This project will also illuminate some of the potential problems which can arise in astronomical observations. The exercise will consist of three parts. First, the system will be set up on the roof during daylight. It is a lot easier getting things working while there is light to work by. We will then take a "flat field" image of the uniformly-illuminated twilight sky. The flat field will show defects such as diffraction patterns due to dust in the optics, as well as variation in the CCD sensitivity near the edges of the chip. Astronomical images will be corrected with this flat field observation. The main activity of the lab will be to measure magnitudes of stars in the constellation Corona Borealis, and also take an image of the globular cluster M13. The third part of the project will consist of data analysis in the lab with the program Maxim DL. The goal will be to obtain measurements of stellar magnitudes for the stars in Corona Borealis, and try image processing operations on M13.

We should review what we learned about stellar magnitudes in General Astronomy. Let F be the flux of radiation from a star (Watts/m^2). Given fluxes F_1 and F_2 from two stars, the difference in their magnitudes is then

$$m_1 - m_2 = 2.50 \log \left(\frac{F_2}{F_1} \right) \tag{1}$$

Attributing a single number to the magnitude of a star is done by essentially expressing its magnitude difference relative to Vega, which by convention has an apparent magnitude of 0. In analysing CCD data, we use the fact that the number of CCD counts (total charge, corrected for dark count and flat fielding) due to a star is proportional to the flux F.

2 Equipment to be Used

- Celestron 8 telescope with finder telescope.
- Adapter, C8 $\rightarrow$ ST-402XME camera
- ST-402XME camera, power cable, and USB cable
- Labtop computer running CCDOPS software
- Work stations in Room 655 running Maxim DL

3 System Setup on the Roof

The first part of the exercise will be done in the late afternoon, close to sundown ("they only come out at night"). This is a chance to make sure we have all the necessary pieces, that they fit, and that we have the necessary software. Once the Sun has set and twilight is in progress, we will take the flat field frames.

1. Begin by making sure the finder scope on the C8 is aligned. This is crucially important, otherwise you will not be able to find the celestial objects we need to measure. Set up the telescope with the finder in place, and a low power eyepiece in the main telescope. Point through the C8 to an object which is easy to find on the horizon, such as a building beyond the airport. Then look through the finder scope. For the telescope to be aligned, the target object should be right on the crosshairs. It won't be. Use the small screw adjustments at the base of the finder scope to adjust the direction of the finder until the target object is right on the crosshairs.

   Check the alignment by looking at a couple of other objects. Choose the object, and move the telescope so that the target is right on the crosshairs of the finder. It should be in the middle of the main telescope field as well. If it is not, continue the adjustments. With the finder scope aligned, you can point at an object with the finder (easy) and be assured it is in the main field of view.

2. Connect the adapter for the ST-402XME camera to the C8, and screw the camera onto the adapter.

3. Download the CCDOPS software from the SBIG site (http://www.sbig.com/sbwhtmls/softpage.htm) onto a laptop computer that can be taken to the roof or remote observing site. *This should be done prior to the lab session. Each working group should be sure that at least one of its members has a laptop computer with CCDOPS installed.* Go to the "software downloads" section of the web page and download CCDOPS version 5 for Windows machines, or the appropriate version for Macs. Each working team should have at least one laptop with CCDOPS installed. If no one in the working team has a laptop, talk to the instructor.

4. Connect the USB cable to the camera, then connect the power cable to the camera. **This is a good time to review the instructions on p76 of the CCDOPS manual, giving the right order for powering up and powering down the camera**.

5. Bring up CCDOPS, connect to the camera, and listen to the contented clicking sounds that indicate the camera is working.

6. When the Sun has been set for 15 minutes or so, point the telescope to the west, and take a frame of the western sky. Experiment with the exposure time, beginning with the shortest and increasing the exposure time. The goal is to obtain a flat field that has high signal to noise ratio, but which is nowhere close to being saturated. Save this frame with an obvious name that contains the word "FLAT". We will apply it to our star frames in CCDOPS as well as applying it with Maxim DL.

7. Find a map of the constellation of Corona Borealis, either in published star charts (preferably with leather binding and an artist's drawings of the mythological figures together with the stars in the constellations), or with a program like *Starry Night Pro* (the modern, soulless approach). Be sure you have a chart showing you the principal stars in

Corona Borealis. Our main calibrator star will be γ Coronae Borealis (8 CrB), which is a spectral class A0 star with U,B, and V magnitudes of 3.800, 3.840, and 3.850, respectively. γ Coronae Borealis is at a distance of 44.5 parsecs. If you have forgotten about U, B, and V magnitudes, or other stellar properties mentioned above, review your General Astronomy textbook, or ask the instructor. In this exercise, we will make measurements with no filter, and equate our magnitudes to the V magnitude. The specific stars we will observe are γ Coronae Borealis (8 CrB,calibrator), δ Coronae Borealis (10 CrB), ϵ Coronae Borealis (13 CrB), ι Coronae Borealis (14 CrB), and ρ Coronae Borealis (15 CrB). ρ Coronae Borealis is a solar type star 17.4 parsecs away. It has a Jupiter-mass planet in an orbit with a period of 40 days.

8. If you are not already familiar with its location in the sky, find the globular star cluster M13 in Hercules, using star charts or *Starry Night Pro*.

4 Astronomical Observations with the CCD Camera

1. Bring to the roof additional equipment you need, such as power strips and the computers for instrument control and data processing. Bringing some chairs will minimize human suffering.

2. With the computers running, connect the USB cable to the ST-402XME, followed by the power cable. Bring up CCDOPS on the control and processor computer.

3. The main task to be accomplished before making observations is to focus the camera. First, point the telescope at a bright star like Vega or Altair and have the telescope track.

4. Check the section on p39 of CCDOPS manual on "Rough Focusing". We follow the same procedures as we did in the lab on focusing. Run the camera in focus mode on the bright star while you adjust the focus knob of the telescope. Continue the focus until the star image is as close to pointlike as possible. The camera is now ready for measurements.

5. This would be a good time to determine directions on the image. Unlocking the hour angle lock on the Celestron will cause the star to move out of the field to the west. Using the declination fine adjust to move the telescope north (increasing declination) will cause the star to move out of the field to the south.

6. Take several exposures of Gamma CrB. Make sure you have several images in which the image is not saturated. Take good records so you know which images correspond to which exposure time.

7. Move the telescope to each of the stars δ, ϵ, ι, and ρ in Corona Borealis. Take a couple of frames of each star, making sure that none of the stars of interest are saturated. Be sure you use the same exposure times as you did for the calibrator, γ CrB, since it is better to do photometry with images of the same exposure time.

8. Keep an eye on the focus. If the focus looks like it is drifting, you will have to go and repeat step # 1 before proceeding again to step # 2.

9. After all images have been acquired and the bookkeeping done, it is a good idea to apply the flat field correction in CCDOPS. Although it can also be done in Maxim DL, it is an easier and more straightforward operation in CCDOPS. Load a star or image frame into CCDOPS. Go to the UTILITY drop down menu box, and choose FLATFIELD. You can choose the flat field image and apply it to the astronomical image; it is easy to apply the correction. Save the flat field-corrected image with a name that makes it easy to identify.

5 Images of M13

In this part of the exercise, you will take images of the magnificent globular star cluster in Hercules, M13. Find M13 and take a few images of it, with different exposure times. Also, find the filter option box in CCDOPS and take images of M13 with the same exposure time, but different color filters. If there is some other non-stellar object that you would like to observe instead of M13, discuss it with the instructor.

The image of M13 (or other Deep-Sky object) will be a particularly good test of the effectiveness of the flat field correction.

When you are done, go through the shutdown procedure described in CCDOPS (in camera option box). Disassemble all of the equipment and carry it down to the lab. Leave the ST-402XME cameras on the lab tables, and set up the Celestrons again. Make sure all dust caps are on the Celestrons.

6 Data Analysis with Maxim DL

Download all image files from the control and analysis computer to the workstations in room 655 that have Maxim DL. Put all images in the folder for your working group. Your report, consisting of worksheets, should contain the raw data and analysis described below. Be sure your report includes the tables and figures indicated. Look at the supplementary document "Photometry with Maxim DL" on the course web page, in the lab schedule sub-page. Mainly look at Sections 1 and 2 of that document.

Contrary to pessimistic statements in that document, the magnitude calibration can be transferred from one frame to another. Just load all images for which photometry is to be done using the same calibration data. Maxim DL is smart enough to correct for different exposure times. It still would be a good idea to do photometry on frames with exposure times as equal as possible, and it is very important to have the calibrator observation close in time.

1. Give a table (Table 1) with your photometry data for the stars in Corona Borealis, giving the peak count and exposure times for the various images.

2. Use the *photometry tool* in Maxim DL to determine magnitudes for all stars. Photometry should be done on images which have had the flat field correction applied. You will use γ CrB to set the photometry tool. The photometry tool determines magnitudes by comparing the number of counts in a circular aperture with those in an annulus outside the main aperture. Present your results in tabular form (Table 2).

3. Determine the angular scale (arcseconds per pixel) for your images, using the formula in the CCDOPS manual, and the fact that the focal length of a Celestron 8 is 2000 mm. Measure the angular distance between some features of interest, such as a binary star or pair of stars.

4. Pick a few of the faintest stars in a long exposure image, and use the photometry tool to measure their magnitudes. Report the magnitudes.

5. Describe how you estimate the errors on your magnitudes. Calculate those out for all of your stars, and include them in another column in Table 2.

6. Find independent estimates of the magnitudes for the brighter stars in Corona Borealis. Describe the source of your information. Give these values in another column of Table 2, and make a plot showing your value of the magnitudes versus the independent values. Did you do a good job, or do you feel ashamed of yourself?

7. Select your best image of M13 and include it in your report. Print the negative of the image, i.e. stars should be black on a white background. This saves toner. Comment on differences in the images in different filters. You should also look to see if there is evidence of improvement when the flat field correction is applied. Examine the M13 images when the flat field correction is made, versus the uncorrect image. Describe differences. Include the images if it will help make your point.