Physics 344 — Lab 2 - Clouds

Observing with a CCD

Take Data: September 14 – September 20 (bad weather permitting)
Report Due: with Lab 3
Text Reference: Chapters 8 & 9

Purpose: This lab introduces the direct-imaging CCD system on the 0.5 m telescope by taking some basic calibration data using the illuminated inside of the dome. We will use this data in Lab 3.

Background: Charge Coupled Devices (CCDs) are solid-state imaging detectors that are the detector of choice for almost all astronomical applications. They have several desirable qualities. 1) High sensitivity – recording up to 85% to 90% of the photons that illuminate them. 2) Photometric stability – measurements of the intensity of the light that falls on them are accurate and reproducible. 3) Stable geometry – measurements of the positions of features in the images are accurate and reproducible. 4) Digital data – measured signals are easily digitized and recorded in computers for later analysis. The only significant limitations to CCDs are the need to cool them to low temperatures to reduce signals from thermal excitation, "dark current", compared to photonic excitation and their limited sizes, although mosaics of multiple CCDs are now becoming common to produce larger effective sizes.

As with any instrument, the signal measured by the combination of telescope and CCD depends both on the incident light and on the properties of the optics and detector. Thus, it is necessary to obtain *calibration data* to measure the properties of the instrument as well as *science data* to measure the object in the sky. For our CCD system we will take images of a uniformly illuminated field to measure changes in the relative sensitivity across the detector and images with zero exposure times to measure the bias level (the output when no signal is present). The former are called *flat field* images and the latter *bias images* (or *bias frames*).

I. Preparation and Planning:

There is not much in this case. Read the instructions on operating the 0.5 m telescope and the instructions below. Since the weather is cloudy, we will just do the initial steps of setting up the telescope and then set up the CCD camera and take a few images.

II. Telescope Setup:

1. Refer to the *0.5 m Telescope User's Guide* and follow the directions for starting up. There are no encoders on the axes of the telescope mount to tell the computer where the telescope is pointing. So an important part of starting up is to use the zenith and then a bright star to synchronize the telescope pointing in *The Sky* with where the telescope is actually pointing. For the practice, follow the procedure through linking the telescope to *The Sky* and synchronizing on a star very close to the zenith.

III. CCD Camera Setup:

1. Slide the fold mirror in the red instrument adapter box to the "CCD" position following the directions in the *0.5 m Telescope User's Guide*. Check the other side of the box to ensure that the spectroscopic pick-off mirror is out (rivet in the "direct" location). Make sure that the plastic plug is in the eyepiece tube. Turn on the imaging CCD system with the power strip in the telescope mount base.

2. Start *IDL* and the imaging *CCDSoft* program on the dome computer. In *IDL,* start RU*PhAst* to view the saved images.

3. In *CCDSoft*, click on *Camera/Setup* to bring up the Camera Control tool. You will use this tool for running the CCD. On the *Setup* tab, click *Connect*, and observe that the Imager and Autoguider become "linked" with Status "ready". Click on the *Temperature* button, and on the pop-up menu enter a setpoint temperature that is 35 to 40 °C cooler than the ambient, select the "On" radio button, and then click "Ok". Observe that the cooler power goes to 100% and the CCD temperature begins dropping. It will take a few minutes for the CCD to stabilize at the selected temperature. Note the percent power used – it will be near 100% while cooling, but should drop to a lower value when the setpoint is reached. If it takes more than about 90% power to maintain the setpoint, raise the setpoint temperature a bit.

4. Select the *AutoSave* tab, and make sure that the *Image* radio button is selected. Click on "*Choose Folder…*" and navigate to *G:/Ph344/lab3/.* Create a new folder there, named with the date and your initials (e.g., sep24tp), and then select this folder. Set the *starting number* to 1. Select a *prefix* image name – you may want to use different names for each group of files created in the steps below. Make sure that *Save As FITS* is selected, and *AutoSave* is on.

5. Select the *Take Image* tab. Set the *Exposure Time* to 1 second, the *Bin* to 2x2, *Series of* to 1, *Subframe* off (*i.e*., read out the whole CCD), *Filter* to V, *Frame* to Light (*i.e*., open the shutter during the exposure) and *Reduction* to None. This last setting means that no calibration data is obtained automatically. In later labs we will use the Autodark setting, which automatically follows each science image by an equal-length dark image (or uses a previously-taken dark image) and subtracts it from the science image.

6. The telescope is focused by moving the secondary mirror using the stepper-motor controller on the observing desk. Turn on the encoder readout above these controls with the green button. Use the focus motion buttons on the panel below to set the encoder to a reasonable first guess at a good focus. This value is −0.45 mm if the air temperature is about 15 °C and increases by about 0.100 mm for every 5 °C *decrease* in temperature.

IV. Acquisition of CCD Calibration Data:

1. Start shutting down the telescope by sending it to the home position. Drop the link with the computer and turn off the black telescope interface box. Point the telescope horizontally by hand.

2. Turn on the dome white lights and point the telescope to a region of the inside of the dome that is unshadowed and as free of "structures" as possible.
3. Select the *AutoSave* tab. Turn *AutoSave* on and choose a filename of flat*V,* since we are observing with the V-band filter.
4. **Flat field images:** Select the *Take Image* tab. Set the *Exposure Time* to 7.5 seconds, *Series of* to 2, and *Reduction* to AutoDark. Click the *Take Series* button to take two sequential images. During these exposures, no one should move in the dome, since this can change the illumination pattern on the dome. Use the cursor on the displayed image to verify that the exposure has produced an intensity of roughly 30,000 ADU per pixel. If the actual intensity is much above or below that value, adjust the exposure time and take the images again.
5. **Bias images:** Change *Reduction* to None and *Frame* to Bias. Take a series of two bias (zero exposure time) images.
6. Cover the telescope and point it to the zenith on the east side of the mount. End the *CCDSoft* program and turn off the power to the CCD at the plug strip in the telescope base. Turn off the focus encoder display and, if the weather is going to be hot, shut down the computer.

V. Data Calibration Part 1: CCD Gain and Read Noise

A fundamental property of a CCD camera (i.e., the solid-state detector and its associated electronics) is the relation between the number of photons detected in a pixel and the output signal for that pixel. The units of this output signal are somewhat arbitrarily designated as digital units (du) or analog-to-digital units (ADU). The *gain* of a CCD camera is the number of detected electrons per ADU. Measuring the gain would be simple if there were a method that deposited a known number of electrons in a CCD pixel. Radioactive decays that produce x-ray photons of known energy (which produce a maximum number of electrons when absorbed by the CCD) are a possibility, but this is inconvenient in practice (it requires a fairly strongly radioactive source!). So the usual method to measure the gain exploits the Poisson statistics of photon arrival, specifically that for a collection of pixels with an average signal of N detected photons, the standard deviation of the detected signals around their mean will be $\sqrt{N}$.

Our camera has two possible gains (high and low) that are selected automatically depending on the selected binning − 2×2 binning has more electrons per ADU (low gain) than does 1×1 binning (high gain). The low versus high nomenclature makes sense if you think in terms of the amount of amplification of the original signal read out of the CCD. In professional CCD cameras, the gain and binning can be selected independently.

Another important property of the CCD camera is the noise added to the measured signal by the CCD electronics, called the *read noise*. This is generally measured by looking at the values from a collection of pixels in a zero-length exposure bias frame. The standard deviation of the values around the mean is the read noise in electrons times the gain.

We start the measurement of the gain and read noise with some practice manipulating images with IDL and measuring the statistical properties of an image.

1. In IDL, create a two-dimensional array of Gaussian random numbers with zero mean and a standard deviation of one by typing the following into the IDL> command line box at the bottom of the developer environment window:

   ```
   a = randomu(seed,400,400,normal=1)
   ```

   Display this array using *RUPhAst* by typing:

   ```
   ruphast, a
   ```

2. Change the display contrast and brightness by holding down the left mouse button and dragging: left-right changes the brightness, and up-down changes the contrast. How does this image appear?
3. Get the image statistics for an 11 x 11 pixel box centered at X=200, Y=200. In your report, list the minimum and maximum pixel values in this region, the mean, the median, and the standard deviation of the pixel values about the mean. (Make sure that you understand the meaning of all these statistics.) Why is the mean not exactly zero, and the standard deviation not exactly one?
4. Repeat the exercise with a 151 x 151 pixel box centered about X=200, Y=200 and report the values. Comment on the differences between the small and large samples.

Now proceed to measure the actual gain and read noise for the low-gain mode of our CCD camera.

5. **IMPORTANT!** Copy all of your Lab 3 CCD images from the folder /home/ph344/lab3/… to a folder in your home area. Make sure that you always work on these copies, not the original images! Use the file manager tool to copy the images (or Linux commands if you are a Linux wizard). Also copy the file /home/ph344/lab3/phast.conf into your lab3 folder. This configuration file initializes certain quantities in *ruphast*, most notably the CCD gain and readnoise. Examine the contents of this file.
6. Depending on where you were in the filesystem when you started IDLDE, you will need to change the path so that you can find your image files. IDL does this with the *cd* command:

   ```
   cd, “/home/yourusername/thedirectorywhereyouputthedata”
   ```

   Note that the quotes are important, as is the comma. Obviously, replace “yourusername” with your user name on the system, and “thedirectorywhereyouputthedata” with the appropriate path to the place where you saved the copies of the original images.
7. Examine one of your Flat and Bias images with *RUPhAst*. Explore the headers of the images to see what information was recorded. Describe the structure that you see in the images.
8. Read in two of your Flat images and your two Bias images into arrays for processing:

   ```
   f1=readfits(‘image.00000001.FIT’,h) * 1.0
   f2=readfits(‘image.00000002.FIT’,h) * 1.0
   ```

```
b1=readfits('image.00000003.BIAS.FIT',h) * 1.0
b2=readfits('image.00000004.BIAS.FIT',h) * 1.0
```

Note that you can use the up arrow key to recall a previous IDL command – saves a lot of typing. Multiplying each image by 1.0 forces them to be saved as floating point numbers rather than unsigned integers. Your images may have different names – obviously, use the actual filenames of your images.

9. Form the difference of the two flats and biases:

```
db = b1 – b2
df = f1 – f2
```

10. Use *RUPhAst* to load and examine these six images (two biases, two flats, and two differences), using the command:

```
phast, b1
```

(and replace b1 with the names of the other 5 arrays). Use the "i" command in RUPhAst to measure the image statistics in a 51 x 51 pixel box centered at x=1000, y=650 in each image, and record the mean and standard deviation for each frame. The ambitious may want to measure more than one region on the image.

11. Calculate the gain (in e^-/adu) and read noise (in e^-) for the system using the statistical data from step 10:

gain = [mean(f1) + mean(f2) – mean(b1) – mean(b2)] / {[stdev(df)]^2 – [stdev(db)]^2}

read noise = gain * stdev(db) / 1.414