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# Report One: CCD Calibration

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## 1. BACKGROUND

The purpose of this lab is to evaluate the CCDs we will be using to image the sky throughout this semester. Gaining an understanding of how CCD cameras work, and what efforts must be done to produce acceptable images of the night sky are important to understanding how optical astronomy is done. Most of the calibration done for optical astronomy is completed by the observatory before astronomers are given the data, but it is still important to see where the data comes from.

We measure the bias by taking a zero second, dark exposure, without opening the aperture. The purpose of the bias is to remove structure such as bad columns, bad pixels, and banding from the science image. The signal in a bias is due to the electronics that make up the sensor.

We measure dark frames by taking exposures with the same exposure time as the science images, but with the aperture closed. The purpose of taking dark frames is to remove the dark current from the image, which is created by thermally induced electrons. If any pixels are more sensitive to long exposures, then that effect will be picked up by the darks. Any time variable effect on the CCD should be picked up by taking darks with similar exposure times to the science images. The effect of the dark current can be mitigated by cooling the CCD.

We take flat fields by providing flat illumination, with constant brightness, for the camera to image. For many telescopes, there is a white board that can be illuminated with different wavelengths and brightness of light to take a flat field. Although the board may not have a continuous surface, it is close enough to the telescope to be out of focus, providing flat illumination. The purpose of flat fields is to account for sensitivity variations in pixels. Dust can settle on the optics, creating out of focus donut shapes on the image if the flat fields are not removed from the science image. Dividing by the flat field will account for variations in the sensitivity in the instrument.

The purpose of measuring the linearity of the CCD is to test if the CCD's response to bright and faint light is the same. The gain is the number of electrons per ADU (or count) of the CCD. We measure it to figure out how many photons we are detecting.

## 2. METHODOLOGY

To begin, we turned on temperature regulation for the CCD, which cooled the camera down to reduce thermal noise in the images. We also made sure that CCD Ops would not reuse previous dark frames, and instead save them all. We also made sure that the photometric clear filter was active.

First, we obtained 10 bias images. We covered the CCD shutter with a lens cap to ensure that no light got in, and chose the option on CCD Ops to only take a Dark, for the shortest exposure time, 0.04 seconds. We noted that the

**Table 1.** Table of the exposure times and average counts of the dark frames after bias subtraction.

| Dark Exposure Time Seconds | Dark Average Counts ADU |
|---|---|
| 0.05 | -5.1121914648212226 |
| 0.25 | -5.331184159938485 |
| 1.0 | -5.152750224272715 |
| 5.0 | -2.0652326028450596 |
| 25.0 | 10.530082019736 |
| 125.0 | 25.492663078303217 |

**Table 2.** Table of the exposure times and average counts of the bright and faint flats after bias subtraction and dark correction.

| Flat Exposure Time Seconds | Average Bright Counts ADU | Average Faint Counts ADU |
|---|---|---|
| 0.04 | 5.511046264257337 | -3.1731239266948603 |
| 0.1 | 18.931091887735487 | 3.0317967448417273 |
| 0.3 | 49.832977829040104 | 2.420100730488273 |
| 1.0 | 172.9949378444188 | 16.006710239651415 |
| 3.0 | 570.8858049468153 | 60.40829885941304 |
| 10.0 | 2454.351035499167 | 198.14677303601178 |
| 30.0 | 5744.984574394463 | 699.4061635268488 |
| 100.0 | 13387.245811867231 | 2783.8719787261302 |

bias frames included a gradient, and made sure that it was due to the behavior of the CCD and not any light leaking into the sensor.

Then, we took the dark frames. Keeping CCD Ops on Dark only mode, we took exposures starting from 0.05 seconds and then increased the exposure time in multiples of $\sim$5. We took dark frames with exposure times of 0.05, 0.25, 1, 5, 25, and 125 seconds, taking three frames per exposure time to combine later. The average values of the dark frames for each exposure are in Table 1. During this, we made sure that no light hit the sensor by covering the opening of the CCD.

Next, we took the bright flats. We found that there was too much ambient light in the classroom to take them without completely flooding the CCD. We set up a notebook to hang over the back of an open laptop so that the paper faced the opening on the CCD, which we set very close to the paper. We also changed the filter to the photometric B filter to remove even more light. We set the CCD to take no darks and started taking exposures in sets of three with exposure times of 0.04, 0.1, 0.3, 1, 3, 10, 30, and 100 seconds. When we took the first sets of exposures, one of the lab group members stood between the CCD and the window, so they stood there during while we took all of the exposures. The movement of someone standing between the CCD and a light source may have impacted the variability of the light entering the CCD during this section of the lab.

For the faint flats, we needed to decrease the amount of light entering the CCD even more. We made a makeshift box over the top and back of the CCD, which seemed to block out enough light. The lab group member who had been standing behind the CCD for the bright flats moved. We set the CCD to take no darks and started taking exposures in sets of three with exposure times of 0.04, 0.1, 0.3, 1, 3, 10, 30, and 100 seconds.

We did not retake 'light' flats for the CCD Gain, instead reusing the bright flats, although the longest exposure bright flats did not go over 30,000 counts.

Equation 1 describes the calibration process. A 'master' bias was made by taking the median of the ten biases taken. The master bias was subtracted from each flat and dark frame. The flats and darks were each median combined within their exposure time groups. The bias subtracted darks were then subtracted from the flats. The exposure times and average count values of the flats post calibration are presented in Table 2.

$$Processed = (Flat - Bias) - \frac{t_f}{t_d}(Dark - Bias) \tag{1}$$

## 3. RESULTS

### 3.1. *Linearity*

Figure 1 shows a plot of the average counts versus exposure time for the bright and faint flats. Both were fit with a line to compare their slopes, which were very similar. The fit slope of the faint flats counts over time is 139.0 when multiplied by 5 to scale with the bright flats, which have a slope of 134.8. Due to the flats not going over 30,000 counts, we do not know the behavior of the CCD when exposed to an even brighter source. We may expect some non-linearity at higher counts, especially near the count limit of 60,000 counts.

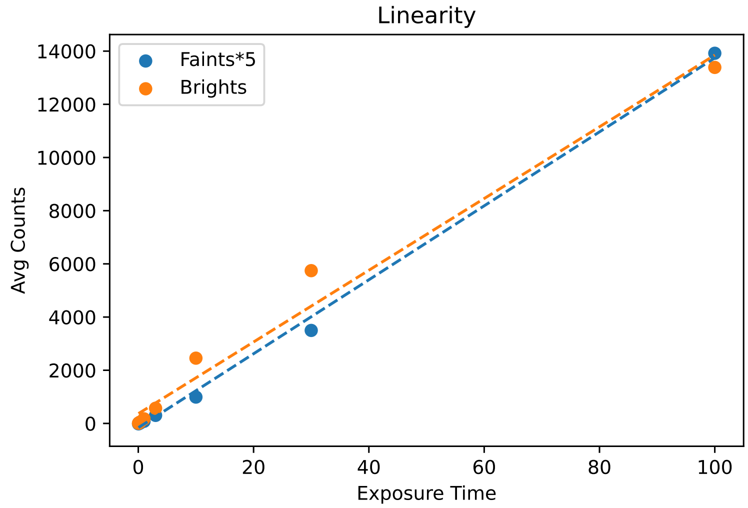


**Figure 1.** Plot to compare the linearity of the CCD when observing something bright versus something faint. The faint points were multiplied by five to scale them to the bright points. Both sets of points were fit with one dimensional lines, which were then plotted over the points to compare their slope.

### 3.2. *Gain*

We used Equation 2 to find the gain of the CCD. F1 and F1 are two flats which were dark subtracted. B1 and B2 are two bias frames which have not been calibrated. The numerator uses the median values of the flats and biases. The denominator uses the standard deviations of the full images. The resulting gain is 1.35 electrons/ADU. According to the image headers, the gain of the CCD is 1.49 electrons/ADU, meaning that the measured gain has a 9.4 % error. The gain should be greater than one. The Kuiper Telescope on Mount Bigelow has a gain of 3.1 electrons/ADU, so the gain of this CCD is less than that of the Kuiper Telescope.

$$gain = \frac{[(F1 + F2) - (B1 + B2)]}{[(\sigma(F1 - F2))^2 - (\sigma(B1 - B2))^2]} \tag{2}$$

## 4. CONCLUSION

We took calibration frames for the lab CCDs: 10 bias frames, 18 dark frames, 24 bright flats and 24 faint flats. We found that the CCD behaves linearly between 0 and 14,000 counts, but we expect that the CCD will behave less linearly and more logarithmic when approaching over-exposure. To accurately determine the behavior of the CCD at larger counts, we would need to either expose the CCD to more light when taking the bright flats, or take longer exposures. We found that the gain of the CCD is 1.35 electrons/ADU with a percent error of 9.4 %. Better calibration could have been done in a darker environment without external light sources and variable surroundings. The exposure times of the darks and flats could have been better matched.