ASTR450 - Homework #3
Noise Calibration
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In order to attempt to calibrate a CCD for noise correction, we made various observations: bias frames, dark frames at various temperatures (-23.5C, -10C, 0C, 10C, 20C), and bright “starfield” frames using a 650C blackbody.

The CCD has many visible defects, as is obvious in figure 1. In order to complete noise calculation I chose a 90x90 subarray in an area of the image relatively unaffected by the physical defects (figure 2).

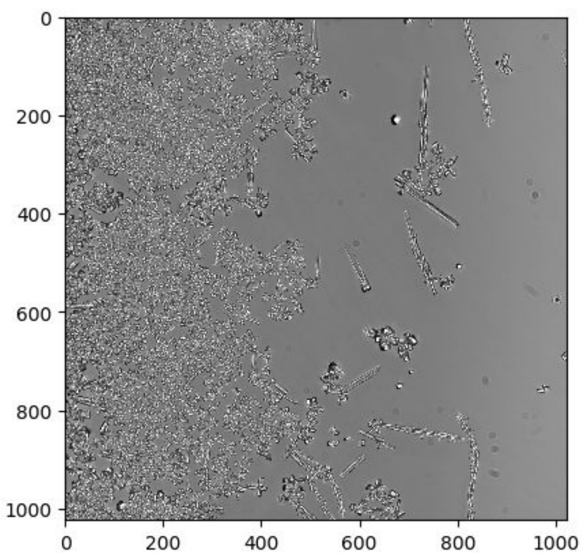


Figure 1: A stacked image of 3 observations

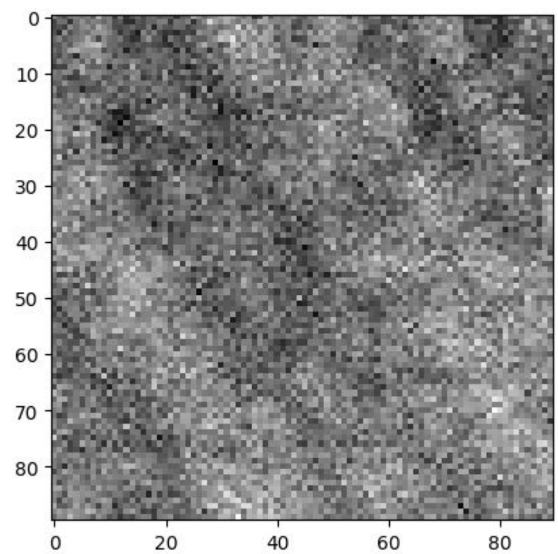


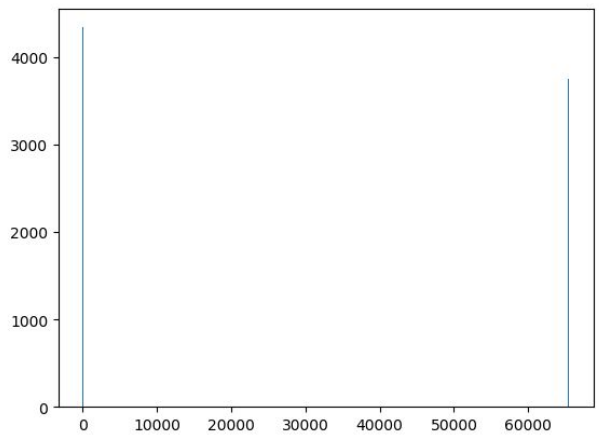
Figure 2: A 90x90 subarray sampled

Using the subarray selected, I measured:

- The read noise in electrons rms
- The dark current at different temperatures in electrons per second
- The gain in electrons per digital unit (noise values in electrons after discussion)

<u>Read noise:</u>
To compute read noise, two bias frames are subtracted. The standard deviation of measured values by all pixels is computed, then divided by the square root of two.

Initially, this computation resulted in a read noise of ~23000 counts, which struck me as unlikely, even for this system. I sorted the counts numerically and created a histogram to examine a possible cause for the large standard deviation, noticing that there was apparently two distinct, widely separated samples. (figure 3)



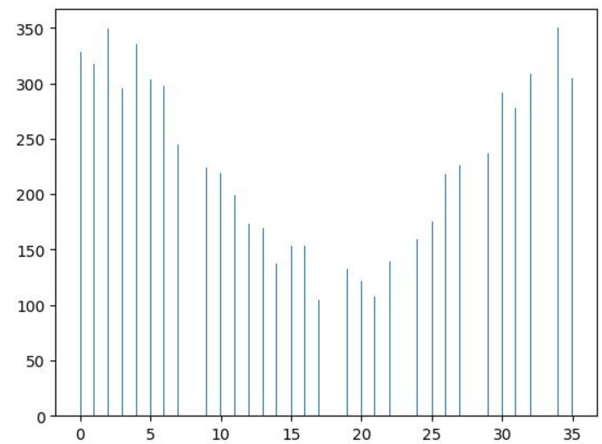


Figure 3 (left): histogram of pixel counts in the difference of two bias frames
Figure 4 (right): histogram of same sample, upon process described

Upon evaluating the array and found that about half of the pixels had a range of 0-33 counts, and the other half had a range of 65501-65535. I assumed this was erroneous, and tried two things to account for this error.

Firstly, I decided that if a pixel had a high count, I would subtract 65500 from the value, resulting in an array of values ranging in 0-35 (figure 4). This resulted in a read noise of 8.3 counts, a more realistic value. In my second method, I split the array into two pieces, one containing pixels with counts ranging 0-33, and a second containing those ranging from 65501-65535. This yielded a read noise of 4.2 counts for the first, and 4.0 counts for the second.

Dark current:

Using the CCD, 100s long exposures at 5 different temperatures were taken, demonstrating a strong effect of temperature on defects. To attempt to determine dark current, the bias frame is subtracted from each dark frame. The mean pixel count in each resulting image is computed, then this value is plotted against temperature to determine the relationship between the two. The following figures show the 90x90 subarray on the left, and a histogram with mean (solid line) and median (dashed line) identified. I chose to exclude the pixel counts at the top and bottom 3% of the distribution.

Each temperature range shows different defects, and counts actually decrease with temperature in colder regimes.

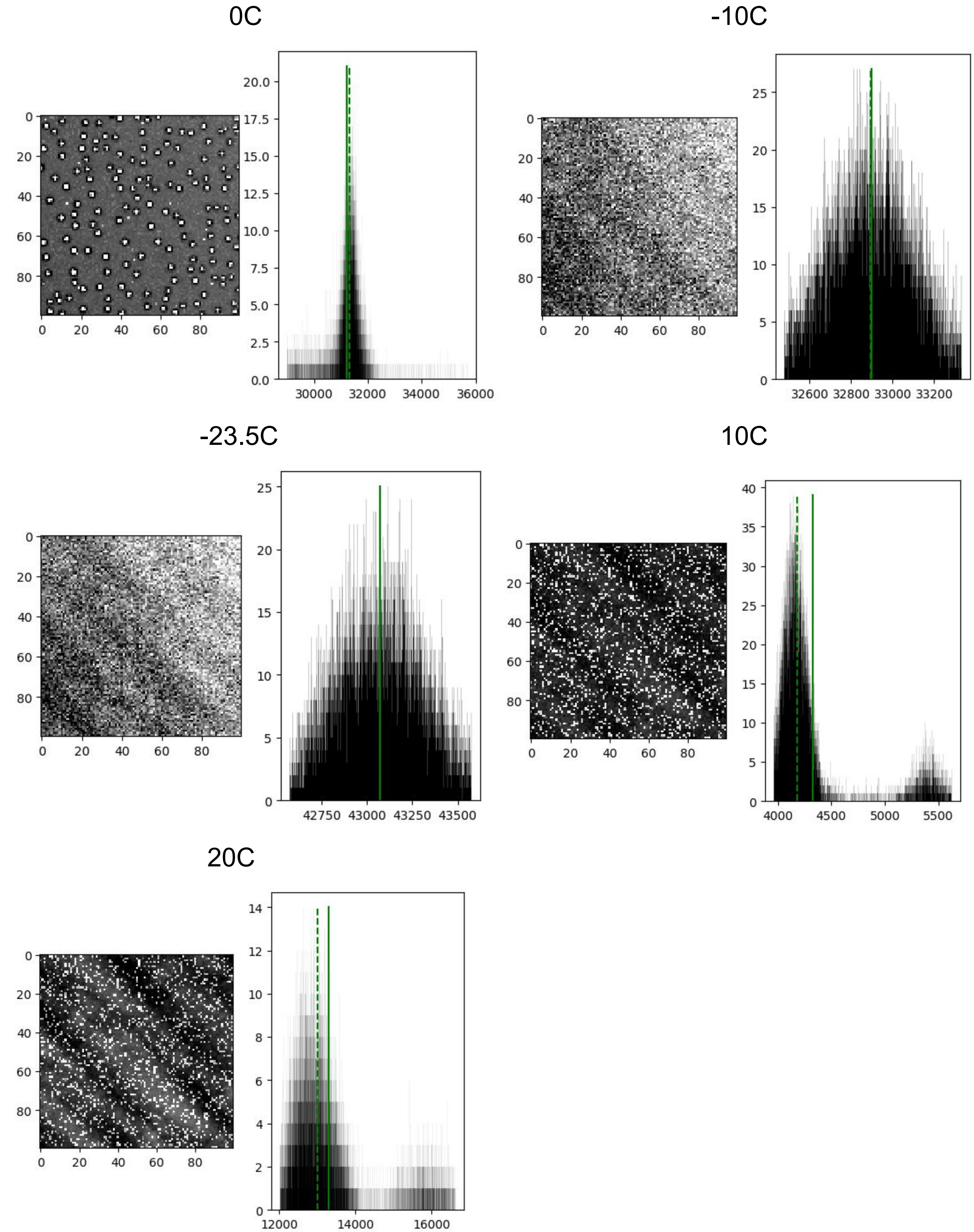
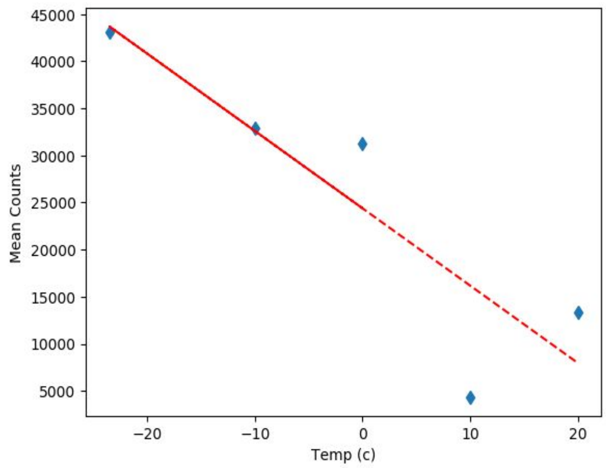


Figure 5: displayed region for each temperature measurement, with distribution of pixel counts displayed through histogram



	mean	median	rms
-23.5C	43072.1	43073.0	230.7
-10.0C	32897.0	32895.0	195.2
0.0C	31224.8	31309.0	700.1
10.0C	4330.7	4185.0	418.9
20.0C	13302.3	13015.0	1056.0

Figure 6: A linear fit of pixel counts plotted against temperature, giving a slope of -821.4 and r = -0.88.

Several alarming things popped out through my attempt at determining dark noise. Outside of visual distortions, evaluating the histogram reveals an entirely different brightness distribution in different temperature regimes. Plotting mean counts shows a decreasing trend, with a linear fit revealing a strong negative linear correlation -- when we would expect dark noise to increase with temperature.

Considering only the values at 10C and 20C, we do see an increase. The slope of 897.1 represents the dark current over the 100s exposure. Or, about 9 counts per second. While this might not be the most reliable measurement, this is a realistic value for dark current, so I will just assume it is true.

Gain (in electrons per digital unit):

To compute gain (g = S_{ad} / N_{ad}^2), we must first determine the noise from all sources:

$$\textit{Noise} = \sqrt{(photon\ noise)^2 + (read\ noise)^2 + (dark\ current)^2}$$

Photon noise is driven by Poisson statistics, which state the RMS noise in number of photons detected by a pixel is equal to the square root of the mean photon flux. The mean signal was determined to be 36140 in the selected 90x90 subarray. Read noise was computed as somewhere from 4.0-8.3 counts (I'll use the maximum). Dark current is assumed to be 9 counts per second, or 45 counts through the 5s exposure.

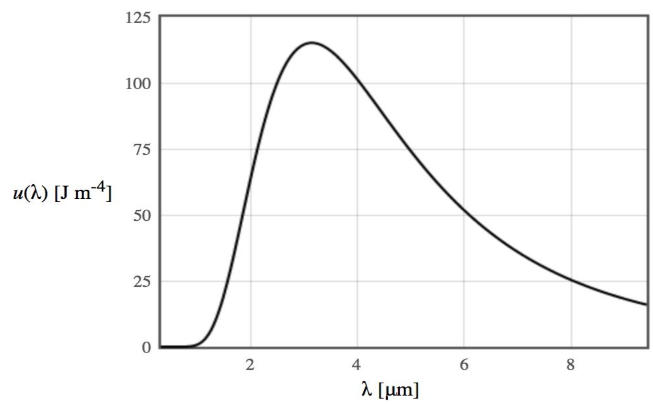
$$\rightarrow \textit{Noise} = \sqrt{36140 + 8.3^2 + 45^2} = 195.5 \text{ counts}$$

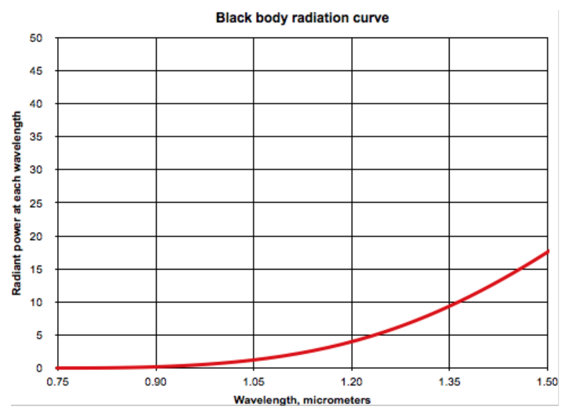
$$\rightarrow \text{g} = S_{ad} / N_{ad}^2 = 36140/(195.5^2) = 0.91 \text{ e- / ADU}$$

Given a gain of 0.91 electrons per ADU, we can determine noise values in electrons. The read noise is found to be 7.6 electrons, and the dark current is found to be 8.1 electrons per second. (However, do note there cannot be fractional electrons)

Bonus calculations!

Since our emission source is a blackbody, we can evaluate the energy distribution, seeing that only a small portion goes into a range observable by the CCD, and the portion below 0.7μm is negligible.





I don't think that one 'count' is equivalent to one photon detection event, as 32000 photons over 1024x1024 pixels in 5s would imply $3.4*10^{10}$ photons were detected from the blackbody. Assuming a 10μm pixel, the CCD has about one cm^2 of light gathering area. Vega's flux is about $3*10^6$ photons per cm^2 per second, a flux of $1.2*10^7$ photons over 5s. Also, in our dark frames the counts were in the 30000s. It seems that the bias frame didn't do its job, perhaps a short exposure is needed to trigger some of the issues that we don't see in the bias frame.