Measuring Linearity, Gain, and Read Noise

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1 Objective

To determine the linearity, gain, and read noise of the SBIG STT-8300 CCD camera, located on the Physics Skydeck. Once calculated, the values will be compared with the manufacturer specifications.

2 Procedure

Initially, flat field images and bias exposures were taken per the procedure outlined in the *Handbook of CCD Astronomy* by Steve Howell (pg.68). A stack of white letter sized paper was used to simulate a flat field, while two compact fluorescent lamps were used to provide equal illumination of the paper. For the bias images, the lens was covered by a cloth and by the plastic lens cover to minimize the light reaching the camera (see Figure 1 and 2). Temperature was set at -20°C, for images in simulation of actual conditions when performing astrophotography. At this temperature, noise should be reduced.

Figure 1: Side view of the CCD camera setup

Figure 2: Top-down view of camera

Exposure times ranged from 0.125s to 3s for flat fields, and 0.12s (lowest possible exposure time) for bias images. CCDOps 5 was used to retrieve and save the images in the FITS format. The software provided a histogram and a measure of the contrast (CBLACK in the header) which is proportional to the signal intensity (CWHITE) providing a rough estimate for linearity. High, medium, and low resolutions were used when collecting data to observe the effects of binning on the linearity, read noise, and gain.

Python was used to process data, perform image transformations, and calculate the values for linearity, gain, and read noise. The images were initially analyzed to confirm the Gaussian distribution (see Figure 2). Python provided the means to gather the necessary statistics on each image, and allowed for image subtraction, allowing us to calculate the values for the gain equation in the handbook (pg. 73).

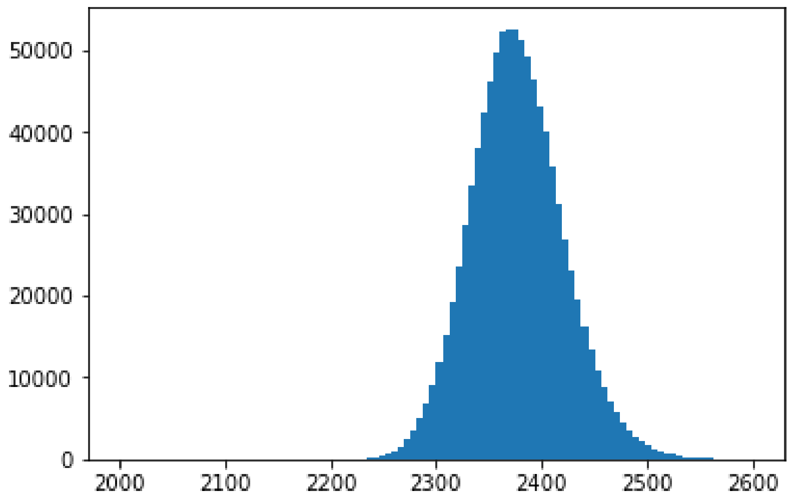

Figure 3: Plot of a bias image showing Gaussian distribution with ADU on the horizontal and signal intensity on the vertical. This distribution allows us to easily calculate the mean and standard deviation.

The linearity calculations involved constructing to arrays of data to represent the x and y values for the regression line. From there, the data was plotted, the linear regression was calculated, as well as the A/D Saturation Level. R^2 values confirmed linearity.

3 Calculations

To calculate the gain of the camera, we use two bias frames and two flat field images (of equal exposure time), labeled 1 and 2 respectively. Mean pixel value is calculated for each image. The mean values for the flat fields are $\bar{F_1}$ and $\bar{F_2}$ and the biases are $\bar{B_1}$ and $\bar{B_1}$. Now, we create difference images in Python and measure their standard deviation ($\sigma_{F_1-F_2}$ and $\sigma_{B_1-B_2}$). The gain for the CCD is then given by the following equation:

$$\text{Gain} = \frac{(\bar{F_1} + \bar{F_2}) - (\bar{B_1} + \bar{B_2})}{(\sigma^2_{F_1-F_2}) - (\sigma^2_{B_1-B_2})}$$

the read noise is calculated subsequently:

$$\text{Read Noise} = \frac{\text{Gain} \cdot \sigma_{B_1-B_2}}{\sqrt{2}}$$

and the width is given by:

$$\sigma_{ADU} = \frac{\sqrt{\bar{F} \cdot \text{Gain}}}{\text{Gain}}$$

Gain, read noise, distribution width values were was calculated by taking the mean value of multiple measurements each respective dataset, and uncertainty was determined using the procedure outlined in the

UWM Physics 121 Lab Manual (cross-referenced with other sources), specifically for $n \leq 10$.

Linearity was calculated in Python using the "StatsModels" statistics package and error values were calculated where applicable using the least squares regression method and finding the standard error of each variable (m and b in this case).

4 Experimental Data

Linearity	
High Resolution	
Slope (m)	23923.962 ± 106.530
Intercept (b)	1061.854 ± 142.879
Coefficient of Determination (R^2)	0.993
Medium Resolution (2xN Binning)	
Slope (m)	114597.714 ± 930.359
Intercept (b)	1883 ± 307.687
Coefficient of Determination (R^2)	1.000
Low Resolution (3xN Binning)	
Slope (m)	233960
Intercept (b)	6937
Coefficient of Determination (R^2)	1.000
A/D Saturation Level (based on SBIG Specifications)	68918.918 ADU
Gain	
High Resolution	0.321 ± 0.012 e-/ADU (3.74%)
Percent Error on Gain	13.24 ± 3.24%
Medium Resolution	0.862 ± 0.030 e-/ADU (3.48%)
Low Resolution	0.941 ± 0.054 e-/ADU (5.74%)
Read Noise	
High Resolution	5.846 ± 0.222 e- rms (3.80%)
Medium Resolution	15.727 ± 0.554 e- rms (3.52%)
Low Resolution	17.145 ± 0.985 e- rms (5.75%)
Distribution Width (σ_{ADU})	
High Resolution	340.786 ± 46.144 ADU (13.54%)
Medium Resolution	186.553 ± 37.640 ADU (20.18%)
Low Resolution	218.173 ± 17.915 ADU (8.21%)

5 Results and Conclusions

The SBIG STT-8300 has a high R^2 value indicating that the data points have a linear relationship and directly follow the regression calculated (see Figure 1). At high resolutions, the gain and read noise are closest to the manufacturer specifications; however, as resolution decreases as a result of binning, the accuracy of these measurements decreases. The high resolution gain is 0.321 ± 0.012 e-/ADU which is in agreement with the manufacturer specifications of 0.37 e-/ADU. At a low resolution, however, the gain is close to 0.94 e-/ADU, which is inconsistent with SBIG's data. The read noise (high resolution) was calculated to be 5.846 ± 0.222 e- rms, falling within SBIG's limits of less than 10 e- rms. With binning this value increases to over 17 e- rms, falling outside the original specifications.

Binning occurs when individual pixels are combined into larger ones, thus resulting in a smaller image resolution, and one where the pixels take a shorter time to absorb light. At a low resolution, saturation is reached within 0.5s, while at a high resolution, saturation occurs after 3s (see Figure 4).

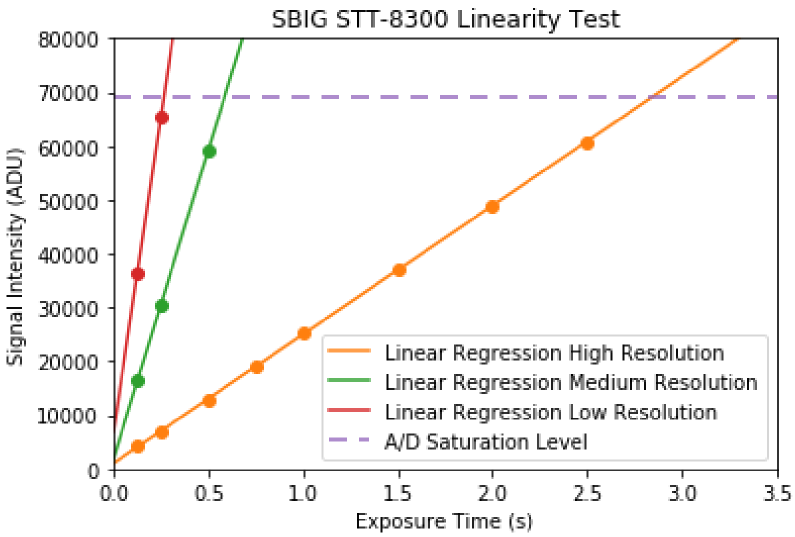

Figure 4: Plot showing signal intensity (ADU) versus exposure time (s). This graph shows the saturation point, as well as linear regression for high, medium, and low resolutions.

6 Discussion of Experimental Uncertainty

Regarding linearity, the 3s data point was the start of the nonlinear portion of the curve. As more pixels become saturated, we eventually reach a point where the output signal intensity slows down and there are fewer unsaturated pixels remaining (see Figure 5).

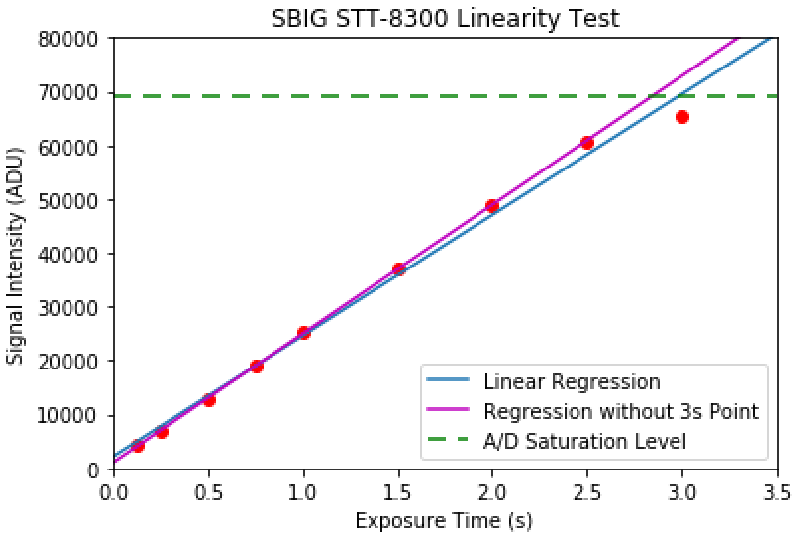

Figure 5: Plot showing signal intensity (ADU) versus exposure time (s). Includes regressions with and without the 3s point. At 3s, nonlinearity begins.

Regarding the images that have pixel binning, the gain and noise is reported higher than actual, and the lack of pixels make the data more unreliable because 1 pixel may now be representing 4 original sized pixels (as an example). You are unable to capture the variability of the response/saturation as accurately. As such, we see higher errors at the low resolution, in comparison to the high resolution images.

The gain is slightly lower than the manufacturer specification of 0.37 e-/ADU; however, a 2.5s Flat Field was used for that particular calculation. Although it has a high output signal, the point deviates from the regression farther than other points with shorter exposure times. If nonlinearity begins at 2.5s, the data may indicate a lower gain than at an earlier exposure time. Another hypothesis to explain the lowered gain could be machine age and impurities in the optics. Should dust contaminate the optics, light may be blocked from reaching the sensor, causing a lower conversion rate, and thus a lower gain.

Since read noise is proportional to gain, a lower gain will lead to a lower value here. It's possible that the read noise may be higher, and using different bias images may lead to slightly different results.

References

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