CCD Characterization: How We Interpret Light Received From The Universe

Mehrnoush Zomederis
*Department of Physics and Astronomy,
York University,
4700 Keele St. Toronto, On
M3J 1P3, Canada*

Introduction

Charge-Coupled Devices (CCDs) are fundamental instruments used for data collection in observational astronomy. A CCD is an integrated circuit chip divided into light sensitive squares called pixels, on a silicon surface. When the CCD is exposed to light, charge is generated as a result of the photoelectric effect.

The York University Astronomical Observatory's newest CCD camera, SBIG STXL-6303E, was characterized to find the gain, non-linearity, bias level, dark current, readout noise, and saturation of the chip. The CCD chip is a Kodak KAF-6303E and is 3072x2048 pixels (27.65 mm x 18.48 mm) in size. The STXL has a 16 bit A/D converter.

There is a linear relationship between the photons received from a celestial target and the readout signal from a charge-coupled device. Understanding when a chip becomes non-linear is not only significant in interpreting astronomical data, but essential in data collection.

Challenges

The optical characteristics of the York Observatory's telescopes results in an image scale for the chip that over samples the sky given the seeing conditions in Toronto. Thus "binning" is often used when collecting data.

When binning, a number of pixels are combined into a larger pixel. This results in faster readout speeds and improved signal-to-noise ratios.

However, interesting and unexpected characteristics were revealed as a result of increasing the number of pixels binned. The chip's non-linearity and saturation point appears to be lower than expected.
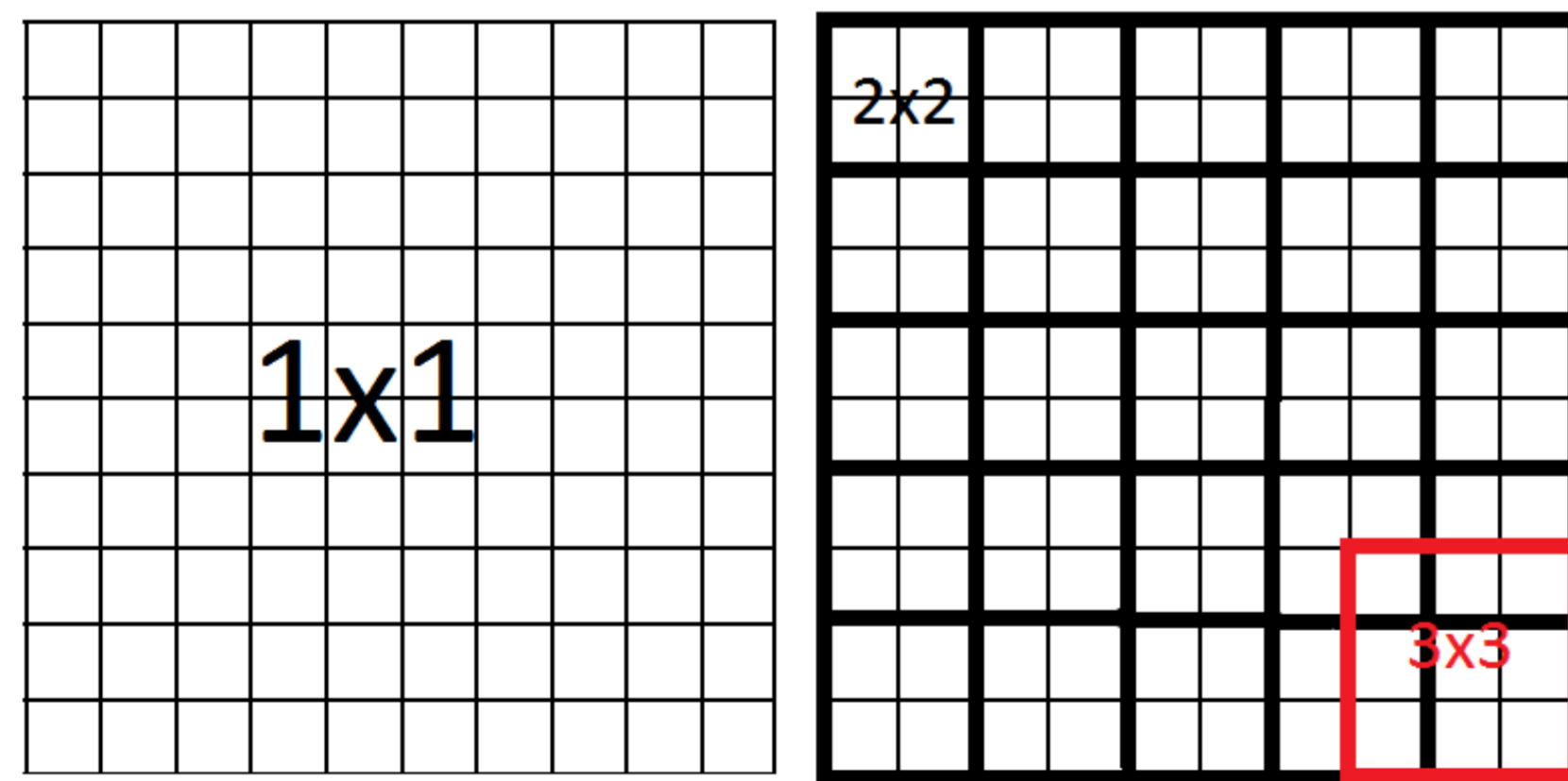

Figure 1. CCD Binning: 1x1, 2x2, and 3x3

Methods & Data

A set of bias, dark, and flat field images were taken at increasing exposures in 1x1, 2x2, and 3x3 binning. The data was reduced, analyzed, and plotted using IRAF, Excel, and Python.

A Photon Transfer Curve is used to characterize CCD performance (Figure 2). The gain is derived from the inverse slope of the linear range.

$$\frac{\delta a}{a} = \frac{\delta r /r}{\sqrt{2}} \qquad (\delta a)^2 = \frac{a}{g} + \left(\frac{\sigma}{g}\right)^2$$

Where a is the mean count of an a averaged flat per exposure, δr is the standard deviation of ratio of two images, r is the ratio mean count, g is the gain, and σ is the readnoise. The variance (δa) consists of the shot, read, and fixed pattern noise in each pixel.

$$\sigma_{total} = \sqrt{\sigma_{read}^2 + \sigma_{shot}^2 + \sigma_{FPN}^2}$$

Figure 2 shows the non-linearity and saturation point of the SBIG STXL-6303E. Table 1 summarizes all findings.
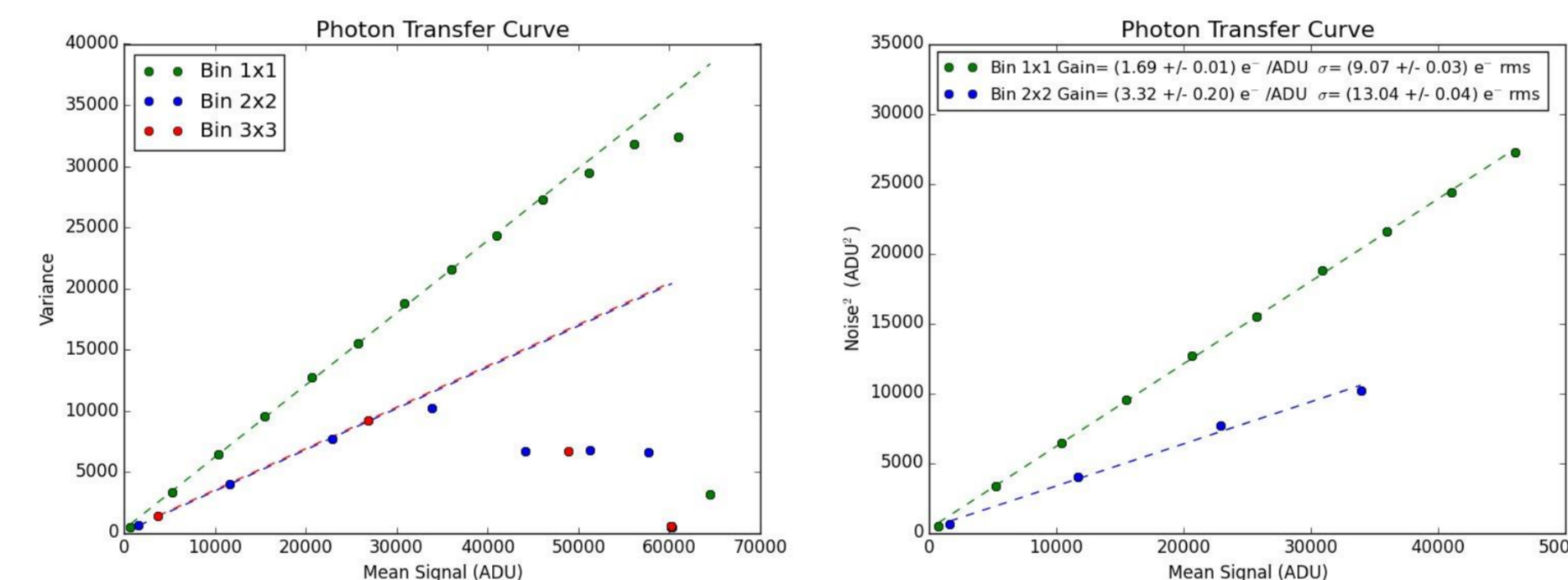

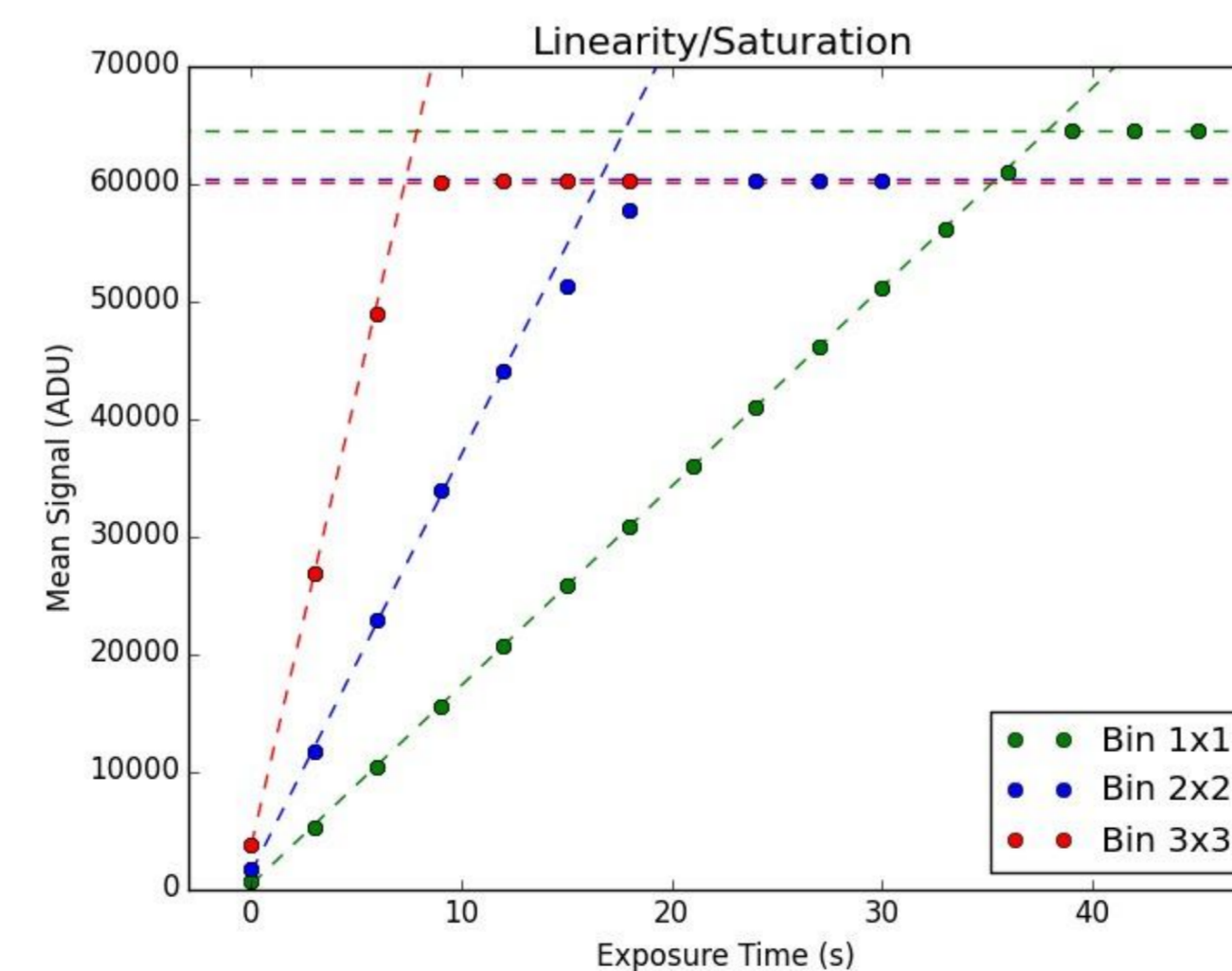**Figure 2.** The Photon Transfer Curve

Figure 3. Signal as a function of time

Results

|	1x1	2x2	3x3
Chip Size in Pixels	[3072,2047]	[1536,1023]	[1024,682]
Gain (e^-/ADU)	1.69 ± 0.01	3.32 ± 0.20	-
Read Noise (e^- rms)	9.07 ± 0.03	13.04 ± 0.04	-
Bias Level (ADU/pixel)	990 ± 2	496 ± 1	518 ± 2
Dark Current (e^-/pixel/sec)	Decreases by approximately ½ with every $5^o C$ temperature decrease		
Temperature Stability	±0.1$^o C$	±0.1$^o C$	±0.1$^o C$
~ 5% Non-Linearity (ADU)	54,000	44,000	44,000
Saturation (ADU)	64,545 ± 14	60,238 ± 17	60,152 ± 18

Table 1. Data Summary
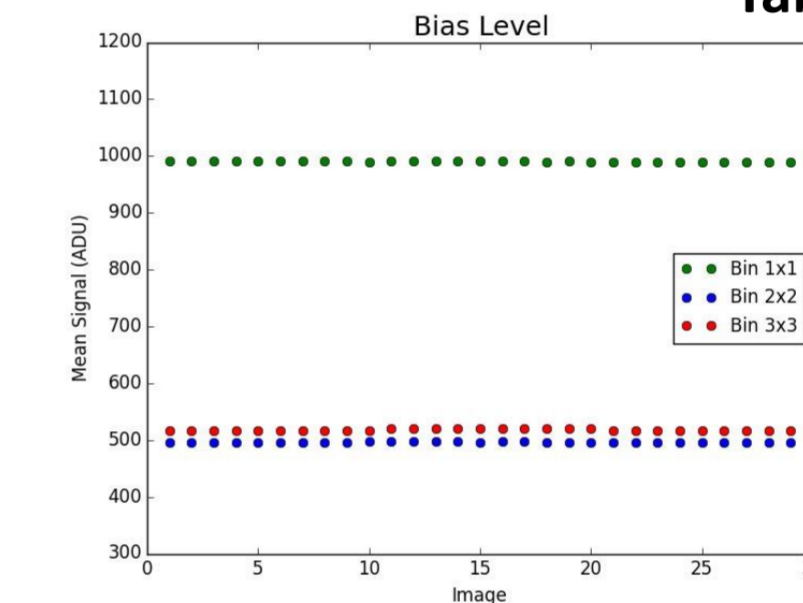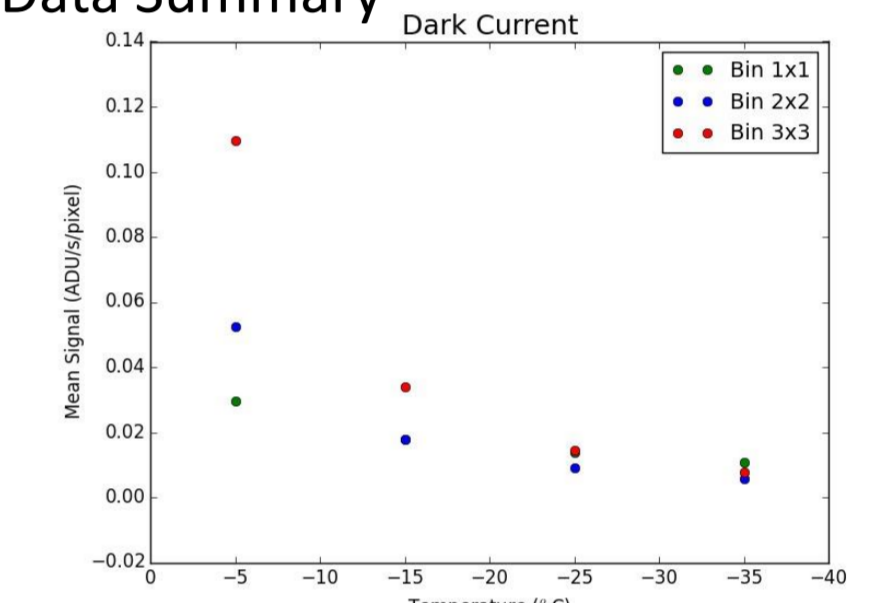

Figure 4. Bias level per frame

Figure 5. Dark Current as a function of temperature.

Conclusions

When collecting data it becomes imperative that one does not enter the non-linear region. This data set shows that the non-linearity and saturation point depends on the binning used. The reason behind this still remains a mystery. However it is clear that a correction to the variance calculation is needed.

Several models in the literature suggest that the non-linearity in the photon transfer curve is due to the spreading or sharing of charge between pixels. This interaction increases as the signal level increases. Since the signal level increases when binning is increased, Mark Downing's (2006) Spatial Autocorrelation Analysis or Bin Ma's (2014) Charge-Sharing PSF model corrections may also explain the lower saturation point when binning. Further investigation is required.
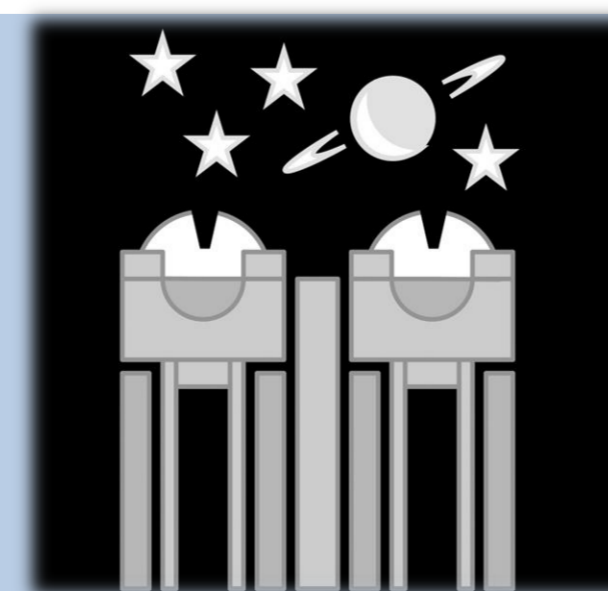
Acknowledgments

Contact

Mehrnoush (Jen) Zomederis
Department of Physics & Astronomy
Email: mzomeder@my.yorku.ca
Website: jenzomederis.com
Twitter: @JenZomederis

York University Astronomical Observatory

References

1. McCall, L.M., 1988, "The UTSO CCD", JRASC,83,179M
2. Richmond, M. "CCD Gain" http://spiff.rit.edu/classes/phys445/lectures/gain/gain.html
3. Santa Barbara Instrument Group,"Operating Manual CCD Camera Models " https://www.sbig.com/site/assets/files/18222/st78910man.pdf
4. BIG Astronomical Instrumentation, "STXL-6303E" https://www.sbig.com/products/cameras/stxl/stxl-6303e/
5. J.R. Taylor (1997). An Introduction to Error Analysis (2nd Edition)
6. Downing, M., et al. 2006, " CCD riddle: a) signal vs time: linear; b) signal vs variance: non-linear", SPIC Conference
7. Ma, B., et al. 2014, " The nonlinear photon transfer curve of CCDs and its effects on photometry", Astro-ph.IM, 1407.8280v1