

Characterization of the SBIG STL-1001E CCD Camera

Jason Arcido and Carlos Salgado
Rapid Response Robotic Telescope
Norfolk State University

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Abstract

We tested the characteristics of a SBIG STL-1001E camera for future use at the NSU's RRRT on Fan Mountain, VA. We performed bench measurements of the basic characteristics of the camera: gain or conversion factor, read-out noise, linearity, uniformity and dark current properties. The report is organized in three parts: first we shortly describe the construction of a low-level light source to produce flat frames; second, we explain the procedure to obtain and analyze the data; and finally, we discuss the results and compared them with manufacturer's specifications.

1 - Introduction

A Santa Barbara Instruments Group (SBIG) camera, model STL-1001E (1) was purchased on May 2006. It contains a 1024x1024 pixels, 24.6x24.6 mm, Kodak Enhanced KAF-1001E CCD chip. The main specifications are (2):

A/D Gain:	2.2 e-/ADU (16 bits)
Read Noise:	15 e- RMS
Dark Current:	34 e-/pixel second at 0 C (~1e-/pixel/second at -30 C)
Full well capacity:	150,000 e-
Full frame download (USB):	2.5 seconds

Each pixel in a CCD chip acts as a single light detector, converting incoming photons into electrons. For each pixel, the electric charge is collected and transformed to a digital signal measured in arbitrary units (ADU - Analog to Digital Unit) through the camera electronics. The conversion factor between electrons produced in a pixel and ADUs is called the pixel “gain”. Pixels are able to produce electrons even when no light is present. Those electrons are called “dark current” as they are produced when the CCD is not illuminated (dark). The electronic read-out introduces a minimum value of signal (ADUs) to prevent negative values on the digital output. This “pedestal” of the signal is called “bias”. All the aforementioned characteristics are “pixel dependent”. They also depend on several environmental factors being temperature normally the most important.

CCD astronomical cameras are used to measure the total number of photons incoming into a pixel in a given, known, amount of time (photon flux). Since the photon flux is affected by all the aforementioned transformations, we will need to make corrections to account for them. The corrections “calibrations”) are normally measured when data are taken. Procedures for data calibration of astronomical frames are explained in the literature [i.e. see (3) and (4)].

In this report, we will measure some of the camera characteristics in the lab (“bench”) to obtain a “bench-mark” characterization and test the initial performance of the camera against manufacturer’s specifications. We were also inspecting the camera to detect possible defects. This initial characterization should be follow for a “working” characterization of the camera, to be done closer to the working environment, with the camera attached to the telescope itself.

Certain amount of randomness, e.g., noise, is introduced in the photon flux measurements by all the phenomena mentioned earlier (read-out, electronic amplification and digitations, dark current). These factors contribute to the error in the measurement and need to be carefully monitored and measured.

To obtain the gain of a pixel we will assume that the photons arrive following a Poisson statistical distribution. Therefore, the variance of the counting distribution is equal to the average number of electrons in a pixel. We will also assume that the silicon chip

produces photoelectrons in a linear proportion to the number of arriving photons. We will test this linearity later.

Let's shortly discuss the production and components of a CCD signal when the chip is illuminated. If $\langle S_{pe} \rangle$ is the average number of photoelectrons accumulated in a given matrix of pixels (n x m) over an exposure time (NOTE: $\langle \rangle$ will indicate average over time *and* pixels), then the variance will be $\sigma_{pe}^2 = \langle S_{pe} \rangle$. We are only able to measure the “sum of all electrons produced”. If $\langle S_e \rangle$ is the average total number of electrons; $\langle S_{pe} \rangle$ is the average number of photoelectrons (produced by the incoming photons); $\langle S_{dc} \rangle$ is the average number of electrons produced by the pixel independent of illumination (dark) and $\langle S_{ron} \rangle$ is the average number of “electrons” introduced by the read-out noise, then:

$$\langle S_e \rangle = \langle S_{pe} + S_{dc} + S_{ron} \rangle$$

Let's call σ_e^2 , the variance of the S_{pe} distribution, therefore:

$$\sigma_e^2 = \sigma_{pe}^2 + \sigma_{dc}^2 + \sigma_{ron}^2 \quad \{1\}$$

Normally, the “dark” signal is subtracted from the measurements after is independently measured, the “dark-subtracted (DS)” sum is then, $\langle S_e^{DS} \rangle = \langle S_e \rangle - \langle S_{dc} \rangle \gg \langle S_{ron} \rangle$, therefore we can use $\langle S_e^{DS} \rangle \cong \langle S_{pe} \rangle$.

Our definition of *gain*, g, is the transformation of electrons to ADUs (e-/ADU), therefore:

$$\langle S_e \rangle = g \langle S_{ADU} \rangle,$$

where $\langle S_{ADU} \rangle$ is the digitalized measured value of $\langle S_e \rangle$, and

$$\sigma_e^2 = g^2 \sigma_{ADU}^2 \quad \{2\}$$

Using that $\sigma_{pe}^2 = \langle S_{pe} \rangle = g \langle S_{ADU}^{DS} \rangle$ and relation {2} in expression {1}:

$$g^2 \sigma_{ADU}^2 = g \langle S_{ADU}^{DS} \rangle + \sigma_{dc}^2 + \sigma_{ron}^2, \quad \text{or}$$

$$\sigma_{ADU}^2 = \frac{1}{g} \langle S_{ADU}^{DS} \rangle + \frac{1}{g^2} (\sigma_{dc}^2 + \sigma_{ron}^2) \quad \{3\}$$

This relation is called “*Transfer Curve*”. If our assumptions are correct, a plot of $\langle S_{ADU} \rangle$ versus σ_{ADU}^2 should give us a linear relation with the slope equal to the inverse of the gain.

There types of data images were used in the analysis:

FLAT FRAME: uniformed illuminated images (all pixels receive equal number of photons). Different time integrations, illuminations and temperatures were used.

BIAS FRAME: Zero-time exposure images. Signal coming ONLY from read-out contribution, pedestal or bias plus read-out noise. Different temperatures were used.

DARK FRAME: Shutter close – no-illumination on the chip. Different time integrations and temperatures were used.

Since we had averaged over pixels to find camera characteristics, at the end, we will need to compare pixel-to-pixel (chip uniformity) to measure the contribution of non-uniformities to our measurements. The characterization of the camera on this report contains the following:

- Inspection of Bias/Dark/Flat Frames.
- Transfer curve.
- Gain or conversion factor.
- Read-out noise.
- Dark current.
- Linearity.
- Uniformity.

2 - Low-level Light Source

To obtain flat frames, a low-level light source was built following the directions in Berry and Burnell book (4) chapter 6. Our purpose is to obtain a stable, low-level, adjustable and uniform illumination source.

A wooden box was made of 1/2 inch thick wood, 6 inches on the side and 16 inches long (plywood was too brittle to cut and handle). The full view of the box is shown in figure 1. The box was painted black (mate) from the inside and all borders were light-sealed with an optical black tape. At one end of the box was the light source and at the other the CCD camera.

The light source was achieve through nine green LEDs connected in parallel and powered through the circuit shown in diagram I (see also figure 2 for a view of the light source setup).

To insure a constant light source, the current through the LEDs is held by a LM317T adjustable voltage regulator. We used nine “green LEDs” connected in parallel to the source. The electric connections are shown in diagram I.

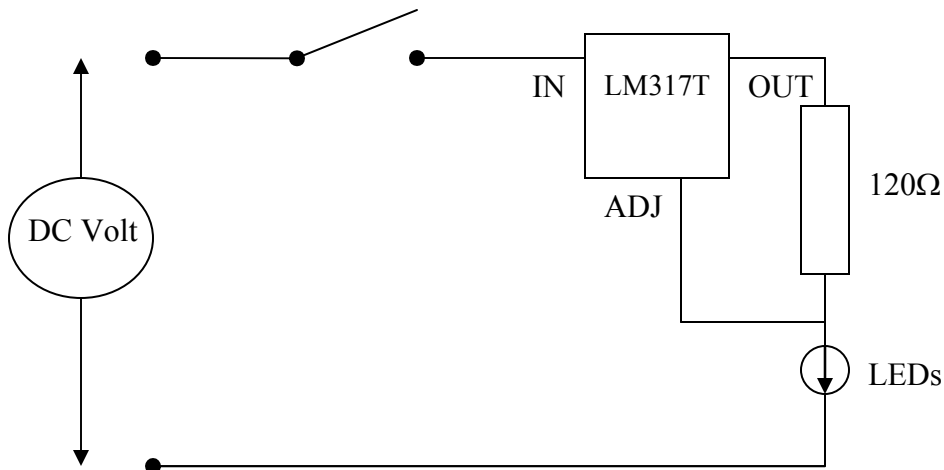


Diagram I : Light Source (4)

Two diffusing screens were mounted inside the box (made of “milky-glass”), one close to the LEDs end, and other close to the camera end. In between the diffusing screen, the “aperture” buffers were placed. Figure 3 shows the layout of diffusing screens and buffers inside the box. The buffers have different size holes drilled at their centers. Using different buffers (we called “apertures”) we are able to control the illumination from the LEDs going through the box to the CCD chip. The illumination could be also controlled by changing the voltage (we used the NSU’s lab DC power system).

The camera was coupled to the box through the 2” nosepiece that came with the camera. Several positions of the buffers, diffusing screens and voltages were tried until illuminations and voltages were acceptable. As it is discussed later, the system provided a reasonable stable and uniform chip illumination for our measurements. At least for the half square of the chip center (see data taken session).

The apertures (diameters) were:

- A0 = 3” ½
- A1 = 1” ½
- A2 = 1” ¼
- A3 = ¼”
- A4 = 2 x ¼”
- A5 = 1/8”
- A6 = 2 x 1/8”
- A7 = 1/16”



Figure 1: Low-level Light Source: view of full box.



Figure 2: Low-level Light Source: Light source.

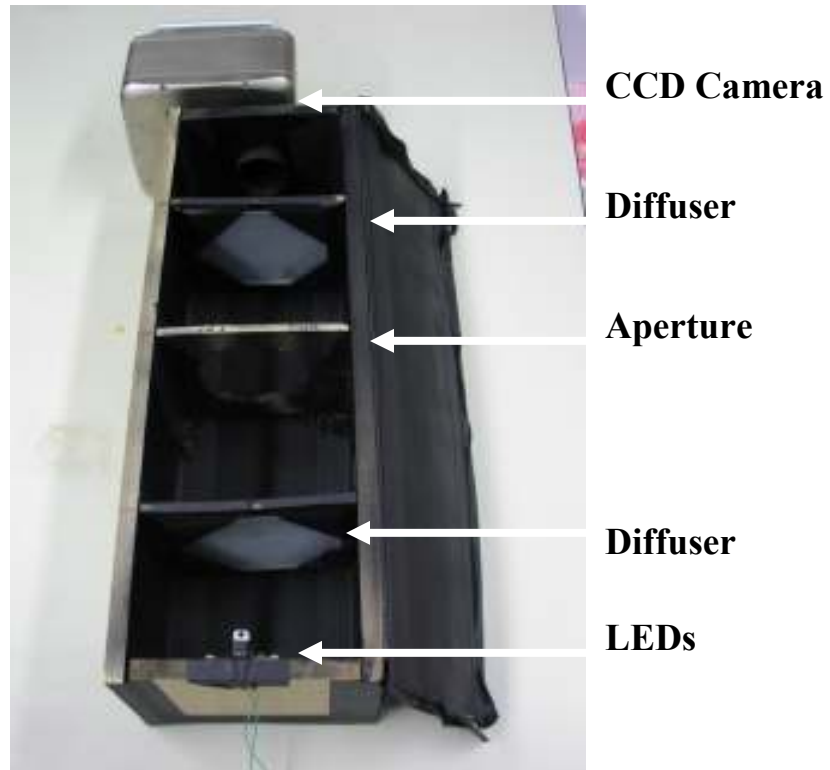


Figure 3: Low-level Light Source: Inside the box/Aperture.

3 - Data Taken Process

I. Procedure for taking the images (using CCD-Soft Version 5):

There were FOUR variables taken into consideration while taking images of FLATs, BIASes, and DARKs: (a) *Exposure Time*, (b) *Light Aperture*, (c) *Light Intensity (Voltage to LEDs)* and (d) *Temperature*.

1. Set camera temperature and wait until equilibrium.
2. Take ten BIAS frames (before, after and during measurements).
3. Take five 3 s DARK frames.
4. Take 3-5 FLATS for each variable change:
 - (a) *Exposure times* were taken in this order: 1, 3, 5, 7, 9, 10, 8, 6, 4, 2, 0.5, 0.25 seconds (using A0, -10°C, and 10V).
 - (b) *Light apertures* were taken in ascending order from A0 to A7 (using an exposure of 5 seconds, -5°C, and 10V).
 - (c) *Voltages* were taken at 3, 5, 7, 10, and 15 V (A0, -5°C, and 5 seconds).
 - (d) *Temperatures* were taken at 10, 5, 0, -5, -10, -14 C (A0, 3 seconds, and 10V).
5. We took at least one dark for each set of flats. (Dark's exposures should match light exposures times).

II. Observations on the Procedure on taking images:

1. For easier notation and tracking of images taken, we set the autosave option and set label of images to take in consideration variable factors. Example of labeling: T-10V10A0S20, where this shows that the temperature was set at -10 C, the voltage at 10 V, and using aperture A0 with an exposure time of 20 seconds.
2. To get to camera control holds Ctrl +W. Temperature regulation is under set up tab; make sure to check options on AutoSave tab.
3. When taking an image use the take image tab and set the desired type of frame (BIAS, FLAT, or DARK) and time settings and number of images taken.
4. Note on timed exposures: for short exposure times (1s or less), do not use series as the camera download time is 2.5 s and may cause stalled response; instead take individual images.

The data show here were collected on two days, July 10 and 12, 2006.

4 – Data Analysis

The data analysis was primarily done using the software MaxIm-DL (5) following procedures detailed in references (4) and (6).

I Calibration of Flats

0. Create copies of images and store in folders of FLAT, DARK, and BIAS.
1. From top menu go to Process > Calibration Wizard > set for Regulated temperature > Automatic > choose a working copy of ALL images taken (make sure each data set where different variables are adjusted is done separately) > Select Calibrate Bias, Calibrate Dark, Dark Subtract Bias, Dark Subtract Flats, and Bias Subtract Flats checkboxes > Remove any folders/directories from screen that include flats > Use auto-scale settings and Median combine type > click OK
2. Go to Process > Create Master Frames and save all BIAS and DARK frames in FITS IEEE Floating Point format.
3. Open all the FLAT frames. Go to Process > Calibrate All. Save as new file names or in a folder noting that images were BIAS and DARK frame subtracted.

II Measure the Flat's Variance

A perfect uniform illumination of a CCD chip is very hard to archive. To eliminate non-uniformities, we used the “difference-of-two-flats” technique (4). Subtracting two flats made on the same conditions will, in principle, only conserve the fluctuations and flatten the non-uniformities. We then measure the variance of this subtracted image and divide it by two (as the fluctuations of both images were added in quadrature over the subtraction). The result is the flat's variance.

Only central regions of the images were used in the measurements. In this region the illumination was very uniform. Figure 4 shows a typical flat distribution close to the

frame center (this is a x-axis cross section). Figure 5 shows a histogram for pixels included in a 300x300 square centered at the frame center. The histogram is represented very well by a Gaussian distribution (see results).

1. Open a set of FLAT frames (usually a group of 3) and go to Process > Combine > Add All > Median Output > save as new file.
2. Click on 3rd Flat then go to Process > Pixel Math > Operation-Subtract (choose first two Flats to subtract) and enter 65535 to be added > save as new file (Maxim DL truncates negative numbers - only recognizes positive numbers! - , this addition is done to avoid negative numbers during subtractions).
3. Find the standard deviation (view>information window) of the subtracted image distribution, squared it and divide by two.

III. Data Analysis:

The final data analysis and plotting was done using Windows Excel software. The Excel datasheet with plotted result values is attached in Appendix A.

1. Plotting Transfer Curve
 - A. Set a table with the following data: Flat Set, Exposure Time (seconds), Mean PV (ADUs), Variance, and Count Rate (ADUs/sec)
 - i. The variance is found by squaring the standard deviation of subtracted frames and dividing by two.
 - ii. Count rate is Mean PV/Exposure Time
 - B. Create a Graph using Variance as Y-axis and MPV as X-axis.
 - C. The inverse of the slope gives the conversion factor and the intercept gives the noise (a more precise measurement for noise can be found analyzing the BIAS frames – see below).
2. Plotting the CCD Linearity Curve
 - A. We took variable exposure times sets in an increasing and decreasing order to decouple exposure dependence from light source variations.
 - B. Separate data into two sets: increasing and decreasing order, and plot rate versus integration time.

5 – Results

(a) Bias Frame Inspection.

The Bias frames were inspected for “wavy patters” (electronic interferences), “popcorn noise” (camera electronics), random “burst noise” and “hot” regions. None were found. However, a small systematic effect was observed, figure 4, producing a slightly increased bias value to the left of the chip (lower x values). This effect is uniform in y for the whole chip and, as show in the figure, it is less than 10% at the maximum. The value of the bias (center frame) for operating temperatures (-10°C) is of about 110 ADUs, increasing to values of about 165 ADUs at room temperatures (see figure 16).

(b) Dark Frame Inspection.

No special patterns were observed on dark frames. Figure 5 shows the middle section distribution of counts in a 30 seconds dark frame exposure at operating temperatures (-10°C). It does show the systematic raise on the left due to the increased bias that can be easily corrected at dark subtraction and very other few pixels with excessive (but moderated) counts. This cross section is representative of the whole frame.

(c) Flat Frame Inspection.

Figure 6 shows a $\{x\}$ cross section distribution of counts in the middle $\{y\}$ of the frame, in a 7 seconds flat frame exposure, at -10°C , using A0 at 10 volts. Similar distributions are seen for other $\{x\}$ values and on $\{y\}$ cross section representing rotation symmetry respect to (approx.) the frame center. This indicates that the chip was not perfectly uniform illuminated. The sides are less illuminated due, perhaps, to the narrow 2" nosepiece that was used to connect the camera to the low-level light source box. This difference in response (if attributed entirely to illumination) is of about 5% at the maximum. For all our measurements we decided to take the central half of the chip (300 x 300 pixels central region), where the non-uniformities are of less than 1%.

Figure 6 shows a central region count histogram. The count statistics in this region is very well represented by a Gaussian distribution, therefore, the statistical assumption of representing the noise by the standard deviations (SD) is well funded.

To obtain the variance (SD squared) of the Flat frame distributions we used the method of the "flat-differences" (4). Figure 7 shows a $\{x\}$ cross section at the center $\{y\}$ of the frame of the counts (+ 65635 ADUs) for the difference between two flat frames. The value 65635 (maximum ADU value) is added to avoid negative values. Figure 7 shows that the flat difference is mostly "constant" over most of the frame. We used this "difference frame" to find the count distribution variance.

(d) Transfer Curves and Gain.

The gain defines the transformation from electrons to ADUs ($g : e^-/\text{ADU}$). We used the method of the "transfer curve" to measure the gain. The transfer curve is the relation between the measured noise (SD or variance) and the mean or average count value (in ADUs) in a pixel region uniformly illuminated (Flats). As we explained in the introduction, the gain (g) is the inverse of the slope of such transfer curve.

We were able to change the illumination on the CCD chip by three different methods: changing the exposure time (figure 9), changing the apertures (figure 10) or by changing the voltage to the LEDs (figure 11).

In figure 9 there are 12 data points corresponding to exposures of 0.25, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 seconds using A0, -10°C , and 10 volts. The relation between the variance and the average count is very linear confirming our assumptions to derive equation (3). The fitted slope value is 0.4778, given a value of $g = 2.09 \text{ e-/ADU}$.

In figure 10 there are 6 data points corresponding to apertures A0 to A7 taken with a 5 seconds exposure, -5°C , and 10 volts. The relation is also very linear confirming to our assumptions to derive equation (3). The fitted slope value is 0.4784, given a value of $g = 2.07 \text{ e-/ADU}$.

In figure 11 there are 4 data points corresponding to voltages of 5, 7, 10, and 15 V using A0, -5°C , and an exposure of 5 seconds. The fitted slope value is 0.4852, given a value of $g = 2.06 \text{ e-/ADU}$.

Using these three measurements we obtained a value of $g = 2.073 \pm 0.015 \text{ e-/ADU}$. The manufacturer's specification value is $g = 2.2 \text{ e-/ADU}$. This is a averaged value, taken for all the 300×300 pixels of the chosen region. This value can also be dependent on environmental variables (temperature ...) that were not explored in this test. The pixel-to-pixel variations will be discussed below.

(e) Linearity.

A CCD camera should be linear, e.g, the obtained signal should be linearly proportional to the number of incoming photons. For a constant light source, linearity implies that there should be a constant rate of signal increase with time exposure.

Figure 12 shows the rate of increase in the signal (ADUs/second) versus exposure time. The figure shows that the rate is mostly independent of exposure time over the range of exposures used in this report. We show two curves as the measures were done in ascending and descending exposure times order. Since the light source could be not totally stable, points that are taken further apart in time may not have repeat the same rates. We found that the maximum difference is less than 0.5%. The camera is, then, pretty linear in this regime. Close to saturation or with less illumination the camera could become less linear. We have not explored those extremes in this test.

(f) Temperature dependence and Dark Current.

The silicon in a pixel is able to produce electrons even if it is not illuminated. This capacity is function of several environmental parameters, but most important: temperature. "Dark frames" need to be measured at the same conditions that "light frames" (flats in this case) are taken and be subtracted from the images. Figure 13 shows how this procedure worked fine in our case. The figure shows a dark subtracted flat. The average ADUs counts are independent of temperature.

Figure 14 shows the mean counts versus temperature in a dark frame of 3 seconds exposure (no bias subtracted). There is a clear increase of the dark current with increasing

temperature. We can notice that in the limit of low temperatures we obtained the value of 110 ADUs counts of the bias.

We also notice that there is not very pronounced improvement after the temperature has reached a value of about -5°C. The camera will not cool below -15°C using only its thermo-electronic (Peltier effect) cooling. The camera is able to use also a water circulation assisted cooling that the manual claims can bring the temperature to -50°C below ambient temperature. We did not use this system in our test.

We used -10°C as the operating temperature of the camera using the thermo-electronic cooling. The system kept the temperature reading constant at this value.

At the operating temperature, the measured average dark current is:

$$\langle S_{DC}^{corr} \rangle = \frac{(\langle S_{DC} \rangle - \langle S_{bias} \rangle) * g}{\text{Exp time}} = \frac{(112 - 110) * 2.07}{3} \approx 1.4 \text{ e}^- / \text{pixel}/\text{sec at } -10^\circ\text{C}$$

The manufacturer's dark current specification is ~1e-/pixel/second at -30 C.

(g) Read-out Noise.

The read-out noise (σ_{ron}) is introduced in the signal by the camera electronics. The bias frame measured the electronic introduced pedestal and accompanying noise, Figure 15 shows how the read-out noise, expressed by the bias variance, is temperature dependent. The read-noise is given by $\sigma_{ron} = g * \sqrt{\text{Variance}}$. At operating temperatures:

$$\sigma_{ron} \cong 2.07 * \sqrt{87} = 19.3 \text{ electrons RMS}$$

The manufacturer specification is of 15 electrons RMS, but no temperature is specified for this value.

Figure 16 shows how the value of the bias itself changes with temperature, from about 110 ADUs at operating temperature up to about 160 ADUs at room temperatures.

(h) Uniformity

A typical flat frame distribution is shown in figure 6. The difference between counts values is less than 5% at the maximum. A 300 x 300 center frame square, smaller region of the frame, shows typical differences of less than 1%. These are normal values for this type of CCD chip (3).

6 –References

- (1) <http://www.sbig.com/sbwhtmls/online.htm>
- (2) SBIG Astronomical Instruments, Operating Manual, STL-1001E Camera, (2003).
- (3) Steve B. Howell, Handbook of CCD Astronomy, Cambridge University Press, (2000).
- (4) Berry, Richard & James Burnell, The Handbook of Astronomical Image Processing, Willman-Bell Inc, (2000).
- (5) Maxim DL: An Advanced CCD Imaging Software; Manual Vol. 4, Diffraction Limited, (2006).
- (6) McDavid, David, Characterizing the SBIG ST-1001E CCD Camera – Lab Exercise #3, University of Virginia, AST313, (2005).

Appendix A: Excel Datasheet

Variable Exposure - FLAT	Exp (s)	AVG PV	variance	Count Rate	sd	error
	1.00	5920.00	2741.41	5920.00	74.05	76.94
	3.00	17643.79	8549.35	5881.26	130.762	132.83
	5.00	28772.53	13972.40	5754.51	167.17	169.62
	7.00	40427.66	19639.04	5775.38	198.19	201.07
	9.00	51557.12	24649.55	5728.57	222.03	227.06
	10.00	57186.25	26878.83	5718.62	231.86	239.14
	8.00	45603.91	22078.36	5700.49	210.14	213.55
	6.00	33827.77	16408.39	5637.96	181.15	183.92
	4.00	22312.30	10834.95	5578.08	147.21	149.37
	2.00	11294.69	5284.43	5647.34	102.81	106.28
	0.50	2973.75	1408.74	5947.51	53.08	54.53
	0.25	1543.28	771.34	6173.12	39.28	39.28

GAIN

2.09

Variable Aperture - FLAT	Exp (s)	AVG PV	variance	Count Rate	sd	error
A0	5.00	28772.53	13972.90	5754.51	167.17	169.62
A1	5.00	20973.35	10229.36	4194.67	143.03	144.82
A2	5.00	16292.61	7756.85	3258.52	124.55	127.64
A3	5.00	664.01	349.06	132.80	26.422	25.77
A4	5.00	1048.73	516.39	209.75	32.14	32.38
A5	5.00	233.29	140.65	46.66	16.77	15.27
A6	5.00	274.81	164.51	54.96	18.14	16.58

GAIN

2.07

Variable Voltage - FLAT	Exp (s)	AVG PV	variance	Count Rate	sd	error	
	3	5	99.264	78.24	19.85	12.509	9.96
	5	5	1716.928	856.73	343.39	41.394	41.44
	7	5	9357.708	4611.55	1871.54	96.037	96.74
	10	5	29539.436	14362.58	5907.89	169.485	171.87
	15	5	65517.109	0.00	13103.42	0	

GAIN

2.182453077

Va Temperature - FLAT	EXP (s)	AVG PV	variance	Count Rate	sd	error	
	10.00	3.00	18281.47	8885.38	6093.82	133.31	135.21
	5.00	3.00	18320.69	8892.84	6106.90	133.36	135.35
	0.00	3.00	18441.33	8987.78	6147.11	134.07	135.80
	-5.00	3.00	18249.32	8806.77	6083.11	132.72	135.09
	-10.00	3.00	18230.84	8902.05	6076.95	133.43	135.02

-14.00	3.00	18303.55	8969.56	6101.18	133.94	135.29
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Var Temp - Dark Frames	Exp (s)	AVG PV	variance	Count Rate	SD	error
20.00	3.00	218.49	346.93	72.83	18.63	14.78
10.00	3.00	138.25	145.47	46.08	12.06	11.76
5.00	3.00	125.60	115.18	41.87	10.73	11.21
0.00	3.00	118.60	92.22	39.53	9.60	10.89
-5.00	3.00	113.98	82.63	37.99	9.09	10.68
-10.00	3.00	111.93	77.74	37.31	8.82	10.58
-14.00	3.00	110.67	76.93	36.89	8.77	10.52

Var Time - Dark Frame	Exp (s)	AVG PV	variance	Count Rate	SD	error
	1.00	109.44	119.14	109.44	10.92	10.46
	3.00	111.39	75.99	37.13	8.72	10.55
	5.00	114.16	80.80	22.83	8.99	10.68
	7.00	117.82	85.67	16.83	9.26	10.85
	9.00	123.13	92.91	13.68	9.64	11.10
	10.00	124.02	99.56	12.40	9.98	11.14
	8.00	123.74	89.26	15.47	9.45	11.12
	6.00	119.46	83.10	19.91	9.12	10.93
	4.00	114.38	76.27	28.60	8.73	10.70
	30.00	132.39	283.52	4.41	16.84	11.51
	0.50	110.38	75.31	220.75	8.68	10.51
	0.25	107.83	74.67	431.30	8.64	10.38

Bias Check	Temp.	AVG PV	SD	variance
	-14.4	109.519	9.417	88.679889
	-13.96	108.959	10.507	110.39705
	-13.96	110.049	9.418	88.698724
	-14.4	109.138	9.517	90.573289
	-14.4	115.333	3.091	9.554281
	18.99	163.389	20.805	432.84803
	19.5	164.49	21.545	464.18703
	18.5	158.644	20.531	421.52196
	20	166.65	22.304	497.46842
	18.5	159.697	19.833	393.34789
	-10.2	108.637	9.572	91.623184
	-9.79	106.214	8.456	71.503936
	-10.2	112.512	11.546	133.31012
	-9.79	110.817	9.583	91.833889
	-9.78	110.484	9.359	87.590881
	-9.79	109.542	9.375	87.890625
	-9.78	109.84	9.472	89.718784
	-9.79	107.462	9.834	96.707556

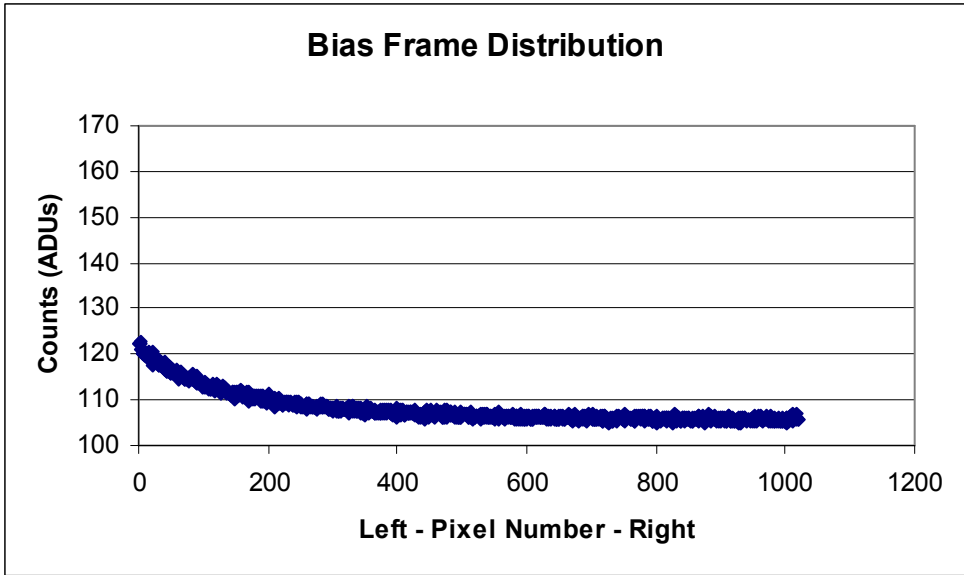


Figure 4: Bias Frame: Counts versus Pixel number (in x) at the frame center.

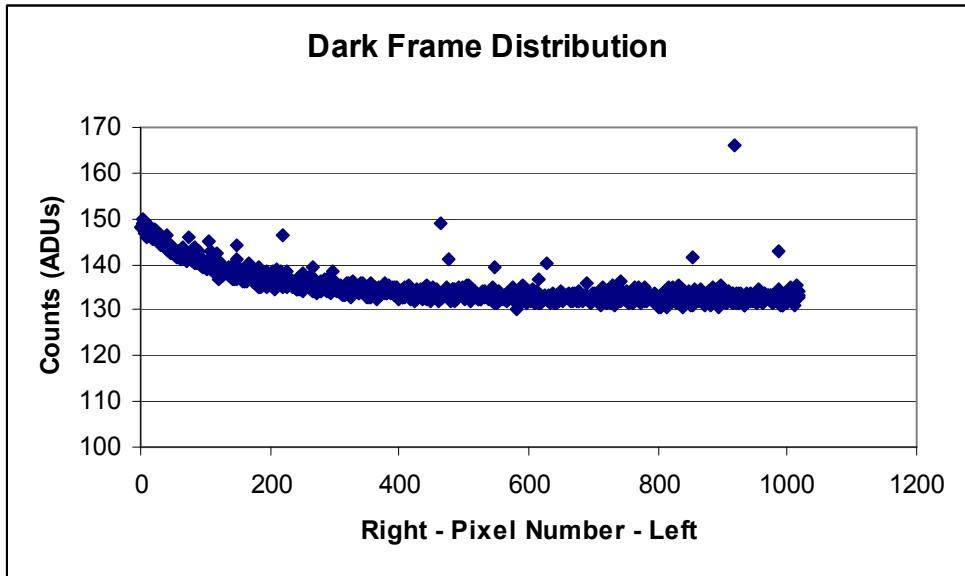


Figure 5: Dark Frame: Counts versus Pixel number (in x) at the frame center (NO bias correction).

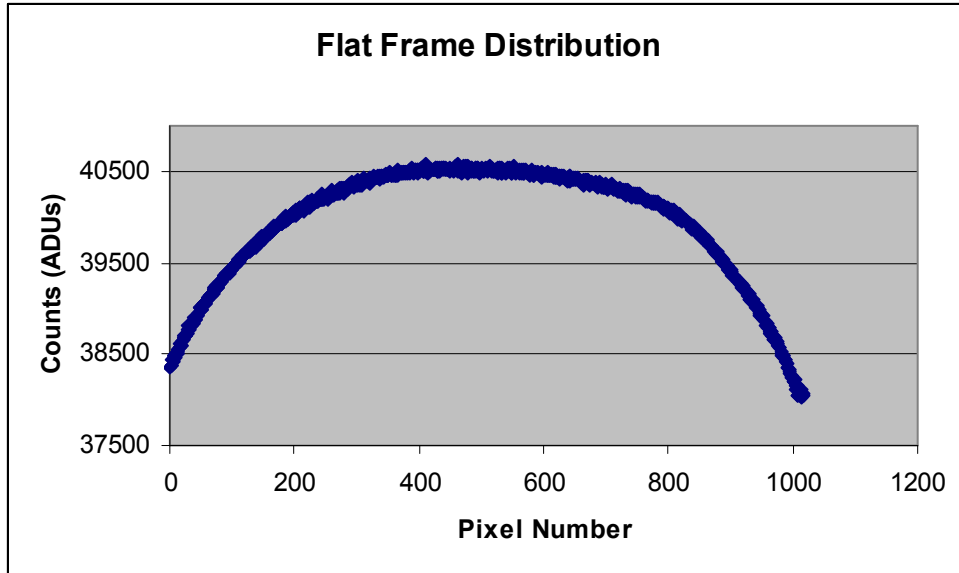


Figure 6: Flat Frame: Counts versus Pixel number (in x) at the frame center (NO corrections).

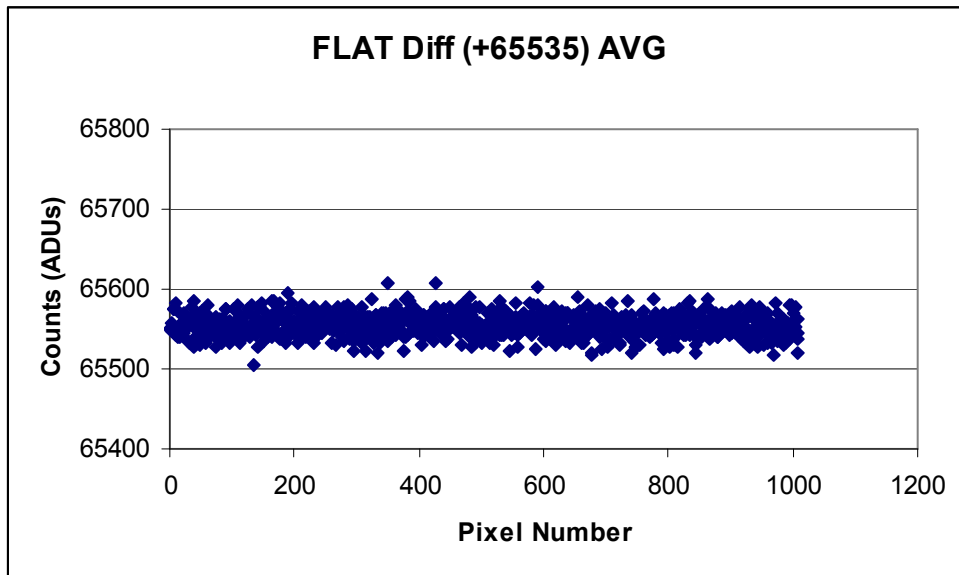


Figure 7: Flat Frame Difference: Counts versus Pixel number (in x) at the frame center.

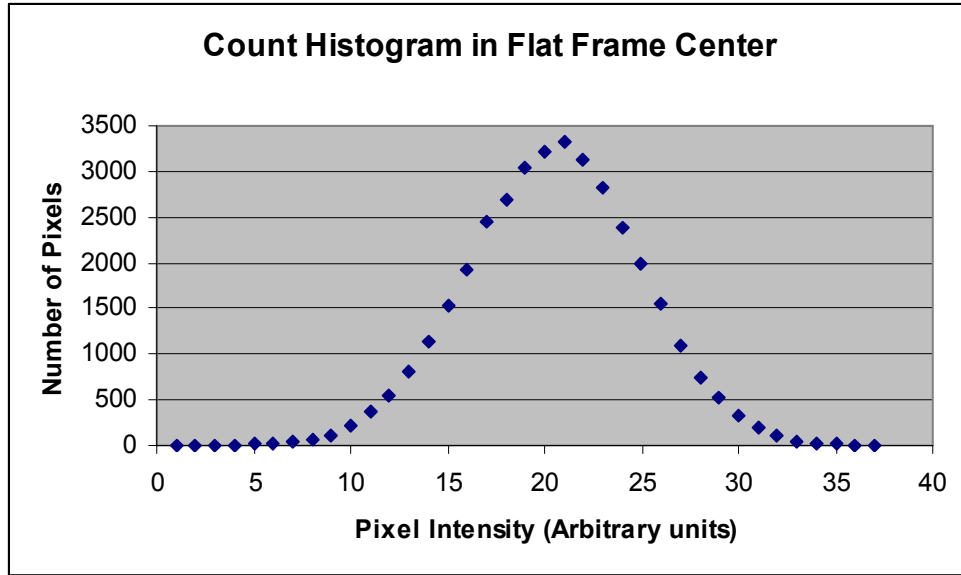


Figure 8: Flat Frame: Pixel Intensity histogram in central frame region.

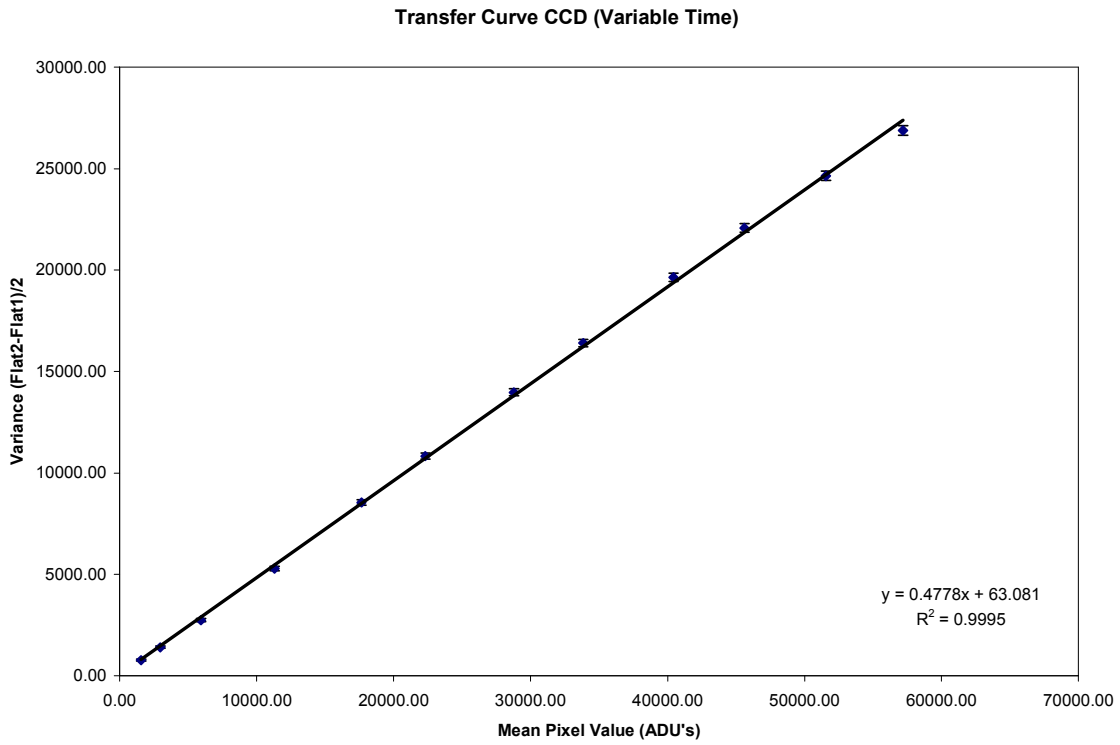


Figure 9: Transfer Curve. Intensity variation by exposure time (see text).

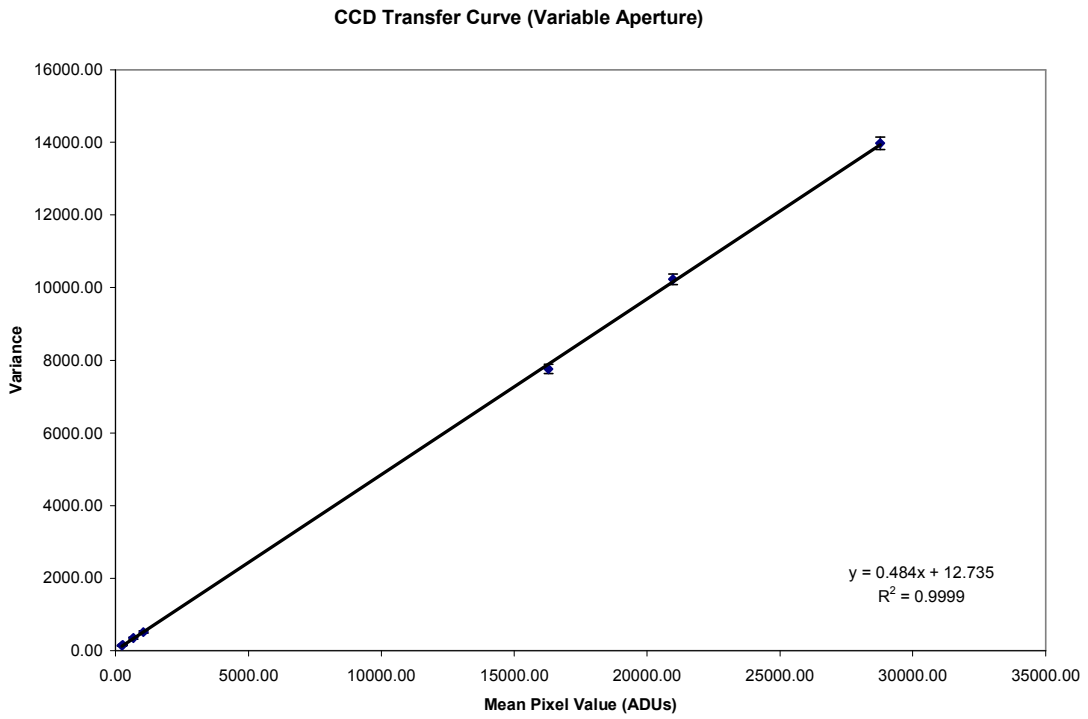


Figure 10: Transfer Curve. Intensity variation by aperture (see text).

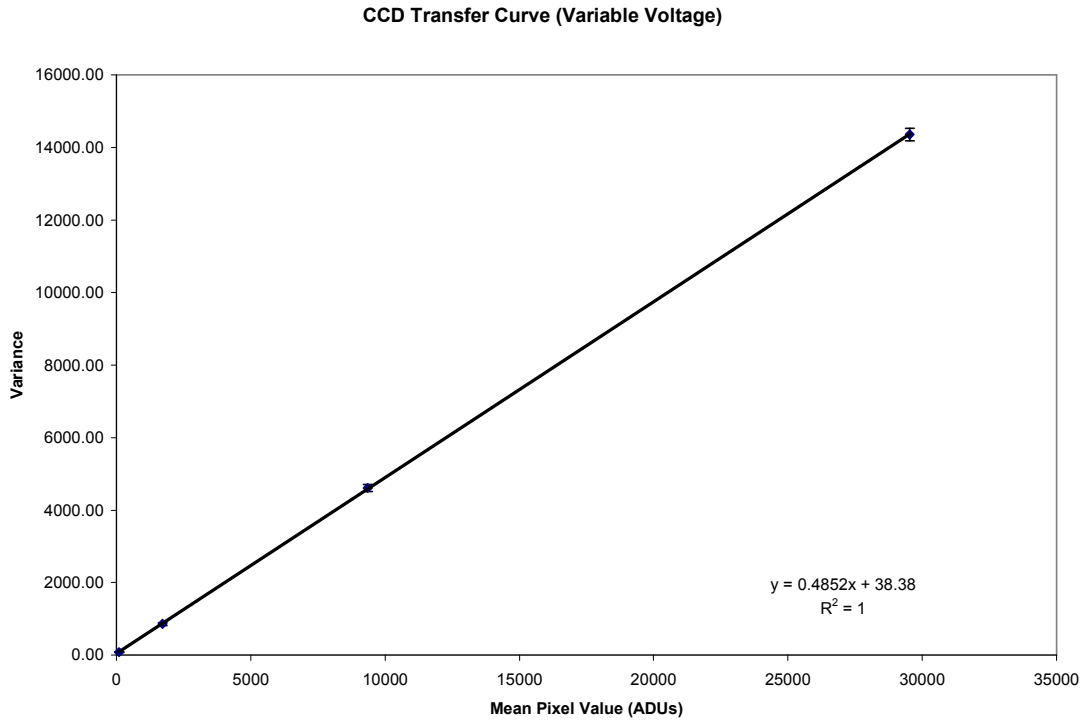


Figure 11: Transfer Curve. Intensity variation by voltage (see text).

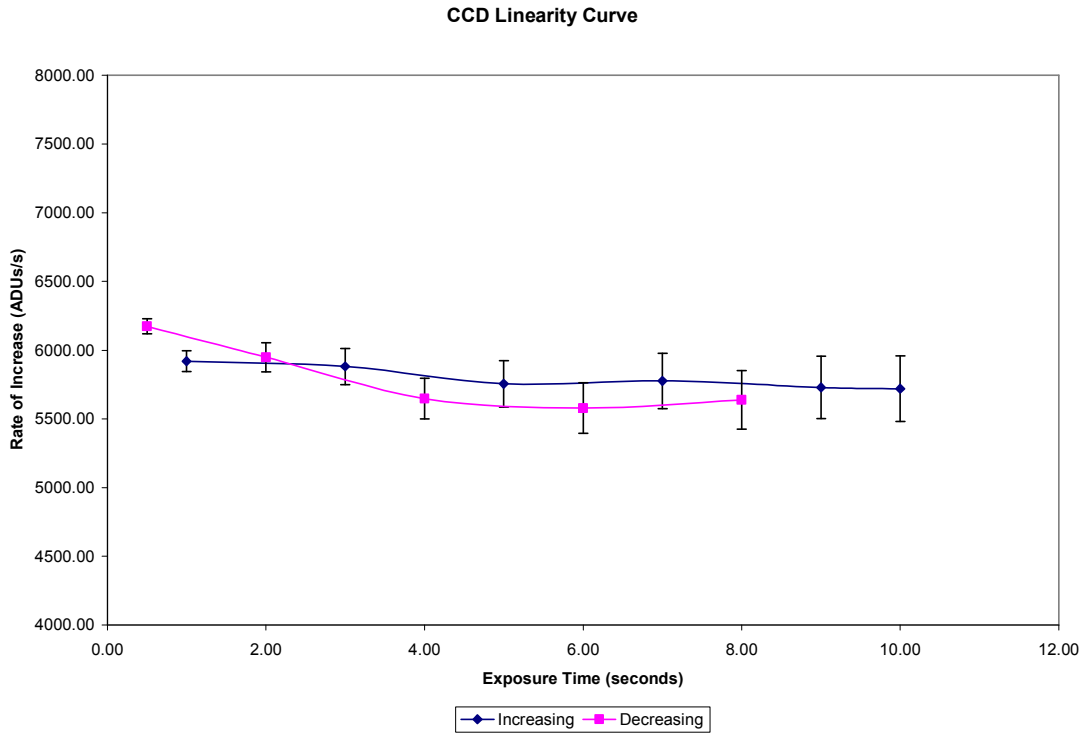


Figure 12: CCD Linearity. Rate of count increase versus time exposure (see text).

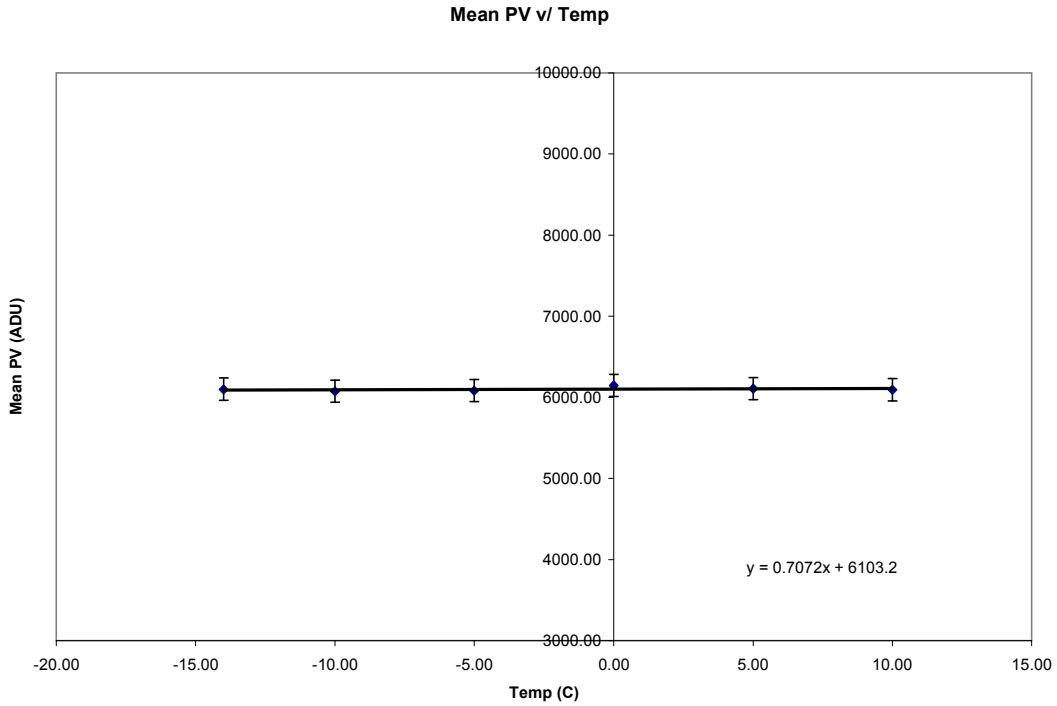


Figure 13: Temperature dependence of dark corrected flats.

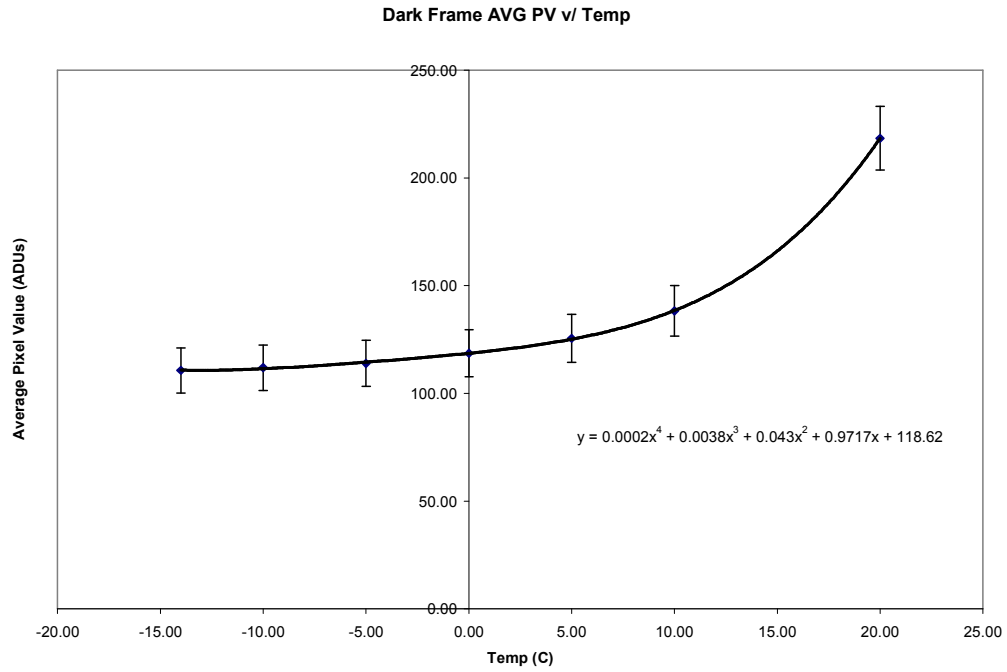


Figure 14: Temperature dependence of dark current (see text).

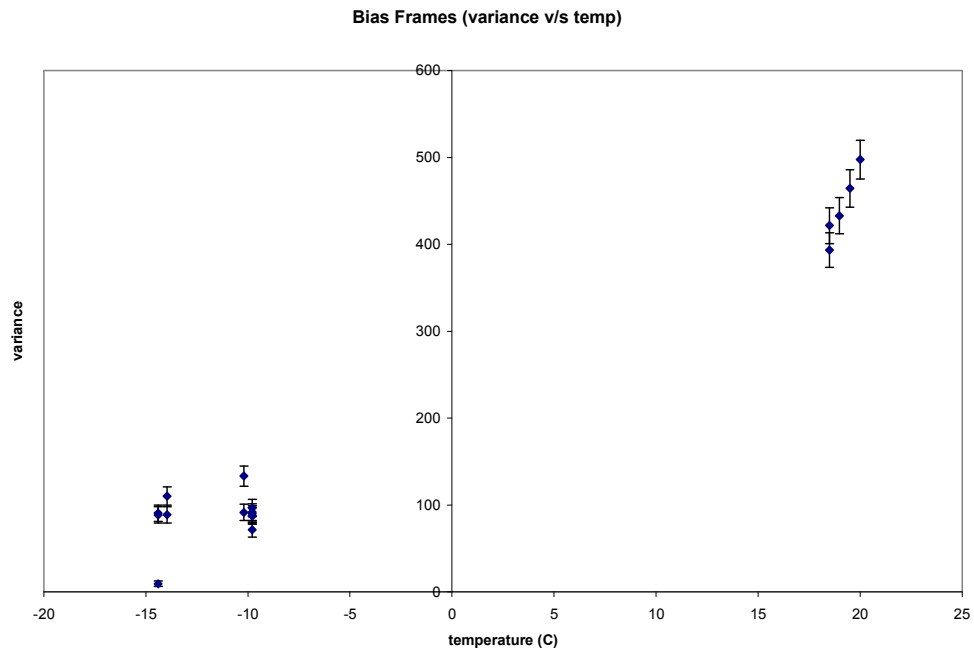


Figure 15: Bias frame noise dependence on temperature (see text).

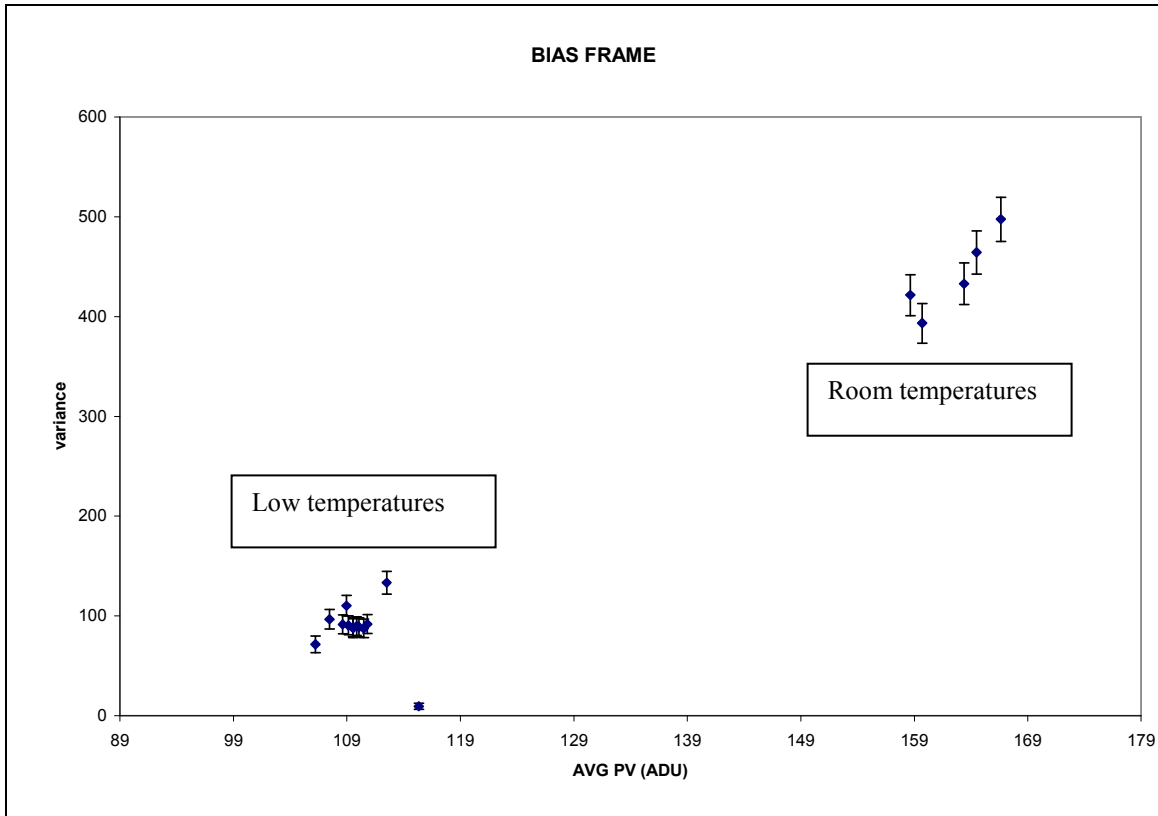


Figure 16: Bias values versus temperature (see text).