CCD Test Report

STA1042 Device Serial Number 5644

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1. Description

The STA1042 CCD device, serial number 5644, was tested in the B-8A lab at NOAO during the period of Feb. 5-15, 2008. The device was tested in the “UGD” dewar with the test interface “snout” attached (see photo below). A MONSOON system was used as the CCD Controller/Image Acquisition System for all tests conducted.

Figure 1 - Lab setup for the STA1042 tests: The test dewar is connected to the integrating sphere and the image projector is visible to the left. The MONSOON DHE is the white box, the UGD is to the right of the DHE, the test interface “snout” is the bright aluminum interface between the dewar and I-sphere.

2. Optimum Operating Parameters

2.1. Parallel Clock Voltage Levels

Signal	Low Voltage	High Voltage
P1	-7.5	2.0
P2	-7.5	2.0
P3	-7.5	2.0
TG	-5.0	3.0

The STA1042 device is very sensitive to the level of the parallel clock swings. If the swing is greater than the 9.5V range as set per the optimized table above, a top-to-bottom gradient becomes evident along the active columns of the device. E.g. a 10.5V range on the parallel clocks creates a 50 e- gradient.

Timing for the parallel clocks is optimized with a 20 us phase overlap during readout and a 10 us phase overlap during clearing.

2.2. Serial Clock Voltage Levels

Signal	Low Voltage	High Voltage
S1	-5.0	5.0
S2	-5.0	5.0
S3	-5.0	5.0
SW	-5.0	5.0
RG	-2.0	6.5

Timing for the serial clocks is optimized with a 250 ns phase overlap during readout and clearing sequences.

2.3. Bias Voltage Levels

Signal	Voltage
VOD	27.0
VRD	15.5
VOG	0.5
SUB	AGND

The drain voltage of the output amplifier (VOD) has a very wide operating range. However, as shown in the following plot of typical STA1042 performance, the gain of the output increases with VOD and gives better noise performance, so the voltage for this bias is set near the maximum safe operating level (28V max).

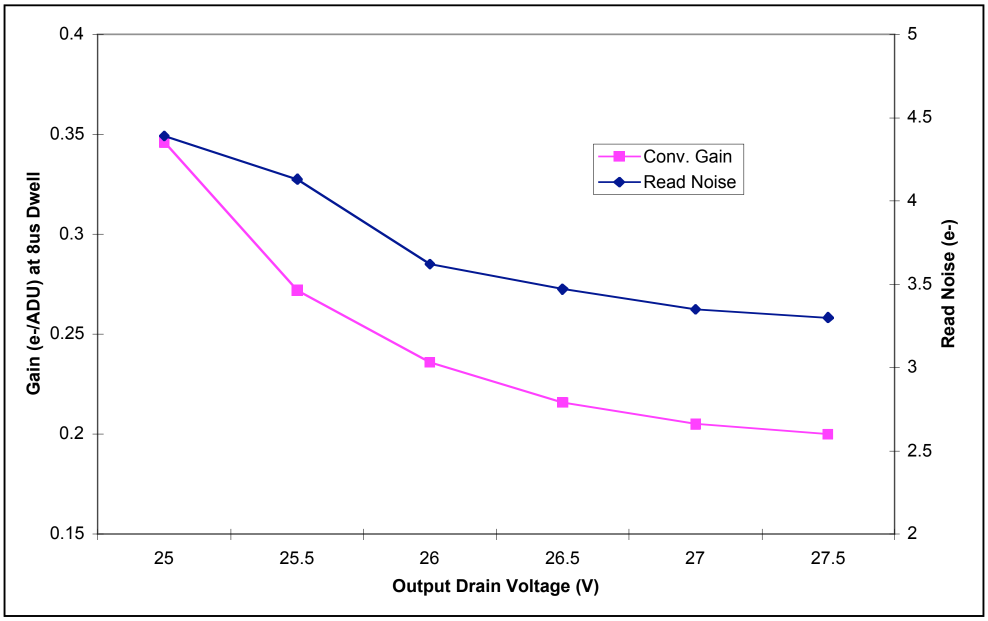

Figure 2 - STA1042 Output Amplifier Characteristics: This plot shows the gain and noise characteristics of a typical STA1042 amplifier.

The drain voltage of the reset amplifier (VRD) has a very narrow operating range and changes in this voltage of 0.25V in either direction will increase the noise performance of the device.

3. Performance Summary

The following table summarizes the performance characteristics of the STA1042-5644 device. Greater details about the tests and measurements are contained in following sections.

Output	Left Amplifier			Right Amplifier		
Dwell	2us	4us	8us	2us	4us	8us
Conversion Gain (e-/ADU)	0.854	0.428	0.214	0.874	0.438	0.219
Readnoise (e-)	4.4	4.1	3.6	4.3	3.7	3.3
Full Well	85,000 e-			87,500 e-		
1% Linearity	Up to 70,000 e-			Up to 63,000 e-		
0.2% Linearity	Up to 10,000 e-			Up to 10,000 e-		
VCTE	Not measured			0.9999998		
HCTE	Not measured			0.9999996		
Dark Current	Not measured			1.5 e-/hour		

4. Cosmetics

Overall the cosmetics of the STA1042-5644 device are very good. No amplifier glow is evident from either output stage, there are no dead columns in the active area, and no obvious traps. The series of images below illustrate some of the features of the device.

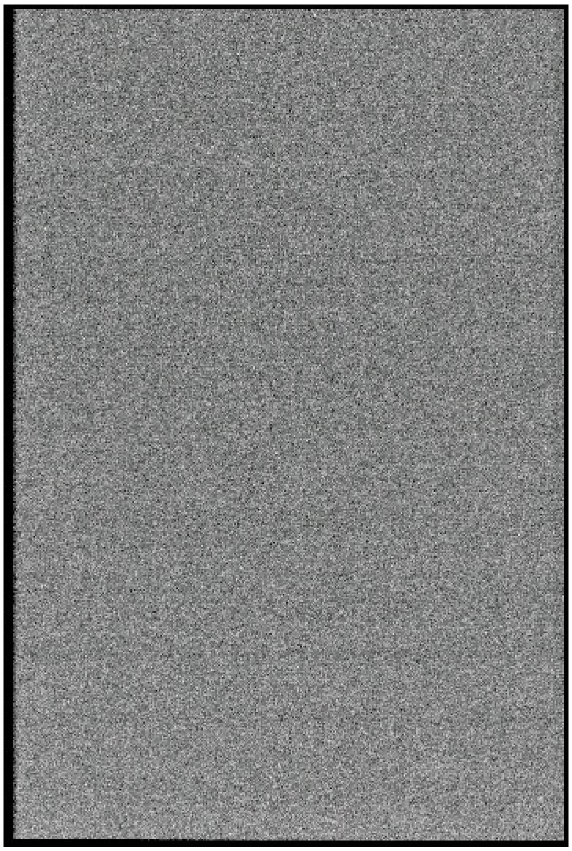

Figure 3

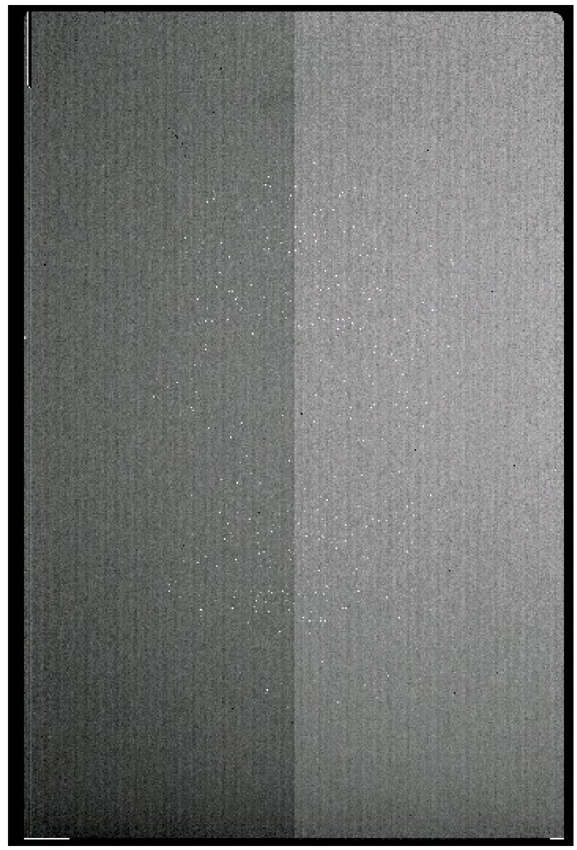

Figure 4

Figure 3 - Image of a Bias: The is a bias taken at 2 us dwell in single (right) amp read mode. Note the low-level horizontal bands (along device rows) and slight top-to-bottom gradient (along device columns). Both features extend into the overscan (along right side of image) and thus should be removed during post-processing.

Figure 4 - Image of a Flat-field: This is a flat taken at 600 nm in dual amp read mode. The two different levels are due to the slight differences in gain between the two amps. Note the vertical line structure (along device columns) - this is best attributed to an artifact of process variations in the pixel-column widths. This effect should be removed with flat-field calibrations. Also note the “sparklers” (ring of bright pixels) – these are caused by contamination on the surface of the device that accumulated during testing (this will be eliminated when cleaned).

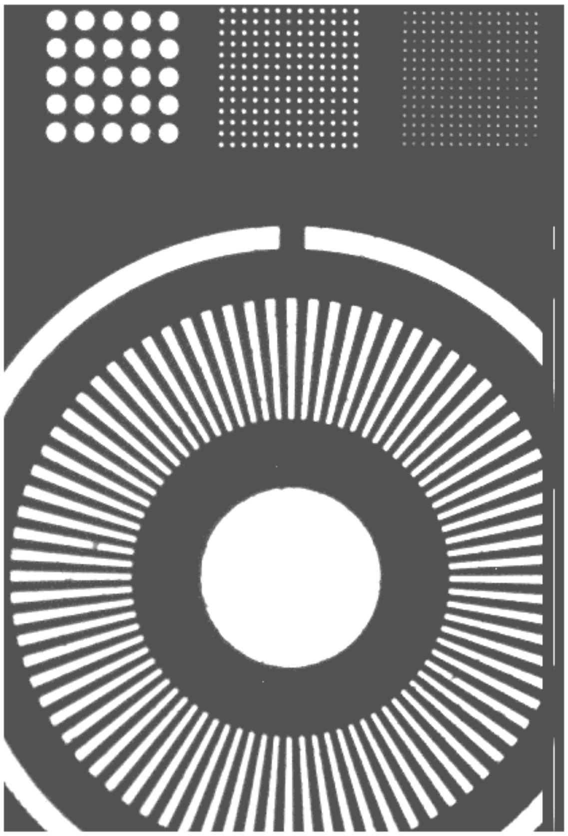

Figure 5

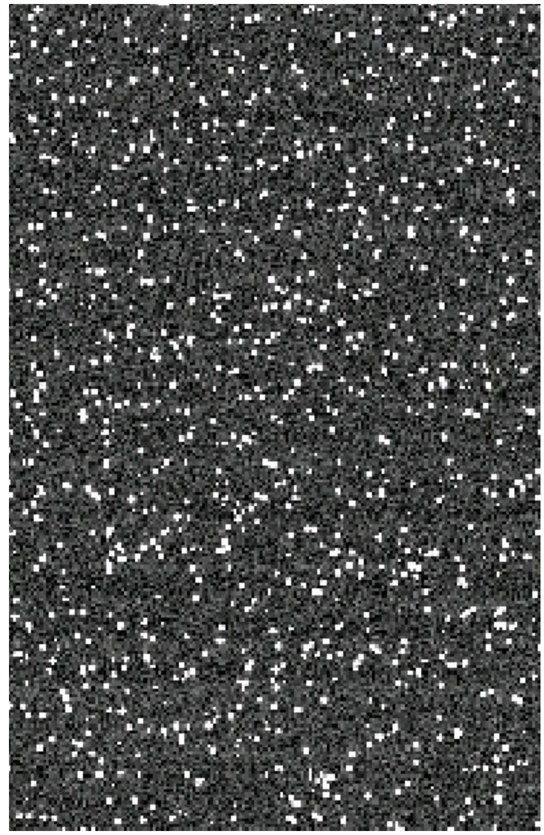

Figure 6

Figure 5 - Image of a Target: Taken in dual amp readout mode. Overscans from each amplifier appear along right side of the image. The bright lines between the overscan regions are a result of a feature of the ADC converter where data conversion is delayed by one pixel and thus the first overscan data are actually image data. This feature will be addressed in future upgrades of the CCD clocking sequencer.

Figure 6 - Close up region of an x-ray image: This image was obtained in single amp mode at a 2 us dwell. The preponderance of single-pixel events demonstrates that the charge diffusion is better than one pixel (12 microns). The sharpness of the x-ray events also illustrates the excellent CTE characteristics of the device.

5. Readnoise and Gain

The readnoise and gain results shown in the summary table (Section 3) were determined using the device in dual readout mode (both amps simultaneously) for the selected dwell times. Gain was determined using an Fe-55 x-ray source. The histogram below is from a typical x-ray image at a dwell time of 2us. The centers of the first two Gaussian peaks (bias level and alpha particle single pixel events) were measured to give the signal level of a single x-ray (1620 e-). The conversion gain was then calculated using,

$$Gain_{Conversion} = \frac{1620e^{-}}{S_{xray}(ADU) - S_{Bias}(ADU)}$$

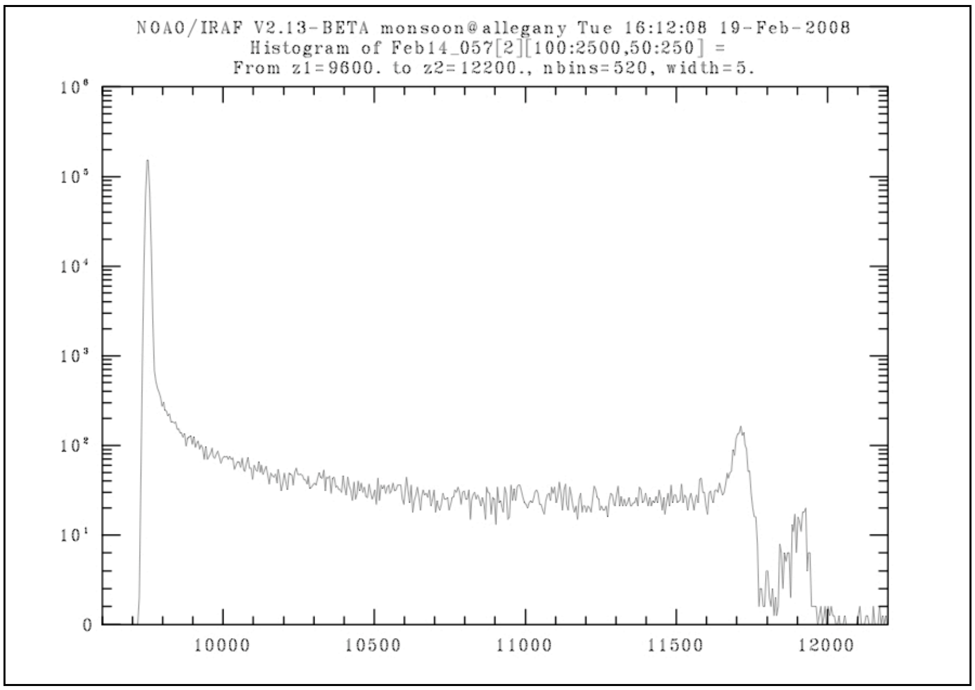

Figure 7 - Histogram of X-ray image: A region of an x-ray image taken in single amp mode at 2us dwell. The peak at left is the bias level, the first peak to the right is the alpha-particle single pixel events, and the second peak is the beta-particle single pixel events. Each alpha particle produces 1620 electrons in the CCD.

The readnoise was determined from the overscan regions of bias exposures. IMPLOT was used to plot single columns from the overscan region which were then used for calculating the RMS at several regions along the overscan. The typical RMS value (ADU) was then converted to readnoise using the conversion gain for each specific amplifier and read mode.

6. Read Times

The read times for any CCD device are dependent on many factors, including the timing of the waveforms generated in the sequencer. However, the most significant factors contributing to the read time of a particular device are the number of outputs used, the dwell time of the CDS integrator, and the binning factor. The table below shows the read time results for the various read modes and typical binning factors for a full-frame readout of the STA1042.

Read Mode		Read Times (sec) for Different Binning Factors				
# of Outputs	Dwell Time	1x1	2x1	2x2	4x2	4x3
Dual Amp Readout	2 us	49	34	17	13	9
	4 us	70	45	22	16	11
	8 us	114	68	33	23	15
Single Amp Readout	2 us	97	65	34	25	18
	4 us	140	87	45	31	22
	8 us	227	131	67	43	29

7. Photon Transfer Characteristics, Linearity, and Full Well

The photon transfer and linearity measurements were made by adjusting the exposure time of flat-field images (using integrating shere) to achieve various signal levels. All measurements were made at a wavelength of 600 nm.

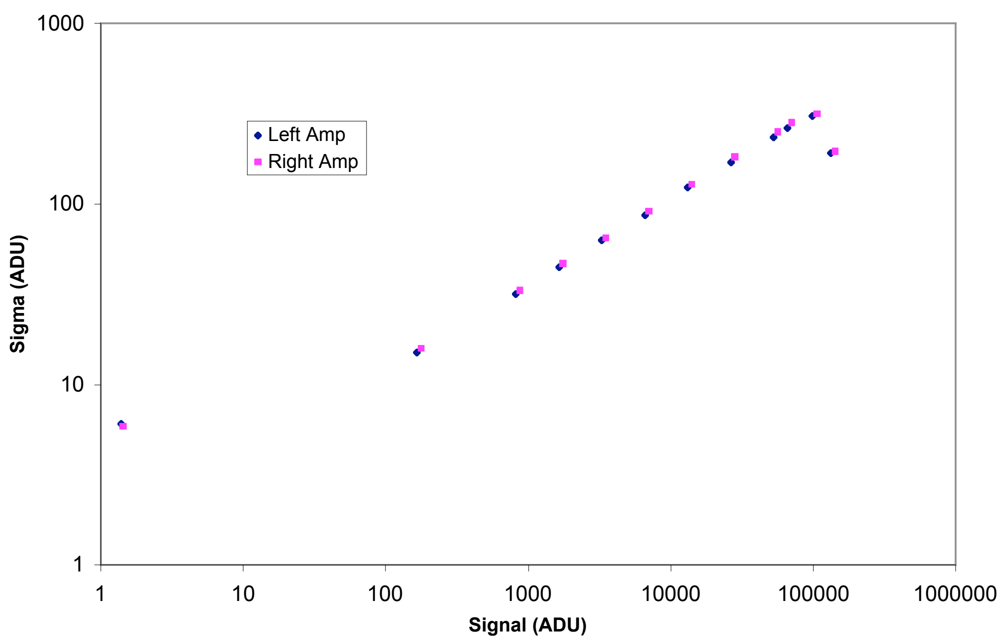

Figure 8 - Photon Transfer Curve: A log-log plot of the standard deviation (sigma ADU) vs the signal Level in ADU. Full well occurs at the roll-off (100,000 ADU)

The photon transfer curve (PTC) looks typical for a CCD and the roll-off suggests that the full-well of the device occurs near 100K ADU (85K e-). However, when we look at the linearity residuals we see that the device exceeds 1% linearity slightly below the full well, so maximum signal levels (in electrons) are stated in in terms of 1% and 0.2% linearity, in addition to the full well..

The linearity residuals are calculated using the equation,

$$\mathrm{Re}\,siduals_{LINEARITY} = 100\left(1 - \frac{S_{Median}/t\exp_{Median}}{S_n/t\exp_n}\right)$$

where, S=signal level in ADU and texp=exposure time

The following plot shows the Linearity residuals as a function of signal level (electrons). The linearity data plotted includes a shutter correction of +1.5 ms to eliminate a large deviation at low signal levels. The "median" datapoint occurred at about a 2-second exposure (3000 electron signal). The results show that the two amplifiers are very similar in their performance, but one (left) is slightly better at higher signal levels.

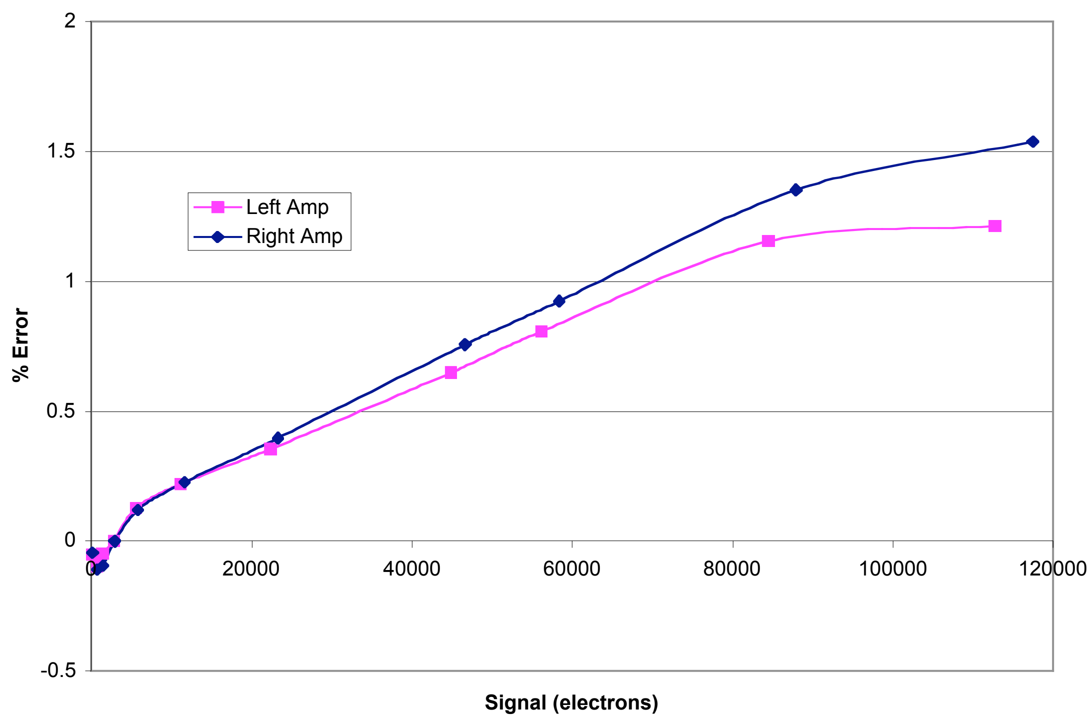

Figure 9 - Linearity Residuals: The results are plotted on a linear scale and show that the device is linear to better than 0.2% for signals up to about 10,000 electrons, and linear to 1% for signals up to 63,000-70,000 electrons.

8. Charge Transfer Efficiency

The charge transfer efficiency (CTE) was determined by measuring the difference in the signal levels of singe x-ray events near opposite edges of the device. The x-ray images were obtained in single-amp read mode (to maximize the number of horizontal shifts) with no pixel binning. IRAF was used to plot the histograms of regions near the edges of the device, and then a Gaussian fitting tool was used to determine the centers of the signal peaks.

The CTE was then calculated using the equation,

$$CTE = 10^{\left[\log\left(\frac{S_n}{S_0}\right)/n\right]}$$

where n=number of pixel shifts, S_n =X-ray signal at pixel n, S_0 = X-ray signal at pixel 0 (no transfer loss)

The CTE of the parallel (vertical) shifting (VCTE) was determined from xray histograms of the regions,

S_0 measured in region [100:2500,50:250]

S_n measured in region [100:2500,3750:3950]

n = 3850 – 150 = 3700

The CTE of the serial (horizontal) shifting (HCTE) was determined from xray histograms of the regions,

S_0 measured in region [50:150,100:3900]

S_n measured in region [2450:2550,100:3900]

n = 2500 – 100 = 2400

Parameter	VCTE	HCTE
S_0	1961.8 ADU	1964.5 ADU
S_n	1960.1 ADU	1962.5 ADU
n	3700 pixels	2400 pixels
CTE	0.9999998	0.9999996

CTE Results for the right amplifier output of device SN5644.

9. Quantum Efficiency (QE)

Quantum efficiency (QE) was measured in the lab using a Tungsten Halogen light source fiber feeding an integrating sphere through a suite of narrow-band filters (10 nm FWHM). The system was calibrated using an STA1042 device, SN5635, that was extensively tested at ITL. Using this calibration CCD, a conversion factor was determined for each of the filter wavelengths using the equation,

$$\frac{Flux_{CCD}}{I_{DIODE}} \times K_{CONV} = QE_{ITL}$$

where, for a given filter illumination, the $Flux_{CCD}$ is the measured number of electrons/sec, I_{DIODE} is the measured current of the reference photodiode, and K_{CONV} is the conversion factor.

The QE measurements were made at each of the wavelengths shown in the following plot for the calibration CCD (SN5635) and for the device under test (SN5644).

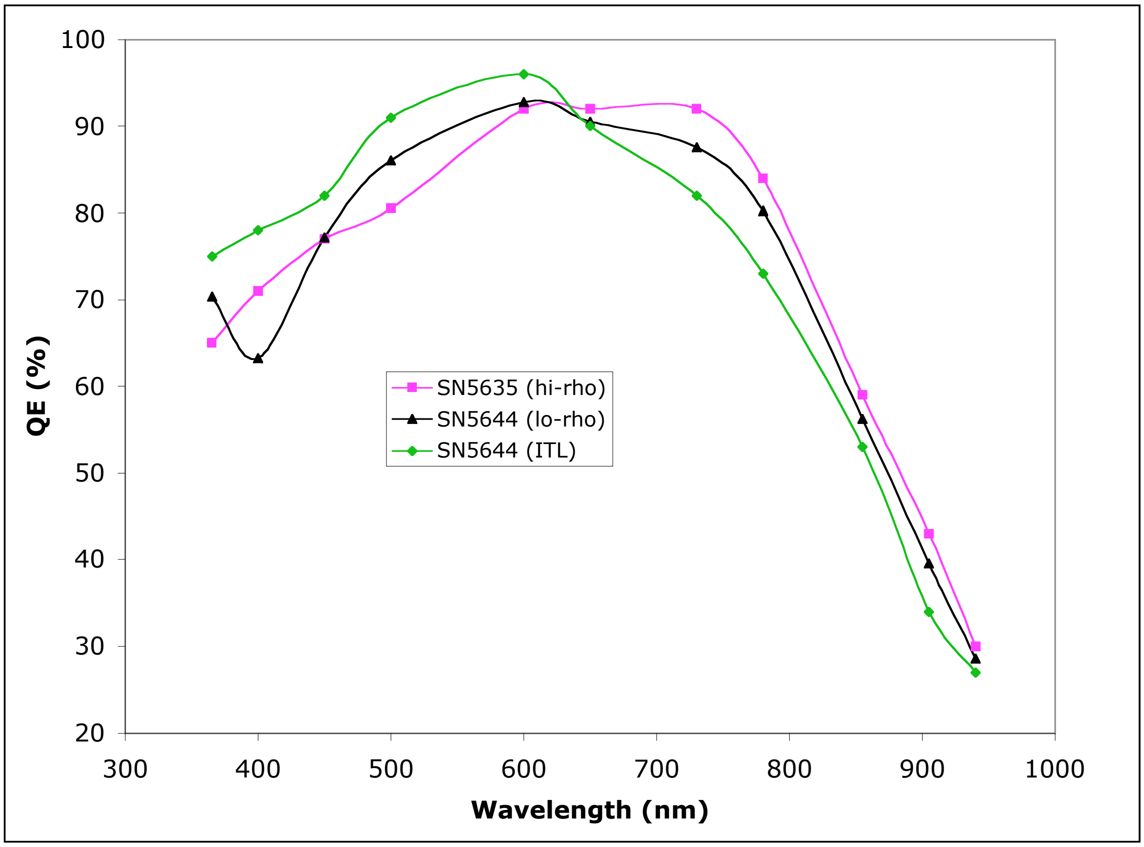

Figure 10 – QE Performance Comparison: QE results for two STA1042 devices tested at both ITL and NOAO. The 5635 device was used as the calibration "standard" and thus one curve (squares) shows the results from both test sties.

The calibration CCD was used to determine the conversion factor and thus the ITL and NOAO results agree exactly and are represented by the "square" points on the graph. The QE for device 5644 as determined at NOAO using the calibration method described above is shown as the "triangle" points on the graph. The QE for device 5644 as measured by ITL is shown as the "diamond" points on the graph. Since our QE measurements were calibrated relative to a know device, the effects of external factors on QE (eg. dewar window) should not account for the differences in results measured between NOAO and ITL, so there is some uncertainty in our results. While our results show general agreement with the ITL results, further refinement and calibration of our test apparatus will be needed before measurements can be made with greater precision.

10. Dark Current

The dark current was measured by subtracting a zero image from a 600 second dark image. The histogram below shows a 200 x 200 pixel region near the center of the bias-subtracted image. The center of the Gaussian peak was measured at 0.3 ADU. This equates to a dark current of,

$$I_{DARK} = \frac{0.3ADU}{600\sec} \times \frac{0.83e-}{ADU} \times \frac{3600\sec}{hr} = 1.5\, {}^{e-}\!/_{hr}$$

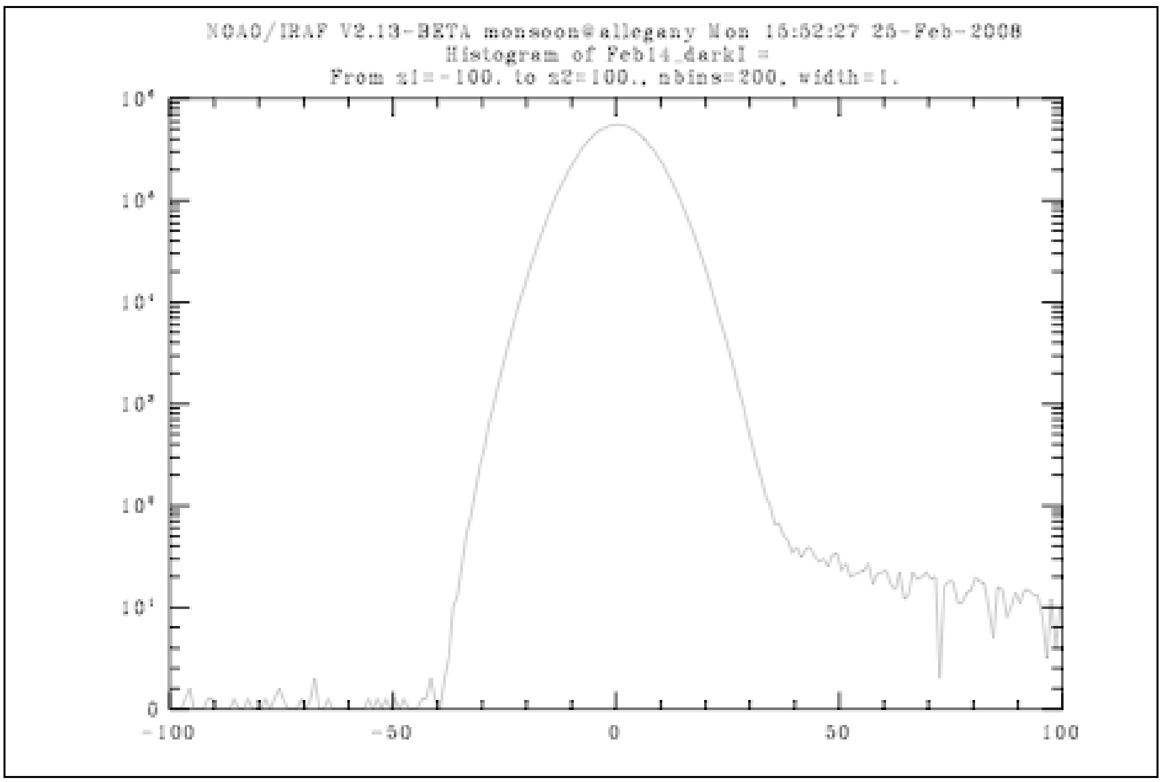

Figure 11 - Histogram of a 600 second dark: The dark has been bias subtracted. The center of the signal peak is at a value of 0.3 ADU and corresponds to a dark current of 1.5 e-/hour.