

Orion SCA Laboratory Test Results Summary

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Introduction

The Orion program^{1,2,3}, a project to develop a 2048x2048 infrared focal plane using InSb p-on-n diodes for detectors, has been carried out by Raytheon Vision Systems with funding from NOAO, USNO Flagstaff, and NASA Ames. The Orion development program itself has successfully concluded. At NOAO we have completed testing all of the Orion II Focal Plane Modules produced by this development effort to aid the selection of the FPM deliverables for NOAO and USNO.

This report summarizes the spatial characteristics of the illuminated and dark images of the development program devices (SCA 011 and SCA 013) and the NEWFIRM foundry run devices (SAC 019 and SCA 022) selected as science arrays for NEWFIRM.

We employed the prototype NOAO Monsoon array controller⁴ that services all 64 outputs simultaneously to perform these tests. Since the Monsoon system was under active development during the course of these tests, one should overlook issues of intermittent outputs and noise pickup when comparing device characteristics.

The images contained herein are half scale (interpolated to lower resolution by a factor of two on both axes). The illuminated images are views of the wall outside the laboratory test dewar through an H band filter. Three quartz bulbs provide the external illumination. Dark images are taken with the cold internal dark slide in place.

Note: Within the dark and illuminated images Column 1 (left edge) and Columns 2048-2112 (far right edge) are derived from reference pixels. The system vignettes somewhat, resulting in the dark band at the top edge (rows 2011-2048) and along the right edge (columns 2023-2047). Internal system light leaks produce the bright areas at top right.

Shared Characteristics

Based on mean-variance measurements, the conversion gain for these measurements was 7.6 electrons/ADU with only minor variation from device to device.

Read Noise

Read noise is a function of the electrical bandwidth of the system and the type of signal filtering employed. Monsoon employs multiple digital sampling of the video signal at each pixel to filter the system electrical noise. As a point of reference, 4 digital samples

corresponds to the degree of analog electrical filtering employed in the Wildfire system used to test ALADDIN arrays here at NOAO. These Orion II devices exhibit read noise performance that meets (indeed, even exceeds) that of their ALADDIN III ancestors. Noise measurements at 32K infer a read noise of 33/24/18 electrons rms for digital multi-sampling of 1/4/16 respectively. Typical results for the variation of read noise with digital sampling is shown in Table 1 and Figure 1. The statistics reflect values for the entire array of active pixels [2:2047,1:2048].

Table 1. Read Noise (electrons RMS) versus Digital Samples					
Digital samples	1	2	4	8	16
mean	33.9	30.4	24.9	20.5	18.8
median	33.2	29.8	24.5	20.1	18.3
mode	33.0	28.8	22.3	19.3	17.7

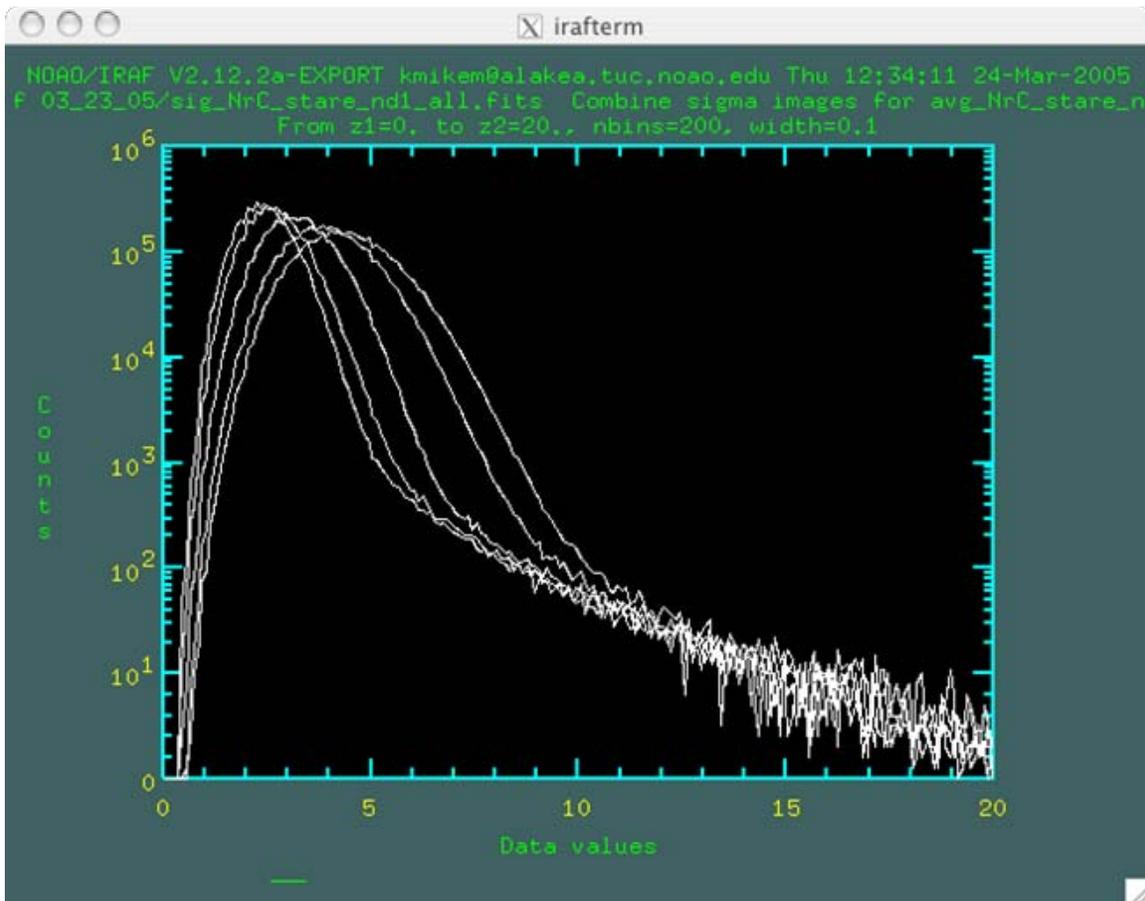


Fig. 1 Histogram of Read Noise (adu RMS) vs digital samples (1, 2, 4, 8, 16 right to left)

Variation of read noise with Fowler sampling for 4 digital samples is shown in Table 2 and Figure 2 for SCA 019. The canonical limiting factor of 3 improvement with Fowler sampling can be seen. Since prior data with the same array indicated a median read noise

of 25 electrons rms for Fowler 1 and 4 digital samples, we suspect the absolute levels reached during the Fowler sampling test were compromised by additional system noise.

Table 2. Read Noise (electrons RMS) versus Fowler Samples for 4 digital samples					
Fowler Samples	1	2	4	8	16
mean	31.7	20.6	16.2	11.5	10.8
median	30.1	19.3	15.0	10.5	9.5
mode	29.2	18.7	14.8	10.3	9.1

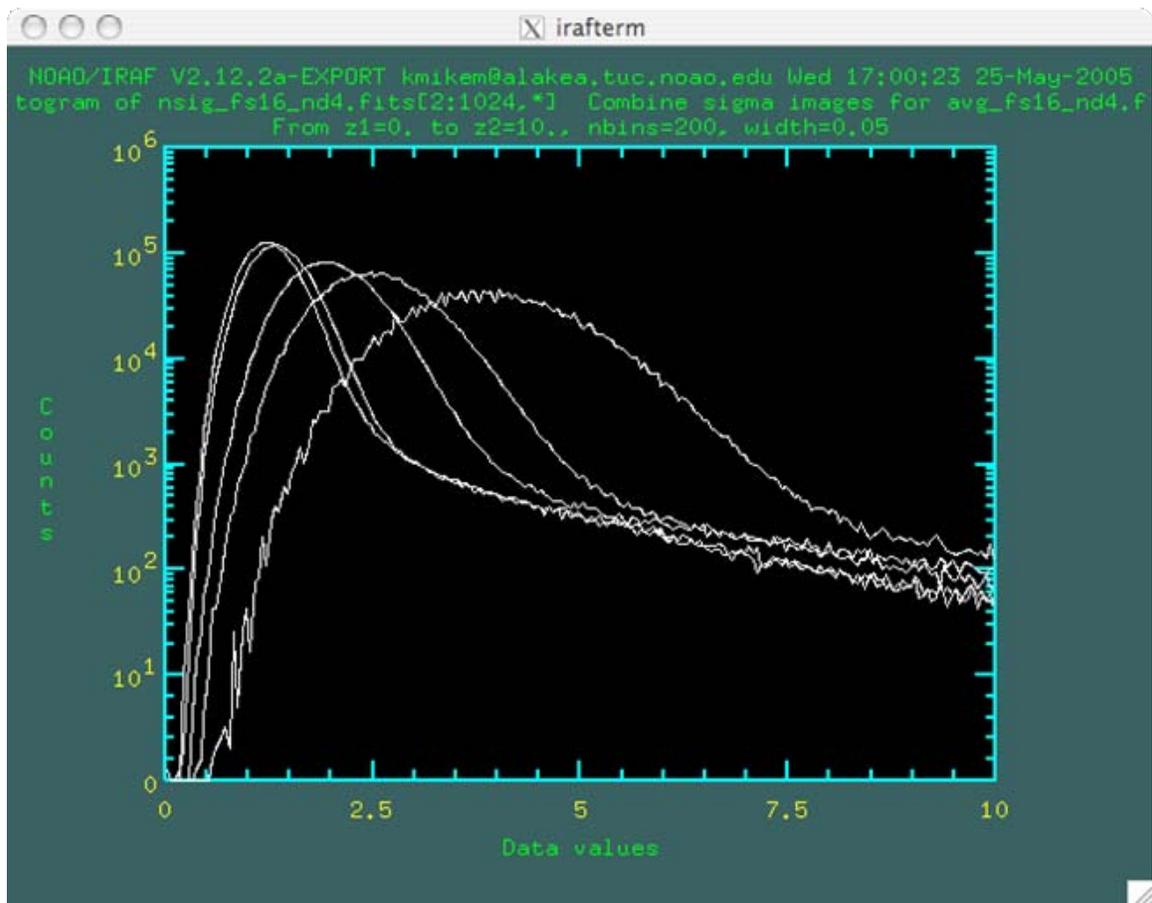


Fig. 2 Histogram of Read Noise (adu RMS) vs Fowler samples (1, 2, 4, 8, 16 right to left) for 4 digital samples.

Full Well

Full well performance is consistent with design goals. Figure 3 summaries full well tests for a typical SCA as a function of bias. Full well capacity exceeds 100K/150K/200K electrons at a bias of 400/600/800 mv respectively.

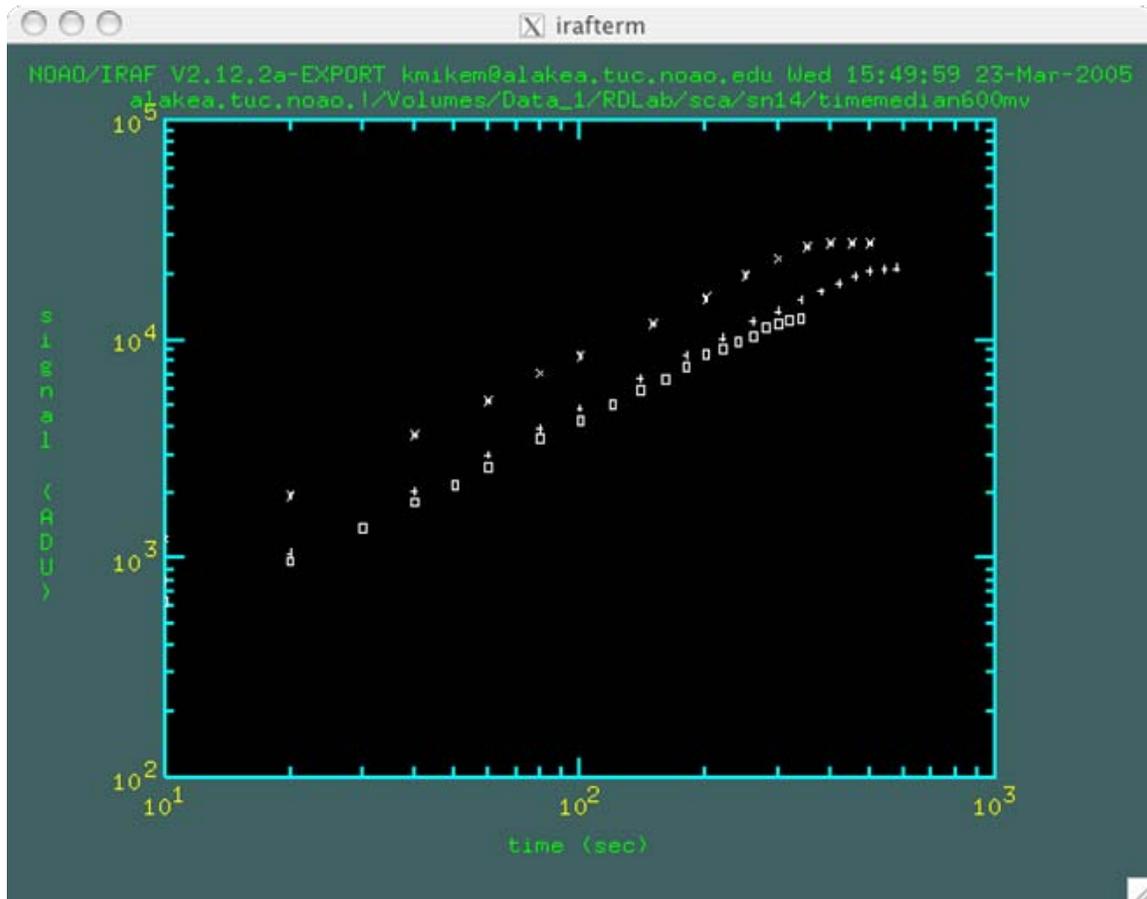


Fig. 3 Full well measurements (adu) for 400mv (square), 600mv (+) and 800mv (x) bias.

Optimal Operating Temperature

Although no attempt was made to select and process these InSb wafers to enhance performance at very low background, the measured dark current is rather low. Based on the difference between 200 and 100 sec exposures, the dark current is 0.21/0.18/0.17 electrons/sec in the mean/median/mode respectively for a typical science quality array.

The performance data reported herein were taken at an operating temperature of 32 K. Figure 4 illustrates the variation of dark current (electrons/sec) with temperature for

Orion II SCA 019. The median value for the dark signal as a function of temperature for a “cool” region of the array with few hot pixels (“X”) and a “hot” region of the array dominated by hot pixels (“+”) is summarized. At 26K there were several indications that array operation was compromised. The ideal operating point for these arrays appears to be in the 30-32 K range, since there was no obvious degradation of read noise performance with decreasing temperature down to 28 K.

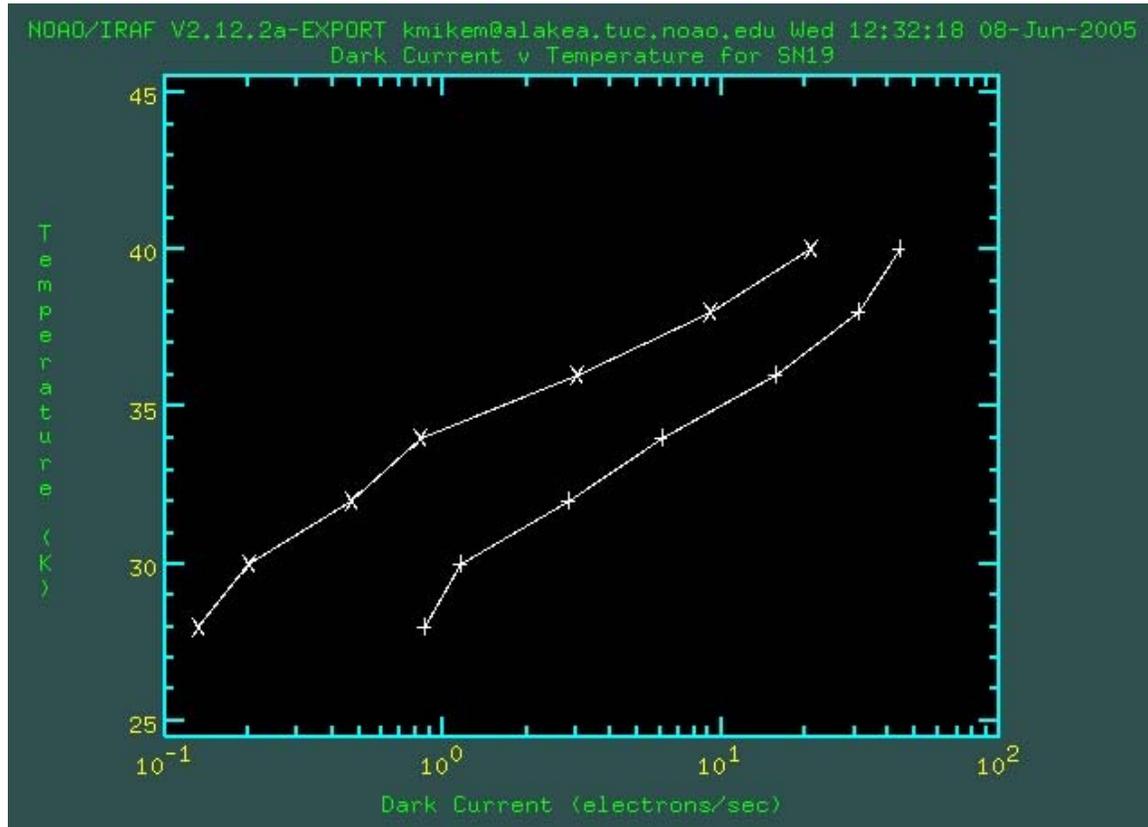


Figure 3. Dark current vs temperature for Orion II SCA 019. X depicts a region with few hot pixels and + depicts a region dominated by hot pixels

Reference Pixels

The Orion II architecture has several types of available reference cells. The Column 1 and Column 2048 references are intended to mimic the behavior of a starved pixel and a saturated pixel respectively. Each of the 64 outputs has its own reference cell that can be read at the start (and/or end) of each row. Although we have yet to fully explore the use of these reference pixels, the degree of array uniformity is such that simple statistics based on the ensemble of 64 reference pixels can be exploited to correct for global drifts across all 64 outputs on a row by row basis. Since all 64 outputs are read simultaneously such a technique circumvents the factor of $\sqrt{2}$ noise increase that would otherwise obtain from using a single reference read to correct a single data channel.

Performance for Individual Focal Plane Modules

SCA011

SCA011 was produced during the Orion Development Project. As can be seen in Figure 4, SCA011 exhibits a number of cosmetic defects associated with the readout and the InSb processing. When illuminated, SCA011 shows the mitigation effects of 6 Photon Emitting Defects (PEDs), plus two circular spots where something is deposited on the array. There is also an irregular region that exhibits both a reduced response (response is 95% of the rest of the array) and an increased dark current (an additional 0.5 electron/sec) when compared to the rest of the array. SCA011 appears to be hybridized completely on all edges. These cosmetic defects are summarized in Table3.

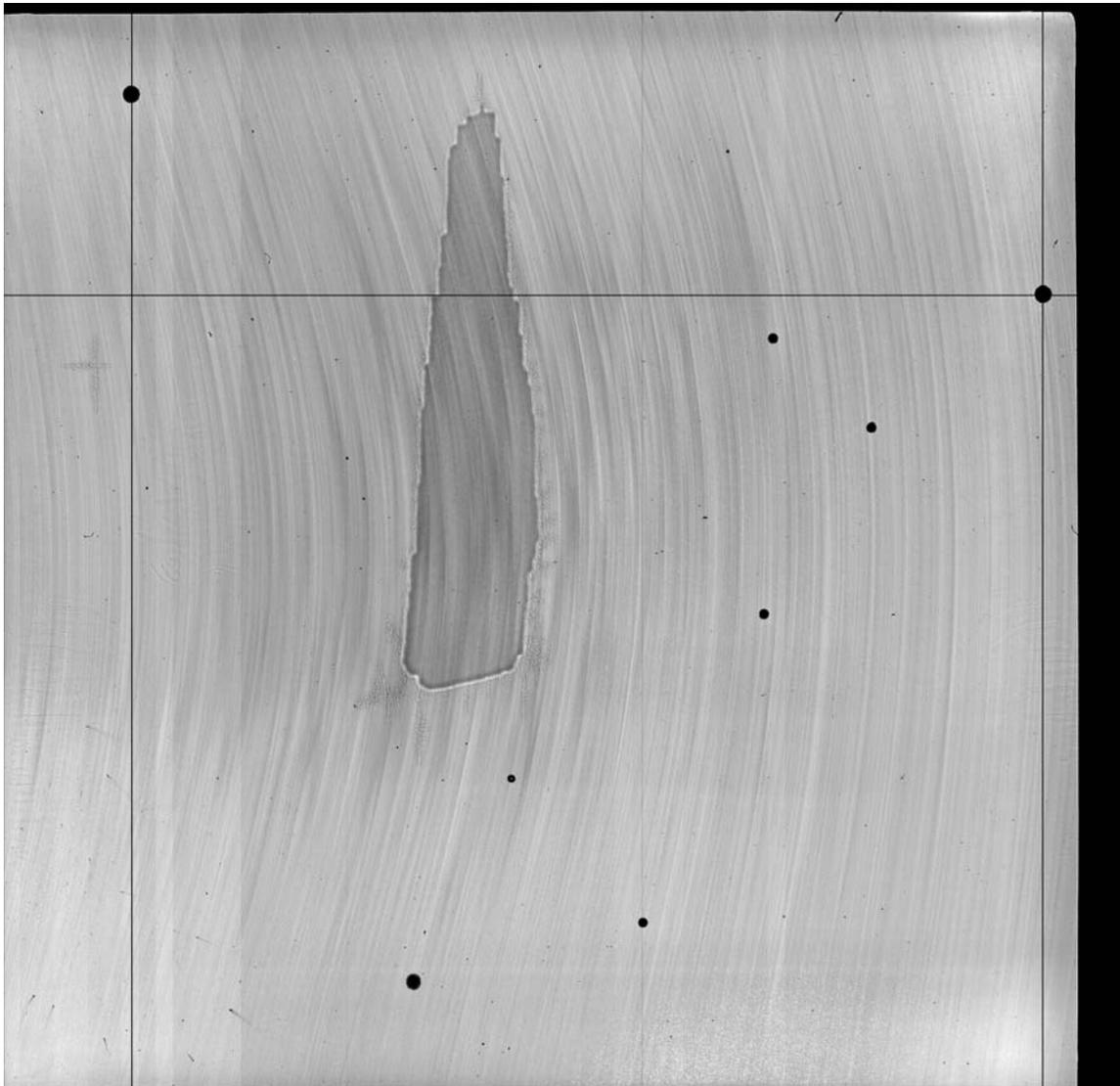


Fig. 4. Illuminated SCA011

Table 3. SCA011 Cosmetic Defects			
Defect description	X	Y	Diameter (pixels)
Column out and PED hole	243	1875	31
Column out and PED hole	1204	312	18
PED hole	1432	895	18
PED hole	1634	1246	18
PED hole	1449	1414	18
PED hole Column & Rows out	1957	1496:1497	32
Deposit	958	585	12
Deposit	774	201	28
Irregular area: 5% lower QE	760:1050	750:1840	

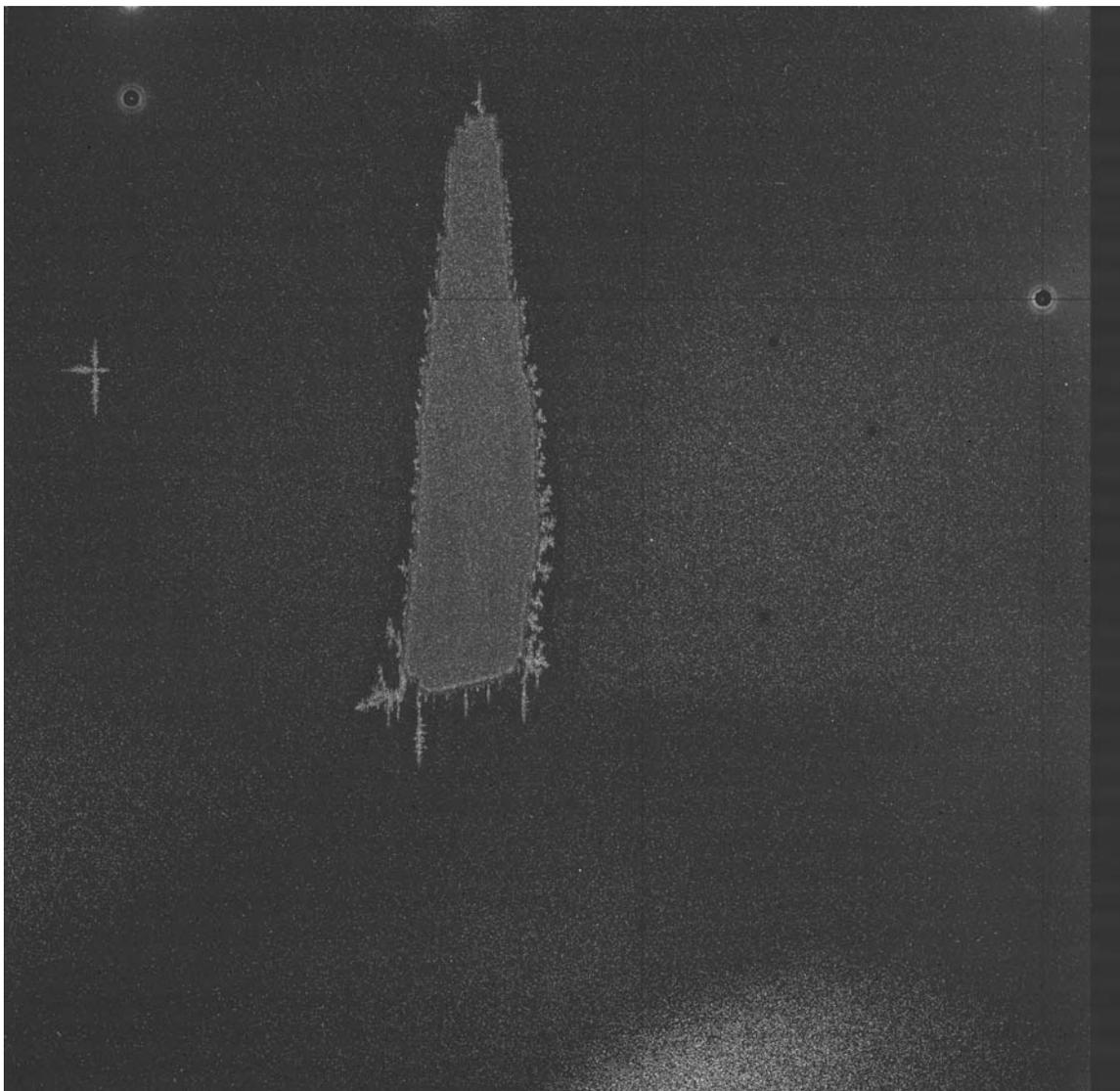


Fig. 5 Differential Dark Current for SCA011 in electrons/sec.

The dark current for SCA011 is shown in Figure 5, where the difference image of a 500 sec and a 300 sec dark exposure is displayed. Note the irregular region with increased dark current mentioned above, the “Arlington Cemetery” cross, and the region near bottom right with an elevated number of hot pixels. The histogram in Figure 6 summarizes the rate of dark current (electrons/sec) over the entire array (upper curve) and within the irregular region (lower curve).

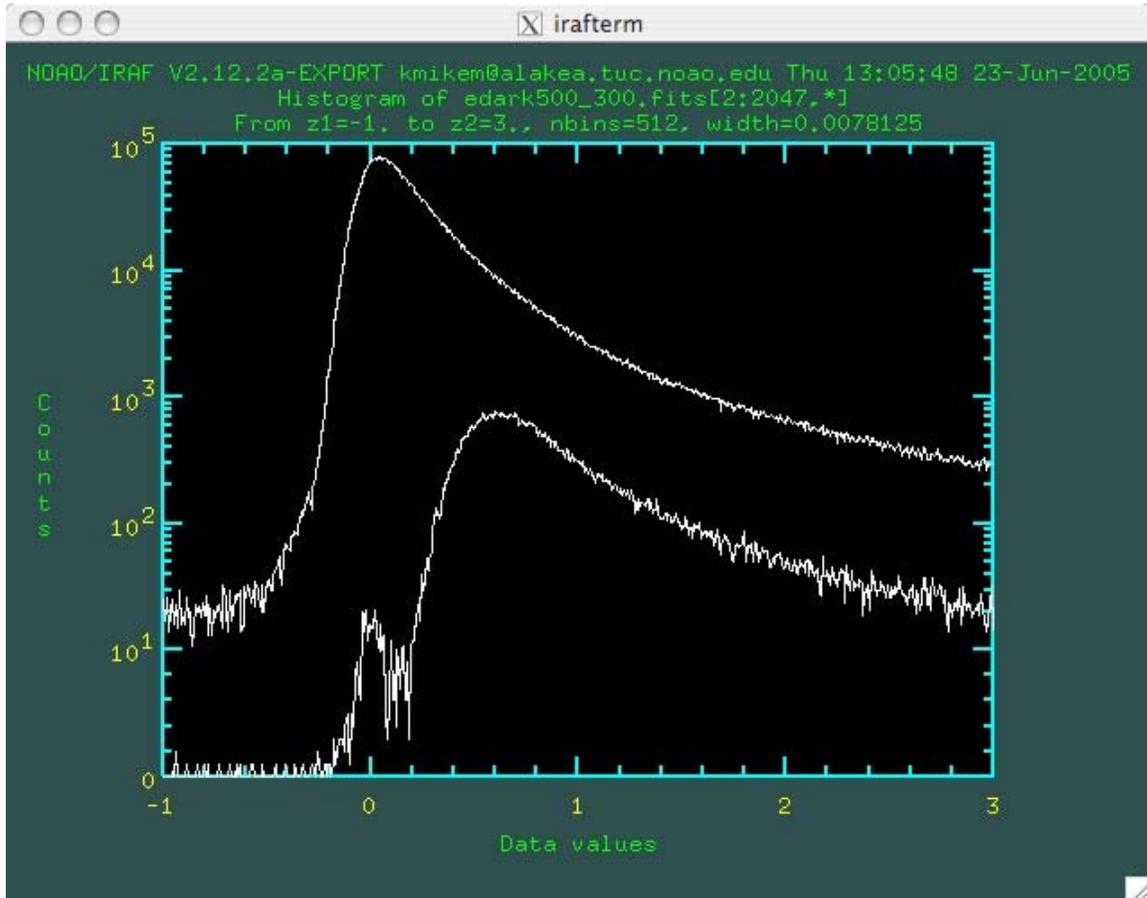


Fig. 6 Histogram of dark current for SCA011 in electrons/sec. Upper curve: entire array; lower curve: irregular region elevated dark current.

The differential dark current for SCA011 is 0.57/0.14/0.09 electrons/sec in the mean/median/mode respectively.

SCA 013

SCA013 was produced during the Orion Development Project. As can be seen in Figure 7, SCA013 exhibits a number of cosmetic defects associated with the readout and the InSb processing. When illuminated, SCA013 shows the mitigation effects of a PED, two unmitigated mini-PEDs, multiple cracks, several rows out, an unhybridized region at the lower right edge (just inside the nonphysical reference pixel stripe), and a region with reduced response in the lower left corner of the device (roughly 80% of the response throughout the rest of the array).

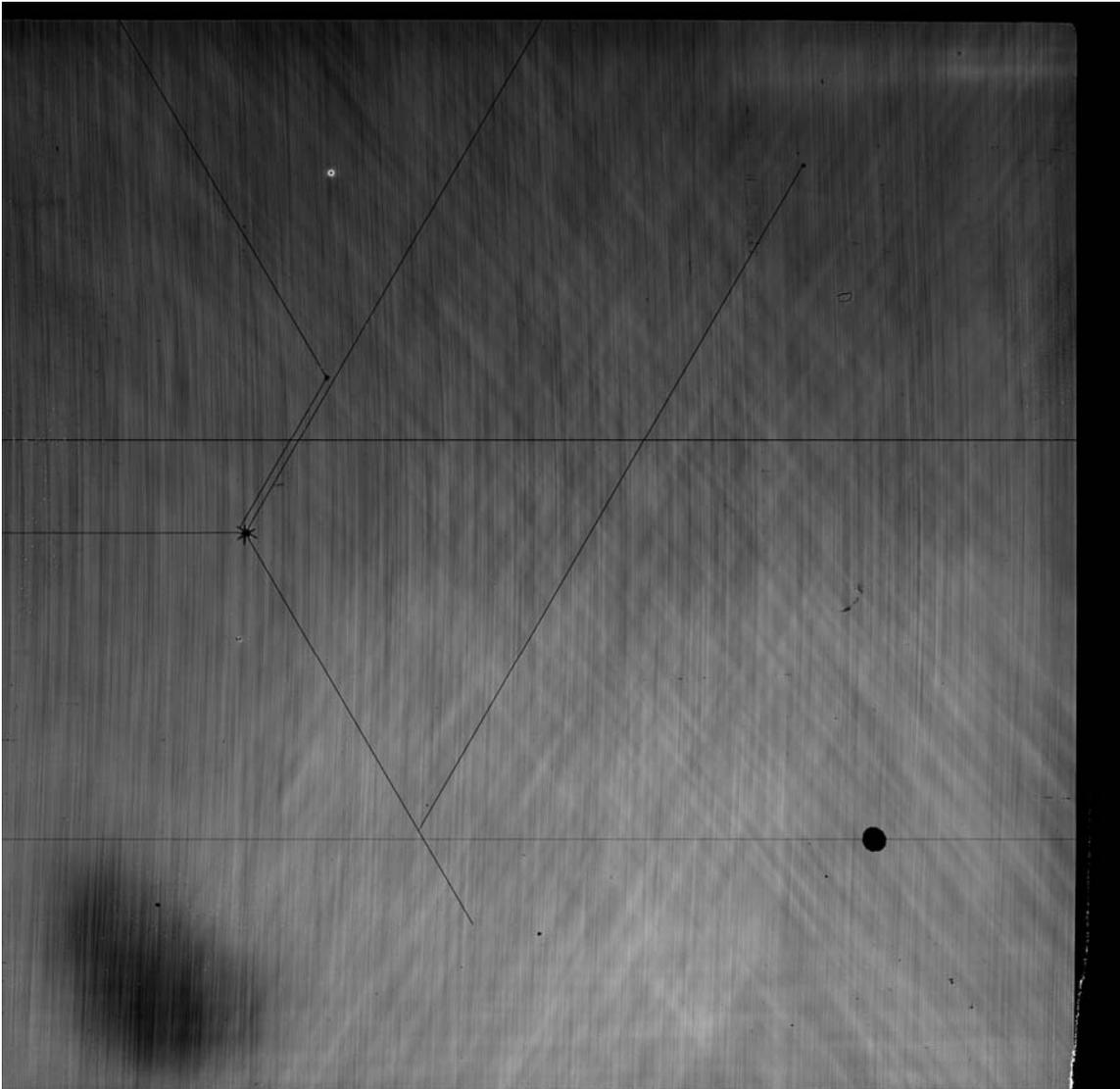


Fig. 7 Illumined SCA013

The differential dark current (600 sec – 200 sec) for SCA013 is shown in Figure 8. Although the mini/micro- PEDs at 460,1049 and 622,1727 are locally bright their direct impact is spatially limited. A detailed assessment of their contribution to the general dark current would need to include possible retro-reflection from elsewhere in the system. A triangular region at the lower left edge and on the bottom edge near the right can also be seen. Since this device has multiple cracks, further post-processing to remove these small PEDs is not recommended.

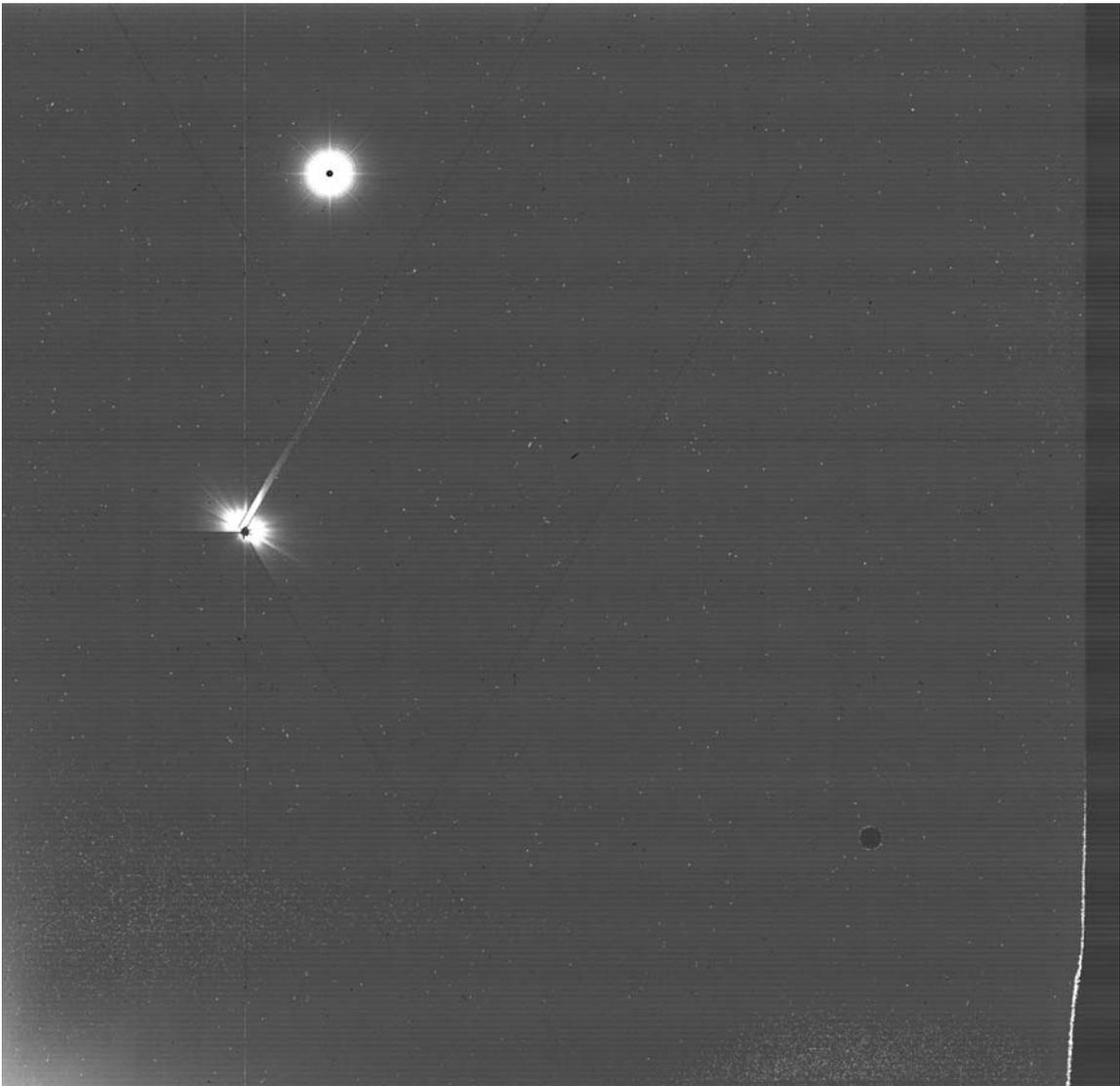


Fig. 8 Differential Dark Current for SCA013 in electrons/sec.

The histogram in Figure 9 summarizes the rate of dark current (electrons/sec) over the entire array. The upward ticks are artifacts of the data processing.

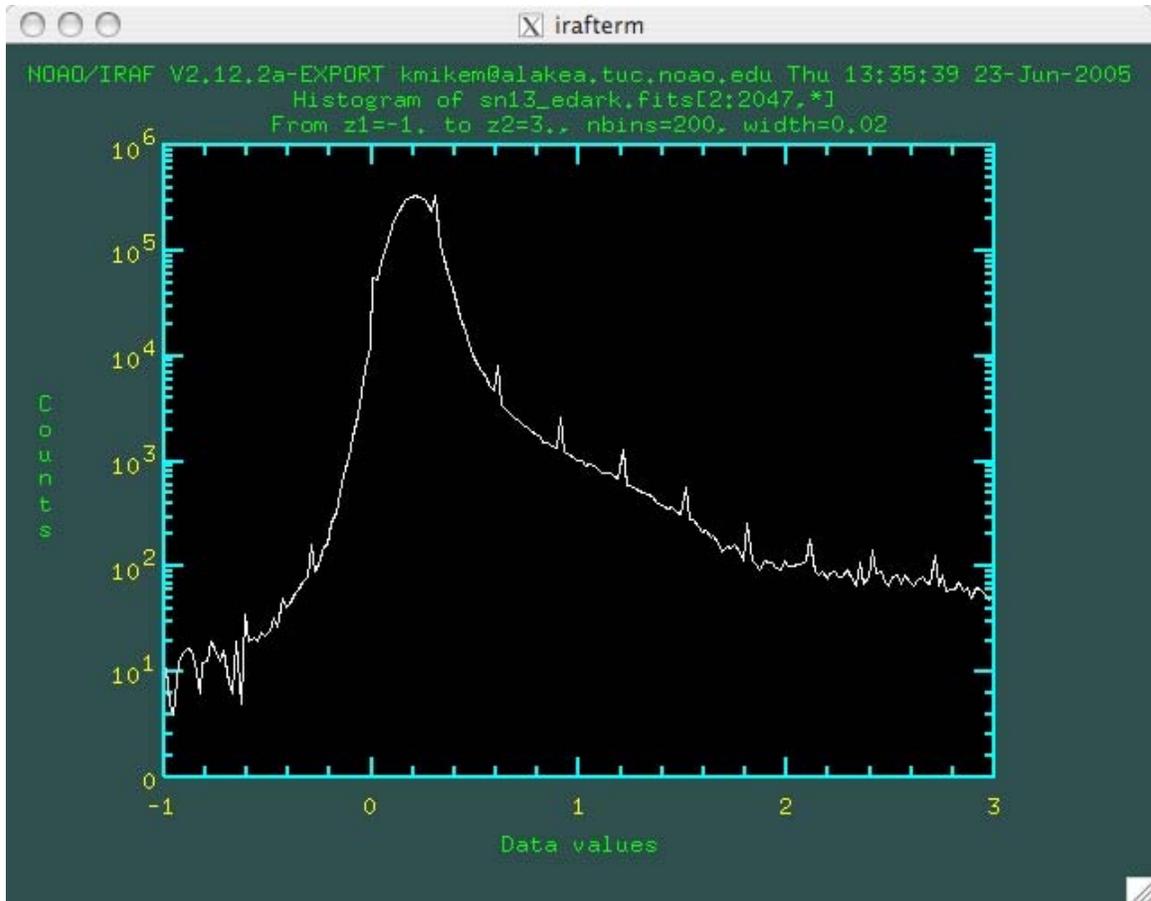


Fig. 9 Histogram of dark current for SCA013 in electrons/sec. Upward ticks are processing artifacts.

The full frame differential dark current for SCA013 is 0.31/0.18/0.15 electrons/sec in the mean/median/mode respectively.

SCA019

SCA019 was produced as part of the NEWFIRM foundry. As can be seen in Figure 22, SCA019 exhibits relatively few cosmetic defects associated with the readout and the InSb processing. When illuminated – apart from a bad column pair and 3 bad row pairs, a narrow curvilinear defect (lower right edge), scattered minor defects, and two removed PEDs this device exhibits both high cosmetic quality and highly uniform response. As mentioned in the Introduction, the bright area at upper right was produced by scattered light in the test Dewar. The device appears to be hybridized completely on all edges.

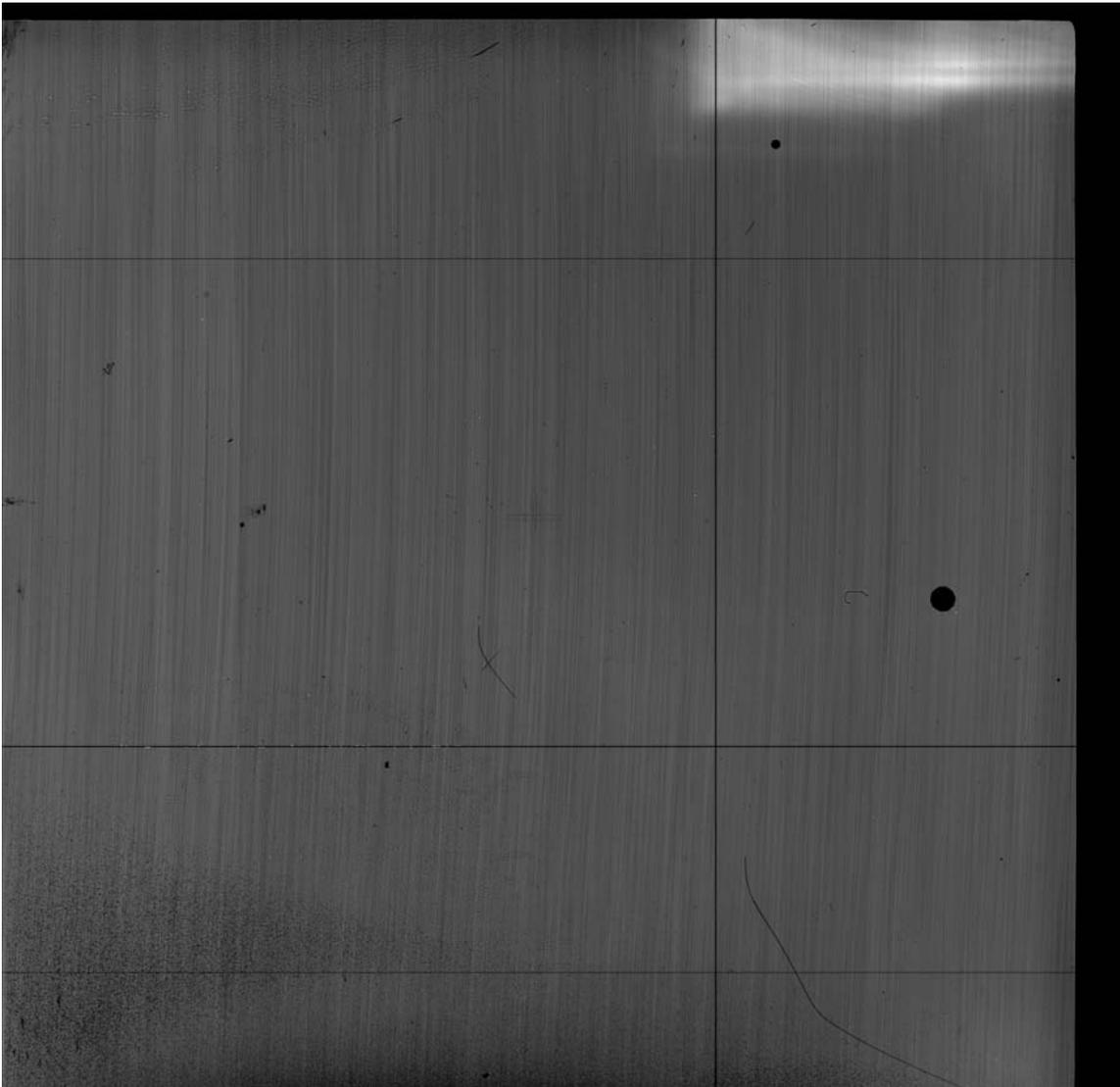


Fig. 22 Illumined SCA019

The differential dark current (240 sec – 30 sec) for SCA019 is shown in Figure 23. The dark current is fairly uniform, apart from local enhancements with the “Arlington Cemetery” (which are generally higher, but not pixilated), a triangular region at the lower right edge, and a region on the bottom edge near the left. The latter two areas are pixilated, indicative of individual hot pixels. See Figure 3 for a plot of the dark current in the “cool” and “hot” areas as a function of temperature.

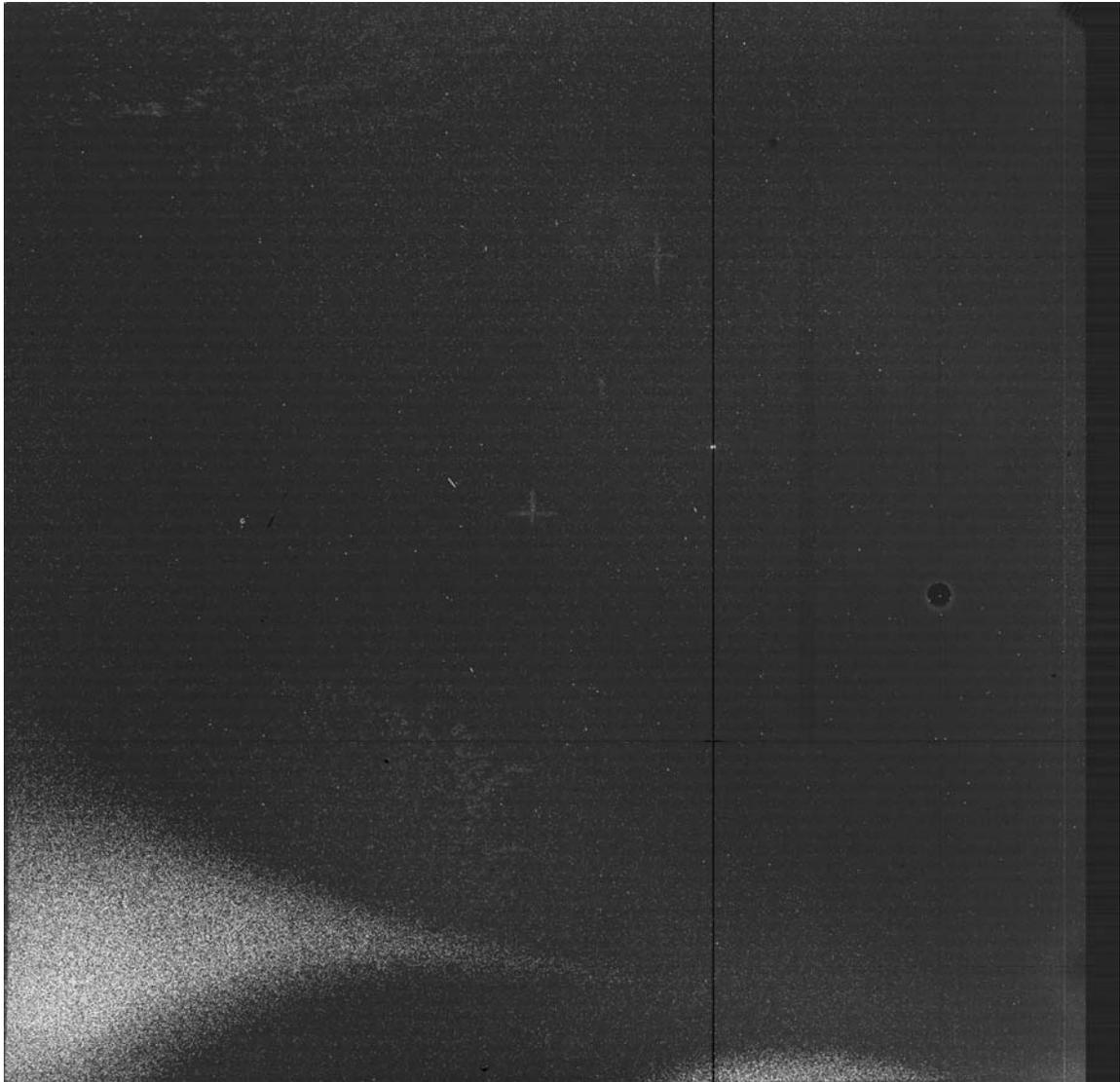


Fig. 23 Differential Dark Current for SCA019 in electrons/sec.

The histogram in Figure 24 summarizes the rate of dark current (electrons/sec) over the entire array. The discreteness is an artifact of the data processing.

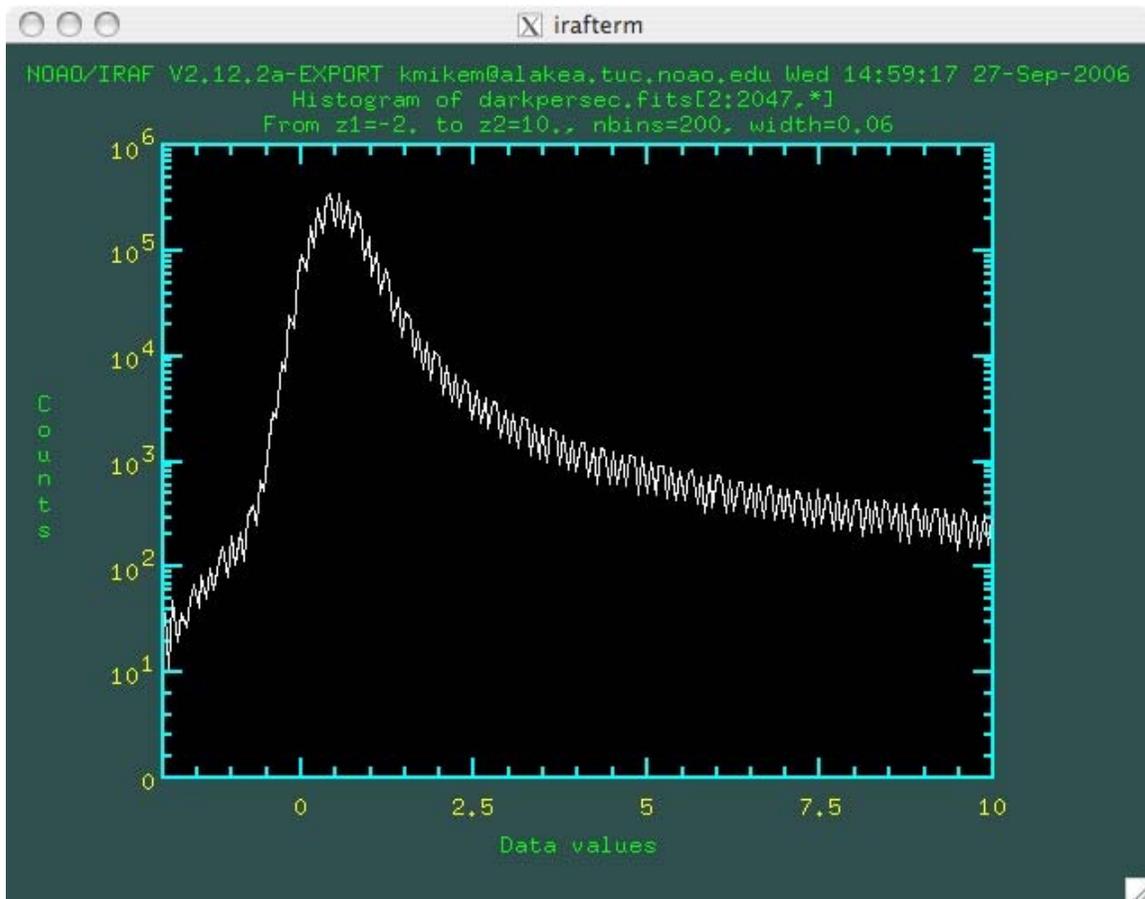


Fig. 24 Histogram of dark current for SCA019 in electrons/sec. Discreteness is due to processing.

The full-frame differential (240 – 30sec) dark current for SCA019 is 1.6/0.3/0.3 electrons/sec in the mean/median/mode respectively. The mean value is dominated by the limited regions of higher dark current.

SCA019 has a different antireflection (AR) coating than the other science arrays. The other arrays have an AR coating optimized for minimum reflectance at 1.7 microns. Due to a power glitch during the AR coating process for SCA019, its coating came out slightly thicker, giving a minimum at 2.2 microns. This results in a reflectance loss of about 10% at 1.7 microns, rather than the normal loss of less than 3%, for this SCA only.

SCA022

SCA022 was produced as part of the NEWFIRM foundry. As can be seen in Figure 25, SCA022 suffers from relatively few cosmetic defects associated with the readout and the InSb processing. When illuminated – apart from a bad column pair and 2 bad row pairs, scattered minor defects, and several removed PEDs this device exhibits both high cosmetic quality and highly uniform response. The PED visible as a bright spot in this image has since been successfully removed. The device appears to be hybridized completely on all edges. Note that the vertical bands on the right are digital artifacts of the data acquisition system (which was repaired after these data were taken).

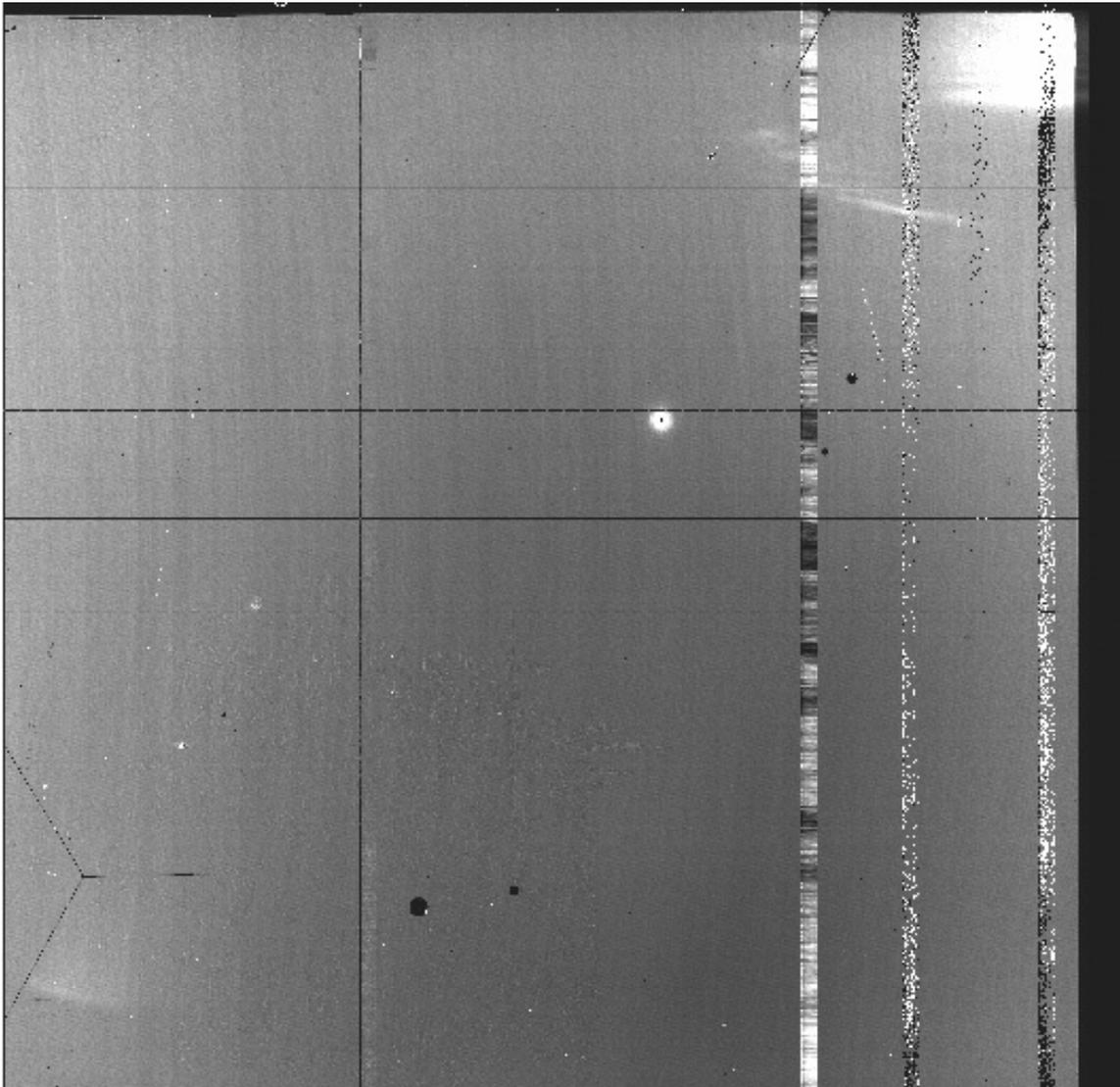


Fig. 25 Illumined SCA022

The differential dark current (110 sec – 10 sec) for SCA022 is shown in Figure 23. The dark current is fairly uniform, apart from local enhancements with scattered instances of enhanced dark near depeds, a few short arcs, and an extended region of scattered hot pixels in lower left. The vertical bands are artifacts of the data acquisition system (which was repaired after these data were taken).

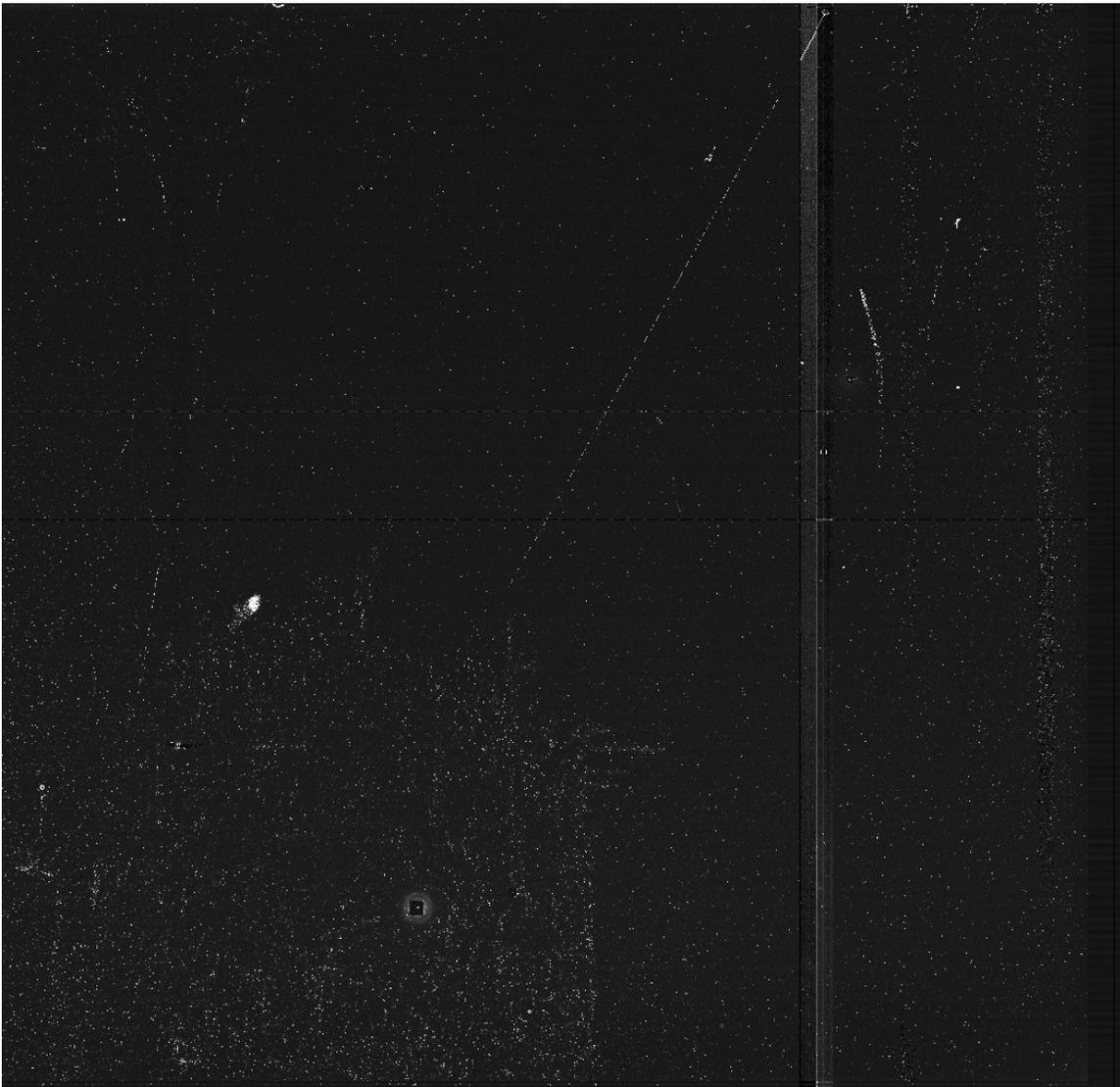


Fig. 26 Differential Dark Current for SCA022 in electrons/sec.

The histogram in Figure 27 summarizes the rate of dark current (electrons/sec) over the entire array. The discreteness is an artifact of the data processing.

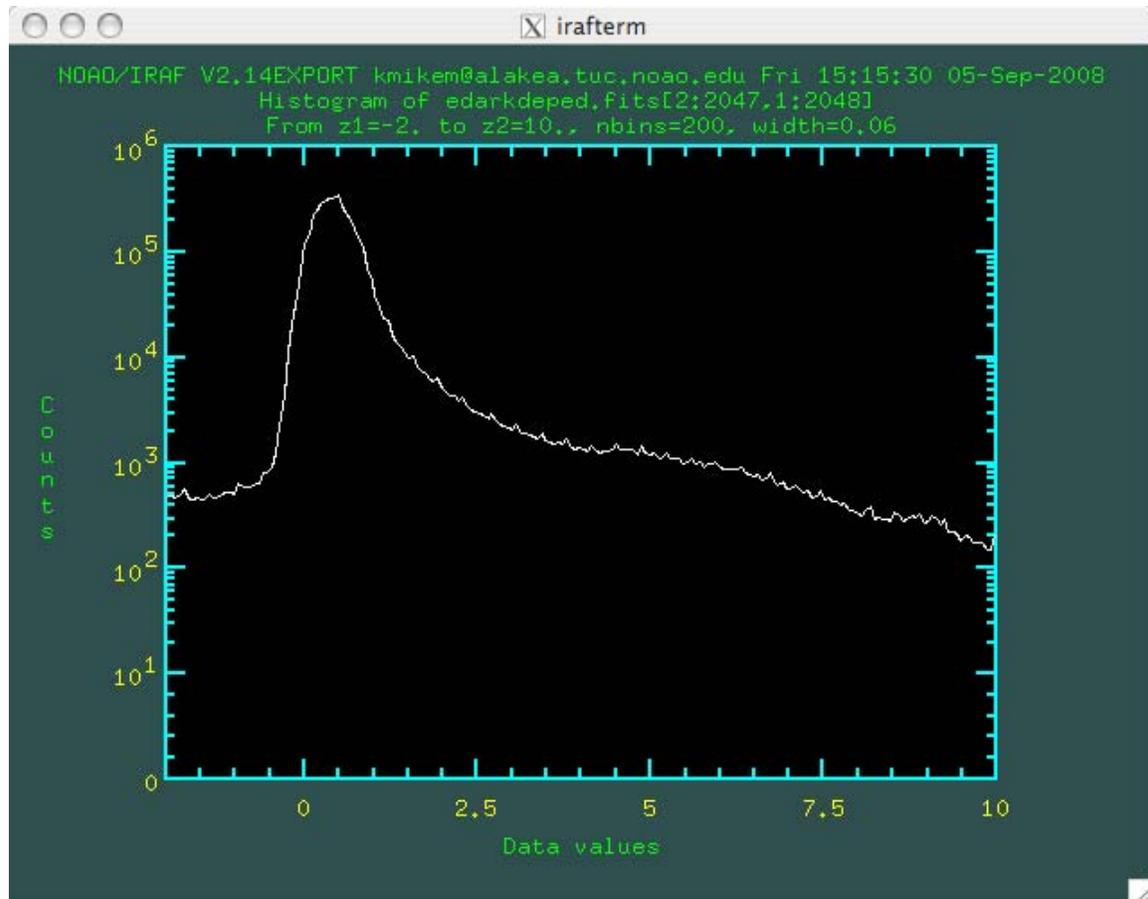


Fig. 27 Histogram of dark current for SCA022 in electrons/sec. Discreteness is due to processing.

The full-frame differential (100 – 10sec) dark current for SCA022 is 0.47/0.42/0.34 electrons/sec in the mean/median/mode respectively.

- 1) Fowler, A.M., Merrill, K.M., Ball, W., Hendon, A., Vbra, F., McCreight, C. 2004, *Scientific Detectors for Astronomy: The Beginning of a New Era*, eds. P. Amico, J. Beletic, and J.E. Beletic, (Kluwer Academic), p. 51-58, "Orion: A 1-5 Micron Focal Plane for the 21st Century."
- 2) Fowler, A.M., Merrill, K.M., Ball, W., Hendon, A., Vbra, F., McCreight, C., 2003, in *Instrument Design and Performance for Optical/Infrared Ground-based Telescopes*, eds. M. Iye, A. F. Moorwood Proc SPIE Vol. 4841, "Orion: The Largest Infrared Hybrid Focal Plane Array in Production" , p. 853-859.
- 3) Merrill, K.M., et al. 2004, in *Focal Plane Arrays for Space Telescopes*, Proc. SPIE Vol. 5167, eds. T.J. Grycewicz and C.R. McCreight (SPIE), 186, "Orion II: The Second-generation Readout Multiplexer for Largest Infrared Hybrid Focal Plane."
- 4) Starr, B.M., Buchholz, N., Rahmer, G., Penegor, J., Schmidt, R., Warner, M., Merrill, K.M., Claver, C.F., Ho, Y., Chopra, K., Mondaca, E., Shroff, C., Schroff, D., 2004, *Scientific Detectors for Astronomy: The Beginning of a New Era*, eds. Amico, P., Beletic, J. W., Beletic, J. E. (Kluwer Academic), p. 269-276, "Monsoon Image Acquisition System."