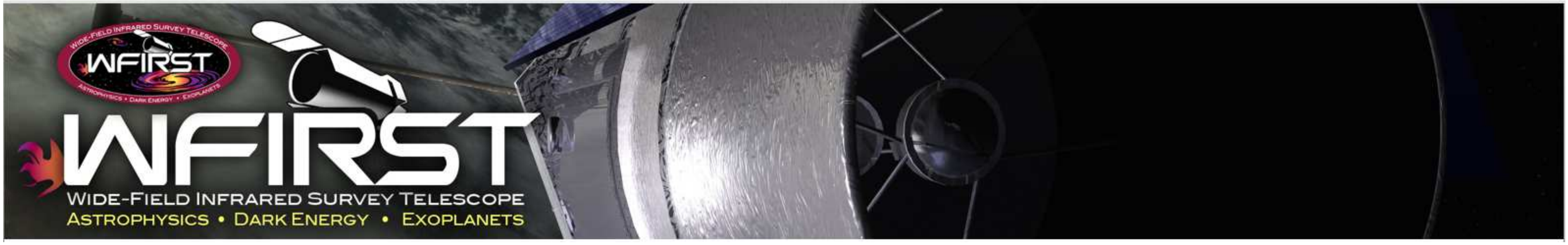
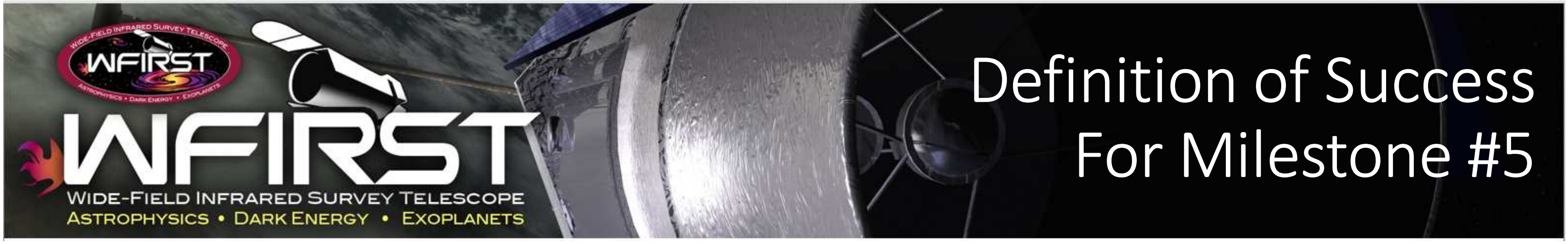


Wide Field Instrument Detector Technology – Milestone #5 Review

January 17, 2017

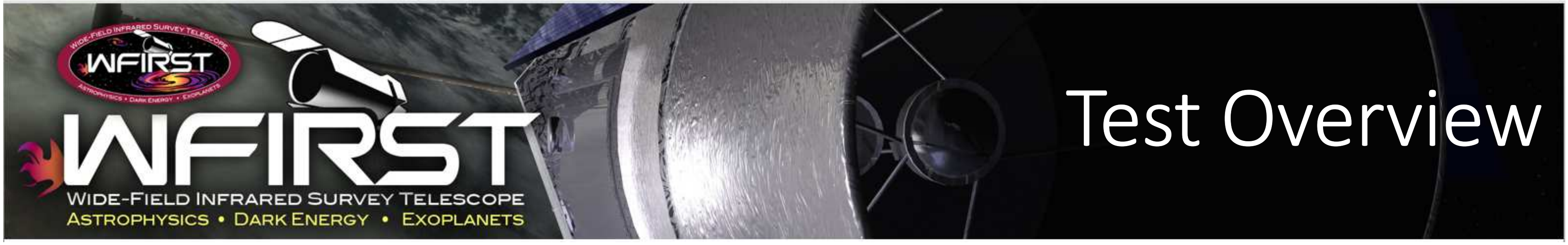
WFIRST Detector Technology Milestones

#		Date
√1	Produce, test, and analyze **2 candidate passivation techniques** (PV1 and PV2) in **banded arrays** to document baseline performance, inter-pixel capacitance, and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, and QE greater than 60% (over the bandpass of the WFI channel) at nominal operating temperature.	7/31/14 **Passed 8/7/14**
√2	Produce, test, and analyze **1 additional candidate passivation technique** (PV3) in **banded arrays** to document baseline performance, inter-pixel capacitance, and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, and QE greater than 60% (over the bandpass of the WFI channel) at nominal operating temperature.	12/30/14 **Passed 12/1/14**
√3	Produce, test, and analyze **full arrays with operability > 95%** and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, QE greater than 60% (over the bandpass of the WFI channel) , inter-pixel capacitance ≤3% in nearest-neighbor pixels at nominal operating temperature.	9/15/15 **Passed 10/8/15**
√4	Produce, test, and analyze final selected recipe in **full arrays demonstrating a yield of > 20%** with operability > 95% and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, QE greater than 60% (over the bandpass of the WFI channel) , inter-pixel capacitance ≤3% in nearest-neighbor pixels, persistence less than 0.1% of full well illumination after 150 sec at nominal operating temperature.	9/15/16 **Passed 9/22/16**
5	Complete environmental testing (vibration, radiation, thermal cycling) of one SCA sample part, as per NASA test standards.	12/1/16



Definition of Success For Milestone #5

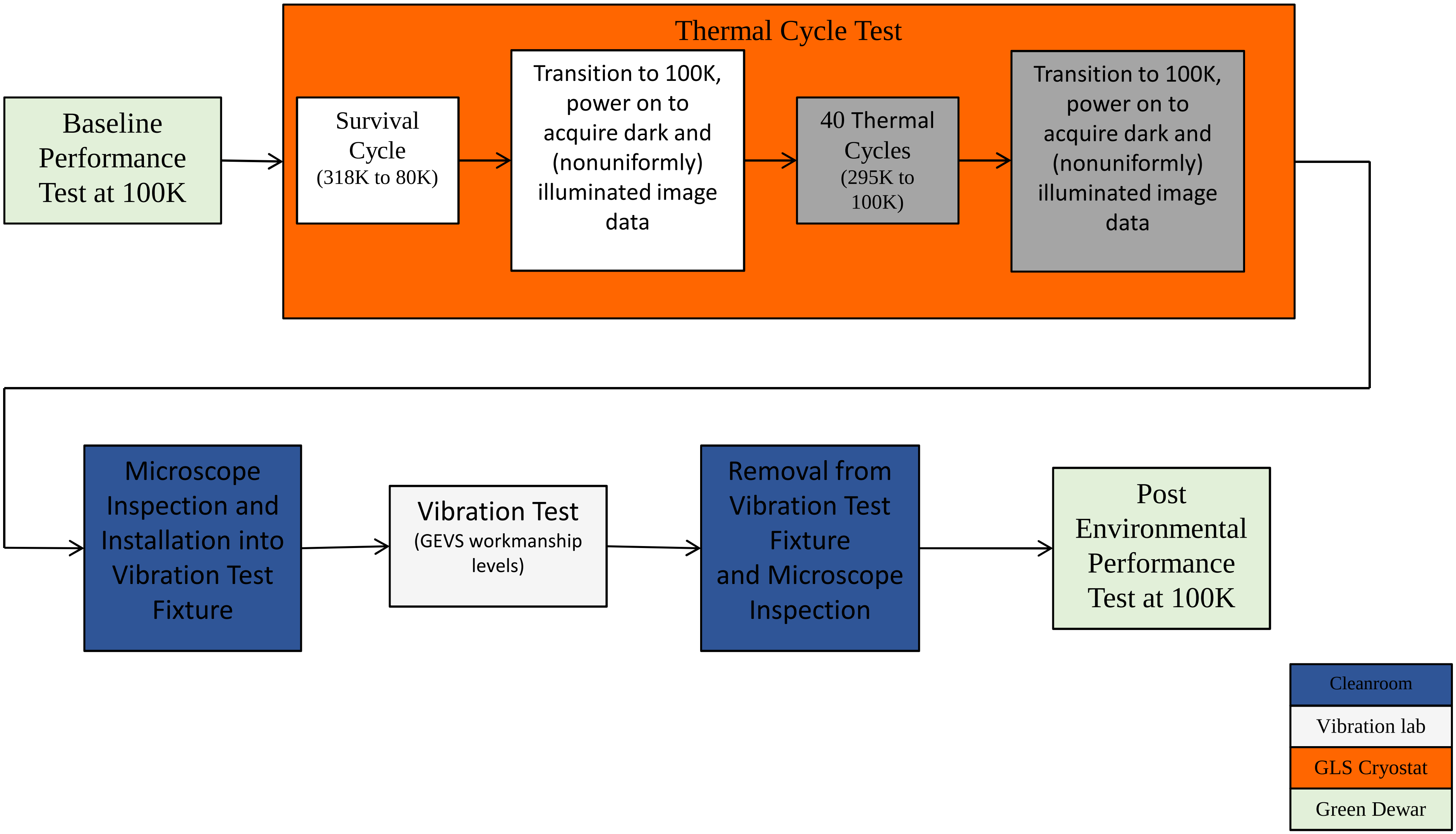
- There are no specific performance criteria associated with Milestone 5.
- The outcome of the environmental testing should provide a high degree of confidence that the final WFIRST flight design can be successfully qualified.
- We have therefore defined success as:
- 1) The thermal cycling and vibration testing should result in no degradation in performance (p. 6-17).
- 2) The degradation in performance following radiation testing is acceptable (p. 18-26) and within family of the degradation seen in previous radiation testing of similar (HxRG) detectors (e.g. JWST & HST WFC3).



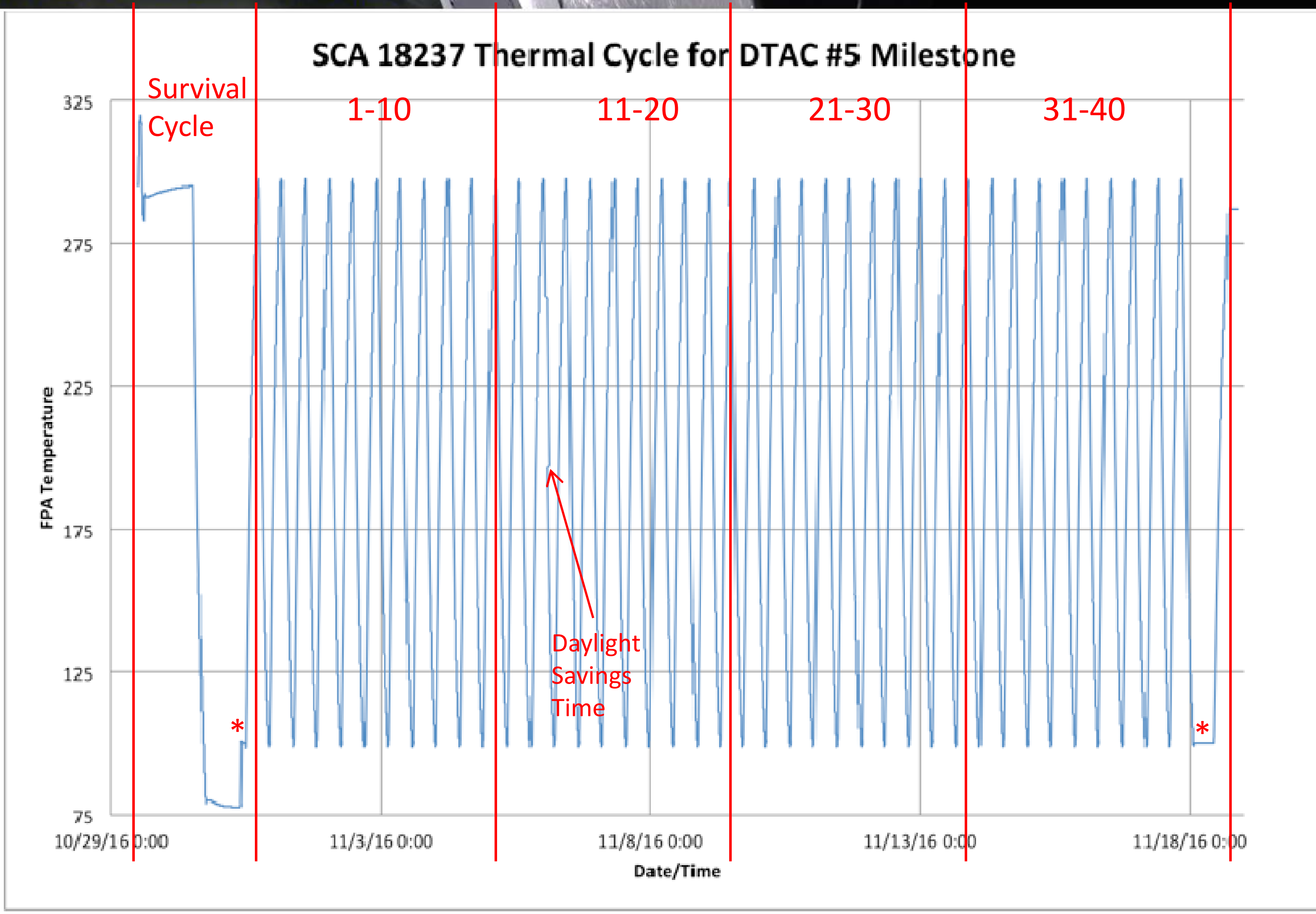
Test Overview

- One SCA (18237)has been exposed to a single survival thermal cycle (318K to 80K) and 40 thermal cycles between room temperature and the WFIRST operating temperature (100K).
- SCA 18237 has also been subjected to a GEVS workmanship level vibration test.
  - These vibe levels are expected to exceed those needed for the WFIRST qualification effort.
- SCA 18239 has been subjected to a 5krad total ionizing dose of 63MeV protons at the UC Davis cyclotron facility.
- Both SCAs are from the PV3 full-array lot used to demonstrate Milestone 4.

Thermal Cycle And Vibration Test Flow

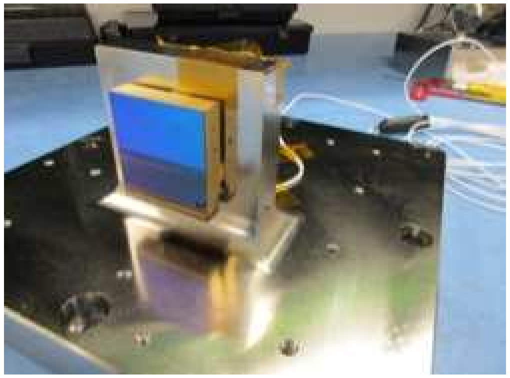


Thermal Cycling



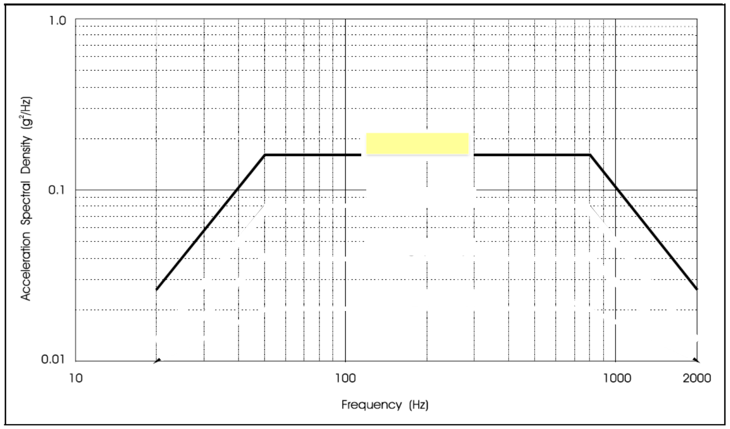
* - Aliveness imaging using SAM board/cryo ASIC (darks and non-uniform illumination)

Vibration Testing

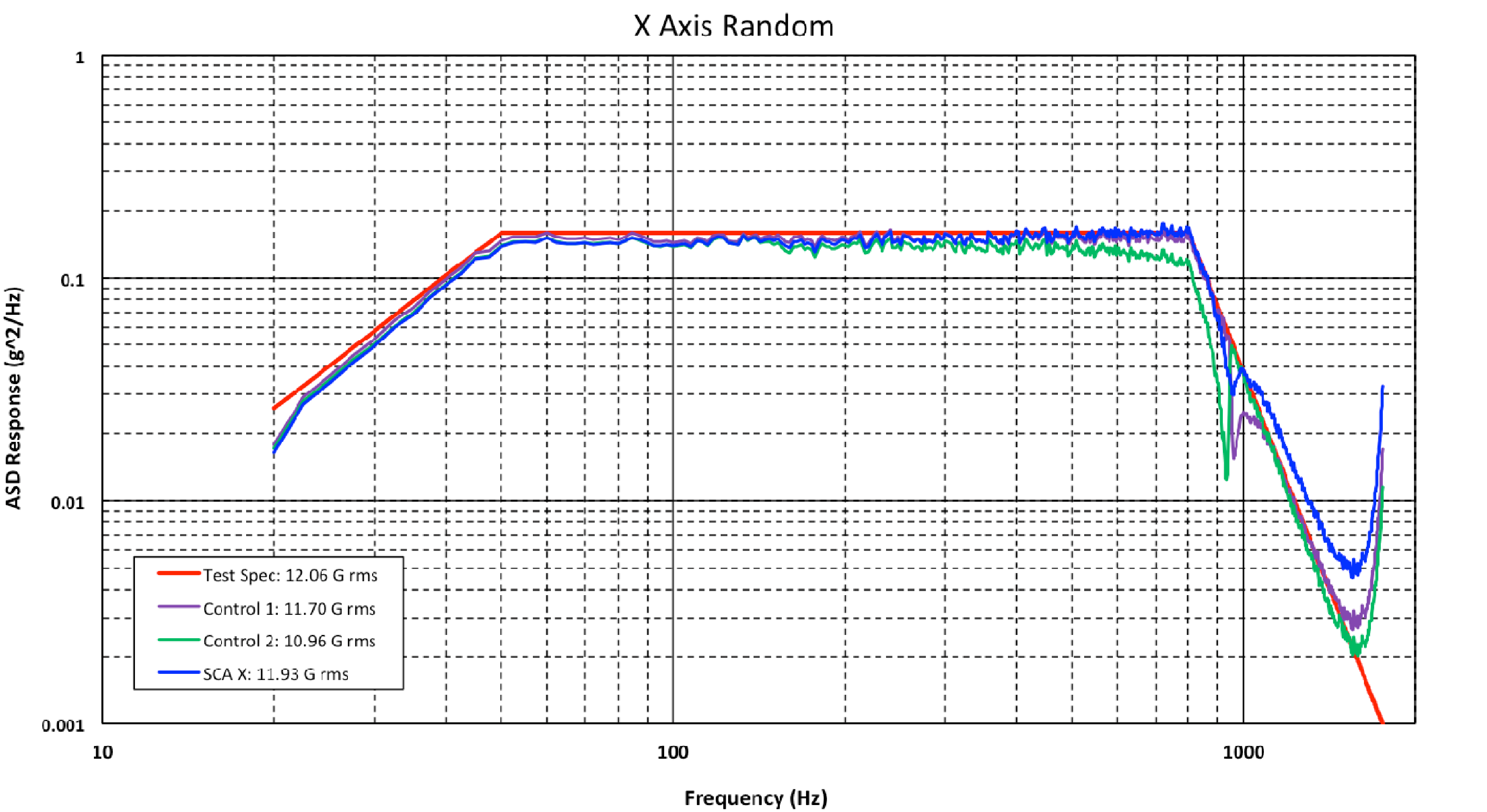


- SCA was installed in the vibration test fixture with cover installed.
  - Response triax accel was installed next to SCA
  - Control uniaxial accel needed to be installed external to the cover.
- GEVS qualification levels (all three axes)
  - Notching required above 1750Hz due to mode in vibration plate (found during dummy-SCA dry-run)

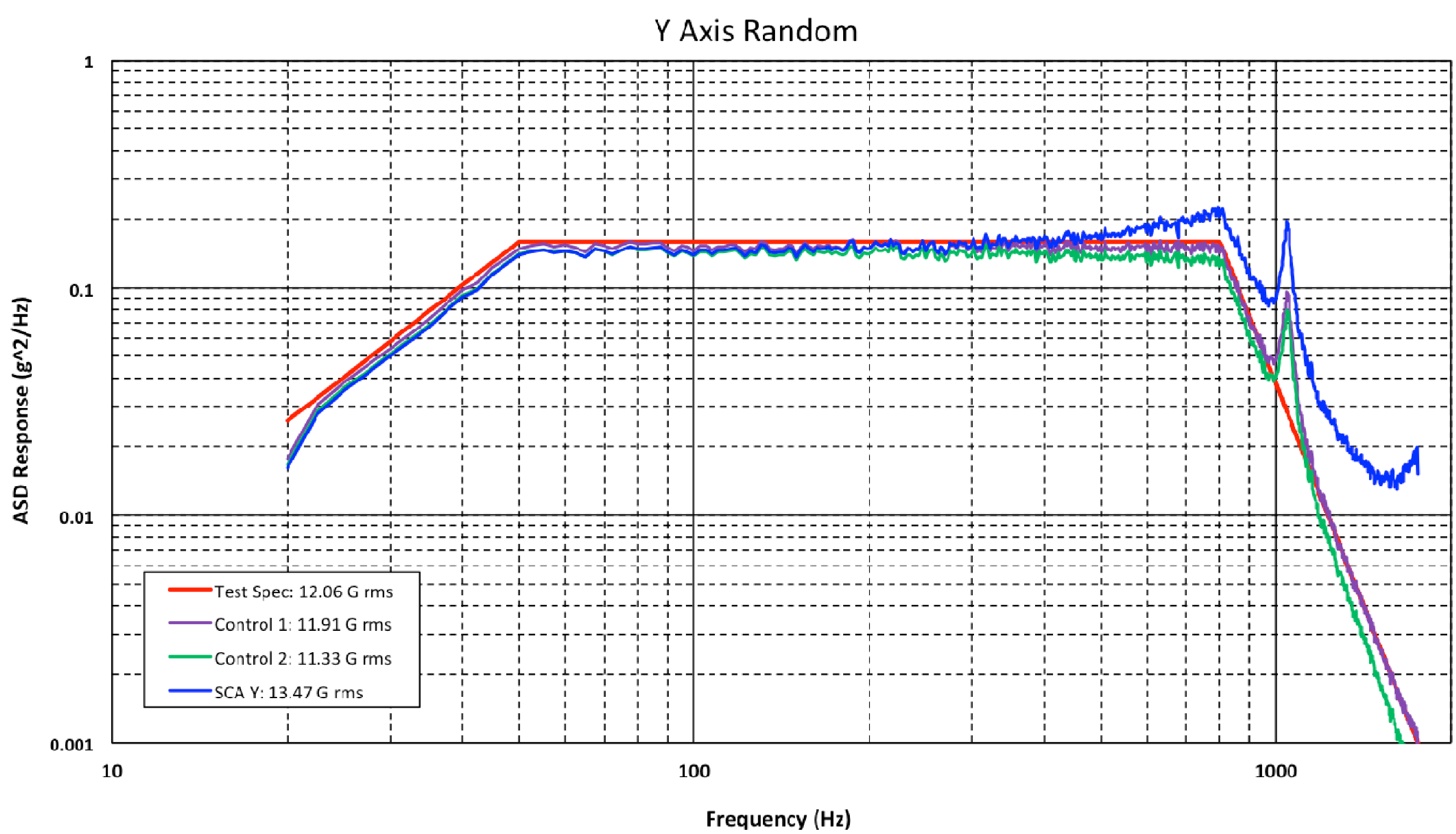
Frequency (Hz)	ASD Level Qualification
20	0.026
20-50	+6 dB/oct
50-800	0.16
800-2000	-6 dB/oct
2000	0.026
Overall	14.1 G_{rms}



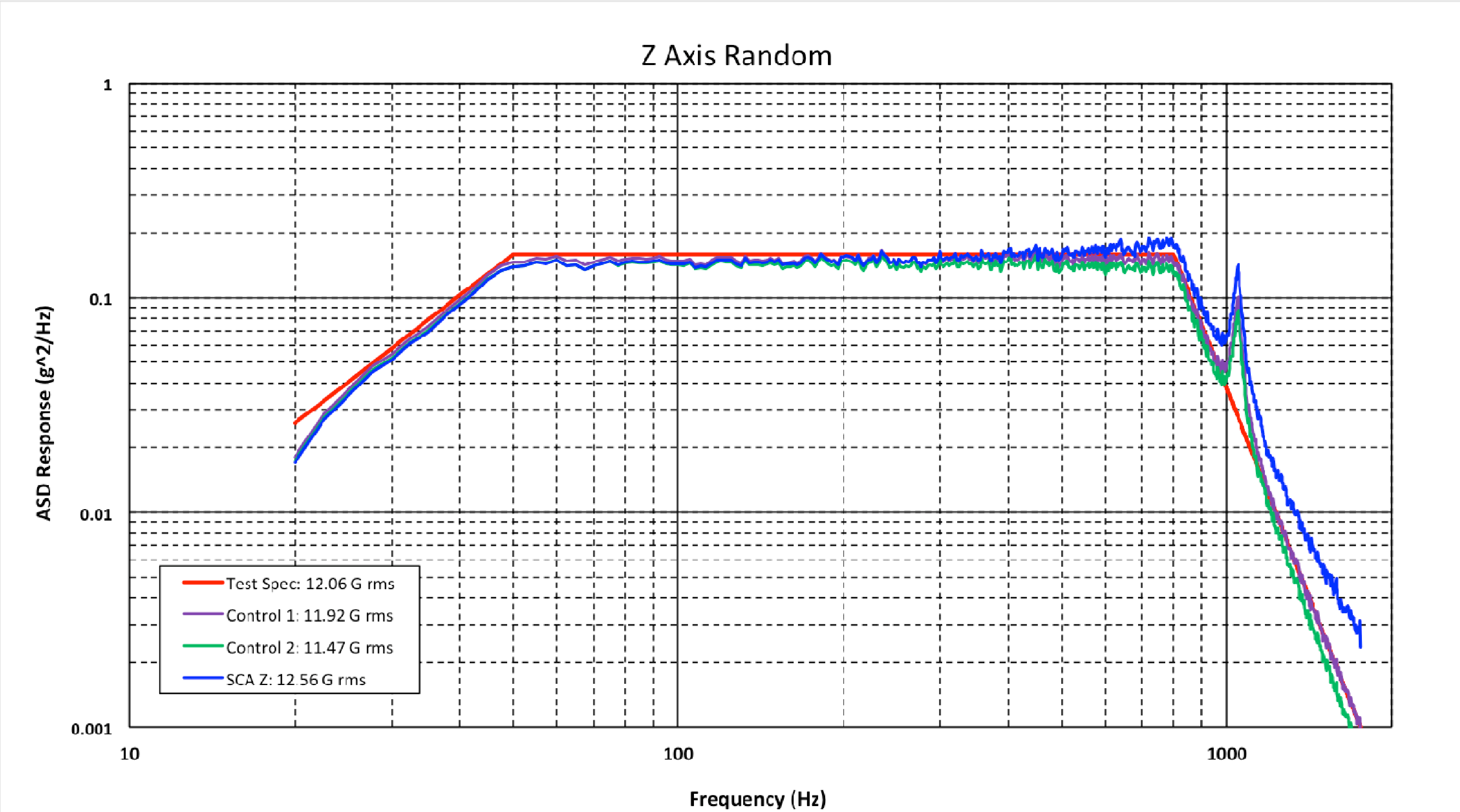
X-Axis Random



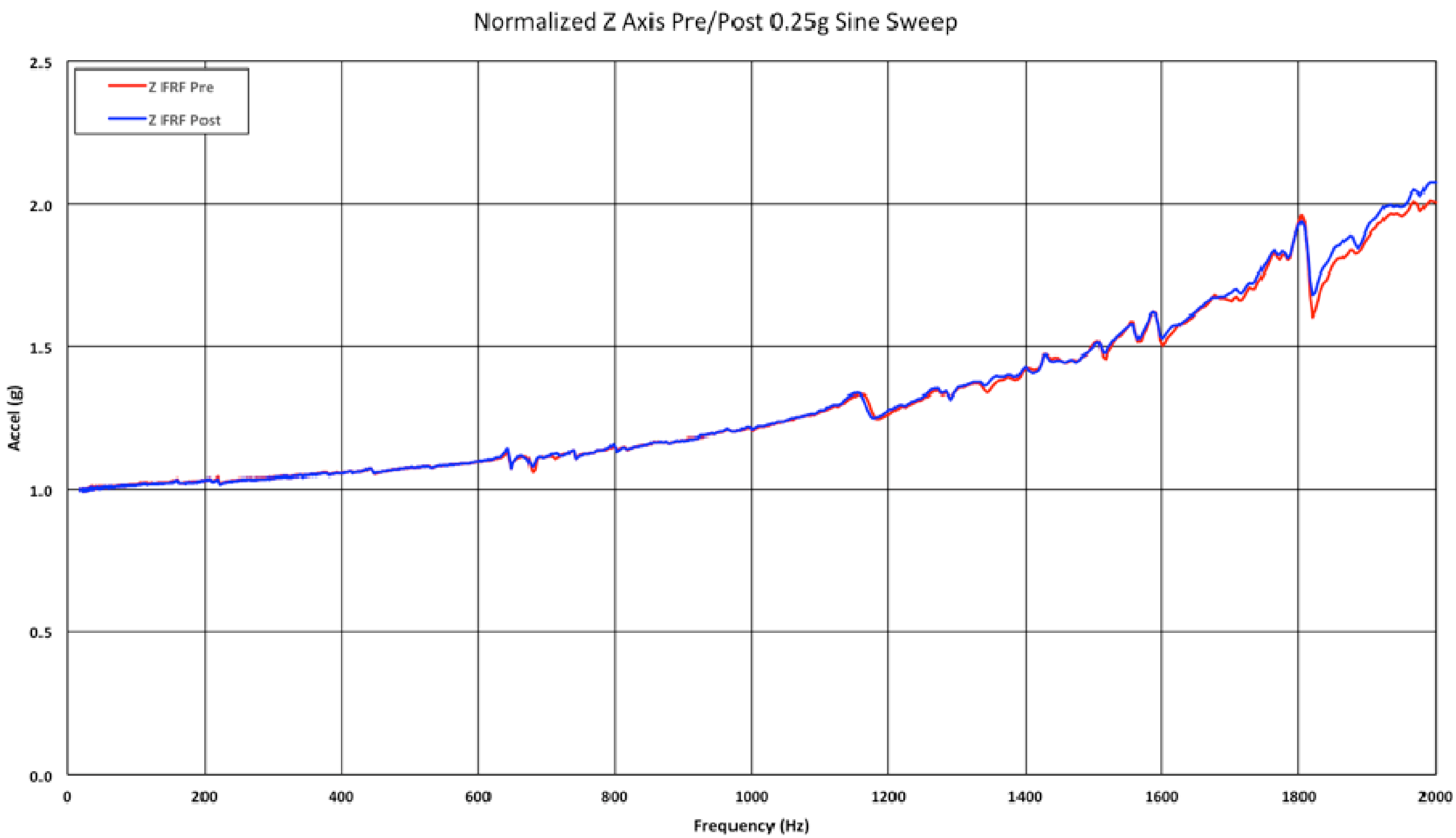
Y-Axis Random



Z-Axis Random



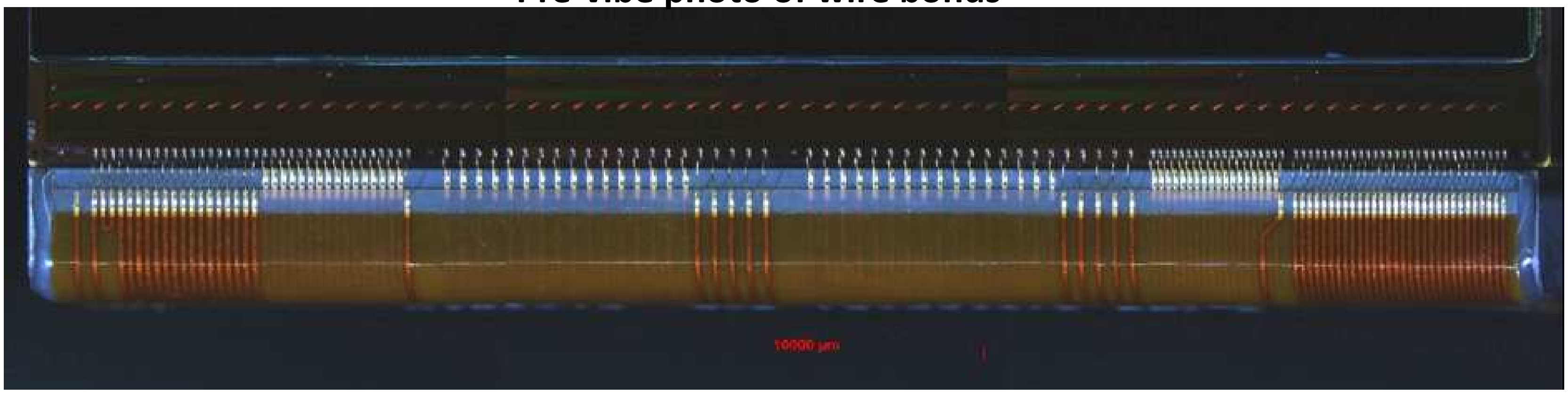
Z Sine Sweep



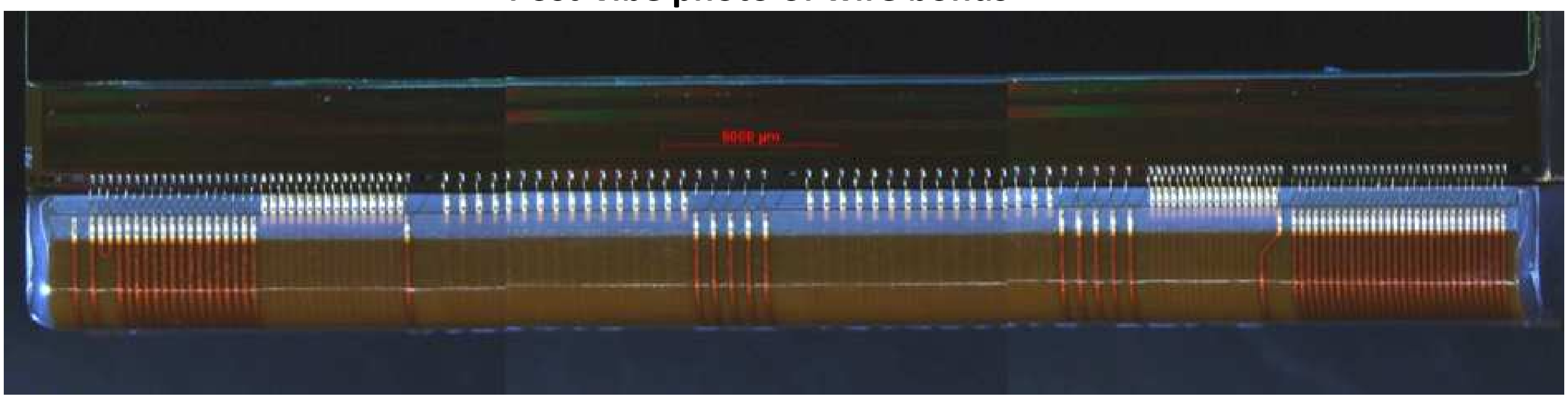
Normalized Z Axis Pre/Post 0.25g Sine Sweep
Z IFRF Pre
Z IFRF Post
Accel (g)
Frequency (Hz)
0.0
0.5
1.0
1.5
2.0
2.5
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Post-Environmental Inspection

Pre-vibe photo of wire bonds



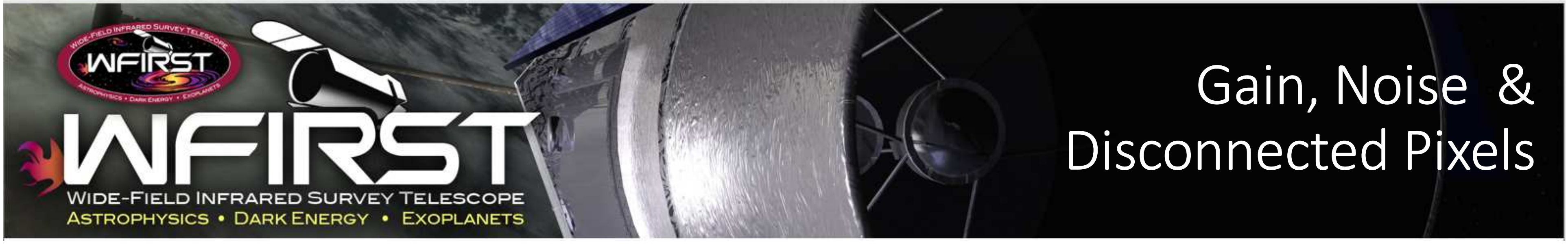
Post-vibe photo of wire bonds



- A comprehensive set of inspection photos of the SCA were made before and after vibration testing
- No noticeable differences are seen in the photos (sample photos of wire bonds shown above)

Post-Environmental Performance Testing

- The post-environmental test results show that the detector performance is unchanged in comparison to its initial performance.
  - The small differences in pre- and post- performance are within experimental error.
- Results are shown here for disconnected pixels, gain, total noise, dark current and relative quantum efficiency.



Gain, Noise & Disconnected Pixels

- **Gain measured via photon transfer curve method**
- **Not corrected for IPC**

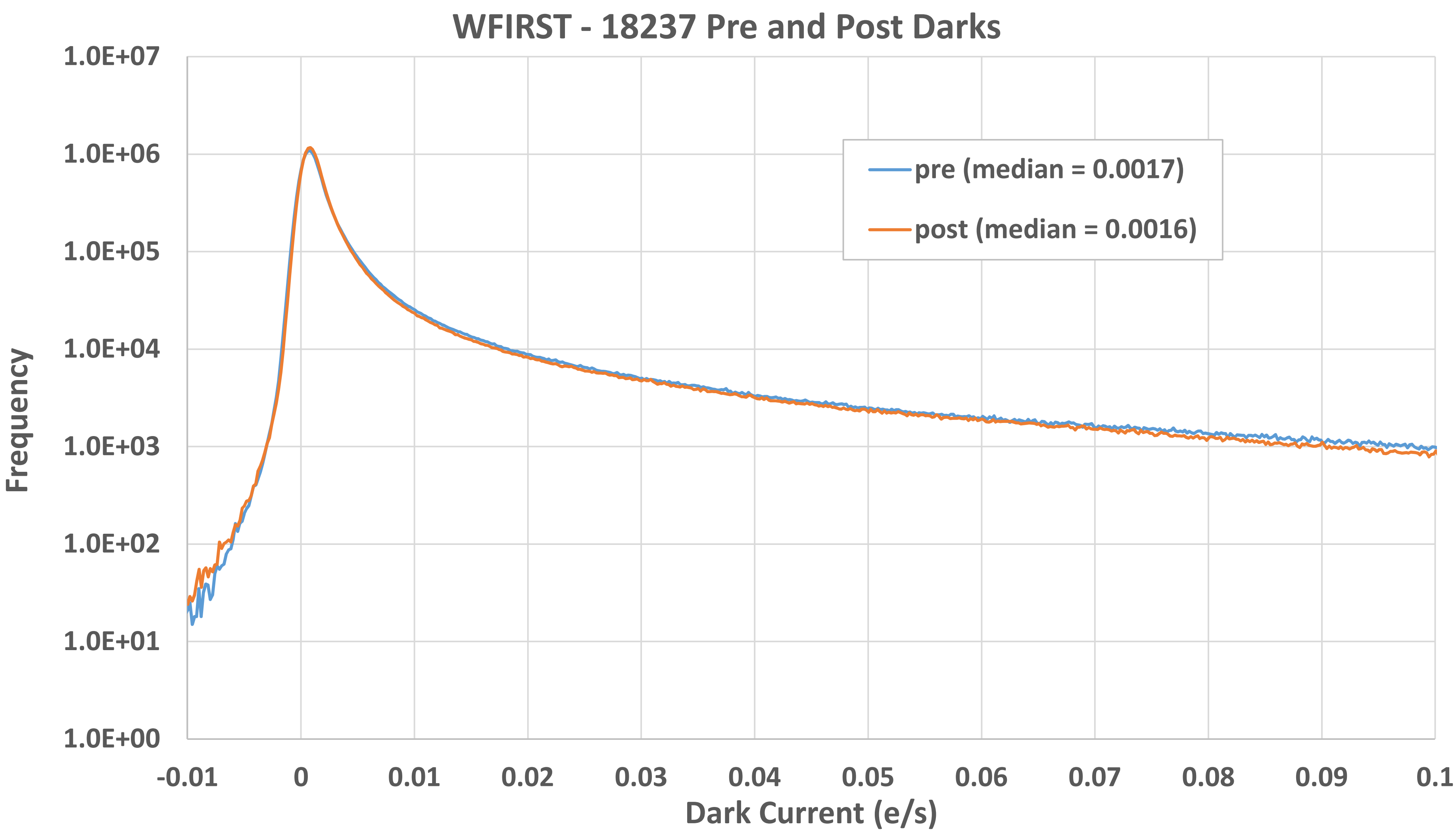
	Gain	
Pre	1.82	e/ADU
Post	1.82	e/ADU

Disconnected Pixels			
	# unresponsive pixels	total # of pixels	% of Good Pixels
Pre	3168	16711744	99.9810%
Post	3230	16711744	99.9807%

Total Noise		
	ADU	Electrons
Pre	4.23	7.71
Post	4.27	7.77

- The gain and total noise are essentially unchanged.
- A total of 62 new disconnected pixels were found following thermal cycling and vibration testing.

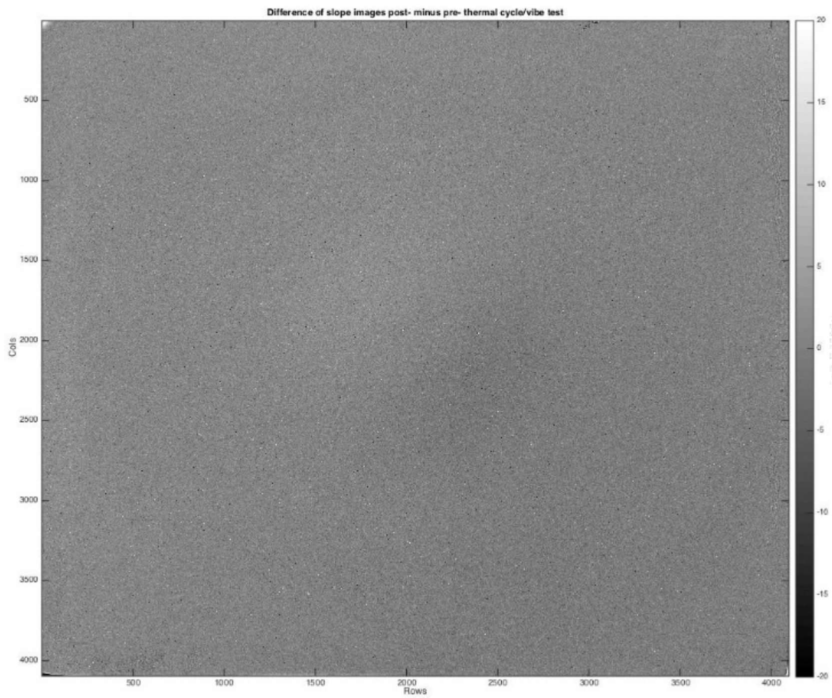
Dark Current



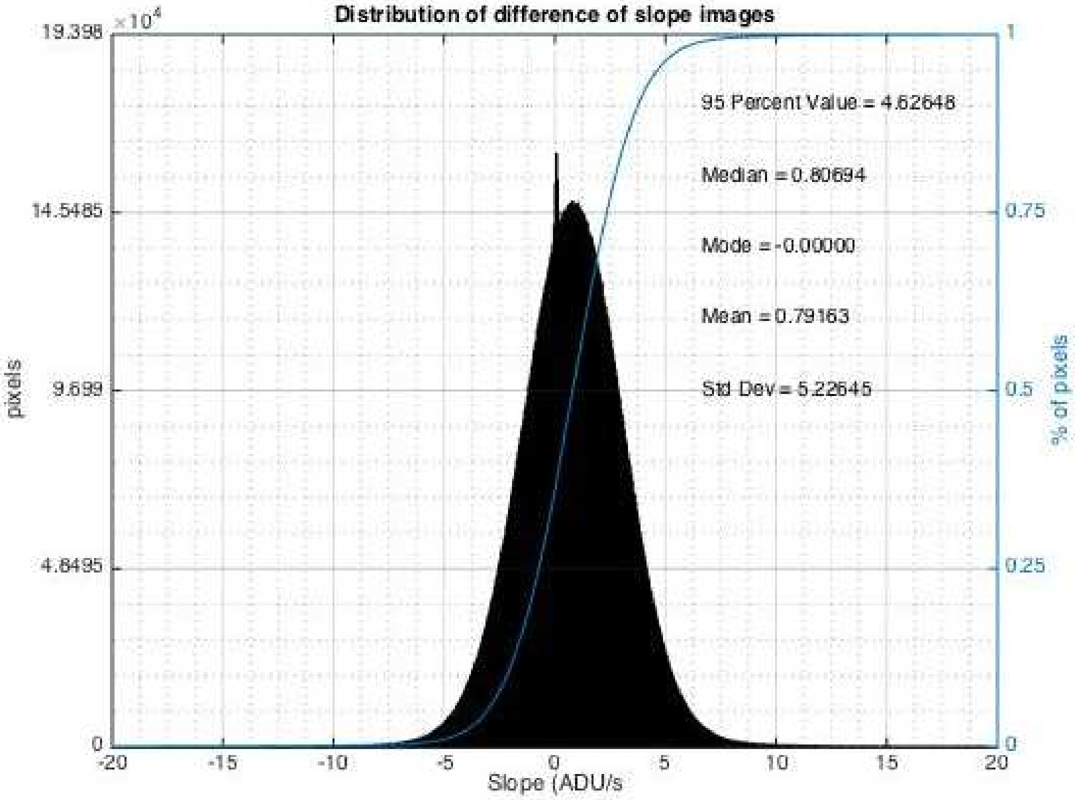
WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

Relative QE

Difference of before and after SUTR images (4k x 4k)



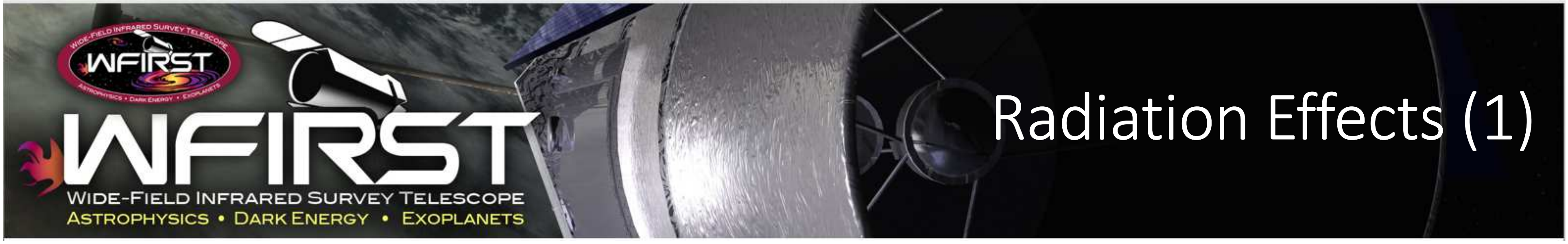
Distribution of slopes in the difference image



- Relative QE was measured by exposing the SCA to a 1.8µm LED at the same current level before and after environmental testing
- SCA response is unchanged (within measurement error).

Radiation Testing

- The radiation test performed here is not intended to be comprehensive.
- The purpose is to show that the WFIRST H4RG-10 design shows degradation similar to that seen in earlier generations of the HxRG family (e.g. JWST H2RG & HST WFC3 H1RG).
- SCA 18239 has been subjected to a fluence of $3e10/cm^2$ of 63MeV protons (5krad total ionizing dose) at the UC Davis cyclotron facility.
  - This dose was recommended by the radiation branch and is the same as the dose used in testing JWST detectors.
  - The JWST orbital environment is the same as WFIRST, but it is expected that the WFIRST instrument will provide more shielding.



Radiation Effects (1)

- HgCdTe detectors are known to suffer performance degradation due to exposure to high energy protons.
  - The number of hot pixels and noisy pixels increases.
  - The median dark current increases, but only by a small amount.
  - QE changes have not been seen following radiation testing.
- Results for dark current, hot pixels and noise are presented here.
- No conclusive post-radiation QE measurement was obtained at UC Davis and a shift in the position of the illuminating LED in shipping precluded a final measurement at GSFC.
  - The QE for this SCA will be re-measured at the DCL at the next opportunity.

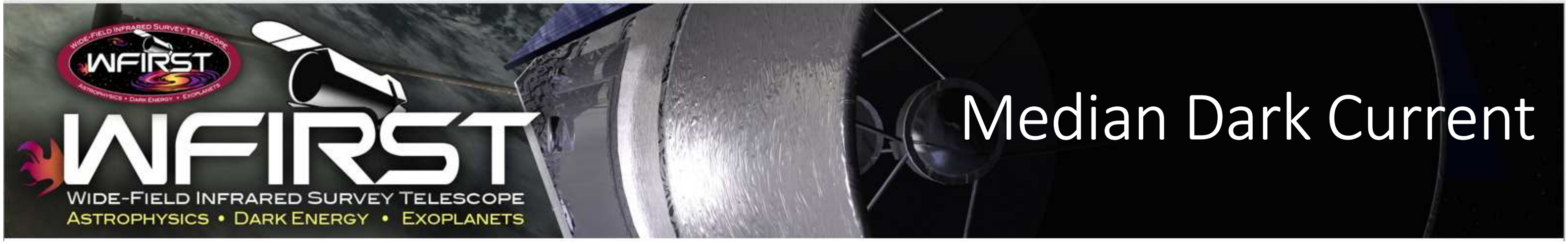
Radiation Effects (2)

- The SCA was maintained at 100K during all testing and irradiation at UC Davis.
- Following irradiation, the SCA typically undergoes some annealing of damage, with a consequent gradual improvement in performance.
- This annealing may continue for several weeks, but the post-radiation testing at UC Davis was performed before the annealing was complete, so the degradation results presented here are likely more severe than should be expected for WFIRST.
- The SCA was at room temperature for shipment back to GSFC, so further (excessive) annealing is likely to have occurred prior to the post-radiation testing at the DCL.

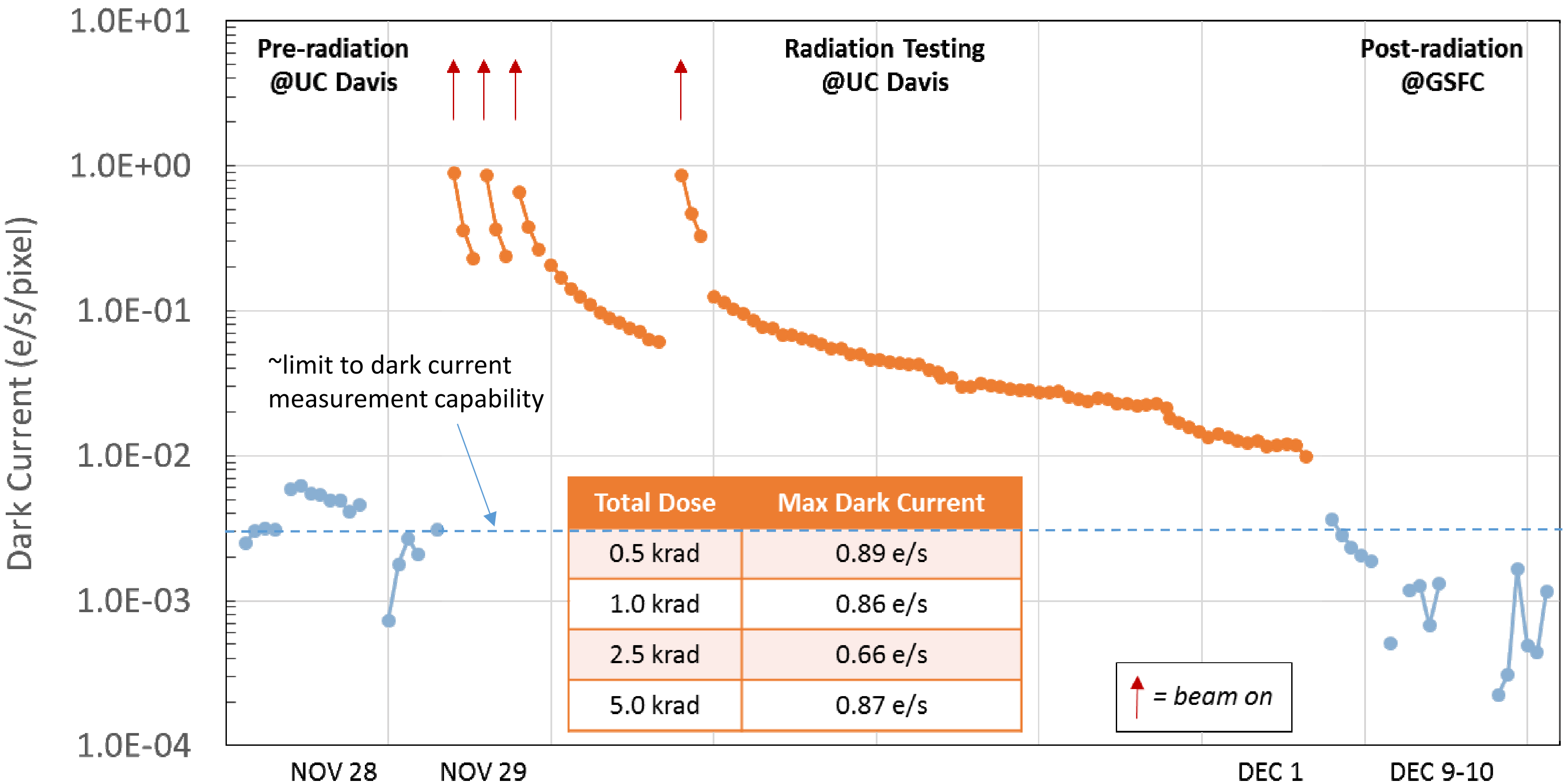
Radiation Steps

Run #	Energy (exiting beam port)	Energy (detector)	Δ Fluence	Tot. Fluence	DDD HgCdTe	TID
	MeV	MeV	cm^{-2}	cm^{-2}	MeV/g	krad(Si)
1-3	64.05	63.77	(very low flux for transient capture)			< 0.01
4	64.05	63.77	3.80E+09	3.80E+09	9.59E+06	0.50
5	64.05	63.77	3.80E+09	7.60E+09	1.92E+07	1.00
6	64.05	63.77	1.14E+10	1.90E+10	4.79E+07	2.50
7	64.05	63.77	1.90E+10	3.80E+10	9.59E+07	5.00

- The total dose was delivered over 7 individual exposures.
- The first three were at very low fluence to investigate transients, followed by four larger doses to bring the total fluence to 3.8e10 cm^{-2}.
- Noise and dark current performance (including the hot pixel population) were measured after each irradiation.



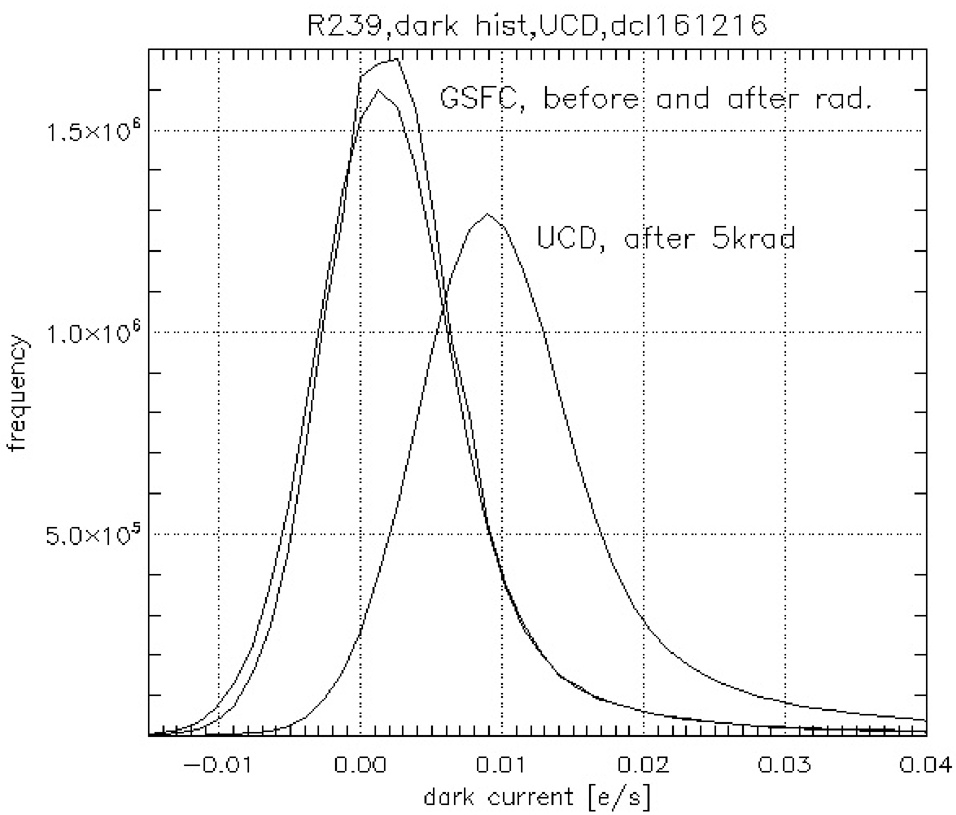
Median Dark Current



Total Dose	Max Dark Current
0.5 krad	0.89 e/s
1.0 krad	0.86 e/s
2.5 krad	0.66 e/s
5.0 krad	0.87 e/s

- Dark current peaks immediately after exposure and then declines.

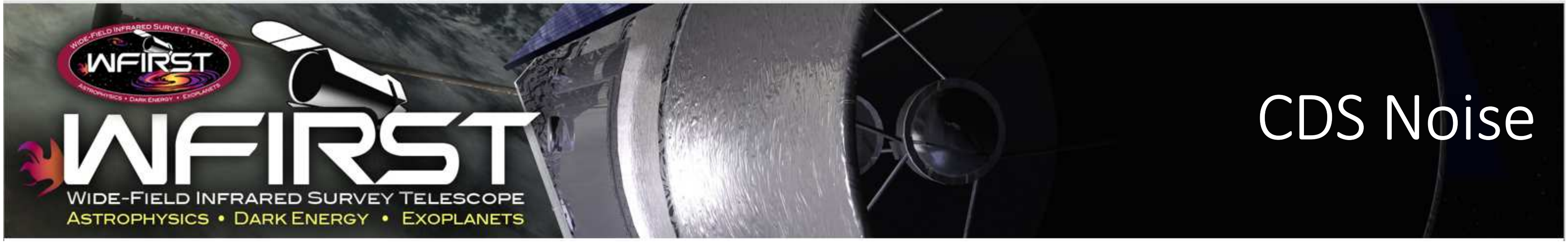
Dark Current & Hot Pixel Details



	Median dark [e/s]	Hot pixels > 0.1e/s	Hot pixels difference
Before radiation	0.003	0.0305	0
CNL – after 5krad	0.012	0.0657	0.0352
GSFC – after 5krad	0.003	0.0344	0.0039

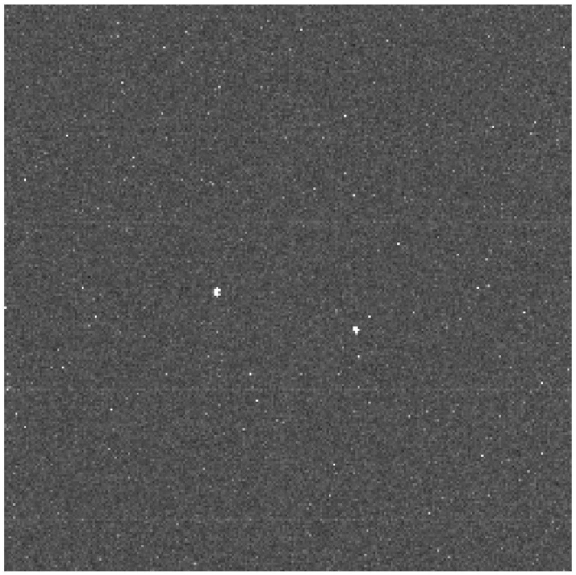
- The post-5krad median dark current was <0.012e$^-$/sec, well below the WFIRST draft spec (0.05e$^-$/sec)
- An additional 3.5% of hot pixels (>0.1 e$^-$/sec) were also created.
- The fractional increase in inoperable pixels (>0.5 e$^-$/sec) is much less (1.2%) .

- The increase in the median dark current is not significant and the increase in hot pixels is both within acceptable levels and consistent with radiation testing of HgCdTe devices from other programs.

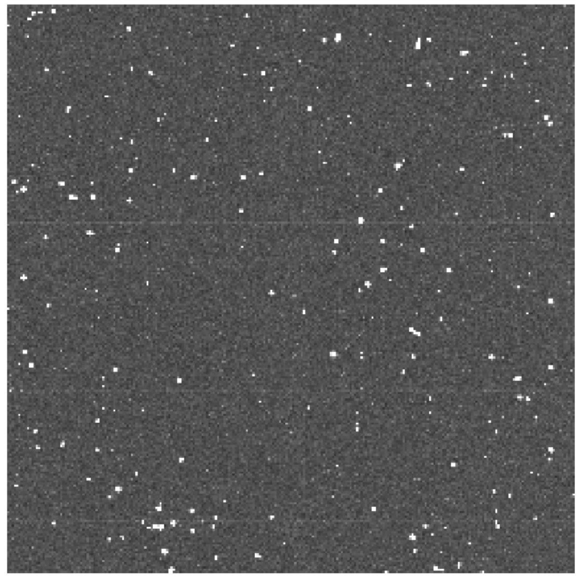


CDS Noise

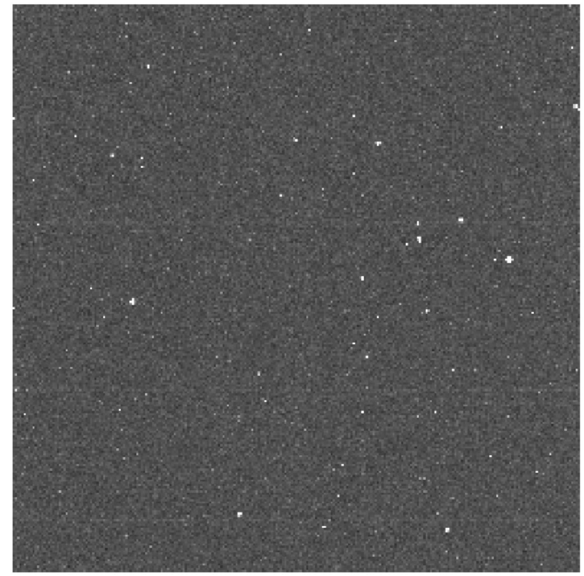
(256x256 region)



Pre-rad (Davis)
16.8 e



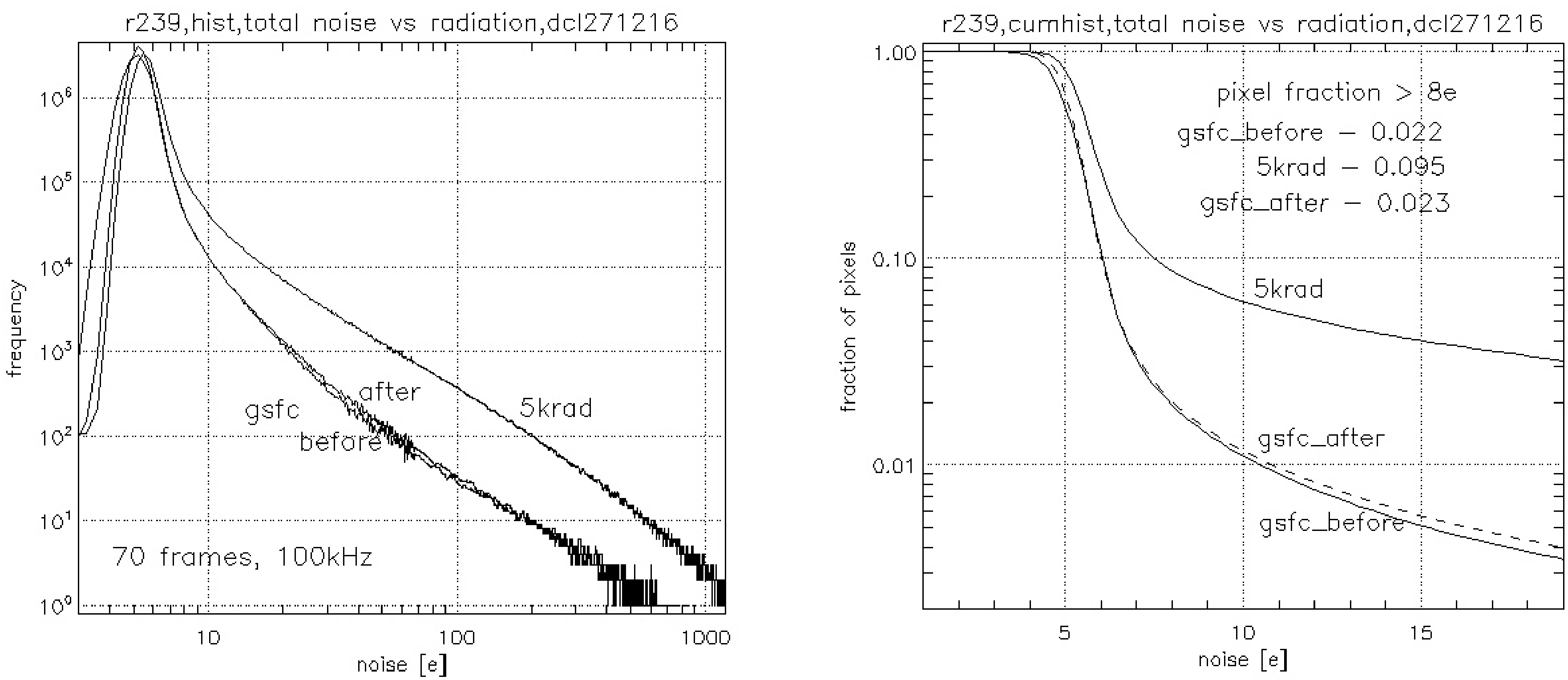
During Rad Testing (Davis)
17.1 e – 19.4 e



Post-rad (Davis)
16.9 e

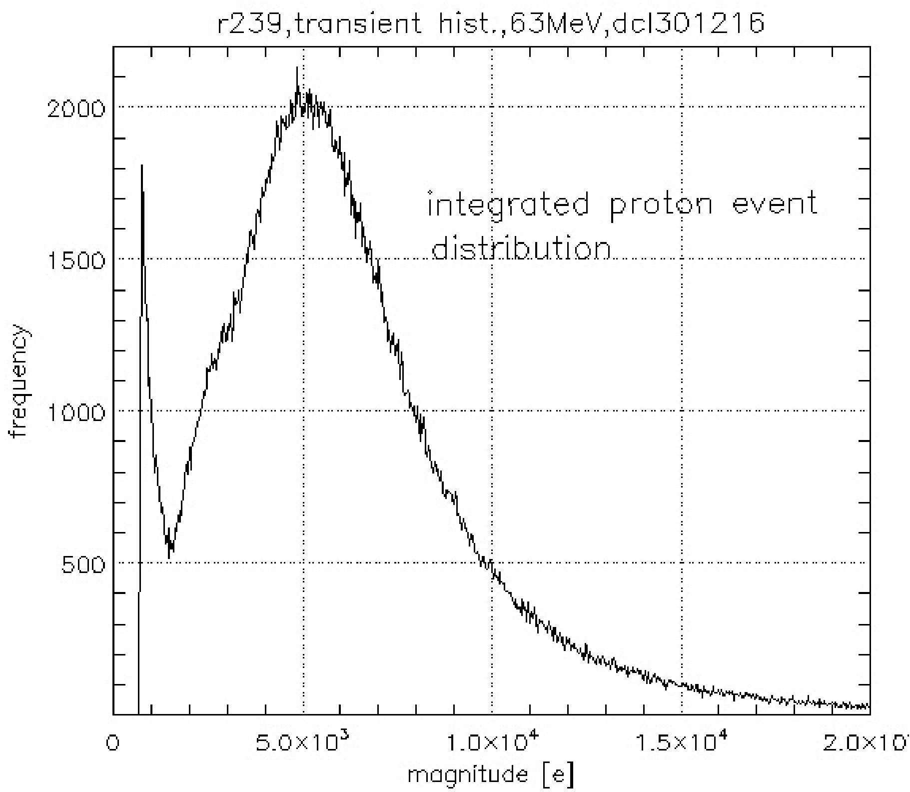
- CDS noise increases during irradiation but returns to its original level after the irradiation is complete.

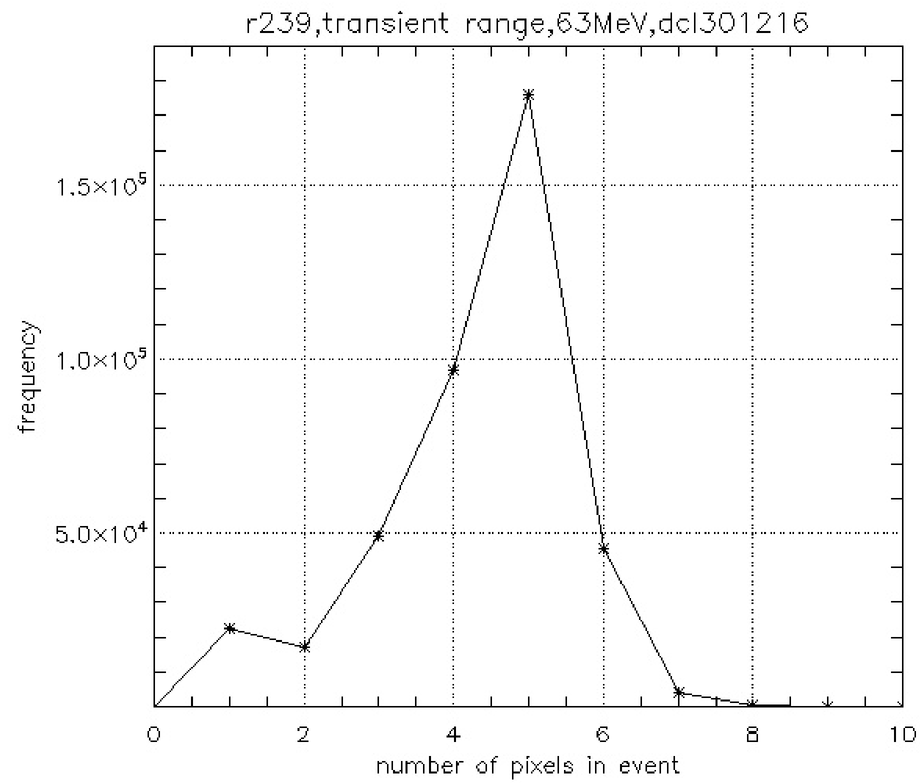
Total Noise



- The median total noise is virtually unchanged by radiation.
- ~7.3% new noisy pixels (>8e$^-$) were created but the fraction of new inoperable pixels is much smaller (1.4% > 14e$^-$).

Transients





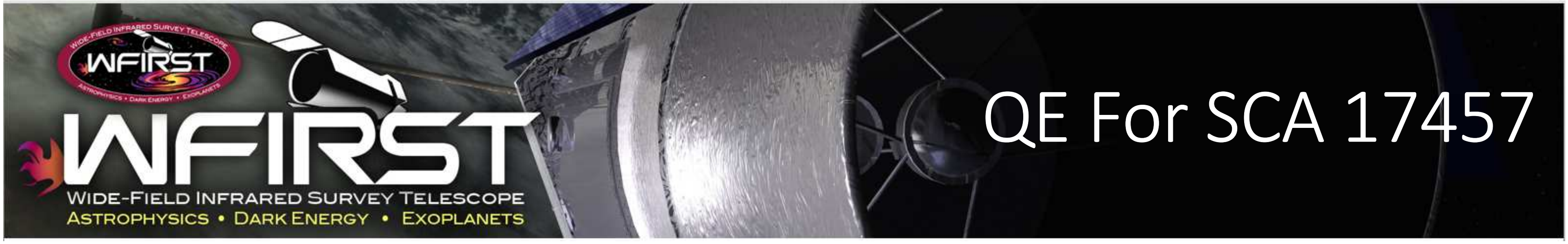
- The typical transient results in several thousand electrons deposited in the detector over ~5 pixels, which is similar to results seen with other HgCdTe detectors.

Conclusions

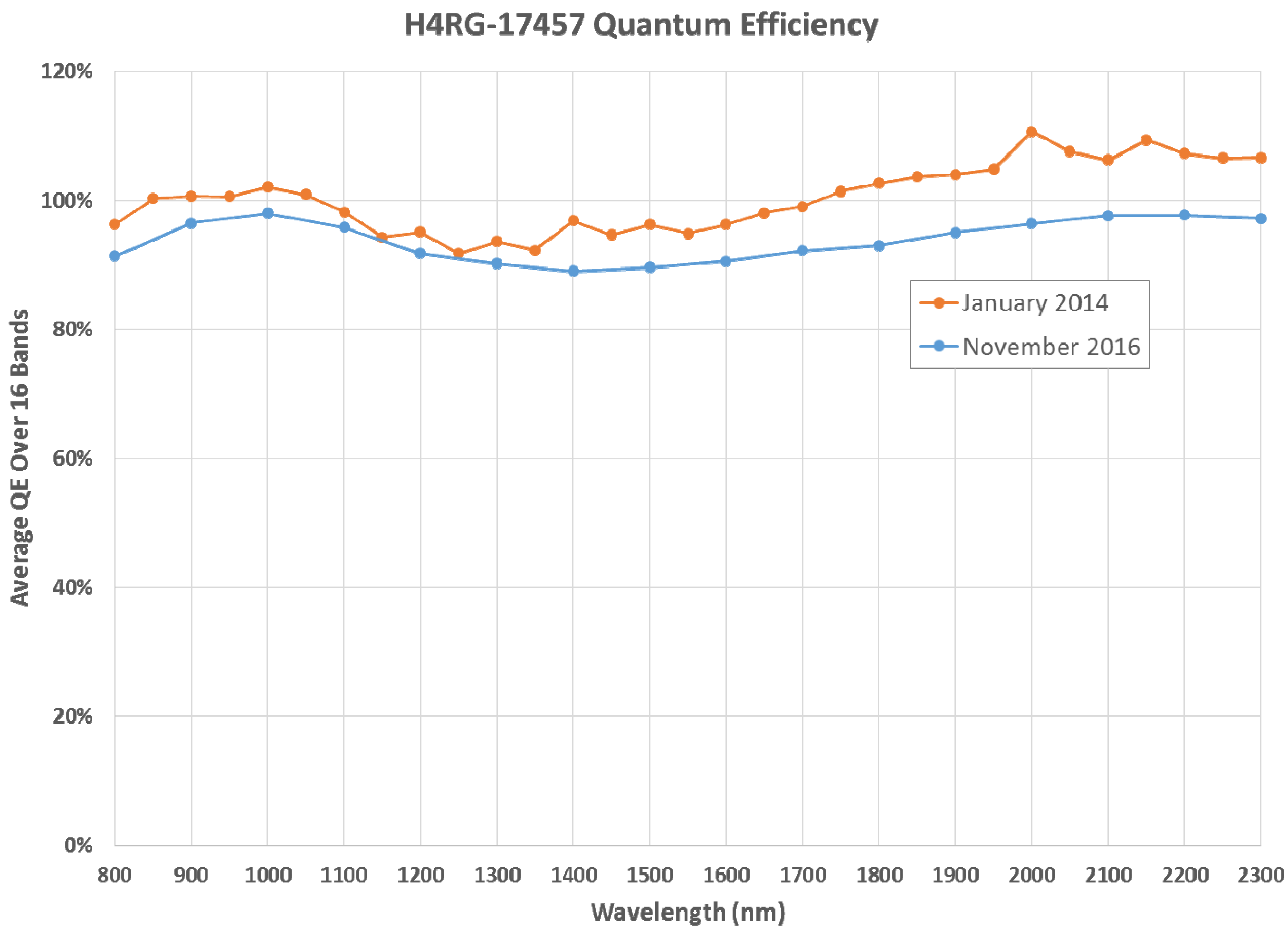
- A 4kx4k PV3 WFIRST SCA has been taken through thermal cycling and vibration testing.
- Post-environmental performance testing shows no change in pixel operability, dark current and noise performance.
- A second 4kx4k PV3 SCA has demonstrated expected and acceptable post-irradiation performance after exposure to the dose expected for the 6-year WFIRST mission lifetime.
- The environmental testing here demonstrates that there should be no significant issues in qualifying the final WFIRST flight design.

Improvements In DCL QE Measurements

- Early QE testing in the DCL often resulted in measured QE > 100%, an indication of an unknown source of systematic error.
- Following an internal DCL design review of the test setup, multiple improvements were made, focusing on the quality of optical baffles and reducing reflections by using coatings that are designed for use in the infrared
- The QE SCA 17457, which showed a QE >100% in the data presented for DTAC Milestone #1, was re-measured in Nov. 2016.
- The new results are systematically lower and below 100%.



QE For SCA 17457



- **Average QE is reduced by 7.0% between 800nm and 2300nm**