Wide Field Instrument Detector Technology – Milestone #4 Review

September 22, 2016

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
5	Complete environmental testing (vibration, radiation, thermal cycling) of one SCA sample part, as per NASA test standards.	12/1/16

Previous Milestones

- For DTAC Milestones 1 & 2, the WFIRST project developed a 10µm pixel design with satisfactory performance for each of two passivation techniques (PV2A and PV3).
  - The same pixel design was found to be the best performer for both passivations.
- Milestone 3 demonstrated that the selected WFIRST pixel design can be scaled up to produce high performance 4k x 4k arrays, again for both passivation types.
- Both passivation types have been carried forward
  - YDL1 = PV2A
  - YDL2 = PV3

Use of PV3 Full-Array Lot for Milestone #4

- When the WFIRST detector development effort was initiated in 2012-13 timeframe, the PV2A passivation technique was more mature and hence the PV2A full-array and Yield Demonstration Lots (YDLs) were produced first.
- However, since then, TIS has made excellent progress on the PV3 design and the full-array PV3 persistence results are significantly better than for PV2A, while other aspects of performance are similar.
- The design of the PV3 full-array lot is thus expected to be much closer to the final flight design than the PV2A YDL.
- We have therefore decided that demonstrating Milestone 4 with the PV3 full-array lot is more appropriate than waiting for the completion of the PV2A YDL.

Deciding on a Final Design for Flight

- We currently plan to initiate the contract for the WFIRST flight detectors with Teledyne in Oct. 2017.
- The YDLs for both the PV2A and PV3 designs will be complete by that date.
- The final decision on the design to be carried forward for flight will be made by the Project, with input from the WFIRST Formulation Science Working Group
- While we are presenting Milestone #4 detector data for only the PV3 design here, if the PV2A design is ultimately selected, a necessary condition will be a demonstration of satisfactory performance from the PV2A YDL.

Testing Approach for Milestone #4

- Testing and analysis approaches for Milestone #4 match closely with the previous Milestones and results are presented in the same manner; plots, figures and images are directly comparable
  - Disconnected pixels measured using shifted DSUB voltage at room temperature
  - Dark Current measured with 2-hour sample-up-the-ramp exposures
  - CDS noise measured using 100 kHz effective readout speed
  - Crosstalk measured using ^{55}Fe and hot pixels
  - Quantum efficiency measured in the same test setup (or linked to the test setup using a reference detector)
- Persistence is formally included for the first time in Milestone #4 (detailed persistence acquisition and analysis information in later slides)
- The presentation of results will begin with persistence and then follow the same order as previous Milestones: disconnected pixels, dark current, CDS noise, QE, crosstalk

PV3 Performance Summary

DCL Results @ T=100K, 1.0V

Detector	Pixels with Nominal Photo Response (%)	Median Dark Current (e/s)	Median CDS Noise (electrons)	QE (%) (av. 800-2350nm)	Crosstalk (%) (nearest neighbor)	Persistence (% of FW in 150 sec. after 150 sec.)
	95%	< 0.1	< 20	> 60	≤ 3	< 0.10
18237	99.99	0.001	11.9	95	2.3	0.02
18238	99.3	0.001	15.1	96	2.6	0.01
18239	99.8	0.001	15.2	89	1.8	0.03
18240	99.97	0.001	15.7	93	2.3	0.01
18241	99.9	0.004	15.2	92	1.9	0.02
18242	99.9	0.040	16.0	93	1.8	0.02
18243	99.9	0.064	16.3	90	1.8	0.03
18244	99.9	0.003	15.1	90	1.9	0.20
18438	99.98	0.001	13.2	86	1.9	0.01
18440	99.96	0.001	14.4	81	2.4	0.01
18441*	99.97					
18442	99.96	0.35	16.2	93	1.9	0.02
18443	99.95	0.003	12.8	87	2.2	0.02

*18441 was not fully analyzed due to an electrical coupling between Vreset and DSUB bias lines

Detectors meeting Milestone #4 Requirements: 10/13 = 77%!

Persistence Requirement in Detail

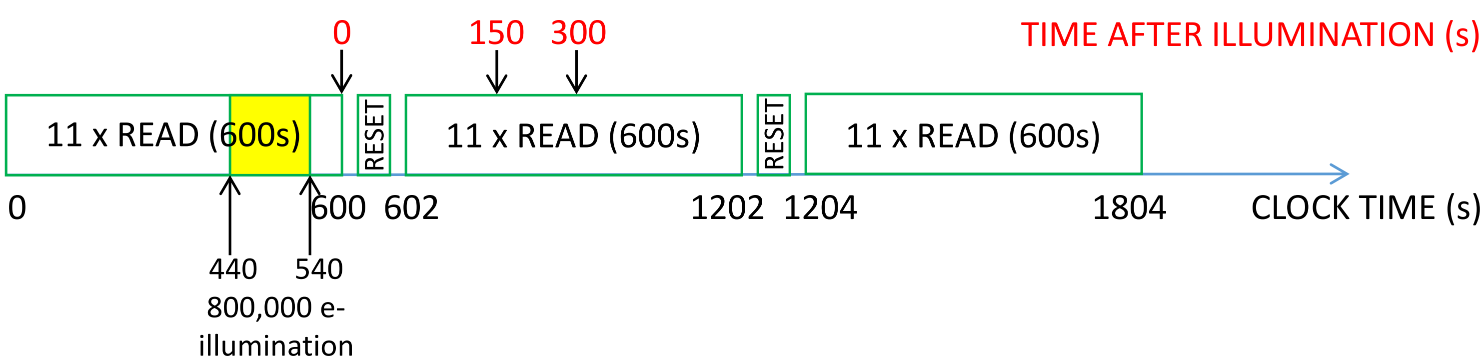
Requirement: "...persistence less than 0.1% of full well illumination after 150 sec at nominal operating temperature."

We interpret the requirement as follows

- Expose the detector to an illumination level $\geq$ full well
- Wait 150 seconds after the detector has been reset following the exposure to full well
- Measure persistence in the next 150 seconds (from 150 to 300 seconds after detector reset)
- Integrate the detector dark current during this 150 second interval
- Subtract baseline dark current per pixel and calculate persistence using median value per array
- Compare the excess dark current to 0.1% of detector full well
  - $\geq$ 0.1% = FAIL, < 0.1% = PASS

Persistence Acquisition Summary

- Measured at 100K, 1.0V, 1400nm illumination
- Persistence measurements were made at an illumination level of 800,000e- for each detector (~8 x FW)
- 10-minute sample-up-the-ramp exposures with 11 total frames were used to measure persistence (1 frame per minute)

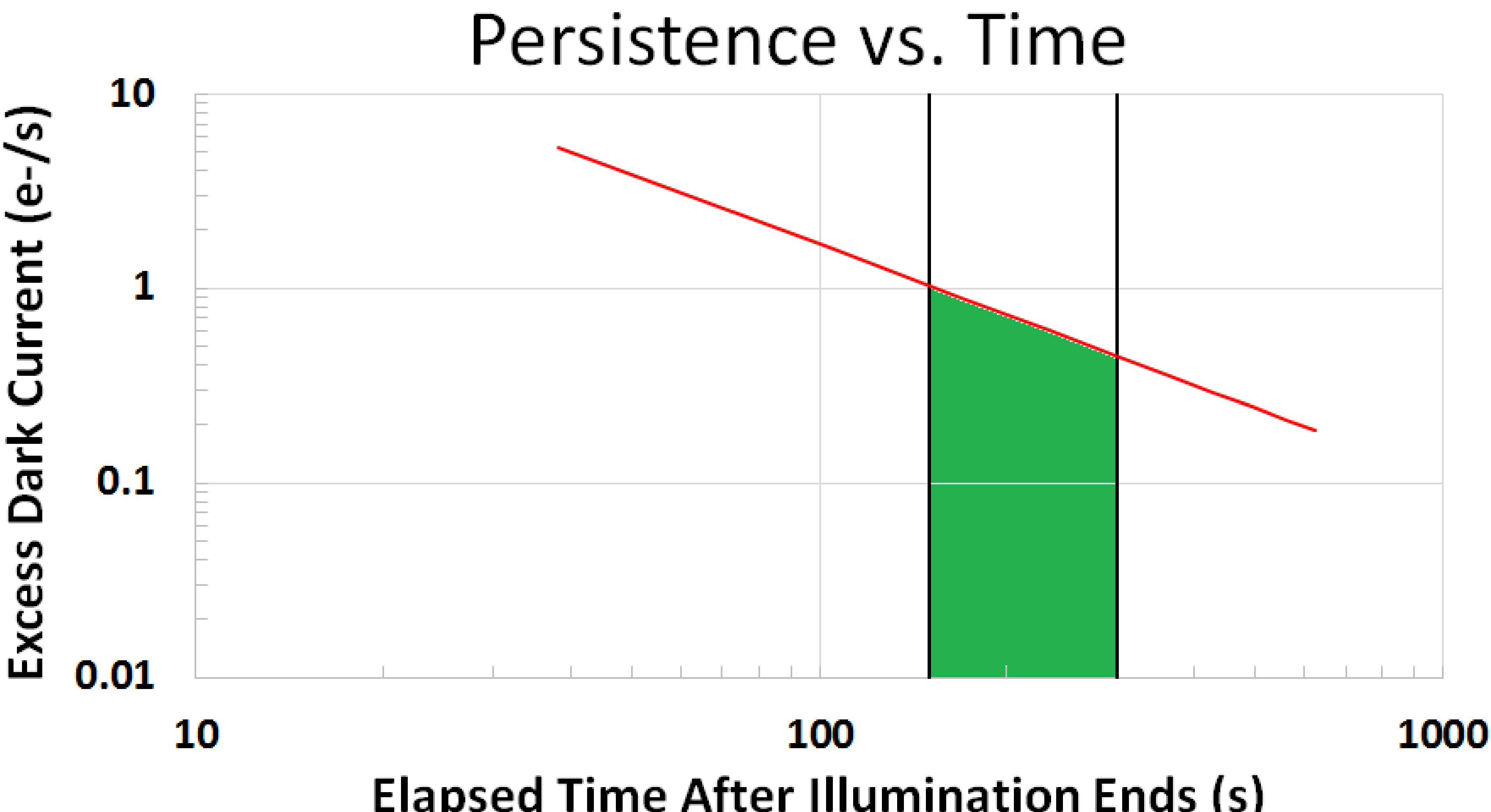


Persistence Analysis Summary

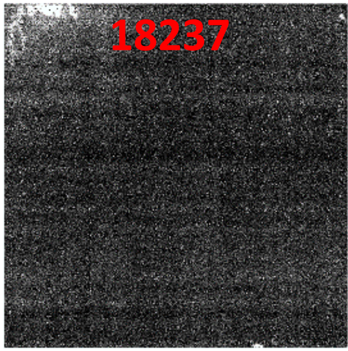
- Full well (FW) has been measured for multiple detectors and has been found to be ~100,000e-. For simplicity, the analysis has been performed using a full well of 100,000e- for all detectors.
  - MS4 requirement = 0.1% of FW → 100 e-
- Even though persistence measurements were made at 8 x FW for each detector, the limit was held to an integrated signal of 100 e- (0.1% of 1 x FW)
- A power law fit was integrated to determine total charge accumulation in 150 seconds (sample plot shown on next slide)
- Image scale: linear [0,0.1%] of FW

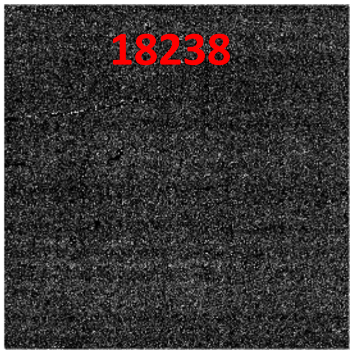
Persistence Analysis

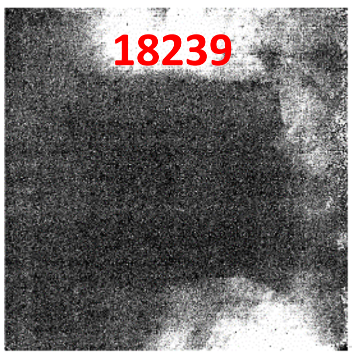
In the sample plot below (log-log scale), the integrated signal (green area) under a power law fit (red line) results in accumulation of 100 e- between 150 and 300 seconds after detector reset.

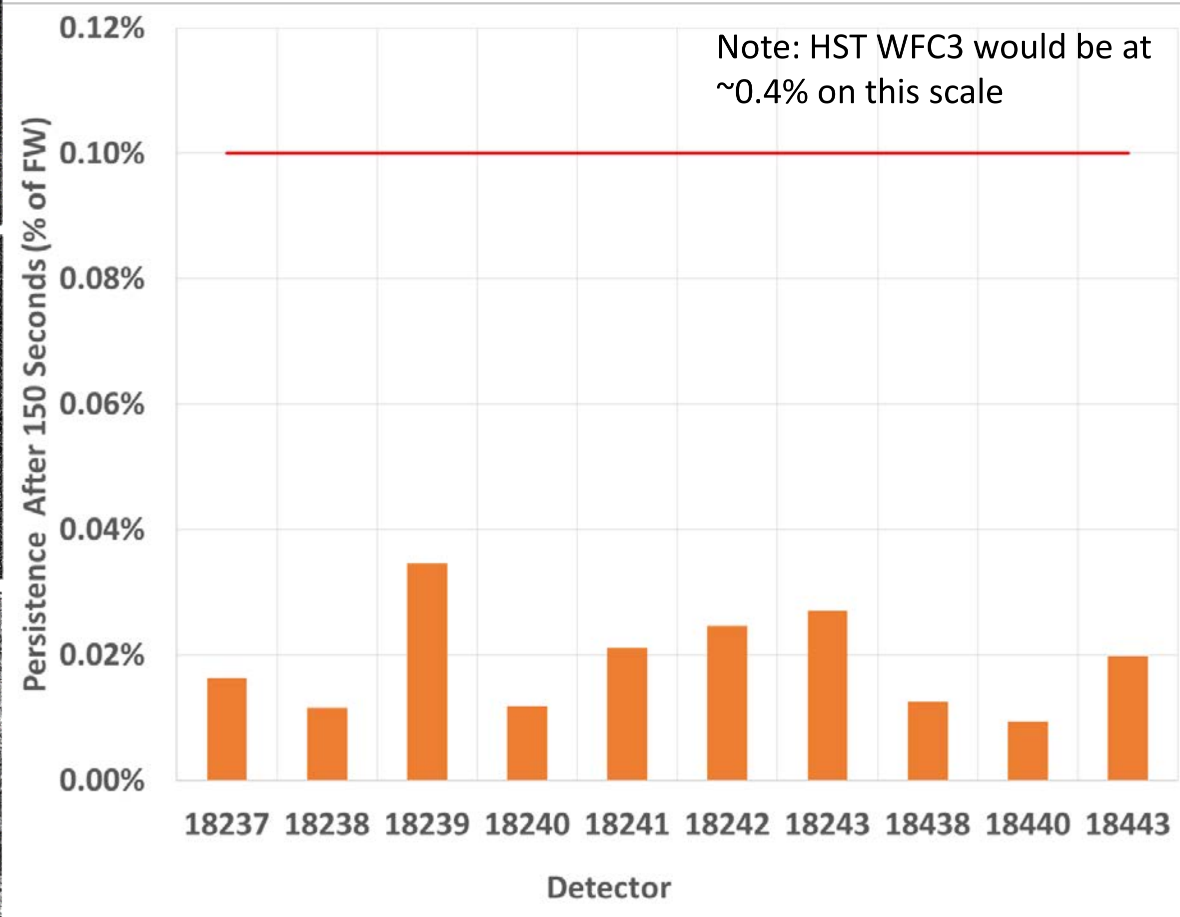


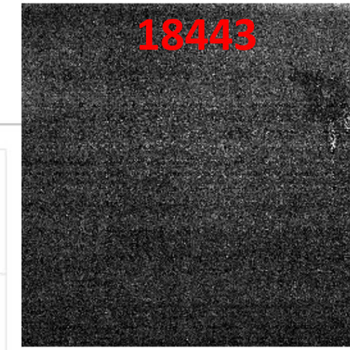
Persistence Summary at 100K, 1.0V

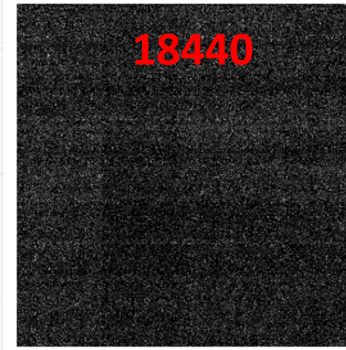


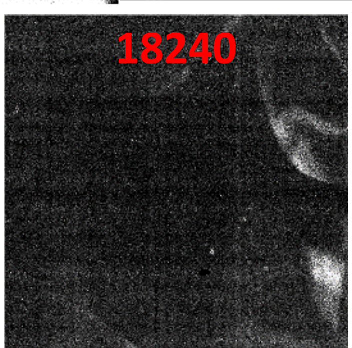


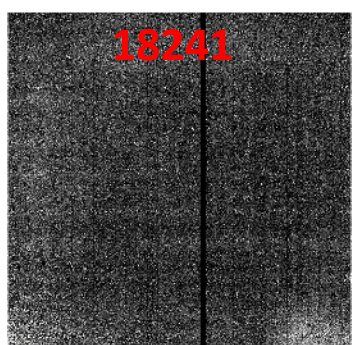


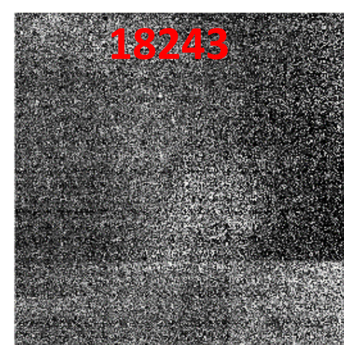








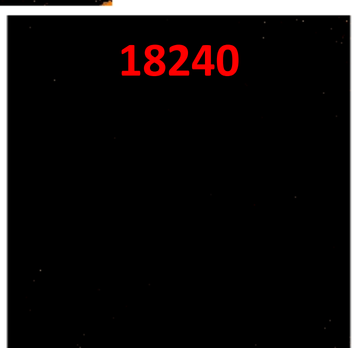




Connected Pixel Summary

(orange pixel = disconnected)

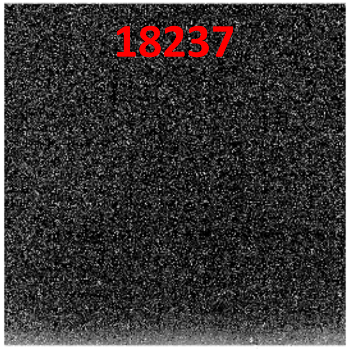
Detector	Connected
18237	99.99%
18238	99.3%
18239	99.8%
18240	99.97%
18241	99.9%
18242	99.9%
18243	99.9%
18438	99.98%
18440	99.96%
18443	99.95%

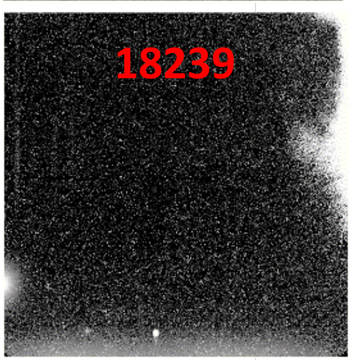


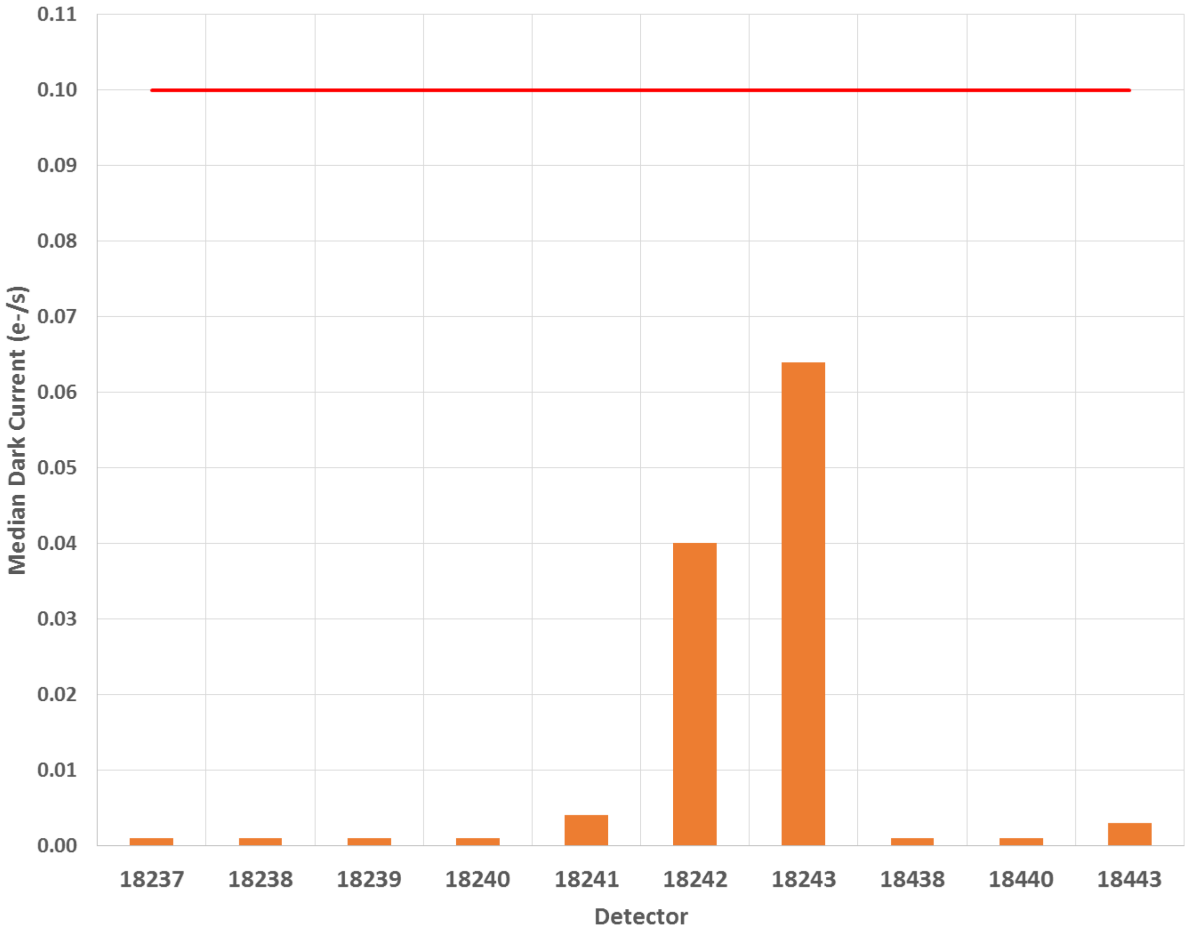
Dark Current Summary

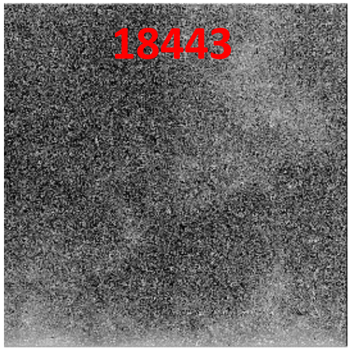
- Uncertainty: 0.003 e-/s
- Results obtained by averaging dark per pixel from multiple 2-hour dark files
- All plotted dark current numbers are median values.
- Images are in log scale [black = 0.001 e-/s, white = 0.1 e-/s]

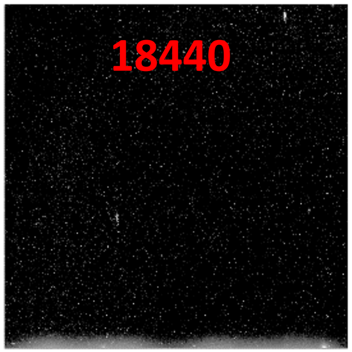
Dark Current Summary at 100K, 1.0V

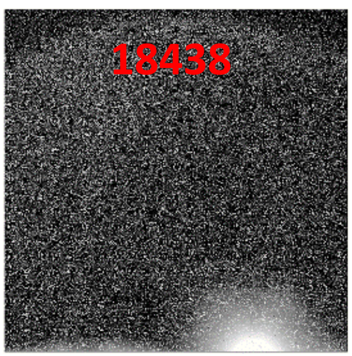


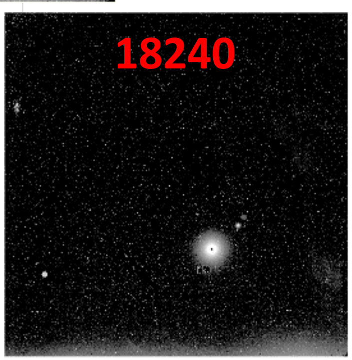


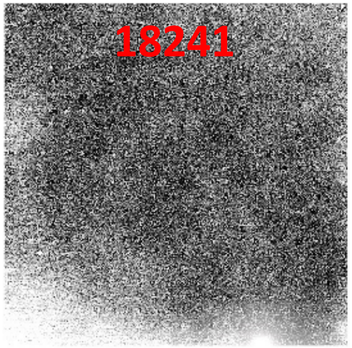


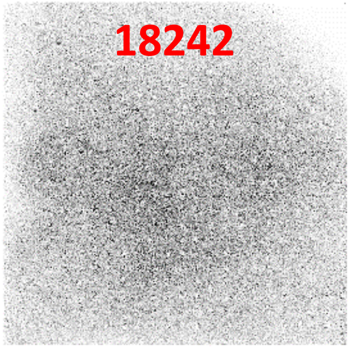


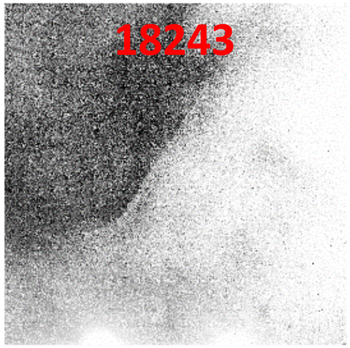








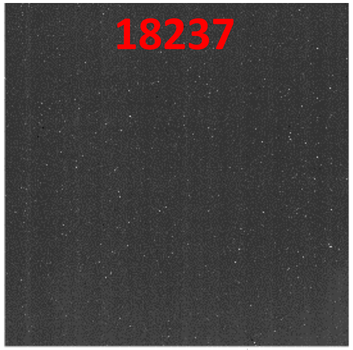


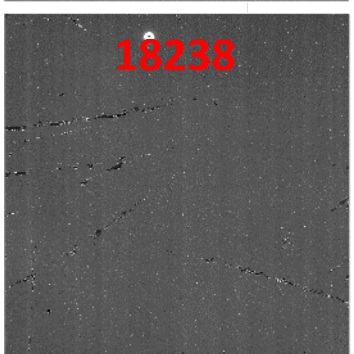


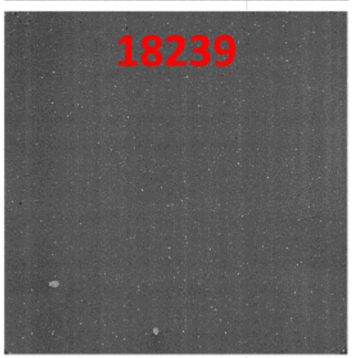
CDS Noise Summary

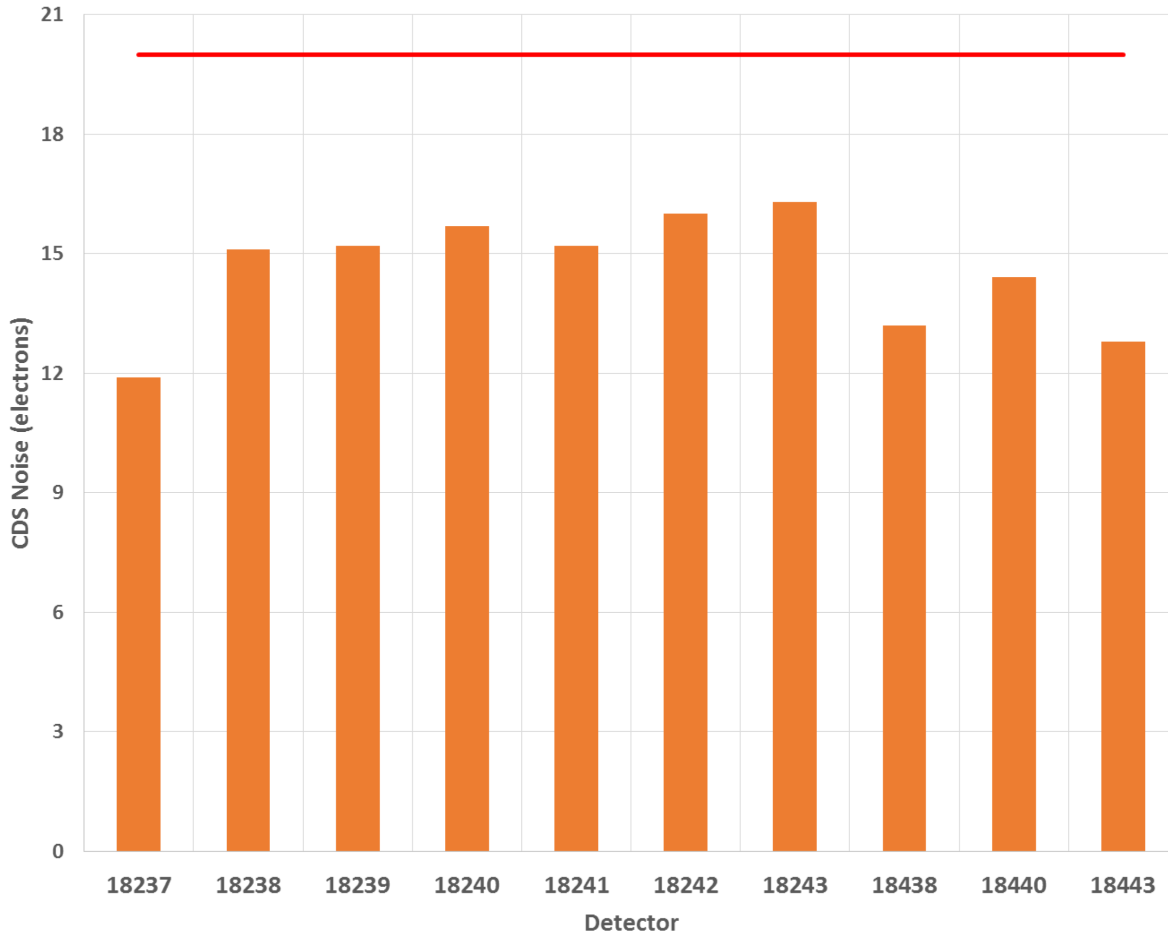
- All plotted CDS noise numbers are median values
- Images are in linear scale: Black=5, White=35 e-

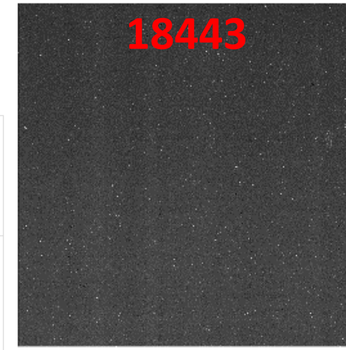
CDS Noise Summary at 100K, 1.0V

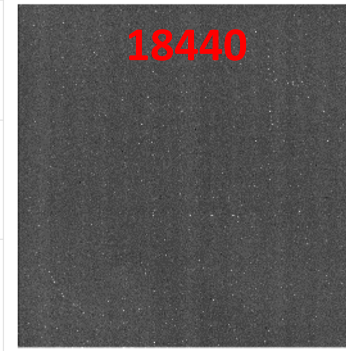


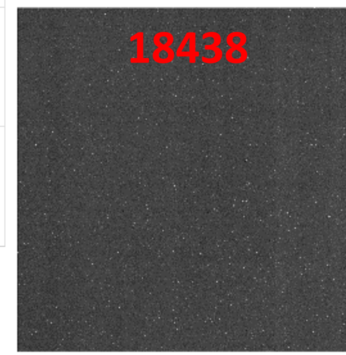


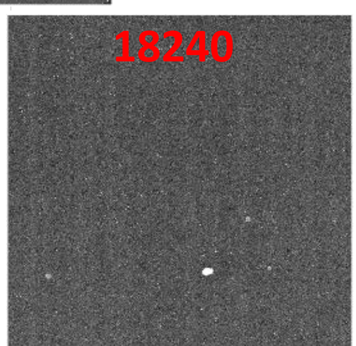


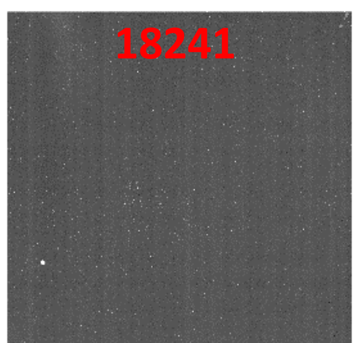


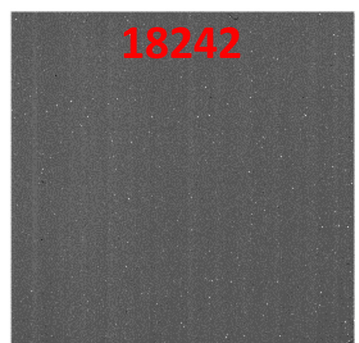


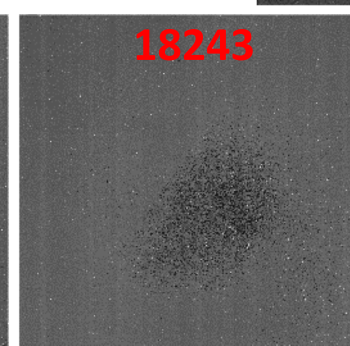








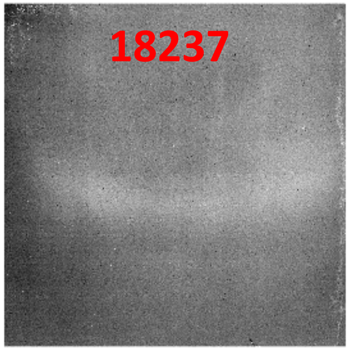


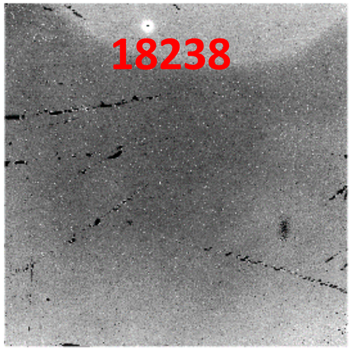


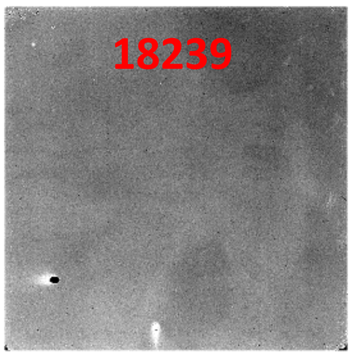
QE Summary

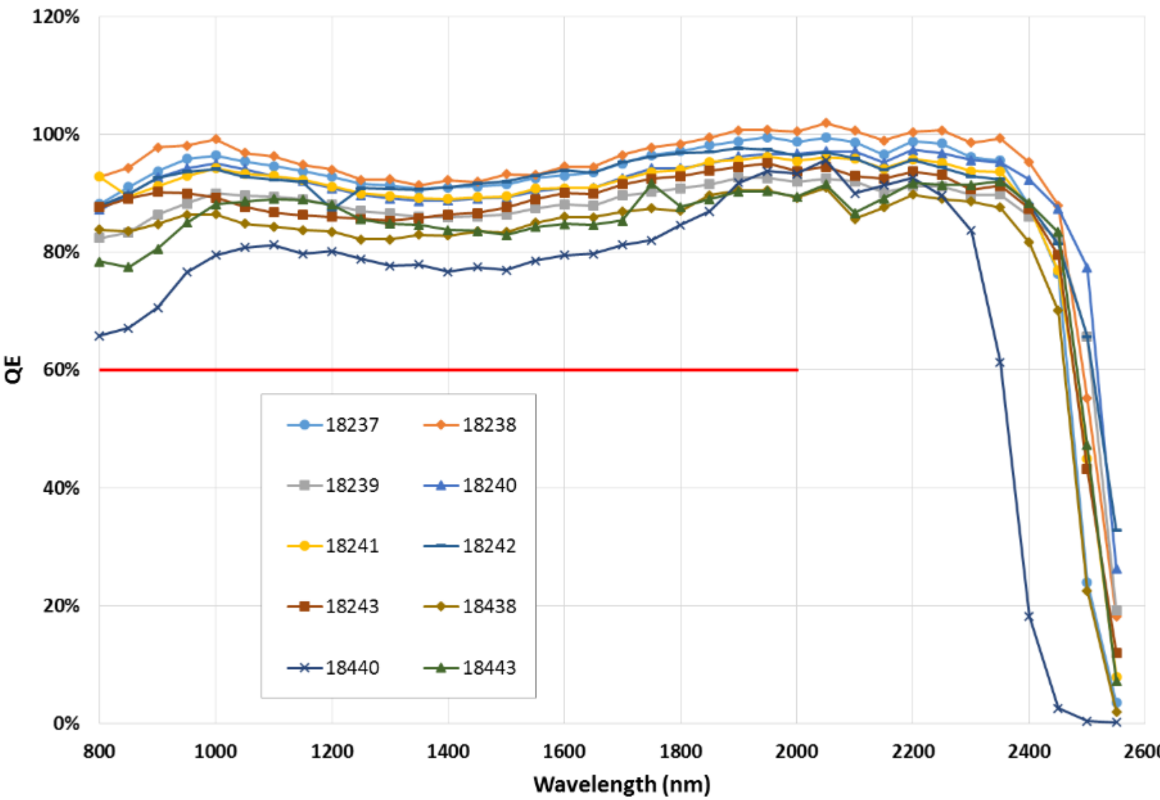
- Detectors tested at 1.0V, 100K
- All plots are IPC corrected median per array
- Images are normalized 1400nm flat fields with linear scale [0.9,1.1]
- Absolute uncertainty is approximately 5% (1 sigma)
- Relative uncertainty (repeatability of measurement) is approximately 2% (1 sigma)
- The DCL has started a collaborative effort with NIST in order to better understand issues with absolute QE calibration and QE measurement methodology
  - The DCL will send a silicon diode test setup to NIST for absolute calibration in the near future
  - A test setup is being assembled in order to directly compare the newly calibrated silicon diode with the previously calibrated InSb diode at operating temperature (80K)
  - The comparison will help the DCL understand QE measurement errors and will likely lead to additional collaboration with NIST

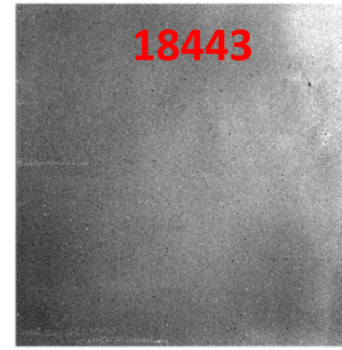
QE Summary at 100K, 1.0V

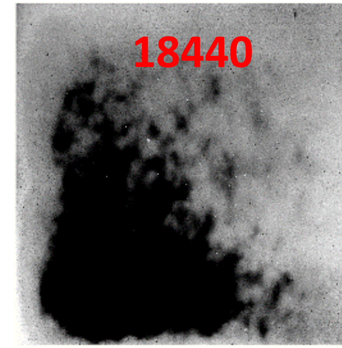


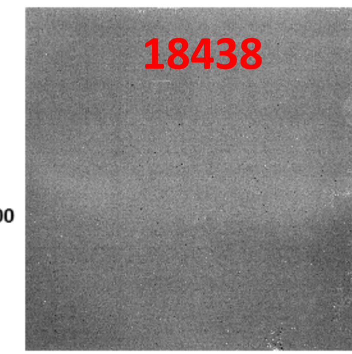


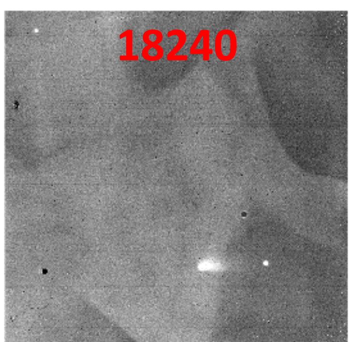


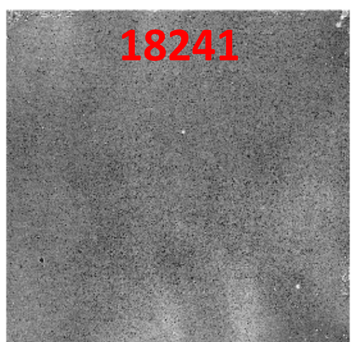


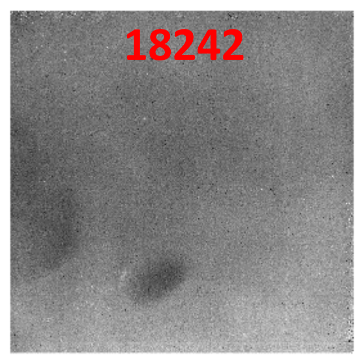


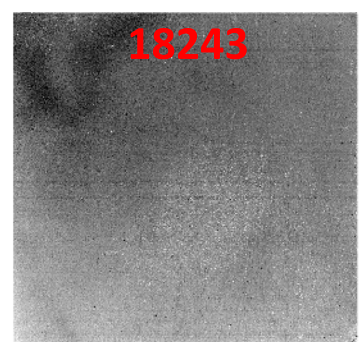






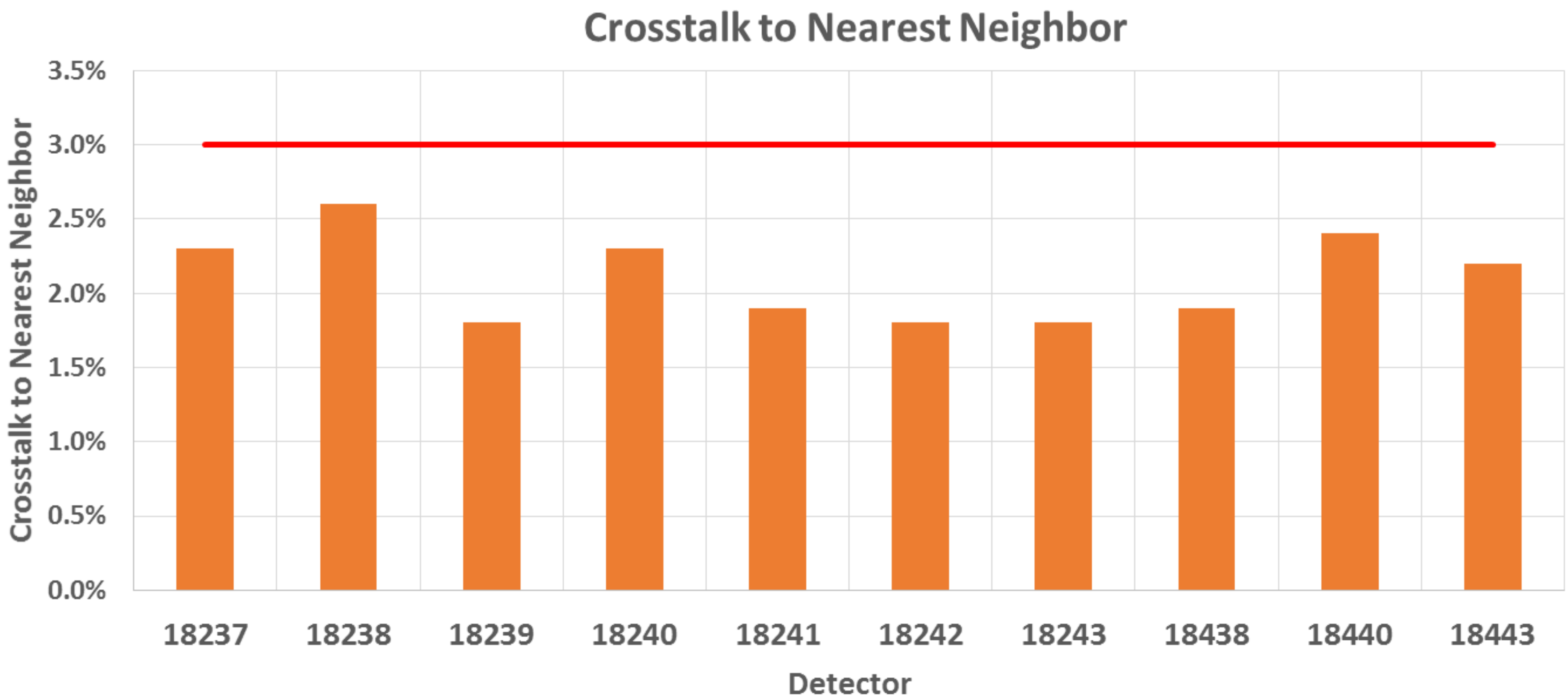






Crosstalk Summary

- From Fe55 X-ray data and dark current data (hot pixels)
- Measured at 100K, 1.0V
- Uncertainty: +/- 0.25% in nearest neighbor



0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.2%	**2.4%**	0.2%	0.0%
0.0%	**2.2%**	90.1%	**2.2%**	0.0%
0.0%	0.2%	**2.2%**	0.2%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%

18237

0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.3%	**2.4%**	0.3%	0.0%
0.0%	**2.8%**	88.3%	**2.8%**	0.0%
0.0%	0.4%	**2.4%**	0.3%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%

18238

0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.2%	**1.7%**	0.2%	0.0%
0.0%	**1.9%**	92.0%	**1.9%**	0.0%
0.0%	0.2%	**1.7%**	0.2%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%

18239

0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.2%	**2.1%**	0.3%	0.0%
0.0%	**2.4%**	90.1%	**2.4%**	0.0%
0.0%	0.2%	**2.1%**	0.2%	0.0%
0.0%	0.1%	0.0%	0.0%	0.0%

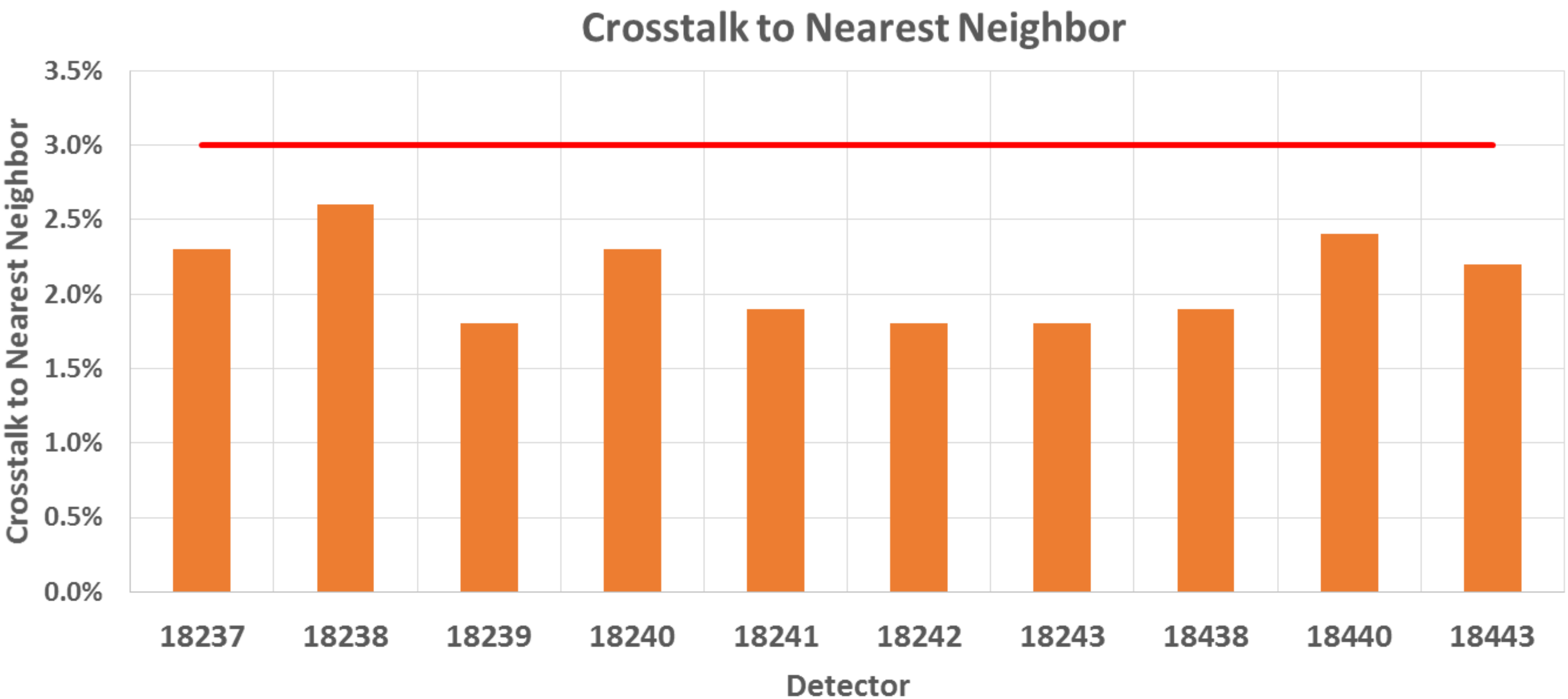
18240

0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.2%	**1.8%**	0.2%	0.0%
0.0%	**2.2%**	91.5%	**2.1%**	0.0%
0.0%	0.2%	**1.6%**	0.2%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%

18241

0.0%	-0.1%	0.0%	0.0%	0.0%
0.0%	0.2%	**1.7%**	0.2%	0.1%
0.0%	**1.9%**	92.3%	**1.9%**	0.0%
0.0%	0.2%	**1.7%**	0.2%	0.0%
-0.1%	-0.1%	-0.1%	0.0%	0.0%

18242



-0.1%	0.0%	0.0%	0.0%	0.1%
0.0%	0.3%	**1.7%**	0.2%	0.0%
0.1%	**1.9%**	**91.7%**	**1.9%**	0.1%
0.0%	0.3%	**1.7%**	0.2%	0.0%
0.0%	0.0%	0.1%	-0.1%	0.0%

18243

0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.2%	**1.9%**	0.2%	0.0%
0.1%	**2.0%**	**91.5%**	**2.0%**	0.1%
0.0%	0.2%	**1.8%**	0.2%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%

18438

0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.3%	**2.4%**	0.3%	0.0%
0.0%	**2.5%**	**89.4%**	**2.5%**	0.0%
0.0%	0.3%	**2.2%**	0.3%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%

18440

0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.2%	**2.2%**	0.2%	0.0%
0.1%	**2.3%**	**90.2%**	**2.3%**	0.0%
0.0%	0.2%	**2.1%**	0.2%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%

18443

PV3 Performance Summary

DCL Results @ T=100K, 1.0V

Detector	Pixels with Nominal Photo Response (%)	Median Dark Current (e/s)	Median CDS Noise (electrons)	QE (%) (av. 800-2350nm)	Crosstalk (%) (nearest neighbor)	Persistence (% of FW in 150 sec. after 150 sec.)
	95%	**< 0.1**	**< 20**	**> 60**	**≤ 3**	**< 0.10**
18237	99.99	0.001	11.9	95	2.3	0.02
18238	99.3	0.001	15.1	96	2.6	0.01
18239	99.8	0.001	15.2	89	1.8	0.03
18240	99.97	0.001	15.7	93	2.3	0.01
18241	99.9	0.004	15.2	92	1.9	0.02
18242	99.9	0.040	16.0	93	1.8	0.02
18243	99.9	0.064	16.3	90	1.8	0.03
18244	99.9	0.003	15.1	90	1.9	0.20
18438	99.98	0.001	13.2	86	1.9	0.01
18440	99.96	0.001	14.4	81	2.4	0.01
18441*	99.97					
18442	99.96	0.35	16.2	93	1.9	0.02
18443	99.95	0.003	12.8	87	2.2	0.02

*18441 was not fully analyzed due to an electrical coupling between Vreset and DSUB bias lines

Detectors meeting Milestone #4 Requirements: 10/13 = 77%!

Looking Ahead To Flight

- The performance of the PV3 SCAs from the full-array lot exceeds, with significant margin, the requirements set out in DTAC Milestone #4
- We continue to work with the WFIRST FSWG to finalize the SCA requirements for flight.
- The flight requirements will differ somewhat from the milestone requirements, and thus it would incorrect to attempt to infer an expected yield for flight from the results presented here.
  - In addition, yield can be expected to vary from lot-to-lot, as has been seen in previous flight programs (e.g. HST, JWST, Euclid).