Wide Field Instrument Detector Technology – Milestone #3 Review

October 28, 2015

WFIRST-AFTA Detector Technology Milestones

MS #	Milestone	Milestone 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
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
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 DTAC3 10/28
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.	Lot started Sep'15 9/15/16
5	Complete environmental testing (vibration, radiation, thermal cycling) of one SCA sample part, as per NASA test standards.	12/1/16

Full-Array Lots Follow From The Banded Array Test Results

- The results from the WFIRST banded array testing (DTAC Milestones 1 & 2) showed that the band 1 pixel design produced the best results.
- Teledyne has fabricated full-array lots of both the PV2A and PV3 passivation using this design.
  - The full-array lots include variations in the cap layer thickness and doping intended to improve persistence response.
- The results presented here are from the PV2A deliveries
- Teledyne packaged and tested 15 PV2A SCAs
  - 11 of these detectors meet the DTAC Milestone #3 requirements
- The PV3 SCAs will be delivered between November 2015 and January 2016

DCL PV2a Full Array Results
(17940, 17941, 17943, 17976
17944, 17975, 18032, 18033
18137, 18138, 18139)

Detector Information

(growth lot 10)

SCA SN	Detector Layer	Cap Thickness	Doping	Peak to Valley Curvature	Package
17940	3-3621	A	M	-16.5 um	CE6
17941	3-3627	B	M	-19.4 um	CE6
17943	3-3629	C	M	±9 um	SiC
17976	3-3628	B	M	-15.8 um	CE6
17944	3-3622	A	M	-4 um	SiC
17975	3-3620	A	M	-15.8 um	CE6
18032	3-3623	A	H	-12.3 um	CE6
18033	3-3625	B	M	+5.6 um	SiC
18137	2-3655	B	M	+8.16 um	CE6
18138	2-3694	B	M	-12.81 um	CE6
18139	2-3657	C	L	+5.4 um	SiC

Summary of Reported Tests

- Low Photo Response Pixels
- Dark Current
- CDS Noise
- Quantum Efficiency (QE)
- Crosstalk

Milestone 3 Performance Requirements Have Been Met

MS #	Milestone	Milestone Date
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

Summary of DCL Results @ T=100K, 1.0V

Detector	Median Dark Current (e/s)	CDS Noise (electrons)	QE (%) (av. 800-2350nm)	Crosstalk (%) (nearest neighbor)	Pixels with Nominal Photo Response (%)
	<0.1	<20	>60	<3.0	>95
17940	0.001	15.0	88	1.8	96.2
17941	0.007	14.5	94	2.0	98.6
17943	0.001	14.7	94	1.8	97.0
17976	0.005	16.6	93	1.9	98.0
17944	0.004	13.3	91	2.0	97.3
17975	0.003	9.1	98	1.7	98.7
18032	0.021	17.6	96	2.0	99.5
18033	0.003	16.4	96	1.6	97.7
18137	0.007	15.6	92	1.5	99.9
18138	0.003	11.2	91	1.3	99.9
18139	0.001	9.0	91	1.7	99.4

Low Photo Response Pixels Summary

- 1400nm illumination (monochromator)
- 100K, 1.0V bias
- Median signal = ~8000 electrons
- Connected pixel threshold = ~2000 electrons

Note: This testing method does not differentiate disconnected pixels from pixels with extremely high dark current or extremely low QE. Therefore, the results should be treated as an upper bound for disconnected pixels.

Low Photo Response Pixels

(orange pixel = low photo response)

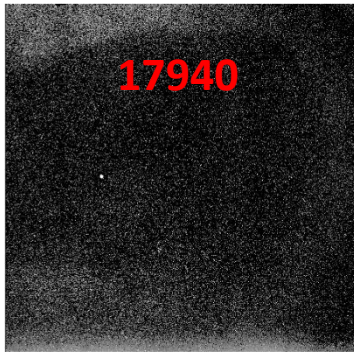
Detector	Nominal Response
17940	96.2%
17941	98.6%
17943	97.0%
17976	98.0%
17944	97.3%
17975	98.7%
18032	99.5%
18033	97.7%
18137	99.9%
18138	99.9%
18139	99.4%

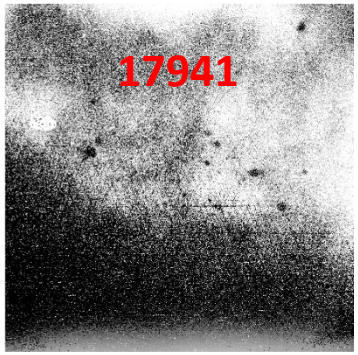
Green boxes:
New hybridization fixture used at TIS

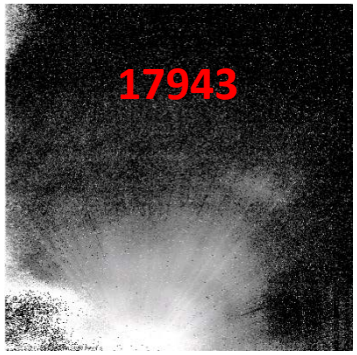
Dark Current Summary

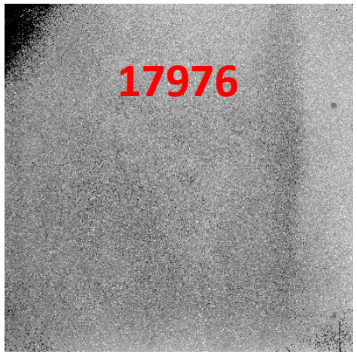
- Uncertainty: 0.003 e-/s
- Results obtained by averaging dark per pixel from 4 x 2hr dark files
- All plotted dark current numbers are median values.
- Images are in log scale [black = 0.001 e-/s, white = 0.1 e-/s]

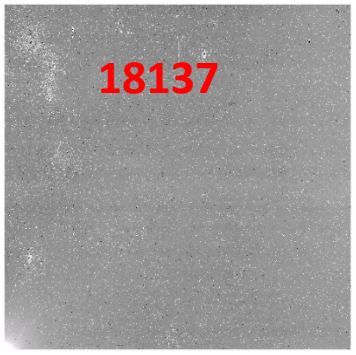
Dark Current Summary at 100K, 1.0V

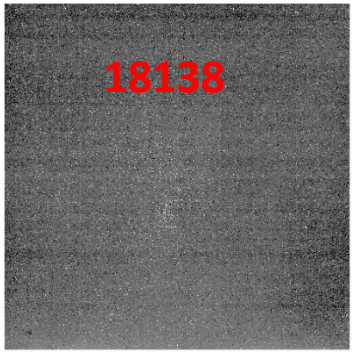


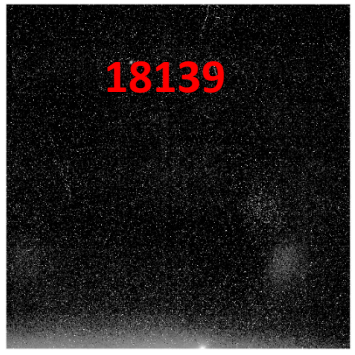


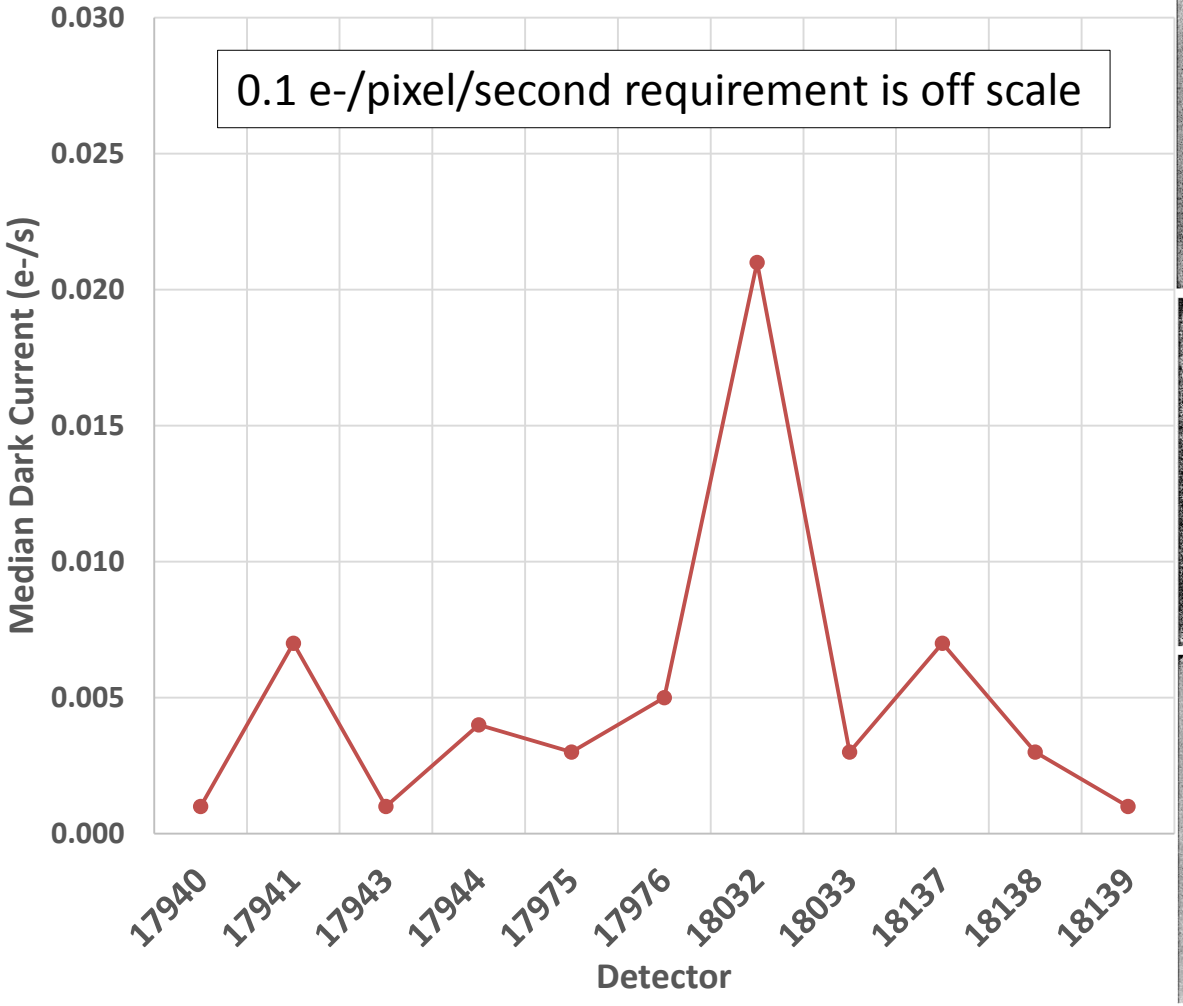


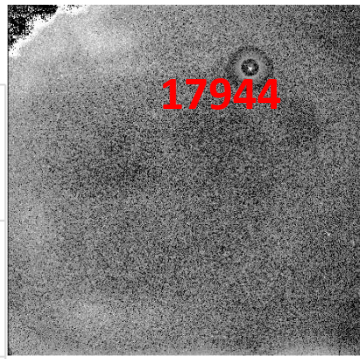


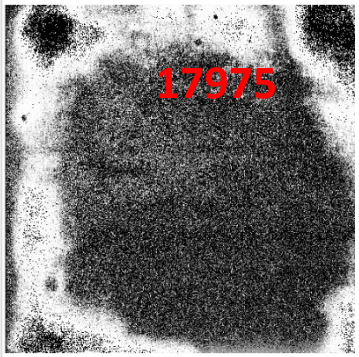


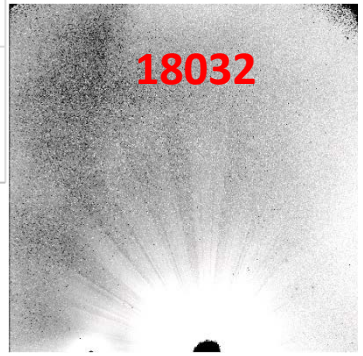


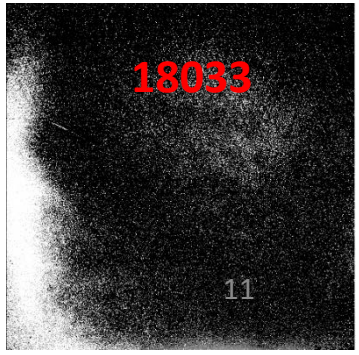






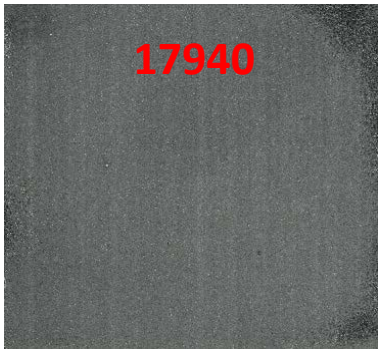


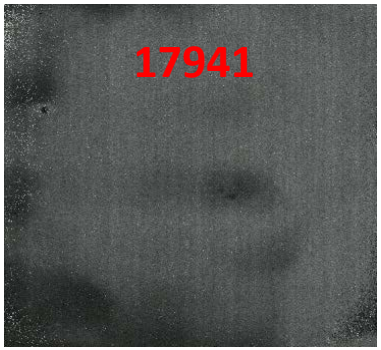


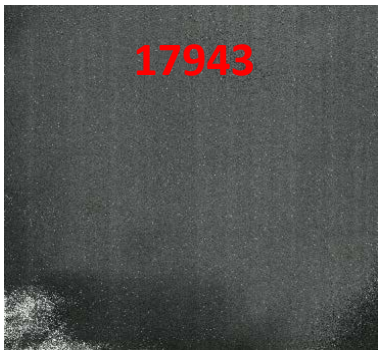


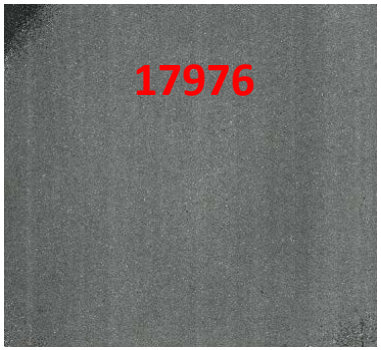
CDS Noise Summary

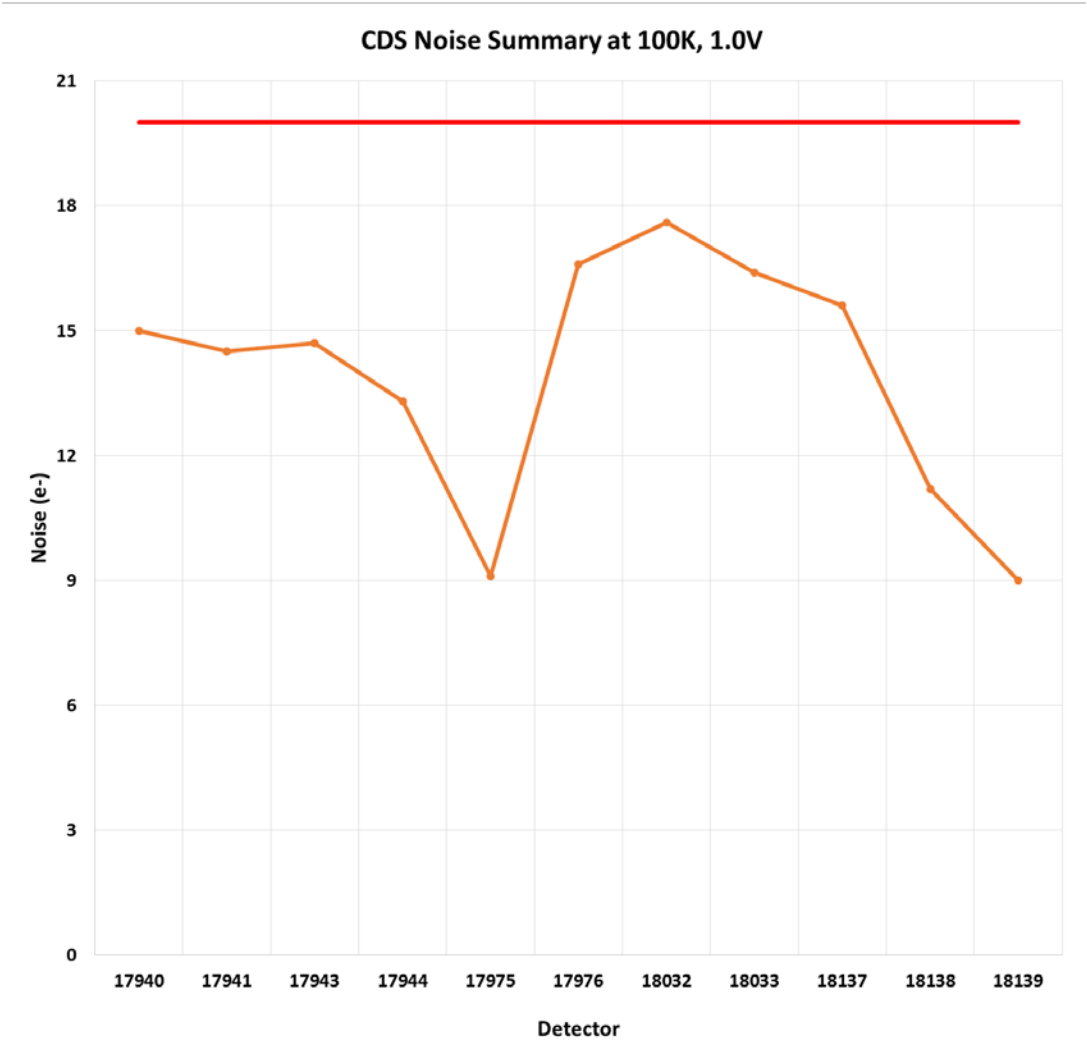
- All plotted CDS noise numbers are median values
- Images are in linear scale: Black=5, White=35 e-


17940


17941

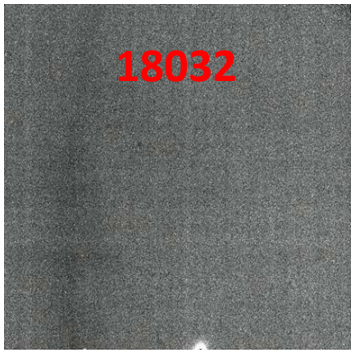

17943

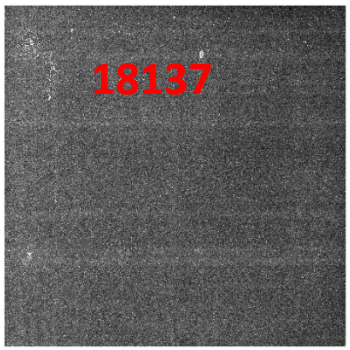

17976


CDS Noise Summary at 100K, 1.0V
Noise (e-)
21
18
15
12
9
6
3
0
17940
17941
17943
17944
17975
17976
18032
18033
18137
18138
Detector


17944

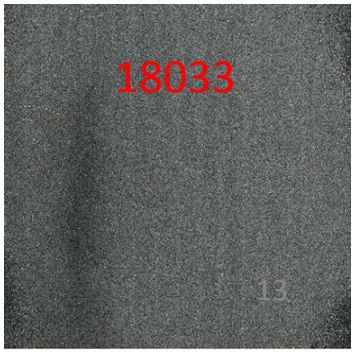

17975


18032


18137

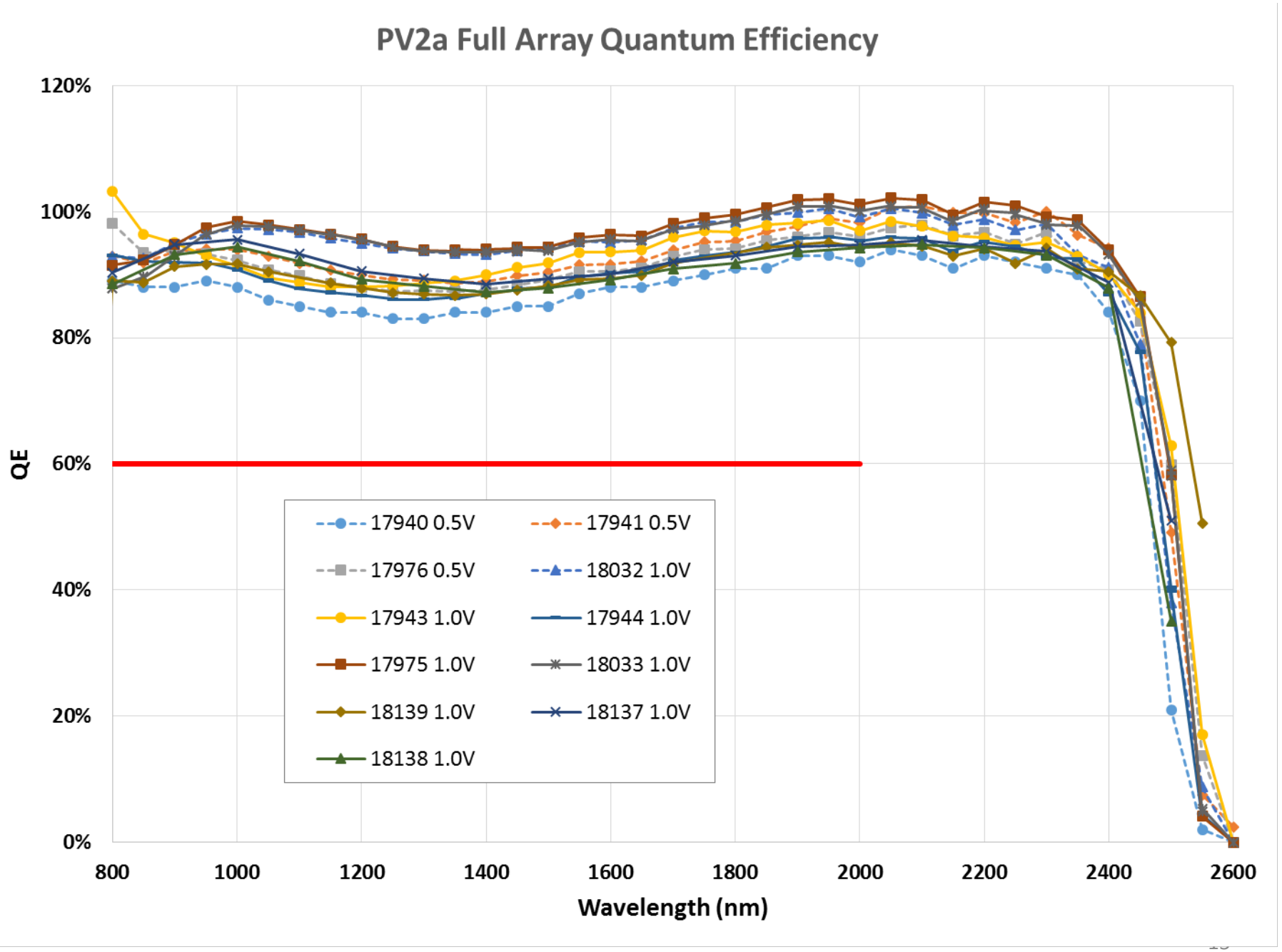

18138

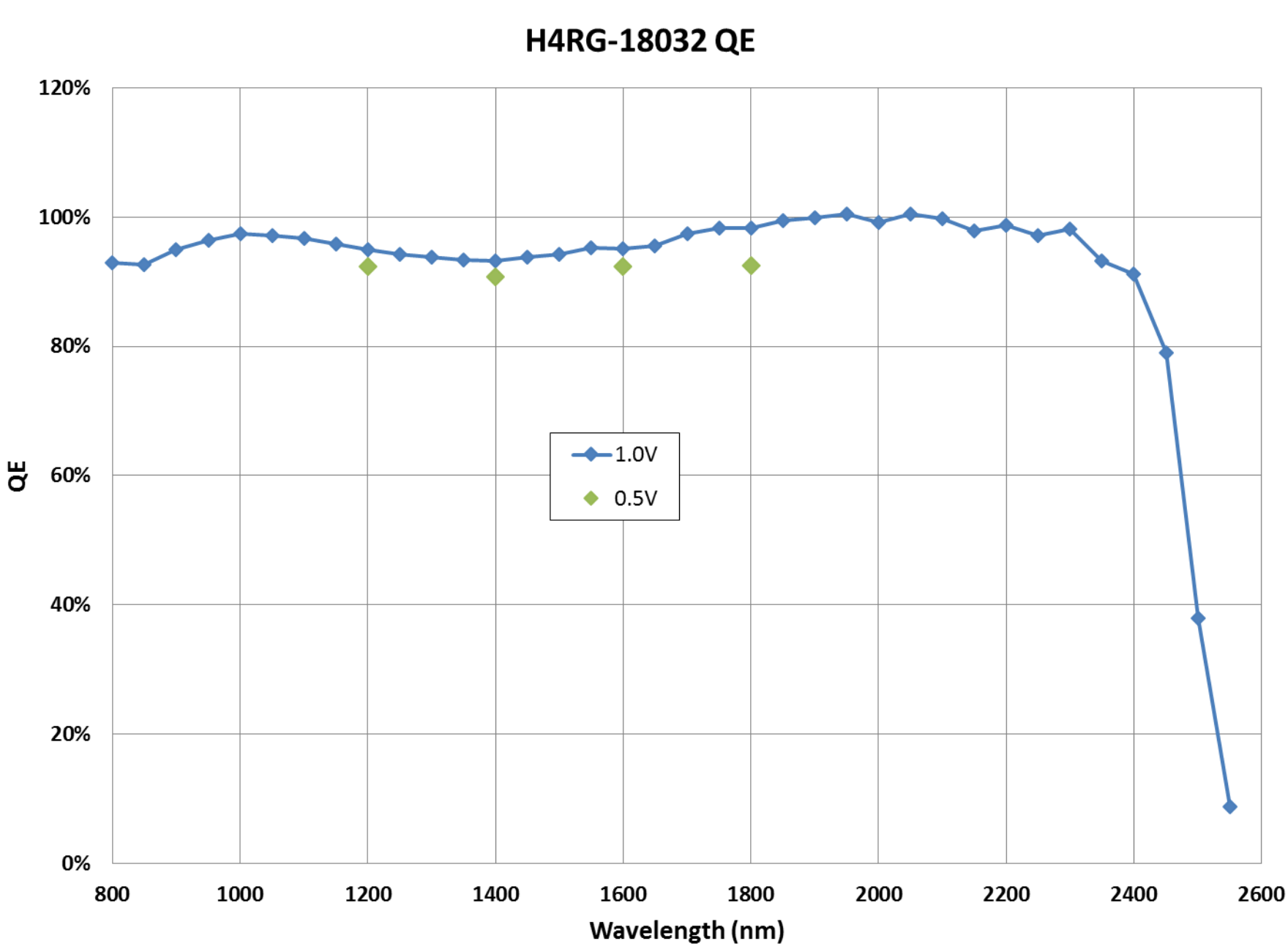

18139


18033

QE Summary

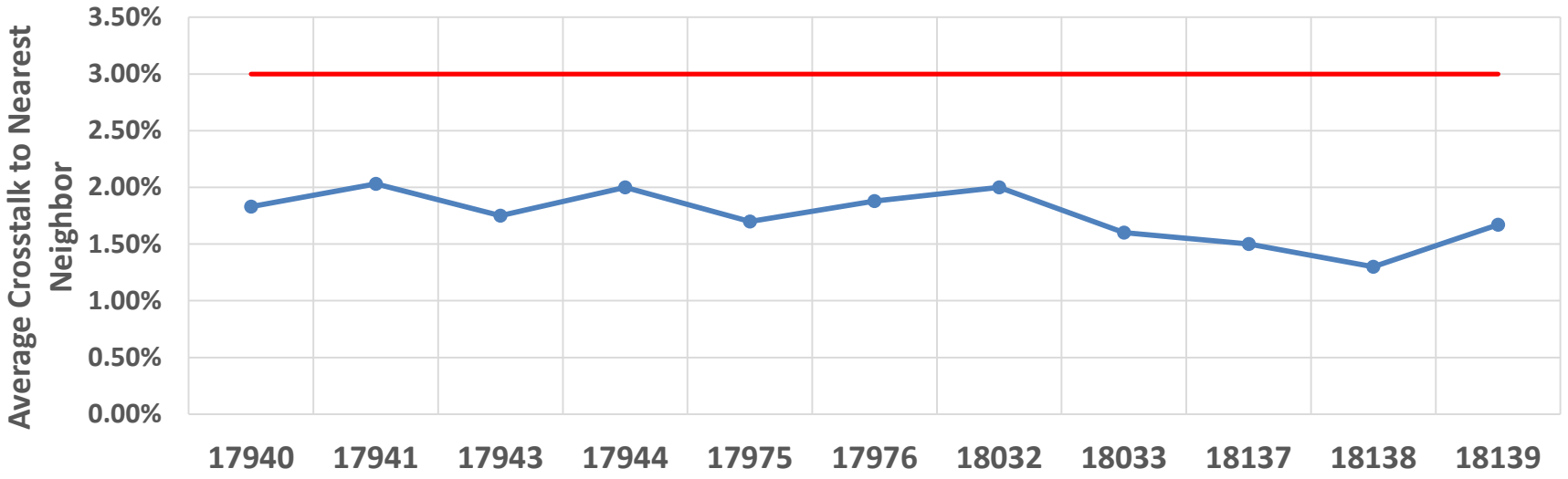
- Detectors tested at 0.5V and/or 1.0V, 100K
  - 17940, 17941, 17976 tested at 0.5V
  - 17943, 17944, 17975, 18032, 18033, 18137, 18138, 18139 tested at 1.0V
- Changes seen between 0.5V and 1.0V are small
- All plots are IPC corrected
- Uncertainty: 5% (1 sigma)
- Since DTAC #2, DCL has made improvements to its QE setup, including coatings of internal dewar surfaces and improved baffles
- **The DCL has started a collaborative effort with NIST in order to address issues with absolute QE calibration and QE measurement methodology**


PV2a Full Array Quantum Efficiency
120%
100%
80%
60%
40%
20%
0%
QE
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Wavelength (nm)
17940 0.5V
17941 0.5V
17976 0.5V
18032 1.0V
17943 1.0V
17944 1.0V
17975 1.0V
18033 1.0V
18139 1.0V
18137 1.0V
18138 1.0V


H4RG-18032 QE
120%
100%
80%
60%
40%
20%
0%
QE
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Wavelength (nm)
1.0V
0.5V

Crosstalk Summary

- From Fe55 X-ray data and dark current data (hot pixels)
- Presented results measured at 100K, 1.0V
- Uncertainty: +/- 0.25% in nearest neighbor
- Slight asymmetry between top/bottom & left/right is being investigated



0.00	0.01	0.00	-0.02	-0.03
-0.01	0.19	**1.76**	0.21	0.04
0.02	**1.91**	**91.83**	**1.92**	0.01
0.02	0.21	**1.68**	0.24	-0.01
0.00	0.02	0.00	0.02	-0.01

17940

0.02	-0.02	-0.04	0.04	-0.07
-0.05	0.24	**1.67**	0.22	-0.03
0.00	**1.88**	**92.75**	**1.83**	-0.01
-0.10	0.19	**1.55**	0.21	-0.04
-0.04	-0.03	-0.03	-0.07	-0.07

17943

0.74	0.10	0.09	0.62	0.85
0.00	0.16	**1.71**	0.59	1.15
0.16	**2.35**	**86.54**	**2.27**	0.02
0.02	0.31	**1.65**	0.24	0.12
0.11	-0.03	-0.02	0.11	0.12

17941

-0.02	-0.01	0.00	-0.03	0.01
-0.04	0.20	**1.78**	0.17	-0.01
0.01	**2.05**	**91.74**	**2.04**	0.01
-0.02	0.24	**1.72**	0.23	-0.01
-0.01	0.01	-0.01	-0.04	-0.03

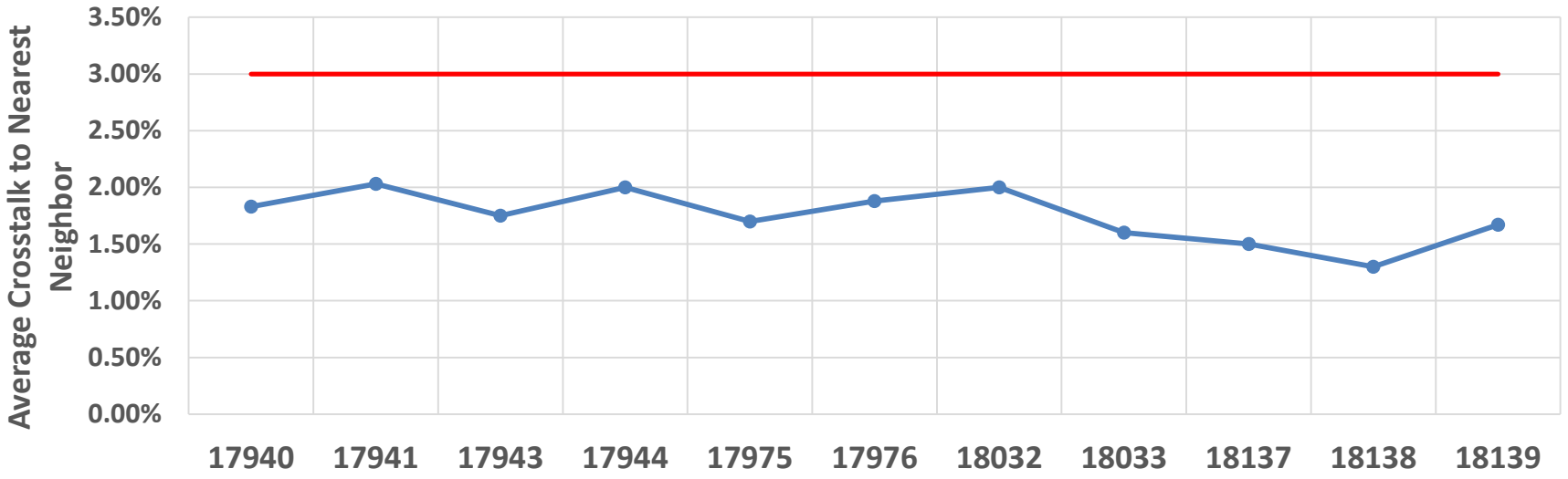
17976

0.24	0.16	0.07	0.04	0.07
0.13	0.51	**1.88**	0.19	0.08
0.09	**2.03**	**89.52**	**2.04**	0.12
0.06	0.31	**1.88**	0.23	0.05
0.18	0.17	-0.02	-0.01	-0.02

17944

0.04	-0.04	0.03	-0.04	0.03
-0.02	0.12	**1.70**	0.10	0.00
-0.01	**1.75**	**92.65**	**1.74**	0.00
-0.01	0.11	**1.70**	0.14	-0.02
0.05	-0.03	0.02	-0.03	0.03

17975



-0.04	0.01	0.05	-0.04	0.02
0.03	0.16	**1.69**	0.25	0.02
0.03	**2.22**	**91.28**	**2.22**	0.02
0.01	0.29	**1.69**	0.25	-0.05
-0.02	-0.02	-0.01	-0.03	0.00

18032

0.00	0.00	0.02	-0.02	0.01
-0.02	0.17	**1.64**	0.16	-0.01
0.02	**1.65**	**92.94**	**1.65**	0.02
-0.02	0.15	**1.48**	0.15	-0.01
0.00	-0.02	0.02	0.00	0.01

18033

0.05	0.04	0.01	0.03	-0.02
-0.01	0.19	**1.62**	0.20	0.06
0.02	**1.71**	**92.03**	**1.72**	0.00
0.01	0.24	**1.62**	0.24	0.01
0.04	0.00	0.01	0.02	0.15

18139

-0.01	0.00	0.01	-0.01	-0.01
0.00	0.14	**1.22**	0.13	0.00
0.01	**1.39**	**94.27**	**1.40**	0.01
0.00	0.13	**1.19**	0.13	0.00
0.00	0.00	0.01	0.00	-0.01

18138

0.01	0.01	0.22	0.00	-0.01
0.03	0.27	**1.48**	0.15	0.01
0.11	**1.51**	**93.25**	**1.51**	0.01
0.01	0.16	**1.51**	0.16	0.00
0.37	0.00	0.02	-0.01	-0.01

18137

The Next Step: A Yield Demonstration Lot

- With the capability of fabricating full 4kx4k arrays that meet our notional requirements having been demonstrated, the next step is to determine the manufacturing yield.
- This will allow the WFIRST project to bound the cost and schedule for the production of flight detectors.
- Teledyne has begun the growth and processing of detector layers for the yield demonstration lot.
- Depending on the availability of funding, it may be possible to produce a second yield demonstration lot if the PV3 detectors (to be received from Nov. 2015 – Jan. 2016) show good results.

Path to Flight Detector Performance Requirements

- A first draft of detector performance requirements should be available by the end of 2015.
- We are also expecting the WFIRST Formulation Science Working Group (FSWG) to be constituted by the end of 2015.
- The Project will work with the FSWG to produce a detailed flowdown of scientific requirements in time for the WFIRST SRR (no earlier than Oct 2017).
  - This effort including important simulations using the planned observation strategies.
- Until these detailed requirements are completed, a notional set of performance targets are used.

- Dark Current: < 0.05 e-/sec
- CDS Readout Noise: < 20 e- rms
- Total Noise: < 5 e- rms (in 180 sec)
- Quantum Efficiency: > 70%
- Persistence: < 0.01% (after 180 sec)
- Inter-Pixel Crosstalk: < 8% (sum of 4 nearest neighbors)

DRAFT: actual values pending SDT inputs.