

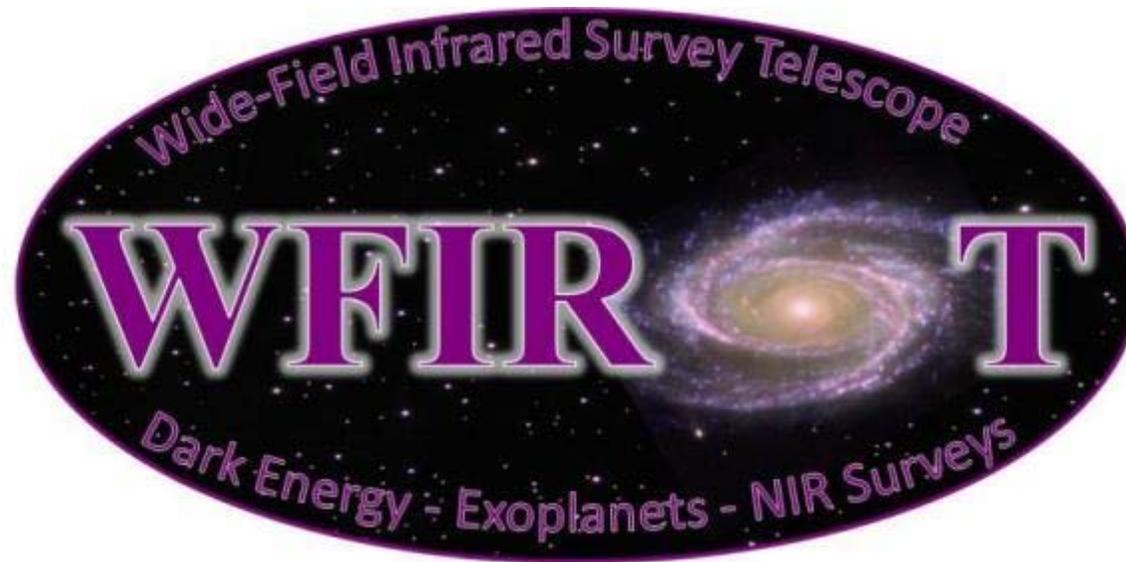
**WFIRST**

Wide Field Infrared Survey Telescope - AFTA

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Wide-Field Infrared Survey Telescope- Astrophysics Focused Telescope Assets

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**Wide Field Instrument Detector Technology – Milestone #1 Review**

**August 6, 2014**

## Agenda

- Detector development plan
  - Overview
  - Context
  - Performance targets
  - Technology milestones
- Detector array test results
  - Crosstalk
  - Dark current
  - Quantum efficiency
  - CDS and total (slope noise)
- Summary and next steps

*This is a slightly abbreviated, public-release version without any vendor proprietary data*

## Milestone1 Performance Requirements Have Been Met

MS #	Milestone	Milestone Date
1	Produce, test, and analyze <b>2 candidate passivation techniques</b> (PV1 and PV2) in <b>banded arrays</b> 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

- The Band 1 pixel design exhibits the best performance across the 8 SCAs tested in the DCL and exceeds the milestone requirements by a significant margin. Choice of band1 includes considerations of manufacturability and persistence.

	Milestone Requirement	Band 1 Average
Median Dark Current (e-/pix/sec)	<0.1	0.002
Median CDS Noise (e- rms)	<20	11.5
Median QE(%)	>60	97
Crosstalk* (%)	N/A	2.1

\* Includes diffusion; therefore an upper limit on IPC



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# DETECTOR DEVELOPMENT PLAN

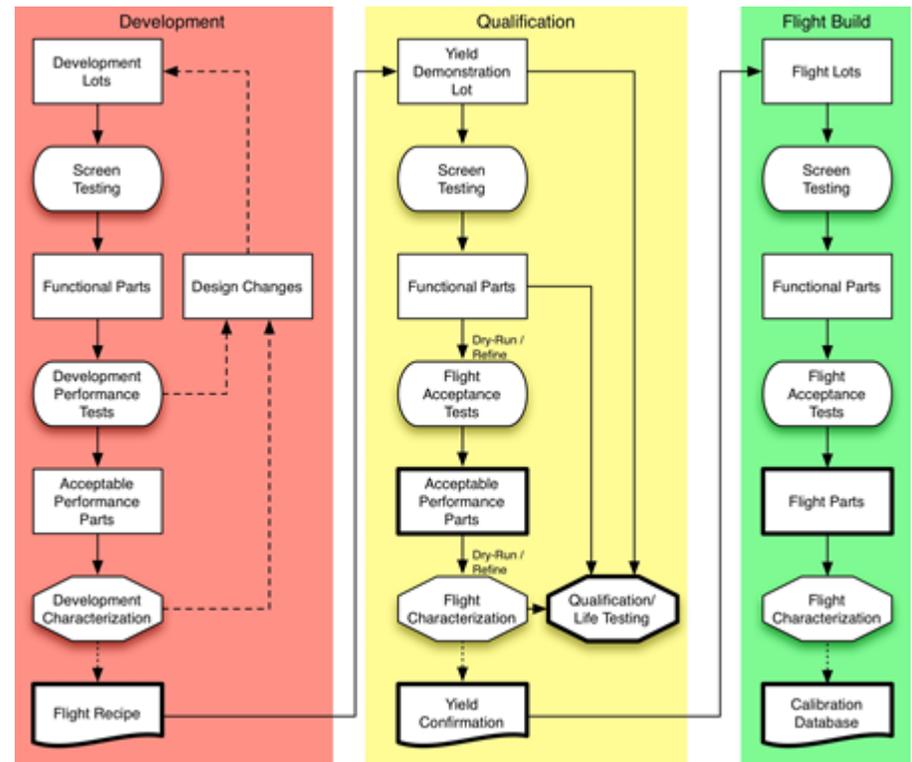
## WFIRST-AFTA

### H4RG-10 Detector Development Overview

- The current WFIRST-AFTA Wide-Field Imager configuration is based on a mosaic of 4K x 4K near-infrared detectors (H4RG-10).
- The Project initiated pilot lot of 4K x 4K, 10 mm pixel pitch, detectors; characterized during FY12.
  - The results were very encouraging and pointed to the need for some minor process improvements.
- A series of small process development experiments were completed to address the issues identified during the Pilot Run.
- In FY13, the Project started a Process Optimization Lot to optimize the potential flight recipes.
  - The growth and processing of the detector material is varied (among different devices).
  - Three main variants in the passivation (PV1/PV2/PV3).
    - “Banded” arrays with spatially dependent recipe for efficiently spanning parameters [eg contact size, implant area size; TIS proprietary details]
    - These devices are currently being delivered, with the final device characterized by the end of FY14.

## Current detector development context

- GSFC's DCL is state of the art facility for this kind of detector development program
  - Used for HST/WFC3, OSIRIS, JWST/NIRISS, JWST/NIRSPEC
  - Our development calendar overlaps Euclid
  - Therefore substantial effort has gone into facilitization to deconflict with Euclid
- In order to minimize potential for conflict, we limit current testing to those performance tests that support selection of a flight recipe for H4RG-10s, and do not include careful characterization until later
- This second phase is followed by the flight build, as shown at right.



Detector build and test flow

## Notional Detector Performance Targets

- Detailed flowdown of scientific requirements is in progress, including important simulations using the planned observation strategies.
- Until these detailed requirements are completed, a notional set of performance targets are used.
- Operating temperature is still an open trade, but is expected to be in the 80-100K range for a 2.5 $\mu$ m detector cutoff wavelength.

- 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:  $< 8\%$  (total)

**DRAFT: actual values pending SDT inputs.**

## WFIRST-AFTA Detector Technology Milestones

MS #	Milestone	Milestone Date
1	Produce, test, and analyze <b>2 candidate passivation techniques</b> (PV1 and PV2) in <b><u>banded arrays</u></b> 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 <b>1 additional candidate passivation technique</b> (PV3) in <b><u>banded arrays</u></b> 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 <b><u>full arrays with operability &gt; 95%</u></b> 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 $\leq 3\%$ in nearest-neighbor pixels at nominal operating temperature.	9/15/15
4	Produce, test, and analyze final selected recipe in <b><u>full arrays demonstrating a yield of &gt; 20%</u></b> 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 $\leq 3\%$ 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

## Design of experiments approach to optimal design

- Overall variables across the Process Optimization lot include
  - Passivation
  - Implant and Contact area size [in mask, same for each device]
  - Substrate [CE6 & SiC]
  - HgCdTe doping level
  - Epoxy backfill – variations in formulation (A=baseline, B, C)



Wide Field Infrared Survey Telescope - AFTA

# DETECTOR ARRAY TEST RESULTS

## Summary

- Crosstalk
- Dark Current
- CDS and Total (Slope) Noise
- Quantum Efficiency (QE)
- Persistence

## Test Description

- **DARK**
  - Computed from long 2-hour exposures for at least 3 different temperatures (80K, 100K, 120K). Results dependent on overall detector stability, in most recent cases each dark measurement was preceded with annealing cycle.
- **NOISE**
  - CDS Noise – 99 frames acquired over 210s with 64ch readout. Noise computed per pixel on basis of 50 samples. Measured for at least 3 temperatures, computed for each band
  - SLOPE Noise – Computed as a mean value of total noise per band from difference of two ramps of 99 frames
- **QE**
  - Measured from 800nm to 2600nm with 50nm resolution at temperature of 100K. Absolute QE calculated by comparing with NIST calibrated photodiode.
- **CROSSTALK**
  - Derived from xray images by selecting central pixel events and computing ratio of the signal in neighboring pixel to total charge. Reported for 100K per band (no significant change with T)
- **GAIN**
  - Computed from photon transfer method of variance versus signal.
- **PERSISTENCE**
  - Illumination applied over 100s has been followed by sequence of dark exposures each of 600s duration with 11 frames up-the-ramp.

AA	BA	BB	CA
CB	CC	DB	DC
BB	CA	AA	BA
DB	DC	CB	CC

## H4RG Banded Array Design

Band identification:

- 1<sup>st</sup> letter is implant size A-D
- 2<sup>nd</sup> letter is contact size A-C

### Implant Size Map

Tan=A Blue=B Cyan=C Green=D

\*a and \*b are identical bands

7b	8b	5b	6b
3b	4b	1b	2b
5a	6a	7a	8a
1a	2a	3a	4a

### Contact Size Map

Tan=A Blue=B Cyan=C

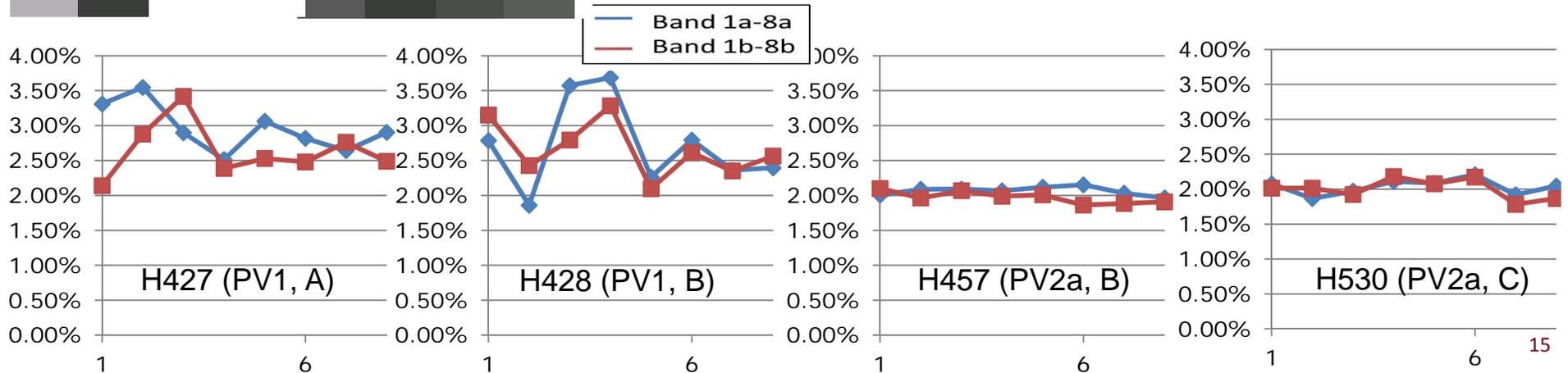
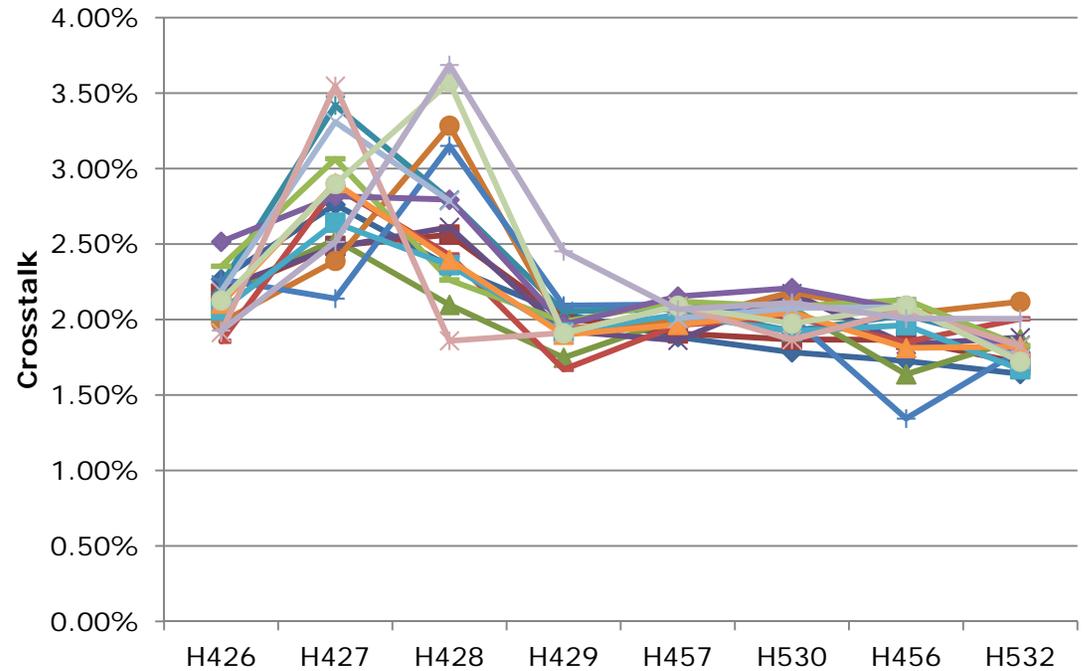
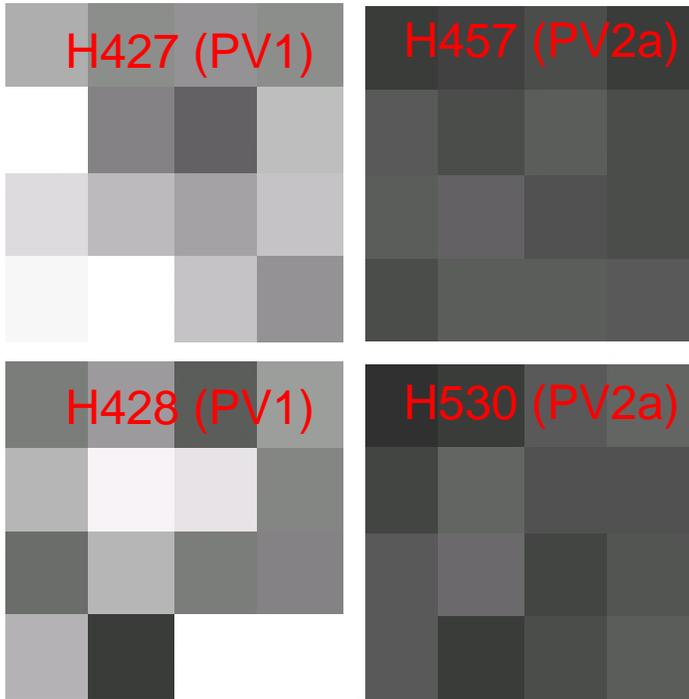
\*a and \*b are identical bands

7b	8b	5b	6b
3b	4b	1b	2b
5a	6a	7a	8a
1a	2a	3a	4a

## Crosstalk Summary

- From Fe55 X-ray data
- Image scaled range: [1.375%-3.125%]

## Crosstalk



Examples of Crosstalk Image (%) in 7X7 Grid

H4RG 429

-	-	-	-	-	-	-
0.01	0.03	0.08	0.06	0.07	0.04	0.11
0.02	0.03	0.05	0.02	0.01	0.03	0.06
-	-	-	-	-	-	-
0.07	0.03	0.23	1.69	0.21	0.10	0.05
-	-	-	-	-	-	-
0.08	0.05	1.90	91.90	1.87	0.03	0.06
-	-	-	-	-	-	-
0.06	0.03	0.29	1.68	0.22	0.02	0.10
0.00	0.09	0.01	0.02	0.06	0.09	0.00
-	-	-	-	-	-	-
0.06	0.00	0.01	0.05	0.05	0.05	0.07

H4RG 426

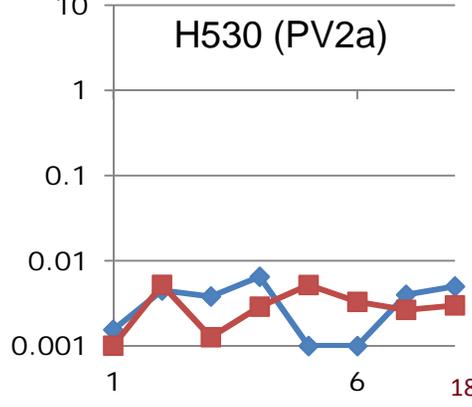
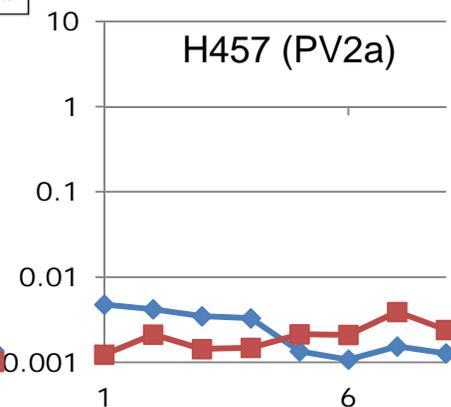
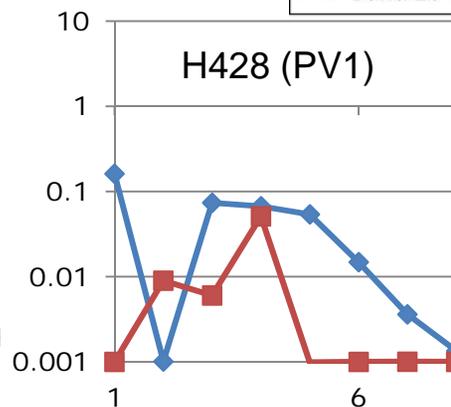
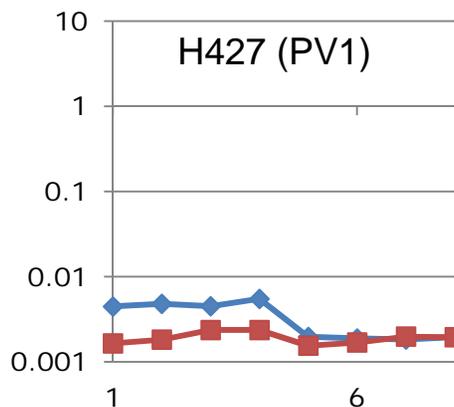
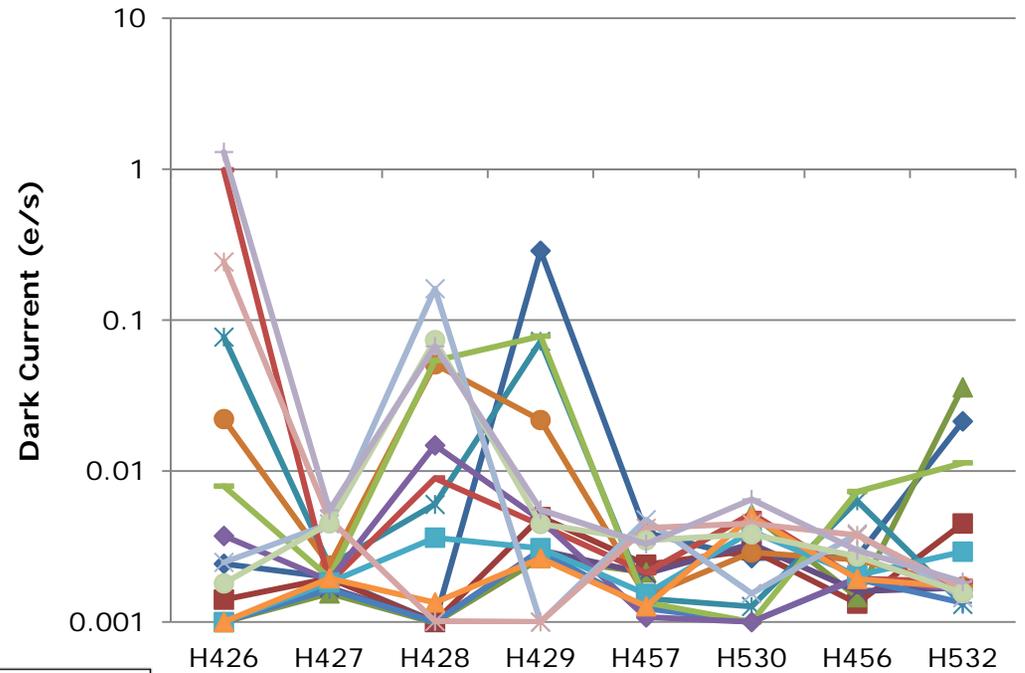
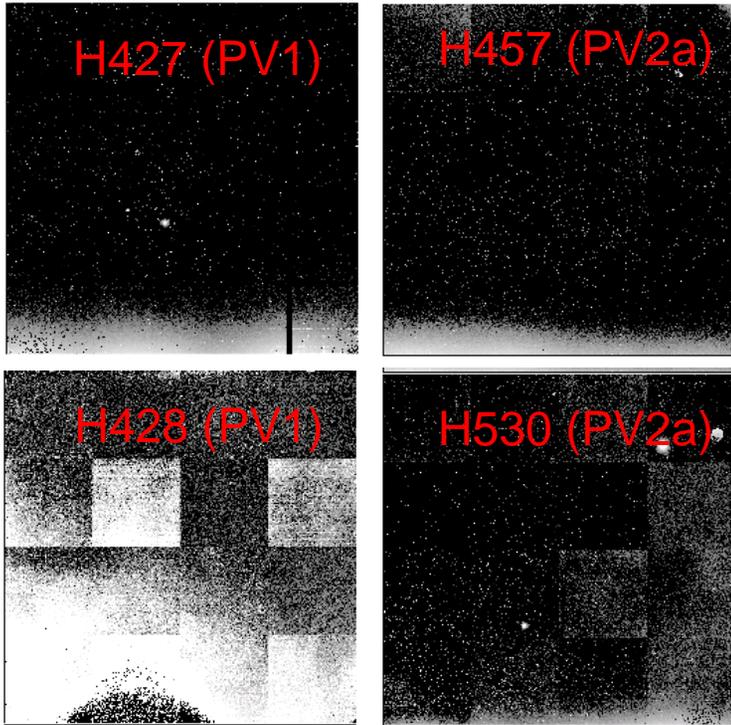
-	-	-	-	-	-	-
0.01	0.01	0.03	0.02	0.03	0.01	0.03
0.01	0.01	0.00	0.05	0.01	0.02	0.03
0.02	0.02	0.23	1.97	0.17	0.02	0.04
-	-	-	-	-	-	-
0.03	0.04	2.01	91.08	1.98	0.07	0.02
0.01	0.01	0.23	1.94	0.23	0.01	0.01
0.03	0.02	0.04	0.03	0.02	0.00	0.00
0.01	0.01	0.03	0.03	0.01	0.01	0.02

## Dark Current Summary

- Uncertainty: 0.003 e-/s
- The dark current floor is set to be 0.001 e-/s in summary section, i.e. any values below 0.001 e-/s or negative are set to be 0.001 in the plots
- All plotted dark current numbers are median values.
- Images are in log scale [black = 0.005 e-/s, white = 0.1 e-/s]

Low level glow along readout register (bottom of SCA) is evident; We plan to address this in redesign/remake of ROIC as we can; however this is still within the requirements for this milestone.

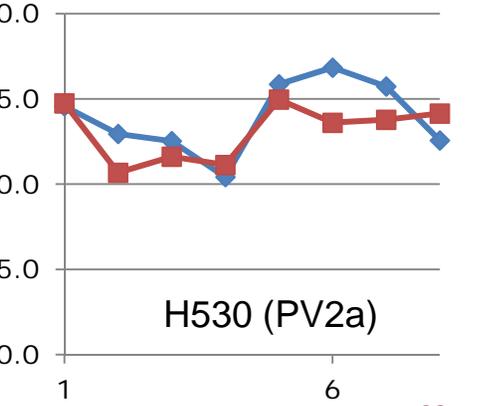
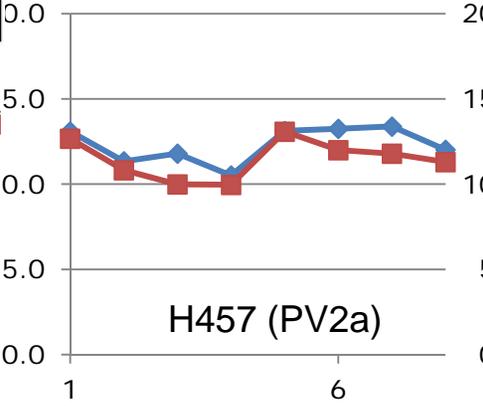
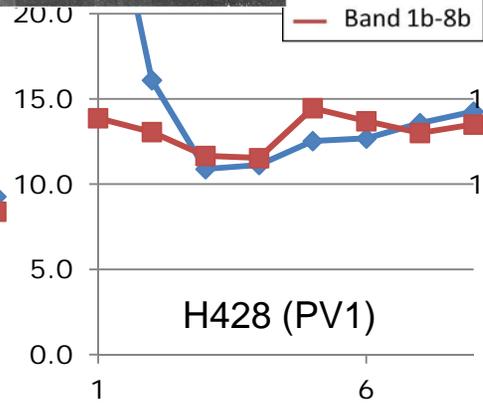
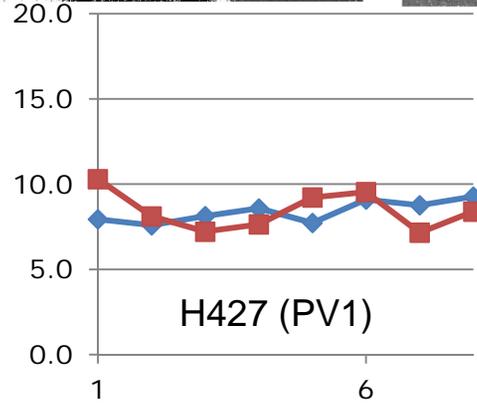
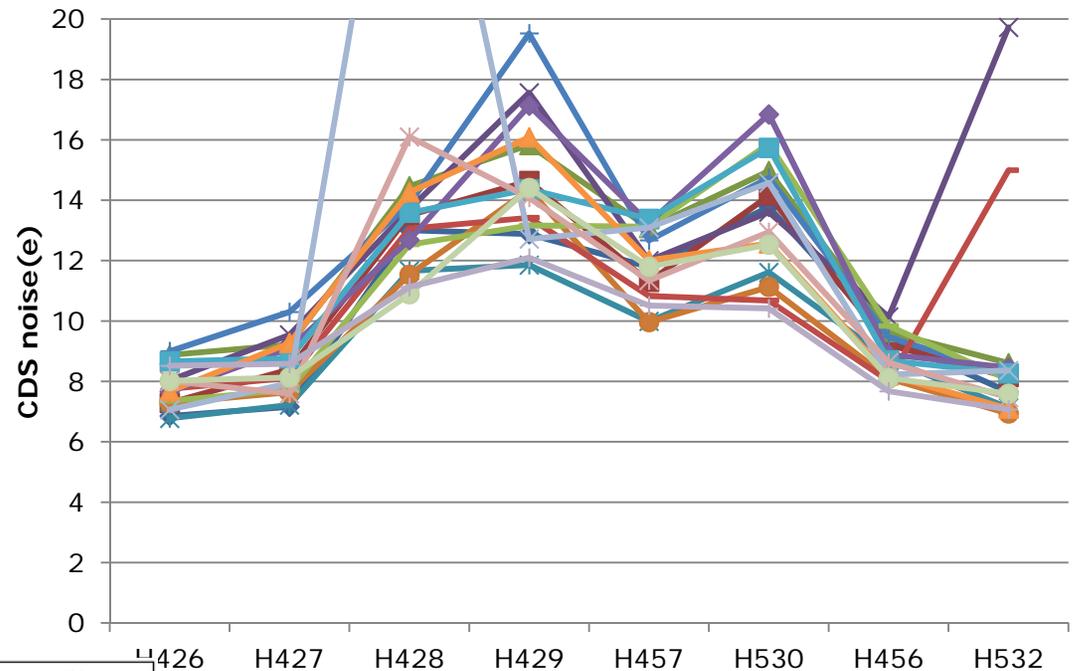
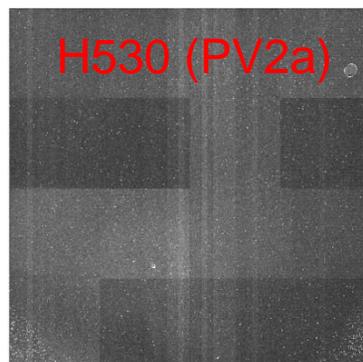
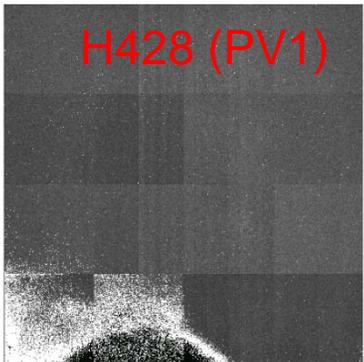
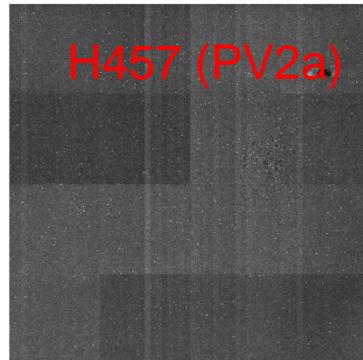
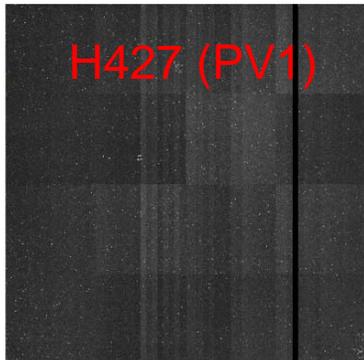
## Dark current summary at 100K



## CDS Noise Summary

- All plotted CDS noise numbers are median values
- Images are in linear scale: Black=0, White=40e

## CDS noise (e-) Summary at 100K

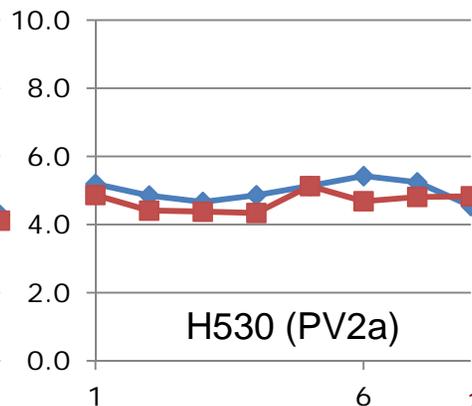
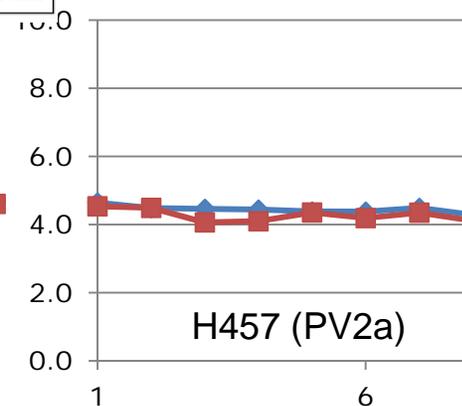
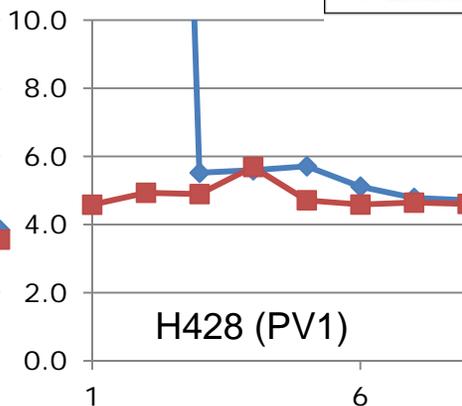
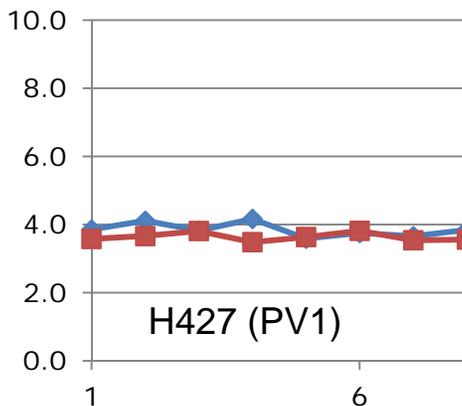
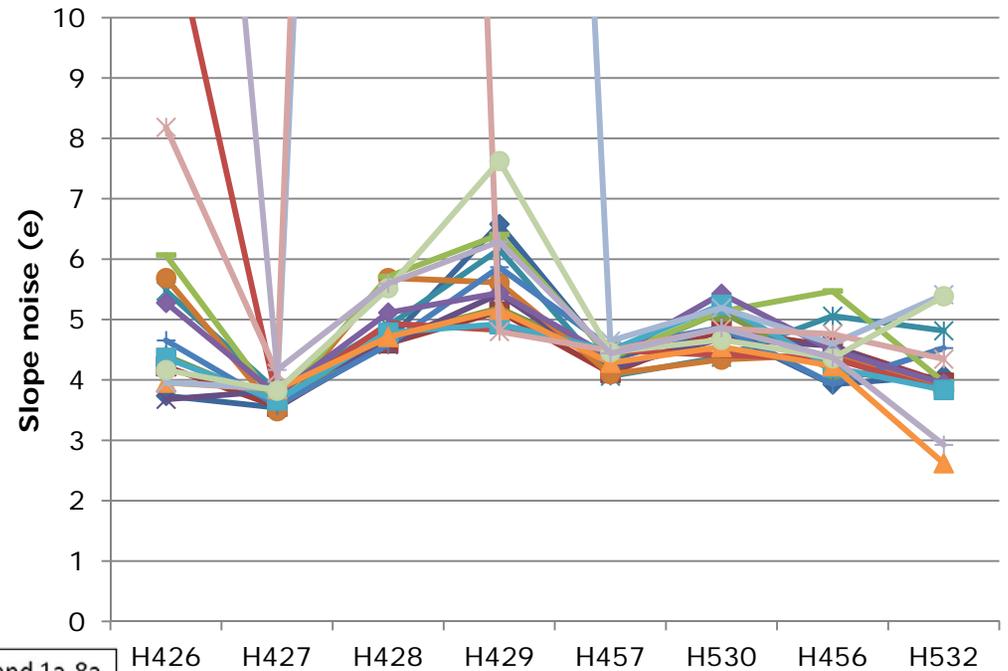
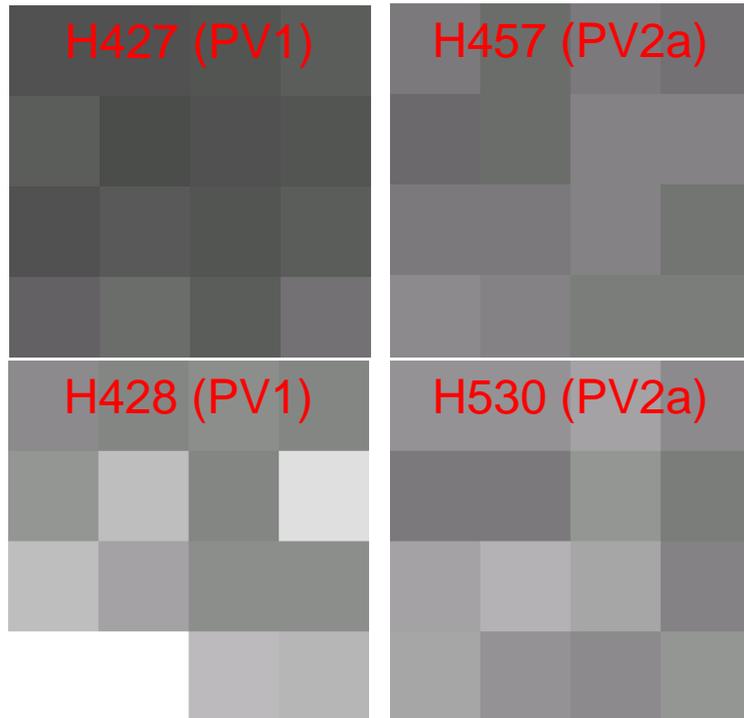


## Total Noise Summary

- Total noise computed as a mean value per band
- Images are in linear scale: Black <math>2e^{-}</math>, White >math>7e^{-}</math>

We include slope noise here even though it is not called out in the milestone. Clearly there are other effects ( $1/f$ ?) limiting the averaging down of the CDS noise through multiple reads, but the slope noise values are low.

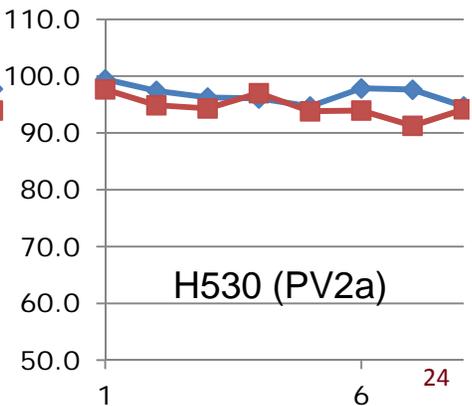
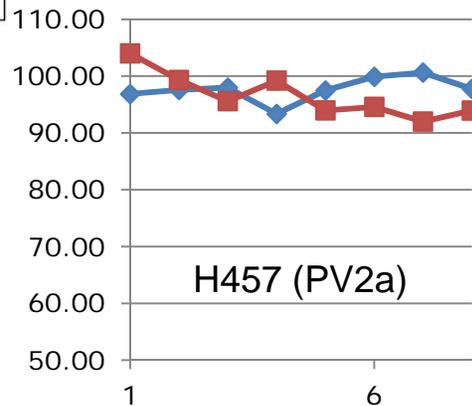
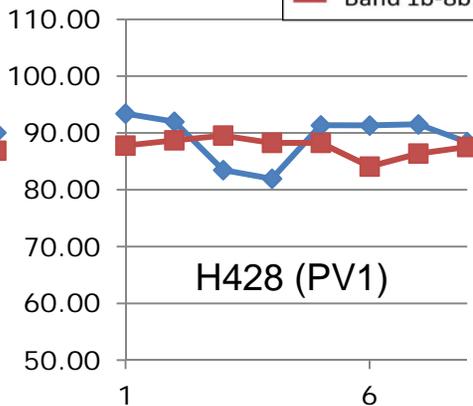
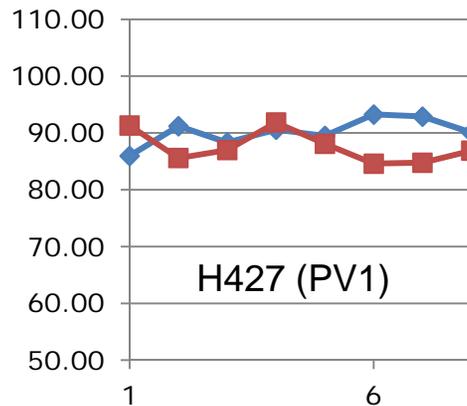
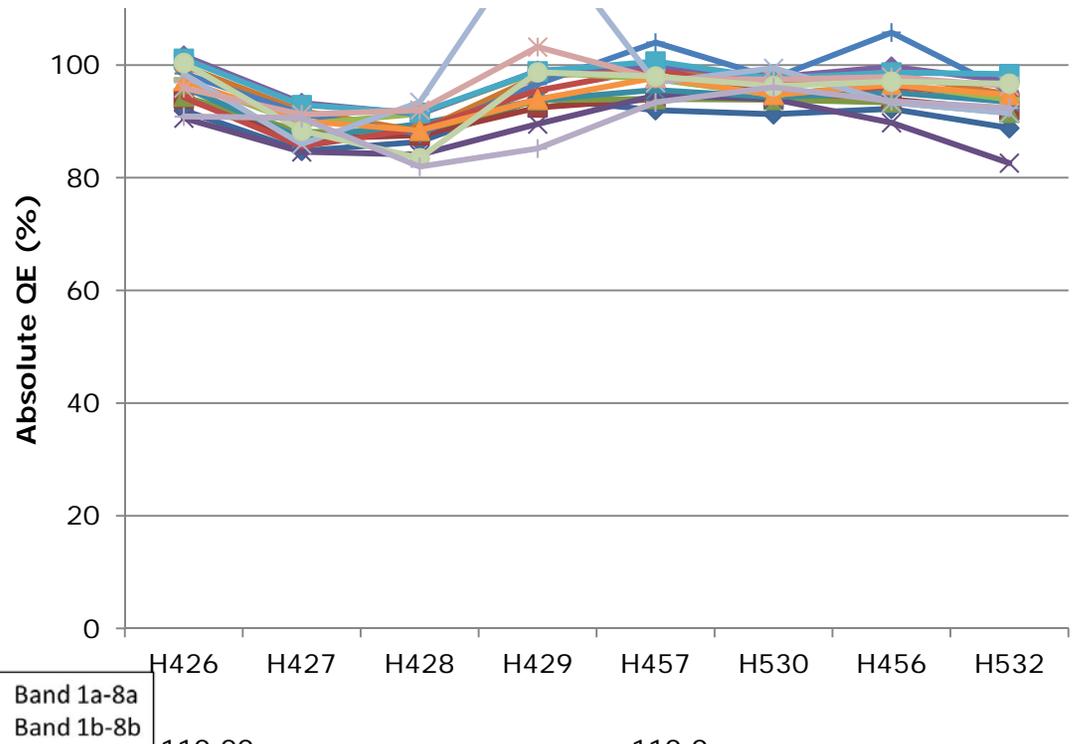
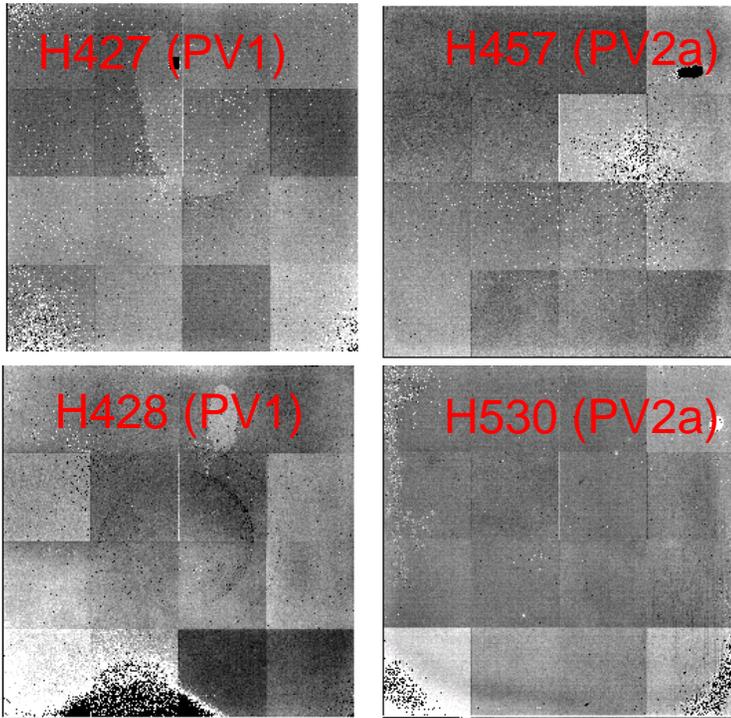
# Total noise (e-) Summary at 100K



## QE Summary

- Plotted values are the averaged QE from 800nm to 2350nm
- Images are flat field images at 1400nm in linear scale: [0.9-1.1]
- All plots are IPC corrected
- Uncertainty: 5% (1 sigma)

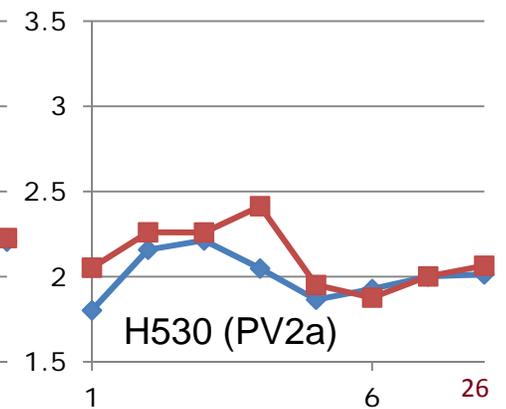
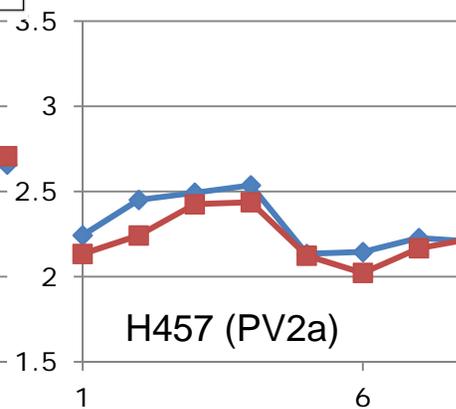
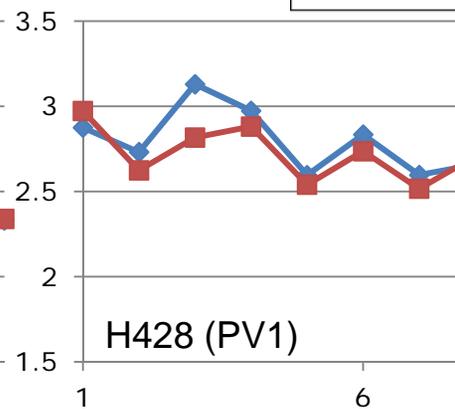
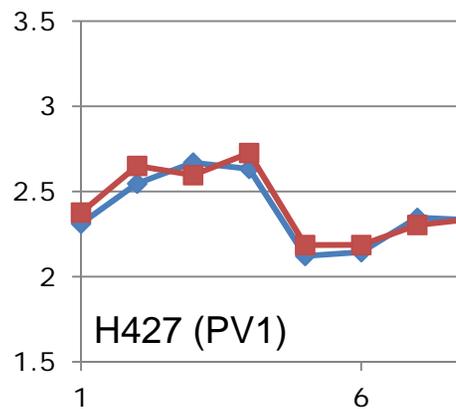
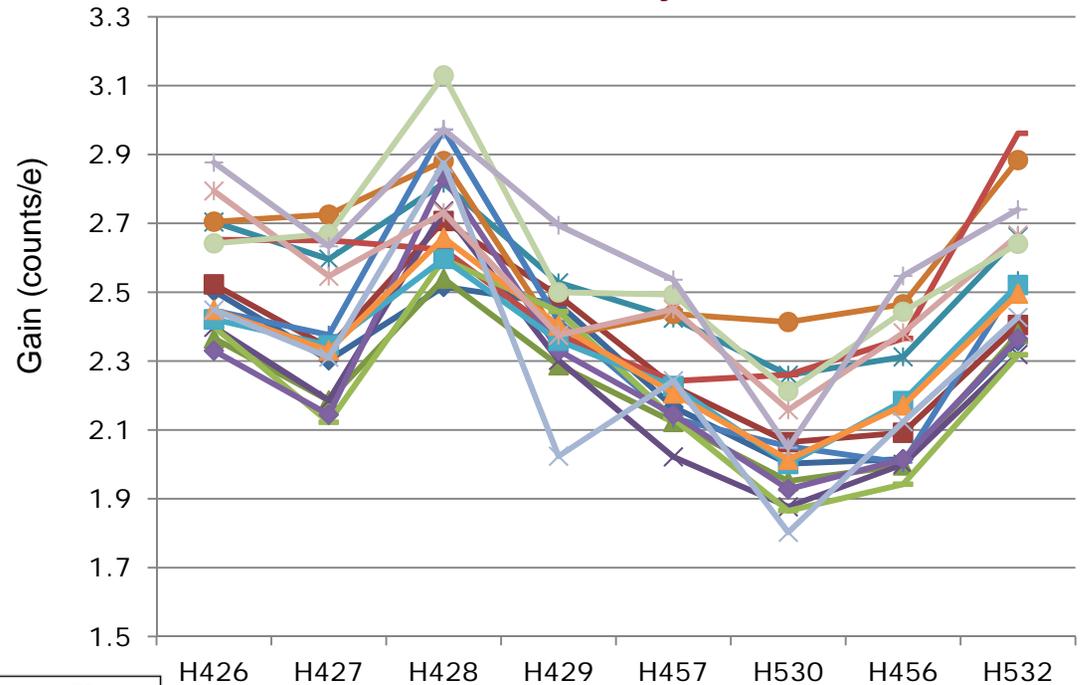
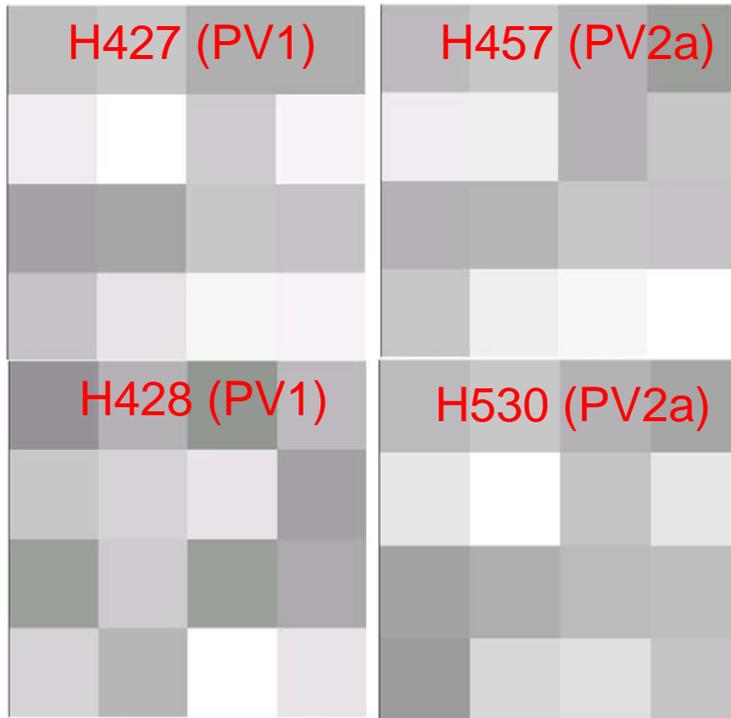
## Averaged QE from 800nm to 2350nm at 100K



## Photon Transfer Gain Summary

- Signal level  $\sim 2ke^-$

# Photon Transfer Gain Summary



# SUMMARY AND NEXT STEPS

## Milestone Performance Requirements Have Been Met

MS #	Milestone	Milestone Date
1	Produce, test, and analyze <b>2 candidate passivation techniques</b> (PV1 and PV2) in <b>banded arrays</b> 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

- The Band 1 pixel design exhibits the best performance across the 8 SCAs tested in the DCL and exceeds the milestone requirements by a significant margin. Choice of band1 includes considerations of manufacturability and persistence.

	Milestone Requirement	Band 1 Average
Median Dark Current (e-/pix/sec)	<0.1	0.002
Median CDS Noise (e- rms)	<20	11.5
Median QE(%)	>60	97
Crosstalk* (%)	N/A	2.1

\* Includes diffusion; therefore an upper limit on IPC

## H4RG-10 Development Upcoming Work

- Towards the end of FY14, a Full Array Lot will be started to focus on producing full arrays of the selected recipe.
  - Downselected to one or potentially two possible variants.
  - Will confirm that the selected recipe(s) scale to the entire array and provide better full array uniformity and yield information.
  - Analysis will be complete by mid-FY15.
- The final pre-flight lot will be the Yield Demonstration Lot.
  - Anticipated start at the end of FY15.
  - A single flight candidate recipe will be used.
  - These detectors are expected to be of fairly high quality, and will be used during instrument development as engineering devices, for qualification testing, and for detailed performance characterization. Thus, detectors for flight instrument build-up will be available quite early.
  - Completion of the Yield Demonstration Lot is planned to be in FY16, after which the flight build can be started.

## Pixel Design Recommendation For Full-Array Lot

- Several of the other pixel designs (aside from Band 1) also meet the milestone performance requirements.
- However, in addition to good dark current, read noise and QE, the pixel design eventually adopted for WFIRST must also demonstrate good persistence (latent image) performance.
  - Image persistence is likely to be one of the most significant factors limiting the photometric accuracy achievable for science data.
- The Band 1 pixel design, combined with the PV2a type passivation and medium doping also shows very good persistence performance (see detailed performance results below).
- For these reasons, this design (Band 1, PV2a passivation, medium doping) is recommended as the baseline design for the full-array lot to be started at Teledyne once the contractual details have been settled.