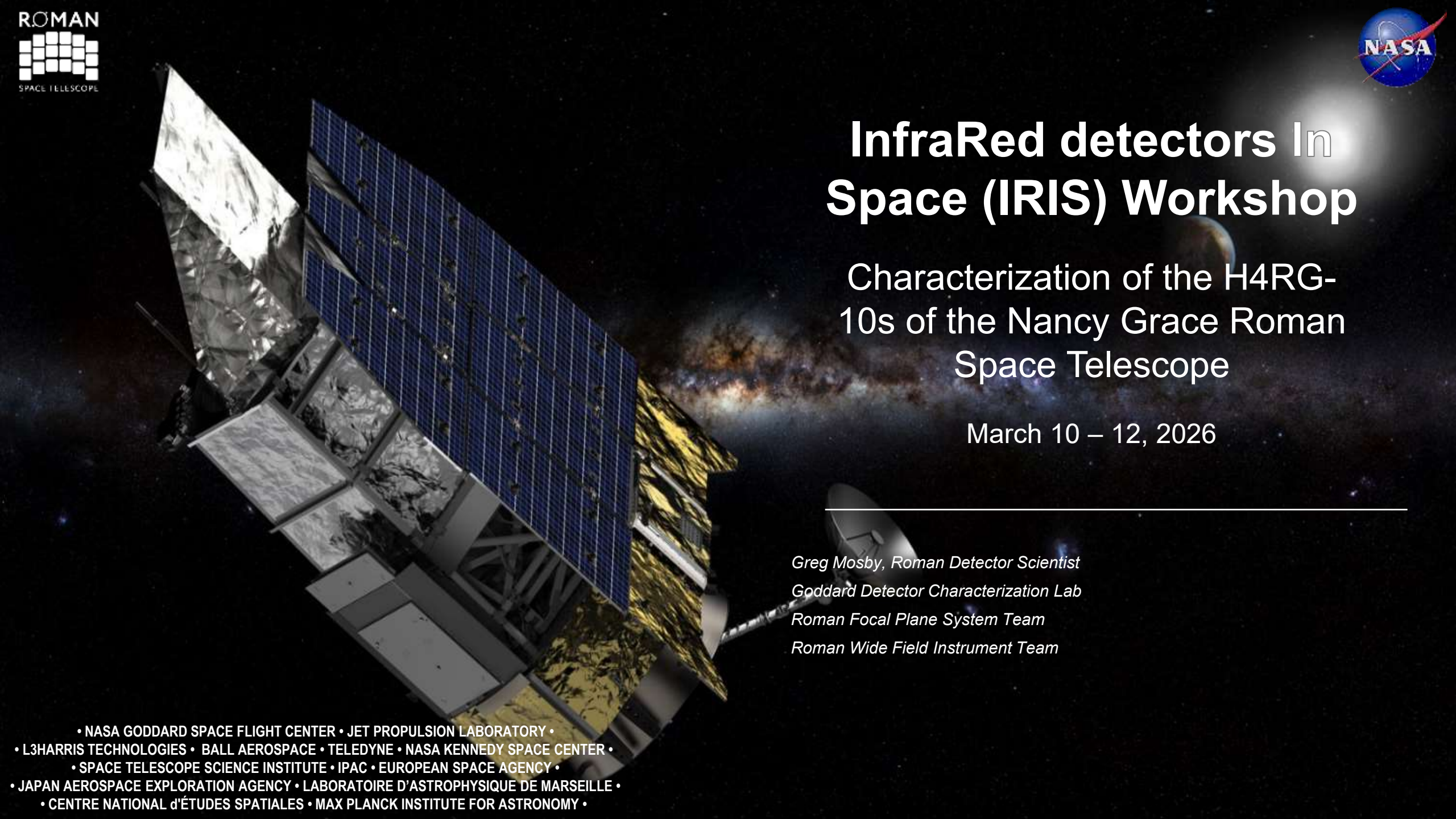

InfraRed detectors In Space (IRIS) Workshop

Characterization of the H4RG-10s of the Nancy Grace Roman Space Telescope

March 10 – 12, 2026

Greg Mosby, Roman Detector Scientist

Goddard Detector Characterization Lab

Roman Focal Plane System Team

Roman Wide Field Instrument Team

• NASA GODDARD SPACE FLIGHT CENTER • JET PROPULSION LABORATORY •
• L3HARRIS TECHNOLOGIES • BALL AEROSPACE • TELEDYNE • NASA KENNEDY SPACE CENTER •
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• JAPAN AEROSPACE EXPLORATION AGENCY • LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE •
• CENTRE NATIONAL d'ÉTUDES SPATIALES • MAX PLANCK INSTITUTE FOR ASTRONOMY •

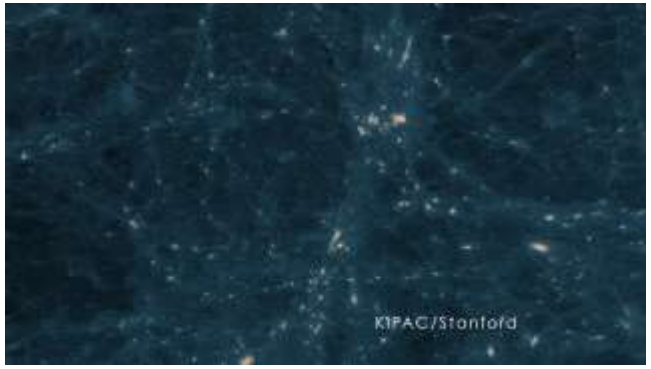
Characterization of the H4RG-10s of the Nancy Grace Roman Space Telescope

Dr. Greg Mosby

Goddard DCL, Roman Focal Plane and Wide Field Instrument Teams

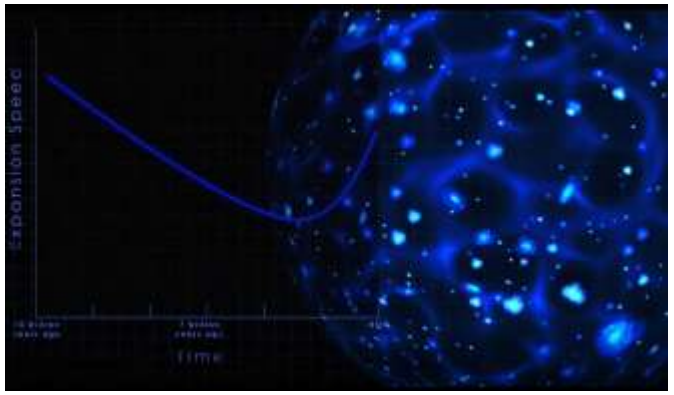
Roman will help answer pressing astrophysics questions...

Dark Matter



What is the structure and distribution of matter in the universe?

Dark Energy



How has the universe's expansion evolved over cosmic time?

Exoplanets

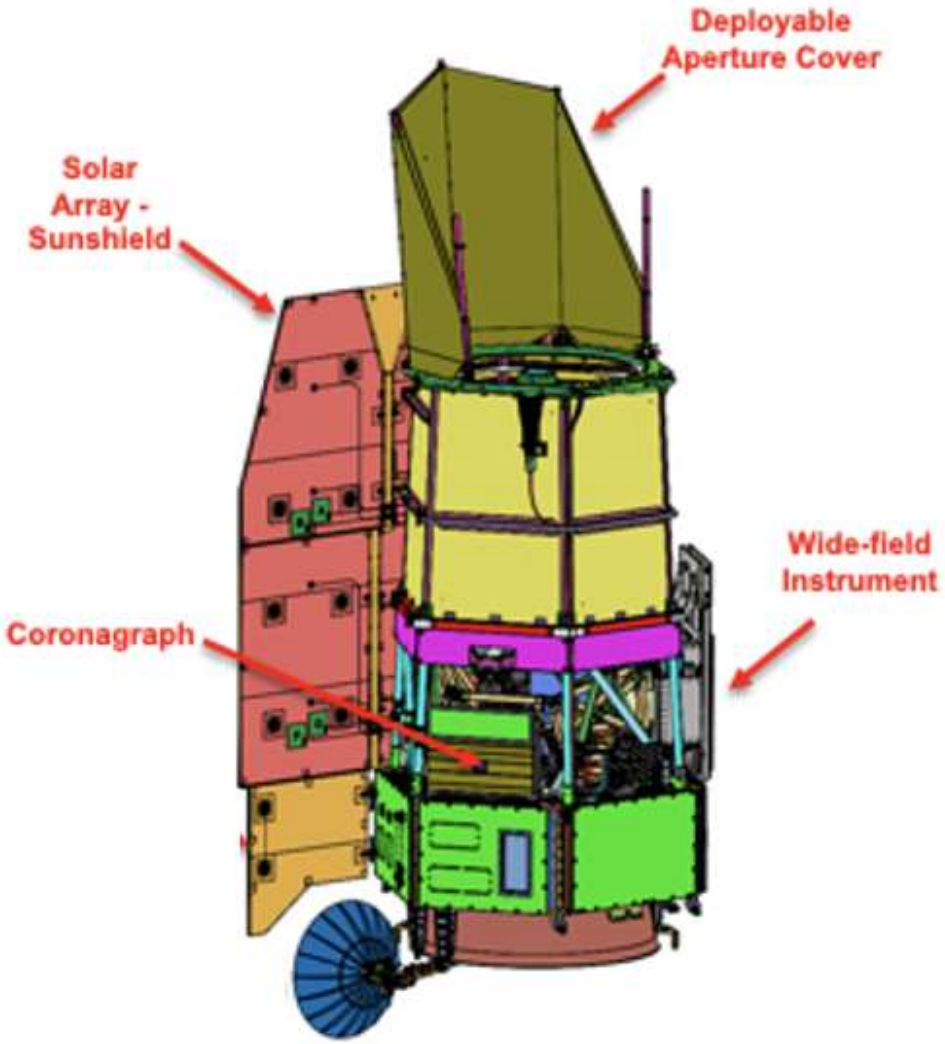
What are the demographics of exoplanets in the Galaxy?

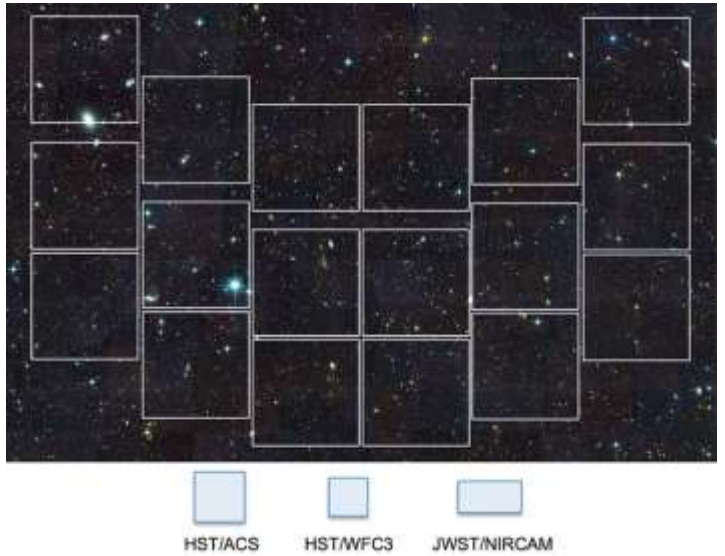
Using large area infrared surveys:

- High Latitude Wide Area Survey
- High Latitude Time-Domain Survey
- Galactic Bulge Time-Domain Survey

And everything in between!

Using a state-of-the-art observatory with 18 sensors.





- 2.4 m Telescope
- Two instruments:
  - The Wide Field Instrument
    - Infrared Imaging and Spectroscopy
  - The Coronagraph Instrument
    - Visible imaging

Roman's H4RG-10 sensors were developed then tested thoroughly.

- **Detector Technology Advancement Program (began in 2008)**
  - Included banded arrays
  - Yield Demonstration Lots (see Mosby et al 2020)
- **Flight Production (began in 2018)**
- **Testing and Characterization**
  - Acceptance Testing (**complete**)
    - Do sensors meet requirements?
  - Triplet (SCA + flight-like harness + flight-like ASIC) Testing (**complete**)
    - How do sensors perform in a flight-like subsystem?
  - Baseline Characterization Testing (**complete**)
    - What are properties of sensors that can be used for calibration?
  - Focal Plane System Testing (**complete**)
  - Wide Field Instrument Testing (**complete**)
  - Spacecraft Integrated Payload Assembly Testing (**complete**)

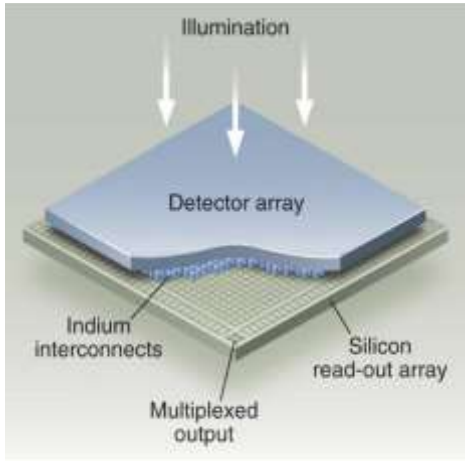


Table 2 Roman space telescope $Hg_{1-x}Cd_xTe$ parameters.

Symbol	Parameter	Value	Comment
λ_{co}	Cut-off wavelength	2.5 μm	Roman requirement
ξ	Pixel pitch	10 μm	—
T	Operating temperature	95 K	—
x	Cadmium mole fraction	0.445	Teledyne design value
Z	Absorber thickness	5 μm	—
$\lvert E_d \rvert$	Drift field strength	20 V cm^{-1}	—
ϵ	Dielectric constant	14.63	—
L_h	Hole diffusion length	20 μm	Teledyne measurements
m_h^*	Hole effective mass	$0.55m_0$	$m_0 = 9.11 \times 10^{-31}$ kg is the free electron rest mass. See Refs. 26 and 27
μ_h	Hole mobility	80 cm^2 V^{-1} s^{-1}	See note[a]
V_{rst}	Reset bias	−1 V	$V_{RESET} - V_{DSUB}$
σ_d	Charge diffusion kernel width	2.04 μm	Computed using Eq. (22) for very blue in-band light.

[a]This very rough approximation follows Refs. 26 and 28 in assuming $\mu_h \approx 10^{-2}\mu_e$, where μ_e is the electron mobility.

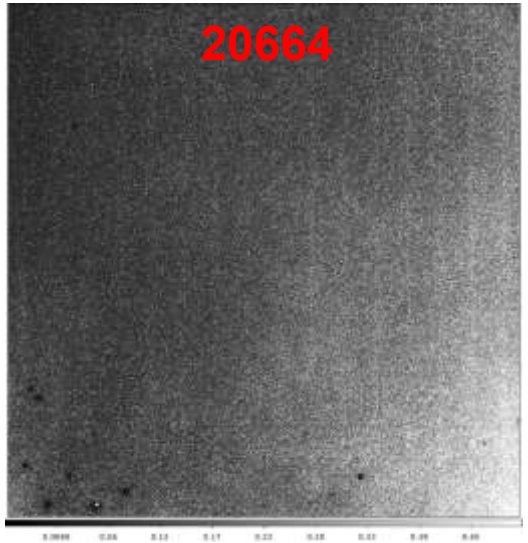
Over 100 devices were acceptance tested for performance.

- Dark current: < 0.5 e-/s/pix (<0.05 e-/s median)
- Total noise: < 12 e-/pix (<6.5 e- median)
- Below full well Persistence: < 0.15 e-/s median
- Above full well Persistence: < 0.8 e-/s/pix (<0.5 e-/s median)
- Interpixel capacitance (IPC): <2.5%
- Pixel crosstalk (cosmic rays): <1% above IPC
- Well Depth: > 80,000 e-
- Quantum Efficiency (QE): >50% for 0.48-0.76 µm, >80% for 0.76 - 2.0 µm
- Power dissipation: < 20 mW
- Guide window mode Functionality

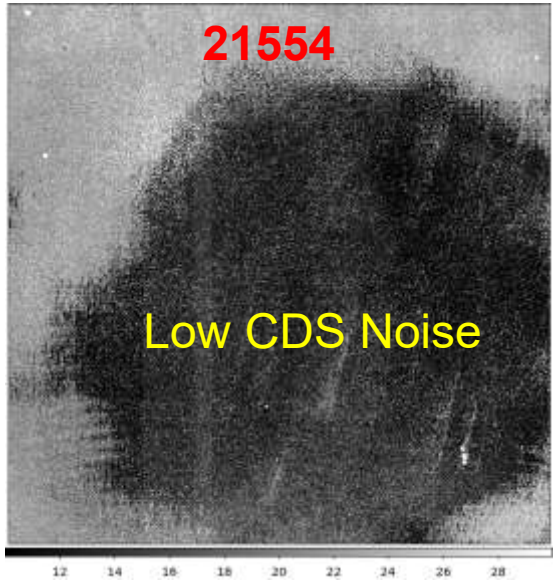
Test Parameter	Requirement	SCA Req. #	Test Results			
Power Dissipation	<20mW	RSCA-011	Measured Power Dissipation (mW)			
			8.2			
CDS Noise	N/A	N/A	Median (e)	Mean (e)	Modal (e)	
			14.55	14.88	14.49	
Total Noise	< 6.5 e- median < 12 e- per px	RSCA-030 RSCA-021	Median (e)	Mean (e)	Modal (e)	(%) Pixels passing
			5.48	6.03	5.44	99.43
QE	>40% for 0.48-0.6µm >60% for 0.6-0.8µm >80% for 0.8-2.1µm > 70 % per px	RSCA-024 RSCA-021	(%) Pixels passing			
			99.85			
Linearity	>80 ke Can be linearized to < 1% for > 97% of px	RSCA-021	(%) Pixels passing			
			98.39			
Dark Current	< 0.05 e-/s median < 0.5 e- /s per px	RSCA-033 RSCA-021	Median (e/s)	Mean (e/s)	Modal (e/s)	(%) Pixels passing
			0.000	0.005	0.000	99.82
Persistence 10 min (50 ke)	< 0.15 e-/s median	RSCA-039	Median (e/s)	Mean (e/s)	Modal (e/s)	
			0.053	0.053	0.047	
Persistence 10 min (300 ke)	< 0.50 e-/s median; < 0.8e-/s per px	RSCA-038	Median (e/s)	Mean (e/s)	Modal (e/s)	(%) Pixels passing
			0.100	0.111	0.092	99.88
Inter-pixel Capacitance	<2.5%	RSCA-035	Mean (%)		Maximum (%)	
			1.48		1.52	
Pixel Crosstalk: Cosmic Rays	< 1% above IPC	RSCA-034	Mean (%)		Maximum (%)	
			1.58		1.61	
Guide mode Functionality	Guide Window size, position, illumination level, shape	RSCA-067	pass			

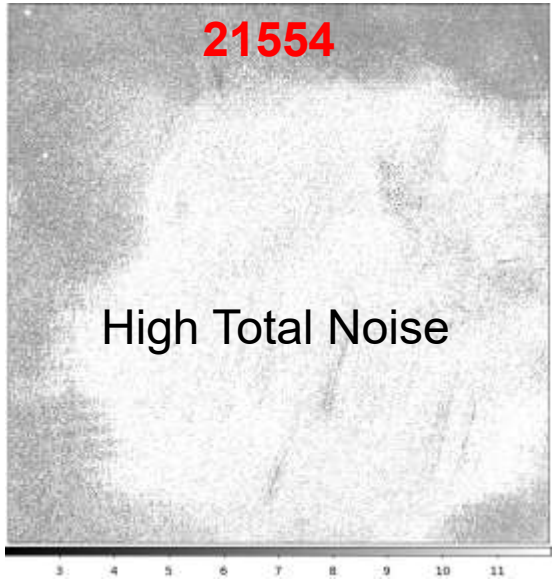
Devices primarily down-selected due to total noise performance

- Dark current: < 0.5 e-/s/pix (<0.05 e-/s median)
- **Total noise: < 12 e-/pix (<6.5 e- median)**
  - Most devices pass median requirements but **~34% devices** fail this requirement.
  - Worse devices tend to have high dark current or low CDS high total noise regions.
  - Median total noise device median is **5.9 e-**
  - Most devices have > 95 % pixels passing, but 36% devices do not..
  - Median % pixels passing is **97.8%**
- Below full well Persistence: < 0.15 e-/s median
- Above full well Persistence: < 0.8 e-/s/pix (<0.5 e-/s median)
- Interpixel capacitance (IPC): <2.5%
- Pixel crosstalk (cosmic rays): <1% above IPC
- Well Depth: > 80,000 e-
- Quantum Efficiency (QE): >50% for 0.48-0.76 µm, >80% for 0.76 - 2.0 µm
- Power dissipation: < 20 mW
- Guide window mode Functionality



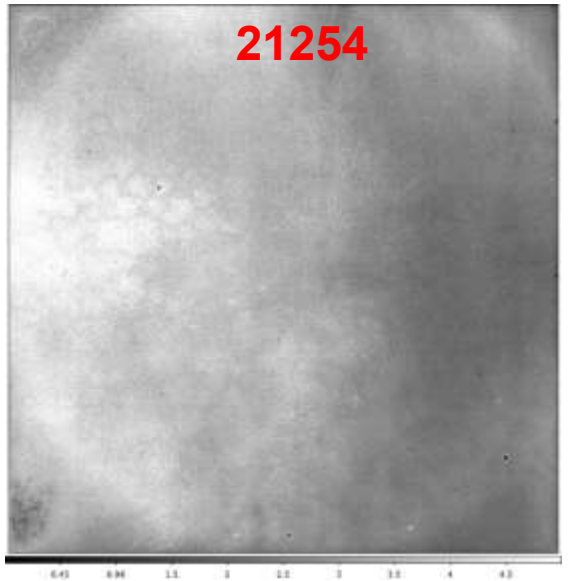
Linear scale:
[-0.05:0.5] e-/sec





Additionally, down-selected due to above full well persistence

- Dark current: < 0.5 e-/s/pix (<0.05 e-/s median)
- Total noise: < 12 e-/pix (<6.5 e- median)
- Below full well Persistence: < 0.15 e-/s median
- **Above full well Persistence: < 0.8 e-/s/pix (<0.5 e-/s median)**
  - Most devices pass median requirements but **~20% devices** failed
  - Median % pixels passing is **96.3%**
  - Minimum % pixels passing is 0.04% due to persistence thresholding effect.
  - A little more than half devices have <98% pixels passing.
- Interpixel capacitance (IPC): <2.5%
- Pixel crosstalk (cosmic rays): <1% above IPC
- Well Depth: > 80,000 e-
- Quantum Efficiency (QE): >50% for 0.48-0.76 µm, >80% for 0.76 - 2.0 µm
- Power dissipation: < 20 mW
- Guide window mode Functionality

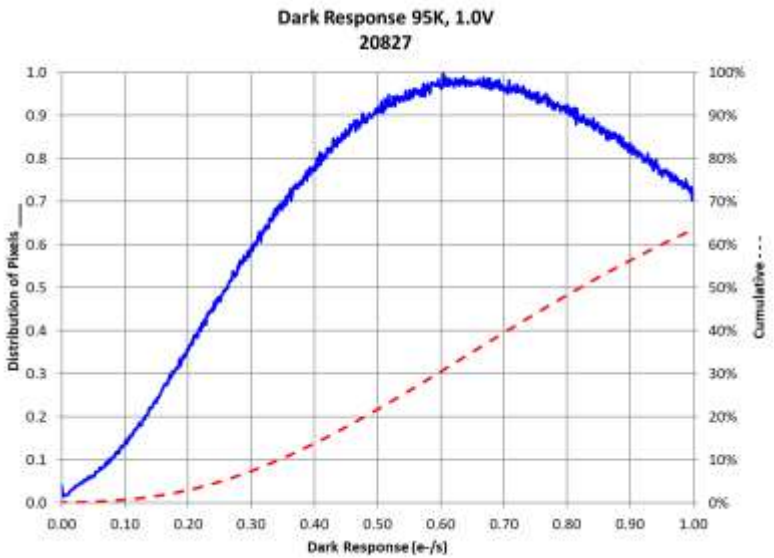


Linear scale: [-0.05:5 e-/sec]

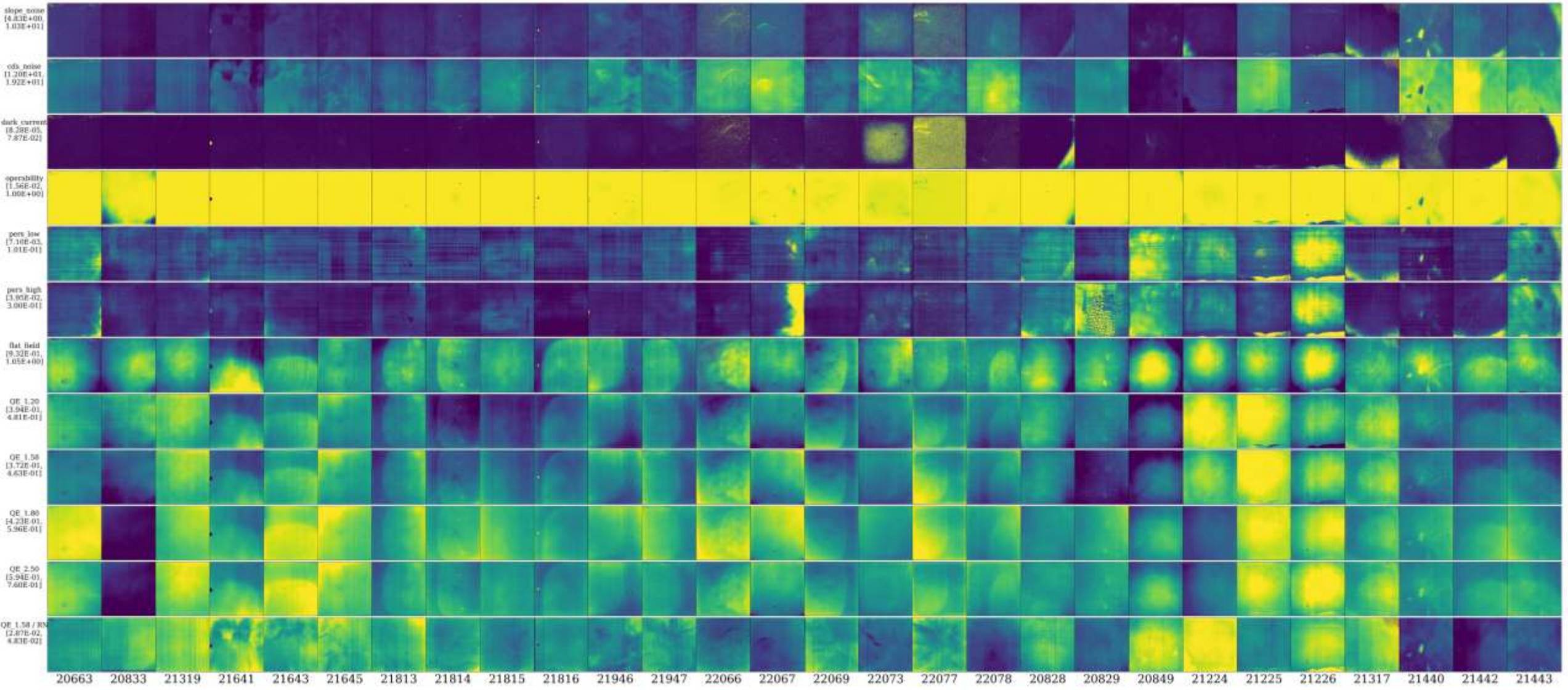
And, due to dark current performance.

- **Dark current: < 0.5 e-/s/pix (<0.05 e-/s median)**
  - Most devices pass median dark current requirement, but ~**16% devices** do not.
  - Most devices that did not pass were made using suboptimal substrate
  - Most devices have >95% pixels passing, but 22% do not.
  - Median % pixels passing is **~99%**
- **Total noise: < 12 e-/pix (<6.5 e- median)**
- **Below full well Persistence: < 0.15 e-/s median**
- **Above full well Persistence: < 0.8 e-/s/pix (<0.5 e-/s median)**
- **Interpixel capacitance (IPC): <2.5%**
- **Pixel crosstalk (cosmic rays): <1% above IPC**
- **Well Depth: > 80,000 e-**
- **Quantum Efficiency (QE): >50% for 0.48-0.76 µm, >80% for 0.76 - 2.0 µm**
- **Power dissipation: < 20 mW**
- **Guide window mode Functionality**

Linear scale: [0.0:3.5] e-/sec



28 devices passed acceptance testing to become flight candidates.



The 28 accepted devices were tested with flight-like ACADIA ASIC.

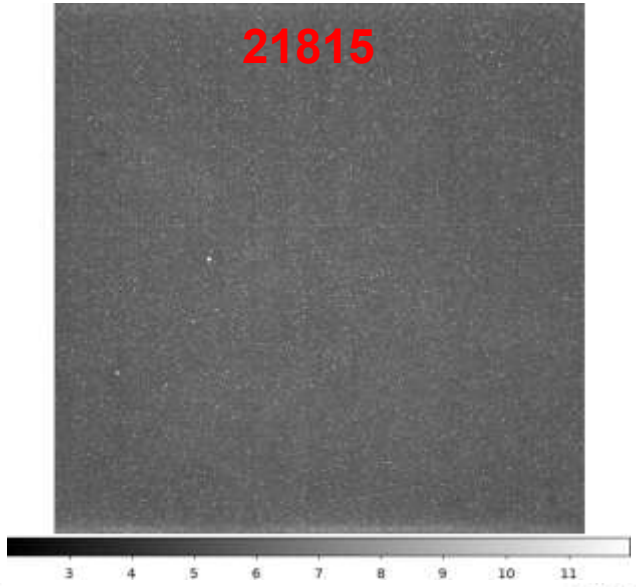
- **Triplet testing of all accepted devices, i.e. flight candidates, was performed (4 devices at a time paired with 4 ACADIA ASICs[1])**
  - Inter-pixel capacitance
  - Total Noise
  - Total Noise with Guide Windows Enabled
  - Dark Current
  - Well Depth
  - Photometric Stability
    - Short Term: Stable to 0.1% for 1000 s
    - Long Term: Repeatable to 1% up to 7 days
  - Crosstalk Output-to-Output: < 0.01%
  - Crosstalk Trailing Pixel: <0.5%

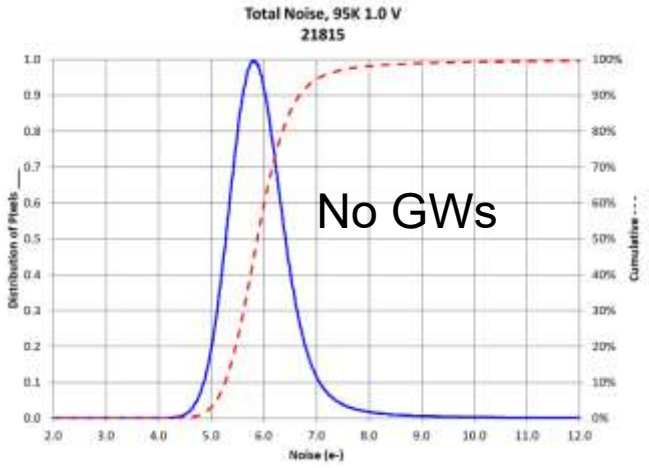
Test Parameter	Requirement	SCS Req. #	Test Results			
Conversion Gain	N/A	N/A	0.780			
Dynamic Range	N/A	N/A	Median (e-)	Mean (e-)	% px > 80 Ke	
			81043.7	81274.8	99.91	
Inter-pixel Capacitance	<2.5%	RFPS-112	Mean (%)	Maximum (%)		
			1.541	1.598		
Thermal Sensitivity SCE	N/A	N/A	[e/k]			
			-0.097			
Thermal Sensitivity SCA	N/A	N/A	[e/K]			
			-7.164			
Total Noise	< 7.5 e- median < 12 e- per px	RFPS-78 RFPS-101	Median (e)	Mean (e)	Modal (e)	(%) Pixels passing
			5.41	5.77	5.36	99.50
Total Noise Guide Window	< 7.5 e- median < 12 e- per px	RFPS-78 RFPS-101	Median (e)	Mean (e)	Modal (e)	(%) Pixels passing
			5.38	5.78	5.34	99.52
Dark Current	< 0.05 e-/s median < 0.5 e-/s per px	RFPS-110 RFPS-101	Median (e/s)	Mean (e/s)	Modal (e/s)	(%) Pixels passing
			0.004	0.007	0.004	99.96
Linearity	> 80 ke Can be linearized to < 1%	RFPS-102	Median (%)	Mean (%)	Modal (%)	(%) Pixels passing
			0.12	0.25	0.10	99.64
Short Term Photometric Stability	Light stable to 0.1 % for 1000 sec or less	RFPS-107	Normalized ratio detector/photodiode (%)			
			0.017			
Long Term Photometric Stability	light shall be repeatable to 1% or better for timescales of up to 7 days	RFPS-108	Normalized ratio detector/photodiode (%)			
			0.057			
Crosstalk Charge Trailing	Less than 0.5%	RFPS-113	Average difference (%)			
			0.12			
Crosstalk Output-to-Output	Less than 0.01%	RFPS-114	Nominal	In saturation		
			<1e-4	-1.68e-4		
Bright Star	N/A	N/A	Sig_Range [Ke]	Stability	Flux [Ke/s]	
			92.2	0.00024	61.5	

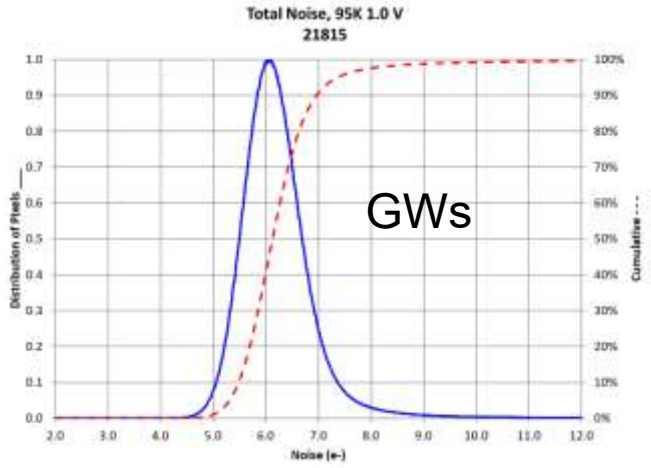
[1]: https://doi.org/10.1117/12.2313067

All candidates continued to meet noise requirements with GWs on.

- **Triplet testing of all accepted device, i.e. flight candidates, was performed (4 devices at a time paired with 4 ACADIA ASICs)**
  - Inter-pixel capacitance
  - Total Noise
    - All* candidates met requirements
    - Median device median total noise was **6.1 e-**
    - Median % pixels passing **99.2%**
  - Total Noise with Guide Windows Enabled
    - All* candidates met requirements
    - Median device median total noise was 6.2 e-
    - Median % pixels passing 99.2%
  - Dark Current
  - Linearity
  - Well Depth
  - Photometric Stability
    - Short Term: Stable to 0.1% for 1000 s
    - Long Term: Repeatable to 1% up to 7 days
  - Crosstalk Output-to-Output: < 0.01%
  - Crosstalk Trailing Pixel: <0.5%

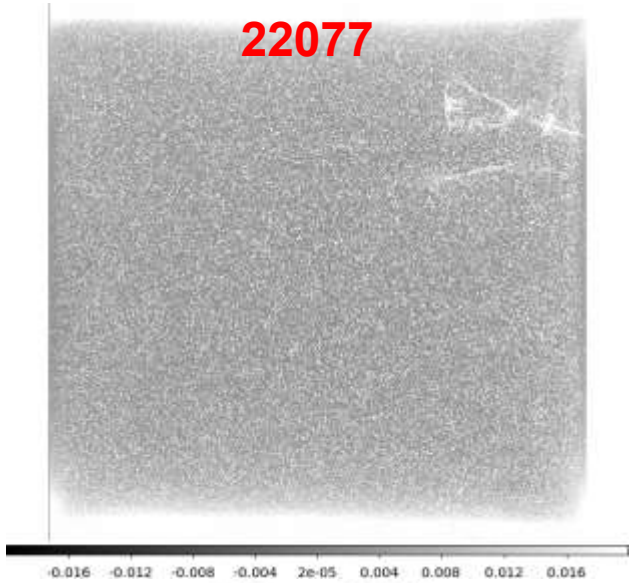




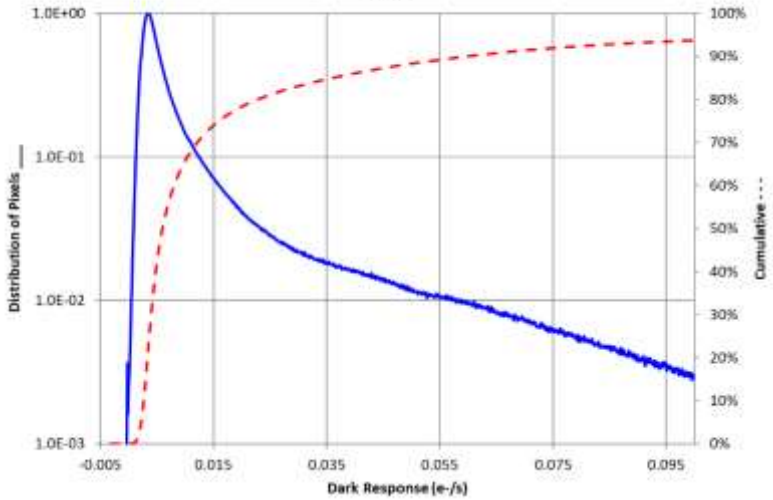


Candidate dark current performance also met requirements.

- **Triplet testing of all accepted device, i.e. flight candidates, was performed (4 devices at a time paired with 4 ACADIA ASICs)**
  - Inter-pixel capacitance
  - Total Noise
  - Total Noise with Guide Windows Enabled
  - Dark Current
    - All candidates met median requirements.
    - Median device median dark current was **0.004 e-/s**
    - Maximum median dark current was 0.006 e-/s
    - Median % pixels passing **99.8%**
    - Lowest % pixels passing 96.8%
  - Linearity
  - Well Depth
  - Photometric Stability
    - Short Term: Stable to 0.1% for 1000 s
    - Long Term: Repeatable to 1% up to 7 days
  - Crosstalk Output-to-Output: < 0.01%
  - Crosstalk Trailing Pixel: <0.5%

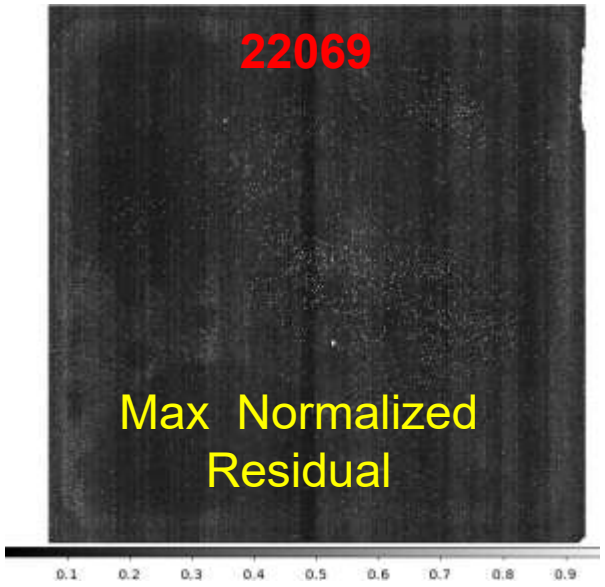


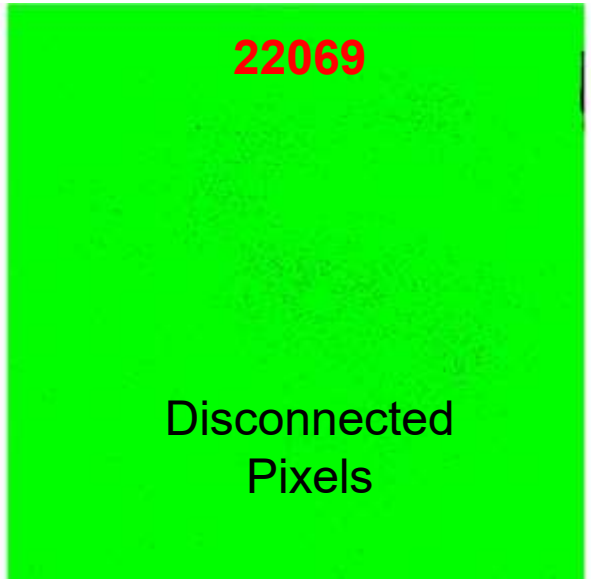
Linear scale [-0.02:0.02] e-/sec

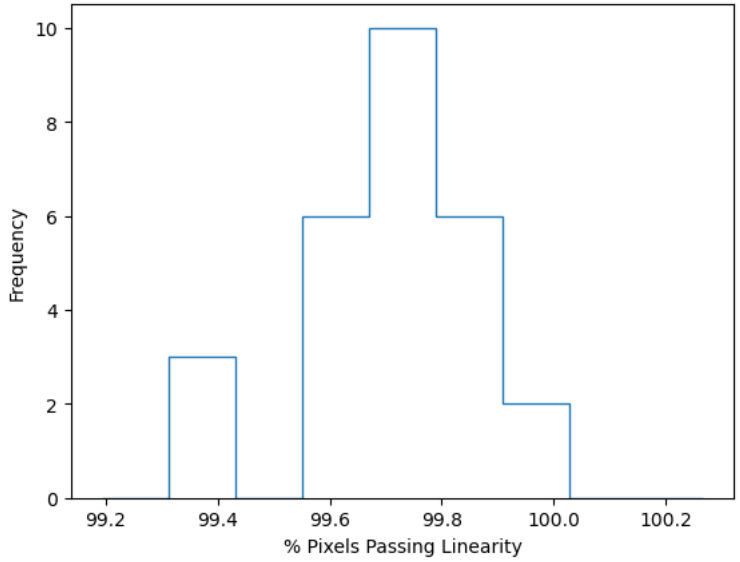


Candidates met linearity requirements as defined as well.

- **Triplet testing of all accepted device, i.e. flight candidates, was performed (4 devices at a time paired with 4 ACADIA ASICs)**
  - Inter-pixel capacitance
  - Total Noise
  - Total Noise with Guide Windows Enabled
  - Dark Current
  - Linearity
    - All candidates met linearity requirements
      - One device did not integrate long enough to assess linearity up to 80 ke-
    - Median % pixels passing was **99.7%**
    - Minimum % pixels passing was 99.3% (in part due to disconnected pixels on edge)
  - Well Depth
    - All candidates except 1 reach well depth requirement.
    - Median of device median well depth was ~92000 e- (pre-amp gain ~ 4)
  - Photometric Stability
    - Short Term: Stable to 0.1% for 1000 s
    - Long Term: Repeatable to 1% up to 7 days
  - Crosstalk Output-to-Output: < 0.01%
  - Crosstalk Trailing Pixel: <0.5%







Candidates were also characterized for count-rate nonlinearity.

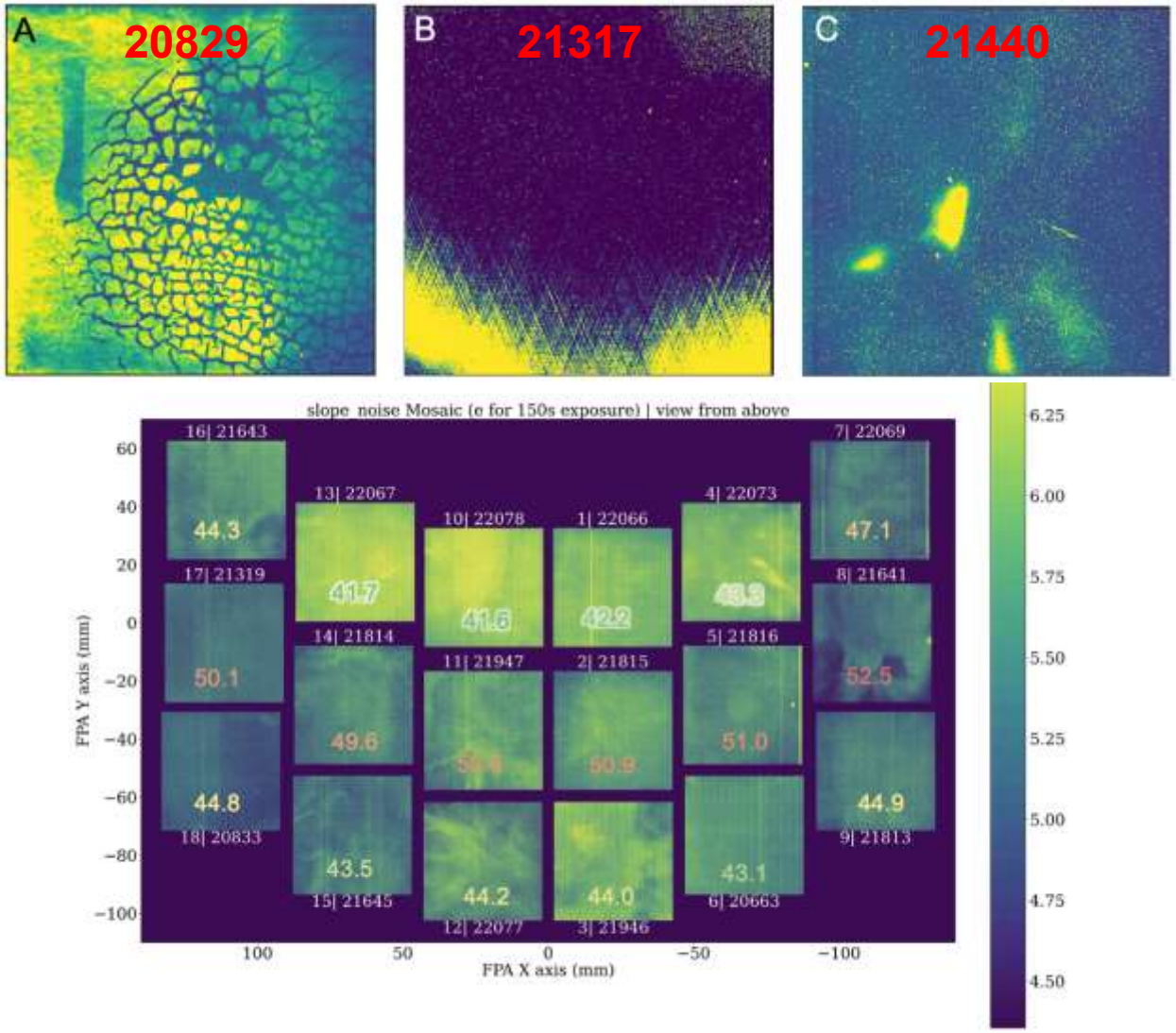
- **Count-rate Nonlinearity Testing (each flight candidate)**
  - In a single detector dewar with non-flight electronics, we characterize response in comparison to a monitoring photodiode at two wavelengths of light.

Other characterization tests on non-flight candidates include:

- **Single Pixel Response (select devices)**
- **Modulation Transfer Function measurement (select devices)**
- **Radiation Testing (proton and heavy-ion)**
- **Talbot Illuminator (select devices)**

Flight detectors were selected and placed in the flight focal plane.

- **Selection Process**
  - Developed metrics based on requirements.
  - Detector and Calibration Working Group Input
  - After eliminating devices with large cross hatch (B) and low CDS, high total noise pixels (C), remaining 18 detectors were selected for focal plane.
- **Placement Philosophy**
  - Place better sensors to compensate poorer optical performance for survey uniformity
    - Best sensors where wavefront error likely worse
  - Avoid placing sensors with disconnected pixels where optical performance is best.
    - Avoided placing sensors with higher numbers of inoperable pixels near best optical performance
  - Avoid placing sensors with inoperable pixels at edges such that it increases the FPA gaps
    - Avoided placing sensors with defects or inoperable pixels on edges that would increase focal plane array gaps



Flight detectors were selected and placed in the flight focal plane.

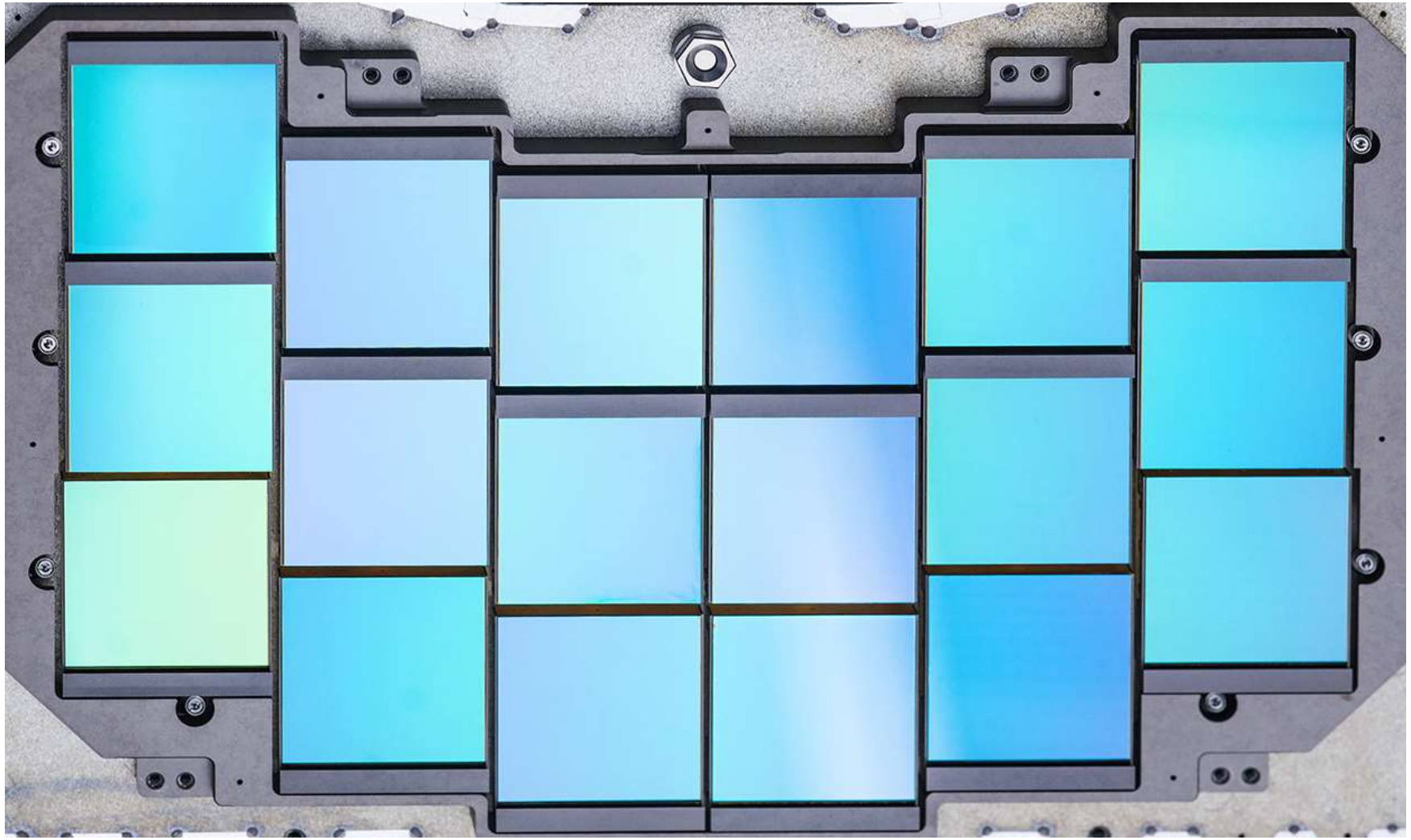
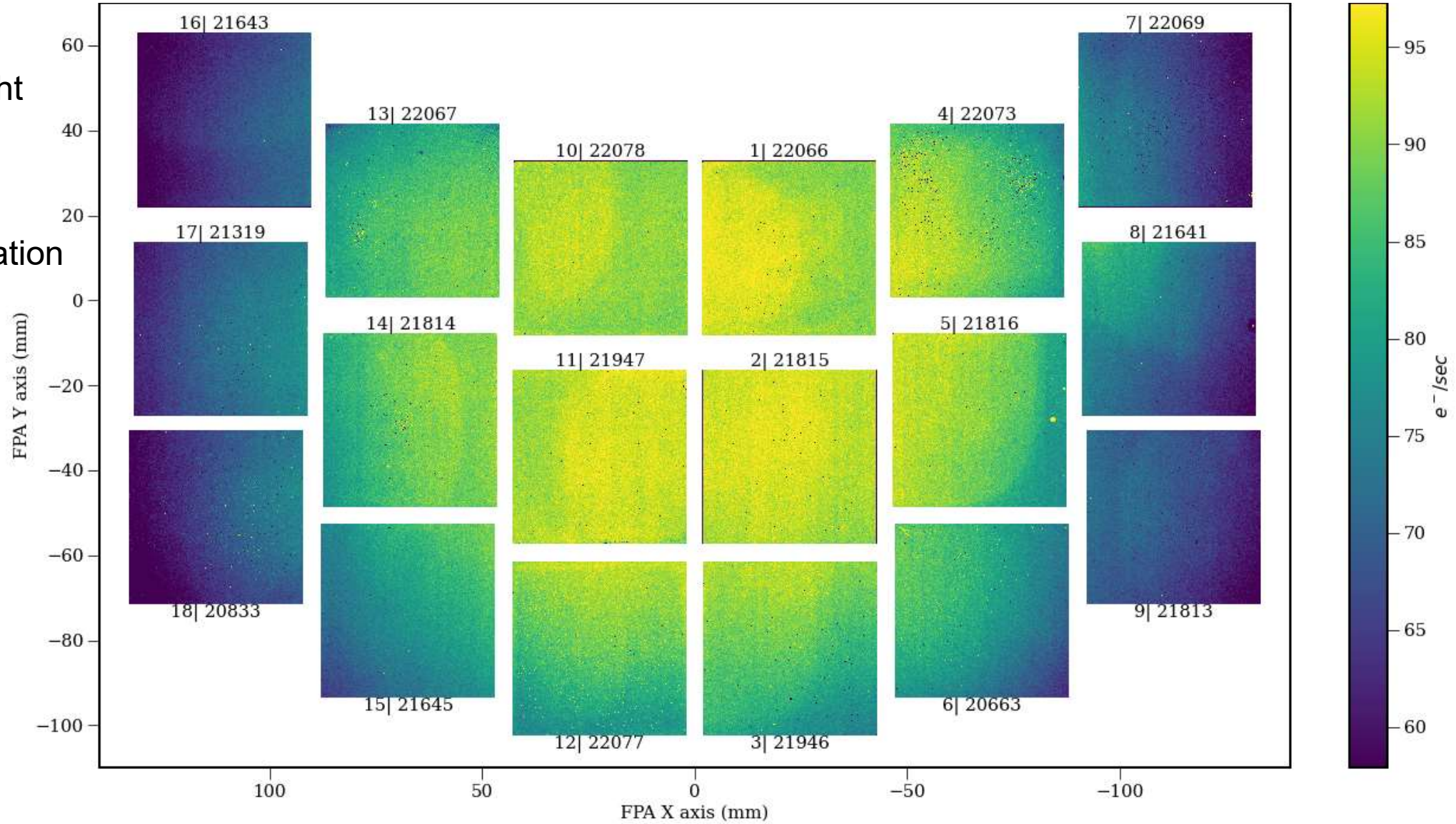


Image credit: NASA/Chris Gunn

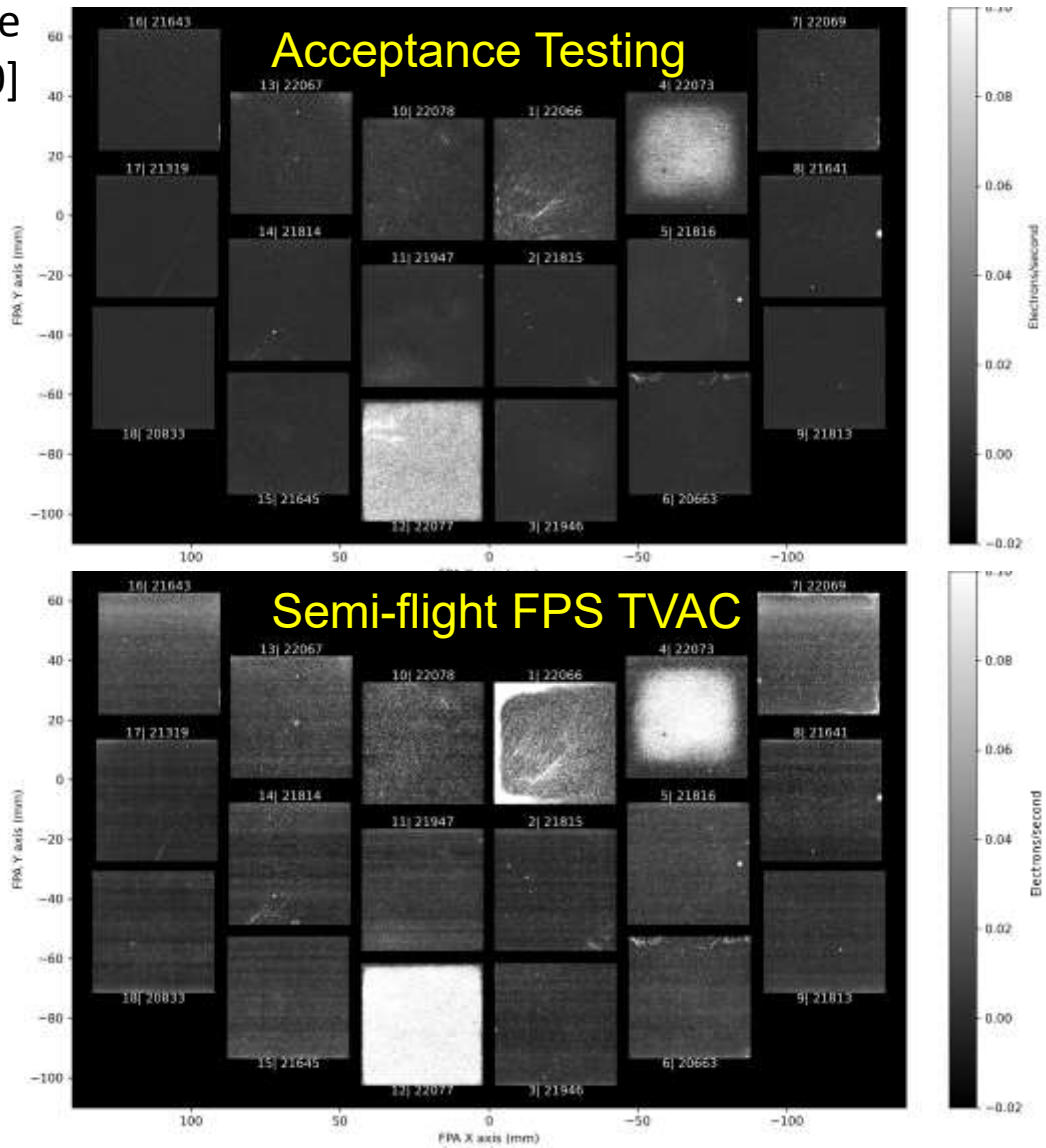
Flight focal plane system was tested at GSFC in 2022 - 2023.

Semi-Flight FPS
- 95 K
- Flat illumination



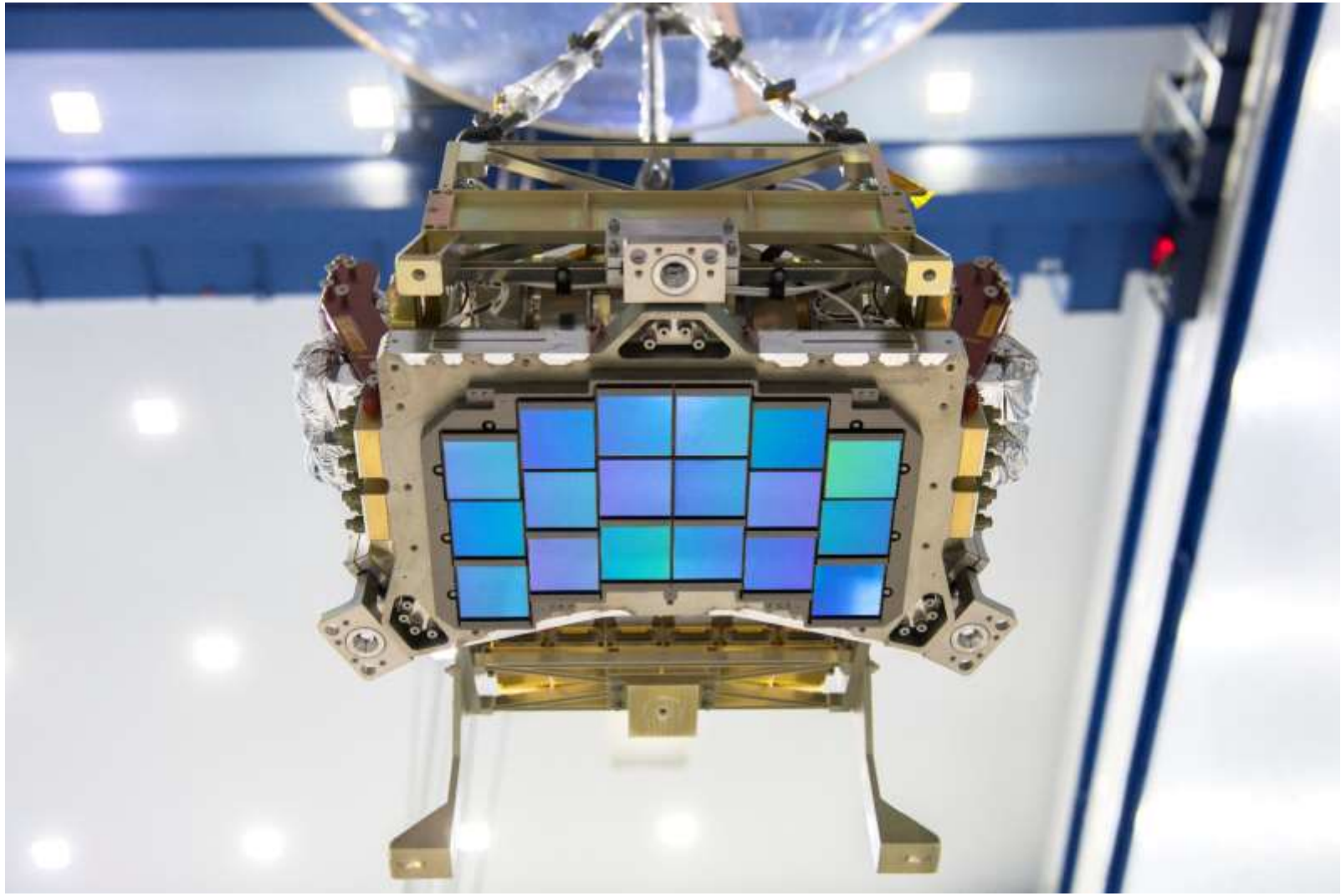
Flight focal plane system was tested at GSFC in 2022 - 2023.

- **Various thermal vacuum (TVAC) campaigns**
  - Semi-Flight Focal Plane System TVAC: 12/2022
  - Flight Focal Plane System TVAC: 04/2023
- **Dark current anomaly**
  - 3 SCAs found to have increased dark
  - 3 SCAs replaced with spares before vibe
  - Anomaly Review Board convened
    - Identified potential root cause
    - Recommended lower operating temperature
    - Recommended limiting temperature excursions of FPA
  - More details at:
    - Resolving the dark current anomaly in the Nancy Grace Roman Space Telescope focal plane
      - Proceedings Volume 13092, Space Telescopes and Instrumentation 2024: Optical, Infrared, and Millimeter Wave; 130923K (2024) https://doi.org/10.1117/12.3020366



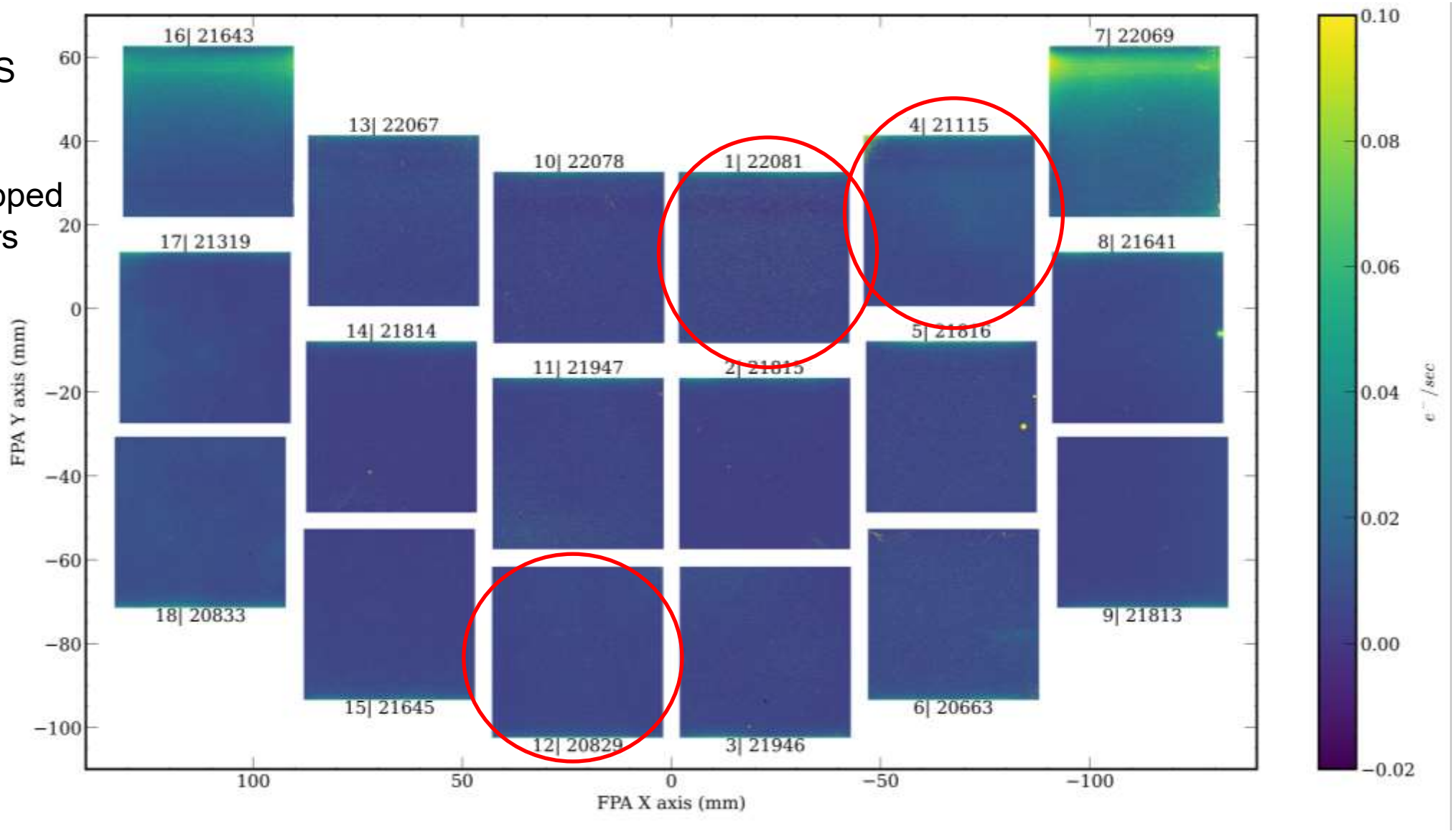
Flight focal plane system was tested at GSFC in 2022 - 2023.

Post swap on the way to vibe.



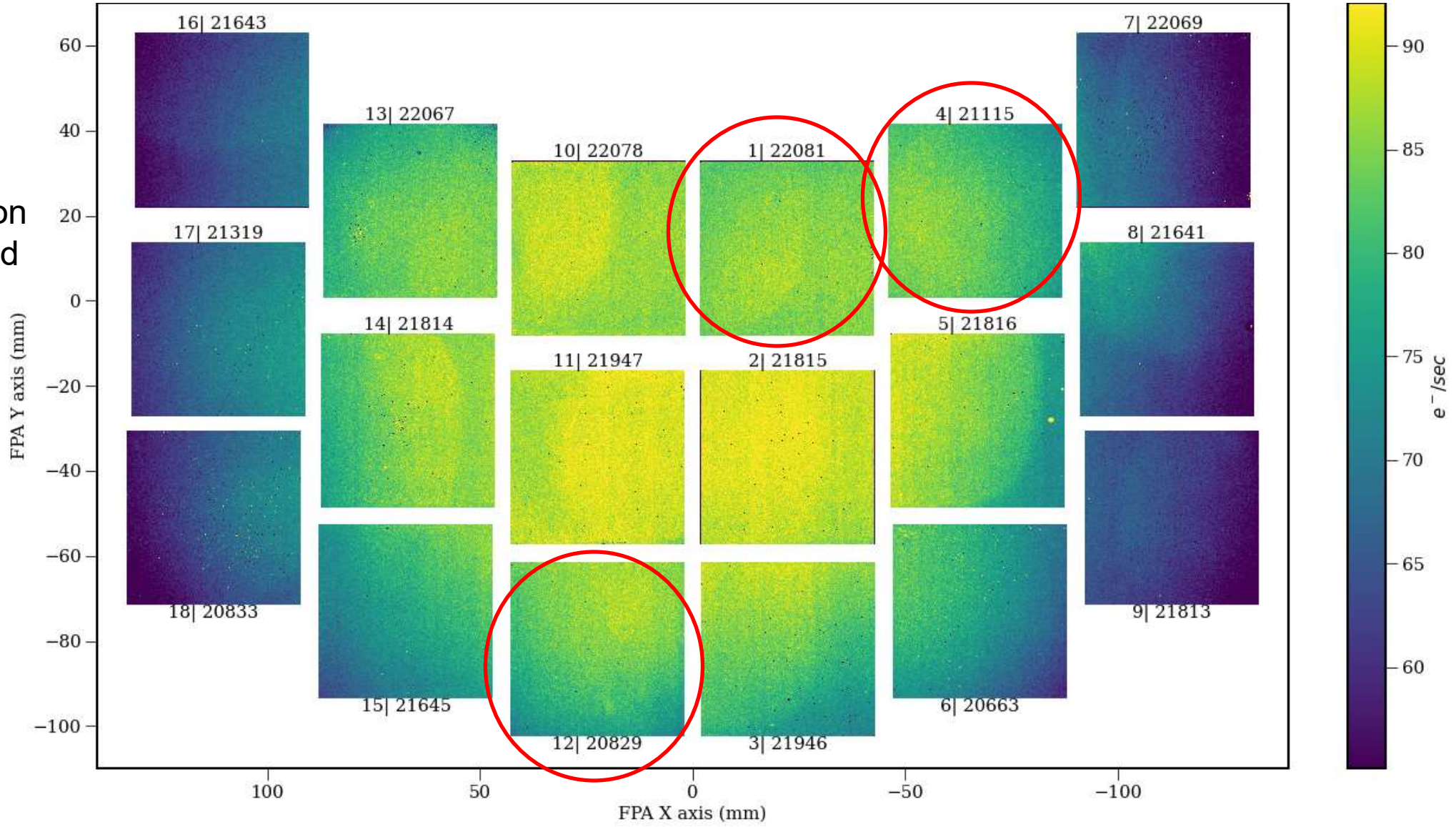
Flight Focal Plane System TVAC April 2023

Flight FPS
- 95 K
- Dark
- 3 swapped
- sensors

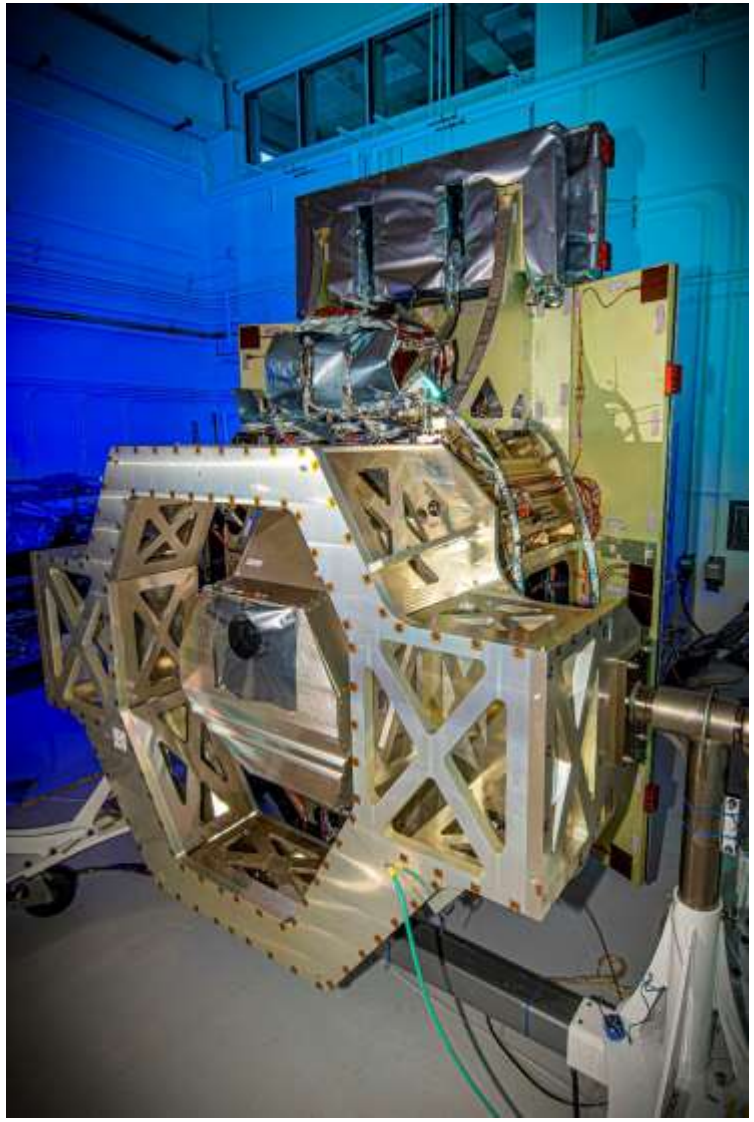


Flight Focal Plane System TVAC April 2023

Flight FPS
- 95 K
- Flat Illumination
- 3 swapped
- sensors



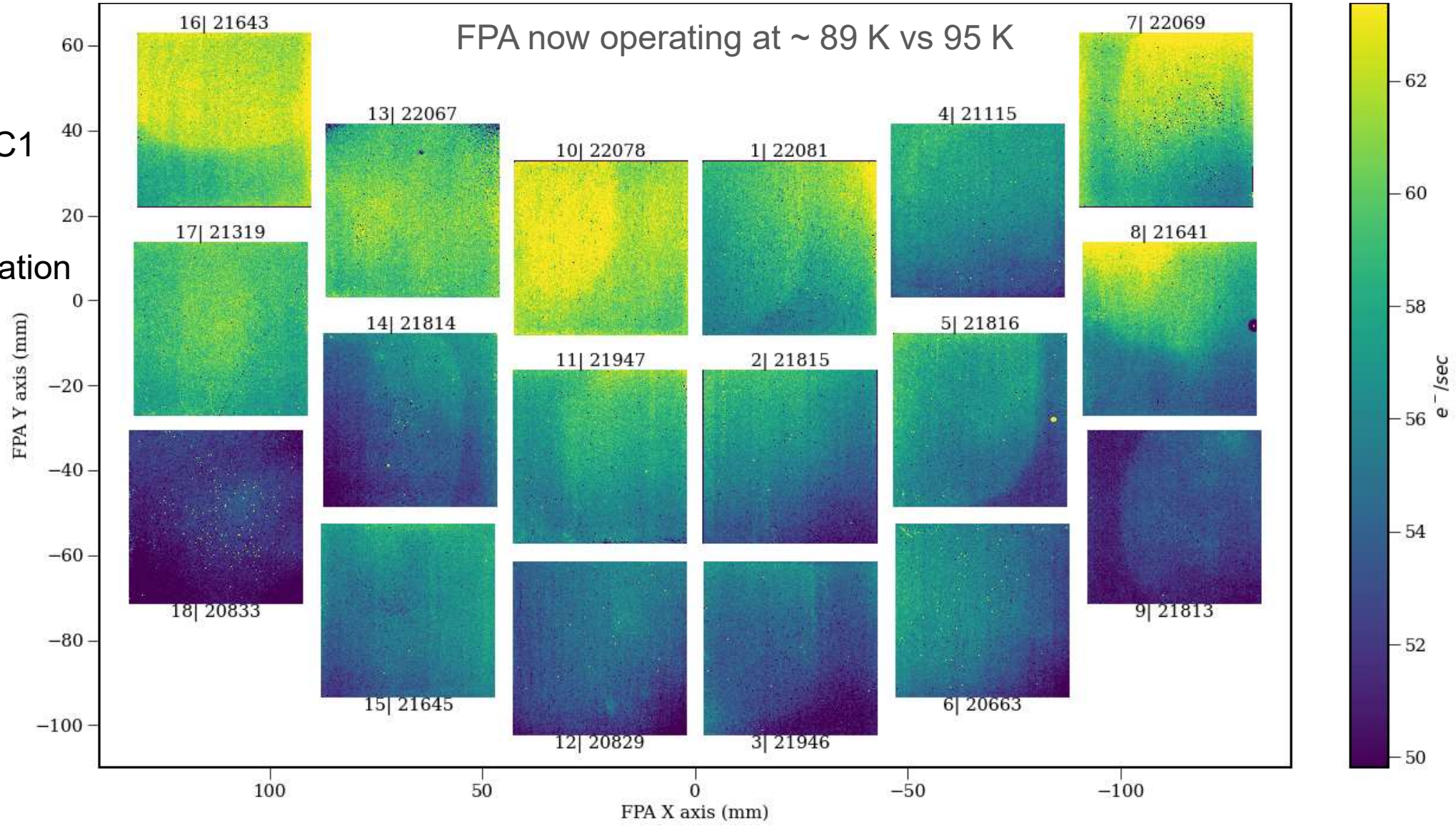
Flight focal plane system has been integrated into WFI at Ball.



WFI TVAC1, Vibe and Acoustics are completed.

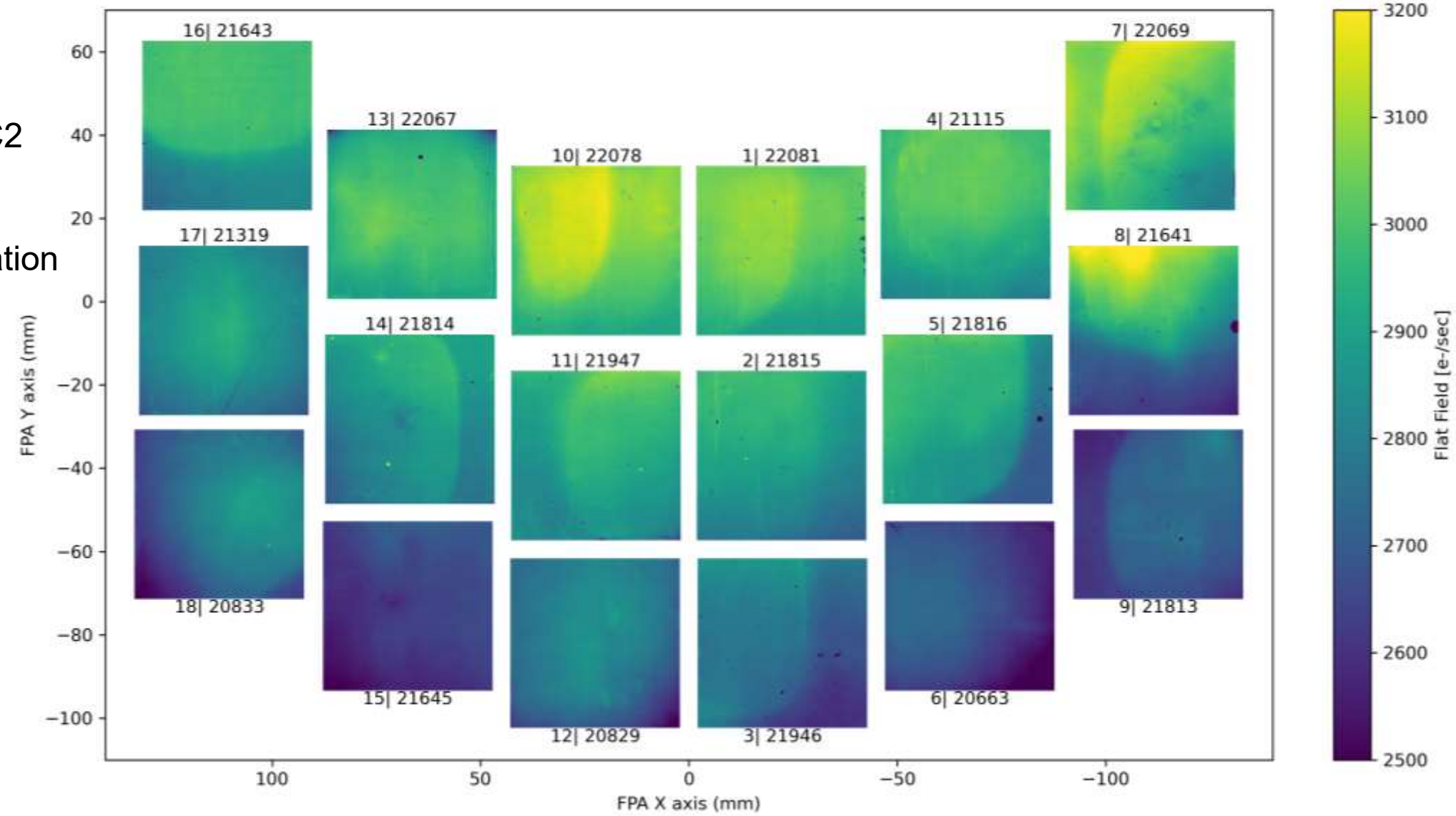
WFI TVAC1, Vibe and Acoustics are completed.

WFI TVAC1
- 89 K
- Flat Illumination



WFI TVAC2 completed!

WFI TVAC2
- 89 K
- Flat Illumination



WFI completed TVAC2, then returned to GSFC.

Image credit: NASA

Spacecraft Visualization: GSFC/SVS

WFI and CGI were integrated with telescope and spacecraft!

Image Credit: NASA/Chris Gunn

Spacecraft Visualization: GSFC/SVS

SCIPA TVAC was completed last winter.

Image credit: NASA/Jolearra Tshiteya

And now we have an observatory!

Image credit: NASA/Jolearra Tshiteya

Spacecraft Visualization: GSFC/SVS

The observatory is undergoing vibe and acoustic testing.

Spacecraft Visualization: GSFC/SVS

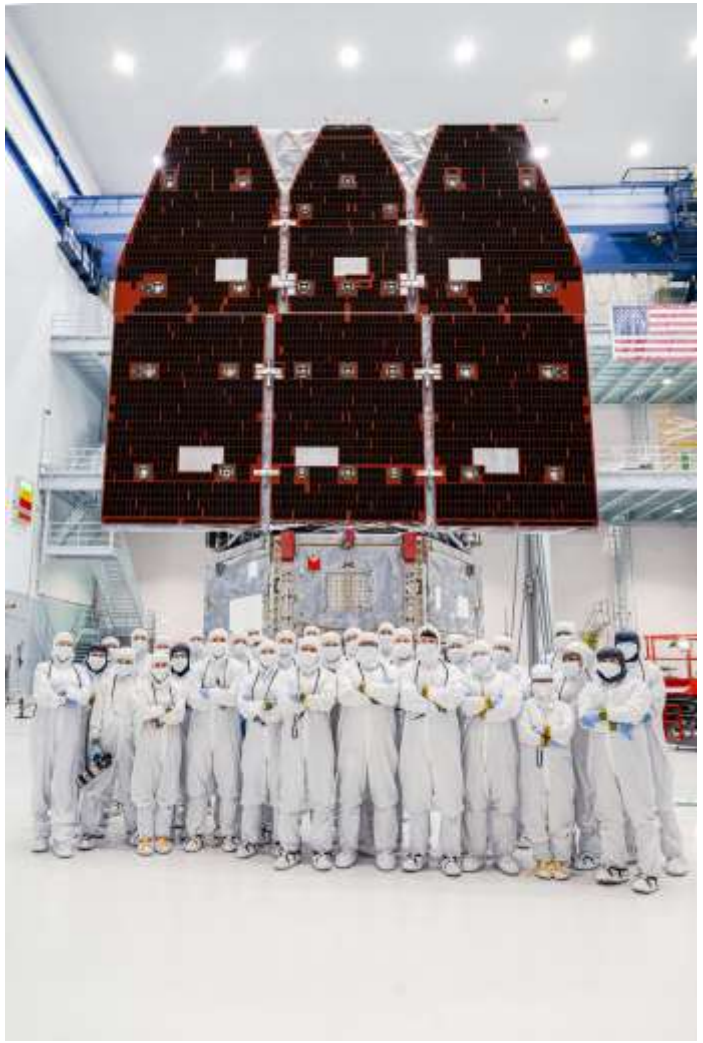


Image credit: NASA/ Sydney Rohde

Roman is on track to launch Fall 2026!

STATUS AS OF: 09-30-2021

Spacecraft Visualization: GSFC/SVS