estec

European Space Research
and Technology Centre
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
Tel. (31) 71 5656565
Fax (31) 71 5656040
www.esa.int

NIRSpec Performance Report
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Authors: Marco Sirianni
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Average Responsive Quantum Efficiency and average distribution of bad pixels in NIRSpec SCAs.

Abstract:

The current focal plane array installed in NIRSpec will be replaced later in the program. We do not yet have performed any test on the newly procured NIR detectors that will be used to build a new flight focal plane array. The calculation of the NIRSpec sensitivity for the instrument acceptance review requires as input the responsive quantum efficiency (RQE) of the detectors and also the average distribution of had pixels. In this document we derive an average RQE and an average bad pixels distribution based on the four detectors made available for NIRSpec as part of the first procurement.

1 INTRODUCTION

The Focal Plane Array (FPA) installed in NIRSpec at the time of the Acceptance Review (Fall 2013) and used for the ground testing at NIRSpec level during the calibration campaign FM1 and FM2 will be replaced between the ISIM CV2 and CV3 because of its degrading performance [1]. The detector response is a crucial component for the estimate of the NIRSpec sensitivity and the verification of the associate requirements.
At the time of writing this report, the procurement of new Sensor Chip Assemblies (SCAs) for NIRSpec is still on going and no test data are available for the new H2RG devices.

2 AVERAGE RQE

Four different flight-grade SCAs have been selected for the NIRSpec as part of the original detector procurement. The four SCAs were mounted in two different FPAs:

FPA 104 consists of SCA 055 [491] and SCA 054 [492]. It is the FPA installed in NIRSpec at the time of writing and the one used (with ASICs S/N 202 and S/N 215) for the NIRSpec Cryo campaigns FM1 [Jan 2011 – Mar 2011] and FM2 [Dec 2012 - Feb 2013]. It will also be the FPA used for ISIM CV2.

FPA105 consisted of SCA 058 [491] and SCA 060 [492]. Initially identified as spare-FM FPA105 was planned to replace FPA104 during ground testing at NIRSpec level and during the first ISIM test campaign. Although it was never installed in NIRSpec the two SCAs in FPA105 were flight quality and have been included in this study. FPA 105 will be refurbished to host the new detector and converted in FPA106.

The Responsive Quantum Efficiency (RQE) of the NIRSpec SCAs was measured during the FPA characterization campaigns at the NASA/GSFC Detector Characterization Laboratory (DCL) (see table 1). An estimate of a mean RQE for the new SCAs that will be used for FPA106 can be derived by averaging the RQE of the four flight SCAs delivered to NIRSpec as part of the first detector procurement (table 2).

Table 1. RQE for the SCAs in FPA104 and FPA105 as measured at the NASA/GSFC DCL

FPA 104				
Wavelength (nm)	SCA-055/(491)		SCA-054 (492)	
	RQE	Sigma	RQE	Sigma
600	0.58	0.04	0.54	0.06
700	0.77	0.06	0.67	0.07
800	0.71	0.05	0.65	0.07
900	0.60	0.04	0.54	0.06
1000	0.68	0.05	0.61	0.06
1200	0.76	0.05	0.69	0.07
1400	0.75	0.05	0.69	0.07
1600	0.71	0.05	0.66	0.07
1800	0.71	0.05	0.67	0.06
2000	0.74	0.05	0.69	0.06
2300	0.76	0.05	0.72	0.06
2600	0.78	0.05	0.74	0.06
2900	0.80	0.05	0.77	0.06
3200	0.78	0.05	0.76	0.05
3500	0.82	0.05	0.81	0.05
3800	0.80	0.05	0.81	0.04
4100	0.79	0.05	0.81	0.04
4400	0.79	0.05	0.81	0.04
4700	0.79	0.05	0.81	0.04
5000	0.76	0.05	0.79	0.04

FPA 105				
Wavelength (nm)	SCA-058/(491)		SCA-060 (492)	
	RQE	Sigma	RQE	Sigma
600	0.59	0.04	0.52	0.05
700	0.78	0.05	0.71	0.06
800	0.65	0.04	0.61	0.05
900	0.60	0.04	0.55	0.05
1000	0.71	0.05	0.65	0.05
1200	0.72	0.05	0.67	0.05
1400	0.68	0.04	0.64	0.05
1600	0.66	0.04	0.62	0.05
1800	0.68	0.04	0.64	0.05
2000	0.71	0.04	0.67	0.05
2300	0.75	0.05	0.71	0.05
2600	0.75	0.05	0.72	0.05
2900	0.78	0.05	0.75	0.05
3200	0.74	0.05	0.73	0.05
3500	0.76	0.05	0.75	0.05
3800	0.76	0.05	0.77	0.05
4100	0.76	0.05	0.77	0.05
4400	0.74	0.05	0.75	0.05
4700	0.73	0.04	0.76	0.04
5000	0.69	0.06	0.76	0.04

In table 2 we also provide the theoretical QE curve for the 5.3 μm cut-off SCAs scaled to match the average RQE of seven H1RG devices developed as part of new procurement of the JWST NIR SCAs (B. Rauscher private communication). The average and the theoretical curve are shown in Figure 1 and compared with the requirement levels.

Table 2. Average RQE for the FPA104 and FPA105 and the theoretical curve

Wavelength (nm)	Average SCA			Theoretical
	RQE	Sigma		RQE
600	0.56	0.03		0.66
700	0.73	0.06		0.82
800	0.66	0.04		0.74
900	0.57	0.03		0.66
1000	0.66	0.04		0.72
1200	0.71	0.04		0.83
1400	0.69	0.04		0.75
1600	0.66	0.04		0.68
1800	0.67	0.03		0.67
2000	0.70	0.03		0.69
2300	0.73	0.02		0.75
2600	0.75	0.03		0.80
2900	0.78	0.02		0.83
3200	0.75	0.02		0.84
3500	0.79	0.03		0.84
3800	0.78	0.02		0.83
4100	0.78	0.02		0.81
4400	0.77	0.03		0.79
4700	0.77	0.04		0.77
5000	0.75	0.04		0.76

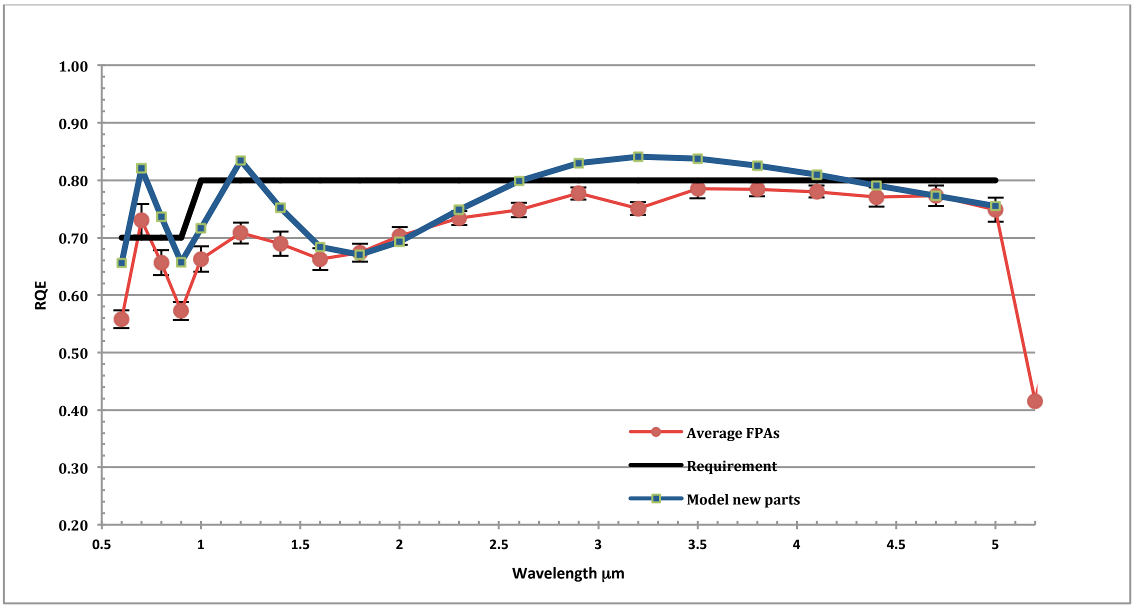

Figure 1. Average RQE for the four SCA delivered to NIRSpec (Red-curve), QE theoretical curve scaled to match recent testing of seven H1RG detector arrays (blue curve) and requirements (black line).

3 BAD AND HOT PIXELS DISTRIBUTION

In the past the impact of bad and hot pixels in the detectors was factored in the sensitivity estimates. As in the case of the RQE we can use the flight parts made available for NIRSpec during the first detector procurement to estimate an average population of bad and hot pixels and their spatial distributions. In calculating the average we will also include SCA 042 of FPA103, more commonly known as the "pathfinder" which shows flight-like performance but was classified as not suitable for flight due to the presence of a photon-emitting diode (PED).

3.1 Bad pixels definition

Bad pixels are easily identifiable under flat field illumination. For each FPA we have used the background exposures acquired during the monochromatic flat field test (typically 60 exposures for each SCA). Once all the exposures have been averaged together we used them as input to the IDL procedure create_BPIX_mask.pro to derive bad pixels masks and statistics for the following types of bad pixels:

- Open Pixels
- Pixels near to open pixels
- Shorted or "dead" pixels
- Low QE pixels

All these types of bad pixels have shown to be stable over time.

3.1.1 Open Pixels

Open pixels are easy to recognize in images with flat illumination as pixels with a value significantly below the average signal and that are surrounded by pixels with enhanced signal (Figure 2.). They are presumed to be open in the sense that the indium bump does not connect (or only partially connect) the HgCdTe substrate to the ROIC [4]. As a consequence, the signal generated within this pixel is not correctly collected by the detector electronics but leaks into neighbouring pixels, altering their values.

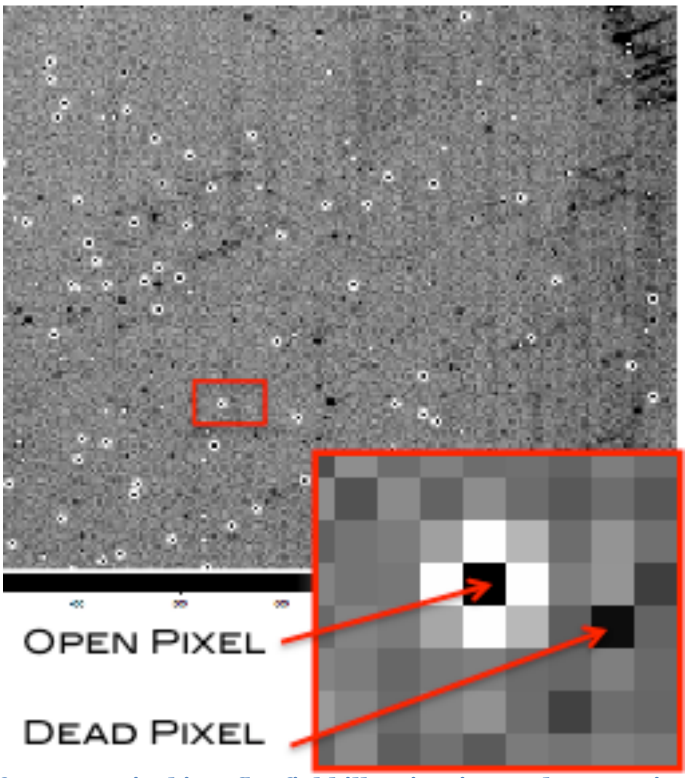

Figure 2 example of an open pixel in a flat field illumination and comparison with a dead pixel.

Open pixels also appear as a clear feature in the normalized distribution of pixels' signal in a flat field exposure. Besides the expected peak of normal pixels, with asymmetrical wings due to the lower QE cross-hatching structure, there are typically three more peaks (position

and amplitude will vary depending on the SCA). These peaks correspond to:
• Dead pixels that do not accumulate signal and show up as peak around zero counts.
• Open pixels that accumulated only a small fraction of the incident flux (between 10 and 15 %)
• The open pixels' nearest neighbors with an excess of light (between 10 and 20%)

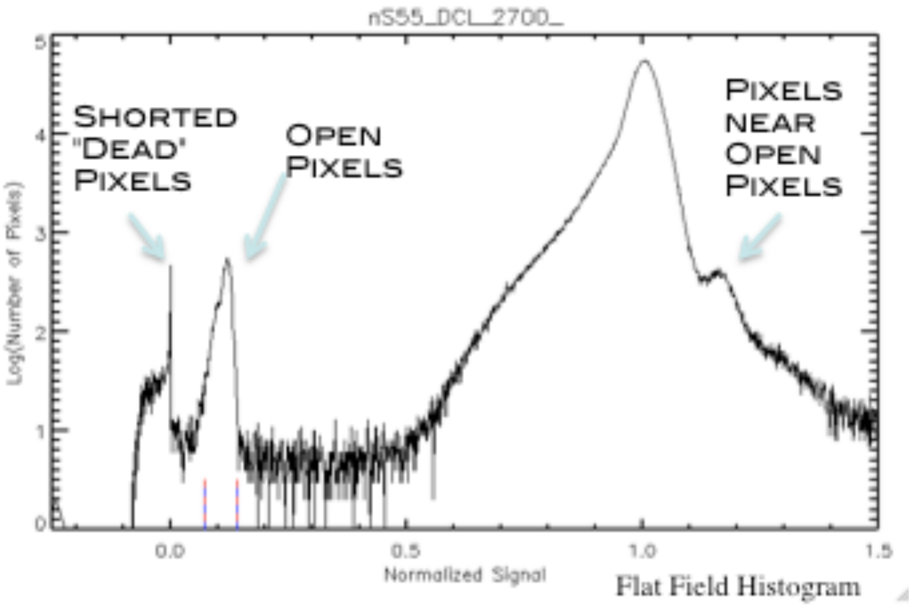

Figure 3. Normalized distribution of Pixel's signal in a flat field exposure.

A pixel is masked as open if its RQE falls between 0.05 and 0.5 times the local median RQE and the median of the four-neighbour pixels is greater than 1.05 time the local median RQE.

Open pixels do not record any useful signal and cannot be used for science. Contrary to the IPC, in fact, the charge coupling seen in open pixels does not conserve the total charge. About 88% of the light is missing in the central pixels, but only ~65% is redistributed into neighbour pixels.

Although isolated open pixels can be found anywhere in the SCA they are mostly concentrated close to the corners or along the edges of the SCA (see section 3.2)

3.1.2 Pixels near Open Pixels

As described in the previous section, open pixels "spills" charges in the surrounding pixels (Figure 2 and 3). When the detector is illuminated, these pixels do not provide any useful reading because their signal is contaminated by the signal "leaking" out the central open pixel. They can be used to collect Dark Current statistics (because in this case there is no signal incident on the central pixel). In addition all eight pixels surrounding each open pixel show a strong persistence. For each isolated open pixel effectively 9 pixels are lost for science and target acquisition. Due to usually localized distribution of open pixels often a pixel may be neighbor of more than one open pixel. The statistics related to the pixels near open pixels include all pixels that are contaminated by at least one open pixel.

3.1.3 Shorted or dead pixels

These are pixels that do no show any response to light (Fig 2). They are selected as pixels whose normalized signal is below 0.05 (see figure 4 for an example). They are mostly isolated pixel, uniformly scattered across the entire SCA.

3.1.4 Low QE pixels

A pixel is flagged as having low RQE if it is not an open pixel (see 3.1) and its RQE falls between 0.05 and 0.5 times the local median RQE (Figure 4).

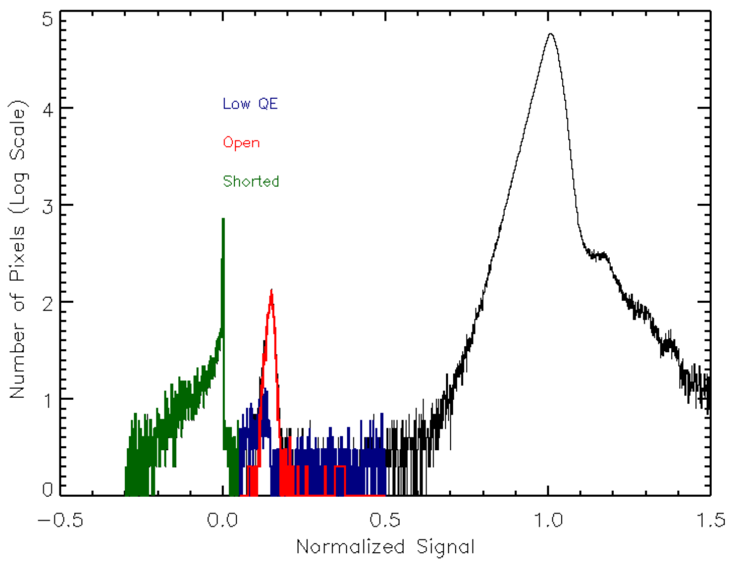

Figure 4. Normalized signal distribution of a flat field exposure for SCA060 of FPA105. The different types of bad pixels are marked.

3.2 Bad Pixel statistics and distribution

Table 3 lists the bad pixels populations in the five SCAs used for this analysis. SCA055, although being the SCA with the best RQE it is the one mostly populated with cosmetic defects. To derive a bad pixel population for a typical SCA we decided to adopt the median of the values listed in the table. Table 4 show the expected bad pixel population for a NIRSpec SCA.

Table 3. Statistics of bad pixels in the NIRSpec flight SCAs and in the pathfinder SCA.

	FPA 104		FPA 105		FPA 103 (Pathfinder)
Bad Pixel Type	**SCA 055**	**SCA 055**	**SCA 058**	**SCA 060**	**SCA 042**
Open Pixels (%)	0.256	0.019	0.007	0.072	0.060
Pixels near Open Pixels (%)	1.878	0.148	0.054	0.549	0.374
Shorted Pixels (%)	0.085	0.257	0.254	0.131	0.462
Low QE Pixels (%)	0.096	0.016	0.010	0.025	0.066

Table 4. Bad pixels on an average SCA

Typical SCA		
Bad Pixel Type	**%**	**Distribution**
Open Pixels	0.050	Localized
Pixel Near Open Pixels	0.357	Localized
Shorted Pixels	0.214	Uniform
Low QE Pixels	0.036	Uniform

As mentioned in the previous section, bad pixels display different spatial distribution depending on their nature. Low QE and shorted pixels tend to be uniformly distributed across the full SCA while open pixels, and as consequence their contaminated neighbours, are more concentrated in selected regions.

Figures 5-7 illustrate the spatial distribution of the different types of bad pixels in the five SCAs used in this analysis. Please note that the symbols used to represent a bad pixel are significantly larger than the pixel size and therefore the apparent level of contamination is artificially enhanced. The figures below are only meant to display the spatial distribution (uniform vs. localized).

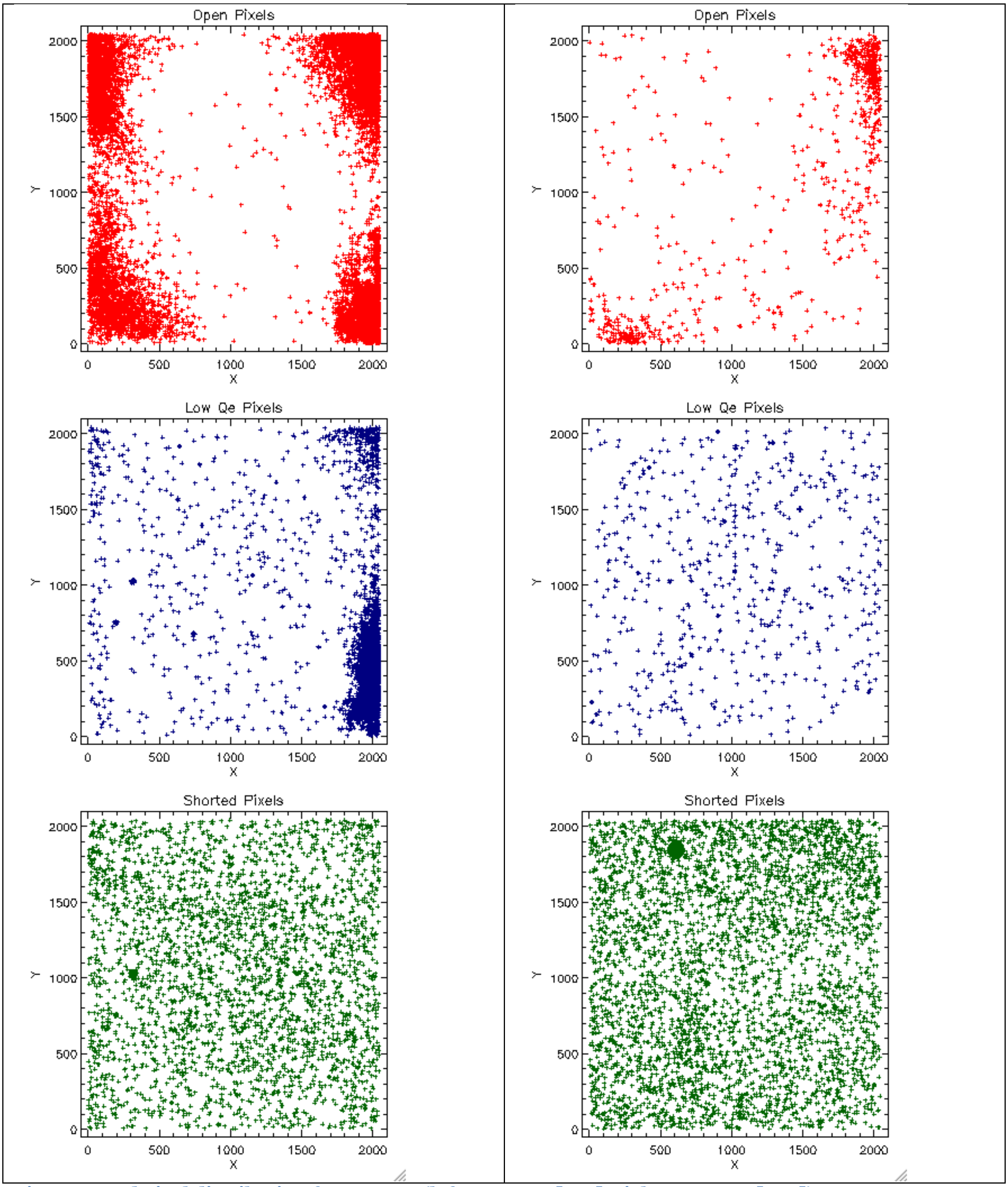

Figure 5. Bad pixel distribution for FPA104 (left: SCA 055 [491], right: SCA 054 [492])

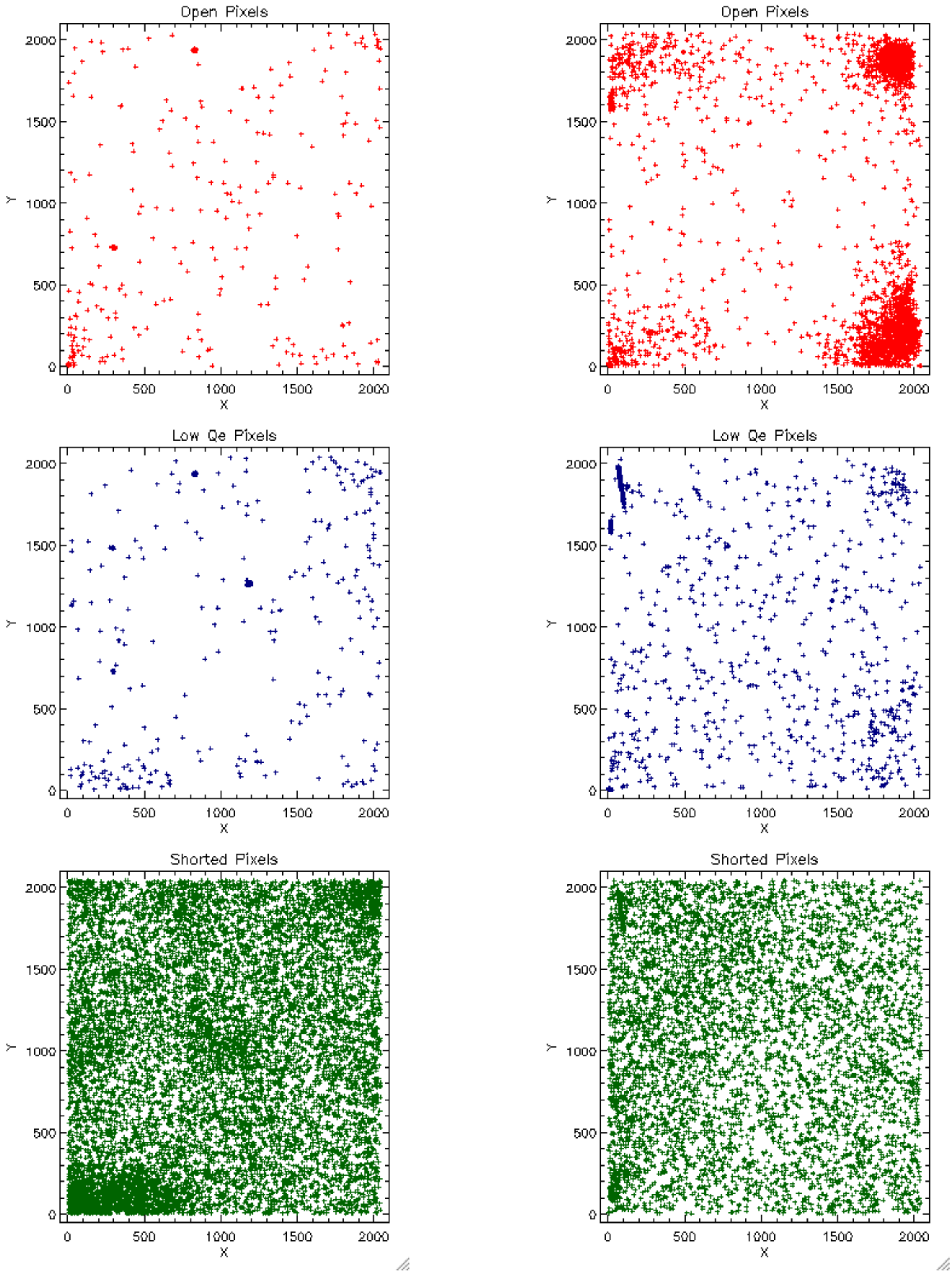

Figure 6. Bad Pixel distribution in FPA105 (Left: SCA 058 [491], Right: SCA 060 [492])

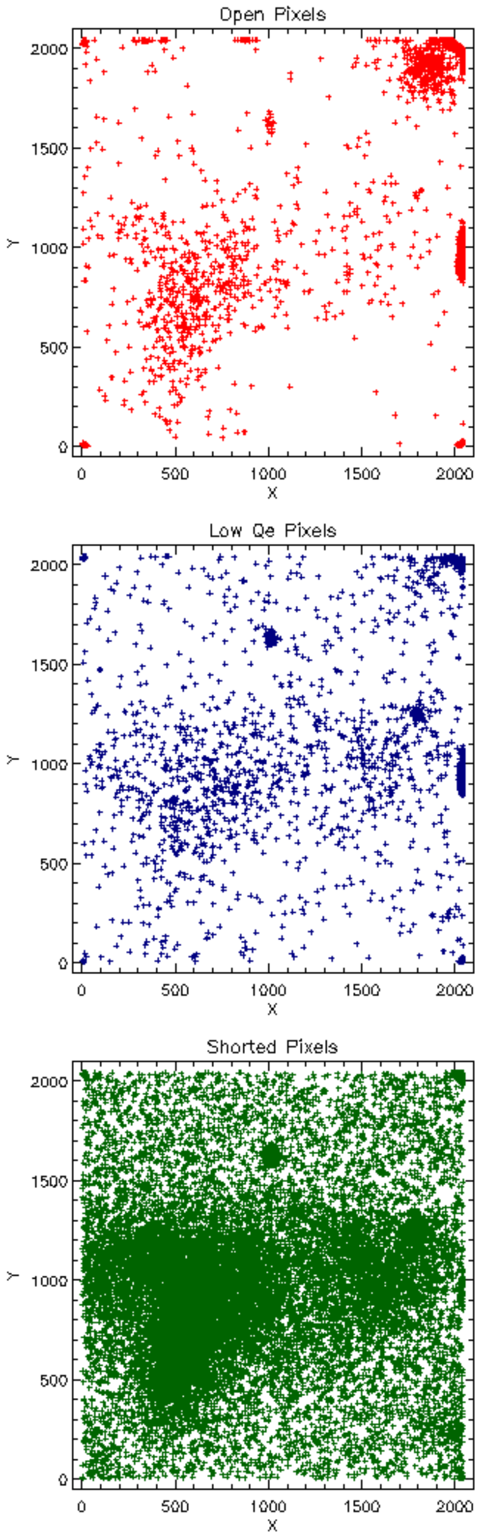

Figure 7. Bad Pixel distribution in SCA 042 (FPA 103 – Pathfinder)

3.3 Hot pixels statistics and distribution

The SCAs in FPA104 and FPA105 are known to degrade with time due to thermal cycling and exposure to ambient temperature [1]. Due to this degradation the number of hot pixels, defined as pixels with dark current in excess of 0.1 e-/s, has been increasing over time [5]. The current maps of hot pixels are therefore not representative of the expected hot pixels distribution for the SCA developed as part of the second detector procurement. For this analysis we will therefore use the data provided by Teledyne as part of the initial testing of the SCAs in 2008 for SCAs in FPA104 and in 2009 for SCAs in FPA105. These data were acquired at an operating temperature of 37K, slightly colder than the optimal operating temperature for FPA104 (38.5K) and FPA105 (41.0K). The percentage of hot pixels listed in table 5 should be therefore regarded as lower limit. An increase of 1-2% is to expected for operating a temperature of 38.5 °K.

Table 5. Hot pixels population in NIRSpec SCA

	FPA104		**FPA105**	
DETECTOR	SCA055 [491]	SCA054 [492]	SCA058 [491]	SCA060 [492]
Hot Pixels [%] (>0.1 e-/s) @37K	0.95	0.86	0.80	1.12
	Average at 37.0K: 0.93 %			

The initial distribution of hot pixels in the NIRSpec SCA was fairly uniform (see Figure 8 and 9).

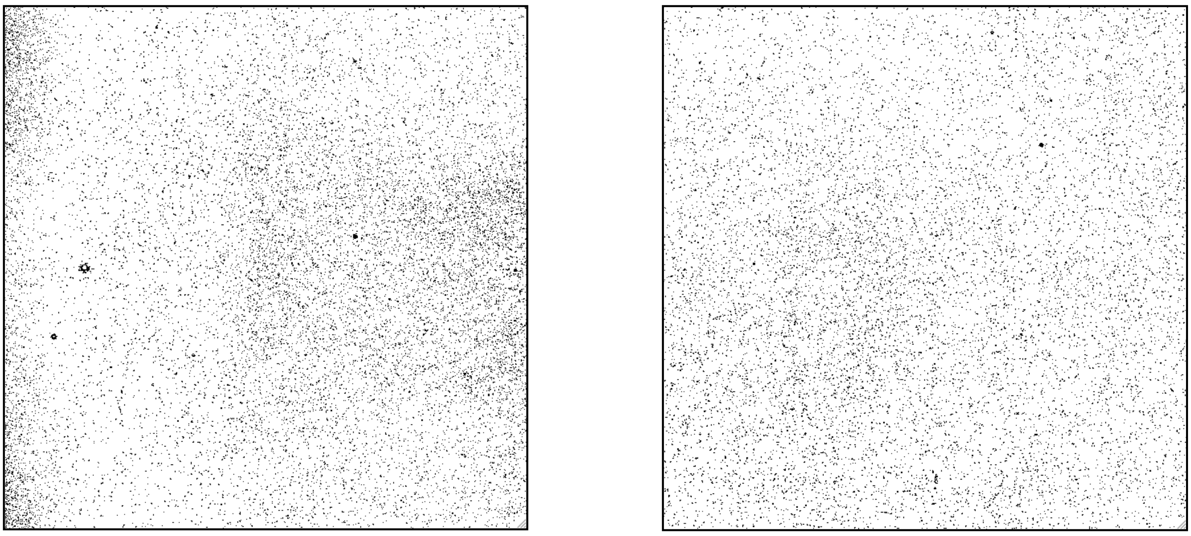

Figure 8. Initial hot pixel map for FPA 104 (left: SCA 055 [491], right: SCA 054 [492])

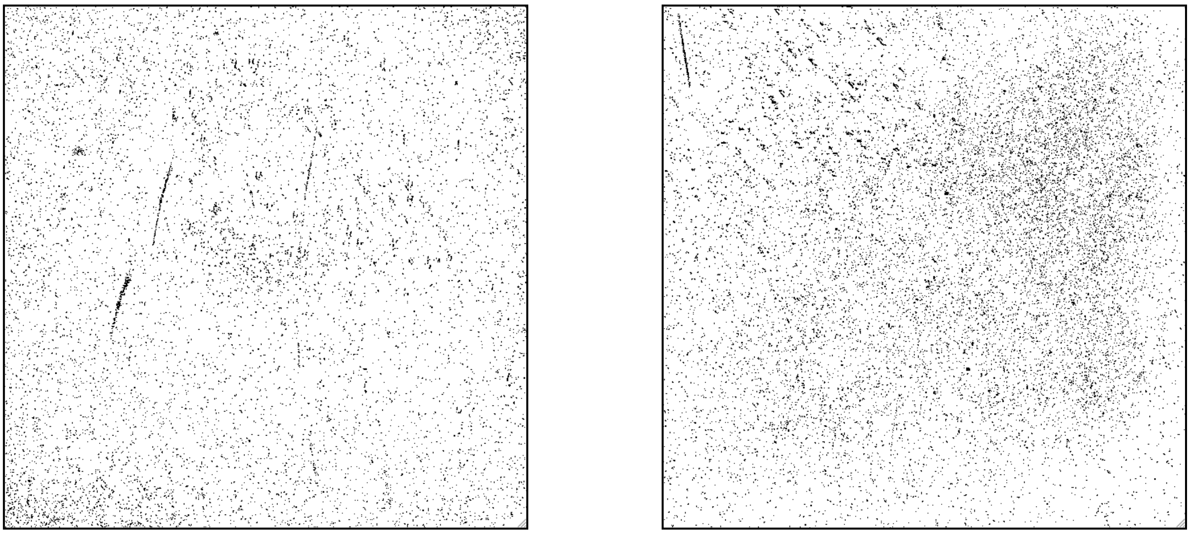

Figure 9. Initial hot pixel map for FPA 105 (left: SCA 058 [491], right: SCA 060 [492])

4 REFERENCES

[1] JWST-RPT-017457 JWST Detector Degradation Failure Review Board (DD-FRB) Executive Summary: Root Cause Determination

[2] JWST-RPT-016094 Near-Infrared Spectrograph (NIRSpec) Detector Subsystem (DS) Focal Plane Assembly S/N 104 Characterization Report

[3] JWST-RPT-017307 Near-Infrared Spectrograph (NIRSpec) Detector Subsystem (DS) Focal Plane Assembly S/N 105 Characterization with SCA S058 and S060

[4] Simm et al. Proc. SPIE 6690 (2007)

[5] NPR-2013-009/ESA-JWST-RP-19568 Status of the NIRSpec Focal Plane Array # 104 after the second (FM2) cyro campaign. M. Sirianni
http://www.rssd.esa.int/llink/livelink/open/3210152