ESA UNCLASSIFIED - For Official Use

STScI

JWST Science & Operations Centre
3700 San Martin Drive
Baltimore MD 21218
USA
www.esa.int

TECHNICAL NOTE

NIRSpec Saturation and Non-Linearity Correction Reference Files for Build 7

Prepared by S. Birkmann

Reference ESA-JWST-SCI-NRS-TN-2016-004
Issue/Revision 1.1
Date of Issue December 2, 2016
Status Draft

European Space Agency
Agence spatiale européenne

APPROVAL

Title NIRSpec Saturation and Non-Linearity Correction Reference Files for Build 7	
Issue Number 1	**Revision Number** 1
Author S. Birkmann	**Date** December 2, 2016
Approved by	**Date of Approval**
TBD	TBD

CHANGE LOG

Reason for change	Issue Nr.	Revision Number	Date
Update to address CDP3 DRB comments	1	1	02 Dec 2016

CHANGE RECORD

Issue Number 1	**Revision Number 1**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Added sentence to clarify orientation of reference files	02 Dec 2016	4	Section 2
Added explanation for peaks in histograms	02 Dec 2016	8& 13	Section 5.1
Updated histogram plots to be on same scale	02 Dec 2016	13&18	Fig. 5-6 & 11-12

DISTRIBUTION

Name/Organisational Unit
SCI-ODJ
STScI

Contents

1 INTRODUCTION

The STScI processing pipeline needs reference files in order to compute count rate images from the input up-the-ramp data, a process often referred to as "ramps to slopes". This document describes the algorithms and data used to create the non-linearity correction and saturation check reference files delivered to STScI.

The linearity correction file provides the polynomial coefficients in order to correct for the integrated counts in NIRSpec exposures for the non-linear response of the detectors. The saturation check files give the number of counts up to which the non-linearity is considered to be correctable. Pixel values above the saturation threshold should be considered saturated and unusable for science.

2 REFERENCE FILE FORMAT

All reference files are stored in fits format as defined by Hanisch et al. (2001). The primary data array is always empty and the actual reference data is stored in image extensions. In the following sections we briefly describe the primary header, the image extensions, and the data quality maps in the delivered reference files.

The orientation of these files are as written out by the STScI fitswriter. There are separate files for each of the NIRSpec detectors NRS1 and NRS2.

2.1 Primary Header and Extensions

Each reference file has an empty primary data array, with the primary header containing all the necessary keywords according to Giardino (2013) and Dixon (2016). For all delivered reference files, the `INSTURME` keyword is `NIRSPEC`. The `REFTYPE` keyword has the value `LINEARITY` for the linearity correction reference files and `SATURATION` for the saturation check reference files. Furthermore, the primary headers contains more (non-mandatory) keywords related to the creation of the reference files. The `SUBARRAY` keyword is set to `GENERIC` for all delivered files, i.e. a section can be cut out when processing subarray data.

The actual reference data is always stored in image extensions. Tables 1 and 2 below lists the extensions in the non-linearity and saturation reference files, respectively.

#	Name	Dimensions	Type	Description
1	COEFFS	2048×2048×5	-32	Linearity correction coefficients data cube
2	DQ	2048×2048	8	Linearity correction quality bit map
3	DQ_DEF	binary fits table	N/A	Meaning of data quality bits/values
4	NONLIN	2048×2048	-32	non-linearity correction at saturation level

Table 1: Number, name, dimensions, type, and description of the extensions in the linearity correction reference files. The given type denotes the BITPIX value of the data, i.e. -32 corresponds to single precision float and 8 to an 8-bit unsigned integer, respectively.

#	Name	Dimensions	Type	Description
1	SCI	2048×2048	16	Pixel saturation threshold map
2	DQ	2048×2048	8	Linearity correction quality bit map
3	DQ_DEF	binary fits table	N/A	Meaning of data quality bits/values

Table 2: Number, name, dimensions, type, and description of the extensions in the saturation check reference files. Description as for Table 1 above.

The COEFFS extension in the linearity correction reference file holds the polynomial correction coefficients for each detector pixel. The linearity correction algorithm uses a polynomial of the form

$$F_c = c_0 + c_1 \times F + c_2 \times F^2 + c_3 \times F^3 + \ldots + c_{n-1} \times F^n \tag{1}$$

where F_c is the corrected count number (in DN), c_0, c_1, c_2, $\ldots$, and c_{n-1} are the polynomial correction coefficients (n in total), and F is the uncorrected count number (in DN). Here, uncorrected means before linearity correction, but after (super) bias subtraction and reference pixel correction. In principle, n can be any number, but for the delivered reference files the polynomial degree is always four. Therefore, the dimension of the COEFFS image extension in the delivered linearity correction files is 2048×2048×5.

The SCI extension in the saturation check reference files holds the pixel-by-pixel saturation information as a 2-D array of integers. Pixel values that exceed the saturation values are considered saturated and should not be used to determine the count rate later. As this saturation detection is one of the first steps in the ramps-to-slopes pipeline, the saturation values are before (super) bias subtraction or reference pixel correction.

The DQ extension holds the data quality bit map as a 2-D array of integers, with the DQ_DEF extension describing their meanings. The currently defined values are given in the next section.

2.2 Data Quality Maps

Data quality maps hold information about bad pixel or unwanted behavior as bit values in a two dimensional map. The currently defined values for the linearity correction and saturation check reference files are listed below in tables 3 and 4, respectively.

Bit	Value	Name	Description
0	1	DO_NOT_USE	Bad pixel, do not use (for whatever reason). Currently never set when creating reference files.
1	2	NONLINEAR	Pixel is (highly) non linear and linearity correction is deemed unreliable.
2	4	NO_LIN_CORR	No linearity correction available, i.e. the coefficients in equation 1 are $c_0 = 0$, $c_1 = 1$, and $c_{2\ldots n-1} = 0$.

Table 3: Bit, value, name, and description of the data quality map bitplanes used in the linearity correction reference files. These are stored in the DQ_DEF extension as a binary fits table.

Bit	Value	Name	Description
0	1	DO_NOT_USE	Bad pixel, do not use (for whatever reason). Currently never set when creating reference files.
1	2	NO_SAT_CHECK	No saturation check data available, e.g. for low dynamic range pixels. The saturation value in the SCI extension is set to 65535 (ADC limit) in those cases. Name was previously NO_SAT_CHCK (mind the missing 'E').

Table 4: Bit, value, name, and description of the data quality map bitplanes used in the saturation check reference files. These are stored in the DQ_DEF extension as a binary fits table.

3 REFERENCE FILE CREATION

3.1 Linearity Correction and Saturation Data

In order to determine the polynomial coefficients for linearity correction, one needs illuminated exposures that i) integrate slowly up the ramp, ii) reach full well or ADC saturation for all pixels eventually, and iii) have stable illumination over time. This data cannot be obtained at NIRSpec level, due to light being blocked in the aperture plane by the MSA and slit masks. Therefore, the necessary exposures have been obtained at FPA level testing at the Goddard DCL for two FPA temperatures. For each temperature, there are 25 exposures with 64 groups each and a count rate of approximately 120 DN/s.

These exposures with counts going slowly up the ramp are then averaged the following way:

1. The super bias obtained under dark conditions is subtracted from each group.

2. Each group and output of input exposures is reference pixel subtracted. This means, that for each group/frame, each output (four in total), and odd/even columns separately, the average of the four top and bottom row pixels is computed. These averages are then subtracted from all pixels in the appropriate output and odd/even columns.

3. The reference pixel subtracted exposures are averaged group by group, pixel by pixel, using a sigma-clipped mean (2.2-σ outlier rejection).

The resulting high signal-to-noise data cube is then used as input to determine the non-linearity correction coefficients. This correction is determined on a pixel-by-pixel basis. For each pixel, the first groups with a total count level of less than 10,000 DN (above the bias) are used to estimate the count rate at zero counts by fitting an exponential function

$$y_i = a + \alpha(1 - \exp(-i/\beta)) \tag{2}$$

to the data, where i is the group number starting at 1 and y_i is the measured data value (in DN) at the given group, for all $y_i \leq 10000$. The slope b at the beginning of the ramp $(i = 0)$ is then

$$b = \frac{\alpha}{\beta}. \tag{3}$$

The predicted counts for a fully linear pixel are then

$$x_i = a + b \times i \tag{4}$$

with a and b from equations 2 and 3, respectively. In order to determine the correction coefficients from equation 1, we fit

$$y_i = c_0 + c_1 \times x_i + c_2 \times x_i^2 + c_3 \times x_i^3 + c_4 \times x_i^4, \tag{5}$$

starting using all groups, i.e. $i = 1 \ldots 64$. As this will likely result in using saturated data, the goodness of the fit will be poor and the χ^2 will be large. In order to find the saturation threshold and obtain a good fit, the number of used groups will be reduced, removing (saturated or highly non-linear) data from the end of the exposure, and the fit in equation 5 is repeated. This is done until χ^2 rises again or is below 1.5 times the minimum χ^2 obtained for any range of i. The count value of the last group for which the goodness of the fit matches the criteria given above is taken as the saturation limit, and its value plus the bias is stored in the `SCI` extension of the saturation check reference file. The bias is added back because in the pipeline saturation flagging will occur before bias subtraction.

For pixels that never reach 10,000 DN (i.e. dead, open or reference pixels) the non-linearity correction cannot be computed, and thus $c_1 = 1$ and all other coefficients will be set to 0. The saturation threshold will be $2^16 - 1 = 65535$ for these pixels. The same applies to pixels for which the polynomial fit is very poor. Data quality bits will be set as described in the following section.

3.2 Data Quality Flags

The algorithms to create the data quality bits for the non-linearity correction reference files that are given in Table 3 are described below:

DO_NOT_USE Never set, not used at the moment.

NONLINEAR Set if the derived non-linearity correction at the computed saturation level is large, i.e. if $F_c/F - 1 > 0.5$ for any value F below saturation level.

NO_LIN_CORR Set if the coefficients could not be determined, e.g. due to a too low dynamic range of the pixel (last group in illuminated exposure below 10,000 DN). This is for example true for all reference pixels. It is also set if the polynomial fit to the data is poor, i.e. the χ^2 of the fit is greater than the average plus five times the standard deviation of the χ^2 for all pixels fitted. In both cases, the linearity correction coefficients are set to $c_1 = 1$ and $c_{0,2...4} = 0$, and therefore $F_c = F$ for these pixels.

The algorithms to create the data quality bits for the saturation reference files that are given in Table 4 are described below:

DO_NOT_USE Never set, not used at the moment.

NO_SAT_CHECK Set if no reliable saturation limit could be determined. This is the case for low dynamic range pixels and reference pixels that never reach 10,000 DN above bias level in the illuminated exposures. For these pixels, the value in the `SCI` extension of the saturation check will be equal to 65,535.

4 DELIVERED REFERENCE FILES

In this section we list the delivered linearity correction reference files. The reference files are derived from data taken at the Goddard Detector Characterization Lab (DCL) during FPA106 characterization in Summer 2014.

Tables 5 and 6 list the reference files provided in this delivery. There are files for two FPA temperatures (FPA at 38.5 K and FPA at 42.8 K). The reference data is independent of the readout mode (traditional or IRS^2) used. For this delivery, the `SUBARRAY` keyword is set to `GENERIC` and thus for subarrays the reference data can be cut out of the full frame files. This will likely change in the future and there will be dedicated files for subarray data, due to the different gain for subarrays that is to be implemented for OTIS testing and in flight operations.

File name	USEAFTER	Comment
nirspec_linc_nrs1_f_04.00.fits	2000-01-01T00:00:00	FPA106 DCL data at 38.5 K
nirspec_linc_nrs2_f_04.00.fits	2000-01-01T00:00:00	FPA106 DCL data at 38.5 K
nirspec_linc_nrs1_f_04.01.fits	2016-01-15T00:00:00	FPA106 DCL data at 42.8 K
nirspec_linc_nrs2_f_04.01.fits	2016-01-15T00:00:00	FPA106 DCL data at 42.8 K

Table 5: List of the delivered non-linearity correction reference files.

File name	USEAFTER	Comment
nirspec_satc_nrs1_f_02.00.fits	2000-01-01T00:00:00	FPA106 DCL data at 38.5 K
nirspec_satc_nrs2_f_02.00.fits	2000-01-01T00:00:00	FPA106 DCL data at 38.5 K
nirspec_satc_nrs1_f_02.01.fits	2016-01-15T00:00:00	FPA106 DCL data at 42.8 K
nirspec_satc_nrs2_f_02.01.fits	2016-01-15T00:00:00	FPA106 DCL data at 42.8 K

Table 6: List of the delivered saturation reference files.

Each reference file has a `HISTORY` entry `DATA USED` that lists the JLAB ID and the JOB ID number for each file that was used in the creation of the reference file. For the DCL data used here the JLAB ID is `jlab81`.

5 PERFORMANCES

In this section we describe the performances of the delivered reference files, i.e. how the data looks like by means of images, histograms and statistics of bad pixels.

5.1 Saturation reference files

The saturation maps in the delivered reference files are shown in figures 1 through 4 and the histograms of their values in figures 5 and 6. As per requirement, the delivered saturation reference files contain the saturation level before bias subtraction. Since the conversion gain is only about 1 e^{-}/DN the ADC limit of 65,535 DN is reached before physical saturation in the pixel occurs. Therefore, and due to the way the saturation thresholds are computed from the linearity correction fit (see section 3.1 above), the maps are all below but close to 65,535 DN. The four science outputs can have different pedestals due to the reference pixel correction, which is performed per output, and hence the different peaks in figures 5 and 6.

The true dynamic range of the detectors is the difference between the saturation reference file and the bias level. Images and histograms of the dynamic range are presented in figures 7 through 10 and 11 and 12, respectively. These were computed by subtracting the appropriate bias frame (Birkmann 2016) and then multiplying the difference by the conversion gain in order to go from DN to electrons. Because the dynamic range governed by the gap between the bias level and the ADC range, it basically looks like an inverted bias frame and the true physical well depth of the pixels is not traced.

Table 7 below list the number of pixels that were marked as having no saturation check data available due to their low dynamic range, e.g. reference pixels. For those pixels, the saturation threshold is set to 65,535 DN, the ADC limit.

File name	NO_SAT_CHECK
nirspec_satc_nrs1_f_02.00.fits	41210
nirspec_satc_nrs1_f_02.01.fits	41351
nirspec_satc_nrs2_f_02.00.fits	37462
nirspec_satc_nrs2_f_02.01.fits	37478

Table 7: Number of pixels that were marked as having no saturation check data available. This includes the 32,704 reference pixels in the four top/bottom rows and left/right columns.

5.2 Linearity correction reference files

This histograms of the polynomial coefficients of the delivered linearity correction reference files are shown in figures 13 through 16 and the number and type of bad pixels in the reference files are listed in table 8 below.

File name	NONLINEAR	NO_LIN_CORR
nirspec_linc_nrs1_f_04.00.fits	2528	46089
nirspec_linc_nrs1_f_04.01.fits	2634	46286
nirspec_linc_nrs2_f_04.00.fits	881	42725
nirspec_linc_nrs2_f_04.01.fits	907	42437

Table 8: Number of pixels in the delivered non-linearity correction reference files that either are highly non-linear and/or have no correction at all. The latter is for example true for all reference pixels.

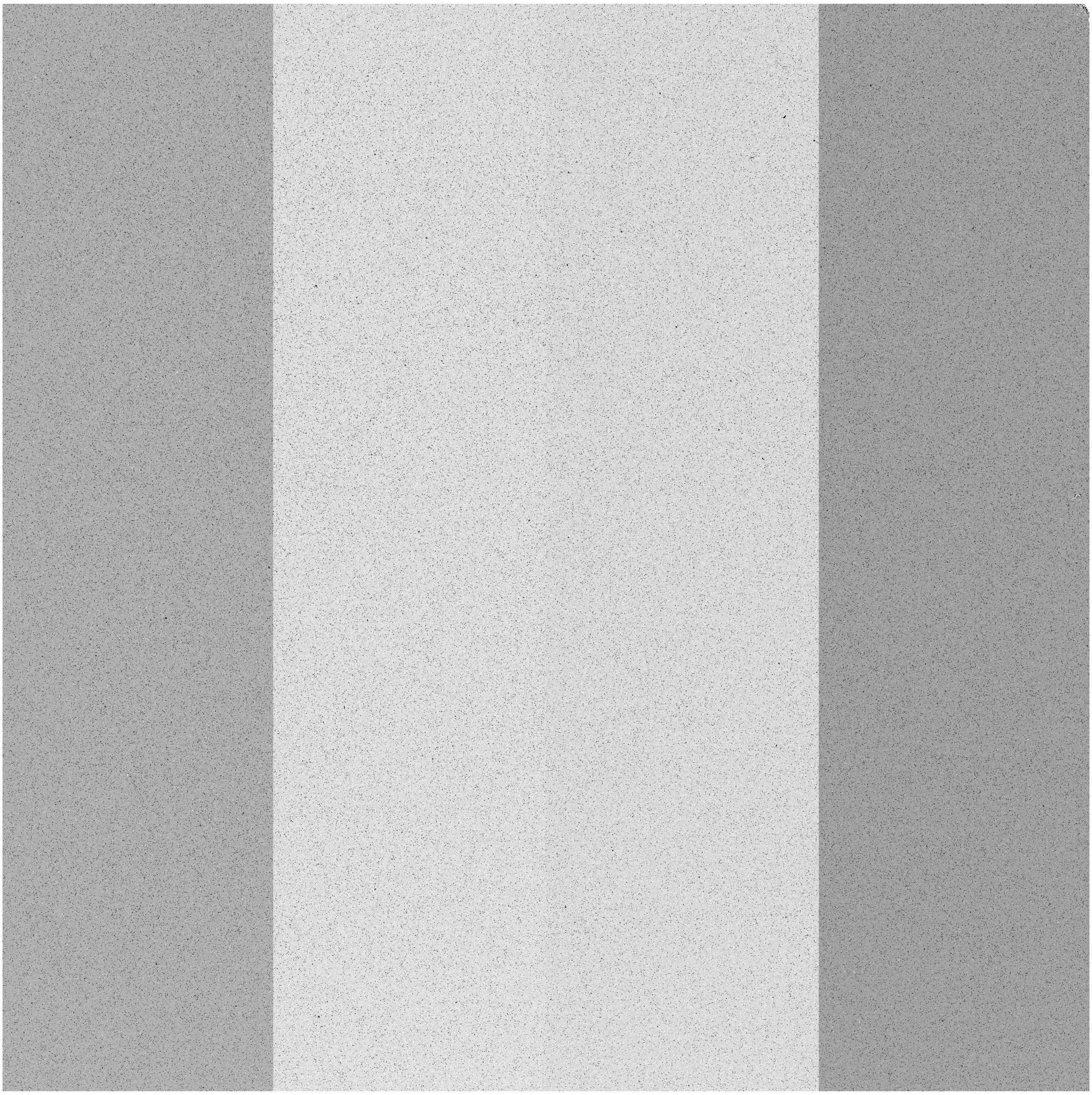

Figure 1: Map of the delivered saturation reference file nirspec_satc_nrs1_f_02.00.fits. The grey scale is linear from 60,000 DN (black) to 65,535 DN (white).

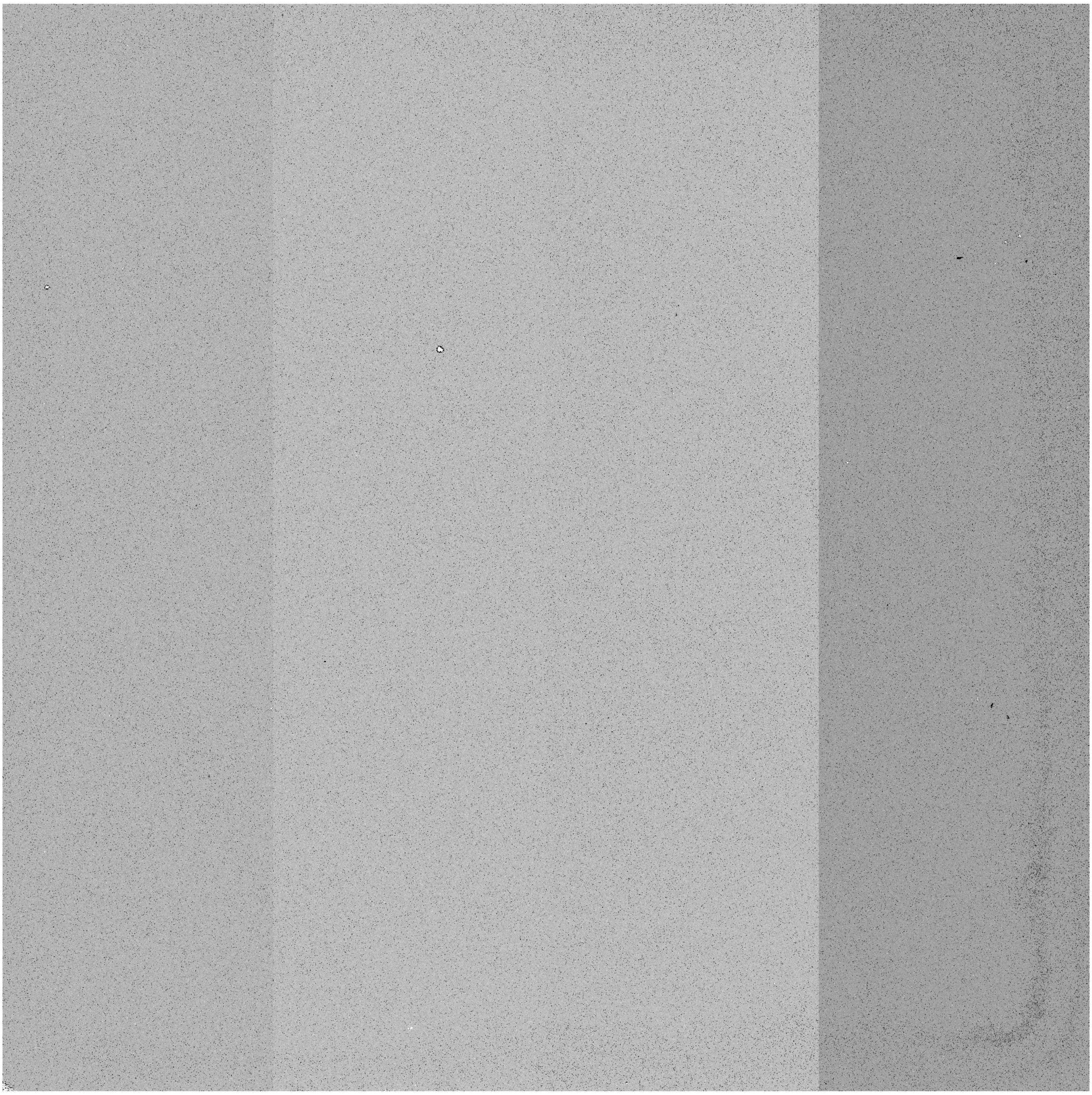

Figure 2: Map of the delivered saturation reference file nirspec_satc_nrs2_f_02.00.fits. The grey scale is linear from 60,000 DN (black) to 65,535 DN (white).

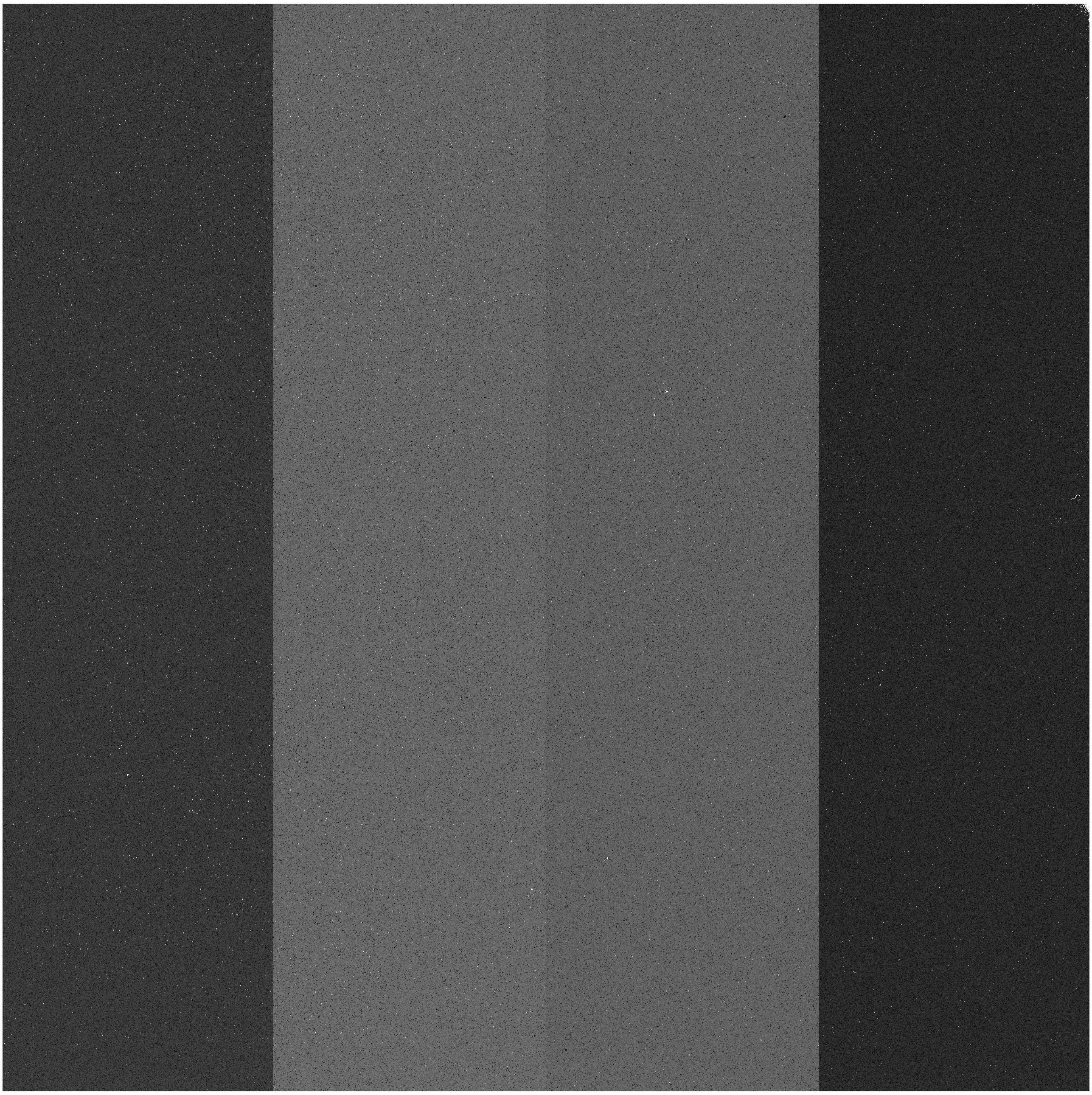

Figure 3: Map of the delivered saturation reference file nirspec_satc_nrs1_f_02.01.fits. The grey scale is linear from 60,000 DN (black) to 65,535 DN (white).

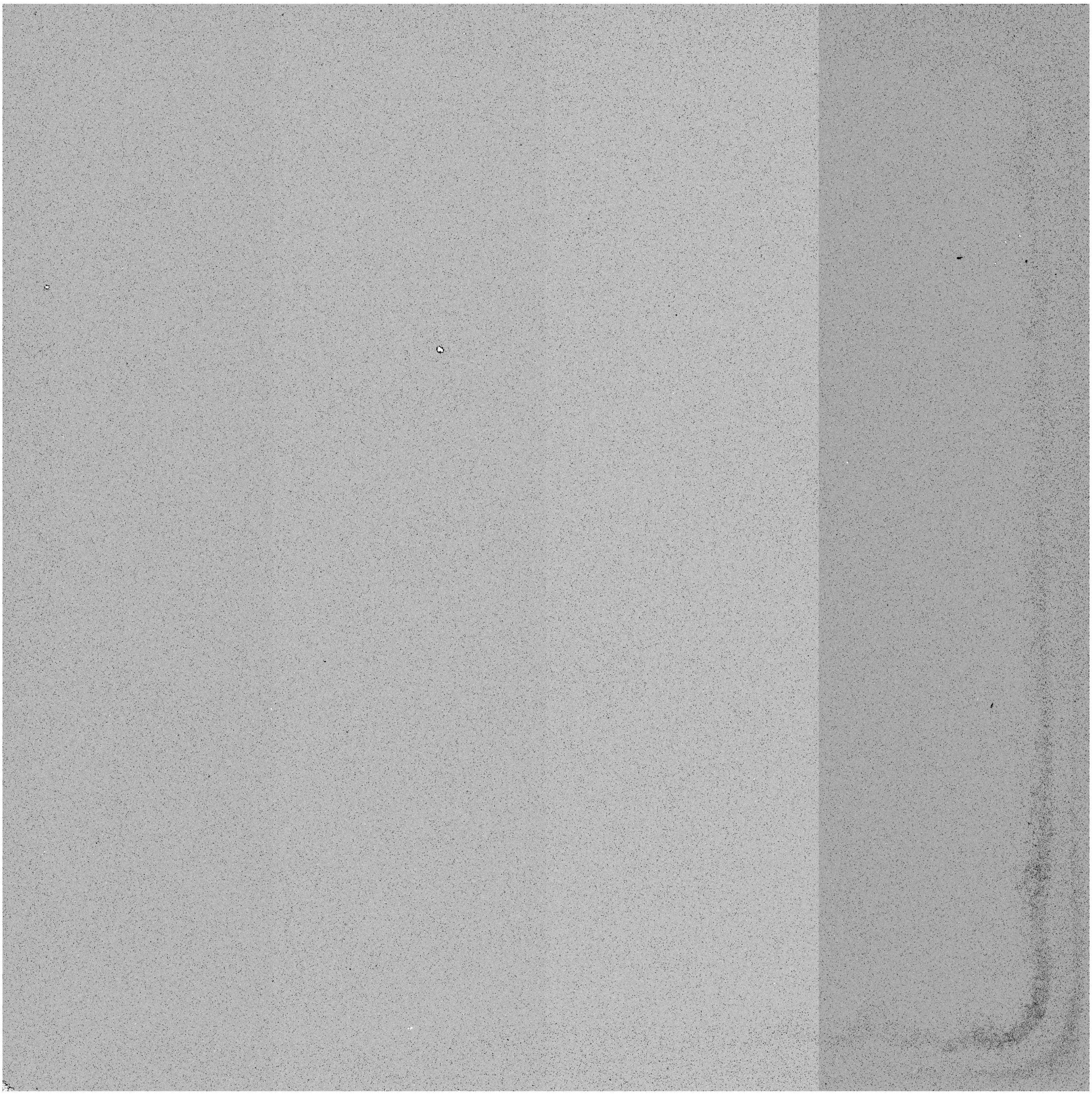

Figure 4: Map of the delivered saturation reference file nirspec_satc_nrs2_f_02.01.fits. The grey scale is linear from 60,000 DN (black) to 65,535 DN (white).

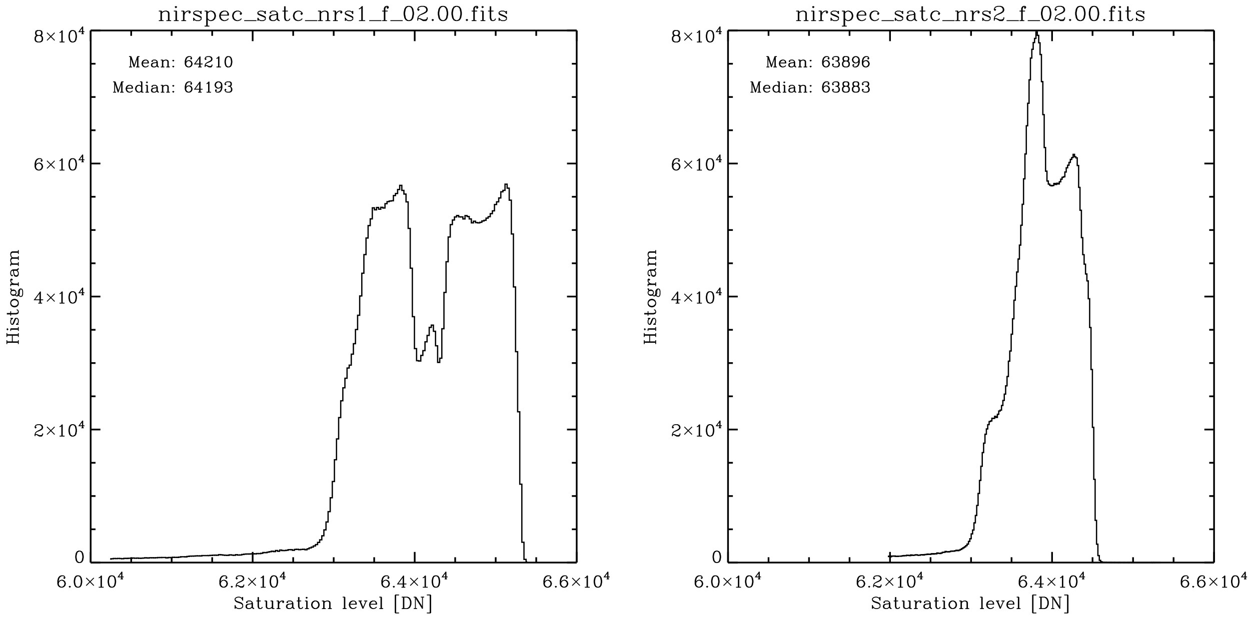

Figure 5: Histograms of the saturation levels in reference file nirspec_satc_nrs1_f_02.00.fits (left) and nirspec_satc_nrs2_f_02.00.fits (right). The peaks are due to the four detector outputs and their slightly different (because independent) pedestals.

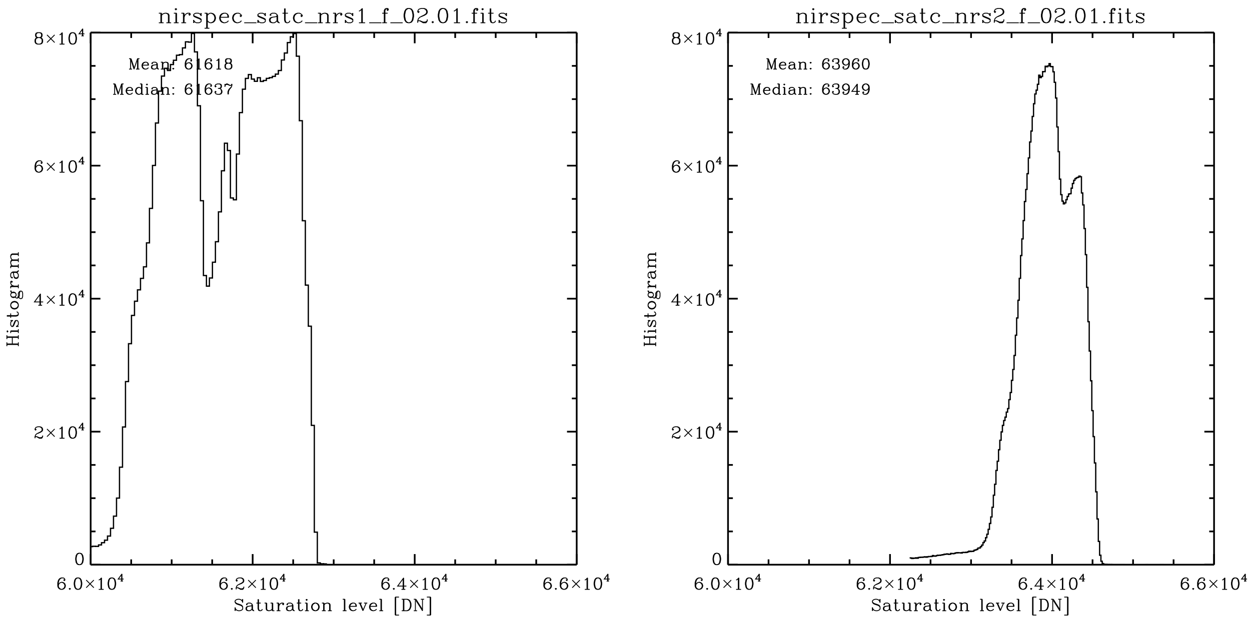

Figure 6: Histograms of the saturation levels in reference file nirspec_satc_nrs1_f_02.01.fits (left) and nirspec_satc_nrs2_f_02.01.fits (right). The peaks are due to the four detector outputs and their slightly different (because independent) pedestals.

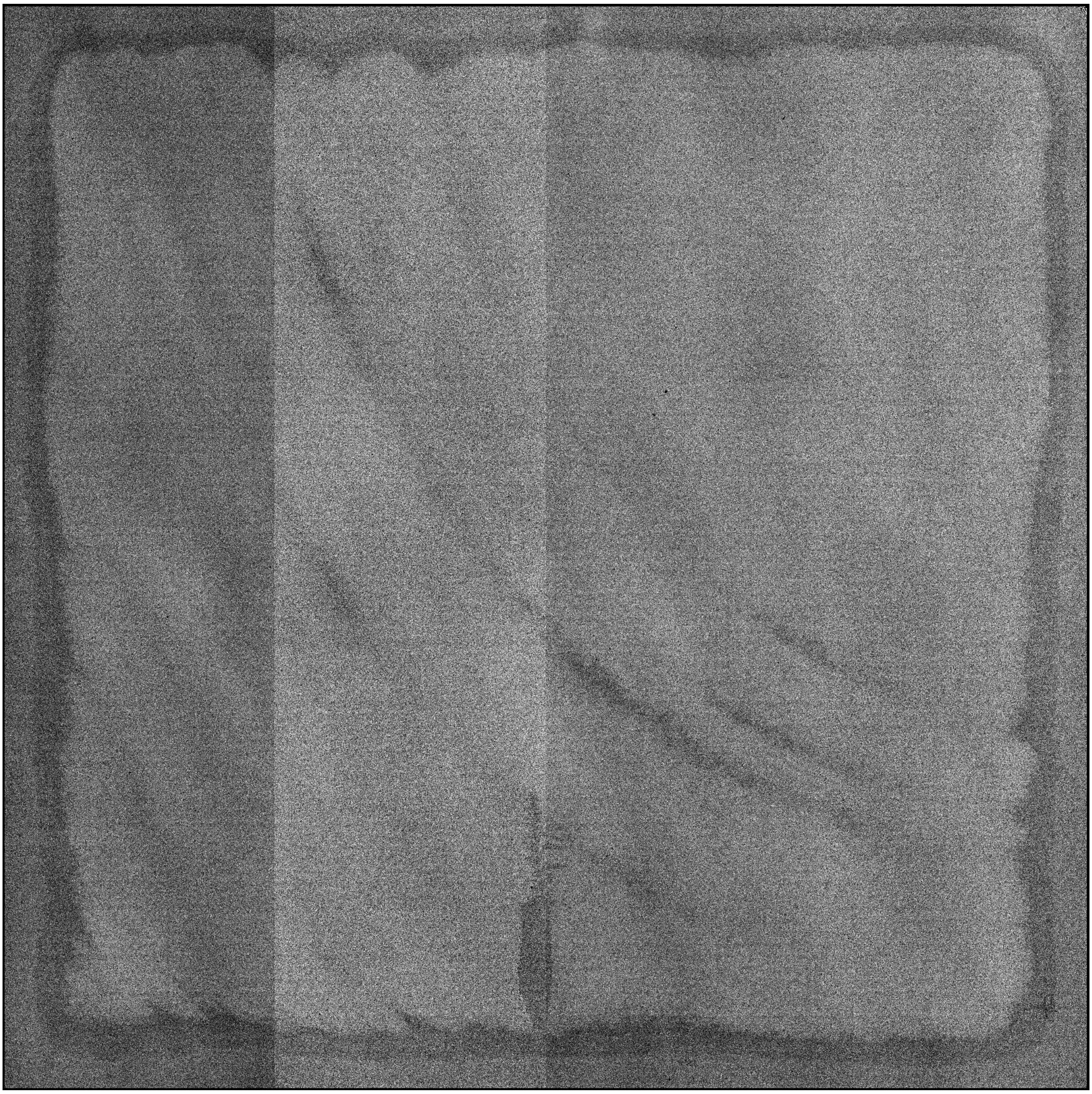

Figure 7: Map of the dynamic range for NRS1 at 38.5 K derived from the reference files delivered saturation reference files nirspec_satc_nrs1_f_02.00.fits, nirspec_bias_nrs1_f_09.00.fits and nirspec_gain_nrs1_f_02.00.fits. The grey scale is linear from 50,000 DN (black) to 65,000 electrons (white).

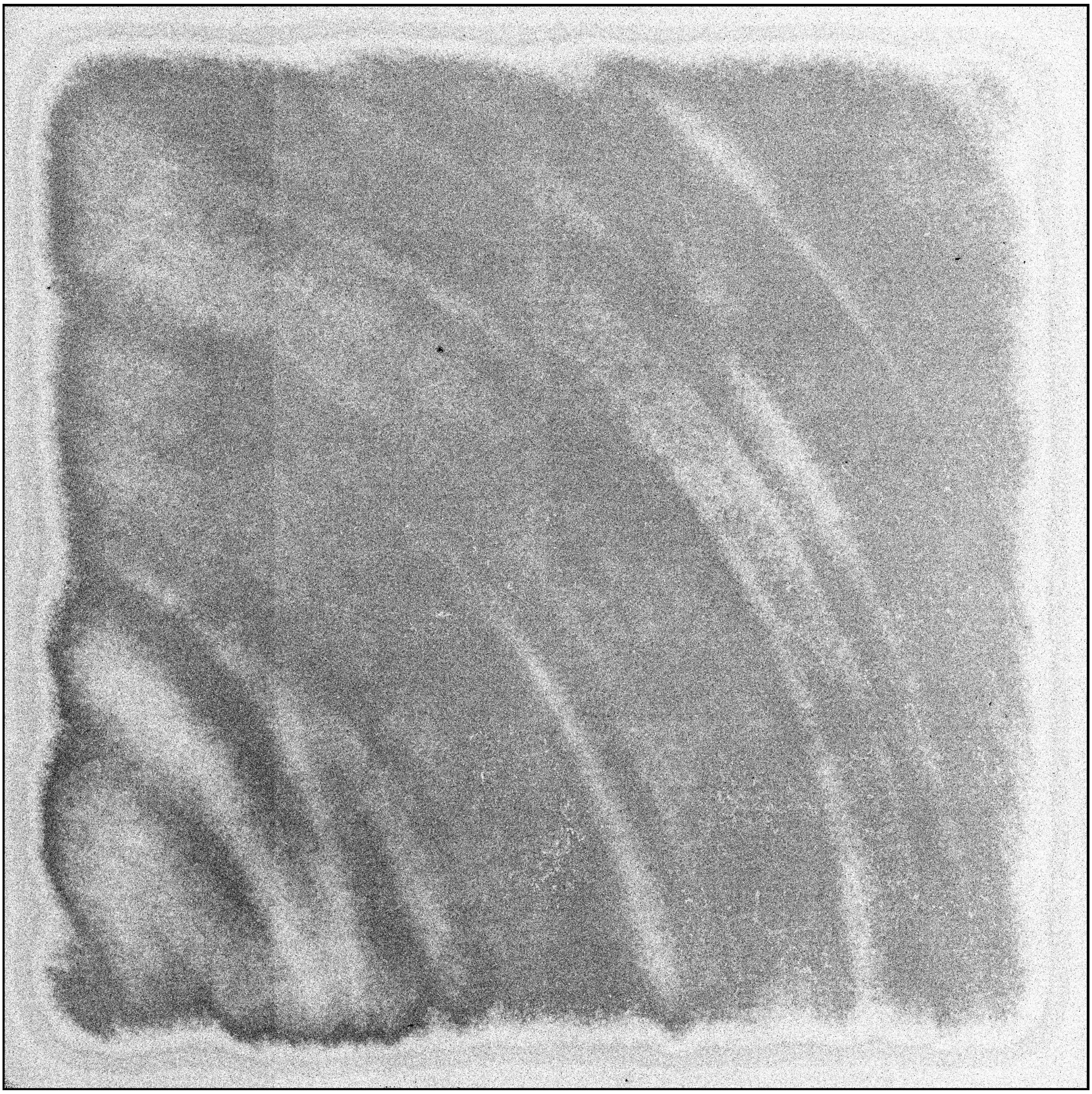

Figure 8: Map of the dynamic range for NRS2 at 38.5 K derived from the reference files delivered saturation reference files nirspec_satc_nrs2_f_02.00.fits, nirspec_bias_nrs2_f_09.00.fits and nirspec_gain_nrs2_f_02.00.fits. The grey scale is linear from 50,000 DN (black) to 65,000 electrons (white).

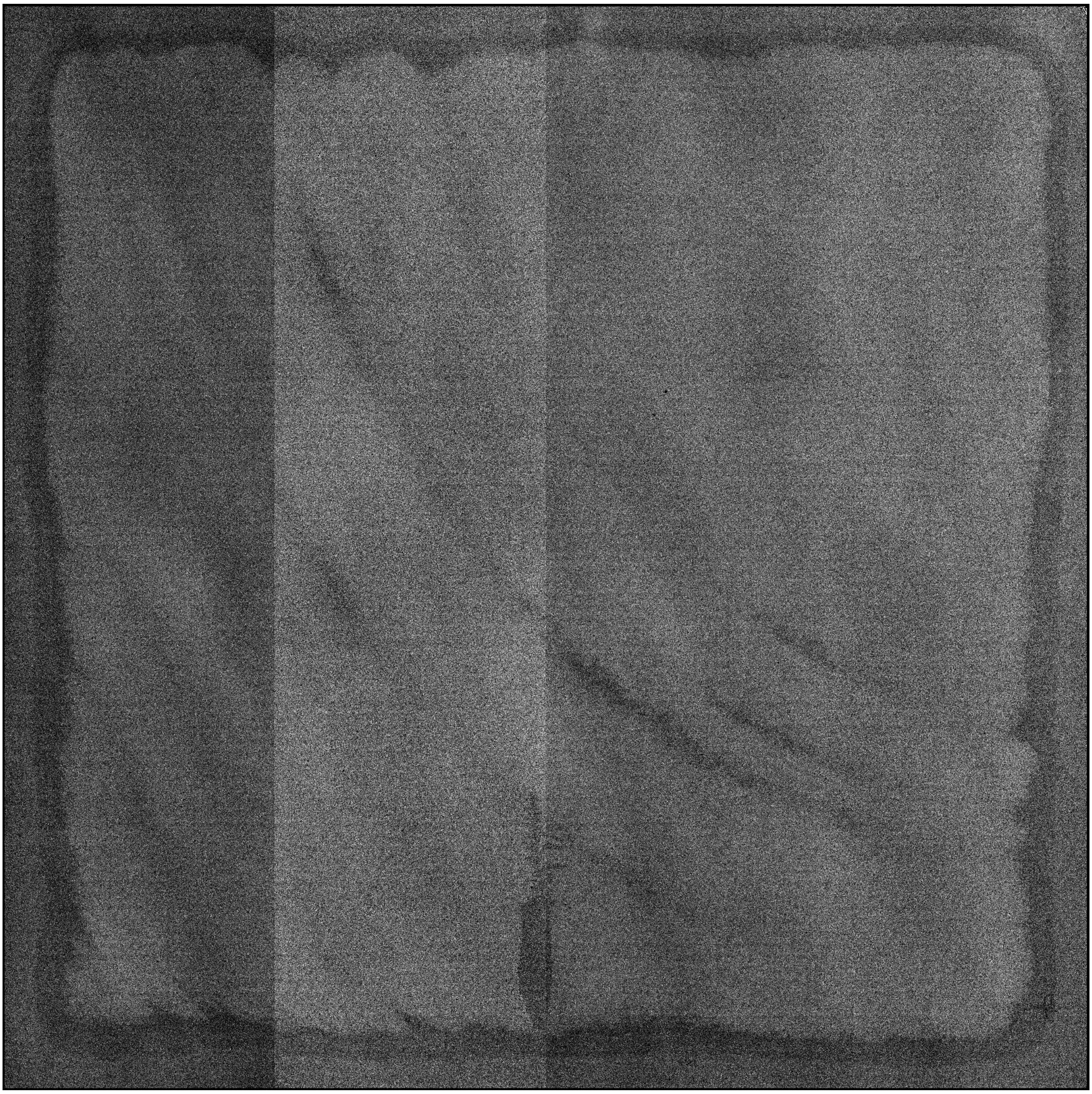

Figure 9: Map of the dynamic range for NRS1 at 42.8 K derived from the reference files delivered saturation reference files nirspec_satc_nrs1_f_02.01.fits, nirspec_bias_nrs1_f_09.01.fits and nirspec_gain_nrs1_f_02.00.fits. The grey scale is linear from 50,000 DN (black) to 65,000 electrons (white).

Figure 10: Map of the dynamic range for NRS1 at 42.8 K derived from the reference files delivered saturation reference files nirspec_satc_nrs2_f_02.01.fits, nirspec_bias_nrs2_f_09.01.fits and nirspec_gain_nrs2_f_02.00.fits. The grey scale is linear from 50,000 DN (black) to 65,000 electrons (white).

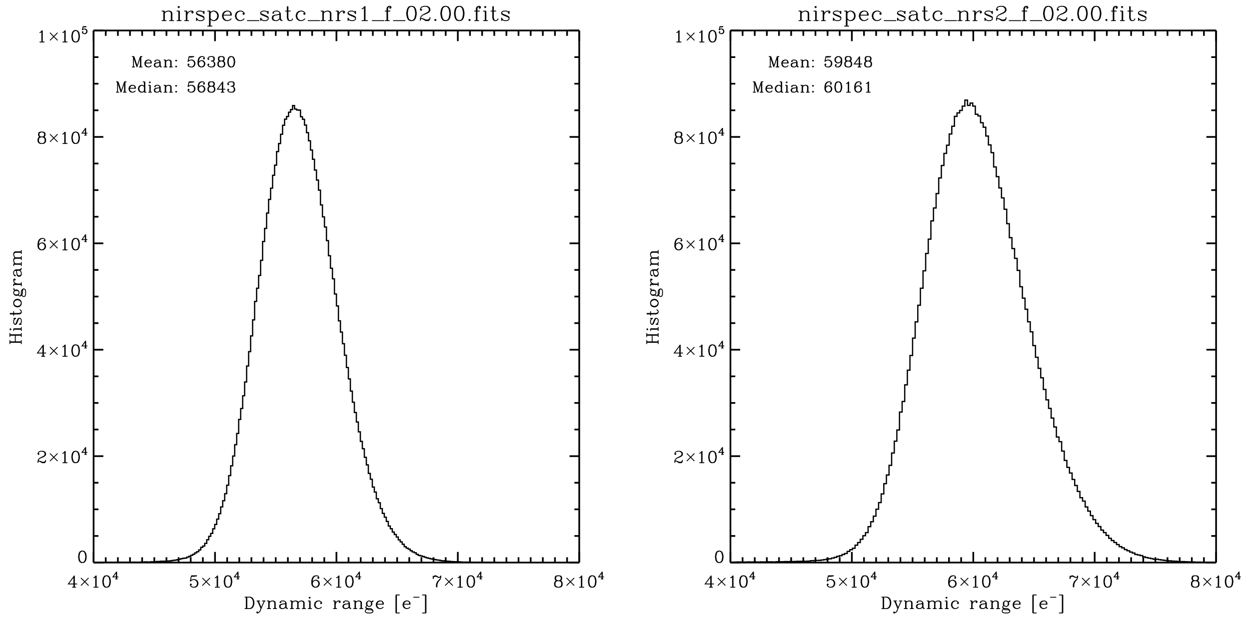

Figure 11: Histograms of the dynamic range for detectors NRS1 and NRS2 at 38.5 K, based on the reference files nirspec_satc_nrs1_f_02.00.fits, nirspec_bias_nrs1_f_09.00.fits and nirspec_gain_nrs1_f_02.00.fits (left) and nirspec_satc_nrs2_f_02.00.fits, nirspec_bias_nrs2_f_09.00.fits and nirspec_gain_nrs2_f_02.00.fits (right).

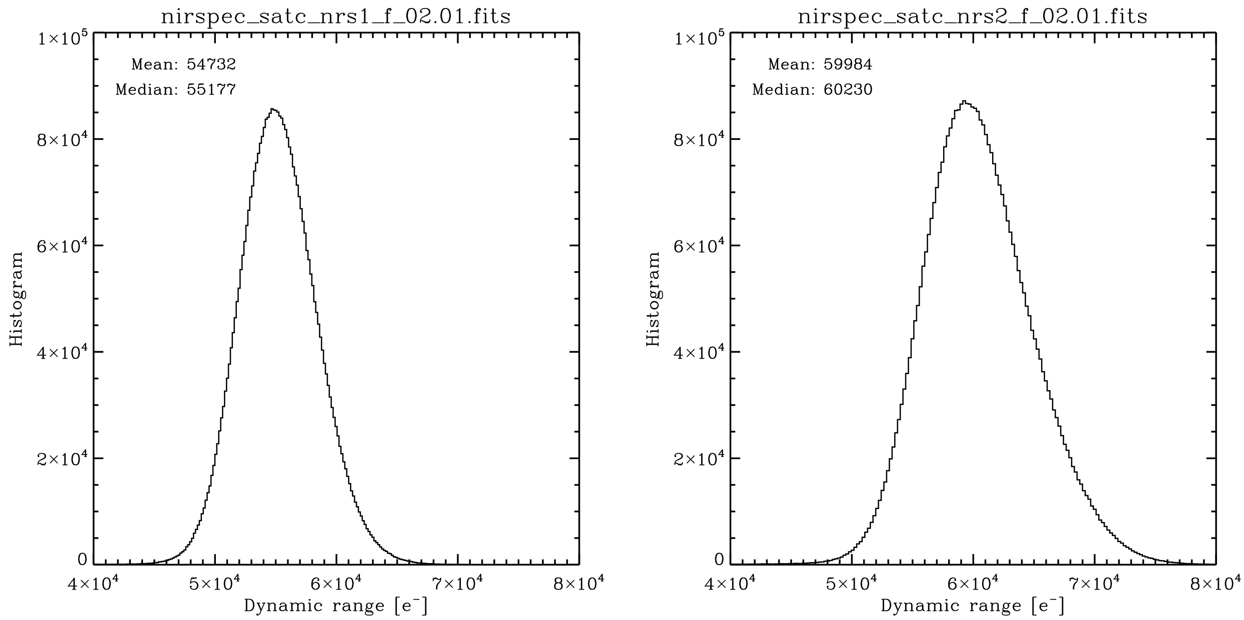

Figure 12: Histograms of the dynamic range for detectors NRS1 and NRS2 at 42.8 K, based on the reference files nirspec_satc_nrs1_f_02.01.fits, nirspec_bias_nrs1_f_09.01.fits and nirspec_gain_nrs1_f_02.00.fits (left) and nirspec_satc_nrs2_f_02.01.fits, nirspec_bias_nrs2_f_09.01.fits and nirspec_gain_nrs2_f_02.00.fits (right).

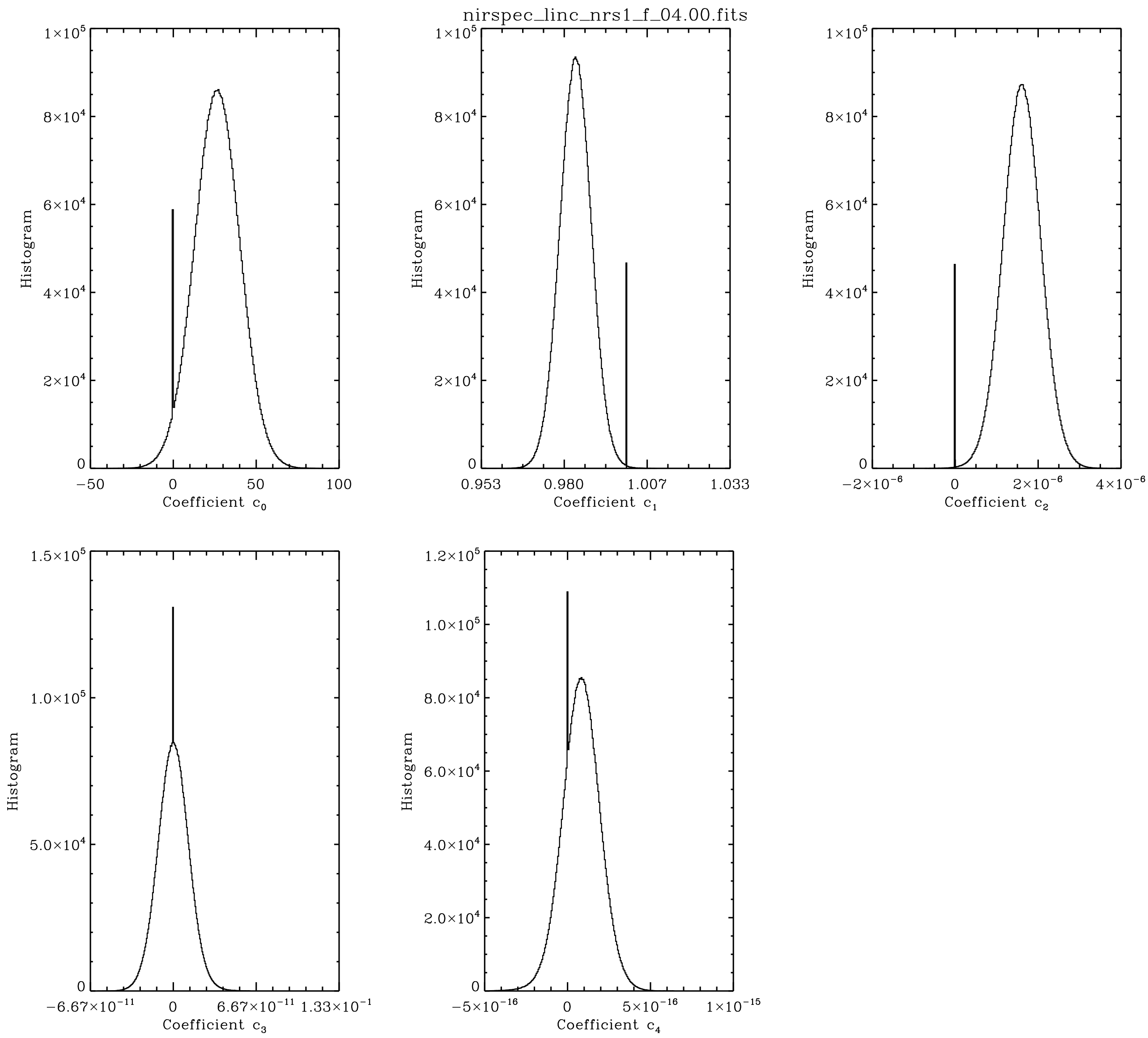

Figure 13: Histograms of the non-linearity correction coefficients for reference file nirspec_linc_nrs1_f_04.00.fits. The peaks at zero for $c_{0,2,3,4}$ and at 1 for c_1 are due to pixels that do not have a non-linearity correction established, e.g. the reference pixels.

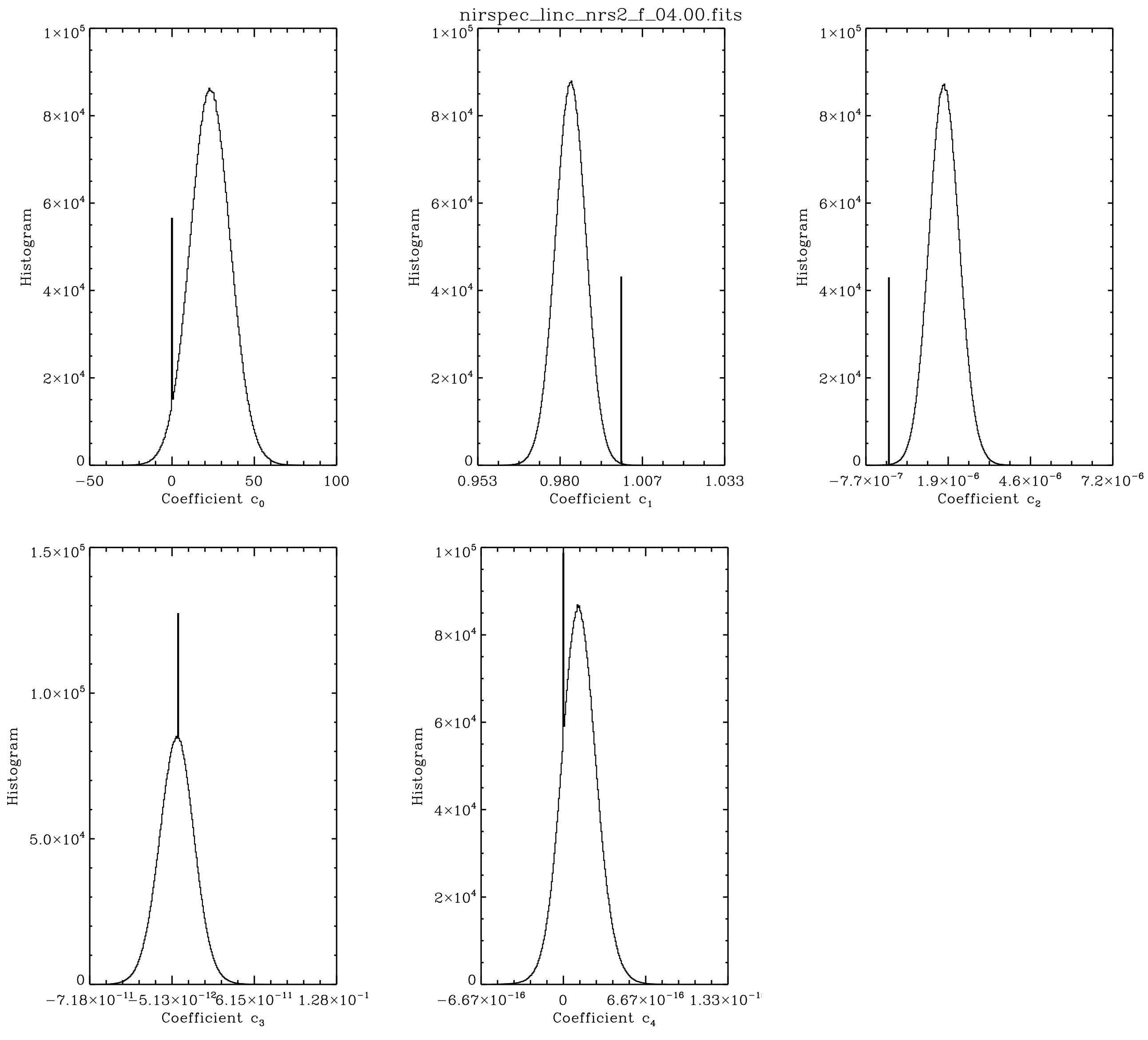

Figure 14: Histograms of the non-linearity correction coefficients for reference file nirspec_linc_nrs2_f_04.00.fits. The peaks at zero for $c_{0,2,3,4}$ and at 1 for c_1 are due to pixels that do not have a non-linearity correction established, e.g. the reference pixels.

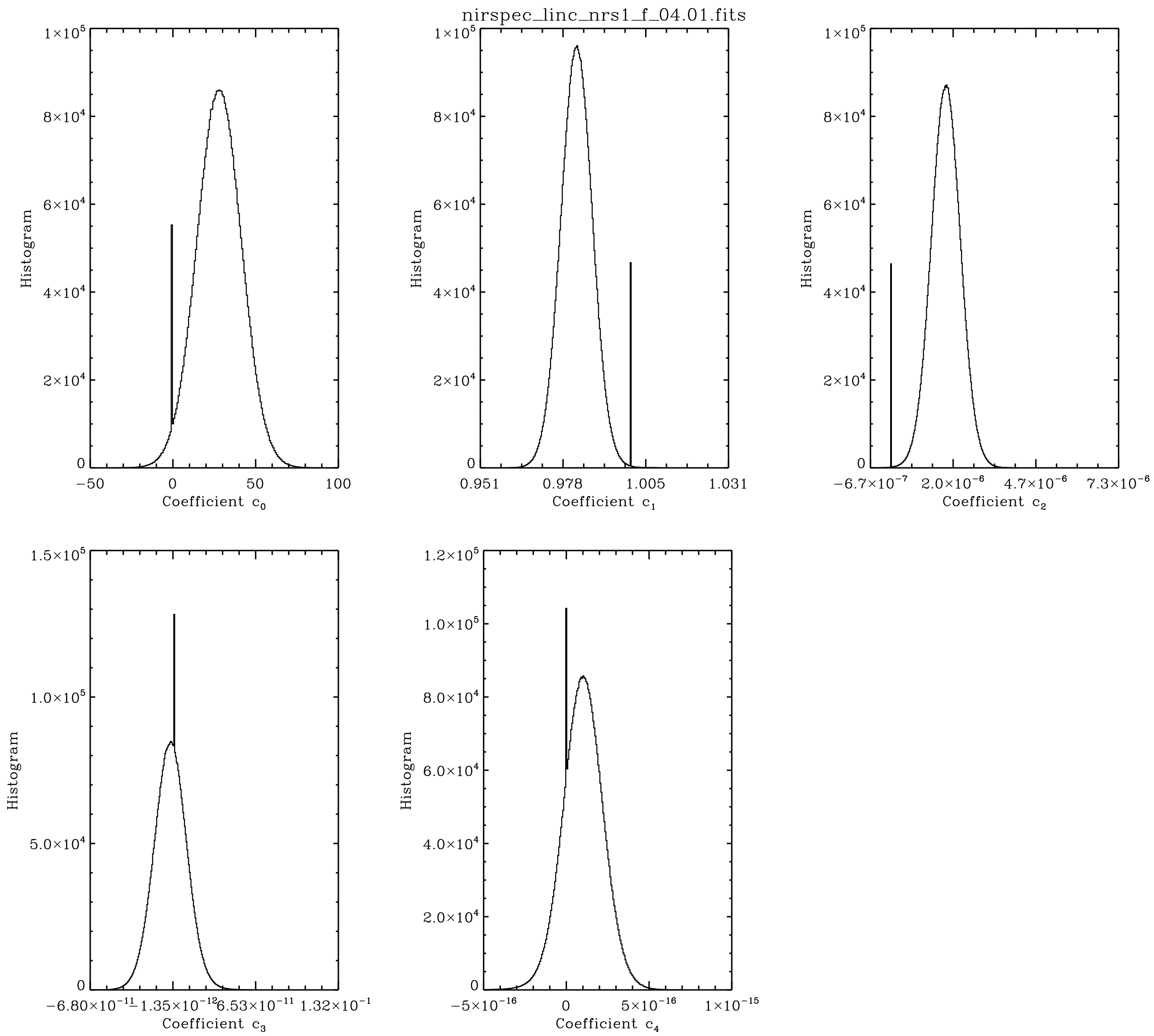

Figure 15: Histograms of the non-linearity correction coefficients for reference file nirspec_linc_nrs1_f_04.01.fits. The peaks at zero for $c_{0,2,3,4}$ and at 1 for c_1 are due to pixels that do not have a non-linearity correction established, e.g. the reference pixels.

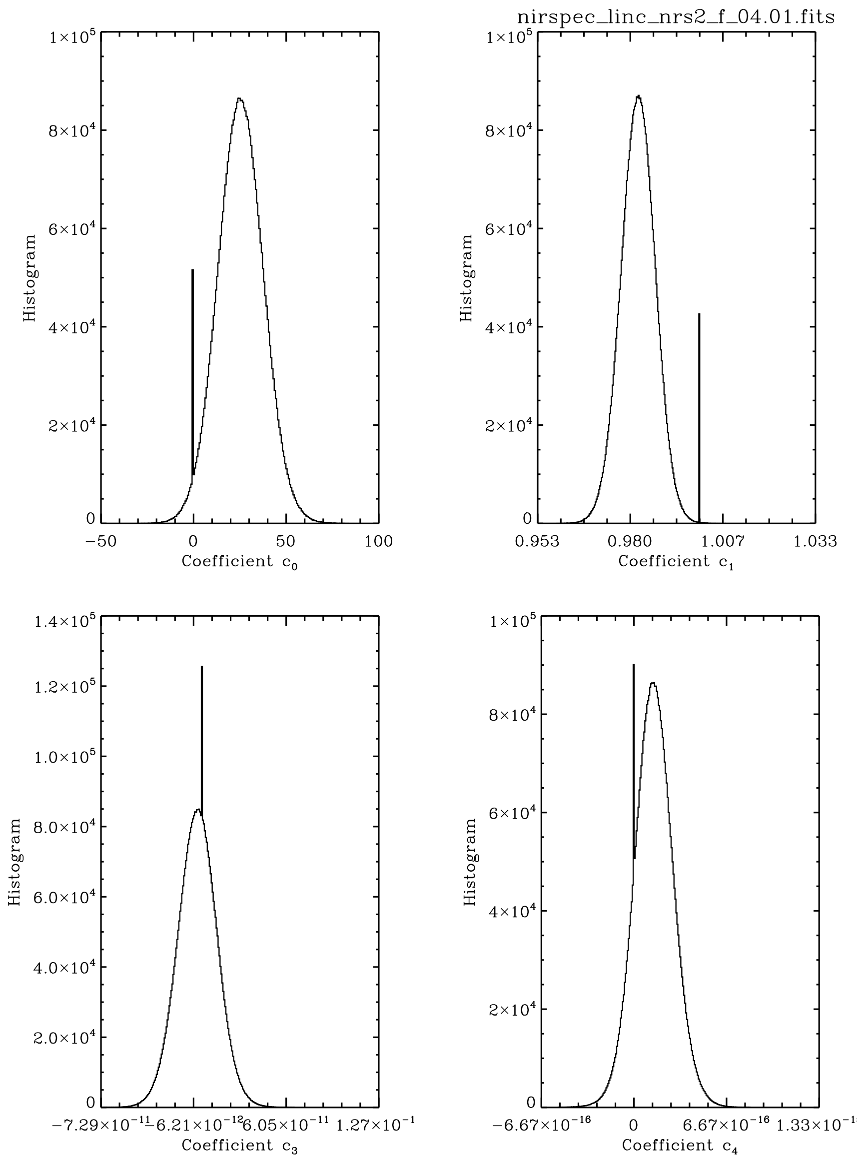

Figure 16: Histograms of the non-linearity correction coefficients for reference file nirspec_linc_nrs2_f_04.01.fits. The peaks at zero for $c_{0,2,3,4}$ and at 1 for c_1 are due to pixels that do not have a non-linearity correction established, e.g. the reference pixels.

The histograms show a gaussian distribution for all coefficients for both detectors. The coefficient maps look basically like white noise, i.e. there seems to be no clear spatial dependence of the non-linearity correction coefficients. Therefore, those maps are not shown here.

6 ACQUISITION OF REFERENCE FILES DURING COMMISSIONING

It is not planned to acquire data during commissioning to re-generate saturation reference files or non-linearity correction files, because the FPA cannot be illuminated homogeneously enough once installed in the instrument. Therefore it is not possible to acquire the data that would be necessary to generate saturation and non-linearity correction files for all pixels in orbit. We can, however, take data to check the saturation levels and linearity for some pixels. Data of this kind will be taken early during commissioning in CAR NIRSpec-003 (SCA+ASIC tuning verification). In general, many of the exposures taken with internal illumination during in-orbit commissioning can be used for this purpose. In case the data will be available in the same format as produced by the fitswriter used for ground testing, it is estimated that basics checks of the existing saturation and non-linearity correction reference files can be done within one week of data availability.

7 REFERENCES

Birkmann, S. 2016, NIRSpec Bias and Dark Reference Files for Build 7, NIRSpec Technical Note ESA-JWST-SCI-NRS-TN-2016-003, ESA

Dixon, V. 2016, JWST Calibration Reference Files: File Formats for the Build 6 Pipeline (24 Feb 2016), https://confluence.stsci.edu/x/gZOeAw, STScI

Giardino, G. 2013, NIRSpec reference data product specification, NIRSpec Technical Note NTN-2013-007, ESA/ESTEC

Hanisch, R. J., Farris, A., Greisen, E. W., et al. 2001, Astronomy & Astrophysics, 376, 359