



NIRSpec Technical Note
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Data product specification of NIRSpec reference files

Abstract:

This document provides an overview of the structure and content of the reference files that are needed to derive count-rate images from NIRSpec raw data cubes – an operation often referred to as ‘ramps-to-slopes’ processing. In addition, an introduction to the flat-field reference files that are needed for the reduction of NIRSpec spectral data is also given.

Change Log:

Version	Date	Description
1.0	Nov. 4, 2013	Initial version for Build 2 of STScI pipeline
2.0	Nov. 18, 2014	Updated to reflect changes in reference files for Build 3 pipeline

1 INTRODUCTION

As described in De Marchi & Boeker (2005), the process of calibrating and correcting NIRSpec raw data to high quality science products requires a set of reference files.

This document specifies the format and content of the calibration reference files needed to derive count rate images from NIRSpec raw data cubes and of the flat-field reference files necessary for the reduction of spectral data. All reference file use the FITS file format (Hanisch et al. 2001) and in this document we describe the format details and the required keywords which are common to all the files. Additionally, for each reference file, a specific document describing the algorithm and the data used to generate the content of that file is also available. File specific keywords will be listed in these documents.

For all reference files, the primary header-data unit (HDU) contains only the header structure, or in other words, the primary data unit is always empty. The primary header contains all keywords not specific to individual extensions. Reference data are contained in image or

table extensions. Keywords specific to a particular extension are contained in the header of that extension.

STScI is the institute responsible for implementing the JWST data-reduction pipeline common to all four JWST instruments. The types of reference files to be delivered to STScI and to be used by its ramps-to-slopes pipeline (Level2A) and spectroscopic and imaging pipeline (Level2B) are (STScI 2013):

- an inter-pixel capacitance (IPC) correction kernel
- a (static) bad pixel mask
- a map of saturation levels
- a linearity correction file
- a high signal-to-noise dark current data cube (or super-dark cube)
- a detector gain map
- a read-noise map
- the flat fielding correction

The data reduction pipeline developed by ESA JWST science operation team (SOT) includes a few extra reduction steps – see Birkmann (2011) – which require the following additional reference files:

- a high signal-to-noise bias image (or ‘super’ bias)
- a weighting function for the subtraction of reference pixel in Fourier space

Additionally, to keep track of the inputs to the static bad pixel mask we generate also reference (binary) images for each type of bad pixels. These are: dead/shorted pixel mask, open pixel mask, adjacent-to-open pixel mask, and low quantum-efficiency (QE) pixel mask. The format and content of all these reference files are described in this document.

The document is organized as follow: Sect. 2 outlines the files naming convention, Sect. 3 describe the formats common to all reference files, listing all the necessary common keywords and Sect. 4 provides a general description of each type of reference files.

2 FILE NAMING CONVENTION

The NIRSpec reference files for the Level 2A pipeline will be named according to the following scheme¹:

`nirspec_type_detector_(readout)_mode_(window_type)_version`

¹Reference files for the spectroscopic and imaging pipeline (Level2B) follow a different scheme

where valid strings are defined in the Table 1. The readout specification is indicated in parenthesis because in case of standard readout it is omitted and the `window_type` string only needs to be specified for ‘window’ or ‘stripe’ mode. Examples of reference file names are the following:

- `nirspec_mask_nirs1_f_01.00.fits`: static bad pixel mask for NIRSpec detector 1, i.e. SCA491, standard readout, full frame, version 1.0
- `nirspec_bias_nirs1_irs2_f_01.00.fits`: super-bias image for NIRSpec detector 1, i.e. SCA491, IRS2 readout scheme, full frame, version 1.0
- `nirspec_bias_nirs2_w_S200A1_G1H_01.01.fits`: super-bias image for NIRSpec detector 2, i.e. SCA492, standard readout, window frame of type A1_G1H (i.e. slit A1, grating band 1 high resolution), version 1.1
- `nirspec_drkc_nirs2_w_S200ALLSLITS_P_01.01.fits`: super-dark cube for NIRSpec detector 2, i.e. SCA492, standard readout, window frame of type ALLSLITS_P (i.e. all fixed slits, prism), version 1.1

3 COMMON FORMATS FOR ALL REFERENCE FILES

In Table 2 the (required) keywords present in the primary header of each reference files of Level 2A (ramps-to-slopes) are listed. Note that these are the same keyword listed in document STScI (2013). The additional keywords required for the reference files for Level 2B of the pipeline are listed in Table 3. A listing of the pipeline steps where each reference file is used by STScI Level2A pipeline is provided in Table 5 of STScI (2013).

When processing NIRSpec data, important keywords for the selection of the correct reference file are the `DETECTOR` keyword which discriminates between the two NIRSpec detector arrays, the `USEAFTER` keyword indicating the date and time after which this particular version of a reference file should be used and the 4 keywords `SUBSTR1`, `SUBSTR2`, `SUBSIZE1`, and `SUBSIZE2` defining the detector area to which a reference file applies – see Boeker (2012) for the definition of NIRSpec detector coordinates. Additionally the `REFTYPE` keyword (also in the primary header) is the keyword which allows the type of reference file to be identified. The value of this keyword for the different types of reference files is specified in section 4.

Table 1: Naming convention for NIRSpec reference files

type	
dead	Dead/shorted pixels mask
open	Open pixels mask
opad	Adjacent to open pixels mask
lowq	Low QE pixel mask
mask	Input bad pixel mask (includes: dead, open, opad, lowq)
satc	Saturation levels
bias	Super Bias image
fftr	Reference pixel weighting function (in Fourier space)
ipcc	IPC correction kernel(s)
linc	Linearity correction coefficients
drkc	Super Dark cube
gain	Gain map
rdns	Read-noise map
flat	Flat field
detector	
nirs1	SCA491
nirs2	SCA492
readout	
(omitted)	standard readout
irs2	IRS2 readout scheme
mode	
f	Full frame
w	Window
s	Stripe
window type	
ALLSLITS	
S200A1_ <i>dbr</i>	Where <i>dbr</i> stands for:
S200A2_ <i>dbr</i>	d = disperser (values: G for grating, M for mirror, P for prism)
S200B1_ <i>dbr</i>	b = band (values: 1, 2, 3)
S400A_ <i>dbr</i>	r = resolution (values: M for medium, H for high)
S1600A1_ <i>dbr</i>	
version	
v.s	version and subversion 2 digit number (v= 01 – 99 and s= 00 – 99)

Table 2: Required keywords for the primary header of all reference files. The comment provides explanation on how the value of a keyword should be filled.

Keywords	Comment
DESCRIP	'Ground-based flat field for XXX mode'
AUTHOR	Person(s) who created the file
PEDIGREE	Options are:
	'GROUND'
	'DUMMY'
	'INFLIGHT YYYY-MM-DD YYYY-MM-DD'
TELESCOP	'JWST'
INSTRUME	NIRSPEC
DETECTOR	Allowed values: 'NRS1' or 'NRS2'
READPATT	Allowed values: 'NRS', 'NRSRAPID', 'NRSN8R2', 'NRSN16R4', 'NRSN32R8'
SCA_ID	Allowed values: '491' or '492'
SUBARRAY	Allowed values: 'FULL', 'WINDOW' or 'STRIPE'
USEAFTER	YYYY-MM-DDThh:mm:ss
SUBSTR1	X-position of corner (column)
SUBSTR2	Y-position of corner (row)
SUBSIZE1	Number of columns
SUBSIZE2	Number of rows
REFTYPE	Type of reference file (values described in Sect. 4)
HISTORY	'Description of Reference File Creation'
HISTORY	DOCUMENT: Name of document describing the strategy and algorithms used to create file
HISTORY	SOFTWARE: Description, version number, location of software used to create file
HISTORY	DATA USED: Data used to create file
HISTORY	DIFFERENCES: How is this version different from the one that it replaces?

In addition, for the flat field reference file to be used by the Level 2B pipeline, the following observing-mode specific keywords are also required.

Table 3: Required keywords for the primary header of the reference files for Level 2B.

Keywords	Comment
FILTER	Filter wheel element: e.g. 'F100LP'
GRATING	Grating wheel element: e.g. 'G235M'

3.1 Quality Flags

Most of the reference file provide information about the quality of the reference value of each pixel in an image extension named DQ using bit-encoded flag values. Only the quality flags applicable to that reference file are included in the DQ array. The definition of the flag values are specified in a Binary Table extension named DQ_DEF; this Binary Table must be present in each reference file with a DQ extension.

4 TYPES OF REFERENCE FILES

4.1 Dead pixel mask

REFTYPE = 'DEAD'

The first (and only) FITS image extension of this file provides a binary mask of dead or shorted pixels, i.e. pixels that do not respond to light. Good pixels have value 0 and dead pixel have value 1.

Dead or shorted pixels are identified as those with response less than 0.05 times the local Quantum Efficiency (QE) calculated over a 15×15 -pixel box. This reference mask is not used directly by ESA processing pipeline nor by STScI pipeline, but it is used as an input to the program that builds the bad-pixel mask reference file – see Giardino & Sirianni (2013).

4.2 Open pixel mask

REFTYPE = 'OPEN'

The first (and only) FITS image extension of this file provides a binary mask of open pixels. Good pixels have value 0 and open pixel have value 1.

Pixels are considered open if the signal generated within this pixel is not correctly collected by the detector electronics but leaks into neighboring pixels, altering their values. Open pixels readings are therefore highly unreliable and cannot be used for science. A pixel is masked as

open if the pixels QE falls between 0.05 and 0.5 times the local median QE and the median of the four-neighbor pixels is greater than 1.05 the local median QE. This reference mask is not used directly by any of the data reduction pipelines, but it is used to generate the bad-pixel mask reference file – see Giardino & Sirianni (2013).

4.3 Adjacent-to-open pixel mask

REFTYPE = ‘OPAD’

The first (and only) FITS image extension of this file provides a binary mask of the eight neighbors of an open pixels. 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, however, they can be used to collect dark current statistics in dark exposures because in this case there is no signal incident on the central pixel.

This reference mask is not used directly by any of the data processing pipelines, but it is in an input of the bad-pixel mask reference file – see Giardino & Sirianni (2013).

4.4 Low QE pixel mask

REFTYPE = ‘LOWQ’

The first (and only) FITS image extension of this file provides a binary mask of pixels with low QE. A pixel is flagged as having low QE if it is not an open pixel and its QE falls between 0.05 and 0.5 times the local median QE. This reference mask is not used directly by any of the processing pipelines, but it is used to generate the the bad-pixel mask reference file – see Giardino & Sirianni (2013).

4.5 IPC correction

REFTYPE = ‘IPC’

The first (and only) FITS image extension of this file provides the 3x3-kernel for the Inter-Pixel Capacitance correction that can be, optionally, executed by the pre-processing pipeline during the computation of the count rate images. For each detector there are 4 different kernels (organized as a cube in the image extension), one for each detector output. For an explanation on how IPC correction can be applied to data of detectors similar to those of NIRSpec, see McCullough (2008).

4.6 Static Bad Pixel Mask

REFTYPE = ‘MASK’

The first FITS image extension of this file is a 16-bits map obtained by computing the flag value for each pixel according to its value in the binary masks of Dead, Low QE, Open, and Adjacent-to-Open pixels. The bit-encoded flag values are specified in the Binary Table extension DQ_DEF, using the following bits and values:

Bit	Value	Name	Description
0	1	DO_NOT_USE	Bad pixel. Do no use
1	2	OPEN	Open pixel
2	4	ADJ_OPEN	Adjacent-to-Open pixel
3	8	DEAD	Dead/unresponsive pixel
4	16	LOW_QE	Low quantum efficiency pixel

See Giardino & Sirianni (2013) for more details on format and content of this file.

4.7 Super-Bias

REFTYPE = 'BIAS'

This reference file comprises of three FITS image extensions: the first extensions containing the high signal-to-noise detector bias image in digital units (DN), the second extension containing the error for each pixel bias value (also in DN), and the third extension providing data quality information.

The bias image is the first group image taken in dark conditions and indeed in our case corresponds to the first group image of the super-dark cube. Note that to improve the statistical significance of this Bias image, the list of dark exposures used to produce the super-dark cube includes also a 100-integration (of 1 group each) dark exposure. The bias image is the average image of all these dark images and the error image (in the second FITS extension) provides the error of the average value for each pixel. The bias image extension header provides the file name of all the exposures that were used by the program to generate the super-bias. The total number of exposures used is also given in the header keyword IMCMB_NO. The data quality information for each pixel is encapsulated in the third image extension using bit-encoded flag values, specified in the DQ_DEF Binary Table extension using the following bits and values:

Bit	Value	Name	Description
0	1	DO_NOT_USE	Bad pixel. Do no use
1	2	UNRELIABLE_BIAS	Unreliable Bias value

See Birkmann (2013a) for more details on format and content of this file.

4.8 Saturation levels

REFTYPE = 'SATURATION'

The first FITS image extension of this file is a two-dimensional array providing the saturation value for each pixel, while the second image extension provides quality information over the saturation value for each pixel. The definition of the quality flags bit-encoding is specified in the Binary Table extension DQ_DEF and uses the following bits and values:

Bit	Value	Name	Description
0	1	DO_NOT_USE	Bad pixel. Do no use
1	2	NO_SAT_CHECK	Saturation level not available for this pixel

See Birkmann (2013b) for more details on format and content of this file.

4.9 Fourier Coefficients for Reference Pixel subtraction

REFTYPE = 'FFTR'

The first (and only) FITS image extension of this file provides the weighting coefficients to be applied to the Fourier transform of the reference pixel signal. This reference file is currently used only by ESA pre-processing pipeline to suppress part of the $1/f$ -noise affecting the detector electronics: before being subtracted from each group image, the signal of the reference pixels is filtered in Fourier domain using the weighting coefficients provided in this reference file – see Moseley et al. (2010) for more detail on this processing step. Details on the algorithm used to derive these weighting coefficients can be found in Giardino (2012).

4.10 Linearity correction

REFTYPE = 'LINEARITY'

This reference file comprises of two FITS image extensions and a Binary Table extension. The first extensions contains, for each pixel, the four coefficients used by the processing pipeline to correct the detector non-linear response and therefore it is a data cube. The second extension provides data quality information for each pixel. Also in this case the bit-encoded flag values are specified in the Binary Table extension DQ_DEF, as follow:

Bit	Value	Name	Description
0	1	DO_NOT_USE	Bad pixel. Do no use
1	2	NONLINEAR	Pixel highly non linear. Unreliable linearity correction
2	4	NO_LIN_CORR	Linearity correction is not available

See Birkmann (2013b) for more details on format and content of this file.

4.11 Dark Currents

REFTYPE = 'DARK'

This reference files comprises of four FITS image extensions and a Binary Table extension. The first extension records a high signal-to-noise ramp of the detector dark signal and it is therefore a data cube. Units are DN. It is constructed by averaging the individual frames of many 88-frame dark exposures. The dark reference data are subtracted from science data on a group-by-group basis. If the dark image is longer than the science image, the extra dark frames are ignored.

The second extension provides the error on the average dark value for each pixel in each group and therefore it is also a data cube of the same size of the data cube in the first extension. The third extension provides data quality information for each pixel. This extension is 2-dimensional. The bit-encoded flag values are specified in the DQ_DEF Binary Table extension, using the following keywords and values:

Bit	Value	Name	Description
0	1	DO_NOT_USE	Bad pixel. Do no use
1	2	WARM	Warm pixel
2	4	HOT	Hot pixel
3	8	UNRELIABLE_SLOPE	High noise pixel/slope variance large
4	16	UNRELIABLE_DARK	Large dark variance
5	32	BAD_REF_PIXEL	Unusable reference pixel

The fourth and last image extension provides a map of the dark-ramp total noise and it is also a 2-dimensional image. This image is included for reference, because it is the image upon which the classification of high-total noise pixel is based. See Birkmann (2013a) for more details on format and content of this file.

4.12 Gain map

REFTYPE = 'GAIN'

The first (and only) FITS image extension of this file provides the coefficient in e^-/DN that can be used to convert the derived count rate, for each pixel, from DN/s to e^-/s . See Sirianni & Birkmann (2013) for more details.

4.13 Read noise map

REFTYPE = 'READNOISE'

The first (and only) FITS image extension of this file provides a map of the detector read noise as computed from the difference of two adjacent frames during a dark exposures (CDS noise). See Sirianni & Birkmann (2013) for more details. See Sirianni & Birkmann (2013) for more details.

4.14 Flat fields for NIRSpec spectroscopic modes

REFTYPE = 'FLAT'

To generate the reference files for flat-fielding operation we followed a modular approach driven by the instrument design. This approach is especially useful given that the light from the internal calibration assembly (CAA) does not pass through the NIRSpec fore optics. In order to use the lamp exposures to generate flat-field reference files, it therefore must be conceptually possible to account for the missing optics separately, which is realized by using a separate reference file for the non-common optical path. Thus, NIRSpec throughput correction is divided into three separate parts: the Fore-optics flat (F-FLAT), the Spectrograph flat (S-FLAT), and the detector flat (D-FLAT).

For a high-level overview of the purpose and concept for each of the various flat-fielding reference files we refer the reader to the document by Böker et al. (2016), which explains how spatial throughput variations are modeled separately from spectral features and why this approach is beneficial.

As described in Böker et al. (2016), while the D-FLAT is common to all NIRSpec spectrographic mode, S-FLAT and F-FLAT have to be generated and applied in different manners for the different NIRSpec modes: fixed-slit (FS), Integral Field Unit (IFU) and Multi-object (MOS) mode. This in turn leads to 7 separate set of reference files for flat-fielding. The D-FLAT set (2 files, one for each SCA), three sets of S-FLATs (each set containing 18 files, specified in terms of detector, grating and CAA source) and three sets of F-FLATs (each set containing 7 files, specified in terms of the selected filter). The file format for each of these set of files is specified in detail in Böker et al. (2016).

Additionally the details of how each separate set of flat fields were generated and their main characteristics are described in the following documents:

- Sirianni (2016) – D-FLAT
- Lützgendorf (2016a) – S-FLAT for FS
- Lützgendorf (2016b) – S-FLAT for IFU
- Rauwle (2016) – S-FLAT for MOS

Note that there are currently no corresponding documents for the F-FLAT because there are no ground data suitable to create these files, the first (non-dummy) version of which will be generated during commissioning.

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