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Description of the NIRSpec bias and dark reference files

Abstract:

This document describes the format of and the data and algorithms used to create the NIRSpec bias and dark reference files that are input for the STScI ramps-to-slopes pipeline.

Change log:

Version	Date	Description of changes
1	Nov 1, 2013	Initial version for build 2 pipeline
2	Nov 17, 2014	Update to reflect changes in reference files for build 3 pipeline

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 dark and bias reference files delivered to STScI. Dark current reference files provide a high signal-to-noise ramp of the detector dark signal, and bias reference files correspond to the first group of a dark reference file.
While the STScI pipeline currently does not support the use of bias reference files, the ESA SOT pre-processing pipeline does. Therefore, we decided to deliver the bias reference files and their description as well.

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.

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 (2013b) and STScI (2014). The `REFTYPE` keyword has the value `'BIAS'` for the bias reference files and `'DARK'` for the dark reference files, respectively. Furthermore, the primary header contains more (non-mandatory) keywords related to the creation of the reference files.
The actual reference data is always stored in image extensions. Tables 1 and 2 below list the extensions in the dark and bias reference files, respectively.

#	Name	Dimensions	Type	Description
1	SCI	NCOL×NROW×NG	-32	Dark current data cube
2	ERR	NCOL×NROW×NG	-32	Dark current error data cube
3	DQ	NCOL×NROW	16	Dark quality bit map
4	DQ_DEF	binary fits table	N/A	Meaning of data quality bits/values
5	TOTNOISE	NCOL×NROW	-32	Total noise map

Table 1: Number, name, dimensions, type, and description of the extensions in the dark reference files. NCOL and NROW correspond to the dimension of the detector area read-out (2048×2048 pixels for full frame). NG gives the number of groups in the dark reference file. The given type denotes the BITPIX value of the data, i.e. -32 corresponds to single precision float and 16 to a short integer (unsigned), respectively.

#	Name	Dimensions	Type	Description
1	SCI	NCOL×NROW	-32	Master bias frame
2	ERR	NCOL×NROW	-32	Uncertainty of master bias frame
3	DQ	NCOL×NROW	16	Data quality bit map
4	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 bias reference files. The given type denotes the BITPIX value of the data, i.e. -32 corresponds to single precision float and 16 to a short integer (unsigned), respectively.

2.2 Data quality maps

Data quality maps hold information about bad pixel or unwanted behavior as bit values in a two dimensional map in the `DQ` extension of the reference files. The mapping of the bit values and their meaning are stored in extension `DQ_DEF` as a binary fits table. The currently defined values and a brief description are listed in tables 3 and 4 on the next page, for the dark and bias reference files, respectively.

Bit	Value	Name	Description
0	1	DO_NOT_USE	Bad pixel, do not use (for whatever reason). Currently set together with the BAD_REF_PIX flag.
1	2	WARM	Warm pixel. Set if $0.01\,\mathrm{e^-/s} \leq$ pixel dark current $i_{dark} < 0.1\,\mathrm{e^-/s}$.
2	4	HOT	Hot pixel. Set if pixel dark current $i_{dark} \geq 0.1\,\mathrm{e^-/s}$.
3	8	UNRELIABLE_SLOPE	Pixel with high total noise. Set if total noise is ≥ 12 $\mathrm{e^-}$. Was previously named HIGH_NOISE.
4	16	UNRELIABLE_DARK	Pixel with unreliable dark correction or unstable dark.
5	32	BAD_REF_PIXEL	Bad reference pixel, should not be used for reference pixel subtraction. Set for reference pixels if they exhibit significant signal, e.g. showing signs of dark current or are sensitive to light.

Table 3: Bit, value, name, and description of the data quality map bitplanes used in the dark 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 for bias reference files.
1	2	UNRELIABLE_BIAS	Unreliable bias. Set if the standard deviation for the pixel is more than five times higher than the average standard deviation of all pixels.

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

3 ALGORITHMS FOR REFERENCE FILE CREATION

3.1 Dark current and bias data

The reference dark cube is created the following way:

1. The first group of the input images (dark exposures) is averaged using a sigma-clipped mean (3-σ outlier rejection, 3 iterations). This averaged group becomes the super bias.

2. The super bias from above is subtracted from all groups of all input images.

3. Each group and output of the bias subtracted input images 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.

4. The reference pixel subtracted groups are averaged group by group, pixel by pixel, using a sigma-clipped mean (3-σ outlier rejection, 3 iterations). The sigma-clipped mean is used in order to remove outliers from the stack that might be, for example, due to cosmic ray hits.

As mention in step one above, the bias is the first group of the dark cube before subtraction of the bias. This also means that first group of the final dark cube will be all zero by design.

3.2 Error data for dark and bias

The error data is created from the standard deviations of the sigma-clipped mean above, with the standard deviation divided by the square root of the number of averaged groups (exposures or integrations). Thus, the data in the `ERR` extension reflects the uncertainty of the measured dark signal for each pixel and group.

3.3 Data quality flags

The algorithms to create the data quality bits for the dark reference files that are given in table 3 are described in the following list:

DO_NOT_USE Currently set only for bad reference pixels. See description for BAD_REF_PIXEL below for details.

WARM Set if the pixel dark current i_{dark} is $0.01\,\mathrm{e}^-/\mathrm{s} \leq i_{dark} < 0.1\,\mathrm{e}^-/\mathrm{s}$. Dark current is determined by running ramps-to-slopes pipeline on the created dark cube with inter-pixel-capacity (IPC) correction turned on and using the pixel to pixel gain map (see Sirianni & Birkmann 2013 for a description of the gain reference files). The IPC correction is done by convolving each group of the input cube with a 3×3 kernel. See Giardino (2013a) for more details on the IPC correction and the associated reference files. The ESA SOT pre-processing (ramps-to-slopes) pipeline is described in more detail by Birkmann (2011).

HOT Set if pixel dark current $i_{dark} \geq 0.1\,\mathrm{e}^-/\mathrm{s}$. Dark current determination is the same as described above.

UNRELIABLE_SLOPE Set if total noise is $\geq 12\ \mathrm{e}^-$. Total noise is computed as the standard deviation of all slopes (in e^-/s) of the input dark exposures times the exposure time.

UNRELIABLE_DARK Set if the standard deviation of the dark current slopes of all input exposures is larger than four times the uncertainty expected from shot and read noise.

BAD_REF_PIXEL Set if the count rate of a reference pixel minus the average count rate of all reference pixels is higher than 3.5 times the standard deviation of all reference pixels. For the four reference pixel columns at the left and right hand side of the detectors, all four reference pixels in a row will be set as bad if one pixel of that row exceeds the threshold. This is done to remove outliers that would negatively affect the full reference pixel subtraction of the ESA SOT pre-processing pipeline, which also corrects row-by-row after filtering in Fourier space (see Birkmann 2011 for more details). Bad reference pixels can also be set as user input.

The algorithms to create the data quality bits for the bias reference files that are given in table 4 are described in the following list:

DO_NOT_USE Never set, not used at the moment.

UNRELIABLE_BIAS Set if the standard deviation of the pixel of all input first frames/groups is more than five times higher than the average standard deviation of all pixels.

4 DELIVERED REFERENCE FILES

In this section we list the delivered dark and bias reference files. The reference files are derived from data taken at the Goddard detector lab as part of FPA104 characterization and during the three NIRSpec instrument level cryovac calibration campaigns. We designate these campaigns as FM1 (early 2011), FM2 cycle 1 (early 2013), and FM2 cycle 2 (August 2013). In all cases FPA104 was installed in NIRSpec.
Table 5 on page 6 lists the reference files provided in this delivery. It is considered complete for the full frame exposures, as all three instrument level calibration campaigns are covered. The dark reference files have a length of 88 groups in all cases. In order to increase the signal-to-noise of the first group (which is used to create the master bias reference file), we also obtained one ore more exposures with 100 integrations with the length of one group only during the FM tests.
For data using the stripe or window mode detector setting, we also provide a few example reference files that were obtained during FM2 cycle 1 testing. The first set (numbers 13 through 16) covers the area that is occupied by the spectra of the five fixed slits in NIRSpec for any disperser. The second set (numbers 17 through 20) is for a small window that covers the image of the S1600A aperture on SCA 491 and the image of S200B on SCA 492 with the NIRSpec target acquisition mirror in place. The last set (numbers 21 through 24) is for a 256 pixel wide stripe that was used during the calibration campaign for the wavelength calibration of the NIRSpec prism, being a showcase for a stripe mode reference file. The delivery of the remaining window/stripe mode reference files will occur at a later time.
Finally, table 6 on page 7 gives the NIDs of the exposures that were used to create the reference files. This information, as well as the full filename of all input files, is also available in the primary header of the reference files.

#	Filename	Dimensions	x_1	y_1	Use after
1	nirspec_drkc_nrs1_f_04.00.fits	2048×2048×88	1	1	2000-01-01
2	nirspec_drkc_nrs2_f_04.00.fits				
3	nirspec_bias_nrs1_f_04.00.fits	2048×2048			
4	nirspec_bias_nrs2_f_04.00.fits				
5	nirspec_drkc_nrs1_f_05.00.fits	2048×2048×88	1	1	2010-06-01
6	nirspec_drkc_nrs2_f_05.00.fits				
7	nirspec_bias_nrs1_f_05.00.fits	2048×2048			
8	nirspec_bias_nrs2_f_05.00.fits				
9	nirspec_drkc_nrs1_f_06.00.fits	2048×2048×88	1	1	2013-01-01
10	nirspec_drkc_nrs2_f_06.00.fits				
11	nirspec_bias_nrs1_f_06.00.fits	2048×2048			
12	nirspec_bias_nrs2_f_06.00.fits				
13	nirspec_drkc_nrs1_f_07.00.fits	2048×2048×88	1	1	2013-07-01
14	nirspec_drkc_nrs2_f_07.00.fits				
15	nirspec_bias_nrs1_f_07.00.fits	2048×2048			
16	nirspec_bias_nrs2_f_07.00.fits				
17	nirspec_drkc_nrs1_f_08.00.fits	2048×2048×88	1	1	2014-07-01
18	nirspec_drkc_nrs2_f_08.00.fits				
19	nirspec_bias_nrs1_f_08.00.fits	2048×2048			
20	nirspec_bias_nrs2_f_08.00.fits				
21	nirspec_drkc_nrs1_w_ALLSLITS_02.00.fits	256×2048×90	897	1	2013-01-01
22	nirspec_drkc_nrs2_w_ALLSLITS_02.00.fits		895	1	
23	nirspec_bias_nrs1_w_ALLSLITS_02.00.fits	256×2048	897	1	
24	nirspec_bias_nrs2_w_ALLSLITS_02.00.fits		895	1	
25	nirspec_drkc_nrs1_w_S1600A_M_02.00.fits	32×2048×88	981	1	
26	nirspec_drkc_nrs2_w_S200B_M_02.00.fits		1036	1	
27	nirspec_bias_nrs1_w_S1600A_M_02.00.fits	32×2048	981	1	
28	nirspec_bias_nrs2_w_S200B_M_02.00.fits		1036	1	
29	nirspec_drkc_nrs1_s_SPECIAL1_02.00.fits	2048×256×8	1	513	
30	nirspec_drkc_nrs2_s_SPECIAL1_02.00.fits				
31	nirspec_bias_nrs1_s_SPECIAL1_02.00.fits	2048×256			
32	nirspec_bias_nrs2_s_SPECIAL1_02.00.fits				

Table 5: The number, filename, dimensions, start column (x_1) and row (y_1), and use after date for the dark and bias reference files. The given dimensions are for the SCI and ERR extensions. The _f_, _w_, and _s_ in the filenames designate full, window, and stripe mode, respectively. The value of the "use after" column corresponds to the USEAFTER keyword in the primary fits header. The values in the x_1 and y_1 columns correspond to the COL_STRT and ROW_STRT keywords, respectively.

Number	Data used
1 to 4	Data taken at the Goddard detector lab prior to the delivery of FPA104. NIDs 4167 to 4200 and 4211 to 4233, (all 88 group full frame dark exposures)
5 to 8	FM1 calibration campaign data, NIDs 4536 to 4545, 6263 to 6292 (all 88 group full frame dark exposures), and 4546 (1 group, NINT=100 exposure for bias)
9 to 12	FM2 cycle 1 calibration campaign data, NIDs 8196 to 8225, 10118 to 10137, 12231 to 12290 (all 88 group full frame dark exposures), and 8226+12291 (1 group, NINT=100 exposures for bias)
13 to 16	FM2 cycle 2 calibration data, NIDs 13798 to 13807, 13809 to 13833, 13835 to 13849 (all 88 group full frame dark exposures), and 13808+13834 (1 group, NINT=100 exposures for bias)
17 to 20	ISIM CV2 test campaign, NIDs 10264, 10269, 10274, 10281, 10285, 10291, 10292, 10293, 10294, 10300, 10307, 10314, 10320, 10325, 10330, 10336, 10343, 10348, 10352, 11531, 11532, 11533, 11534, 11535, 11536, 11537, 11538, 11539, 11540 (all 88 group full frame dark exposures)
21 to 24	NIRSpec FM2 cycle 1 test data, NIDs 12332-12351 (90 group window mode dark exposures) and 12674 (NINT=100 exposure)
25 to 28	NIRSpec FM2 cycle 1 test data, NIDs 12492-12511 (88 group window mode dark exposures) and 12682 (NINT=100 exposure)
29 to 32	NIRSpec FM2 cycle 1 test data, NIDs 12691-12710 (8 group stripe mode dark exposures) and 12811 (NINT=100 exposure)

Table 6: The data used to create the reference files listed in table 5.

5 REFERENCES

Birkmann, S. 2011, Description of the NIRSpec pre-processing pipeline, NIRSpec Technical Note NTN-2011-004, ESA/ESTEC

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