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NIRSpec Technical Note
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Assessing the impact of performing no master bias subtraction when using the current linearity correction files

Abstract:

In this document we assess the impact of using the current STScI pre-processing approach with the delivered NIRSpec linearity correction files both on the count rate and signal to noise. We find that the derived count rates are higher than with the SOT pre-processing approach, due to the over correction of the detector non linearity, and that the achieved signal to noise is slightly smaller, probably due to the impact of the non corrected pedestal in the STScI approach.

1 INTRODUCTION

The NIRSpec Focal Plane Array (FPA) consists of a mosaic of two H2RG HgCdTe Sensor Chip Assemblies (SCA). Those detectors are read up-the-ramp, and in order to derive scientific data in form of a count rate map, the up-the-ramp data has to be pre-processed. This step is also referred to as ”from ramps to slopes” processing and often requires the use of reference data.

The first set of NIRSpec pre-processing reference files was delivered by ESA in late 2013. For the linearity correction step, the delivered reference files (see RD2) were created assuming that a (super) bias (see RD3) correction would take place before performing the linearity correction (see RD1 for the NIRSpec Science Operations Team (SOT) pre-processing documentation).

The scope of this technical note is to assess the impact of not performing the bias subtraction prior to the linearity correction. Instead, the current STScI approach is to subtract the first group from all data and add it back after the reference pixel subtraction. We analyse the difference in measured count rates and signal to noise for the two different pre-processing approaches.

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1.1 Reference Documents

Reference	**Identifier**	**Title, Issue & Date**
RD1	ESA-JWST-TN-18257	Description of the NIRSpec pre-processing pipeline, Issue 1.1, 03 May 2012
RD2	ESA-JWST-TN-20071	Description of the NIRSpec linearity correction reference files, Issue 1, 01 November 2013
RD3	ESA-JWST-TN-20072	Description of the NIRSpec bias and dark reference files, Issue 1, 01 November 2013

2 DATA USED AND DATA PROCESSING

The exposures used for the analysis in this note were taken during the NIRSpec FM2 cycle 1 calibration campaign carried out in January/February 2013. The NIDs of the exposures and the corresponding instrument configuration are listed in Table 1 below.

NID	OBS ID	Frame size [pixel]	n_g	t_g[s]	GWA	Source
8124	PREP-RCSS-C	2048 × 2048	5	10.73676	MIRROR	CAA/TEST
9102	IMA-DIST-005	2048 × 2048	10	10.73676	MIRROR	CAA/TEST
9276	IMA-FF-001	2048 × 2048	15	10.73676	MIRROR	CAA/TEST
8501	SCI-OBS-SIM-C-11	2048 × 64	22	1.55724	G140H	CAA/FLAT1

Table 1: The NID, OBS ID, detector, and instrument settings for the exposures analysed in this technical note.

The first three exposures were taken with NIRSpec in imaging mode, illuminating the detectors through the fully opened MSA with the CAA/TEST lamp. The only difference is the number of groups (5, 10, 15) and thus exposure time. The last exposure was obtained in window mode and has a total of 40 integrations taken with the G140H grating thorough the S1600A aperture illuminated with the CAA/FLAT1 lamp. As the lamp switched off in integration 32 (1000 s on time limit reached), we only look at the first 31 integrations in this note.

In order to derive count rate images (ramps to slopes), we used the NIRSpec SOT pre-processing pipeline, which is described in RD1 in more detail. For the standard processing (SOT approach), we used the following steps:

1. super bias subtraction
2. reference pixel subtraction
3. linearity correction
4. estimate count rates with optimum weights

For the processing without subtracting the super bias (the current STScI approach), the following pre-processing steps were performed:

1. subtract first group from all groups
2. reference pixel subtraction
3. add back initial first group to all groups
4. linearity correction
5. estimate count rates with optimum weights

The reference files were the same for the two different approaches, with the exception of the bias reference file, which was not used in the STScI like approach. No dark current subtraction was performed in either case.

3 RESULTS

In this section we present the impact of not performing the bias subtraction step with the current set of linearity correction files on i) the estimated count rates and ii) the achieved signal to noise.

3.1 Impact on count rates

In order to assess the impact of applying the linearity correction without bias subtraction with the current set of reference files, we compared the count rates derived with the SOT approach with those of the STScI approach.
In each case, we selected the pixels that were illuminated based on the theoretical signal to noise (greater equal 10) estimated with the SOT approach. We removed pixels with non zero data quality values (e.g. hot pixels). Then we compared the count rates of the two different approaches pixel by pixel.
As an example, we show plots for NID 9102 and 8501 in Figures 1 and 2, respectively. Both the histograms and the pixel by pixel count rate versus count rate plots indicate that the count rates are higher with the STScI approach. This is as expected, because the bias present there will lead to an over correction of the non linearity and thus higher count rates. In a few cases the count rates differ a lot, which is due to early saturation and incorrect flagging with the STScI approach when using the current linearity correction files that are meant to be used with the SOT approach. Those pixels stand out in the b) panels. Therefore, for panels c) and d) in the figures, we only selected pixels that did not saturate early in the STScI approach (at least four good reads) and also had a S/N of at least 50. For the full frame exposures this still left about 1.5 million pixels per SCA for analysis, and about 55,000 good pixels in the sub array exposure.
In all cases, there is an increase in count rates when using the STScI approach by a few percent. As evident from the d) panels in the Figures, this results in a fairly constant average

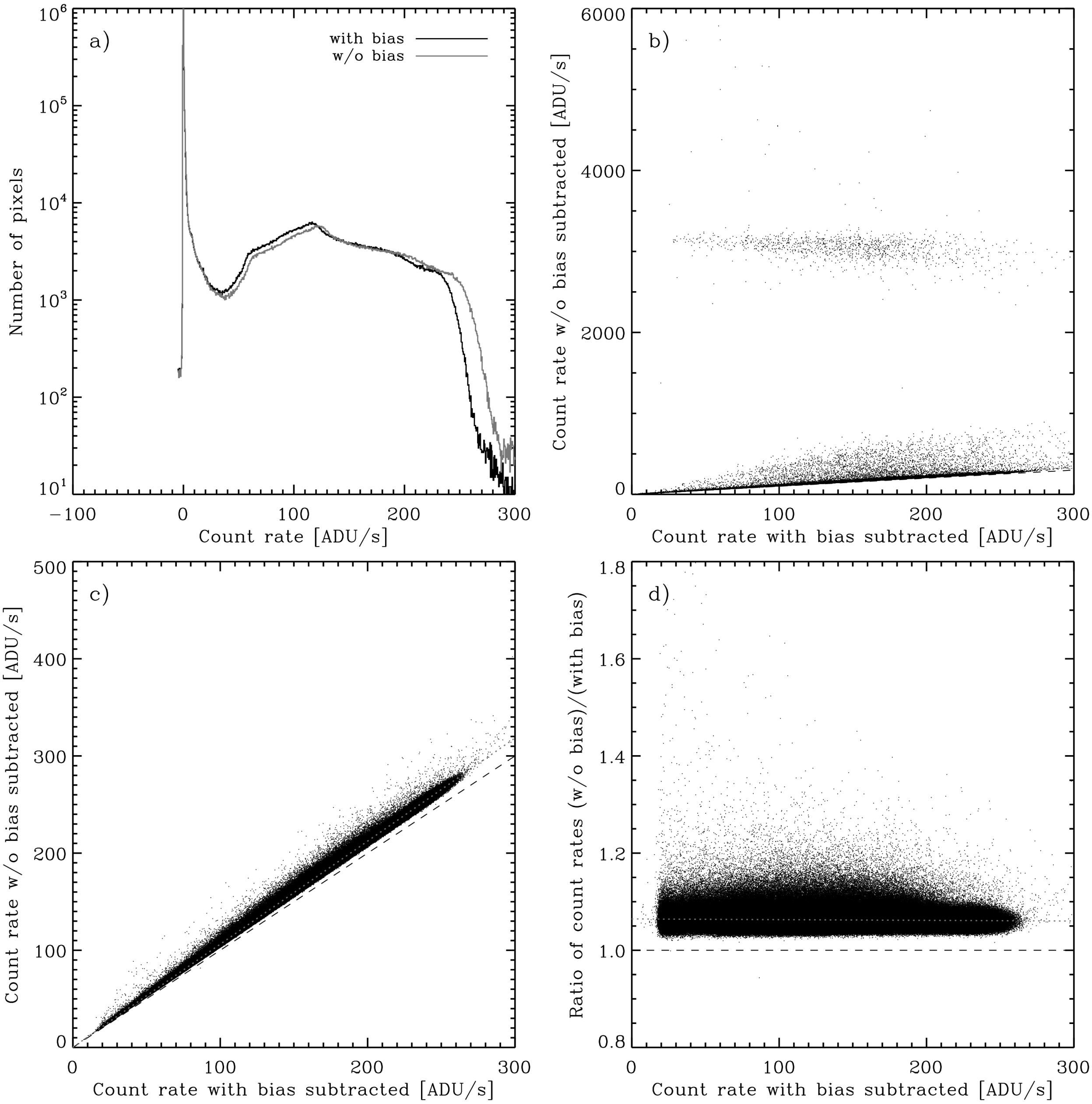

Figure 1: Count rate comparison for NID 9102 SCA 491. Panel a) shows the histogram of count rates for the SOT (black) and STScI (grey) approaches. Panel b) shows a count rate versus count rate plot with all illuminated data (no hot pixels). The cloud of high count rate points in the STScI approach are due to high bias pixels that saturate early but are not flagged correctly with the current linearity correction files. Panel c) shows the same plot but with data removed that saturates within the first four reads. Panel d) shows the ratio of the STScI/SOT count rate versus the SOT count rate for the same data as in c). In both c) and d) the dashed black line shows the 1:1 rate and the dotted grey line the best fit to the data.

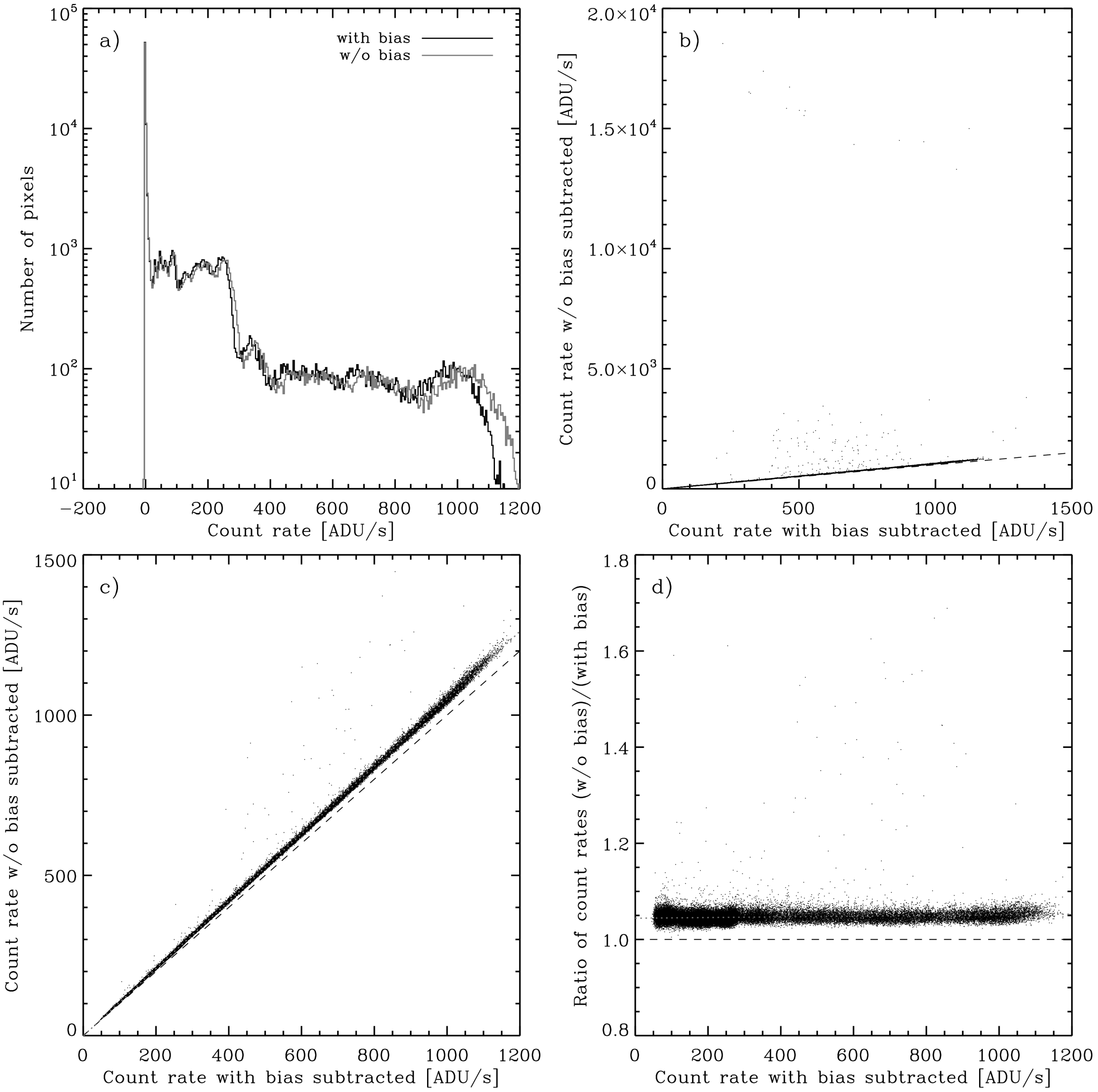

Figure 2: Count rate comparison for NID 8501 SCA 491. Since this data was taken in subarray mode, there are fewer data points compared to Figure 1. The description of the panels is the same.

ratio of the count rates of the two different pre-processing approaches, regardless the actual count rate. The measured ratios are for the analysed exposures are shown in Table 2 below. We used a clipped mean (three sigma threshold, five iterations), in order to prevent a few outliers to skew the derived ratios.

NID	SCA	average ratio ± stddev
8124	491	1.059 ± 0.013
	492	1.035 ± 0.008
9102	491	1.062 ± 0.015
	492	1.036 ± 0.008
9276	491	1.066 ± 0.017
	492	1.038 ± 0.009
8501	491	1.046 ± 0.009
	492	1.030 ± 0.009

Table 2: The ratio and stand deviation of the derived count rates (STScI divided by SOT) for the analysed exposures.

The estimated count rates when using the current linearity correction files on non bias subtracted data are systematically higher than the ones for the bias subtracted data, yielding the greater than 1 ratios in Table 2. As mentioned above, this is due to the fact that the average bias level of about 11,000 to 14,000 ADU (SCA dependent) leads to the overcompensation of the detector non linearity in the linearity correction step. As the non linearity increases with larger ADUs, the effect becomes bigger for exposures that fill the ramp more, for example by going from 5 to 10 to 15 groups as is the case for NIDs 8124, 9102, and 9276, respectively. Furthermore, detectors that have a higher bias value to begin with should be more impacted. The average bias for SCA 491 is 14,200 ADU, whereas it is less than 11,000 ADU for SCA 492, thus supporting the lower ratios found for SCA 492. Obviously, a different magnitude of the non linearity for the build of pixels in a given SCA would also lead to different ratios observed.

3.2 Impact on signal to noise

The increased count rates for the STScI approach with respect to the SOT pre-processing is a result of over correcting the non linearity due to the use of the same linearity correction files. Therefore, it can be expected that the same count rates will be achieved, if the linearity correction files are adapted accordingly.

However, the step of adding back the initial frame to the data after reference pixel subtraction will not only add back in the bias, but also the (output and time dependent) pedestal that is otherwise removed by the reference pixel subtraction step. This pedestal can change from ramp to ramp and thus might - together with the non linearity correction - slightly change the derived count rate and therefore also affect the obtained signal to noise ratio.

In order to study that possible effect, we looked at the exposure NID 8501. This exposure has 40 integrations of 22 groups each, where the spectrum of the CAA/FLAT1 lamp is observed through the S1600A aperture. As the lamp turned off after 1000 s (during the 32nd integration), we only analysed the data of the first 31 integrations.

For each pixel and each integration we derived the count rate with three different pre-processing approaches: i) the standard SOT approach, ii) the SOT approach but adding the master bias after the reference pixel subtraction, and iii) the STScI approach. Then, for each pixel i we derived an average count rate c_i for the 31 integrations and also the standard deviation σ_i, yielding the signal to noise ratio $SNR_i = c_i/\sigma_i$ for each pixel.

We defined three count rate bins based on the count rates derived with the standard SOT approach: 180 to 220, 450 to 550, and 900 to 1100 ADU/s for SCA 491 and 270 to 330, 540 to 660, and 1080 to 1320 for SCA 492, respectively. For each bin, we computed the average SNR for all pixels in the respective bin. The results are summarized in Table 3 below.

SCA	Count rate	number of	average SNR for		
#	bin [ADU]	pixels in bin	SOT approach	SOT + bias	STScI approach
491	200 ± 20	7116	100.07 ± 0.16	99.96 ± 0.16	99.92 ± 0.16
	500 ± 50	2204	165.28 ± 0.48	164.45 ± 0.48	163.74 ± 0.47
	1000 ± 100	3955	241.57 ± 0.51	238.03 ± 0.50	237.09 ± 0.50
492	300 ± 30	33363	120.17 ± 0.09	120.06 ± 0.09	119.93 ± 0.09
	600 ± 60	657	175.95 ± 1.02	174.34 ± 0.97	173.79 ± 0.97
	1200 ± 120	21480	260.95 ± 0.24	257.21 ± 0.23	255.13 ± 0.23

Table 3: The derived signal to noise ratio (SNR) for three different pre-processing approaches in three defined count rate bins for the first 31 integrations in NID 8501. The quoted uncertainty for the SNR is the error of the mean.

While the achieved SNR with the three pre-processing approaches is very similar, there are measurable differences at high count rates and signal to noise ratios. For example, for the 900 to 1100 ADU/s count rate bin for SCA 491, the standard SOT pre-processing yields an SNR that is approximately 1.5 % higher than the SOT approach with back the super bias and 1.9 % higher than the STScI approach (9-σ significance). Similar results are obtained for SCA 492, where we find an SNR that is about 1.5 % and 2.3 % higher for the SOT approach compared to SOT plus bias and the STScI approach, respectively, in the highest count rate bin.

The reason for the difference in achieved SNR for the three pre-processing approaches is twofold:

1. Adding back the bias puts the ramp at higher counts where the linearity correction is higher/stronger, thus amplifying small variations in the slope.

2. The varying pedestal (from integration to integration, exposure to exposure) that is left in the STScI approach imprints on the derived count rate, due to the non linear nature of the non linearity correction.

It has to be noted that these results were obtained in sub array mode (only one output active). No analysis could be performed for full frame data, because no such data (multiple integrations and/or exposures under stable conditions with the same instrument configuration) exists for NIRSpec instrument level testing.

4 CONCLUSION

Using the current linearity correction files as delivered to STScI in late 2013, we find that:

1. The derived count rates are higher with the STScI approach, due to the overcompensation of the detector non linearity.
2. In the high signal to noise regime, the obtained SNR with the STScI approach is slightly lower than the one achieved with the SOT approach. This is due to
   a) The impact of the added bias, putting the linearity correction in a more ”volatile” area.
   b) The impact of the changing pedestal happening at ASIC level, that is not corrected with the current STScI approach.

Points 1. and 2.a) can be addressed by using different linearity correction files for data that is not bias subtracted (or where the bias is added back) during pre-processing. Point 2.b), however, seems to be a consequence of adding back the initial frame (and thus the changing pedestal) to the data before performing the linearity correction step. While the magnitude of this effect might change with the use of different linearity correction files and/or weighting scheme (count rates obtained with uniform weighting should be less affected), it is doubtful that it will completely disappear.