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TECHNICAL REPORT

Title: NIRISS Commissioning Results: NIS-015 – NIRISS GR150C/R Trace Calibration (NGAS CAR-699, APT 1089)	Doc#: JWST-STScI-008386, SM-12 Date: 31 January 2023 Rev: -
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1 Abstract

This report presents analysis and results of commissioning program NIS-015 (NGAS CAR-699, APT 1089). We describe the observations, data reduction and analysis to measure the spectral traces for the GR150R and GR150C grisms in the NIRISS WFSS mode. The data used for the trace measurements from the NIS-015 commissioning program were the observations taken primarily for the WFSS flux calibration by observing two flux standards: (1) WD1657+343 in the FULL array, and (2) P330E in the WFSS64C/R subarrays. Only the WD1657+343 observations were used for spectral trace measurements because direct images were not taken for P330E. The spectral traces for the different orders (-1, 0, +1, +2, +3) were measured for each grism crossed with the six filters supported for the NIRISS WFSS mode. The traces were measured for the flux standard which is located at the center and is bright enough to offer the signal-to-noise ratio required for measuring the trace for all the spectral orders. In the cases where the trace was contaminated, other bright sources located close to the center were used to get the trace information. The spectral traces are curved for both grisms which is consistent with the results from pre-flight ground tests, and are characterized using a quadratic function. The *specwcs* reference files for NIRISS WFSS spectral traces were created and delivered to CRDS for use with the JWST calibration pipeline.

2 Introduction

The NIRISS Wide-Field Slitless Spectroscopy (WFSS) mode is enabled by two nearly identical (R~ 150) grisms GR150R and GR150C which are mounted on the Filter Wheel (FW). The grisms are crossed with one of the 6 blocking filters (F090W, F115W, F140M, F150W, F158M, and F200W) in the Pupil Wheel (PW) to obtain the dispersed images of astronomical sources. The WFSS science primarily uses the spectral order +1 for the six filters that cover the wavelength range from 0.8 – 2.2 microns. In the slitless spectroscopy mode, every source that falls on the detector gets dispersed and the spectrum of any given source can be contaminated by the spectral orders of other neighboring sources. In order to model and subtract the contamination produced by sources that are not of interest, it is important to know the trace locations of all the significant spectral orders (-1, 0, +1, +2, +3). The NIRISS WFSS trace measurements were done using the observations from the NIS-015 commissioning program which was designed for WFSS flux

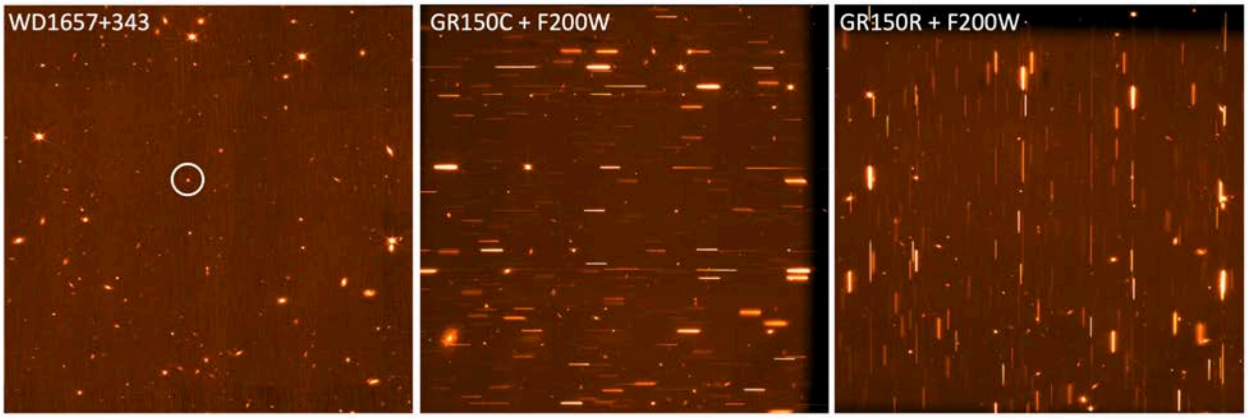

Figure 1: The direct and dispersed images for the WD1657+343 field in full array. The direct image (left) shown here was taken using the F200W filter, and the same filter crossed with GR150C (middle) and GR150R (right) are shown in the other panels. The star WD1657+343 is marked with white circle in the left panel. The field of view shown is 2.2 arcmin x 2.2 arcmin.

calibration by observing two flux standard stars in 3 visits during May 22-23, 2022 through the APT program 1089 (Ravindranath et al. 2022). The details of the observations are provided in Table 1. The standard star WD1657+343 (spectral type DA1; K=17.6 Vega magnitude) was observed with the GR150C and R grisms crossed with each of the 6 blocking filters using the FULL array. In the special requirements an offset of (6.3101", -0.6635") was applied to match the NIS_WFSS SIAF aperture location and ensure that the direct and dispersed images do not fall on the rows separating the detector channels. The 4-point large WFSS dither pattern was chosen for removal of ghosts and bad pixels. The direct and dispersed images are shown in Figure 1 for GR150R and GR150C crossed with the F200W grism. The standard star P330E (spectral type G0V; K=11.4 Vega magnitude) was also observed in this program in vists 2 and 3 using the WFSS64R subarray for GR150R grism and WFSS64C subarray for GR150C. The grisms were crossed with the wide passbands (F090W, F115W, F150W, and F200W) using 2-point small dithers. Since the star is too bright to be observed in the full array, the observations with P330E were done using the subarrays to avoid saturation. No direct images were taken for P330E, so the subarray observations were not used for the trace measurements. Instead, the P330E spectra were used to check and confirm the relative offsets of the orders with respect to the zeroth order. The exposure times, which are specified in the APT using the number of groups and integrations for each observation were calculated using the JWST Exposure Time Calculator (ETC) to get several thousand counts in the first order of the trace without saturating. The total time for executing the NIS-015 program was 8.0 hours.

3 Data Processing

The data processing was done using the JWST calibration pipeline version 1.5.1. The *_uncal.fits* files for both the direct and the dispersed grism images were converted to rate images using the *Detector1* step of the pipeline. The bad-pixel mask generated from the commissioning data was used to identify and flag the bad pixels in this step. The direct images were processed through the *Image2* pipeline steps to assign WCS and to do flat-fielding using the distortion reference files and

Table 1: Details of the observations from program APT 1089

FITS file root ID	Pupil	Filter	PWCPOS	FWCPOS	Subarray	Dithers	Ngroups	Nints	Duration per single exposure (Seconds)
Target: WD1657+343, Observation / Visit 1									
jw01089001001_32101	F090W	CLEAR	325.0453	74.9042	FULL	1	5	1	64.421
jw01089001001_33101	F090W	GR150R	325.0478	33.6722	FULL	4	20	1	225.473
jw01089001001_34101	F090W	CLEAR	325.0648	74.7624	FULL	2	5	1	128.842
jw01089001001_35101	F090W	GR150C	325.0673	354.3371	FULL	4	20	1	225.473
jw01089001001_36101	F090W	CLEAR	325.0673	74.7599	FULL	1	5	1	64.421
jw01089001001_26101	F115W	CLEAR	4.9768	74.9237	FULL	1	5	1	64.421
jw01089001001_27101	F115W	GR150R	4.9768	33.6355	FULL	4	20	1	225.473
jw01089001001_28101	F115W	CLEAR	4.9768	74.7624	FULL	2	5	1	128.842
jw01089001001_29101	F115W	GR150C	4.9768	354.3224	FULL	4	20	1	225.473
jw01089001001_30101	F115W	CLEAR	4.9768	74.7477	FULL	1	5	1	64.421
jw01089001001_08101	F150W	CLEAR	124.9475	74.8993	FULL	1	5	1	64.421
jw01089001001_09101	F150W	GR150R	124.9499	33.6551	FULL	4	20	1	225.473
jw01089001001_10101	F150W	CLEAR	124.9548	74.7502	FULL	2	5	1	128.842
jw01089001001_11101	F150W	GR150C	124.9573	354.3542	FULL	4	20	1	225.473
jw01089001001_12101	F150W	CLEAR	124.9573	74.7306	FULL	1	5	1	64.421
jw01089001001_02101	F200W	CLEAR	165.0062	74.8944	FULL	1	5	1	64.421
jw01089001001_03101	F200W	GR150R	164.8864	33.4766	FULL	4	30	1	332.841
jw01089001001_04101	F200W	CLEAR	164.8913	74.7477	FULL	2	5	1	128.842
jw01089001001_05101	F200W	GR150C	164.8913	354.3224	FULL	4	30	1	332.841
jw01089001001_06101	F200W	CLEAR	164.8913	74.7257	FULL	1	5	1	64.421
jw01089001001_14101	F140M	CLEAR	84.7911	74.9017	FULL	1	5	1	64.421
jw01089001001_15101	F140M	GR150R	85.0135	33.6624	FULL	4	20	1	225.473
jw01089001001_16101	F140M	CLEAR	84.9304	74.7526	FULL	2	5	1	128.842
jw01089001001_17101	F140M	GR150C	84.9353	354.3566	FULL	4	20	1	225.473
jw01089001001_18101	F140M	CLEAR	84.9353	74.7551	FULL	1	5	1	64.421
jw01089001001_20101	F158M	CLEAR	44.9597	74.9066	FULL	1	5	1	64.421
jw01089001001_21101	F158M	GR150R	44.9622	33.6551	FULL	4	20	1	225.473
jw01089001001_22101	F158M	CLEAR	44.9671	74.7966	FULL	2	5	1	128.842
jw01089001001_23101	F158M	GR150C	44.9671	354.3151	FULL	4	20	1	225.473
jw01089001001_24101	F158M	CLEAR	44.9695	74.7404	FULL	1	5	1	64.421
Target: P330E, Observation / Visit 2									
jw01089002001_03102	F090W	GR150R	324.8962	33.6551	WFSS64R	2	10	5	37.672
jw01089002001_03104	F115W	GR150R	5.023346	33.4717	WFSS64R	2	10	5	37.672
jw01089002001_03106	F150W	GR150R	124.9695	33.5255	WFSS64R	2	10	5	37.672
jw01096002002_03108	F200W	GR150R	164.9646	33.5182	WFSS64R	2	10	5	37.672
Target: P330E, Observation / Visit 3									
jw01089003001_02107	F090W	GR150C	325.0453	354.1611	WFSS64C	2	5	2	37.474
jw01089003001_02105	F115W	GR150C	4.95245	354.1611	WFSS64C	2	5	2	37.474
jw01089003001_02103	F150W	GR150C	124.8937	354.1562	WFSS64C	2	5	2	37.474
Jw01089003001_02101	F200W	GR150C	164.9084	354.3395	WFSS64C	2	5	2	37.474

flat-field reference files from the commissioning programs. The *Image3* pipeline step was used to create the source catalogs. The GR150R and C dispersed rate images were processed through the first few steps in the *Spec2* pipeline to assign WCS, apply the flat-field correction and subtract background. The *_cal.fits* files for the different dither positions within the grism exposure sequence were then combined using astrodrizzle, by applying X and Y shifts from the XOFFSET and YOFFSET header keywords to align all the dispersed images to the first dither position. This

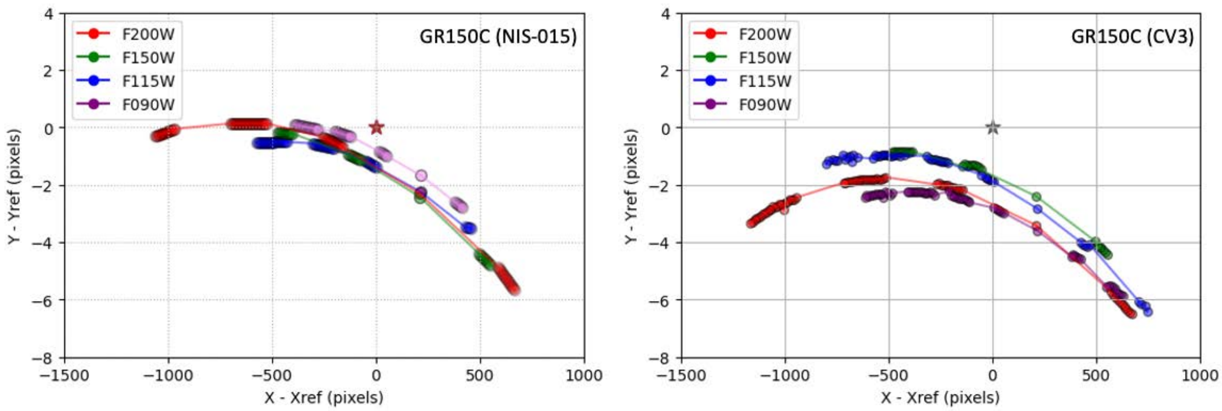

Figure 2: The measured traces for the GR150C from NIS-015 commissioning program (left) and from the CV3 ground tests (right). The filled circles are the trace measurements for the different spectral orders. The location of the source in the direct image (Xref=0, Yref=0) is shown using star symbols. The (X-Xref) and (Y-Yref) correspond to the offsets in the dispersion direction and in the cross-dispersion directions respectively. The traces show curvature as seen from the CV3 ground tests and are can be described using a quadratic function.

improves the signal-to-noise ratio which is particularly useful for the trace measurements of the higher spectral orders.

4 Analysis

The trace measurements were done using the drizzled dispersed image that combines all the dithered exposures for each grism+filter combination. The direct image (single dither) taken at the start of the grism exposure sequence (first dither position) was used for creating the source catalog. The first direct image dither position is equal to the first grism position in GR150R and the third direct image dither position is equal to the first grism position in GR150C. The combined spectra are all aligned to their first dither position. The analysis steps performed on each filter + grism combination are listed below:

1. The detector positions (*Xref, Yref*) of the source from the source catalogs were used to locate the trace positions for the standard star and create a bounding box that encloses the spectral trace. To create the bounding boxes, it is required to know the offset of the star of the trace from the source position. Since the offsets and extent for the spectral traces were close to that observed during the ISIM cryo-vaccum 3 (CV3) ground tests, we used that as initial information to determine the bounding boxes. The size of the bounding box varies with the length of the trace for each filter along the dispersion direction, and the extent of the PSF in the cross-dispersion direction is defined using an isophote which is 3-sigma above the source detection threshold. The bounding boxes were used to create 2D-cutouts of the spectral traces.
2. Any remaining bad pixels or contaminating spectral orders of nearby sources inside the extraction box were masked. The masked pixels were replaced by interpolation from the neighboring pixels. The +1 order of the flux standard is fairly isolated in all the filters and there is no significant contamination within the 2D-cutouts used for the trace measurement.

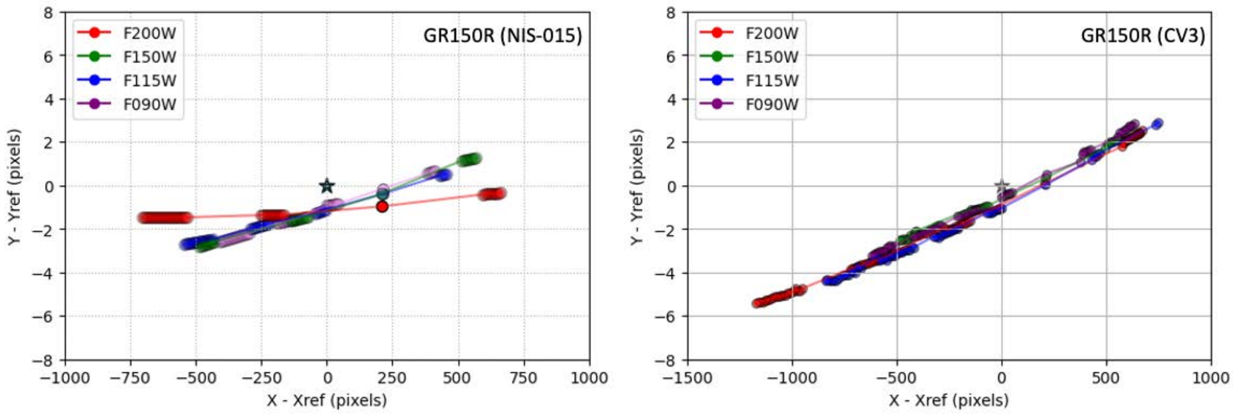

Figure 3: The measured traces for the GR150R from NIS-015 commissioning program (left) and from the CV3 ground tests (right). The filled circles are the trace measurements for the different spectral orders. The location of the source in the direct image (xref=0, yref=0) is shown using star symbols. The (X-Xref) and (Y-Yref) correspond to the offsets in the dispersion direction and in the cross-dispersion directions respectively. The traces show curvature as seen from the CV3 ground tests and are consistently described using a quadratic function.

The masked regions were mostly close to the edges of the bounding boxes and did not affect the centroids for the trace measurements.

3. Some of the higher orders of the flux standard star spectrum have significant contamination from the sources within the field of view, and were not easy to mask. We identified other bright stars around the central region of the detector where one or two higher spectral orders were available without contamination. When available, we used the measurements from those stars to tie into the measurements of the trace from WD1657+343 to create the full spectral trace. Only the trace measurements from the stars in the central regions were combined to get the full trace in order to reduce the effect of spatial variation across the detector FOV.
4. After defining the 2D-cutouts for the individual spectral orders for a given star the trace measurements were made by determining the centroids (*Xpos,Ypos*) in small segments along the dispersion direction. The step size for the segments was 2 pixels wide. The centroids of the segments were determined using the center-of-mass in *photutils.centroids*. The displacements in the X and Y directions were measured as *delta_X = (Xpos – Xref)* and *delta_Y = (Ypos – Yref)*. The trace measurements were verified using *apall* routine in *IRAF/Specred* package which measures the centroid at every pixel along the trace and the results were identical to those from the *photutils* measurements.
5. The trace measurements of the different spectral orders are then stitched together to get the complete trace for a given source position (see Figure 2 and Figure 3).
6. The trace is defined using a polynomial fit to the displacement in the cross-dispersion direction as a function of the distance along the dispersion direction. For both grisms, the trace is curved and is best fit by a quadratic function. This is consistent with the curved traces seen for both grisms during the ground tests. The offsets of the spectral traces are different from what was seen in the CV3 data for both grisms (see Figure 2 and Figure 3).

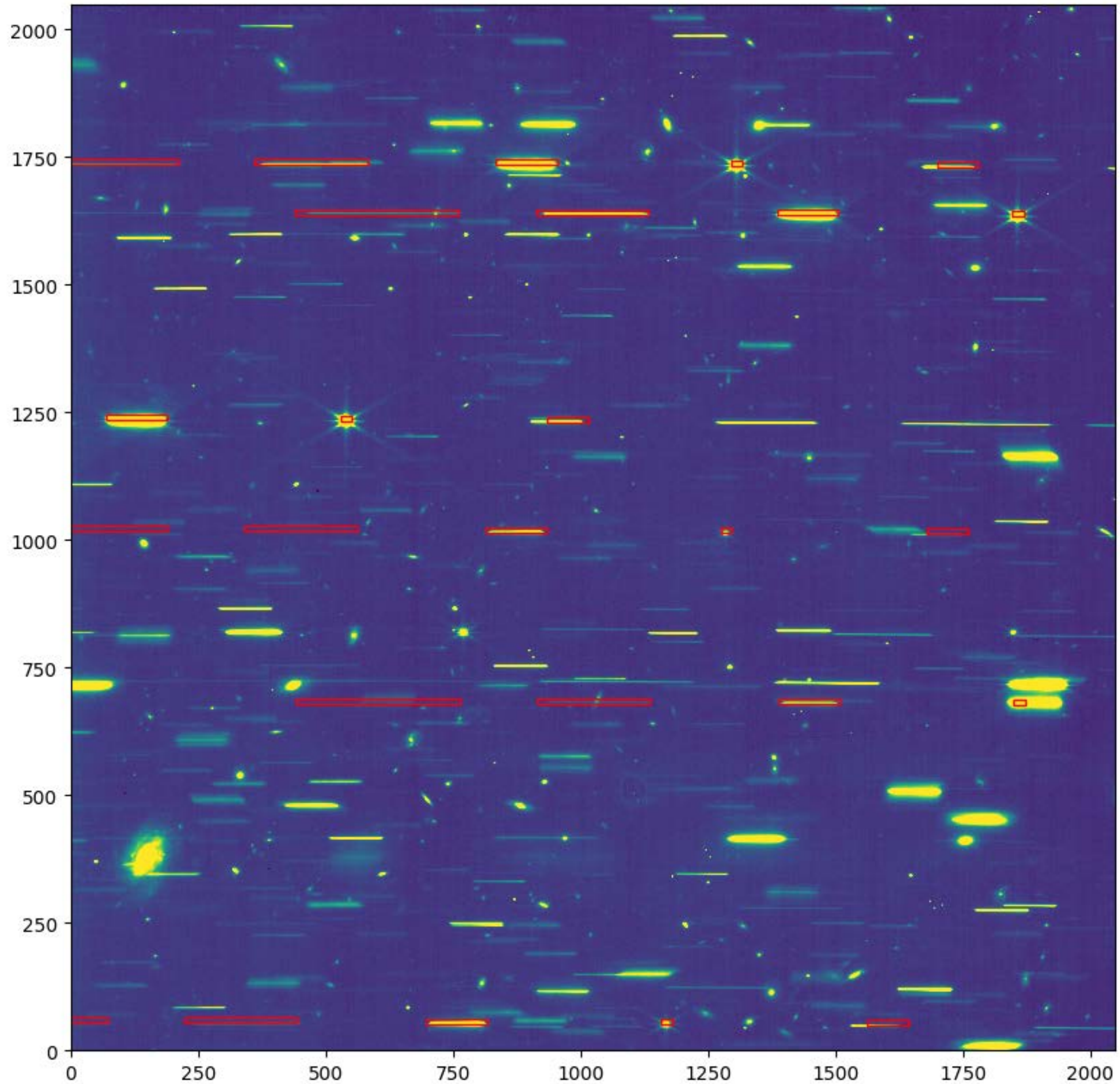

Figure 4: The dispersed images for the WD1657+343 field using GR150C grism and F200W filter. The red boxes show the bounding boxes for the spectral orders of different stars using the reference files created using the NIS-015 commissioning data. There are clear offsets in the centering of the bounding boxes for the stars that are further away from the center. The curvature is larger for the higher orders and this may indicate that the curvature of the trace is not the the same as for the traces in the detector center. In commissioning, only the flux standard in the center was used for trace measurements. The spatial variation of the trace will require to be calibrated using suitable calibration data in future cycles. Note that 0th order spectrum at ~ (x=700, y=1800) has contamination from the +1 order of a bright star to the right of the detector edge.

The GR150R+F200W grism shows a significant departure from the traces observed in CV3 (Figure 3). As a check, the trace measurements were repeated using another star in the field and the results were the same. At this time, it is not clear why the spectral trace for GR150R+F200W is different, but we hope to address this in future by using other available data from commissioning and Cycle 1.

The data taken during commissioning only has suitable source in the center of the detector to measure the trace. For creating the reference files, we assumed that the trace is the same across the detector. However, from ground test done during the CV3 campaign it was clear that the curvature of the trace shows spatial dependence. We plan to use further calibration observations in future cycles to map the spatial variation of the trace by observing a suitable bright star placed in the four corners of the detector using the mosaic option in the APT.

5 Creation of reference files

The information about the NIRISS WFSS trace is required in the specwcs reference files for the JWST pipeline to enable spectral extraction. The trace information is also required for creating the .conf files used by the MIRAGE simulation tool to simulate the NIRSS WFSS spectra. The .conf files contain information about the trace polynomials and their spatial variation across the detector. The trace polynomials are defined in the same way as done for the HST/WFC3 grisms and are described in detail in Pirzkal et al. (2016) and Pirzkal & Ryan (2017). The reference files were created in two steps. First, the .conf files were created using the script provided by N.Pirzkal (Private communication) based on the formalism described in Pirzkal & Ryan (2017) and using the NIRCam grismconf python modules. In the second step, the .conf files were converted into specwcs files using the format required for the JWST pipeline datamodels.

In order to prepare for the creation of reference files, the traces measured in step 4 in the previous section are used as the starting point. For each filter+grism combination, the trace measurement results in an output file with the delta_X (along the dispersion axis) and delta_Y (along the cross-dispersion axis) for the GR150C grism. The delta_X are converted to wavelength units using the dispersion solution from NIS-016 commissioning program (Pacifici et al. 2022). The wavelength calibrations for the higher orders are determined from the basic grating equation since those are not directly measured in the NIS-016 program. For each spectral order (-1, 0, +1, +2, and +3), the creation of the .conf file requires an input file with Xref, Yref, wavelength, delta_X, and delta_Y. The input file also includes the same set of information for a grid of Xref, Yref positions on the detector. Ideally, there may be spatial variation of the trace. However, since we did not determine the traces by using a bright star placed at different positions along the detector, we assume that the delta_X and delta_Y are the same across the detector (see Figure 4). For the GR150R the only difference is that the trace measurement results in delta_X (along the cross-dispersion axis) and delta_Y (along the dispersion axis). The input parameter files are used to create the generalized 2D polynomials and written into the .conf files that can be read using grismconf. The .conf files were then converted into the specwcs reference files in ASDF format and delivered to the CRDS for use with the JWST pipeline.

6 References

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