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JWST TECHNICAL REPORT

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1 Abstract

This series of JWST Technical Reports comprises five parts, one for each SI. It describes and documents the S&OC's Science Instrument Aperture File (SIAF) as implemented for that SI, in this case NIRSpec. This series is a complement to *Description and Use of the JWST Science Instrument Aperture File,* JWST-STScI-001150, Rev. A, 2017, by Cox & Lallo, which should be considered prerequisite reading.

The drivers and rationale for the NIRSpec-specific SIAF implementation are provided, together with references to the various sources of the pre-flight data. This report should thus serve as a resource for the "certification" of the flight-ready SIAF as installed in the PRD release PRDOPSSOC-G-010, by providing the pedigree of the content, with traceability to its sources, whether optical models, ground-test measurements, or science operational expectations.

The introduction refers readers to SIAF general documentation then summarizes the salient characteristics for the NIRSpec implementation. The use of the NIRSpec Parametric Instrument model in the SIAF are discussed in detail as are ways in which NIRSpec departs from the usual SIAF conventions. NIRSpec's major coordinate frames and transformations are then covered, followed by an inventory and discussion of the particular entries (SIAF "Apertures").

Importantly, a section on the source Excel file's logic and processes highlights some of the connections and calculations used within the SIAF spreadsheet to a level sufficient to inform the maintenance of the spreadsheet and the understanding of the considerations, dependencies, and impacts of changes to various parameters or characteristics such as when updating NIRSpec on-orbit. Such plans for initial in-flight geometric characterizations are briefly referenced.

Appendices contain a "snapshot" of the NIRSpec SIAF pre-flight data as delivered and described here, references to the corresponding PRD (Project Reference Database) files themselves, and visualizations and plots.

2 Introduction

2.1 SIAF Overview

The SIAF contains the characteristics of the JWST Instruments' SCAs, along with sub-regions and various fiducial points of operational interest, described in the basic relevant coordinate systems, along with the parameters used in the transformation between these systems. The primary SIAF products, feeding other systems, are five XML files, one for each instrument, residing as part of the S&OC PRD. These files are read and utilized by a variety of S&OC

subsystems spanning three main areas of S&OC operations: pre-observation (science proposal planning), execution (target placement and pointing), and post-observation (science pipeline). See Cox & Lallo (2017) Section 2 for details.

The SIAF XML specification, provided in Groebner (2017), defines a "SiafEntry" and its elements. Each unique SiafEntry is commonly referred to as an *aperture* and the elements contained within as *fields*. The SIAF captures certain basic geometric characteristics (in various frames) of the usable modes, subarrays, coronagraphs, physical apertures, etc., or stated more generally, any unique targetable fiducial point and an associated region, used in support of JWST science operations. So in the context of the SIAF the term *aperture* is used by the S&OC in this broad sense.

While the XML file is the PRD product used by the S&OC systems, the source information used to produce the XML is maintained, calculated, and updated via an Excel spreadsheet in which the XML SiafEntry and fields map to rows and columns These spreadsheets (one for each instrument) are currently maintained by the Telescopes Team within the Instruments division at STScI. They contain logic for calculating aperture information based on the SI teams' or ISIM group's ground or flight characterizations, and for relating the various apertures as appropriate. Some content is derived and calculated external to the spreadsheet, which then houses the resulting values. Much of the remainder of this document serves to detail these calculations and definitions for the SIAF content specific to NIRSpec.

2.2 The NIRSpec Parametric Model

NIRSpec SIAF entries and coordinate transformations are based on the parametric instrument model developed by the NIRSpec IDT (Dorner et al. 2016), and updated based on lamp observations taken during ISIM CV3 (Giardino & Luetzgendorf 2015). Giardino 2013, (NTN-2013-011), introduces this model, and a high-level overview is illustrated in Figure 1. The optical path is divided into four modules, OTE (optical telescope element), FORE (fore-optics), COL (collimator optics), and CAM (camera optics), with two additional modules called IFUFORE and IFUPOST for optical paths involving the IFU. The model calculations supply the transforms between the coordinate systems of the principle image and pupil planes bounding each of these modules. Mathematically, each of these transforms consists of three parts as described in Ferruit et al. 2008, NIRS-CRAL-MO1004.

1. A rotation around a specified center, corresponding to the nominal rotation introduced by an equivalent ideal optical system.
2. A homothetic transform with same center as the rotation, corresponding to the magnification or reduction introduced by the equivalent ideal optical system.
3. A 2D polynomial containing the remaining distortions in the transform. In the NIRSpec instrument model, these polynomials are of 5^{th} degree in the image or pupil plane coordinates. For the FORE module, due to the inclusion of a selectable transmission optical filter that resides in the Filter Wheel Assembly (FWA), each of these polynomial terms are assumed to be a linear function of wavelength, leading to a doubling of the total number of coefficients. The COL and CAM transforms are assumed to be achromatic (Dorner et al. 2016).

In the NIRSpec parametric instrument model, the "forward" direction is defined as going from the sky towards the detector. Equations for performing the transformations in both the "forward" and "backward" directions are described in Ferruit et al. (2008), and a 2nd set of polynomial distortion coefficients for the "backward" direction are included in in the reference files that describe the parameterization of the coordinate transforms between the main optical planes. Since the FORE optics module includes the filter wheel assembly (FWA) there is a separate transformation and associated data file for each of the FWA positions: CLEAR, F070LP, F100LP, F110W, F140X, F170LP, and F290LP.

For the forward transformation between two image planes, the rotation and homothetic part of the transform is given by

$$x - x_c^{out} = \gamma_x \times \left[+\cos(\theta)\times\left(x_{in} - x_c^{in}\right) + \sin(\theta)\times\left(y_{in} - y_c^{in}\right)\right] \quad \text{(Eq. 1)}$$

$$y - y_c^{out} = \gamma_y \times \left[-\sin(\theta)\times\left(x_{in} - x_c^{in}\right) + \cos(\theta)\times\left(y_{in} - y_c^{in}\right)\right] \quad \text{(Eq. 2)}$$

after which the 2D polynomial transforms are applied to complete the transformations using the equations

$$x_{out} = \sum_{i=0}^{n} \sum_{j=0}^{n-1} a_{ij}^{x,f}(\lambda) \times x^i \times y^j \; with \; a_{ij}^{x,f} = \alpha_{ij}^{x,f}\lambda + \beta_{ij}^{x,f} \quad \text{(Eq. 3)}$$

$$y_{out} = \sum_{i=0}^{n} \sum_{j=0}^{n-1} \mathrm{a}_{ij}^{y,f}(\lambda) \times x^i \times y^j \; with \; a_{ij}^{y,f} = \alpha_{ij}^{y,f}\lambda + \beta_{ij}^{y,f} \quad \text{(Eq. 4)}$$

Very similar equations are applied for the backwards transforms and for transforms between image and pupil planes. See Ferruit et al. 2008 for full details.

The applicable modules of the parametric model, their bounding planes, (note that the field stop is located at the OTE image plane –OTEIP), and the delivered reference file names containing the respective transforms are listed in Table 1. While the IFU transforms themselves are not directly included in the SIAF file, the IFU FORE module is needed to calculate how the individual elements of the IFU Slicer project onto the sky and it is therefore used to create the IFU SLIT entries needed for the SIAF.

An additional complication is caused by the non-perfect repeatability of the NIRSpec Grating Wheel Assembly (GWA) mechanism (e.g., Alves de Oliveira 2015, 2016). This can cause a small but significant shift of up to a few pixels in the location of images or spectra at the detectors and needs to be considered by using the GWA X and Y tilt sensor measurements when calculating the projection of the MSA plane positions onto the FPA plane. The details of this transformation for the special case of the MIRROR optical element when used for target acquisition are discussed by Giardino et al. 2014 (NTN-2014-005), and the equations are reproduced below in section 5. For the case where the GWA is at its nominal MIRROR position, this part of the transformation reduces to a change in sign in both GWA coordinates.

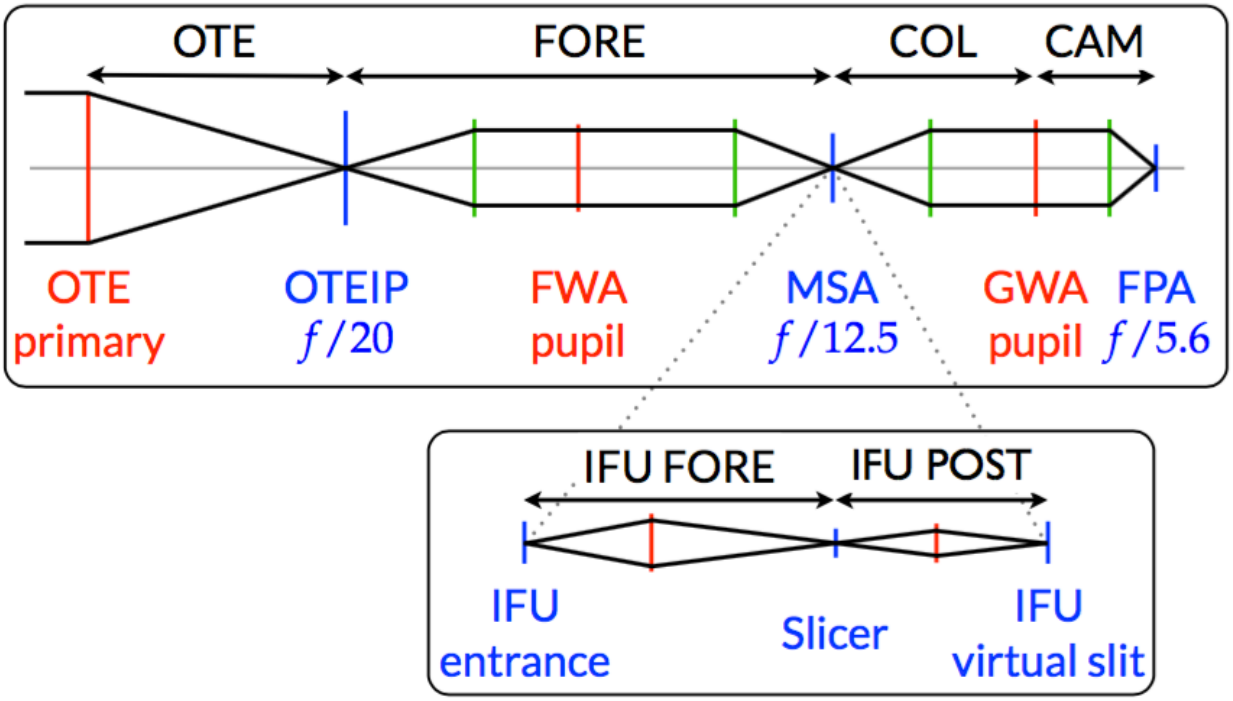


Figure 1: This illustration from Dorner et al. (2016) shows the paraxial layout of the JWST telescope and NIRSpec optical train with elements at principal planes, and the insert for the IFU case. Focal planes are blue, pupil planes red. All these elements are encapsulated in the NIRSpec parametric model.

Table 1: Transformations in the NIRSpec Parametric Model for its six modules and for the reflection at the GWA pupil plane.

Module	Input Plane (type)	Output Plane (type)	Transform Filename
OTE	V2/V3 (angular)	OTEIP (position)	OTE.pcf
FORE	FIELD-STOP (position)	MSA (position)	Fore_*.pcf
COL	MSA (position)	GWA-ORF in (cosine)	Collimator.pcf
CAM	GWA-ORF out (cosine)	FPA (position)	Camera.pcf
IFU FORE	IFU Entrance (MSA in)	Slicer reference	IFU_FORE.pcf
IFU POST	Slicer reference	IFU Virtual Slit (MSA out)	IFU_POST_*.pcf
“GWA”	GWA-ORF in (cosine) detector side	GWA-ORF out (cosine) sky-side	Disperser_*.dis, disperser_*_TiltX.gtp, disperser_*_TiltY.gtp

2.3 Application of the NIRSpec Parametric Instrument Model in the SIAF file

The uses of the NIRSpec rows in the SIAF files can be divided into three different functions, although for some of these cases multiple SIAF rows need to be combined to achieve the desired purpose. The implementation of these transforms differs significantly from the usual SIAF conventions defined by Cox & Lallo (2017), especially as regards the role of the ideal plane in the coordinate transformations. The detailed information for each SIAF row will be discussed in the appropriate parts of section 4 below. In this introduction we will provide high-level overview of how the parametric model is translated in SIAF entries for each of the three major use cases, MSA planning, Target Acquisition Transformations, and Aperture Locations.

2.3.1 Departures from normal SIAF Coordinate system conventions

As discussed in Cox & Lallo (2017), "V-frame" coordinates are normally used to specify field-angle positions in the OTE field of view. The normal SIAF convention, as detailed in section 3.1.3 of Cox & Lallo (2017), is that the polynomial distortion coefficients effect a transformation from pixels in a detector SCI frame to ideal frame coordinates which are treated as locations in a tangent plane projected onto the V-frame, but with a local coordinate system centered on the reference point of the aperture in question, and oriented with the aperture. The final transformation to the V-frame is then accomplished with a simple translation and rotation using the SIAF columns V2Ref, V3Ref, and V3IdlYAngle.

This approach cannot be used directly for NIRSpec, as the non-repeatability of the Grating Wheel Assembly (GWA) requires splitting this transformation into at least two pieces, with a correction for the measured GWA positions applied in between (see section 2.3.3).

Moreover, the OSS code for NIRSpec target acquisitions, (sections 2.3.3 and 4.2), was written to expect transformation polynomials that convert coordinates to the XAN/YAN coordinate system, (where XAN = V2 but YAN = −v3−0.13 degrees), rather than either the usual ideal coordinate system or V2/V3. Because of the overhead associated with modifying the OSS code it is necessary that the polynomial transformations coefficients provided in the CLEAR_GWA_OTE, F110W_GWA_OTE, and F140X_GWA_OTE SIAF rows of type TRANSFORM continue to conform to this alternate convention. Note that these transforms are the only places in the NIRSpec SIAF file were XAN/YAN coordinates are used instead of V2/V3.

The final stage of the MSA planning transformation, (sections 2.3.2 and 4.7.2), also go directly to the OTE field-of-view, rather than to an ideal coordinate system, although in this case they do use V2/V3 rather than XAN/YAN.

While the NIRSpec detector-to-sky transformation calculations bypass the ideal plane, it is still necessary to define the ideal plane in many cases. The vertices used to define the aperture corners are defined in the SIAF using the ideal frame, while for those SIAF rows used as reference for telescope pointing the Ideal plane is the frame used to specify dithers and offsets.

2.3.2 MSA planning

The overall error budget for planning NIRSpec MSA observations requires that targets be placed with respect to the MSA with an accuracy of better than 10% of a microshutter's width, which is equivalent to about 20 mas on the sky (Böker 2008). The accuracy of the transforms is only one of a number of contributions to the total error budget. The requirements detailed in Böker 2008 allocate 5 mas for the accuracy of the transformations that align the MSA to the SCAs and the sky to the SCAs, (see their Figure 3.3-2). The information for performing the SKY-to-MSA transformation is included in the SIAF by directly transcribing the coefficients from the parametric model OTE and FORE modules into SIAF TRANSFORM rows.

The OTE module maps into the NRS_SKY_OTEIP SIAF row, while for each FWA filter the FORE module maps into a pair of TRANSFORM rows, one including the polynomial coefficients at zero wavelength and the other with the linear dependence on wavelength. As an example, for the CLEAR filter wheel position the AperName for these rows are NRS_CLEAR_OTEIP_MSA_L0 and NRS_CLEAR_OTEIP_MSA_L1 respectively.

For these transforms, the polynomial distortion coefficients, (Eqn. 3 above), are recorded in the SIAF columns normally used for the SCI2IDL and IDL2SCI transformation polynomial coefficients, while the homothetic portion of the transform from each of these modules that includes the rotation, scaling, and coordinate system origin shifts, (Eqns. 1 & 2), is recorded using the existing SIAF column names as detailed in Table 5.

The ordering of the polynomial distortion coefficients for these MSA transform rows in the SIAF file follows the IDT parametric model convention of considering the "forward" direction to be from the sky towards the detector. To reflect this, the coefficients for these transformations in this direction are placed in the SIAF columns named "Sci2Idl*", while the coefficients for the reverse transformation in the direction away from the detector and towards the sky are in the columns named "Idl2Sci*". This is the opposite of the usual SIAF practice. See Table 4 for additional details about how these coefficients are stored in the SIAF.

The SIAF concepts of the SCI and ideal planes are completely bypassed in these MSA transformations, as the application of the transforms in the NRS_SKY_OTEIP row goes directly from V2/V3 coordinates to the OTEIP image coordinates, while the OTEIP_MSA row transforms go directly from there to the MSA image plane coordinates.

These SIAF rows contain the transforms necessary to calculate how positions on the sky translate to positions on the MSA, but they do not contain any information about the sizes or locations of the individual MSA shutters. The exact physical information for the MSA such as shutter pitch in both directions as well as shutter inner dimensions are provided in the MSA.msa FITS file that is delivered as part of the parametric model and incorporated separately into the Proposal Planning System (PPS).

SIAF TRANSFORM rows for the conversion between the OTE image plane and the MSA plane are provided for all NIRSpec FWA filters. In principle, this can allow the MSA planning tool to optimize the pointing and shutter configuration for any supported filter combination. Currently, (PPS 14.1 and APT 25.1.1), the MSA planning tool only uses the SIAF information for the clear aperture at a nominal wavelength of 2 microns. This may be updated in the future to allow the observer to choose the grating and filter for which the MSA configuration in a particular observation is optimized.

2.3.3 Target Acquisition Transforms

When performing target acquisition with NIRSpec it is necessary for the Onboard Scripting System (OSS) to translate the measured positions of stars on the detector into the equivalent locations in the OTE plane. This then allows calculation of the slew needed to achieve the desired pointing of NIRSpec on the sky. Since these transformations need to be done on the spacecraft for as many as 20 reference stars at two different dither positions, applying the full set of transformations for each of the modules in the NIRSpec Parametric model was judged to be too resource intensive and a simplified form of the calculation was developed (Giardino, Ferruit, & Alves de Oliveira, 2014). However, since the exact position of the GWA as measured by the mechanism positioning sensors needs to be taken into account when calculating the reflection at the MIRROR, the transformation still involves three separate steps. Full details of the equations are presented in section 5.5, but we will summarize the purpose of each step here.

1. Transform the xy pixel location measured in either the SCA491 or SCA492 detector to angular coordinates at the GWA pupil plane (detector side).
2. Compute the angular coordinates at the GWA (skyward side), given the detector side angular coordinates, and the measured values for the GWA positioning sensors.
3. Transform the angular coordinates at the GWA (skyward side) to OTE coordinates, XAN/YAN, on the sky. (OSS then immediately converts XAN/YAN to V2/V3).

The first piece, covering the transformation from each of the detector's SCA planes to the GWA, corresponds to the CAM module in the parametric model. In the SIAF there are two rows for each of the detectors that contain this information. The NRS1_FULL_OSS and NRS2_FULL_OSS rows are of AperType OSS, while the NRS1_FULL and NRS2_FULL rows are of AperType FULLSCA. The OSS and FULLSCA rows for each FPA encode exactly the same transformation in slightly different forms.

In both cases, the transformation is assumed to start from the detector coordinates, where for NIRSpec the slow read direction is considered to be the detector (DET) X coordinate and the fast read direction detector Y. The sequence assumed in these SIAF rows starts off following the normal SIAF conventions for OSS and FULLSCA rows, in that the DET coordinates are first converted to a SCI frame and then the polynomial distortion coefficients are applied. However, instead of going to an ideal plane (IDL) as is the usual SIAF convention, application of this polynomial transformation instead goes directly to the GWA pupil plane. This requires inclusion of the rotation and homothetic parts of the parametric model module into the polynomial coefficients along with the distortion terms.

The OSS and FULLSCA rows differ only in the requirement that for the OSS rows the SCI frame be defined to be identical to the DET frame. For NRS2_FULL where the definition of the SCI frame differs from that of the DET frame, the polynomial coefficients are redefined so the net transformation from the DET to GWA plane is the same as is obtained when the NRS2_FULL_OSS row is used.

The second step applies the reflection in the MIRROR taking into account the correction to the GWA position as derived from the sensor readings and their calibration relation. The four coefficients needed for this calculation are taken from columns L through O of the CLEAR_GWA_OTE, F110W_GWA_OTE, or F140X_GWA_OTE SIAF rows of type TRANSFORM. Since in the case of the MIRROR light is only reflected, the relation is wavelength-independent and each coefficient was simply repeated in all three rows.

The final part of the transformation then goes directly from the GWA pupil plane to the sky. This requires combining all of the rotations, scaling factors, and distortions in the parametric model OTE, FORE, and COL modules into a single set of polynomial coefficients. These polynomial coefficients are also stored in the CLEAR_GWA_OTE, F110W_GWA_OTE, or F140X_GWA_OTE SIAF in rows AH onwards, and in this case the coefficients will depend on the filter in use. In principle these transforms are wavelength dependent, but for these rows the 2D polynomial coefficients are set to the values they have at a fixed wavelength for each filter (2.5, 1.1, and 1.4 μ for the CLEAR, F110W, and F140X filters respectively).

The original set of these coefficients that were delivered during early OSS code development transformed to XAN/YAN coordinates rather the more usual V2/V3, where XAN = V2 but YAN = −v3−0.13 degrees[1].

The SIAF rows used for the TA transforms follow the usual SIAF convention that the "forward" direction corresponding to the first set of polynomial coefficients in a given row is for the transformation in the direction going away from the detector and towards the sky. This is the reverse of the convention adopted for the polynomial coefficients in the rows used for the MSA transforms discussed above.

Although the usual SIAF ideal plane is completely bypassed in these target acquisition calculations, in the OSS and FULLSCA rows an ideal plane is nevertheless defined by choosing a reference point near the center of each detector and using the combined TA transformations to project the detector reference points and corners onto the sky. The adopted values assume the CLEAR filter and the nominal GWA MIRROR sensor positions. These ideal coordinates are also a bit unusual in that projecting the detector onto the sky in this way includes portions that are blocked from the sky in imaging mode. The vertices given in the ideal frame of the FULLSCA or OSS rows are not trimmed to reflect this vignetting.

2.3.3.1 Derivation of "rolled-up" transforms

The TA transforms have been derived from the full NIRSpec Parametric Model by:

i) folding together the computation of the focal plane position from a detector pixel coordinate and the transformation from FPA to GWA plane to derive the polynomial coefficients of the SCA-to-GWA transforms listed in in the files:

- delivery_SCA491toGWA.pcf
- delivery_SCA492toGWA.pcf

ii) folding together the COL transform, the FORE transform for the three TA acquisition filters and the OTE transform, where the OTE plane coordinate system is that of XAY-YAN to derive the polynomial coefficients of the transform GWA-to-OTE listed in the files:

- delivery_CLEAR_GWA2XanYan.pcf
- delivery_F110W_GWA2XanYan.pcf
- delivery_F140X_GWA2XanYan.pcf

Note that in this case the forward direction of the transforms goes from the detectors to the sky.

The polynomial coefficients for these transformations were derived by creating a grid of more

[1] Since the OSS code was written to conform to this convention it remains necessary that the coefficients delivered for these rows of the SIAF file continue to follow it, even though the first action that the OSS performs after calculating the XAN/YAN position of a reference star is to convert it back to V2/V3!

than 400 points at each SCA and then using the geometrical transforms of the Parametric Model to derive their coordinates in the GWA planes (input and output plane) and the OTE plane. The coefficients of the TA transform SCA-to-GWA and GWA-to-OTE where then computed by fitting the coefficients of the fifth order polynomials in x and y (21 coefficients) defining these new transforms.

2.3.3.2 Accuracy of the TA transforms with respect to the Parametric Model

The TA transform are therefore an approximation of the transforms of the Parametric Model. To assess the accuracy of the TA expressions, the coordinates of the grid of points on the sky transformed from the SCA grid points and computed with the TA transforms ware compared with those computed using the Model. The results in terms of difference between the two sets of transformed points are displayed in Figure 2.

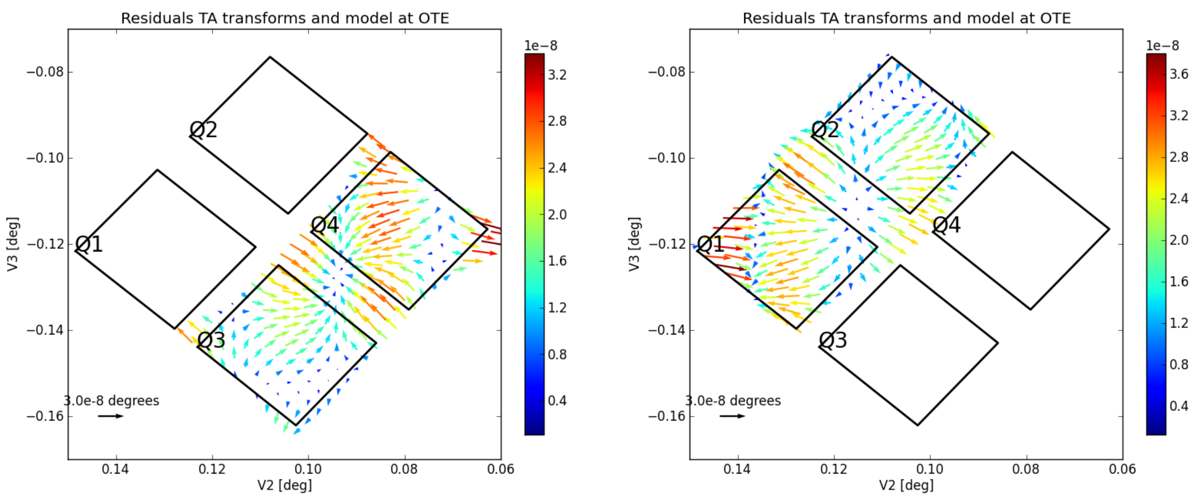


Figure 2: Residuals between the coordinates of the grid-points from SCA491 (left) and SCA492 (right) transformed to the Sky-plane with the TA transforms and the transforms of the Parametric Model. Note that in the figure the sky coordinates are in V2-V3, although the TA transforms land in the sky plane in XAN-YAN.

The average value of the difference between the two coordinate sets is 0.006 mas with an RMS of 0.065 mas, in the absence of any GWA tilt away from the model reference position. The maximum value of the difference is approximately 0.13 mas.

Besides the fitted transformations between the detectors and the sky, the TA algorithm also include a linearization of the transformation between the input and output plane of the GWA when using the mirror, (see section 5.5.2), which will also introduce a discrepancy with respect to the (geometrically exact) transforms of the Parametric Model. Including representative values for the GWA tilt in X and Y, e.g. delta theta $\delta\theta_X$ = 0.07 arcsec and $\delta\theta_Y$ = 29.62 arcsec, the average difference between the coordinate sets on the sky derived with the TA transforms and the Parametric Model transforms is 0.007 mas, with a RMS of 0.065 mas.

These differences are all very small relative to the accuracy requirements discussed in section

2.3.2.

2.3.3.3 Other uses of the TA Transforms

In addition to being used by OSS to translate the measured position on the detector into a location in the JWST's image plane, PPS also needs to provide the locations of the 32x32 pixel "postage stamp" extraction regions where each reference star is expected to be located. This requires performing the above transformation in the "reverse" direction, taking an expected location on the sky and converting it to a detector location in pixels. For this calculation, it is assumed that the GWA is at its nominal MIRROR position, and the result is rounded to an integer pixel. Since the actual GWA position will not be known in advance, this leads to an uncertainty of several pixels in the APT prediction for this location. For the reference star to be used, the centroid location found by scanning a 3x3 checkbox must be in the interior of the postage stamp predicted by APT. So, this GWA offset needs to be considered in the budget for the required initial pointing accuracy, even though it is properly taken into account in the OSS calculations.

2.3.4 Aperture Locations

The NIRSpec SIAF file also contains several rows of AperType=SLIT that correspond to physical apertures and other locations in the MSA and SLICER planes. A full list will be given in section 4.5. Unlike the TA or MSA transformations, for these rows an ideal coordinate system is needed to set the coordinate system for dithers and offsets when an observation is using that aperture.

The parameters for these slit locations were provided by the IDT by using the parametric model to predict the V2/V3 locations for each slit's centers, corners, and angles based on the corresponding physical locations in the in MSA or SLICER planes. The SIAF rows for these entries contain the V2 and V3 reference locations, the angle between V3 and the ideal frame for each aperture, and the coordinates of the four vertices of each aperture in the ideal frame. However, the information on the physical location of each aperture in the MSA plane is not recorded in the SIAF itself.

The positions at which the NIRSpec slits project onto the sky will depend on filter and wavelength, but for the SIAF file, the V2/V3 slit positions are calculated assuming the CLEAR filter at a wavelength of 2 microns.

The SLITs included in the SIAF for NIRSpec include each of the fixed slits and the IFU. There is also a SLIT entry for each individual IFU slice, and a number of rows for the MSA. A full discussion of these SLIT rows can be found in section 4.5.

3 NIRSpec Frame Relationships

3.1 Basic Frame Characteristics

The basic coordinate frames used in the NIRSpec SIAF are illustrated in Figure 3 and Figure 4. These frames are defined initially for the FULLSCA rows that are intended to present the primary representation of how the detectors project onto the sky.

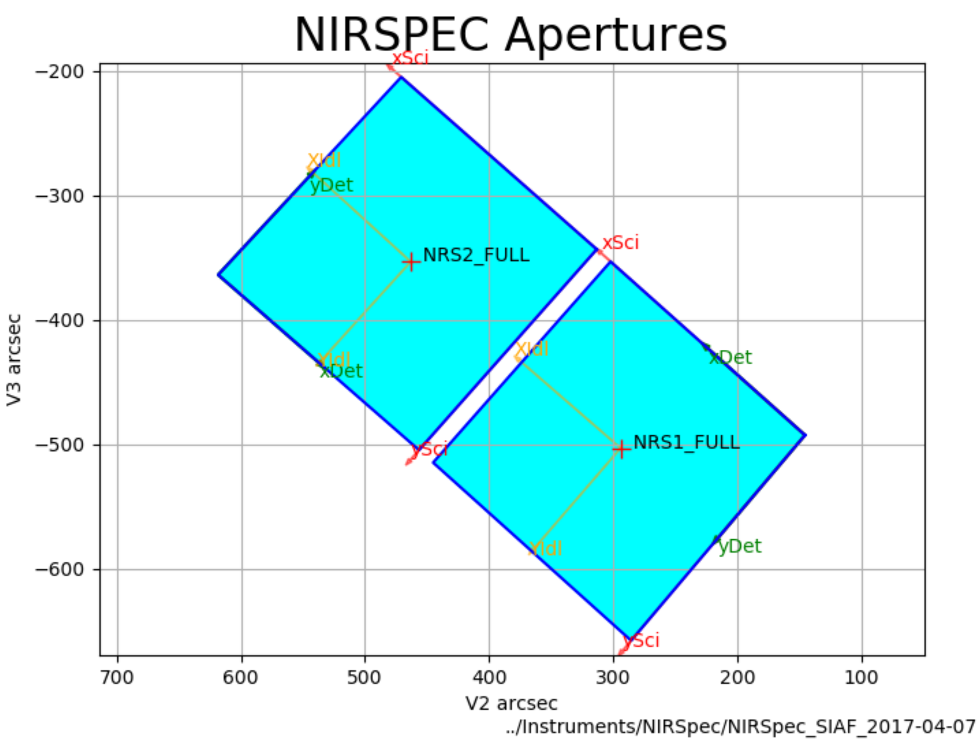


Figure 3: NIRSpec coordinate systems as defined for the NRS1_FULL and NRS2_FULL entries of AperType= FULLSCA.

3.1.1 Detector Frame

For NIRSpec, the (X, Y) detector pixel coordinates correspond to the (slow, fast) or (row, column) readout directions. The relationship between detector (DET) and science (SCI) pixels involves only axis rotations of 90 degree multiples. A special treatment has been arranged for OSS operations that keeps the Science coordinate system identical to the detector layout. This is to avoid an extra on-board calculation step. For non-OSS apertures and with post observation analysis in mind, a Science coordinate system is defined to represent a normally displayed image with the x axis running from left to right and the y axis pointing upward. An (x,y) pair is defined in each system referring to a matching reference pixel thereby fixing the science aperture on the detector. In the NIRSpec FULLSCA rows, the SCI frame is identical to the detector frame in NRS1, but in NRS2 it is rotated by 180 degrees with the coordinate system origin shifted to the opposite corner. In the OSS rows, the SCI frame is defined to be identical to the detector frame.

3.1.2 Ideal Frames

For most instruments, the polynomial coefficients are used to transform between SCI coordinates and the ideal frame for each aperture. As discussed in sections 2.3.3 and 3.2, for NIRSpec a different approach is used, and the ideal frame is bypassed when transforming between detector and OTE coordinates. Since the ideal frame may still be needed to define the aperture vertex entries, for display on the sky, and to define the frame for dithers and offsets, the ideal frame for many apertures still needs to be defined. OSS ideal coordinates have been defined to have the same parity as the V2V3 whereas the FULLSCA versions match those used in DMS and have a negative parity so as to provide a conventional x,y image view. This is accounted for in the SIAF parameter VIdlParity.

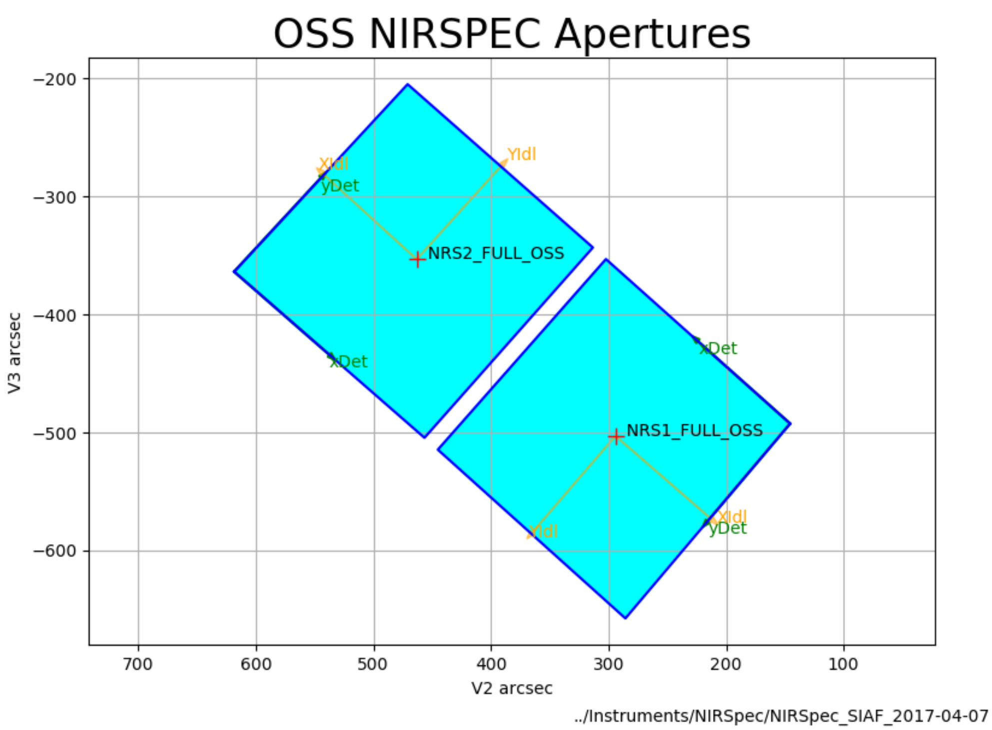


Figure 4: NIRSpec coordinate systems as defined for the NRS1_FULL_OSS and NRS2_FULL_OSS entries of AperType=OSS.

3.1.3 V2V3 Frame

Each reference point also has a corresponding V2V3 position defining where it is placed in the telescope coordinate system. To transform from ideal to V2V3 the ideal coordinate system about this point is rotated about this point and the offset corresponding to the V2V3 reference values is applied.

3.1.4 Normal SIAF FRAME Conventions

XDetSize and YDetSize give the size of the detector or SCA on which the aperture is defined. These are given in pixels and for NIRSpec are always equal to 2048. XSciSize and YSciSize give the aperture size, also in pixels. For OSS and FULLSCA types these will be identical to the detector sizes. XDetRef and YDetRef give the pixel position of a reference point on the detector, assuming the count of indices in each axis starts from 1 for the first pixel. Typically, this reference point is at the geometrical center of the detector but this is not a SIAF requirement. This might be changed later if, for instance, we find some detector blemish that makes the area containing this point unusable.

XSciRef and YSciRef refer to the same position counted in aperture pixels. For apertures occupying the full detector these are forced to be the same as the detector numbers except where detector and science axes are in different directions. There are FULLSCA apertures used purely for telescope focusing containing MIMF in their names. These are almost identical to the FULL apertures except that they have non-central reference positions. For the NRS2 FULLSCA apertures the axes are in opposite directions and so the XSciRef and YSciRef differ from the XSciDet and YSciDet. In fact XSciRef = 2047-XDetRef and YSciRef = 2047-YDetRef for these cases referring to exactly the same pixel.

DetSciYAngle and DetSciParity relate the Science coordinates to the Detector coordinates. Figure 1 shows that the Science axes are aligned with the Detector axes for NRS1 but are opposite for NRS2. This is expressed by setting DetSciYangle to 0 and 180 in turn. The parity is +1 in both cases. For the OSS case we require that the Detector and Science arrays be identical, so DetSciYAngle is zero and DetSciParity is +1for both detectors.

For the DMS processing (SCI frame) we choose the ideal coordinates y axis for NRS1 to align exactly with the Detector Y. The ideal x axis is then normal to this axis but may not be exactly along the Detector x axis due to the distortion between the detector and ideal frames. In the detector plane, the NRS1 is defined to have zero rotation. CV3 results found that the NRS2 has a rotation angle with respect to the x-axis (dispersion direction) of 1.49359632455e-05 radians (positive anticlockwise). These conventions are described in document ESA-JWST-TN-20931 (Giardino 2015), and the rotation angle in the detector plane is included in the parametric model file "FPA.fpa" under the label SCA492_RotAngle.

For NRS2 the ideal y is opposite to the Detector y thus making it align approximately with the NRS1 ideal directions and both Science axis directions. The parity with respect to the V2V3 axes, named VIdlParity, is -1, meaning that the rotation from x toward y is opposite to that from V2 to V3. For OSS, the ideal directions have been defined as shown implying that the V2V3 parity is +1.

3.2 Distortion Polynomials

The distortion polynomials used in NIRSpec FULLSCA, OSS, and TRANSFORM entries are derived from the NIRSpec IDT's Parametric Instrument Model (see section 2.2 above and Dorner et al. 2016). The replacement of the NIRSpec MSA and detectors in early 2015, necessitated a revision of this model, and it was re-optimized as described in Giardino & Luetzgendorf (2015) by using a series of internal lamp exposures obtained during the ISIM-CV3 test. This recalibrated parametric model was then used to generate the distortion coefficients and other parameters needed for the NIRSpec SIAF entries. They will be updated during commissioning.

3.2.1 SIAF implementation of distortion.

For the TRANSFORM rows, NRS_SKY_OTEIP and NRS_*_OTEIP_MSA_*, that are used for MSA planning, the full fit of the instrument model for the SKY-to-MSA mapping is included in the SIAF file.

As discussed in section 2.2.2 above, a combined version of the transforms is included in the OSS and FULLSCA rows for use in target acquisition calculations. Additional details of this SIAF implementation are given below in section 5.1.

3.2.2 OSS vs. DMS formulations.

For on-board target acquisition calculations, OSS uses a rolled up version of the transformations , which combine a number of the steps in the parametric model, and which also ignores the detailed wavelength dependence. The calibrations applied by DMS will make use of the complete NIRSpec parametric model. It is important that any changes to the parametric model are consistently propagated to both the DMS distortion reference files and the SIAF files. However, these files are otherwise independent. See section 2.2.2 above and section 5.5 below for additional details of the SIAF implementation.

4 Inventory of NIRSpec SIAF Apertures

The AperType Column was added to the SIAF in 2016 to clarify the intended use of different SIAF rows. Only some of the defined types are used for NIRSpec, and even for many of those the interpretation of the NIRSpec entries differ from the SIAF standard as specified in TR 001550 (Cox & Lallo 2017, pending revision).

4.1 AperType = FULLSCA

Apertures of type FULLSCA are intended to provide the primary representation for how JWST detectors project onto the sky.

NRS1_FULL and NRS2_FULL correspond to the two NIRSpec detectors and implement the basic detector coordinate systems as described in section 3.1. In addition, four of the five NIRSpec MIMF points are of AperType=FULLSCA. One of these is located in each MSA quadrant. These are NRS1_FP2MIMF, NRS1_FP3MIMF, NRS2_FP4MIMF, and NRS2_FP5MIMF. As discussed in sections 2.2.2, 4.7, and 5.1.3 of this document, the NIRSpec use and implementation of the FULLSCA rows differs significantly from the normal SIAF conventions.

The location of the MIMF points were initially decided upon at the June 2016 WFSCOWG Meeting to be a subset of all the ISIM CV test's field points denoted by "MIMF"# and "ISIM"#. These points have identical pixel values to those used in ISIM testing, or in the case of NIRSpec's slit-based point, have identical definitions (i.e. centered on the best-calibrated slit location in V-frame). These definitions, consistent with the ISIM tests, are captured in the *ISIM to OTE & Spacecraft IRCD* (aka the "IOS"), the RTC for which can be found as an attachment on JWSTSIAF-29, entitled *IOS_Test_Field_Point_Def_RTC_Oct2016.doc*.
One can trace the pedigree and implementation by the JWSTSIAF-29 attachment, *MIMF_points_SIAF_Preflight_Aug2016.xlsx*. That table gives implementation notes, references

the source material, and maps the SIAF AperName to the corresponding IOS/CV3 field point name.

4.1.1 Source of Coefficients

The polynomial distortion transforms given in the NIRSpec FULLSCA rows do not transform to V2/V3, but instead transform from the SCI frame to the GWA pupil plane. These distortion coefficients were calculated by the NIRSpec IDT from the parametric instrument model (Dorner et al., 2016) as updated using CV3 data (Giardino & Luetzgendorf 2015), and were delivered in the files `delivery_SCA491toGWA.pcf`, and `delivery_SCA492toGWA.pcf`. Some algebraic manipulations were performed on these coefficients, as has been done for the other instruments, so as to take as inputs the pixel displacements from the central reference position, (see section 5.1 for details). Additional transformations using information from one of the TRANSFORM rows CLEAR_GWA_OTE, F110W_GWA_OTE, or F140X_GWA_OTE need to be applied to complete the calculation of positions on the sky (see the discussions in sections 2.2.2, 4.7, and 5.5.3). The ideal plane specified in the FULLSCA row is not used for the detector-to-sky transformation, but is calculated retrospectively assuming that the CLEAR_GWA_OTE TRANSFORM is used to complete the calculation and that the GWA is at its nominal position.

4.1.2 Test Data for the TA Transforms

The NIRSpec IDT has delivered standard test data along with the CV3 delivery of the TA transform coefficients. For each combination of detector and TA filter, two fits files were delivered – one corresponding to the results for the nominal GWA tilt and one for an off-nominal GWA tilt value. These files are for verification/cross checking purposes only, and will continue to be included with future deliveries of new coefficients.

The test data contained in each file consists of a 21 × 11 grid. The points are chosen to cover the SCA detector coordinates from 1025 to 2060 in detector X, and −10 to 2060 in detector Y with a spacing of 103.5 pixels in each coordinate. Note that this includes some points that fall slightly off each detector, but excludes most of the detector area that cannot be imaged through the MSA.

At each grid point, x and y coordinates are supplied in the following image or pupil planes:

- SCA detector coordinates
- GWA "out" coordinates (section 5.1.2)
- GWA "in" coordinates (section 5.1.2)
- Coordinates on the sky in XAN/YAN units

The GWA and XAN/YAN coordinates are calculated from the detector coordinates using the simplified "rolled-up" versions of the transforms that are calculated for TA rather than the full model.

These following files were included in the `transforms_TA` directory of the CV3 delivery, and will be updated together with every new delivery:

- `/testDataNoTilt/testDataTA_SCA491CLEAR.fits`
- `./testDataNoTilt/testDataTA_SCA491F110W.fits`
- `./testDataNoTilt/testDataTA_SCA491F140X.fits`
- `./testDataNoTilt/testDataTA_SCA492CLEAR.fits`

- ./testDataNoTilt/testDataTA_SCA492F110W.fits
- ./testDataNoTilt/testDataTA_SCA492F140X.fits
- ./testDataWithGWATilt/testDataTA_SCA491CLEAR.fits
- ./testDataWithGWATilt/testDataTA_SCA491F110W.fits
- ./testDataWithGWATilt/testDataTA_SCA491F140X.fits
- ./testDataWithGWATilt/testDataTA_SCA492CLEAR.fits
- ./testDataWithGWATilt/testDataTA_SCA492F110W.fits
- ./testDataWithGWATilt/testDataTA_SCA492F140X.fits

In these fits files, the measured GWA sensor telemetry readings are included in the header keywords.

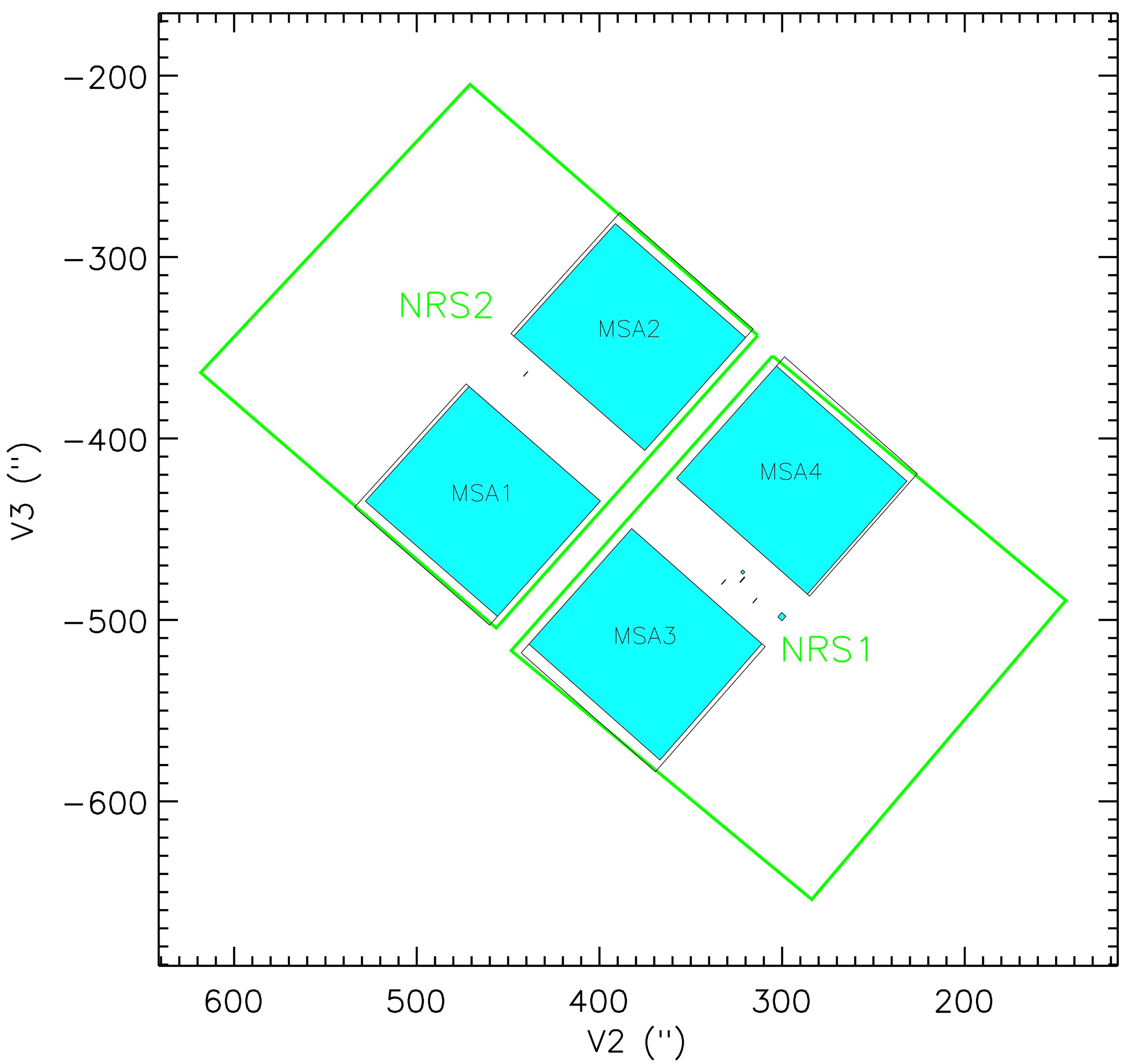


Figure 5: The footprints of the NIRSpec detectors are shown in V2/V3 by the green lines, and are compared with those of several SLIT SIAF entries, which are outlined by thin black lines. For the individual MSA

quadrants we show both the full extent of the MSA (SIAF entries NRS_FULL_MSA1, NRS_FULL_MSA2, NS_FULL_MSA3, and NRS_FULL_MSA4), as well as the somewhat smaller area of each MSA which can be used with external targets, (SIAF entries NRS_VIGNETTED_MSA1, NRS_VIGNETTED_MSA2, NRS_VIGNETTED_MSA3, and NRS_VIGENTTED_MSA4 shown in blue). Also shown are the fixed slits, and the IFU. The following three figures follow the same conventions as this one, but zoom in on the smaller details.

4.2 AperType = OSS

Apertures of type OSS are normally similar to the FULLSCA apertures, but include some differences in coordinate system definitions to meet OSS conventions. They should only be accessed by OSS and never by other subsystems.

NRS1_FULL_OSS and NRS2_FULL_OSS correspond to the two NIRSpec detectors and implement the basic detector coordinate systems as described in section 3.1. These encode the same transforms as NRS1_FULL and NRS2_FULL, however, the SCI and IDL coordinate systems in the OSS rows are defined to be consistent with the conventions expected by OSS.

4.2.1 Source of Coefficients

The source of the OSS coefficients are the same as for those used in the FULLSCA rows and is discussed in section 4.1.1.

4.2.2 Test Data

The same test data used for the FULLSCA rows applies, (section 4.1.2) to the OSS rows.

4.3 AperType = SUBARRAY

While NIRSpec uses subarrays for many spectroscopic observations and for some imaging target acquisition modes, these are not used to directly control the telescope pointing, and as such do not need corresponding entries in the SIAF file. For normal NIRSpec Operations SIAF entries of type SLIT are instead used as the pointing reference.

4.4 AperType = ROI

NIRSpec does not include any SIAF lines for ROIs.

4.5 AperType = SLIT

Most NIRSpec APT templates for external observations use a SIAF SLIT entry as the reference point for positioning of the target in the V2/V3 plane. This differs from many of the templates for other JWST instruments, which use FULLSCA or SUBARRAY entries as the pointing reference. The SIAF SLIT entries are also used by APT for display in Aladin.

The NIRSpec micro-shutter assembly (MSA) has four microshutter arrays, each with a 365 X 171 grid of micro-shutters. In addition, the MSA contains five fixed slits and an opening for the Integral Field Unit (IFU). SIAF rows of AperType=SLIT are used to represent these apertures in the SIAF file.

Because the filter wheel assembly (FWA) is in the optical path between the OTE and the MSA, the actual locations at which NIRSpec apertures will project onto the sky will vary slightly as a function of both the filter, (each filter has a slightly different residual wedge angle), in use and the wavelength being considered, (due to wavelength dependent dispersion of the glass material). To create the NIRSpec SIAF SLIT entries, the locations of the aperture corners on the MSA as tabulated in the NIRSpec parametric instrument model were projected to the V2/V3 plane for the case of the CLEAR filter wheel position at a wavelength of 2 microns by using the transforms discussed in section 2.2.2 and 5.1.

4.5.1 Source of Values

The SIAF SLIT entries are based on data delivered by the NIRSpec IDT. The data is delivered in a fits file, `positionsSIAFApertures.fits`, which contains one row for each SIAF entry of type SLIT. The reference positions and corners of each SLIT are defined in the MSA plane and then transformed to V2/V3 using the parametric instrument model assuming the "CLEAR" aperture, (keyword FWA_POS in the fits file header), at a wavelength of 2 microns, (keyword WAVELNGH in the file header). The angle at which each slit projects onto the sky relative to V3 is also supplied. The column names in this file are as follows:

- SIAF_NAME, name to be used in SIAF file, e.g., 'NRS_S200A1_SLIT'
- C1_XPOSMSA, x position of 1st slit corner in MSA coordinates (m)
- C1_YPOSMSA, y position of 1st slit corner in MSA coordinates (m)
- C2_XPOSMSA, x position of 2nd slit corner in MSA coordinates (m)
- C2_YPOSMSA, y position of 2nd slit corner in MSA coordinates (m)
- C3_XPOSMSA, x position of 3rd slit corner in MSA coordinates (m)
- C3_YPOSMSA, y position of 3rd slit corner in MSA coordinates (m)
- C4_XPOSMSA, x position of 4th slit corner in MSA coordinates (m)
- C4_YPOSMSA, y position of 4th slit corner in MSA coordinates (m)
- REFXPOSMSA, reference X position for aperture in MSA coordinates (m)
- REFYPOSMSA, reference X position for aperture in MSA coordinates (m)
- C1_XPOSSKY, V2 position of 1st slit corner (arc-sec)
- C1_YPOSSKY, V3 position of 1st slit corner (arc-sec)
- C2_XPOSSKY, V2 position of 2nd slit corner (arc-sec)
- C2_YPOSSKY, V3 position of 2nd slit corner (arc-sec)
- C3_XPOSSKY, V2 position of 3rd slit corner (arc-sec)
- C3_YPOSSKY, V3 position of 3rd slit corner (arc-sec)
- C4_XPOSSKY, V2 position of 4th slit corner (arc-sec)
- C4_YPOSSKY, V3 position of 4th slit corner (arc-sec)
- REFXPOSKY, V2 position of slit reference point (arc-sec)
- REFYPOSKY, V3 positions of slit reference point (arc-sec)
- ANGLEV3, angle of SLIT "Y" direction with respect to V3 (degrees)

4.5.2 MSA Slit apertures

The SIAF file does not attempt to describe the individual micro-shutters. Instead, SIAF SLIT entries describe how the individual quadrants and the overall array project onto the sky. The corners of the `NRS_FULL_MSA1`, `NRS_FULL_MSA2`, `NRS_FULL_MSA3`, and

NRS_FULL_MSA4 entries of type SLIT are defined to be coincident with the corner shutters in each quadrant, while NRS_FULL_MSA is defined to circumscribe all four quadrants.

The instrument field stop blocks part of the field of view, preventing some micro-shutters from receiving light from external targets. To reflect the area of the MSA quadrants that can be used to view external targets, additional SLIT entries have been defined that are trimmed to reflect the vignetting by the field stop. For the four quadrants, these are NRS_VIGNETTED_MSA1, NRS_VIGNETTED_MSA2, NRS_VIGNETTED_MSA3, and NRS_VIGNETTED_MSA4, while the entry NRS_VIGNETTED_MSA circumscribes all four quadrants (**Error! Reference source not found.**). The reference point for each of these apertures was chosen to be near the geometrical center defined by its corners.

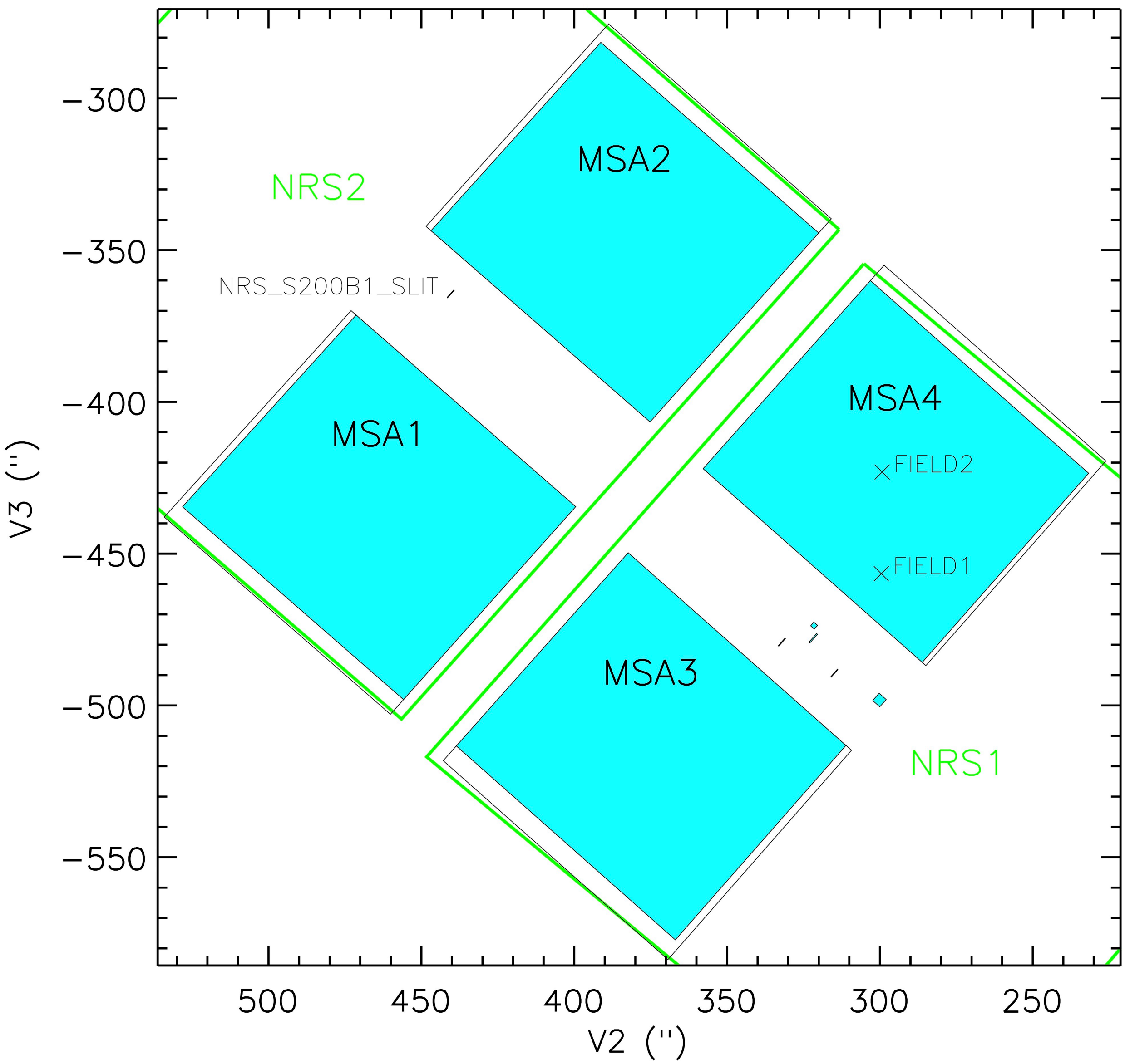


Figure 6: This figure zooms in on the MSA quadrants, adopting the same conventions as Figure 5. The reference locations of the field points NRS_FIELD1_MSA4 and NRS_FIELD2_MSA4 are also marked.

For use with extended and moving targets, two additional apertures were defined for which the reference point is significantly offset from the center. These are `NRS_FIELD1_MSA4` and `NRS_FIELD2_MSA4`. Both of these are located on MSA quadrant 4. The locations chosen for these points were selected taking into account the shutter operability map, and may be redefined after launch. The FIELD1 reference is defined to be coincident with quadrant 4 shutter # 250, 25 (dispersion, cross-dispersion) and is located 26.9" away from the S1600A1 aperture. The intent is that a target could be acquired in the S1600A1 and then offset to the FIELD1 position while using a custom MSA configuration such as a column of open slitlets (see https://www.ess.stsci.edu/prsystem/servlet/prbrowse/pr.87182). The need to keep within comfortable visit splitting distance of the S1600A1 does force this position to be separated in the spatial direction by only about 12.5" from the edge of quadrant 4. For observations that do not require an acquisition using the S1600A1, the `NRS_FIELD2_MSA4` was also defined at shutter 168, 73. At ~55" from the S1600A1, this position is expected to be useful only when no target acquisition is required. The locations of the reference points for these field positions are tabulated in Table 2 and illustrated in Figure 6. Their corners are defined to be coincident in the V2/V3 plane with those of the `NRS_VIGNETTED_MSA` SLIT entry.

Table 2: SLIT entries for the NIRSpec MSA Quadrants

AperName	V2Ref (")	V3Ref (")	V3IdlYAngle	Height (")	Width (")
NRS_FULL_MSA	378.771	-428.156	138.492	218.790	217.994
NRS_FULL_MSA1	466.483	-436.164	138.242	98.153	91.425
NRS_FULL_MSA2	381.890	-340.887	138.296	97.344	89.477
NRS_FULL_MSA3	375.823	-516.367	138.742	98.153	91.408
NRS_FULL_MSA4	291.775	-420.645	138.690	97.332	89.467
NRS_VIGNETTED_MSA	378.567	-428.334	138.493	215.001	205.276
NRS_VIGNETTED_MSA1	463.528	-434.491	138.247	95.946	84.961
NRS_VIGNETTED_MSA2	383.176	-343.939	138.298	95.209	83.230
NRS_VIGNETTED_MSA3	374.611	-513.150	138.737	95.703	84.943
NRS_VIGNETTED_MSA4	294.619	-422.668	138.689	95.742	82.700
NRS_FIELD1_MSA4	299.527	-456.599	138.493	215.001	205.276
NRS_FIELD2_MSA4	299.258	-423.097	138.493	215.001	205.276

4.5.3 Fixed Slits and IFU Slicer

The MSA also includes five fixed slits, which are located between the micro-shutter quadrants. The locations, sizes, and orientations of these apertures are given in Table 3, and their locations are labeled in Figure 6 (`NRS_S200B1_SLIT`) and Figure 7 (Other fixed slits and the IFU). There is also a `NRS_FP1MIMF` slit entry, which is identical to the `NRS_1600_A1` slit.

The SIAF information for the IFU and its slices differs from the fixed-slits in that the IFU locations given in the SIAF file are projections of the slicer and its components onto the sky, rather than a projection of the IFU opening in the MSA. The MSA locations given for the IFU entries in the `positionsSIAFApertures.fits` file show the positions of the slicer in the MSA plane as calculated from the IFU FORE transform.

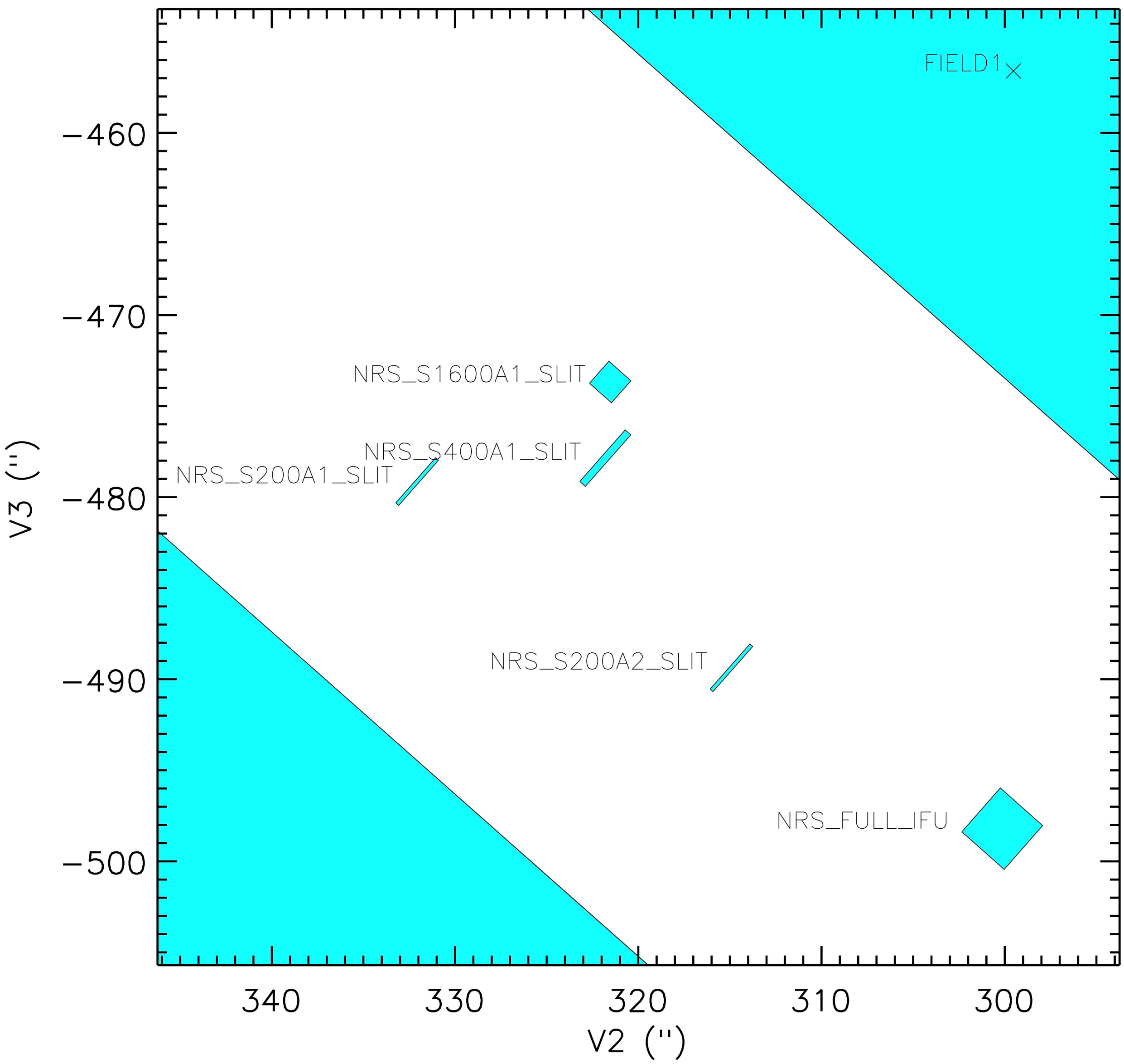


Figure 7: Conventions are as in Figure 5 above, but here zoomed in on the "A" slits and the IFU.

Table 3: SIAF Slit entries for the NIRSpec Fixed Slits and IFU.

AperName	V2Ref (")	V3Ref	V3IdlYAngle	Height (")	Width (")
NRS_S200A1_SLIT	332.136	-479.224	138.761	0.193	3.274
NRS_S400A1_SLIT	321.872	-477.939	138.783	0.395	3.759
NRS_S1600A1_SLIT	321.532	-473.679	138.771	1.599	1.603
NRS_S200A2_SLIT	314.985	-489.451	138.833	0.194	3.303
NRS_S200B1_SLIT	440.485	-364.516	138.158	0.201	3.301

AperName	V2Ref (“)	V3Ref	V3IdlYAngle	Height (“)	Width (“)
NRS_FULL_IFU	300.150	-498.125	138.893	3.097	3.193
NRS1_FP1MIMF	321.532	-473.679	138.771	1.599	1.603

4.5.4 IFU Slices

The SIAF also contains SLIT entries for the 30 individual IFU slices. These are named `NRS_IFU_SLICE00` through `NRS_IFU_SLICE29`. Note that this numbering convention follows that of the parametric instrument model, and the slices numbers do not form a continuous sequence on the sky, but instead alternate from near the center. Their ordering is illustrated in Figure 8. If a future APT build allows display and labeling of the individual slices in the Aladin, the numbering convention displayed there should probably correspond to the ordering of the slices in the final image cube as detailed in the JDOX user documentation rather than to the convention adopted here. However, to ensure ease in traceability we recommend that the SIAF file itself continue to use a naming convention consistent with that adopted for the parametric model.

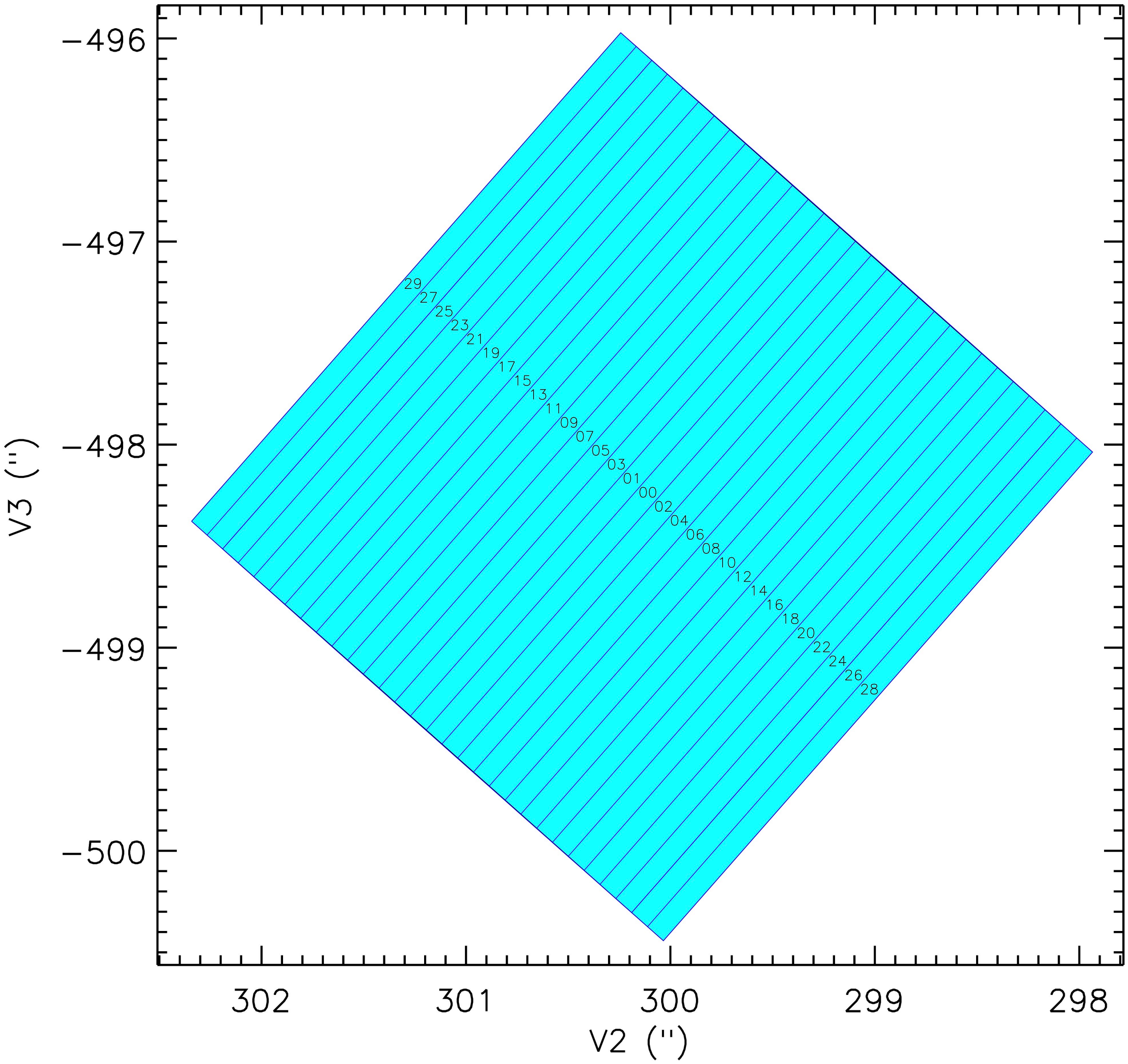


Figure 8: The location, orientation, and numbering scheme for the NIRSpec IFU slices are illustrated. Note that the slice numbers alternate left and right starting near the center.

Prior to the G-010 SIAF release, (September 2017), the reference location for the full IFU aperture, `NRS_FULL_IFU`, had been defined to be at the geometric center of the IFU. This put the reference point close to the boundary between the 0 and the 1 slice. In the G-010 release, the IFU reference position was updated to put the reference position close to the center of IFU slice 0. This ensures that targets accurately placed at the default reference point won't be on the slice boundary. New IFU dither patterns consistent with the redefined reference point were also delivered as a separate part of the same PRD release, (see PRD change request 2507 for details).

4.6 AperType = COMPOUND

NIRSpec does not currently include any SIAF entries of AperType= COMPOUND, although in principle the IFU entry could be specified as a combination of the individual slitlet's apertures.

4.7 AperType = TRANSFORM

The NIRSpec transform rows can be divided into two subtypes. One of these groups is used as part of the target acquisition transforms, and the other for transforming between sky and MSA coordinates.

4.7.1 Transform rows used to support target acquisition

The first set, with the SIAF aperture names `CLEAR_GWA_OTE`, `F110W_GWA_OTE`, and `F140X_GWA_OTE` are part of the target acquisition calculations and include the rolled-up polynomial transitions from XAN/YAN coordinates to the front side of the GWA. They are intended to be used together with either the OSS or FULLSCA rows to translate between positions in the JWST OTE plane and NIRSpec detector locations when the detectors are used in imaging mode.

Table 4: The SIAF column names used for the coefficients discussed in Giardino et al. (2014) in the NIRSpec SIAF for each *Filter*_GWA_OTE row are listed, along with the source file names for each quantity. There is one SIAF TRANSFORM row of this type for each of the three imaging filters, CLEAR, F110W, and F140X.

Coefficient	Description	SIAF Columns Used to Hold Values	Source File Name
A_x	CoeffsTemperature00	XSciRef	disperser_MIRROR_TiltX.gtp
A_y	CoeffsTemperature00	YSciRef	disperser_MIRROR_TiltY.gtp
r_0^x	Zeroreadings	XSciScale	disperser_MIRROR_TiltX.gtp
r_0^y	Zeroreadings	YSciScale	disperser_MIRROR_TiltY.gtp
$P_x(x,y)$	Polynomial to compute XAN from GWA pupil coordinates	Sci2IdlX00 … Sci2IdlX55	delivery_*Filter*_GWA2XanYan.pcf
$P_y(x,y)$	Polynomial to compute YAN from GWA pupil coordinates	Sci2IdlY00 … Sci2IdlY55	delivery_*Filter*_GWA2XanYan.pcf
$P_x^r(x,y)$	Polynomial to compute x'_{gwa} from XAN/YAN	Idl2SciX00 … Idl2SciX55	delivery_*Filter*_GWA2XanYan.pcf
$P_y^r(x,y)$	Polynomial to compute y'_{gwa} from XAN/YAN	Idl2SciY00 … Idl2SciY55	delivery_*Filter*_GWA2XanYan.pcf

These rows also contain the coefficients used to correct the coordinates at the GWA image plane for variations in the positioning of the GWA. The mapping between these coefficients as defined in Giardino et al 2014 and the SIAF columns is given in Table 4. Note that the use of these coefficients differs from that of the SIAF quantities normally placed in these columns.

Test data supplied by the IDT for the TA transforms is discussed in section 4.1.2 above.

4.7.2 Transform rows for sky to MSA conversions

The next two groups are both used as part of the translation from V2/V3 to MSA image plane coordinates. These tables contain coefficients for the coordinate transforms for individual modules of the NIRSpec parametric model. The coefficients are as described in Table 4.1-1 of Ferruit et al. 2008. In Table 5 we provide the mapping between the quantities discussed there and the corresponding column in the NIRSpec SIAF row.

4.7.2.1 Test data for sky to MSA transformations

For the CV3 delivery of the MSA transformation coefficients, the IDT delivered a set of test data in `sky_fpa_projectionMSA_Q1.fits`, `sky_fpa_projectionMSA_Q2.fits`, `sky_fpa_projectionMSA_Q3.fits`, and `sky_fpa_projectionMSA_Q4.fits`. These files each contain a grid of 171 x 365 locations in the MSA plane, SKY plane (V2/V3), and the FPA detector plane, which correspond to the location of each microshutter in the corresponding quadrant. The transformations between these planes were calculated using the full parametric instrument model assuming the CLEAR aperture and a wavelength of 2 microns, and as a result there may be slight inconsistencies, (of order 0.1 mas), between the detector locations calculated here and those in the TA transform test data discussed in section 4.1.2.

The following columns are defined in these test files:

- Q, the MSA quadrant of the data file, (1, 2, 3, or 4)
- INDEX, a running index of the shutter number, (1 to 62415)
- I, the index of the shutter location in the dispersion direction, (1 to 365)
- J, the index of the shutter location in the spatial direction, (1 to 171)
- XPOSMSA, the X coordinate in the MSA plane (m)
- YPOSMSA, the Y coordinate in the MSA plane (m)
- XPOSSKY, the V2 coordinate on the sky (degrees)
- YPOSSKY, the V3 coordinate on the sky (degrees)
- XPOSFPA, physical coordinates in the detector plane (m)
- YPOSFPA, physical coordinates in the detector plane (m)
- IPOS491, detector X pixel coordinate for the SCA491 (NRS1) detector
- JPOS491, detector Y pixel coordinate for the SCA491 (NRS1) detector
- IPOS492, detector X pixel coordinate for the SCA492 (NRS2) detector
- JPOS492, detector Y pixel coordinate for the SCA492 (NRS2) detector

Pixel locations are provided for both detectors, even though when used with the MIRROR each quadrant only illuminates part of one of the two NIRSpec detectors (see Figure 4.2), and some individual shutters project onto neither detector. Equivalent test files will be delivered with every update of the reference files.

Table 5: Parameters used for coordinate transform in the NIRSpec parametric model, and the names of the SIAF columns which are used to hold these quantities in those NIRSpec TRANSFORM rows that include the full model parameterization.

Parameter(s) of fit to parametric model.	**Description**	**SIAF Column(s) Used to hold value(s)**	**Comments**
x_c^{in}, y_c^{in}	Coordinates of the center of the rotation and of the homothetic transform in the input plane.	**XSciRef, YSciRef**	
x_c^{out}, y_c^{out}	Coordinates of the center of the rotation and of the homothetic	**V2Ref, V3Ref**	

	transform in the output plane prior applying the fifth order polynomial .		
$\boldsymbol{\theta}$	Rotation angle applied to the input coordinate system to match the output one.	**V3IdlYAngle**	
γ_x, γ_y	Scaling factors along the input x and y-axes for the homothetic transform.	**XSciScale, YSciScale**	
$\boldsymbol{P_x^f(x,y,\lambda)}$	Polynomial function used for the x- coordinate in the forward, (from sky-towards-detector), direction.	**Sci2IdlX00 ... Sci2IdlX55**	**Two SIAF rows are needed for those polynomials that are a function of wavelength. The "L0" row contains the constant term, and the "L1" row the slope with λ.**
$\boldsymbol{P_x^f(x,y,\lambda)}$	Polynomial function used for the y- coordinate in the forward, (from sky-towards-detector), direction.	**Sci2IdlY00 ... Sci2IdlY55**	"
$\boldsymbol{P_x^b(x,y,\lambda)}$	Polynomial function used for the x- coordinate in the reverse, (from detector-towards-sky), direction.	**Idl2SciX00 ... Idl2SciX55**	"
$\boldsymbol{P_x^b(x,y,\lambda)}$	**Polynomial function used for the x- coordinate in the reverse, (from detector-towards-sky), direction.**	**Idl2SciY00 ... Idl2SciY55**	"
$\boldsymbol{n}$	**Degree of polynomial function**	**Sci2IdlDeg**	**Has a value of 5 for all cases considered here.**

Table 6: The SIAF TRANSFORM rows used to convert between sky and MSA coordinates are listed. The columns of these SIAF rows contain the information discussed in Table 5. For the OTEIP to MSA transforms, there is a separate pair of SIAF rows for each of the NIRSpec filters, CLEAR, F070LP, F100LP, F170LP, F290LP, F110W, and F140X.

SIAF ROW	Transform	Source File(s)	Comments
NRS_SKY_OTEIP	V2/V3 to OTEIP	OTE.pcf	λ independent transform
NRS_*FILTER*_OTEIP_MSA_L0	OTEIP to MSA	Fore_*FILTER*.pcf	Includes polynomial coefficients P at $\lambda = 0$
NRS_*FILTER*_OTEIP_MSA_L1	"	"	Includes slope of coefficients with λ

4.8 MIMF Rows

The original concept for NIRSpec support of MIMF (Multi-Instrument Multi-Field wavefront sensing) activities was described in Tumlinson et al. 2012. The intent of the SIAF MIMF entries is to define a set of fixed test points that will be used for wavefront sensing calibration. For NIRspec, five points were defined – four of these, defined as APERTYPE=FULLSCA, refer to points on the detector that project onto the quadrants of the MSA, while the fifth, NRS1_FP1MIMF, is of APERTYPE=SLIT and is defined to be coincident with the 1.6” x 1.6” S1600A1 aperture. Their locations are illustrated in Figure 9. Apart from selecting off-center locations for the reference points, the FULLSCA MIMF apertures are otherwise defined in the same way as the normal FULLSCA entries that describe the detectors.

The non-repeatability of the GWA results in that light entering the instrument is not dispersed or reflected always to the exact same location on the detector. This has the implication that the projected location of NIRSpec apertures on the detector plane is not constant. In the current SIAF, the location of the MIMF points on the ideal and V2V3 frames have been derived from coordinates on the detector. Given the GWA behavior, however, to ensure the telescope will place an astronomical source in the desired MIMF position, they would be better defined as points on the MSA plane. Based on those, the locations on the ideal and V2V3 frames can be derived in the same way as all other APERTYPE=SLIT entries contained in the SIAF file. It is foreseen that this improved derivation of the MIMF entries will be implemented in a future version of the SIAF file.

These SIAF entries are intended for use only with the NIRSpec MIMF template. As MIMF observations may be needed before the instrument to FGS alignment is known to better than 1”, the MIMF template uses special dither patterns to ensure that at least one image is well centered in the S1600A1, and to appropriately sub-sample the MSA grid for the other MIMF locations. In practice it is unclear whether images taken through the MSA grid will be useful for phase retrieval to estimate focus and so in practice the bulk of NIRSpec MIMF activities may rely on the NRS1_FP1MIMF position.

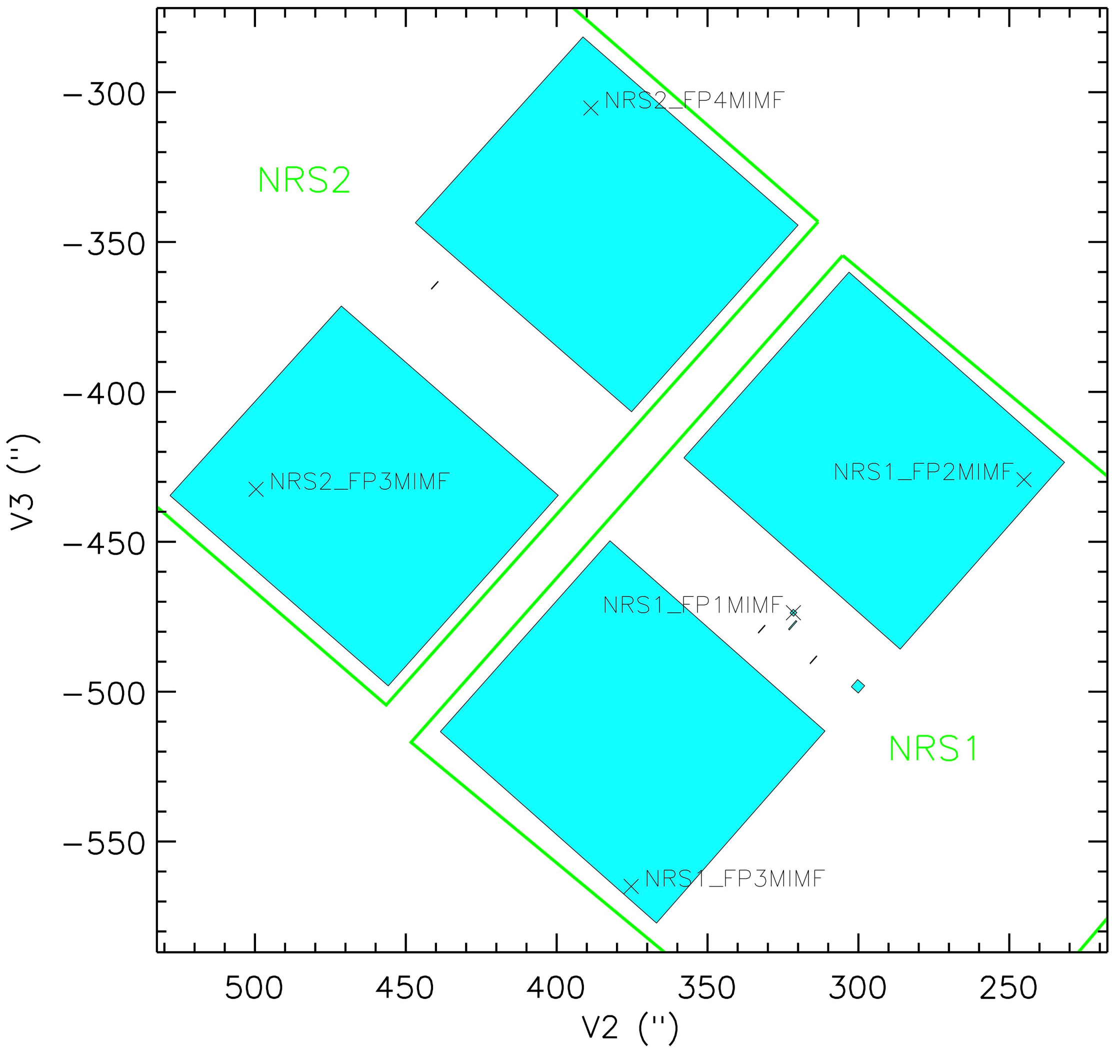


Figure 9: This figure zooms in on the MSA quadrants, adopting the same conventions as Figure 5, but marks the locations of the MIMF points.

5 Spreadsheet Logic and Processes

This section describes how the SIAF Excel worksheet has been constructed and how it will be maintained as we obtain new information. It would be useful to have a copy of a recent NIRSpec SIAF worksheet on hand while reading this section. By worksheet we mean the whole Excel or xlsx file containing several sheets indicated by tabs at the lower edge of the display. Select the "SIAF" tab. This is the sheet from which the xml file is generated and installed in the database. Other sheets are "Calc" which contains various intermediate calculations, "DDC" which selects the Differential Distortion Correction" aperture name and "XML" containing a small table needed for making the xml file from this spreadsheet. Other tabs refer to plots that have been used in checking inputs, but are not complete or maintained. No use is made of these in connection with data delivery. In following the logic, we recommend making use of the "Trace Precedents" and 'Trace Dependents" under "Formulas" in the toolbar.

There are several groups of apertures distinguished by the value of AperType. Those of type FULLSCA and OSS contain the full complement of column entries and will be discussed first. Currently NIRSpec does not make use of the SUBARRAY or ROI type.

5.1 Normal SIAF conventions for rows using all columns (FULLSCA & OSS Entries)

The first few columns are entered manually and describe the basic layout of each aperture. InstrName, AperName and AperType need no further explanation. (DDCName will be explained later.) AperShape may be QUAD or CIRC although no instrument has used anything other than QUAD. Many of the other columns, including XDetSize, YDetSize, XDetRef, YDetRef, XSciRef, YSciRef, DetSciYAngle, and DetSciParity follow normal SIAF frame conventions as discussed in section 3.1.4.

The coefficients that transform between detector and OTE coordinates are split between these aperture rows and the rows of AperType TRANSFORM. Column AH, Sci2IdlDegree, gives the degree of the polynomials. As the name implies the coefficients normally transform between the Science and Ideal values. Other column names, chosen for the majority of the instruments, are similarly at odds with their use in NIRSpec. In this case the values in columns AI to BC provide a transformation from detector pixels to positions in the GWA plane to the angular position of the ray at the mirror/GWA expressed in cosines (number unit) as described in ESA document ESA-JWST-TN-21403. Columns BD to DN provide the reverse transformations.

The values in the earlier columns, N through R and the angles and vertices in V through AE are all calculated from the coefficients, sizes and pixel positions already described. Positions are given in arc-seconds. Scales are in arc-seconds/pixel. All angular values are in degrees.

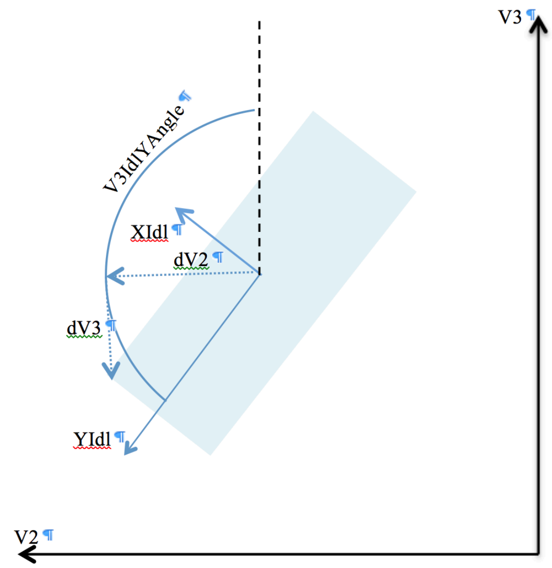
The DDCName is used for Differential Distortion Correction. This is used to correct for changes in the target-to-guide star positioning as the Fine Steering Mirror tilts during fine guiding (Lallo et al. 2016, TR JWST-STScI-033453). The results are only stored for a select group of positions at the reference point of some of the apertures. The DDCName gives the name of the aperture in the select group that is closest to the current aperture. The sheet "DDC" performs a nearest neighbor calculation and feeds the proper aperture name back to the SIAF sheet.

The UseAfterDate in column AF is intended to support the maintenance of multiple versions of the data entries. Exactly how this will be used has not been formally defined but as it stands the meaning is "do not apply these data to any observations before this date". During pre-flight development we are setting this to 2014-01-01 throughout so that any testing software that pays attention to this date may use any delivered values.

5.2 Conventions for SLIT Rows

The AperType SLIT entries describe physical location not associated with a detector. The essential feature of these is the position in the V2V3 system. Since they are not attached to a single SCA, the pixel dependent relationships, including the distortion coefficients have no clear meaning and are omitted .

The stored vertex positions are not the absolute V2V3 positions, but are the values of XIdl and YIdl instead, referred to an Ideal coordinate system as for all the other apertures. This permits an indication of how the slit is aligned and which way light is dispersed. The diagram shows an example with one of the vertices labeled in detail. The conversion from XIdl, YIdl to V2,V3 is



$$V2 = V2Ref + VIdlParity \cdot XIdl \cdot \cos(V3IdlYangle) + YIdl \cdot \sin(V3IdlYangle)$$

$$V3 = V3Ref - VIdlParity \cdot XIdl \cdot \sin(V3IdlYangle) + YIdl \cdot \cos(V3IdlYangle)$$

For NIRSpec, the SLIT locations are defined as part of the parametric instrument model by projecting locations on the MSA or SLICER planes to V2/V3, (sections 2.3.4 and 4.5), and then projecting these to an ideal plane by using the inverse relations given by

$$XIdl = VIdlParity(dV2 \cdot \cos(V3IdlYAngle) - dV3 * \sin(V3IdlYAngle)$$

$$YIdl = dV2 \cdot \sin(V3IdlYangle) + dV3 * \cos(V3IdlYangle)$$

in which *dV2 = V2-V2Ref* and *dV3=V3-V3Ref*.

5.3 Conventions for TRANSFORM rows

Several NIRSpec TRANSFORM rows are defined to encode transformations that use the conventions defined for the NIRSpec parametric model (Section 2.2) in place of the normal SIAF conventions. The values of the polynomial distortion coefficients for these rows are copied from the instrument model input without any redefinition of the coordinate systems, although, as is the case for the FULLSCA and OSS rows the naming and the ordering of the polynomial terms is rearranged to match SIAF conventions (see section 5.4).

Other parameters are copied directly from the delivered inputs and placed in SIAF columns normally intended for other purposes. The mapping between Parametric Model Quantities and SIAF rows used for MSA transforms is given in Table 5 and the input file names are listed in Table 6 in section 4.7.2. For the rows used for MSA transforms, the columns that normally contain XSciRef, YSciRef, XSciScale, YSciScale, and V3YIdlAngle are used to store the coefficients x_c^{in}, y_c^{in}, γ_x, γ_y, and θ used for the homethetic part of the transform.

For the CLEAR_GWA_OTE, F110W_GWA_OTE, and F140X_GWA_OTE rows used to complete the transformation between the GWA and OTE angular coordinates, the homothetic part of the transformation was folded into the polynomial distortion coefficients, and the XSciRef, YSciRef, XSciScale and YSciScale columns instead contain the parameters A_x, A_y, r_0^x r_0^y used to correct for variations in the GWA sensor position as detailed in section 4.7.1 and Table 4.3.

5.4 Data installation

The InstrName name is simply the generally accepted instrument name but given in all capitals. The AperName is a descriptive name always beginning with "NRS" for NIRSpec. This convention has been embedded in much of the software including that which generates the SIAF. Each instrument has its own 3-character code.

The source of all coefficients are files delivered with extension .pcf plus two files named disperser_MIRROR_TiltX.gtp and disperser_MIRROR_TiltY.gtp. The polynomials converting from the two detectors to the GWA plane come from files named SCA491toGWA.pcf and SCA492toGWA.pcf. The coefficients get reordered to the standard way used for other instruments. As delivered the coefficients describe the polynomial as $Xgwa = \sum_{i=0}^{order} \sum_{j=0}^{order-i} A_{i,j} x^i y^j$ whereas the layout stored in the SIAF supports $Xgwa = \sum_{i=0}^{order} \sum_{j=0}^{i} A_{i,j} x^{i-j} y^j$, where $x = xSci - xSciRef$ and $y = ySci - ySciRef$. These are stored as a flat array in the order A_{00}, A_{10}, A_{11}, A_{20}, A_{21}, A_{22} etc., that is with the j index running faster.

In the pcf and gtp files there are keywords consisting of a string beginning with '*'. The lines of text following this keyword have the data.

The polynomials are read and reordered as previously described. All polynomials are preceded by the keywords xForwardCoefficients, yForwardCoefficients, xBackwardCoefficients or yBackwardCoefficients.

Rows with names including "GWA_OTE" come from the matching delivered files containing the strings "GWA2OTE". Additionally, these files contain constants placed in columns labeled XSciRef, YSciRef, XSciScale and YSciScale which are read from the TiltX and TiltY gtp files. XSciRef is copied from the first value following the pcf keyword ZeroReadings1in the TiltX file and YSciRef comes from the corresponding value in the TiltY file. XSciScale and YSciScale are copies of the first value following the keyword CoeffsTemperature in the TiltX and TiltY files respectively.

The final group of TRANSFORM rows contain the transformations between the MSA plane and the field angles, given in this case as V2 and V3 values in degrees. The polynomials in these files are treated as described above. Additional constants are, in this case, supplied within the same pcf files. The values in XSciScale, YSciScale are read from the pcf keyword Factor 2. XSciRef, YSciRef are given in InputRotationCentre. Other entries, not in the other TRANSFORM rows, are V2Ref and V3Ref read from OutputRotationCentre and V3IdlYAngle obtained from the keyword Rotation. Apart from coefficient reordering, these values are retained in the SIAF exactly as delivered.

In all cases the coefficients labeled in the pcf files as Forward appear first in the SIAF row under the labels Sci2IdlX or Sci2IdlY and the Reverse coefficients follow under the labels Idl2SciX and Y.

For the MSA calculations the pcf file contains coefficients for equations 3 and 4 that have wavelength dependent terms. The wavelength independent terms, β_{ij} in equations 3 and 4, are stored in rows with AperNames like NRS_F070LP_OTEIP_MSA_L0 while the wavelength dependent terms α_{ij} are in the following row with an AperName like NRS_F070LP_OTEIP_MSA_L1. So each MSA pcf file produces two SIAF rows. The constants are duplicated in the L1 row.

5.5 Calculations for FULLSCA and OSS apertures.

These use two sets of polynomials, one converting between detector and GWA plane and the other between GWA plane and field angle, XAN,YAN. For all apertures beginning with NRS1 or NRS2 the applicable coefficients are contained in the named FULLSCA row and the CLEAR_GWA_OTE TRANSFORM row. The FULLSCA delivered data are copied exactly into the first 2 rows of the Transform rows for sky to MSA conversions with names in the Calc sheet of 491_GWA and 492_GWA. The 3 OTE rows follow. The GWA rows contain coefficients converting from raw detector pixels to GWA plane positions. The rows in the Calc sheet labeled 491_GWAshifted and 492_GWAshifted are designed to take as input the displacement in pixels from the central reference point, (1024.5, 1024.5). So all the coefficients are modified. These numbers are calculated in the spreadsheet via formulae embedded in rows 8 and 9. Details of the formulae are given in 5.6. Row 10 contains a version of row 9 with changes of sign. This is to accommodate the reversal of detector axes in NRS2 compared with NRS1 These 3 rows are used to populate aperture specific rows 20 to 28. The MIMF apertures have non-central reference positions and so are shifted further according to the offsets calculated in columns C and D. These rows are then transferred by reference to the SIAF rows 3 to 6 and 56 to 59 with matching aperture names.

The inverse transformations are treated similarly. The delivered values are copied into Calc rows 13 to 17. The shift calculation in the inverse direction is simple, only requiring an addition to the constant term. So these rows transfer directly to the Idl2Sci columns of SIAF with the shift value applied by a formula in columns BY and CT, labeled Idl2SciX00 and Idl2SciY00. NRS1_FP1MIMF is an exception because it is treated as a SLIT aperture duplicated from the NRS_S1600A1_SLIT

Rows 31 to 39 contain the calculations of scales and angles as described in section 5.1.4 which are then transferred to the SIAF columns N to R.

Rows 43 to 51 calculate the positions of the aperture corners. The columns labeled x1, x2,..y4 are pixel positions calculated from the pixel sizes and reference positions set up in the first few columns of the SIAF sheet. The detector to GWA polynomials are then used to first find the corner positions in GWA coordinates and subsequently the GWA to XAN,YAN in absolute V2,V3 values. The vertex positions in columns X to AE in the SIAF sheet are in Ideal coordinates and so the shift and rotation is incorporated as a formula in the SIAF cells referring to the Calc cells.

5.5.1 Details of calculations from Detector to GWA Coordinates

This transformation begins by using one of the NIRSpec FULLSCA or OSS SIAF rows. The detector coordinates are transformed to SCI coordinates using the normal SIAF conventions.

In these rows, the XSciRef and YSciRef columns have their conventional meaning, and do not contain alternate coefficients as in the TRANSFORM rows discussed in the previous section. However, the 5th degree polynomial coefficients in these rows labeled Sci2IdlXij, Sci2IdlYij, Idl2SciXij and Idl2SciYij, actually transform to GWA pupil plane, so to clarify the equations below we will rename them Sci2GwaXij, Sci2GwaYij, Gwa2SciXij and Gwa2SciYij for this discussion.

This part of the transformation is then

$$x_{gwa} = \sum_{i=0}^{order} \sum_{j=0}^{i} Sci2GwaX_{i,j}(xSci - xSciRef)^{i-j}\,(ySci - ySciRef)^{j}$$

and

$$y_{gwa} = \sum_{i=0}^{order} \sum_{j=0}^{i} Sci2GwaY_{i,j}(xSci - xSciRef)^{i-j}\,(ySci - ySciRef)^{j}$$

where x_{gwa} and y_{gwa} are angular direction cosines in the GWA pupil plane and the order of the polynomial is equal to 5. The Sci2Gwa terms are chosen appropriate to the detector.

5.5.2 Transforms for the GWA MIRROR at off-nominal mirror positions

The polynomial transforms given in the forward direction of the OSS and FULLSCA rows transform from detector coordinates in pixels to angular position at the GWA. For consistency with existing documentation we will refer to these coordinates as the “GWA input coordinates”, x_{gwa} and y_{gwa}, while the coordinate system after the reflection will be called the “GWA output coordinates” x'_{gwa} and y'_{gwa}. Note that the “in” and “out” convention adopted here is the reverse of the actual path the light travels. Full details of the transformation between these coordinates are given in Giardino, Ferruit, & Alves de Oliveira (2014), but for completeness the equations are reproduced here.

Given the mirror tilt sensor readings, `GWA_YTIL` and `GWA_XTIL`, and the coefficients A_x, A_Y, r_0^x, and r_o^y as read from the SIAF file columns XSciScale, YSciScale, XSciRef, and YSciRef in the GWA_OTE transform rows, the angular offset from the nominal mirror positions become

$$\delta\theta_x = 0.5 A_X(\texttt{GWA\_YTIL} - r_0^x)$$

$$\delta\theta_y = 0.5 A_Y(\texttt{GWA\_XTIL} - r_0^y)$$

Assuming that all angles are small, the direction cosines are then computed as:

$$|v| = \sqrt{1 + x_{gwa}^2 + y_{gwa}^2}$$

$$x_0 = x_{gwa}/|v|$$

$$y_0 = y_{gwa}/|v|$$

$$z_0 = 1\,/|v|$$

After rotation normal to the mirror and reflection the coordinates become

$$x_1 = -\left(x_0 - \delta\theta_y\sqrt{1 - x_0^2 - (y_0 + \delta\theta_x z_0)^2}\right)$$

$$y_1 = -(y_0 + \delta\theta_x z_0)$$

$$z_1 = \sqrt{1 - x_1^2 - y_1^2}$$

Then an inverse rotation around each axis is applied to get to the output coordinate system

$$x_2 = x_1 + \delta\theta_y z_1$$

$$y_2 = y_1$$

$$z_2 = \sqrt{1 - x_2^2 - y_2^2}$$

$$x_3 = x_2$$

$$y_3 = y_2 - \delta\theta_x z_2$$

$$z_3 = \sqrt{1 - x_3^2 - y_3^2}$$

Finally these are converted from the direction cosines back to cosines

$$x'_{gwa} = x_3/z_3$$

$$y'_{gwa} = y_3/z_3$$

Note that for the case of the nominal GWA tilt angles, $\delta\theta_x = \delta\theta_y = 0$ and it suffices to assume that

$$x'_{gwa} = -x_{gwa}$$

$$y'_{gwa'} = -y_{gwa}$$

5.5.3 Transform from GWA Pupil Plane to the Sky

Once the reflection has been computed, the second filter dependent polynomial are applied according to

$$XAN = \sum_{i=0}^{N}\sum_{j=0}^{i} Gwa2XAN_{i,j}(x'_{gwa})^{i-j}\,(y'_{gwa})^{j}$$

and

$$YAN = \sum_{i=0}^{N}\sum_{j=0}^{i} Gwa2YAN_{i,j}(x'_{gwa})^{i-j}\,(y'_{gwa})^{j}$$

With the coefficients as supplied, these values are in degrees. To obtain V2,V3 in arc-seconds we have

V2 = 3600*XAN and V3 = -3600(YAN + 0.13) or V3 = -(3600*YAN + 468) with the offset in arc-seconds. XAN and YAN are both in degrees. The position (0.0, -468.0) is where the center of the NIRCam apertures is located in the V2V2 system that defines the XAN, YAN origin.

5.6 Converting a distortion solution to a new origin.

We begin with a polynomial distortion solution of order N of the form

$$u = \sum_{i=0}^{N}\sum_{j=0}^{i} A_{i,j}x^{i-j}\,y^{j}$$

which expanded looks like $u = A_{00} + A_{10}x + A_{11}y + A_{20}x^2 + A_{21}xy + A_{22}y^2 \dots A_{NN}y^N$

This may be a solution for which the origin is at a corner of a detector. We wish to express the same solution centered on the position x_0, y_0 with a new set of coefficients A' in terms of $x'=x-x_0$ and $y'=y-y_0$.

In terms of the original x,y, $x=x'+x_0$ and $y=y'+y_0$ so that now

$$u = \sum_{m=0}^{order}\sum_{n=0}^{m} A'_{m,n}x'^{m-n}y'^{n} = \sum_{i=1}^{order} A_{i,j}(x'+x_0)^{i-j}(y+y_o)^{j}$$

Now the binomial expansion of $(x'+x_0)^{i-j} = {}^{i-j}C_k x'^k x_0{}^{i-j-k}$ in which the summation over the repeated index k is implied. (${}^nC_r$ is the number of ways of choosing r elements out of n.)

Similarly $(y'+y_0)^j = {}^jC_l y'^l y_0^{j-l}$ Multiplying them together gives

$$u = A_{i,j}\ {}^{i-j}C_k\ {}^jC_l x'^k y'^l x_0^{i-j-k} y_0'^{\,j-l}$$

in which summations over i, j, k and l are implied.

To obtain the shifted coefficient A_{mn} corresponding to $x'^{(m-n)}y'^n$ we select terms where k=m-n and l=n.

Then we do a restricted summation over i and j with the limits implied by the ${}^nC_r$ selections in which n and r must be positive and n not less than r. The first condition is i-j ≥k≥0 while the second is j≥l ≥ 0.

In terms of m and n these limits are . i-j ≥ m-n ≥ 0 and j ≥ n ≥ 0 So i ≥ m+j-n ≥ m and j ≤ i-(m-n) i runs from m to the order N while j runs from n to i-(m-n). Summarizing

$$A'_{m,n} = \sum_{i=m}^{N} \sum_{j=n}^{i-(m-n)} {}^{i-j}C_{m-n} \, {}^{j}C_{n} \, x_0^{\,(i-j)-(m-n)} \, y_0^{\,j-n} A_{i,j}$$

5.7 Population of SLIT Apertures

Rows 55 to 102, columns A to L refer to the IFU and the slices. They are extracted from the file positionsSIAFApertures,fits using the table columns named C1_XPOSSKY, C1_YPOSSKY up to C4_YPOSSKY and RefXPOSKY, RefYPOSKY and AngleV3. In this file, positions are given in V2V3 coordinates in degrees and so are multiplied by 3600 to convert to arc-sec to place in the worksheet. These give the corner positions, the pointing reference position and the direction of the slit y axis, being the angle between the aperture Ideal y axis and the V3 direction. Subsequent columns are derived from these. The column V3Angle is defined so as to make a right-handed coordinate system with x being in the positive dispersion direction. This direction is at approximately 45 degrees in the +V2, +V3 quadrant so the V3Angles are near 135 degrees. Columns O to V contain the formulae that convert each V2V3 corner to Ideal positions. These last values are copied to columns X to AE in the SIAF sheet.

5.8 The Differential Distortion Correction Sheet.

The aperture to use for the DDC correction is chosen in the sheet labeled DDC. In this sheet, the AperNames in column A are copied by reference from column B in the SIAF sheet. Then columns C and D, the V2 and V3 position of the reference point are found using Excel's VLOOKUP function keyed off AperName in the SIAF sheet. The top row refers to the set of available DDC reference apertures, as named in the SIAF, and their V2V3 positions are given in rows 2 and 3, again using the VLOOKUP function. In the block E4:G60 each entry is the distance between the apertures named in first entry in the cell's row and column. Column H shows the minimum value in each row of the block. Then columns I to K are logical variables testing whether columns E to G are equal to the minimum. Only one of these will contain the value TRUE. Finally using HLOOKUP keying off the TRUE value, the name of the aperture at the bottom of the block is found and placed in column B. The name at the bottom is used because the DDC name is not always identical to the SIAF name. Finally the DDCName in column B is copied to the row with matching AperName in the SIAF column C.

6 On-orbit Updates

Different sets of transforms in the SIAF are used for MSA planning and for target acquisition. For the acquisition to successfully place the selected targets accurately in their planned microshutters, these separate transformations need to be consistent to within ~ 5 mas or better. Because many of the NIRSpec distortion transforms go directly to OTE coordinates rather than to Ideal planes, once target acquisitions are in use, updating the overall alignment cannot simply be done by adjusting the V2Ref, V3Ref, and V3toIDLYangle as is the case for other instruments, and if a full refit of the instrument model is not redone, care must be taken to maintain the consistency between these transforms when adjusting the zeropoints. Normally this would best be done by updating the instrument model to generate the update of all the NIRSpec SIAF entries.

The commissioning activity OTE-027 is intended to do an initial check of the NIRSpec alignment in the OTE plane to ensure that the alignment is close enough to allow subsequent Multi-Instrument-Multi-Field Point (MIMF) activities to succeed. If this initial activity were to find that the alignment was insufficient to allow a target to be placed into the S1600A1 aperture with 1" or better accuracy, a SIAF update to adjust the zero-points would likely be required. For this purpose, however, it may not be necessary that the distortion transformations be self-consistent.

The Commissioning Activity Request (CAR) NIRSpec-041, "NIRSpec Instrument Model Verification", will use a set of internal lamp exposures to verify and refit the parametric instrument model, as was done using the CV3 data. This will produce revised estimates for some of the transformations used in the SIAF files, and new model information will be available to revise the SIAF file if necessary. Subsequently, CAR NIRSpec-018 will optimize the instrument focus, and the CAR NIRSpec-019, "Astrometric Calibration", will take images of an external field with all seven filters in coordination with additional internal LAMP exposures and specialized MSA shutter patterns. When combined with the data from CAR NIRSpec-041, this will allow the parametric model to be refit, and will provide the on-orbit aperture locations, orientations, plate scales, and distortions for the entire imaging FOV. The recalibrated parametric instrument model will then be used to recalculate all of the transformation coefficients and test data that were used for the construction and testing of the SIAF file. Updates to the SIAF file based on these observations need to be delivered and propagated to all subsystems in advance of the execution of CAR NIRSpec-016 which will test the performance of the standard target acquisition algorithm.

The frequency with which SIAF updates will be needed after the initial alignment and commissioning is not yet known and will need to be determined on-orbit. Monitoring of the slews generated by acquisition observations could be used to check for drifts in the relative alignment of NIRSpec with respect to the FGS detectors, while routine internal lamp calibrations can be used to monitor the stability of the parametric instrument model.

6.1 Verification of Updates

When the parametric model is updated, it is necessary to both generate new test data and then validate that the revised test data is consistent with the new version of the transforms. Next we need to verify that SIAF correctly implements the new coefficient delivery. Under some circumstances, we will also want to directly verify that PPS and OSS are continuing to do the correct calculations.

The TEL branch maintains a set of spreadsheets that is used to test the detector-to-OTE plane transformations in both the forward and reverse direction for consistency. These results are also compared to the parametric model test data described in section 4.1.2. The NIRSpec team maintains parallel sets of IDL and python scripts which calculate the same transformations directly from the delivered version of the parametric instrument model to ensure that the provided test data are consistent with the delivered transforms and the TEL branch spreadsheet calculations.

The MSA transforms were tested by PPS by using the test data files described in section 4.7.2.1 after ingestion of the earlier (April 2017) F-008 SIAF delivery into the MSA Planning Tool (MSA). These transforms did not change for the G-010 delivery.

OSS had incorporated the F-008 delivery into recent versions of OSS 6 and OSS 7 and is in the process of testing the TA algorithms using these versions of the OSS software (Koehler et al. 2017 in preparation) against detailed test data provided by the NIRSpec team. This test data consists of simulated TA images, together with the locations of a number reference stars in both detector and V2/V3 coordinates. In the detector plane, the SCA491 is defined to have zero rotation. CV3 results showed that the SCA492 has a rotation angle with respect to the x-axis (dispersion direction) of 1.49359632455e-05 radians (positive anticlockwise). All conventions are described in document ESA-JWST-TN-20931 (Giardino 2015). This rotation angle is included in the parametric model file "FPA.fpa" under the label SCA492_RotAngle. The V2/V3 locations calculated from the stellar centroids in this test data used the F-008 version of the SIAF transformations (Keyes & Pena-Guerra 2017 in preparation). The values for the OSS transforms in the G-010 delivery differ slightly from the F-008 values due to the correction of some round-off errors in the earlier implementation, but this should not affect the tests being done to verify the target acquisition algorithms.

The tests described above validate the consistency of the code, coefficients, and test results, but it is also important to validate these against direct measurements. The target acquisition transformations in the SIAF file delivered during JWST commissioning will be tested by using the final transforms to compare the measured detector positions and catalog positions of stars observed during CAR NIRSpec-19, “Astrometric Calibration”. A detailed description of this procedure will be included in the analysis plan for that CAR. Additional checks will be performed using data from CAR NIRSpec-15, “Standard TA Verification”, and CAR NIRSpec-017, “Bright Object (WATA) TA Verification”.

6.2 Delivery to other subsystems

For target acquisition to function properly, the new SIAF file then needs to be incorporated into APT, MPT, and OSS via the PRD, all proposals need to be reprocessed, and the revised OSS scripts uplinked to the spacecraft. Each version of the parametric instrument model is also delivered as part of the Calibration Data Package (CDP), which is used by DMS and CRDS for pipeline data reductions. Deliveries of the model to the CDP and SIAF must be coordinated to ensure consistency between these subsystems and avoid duplication of effort.

7 References

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Appendix A. Pre-flight NIRSpec SIAF Snapshot

Apert			Detector Frame				Science Frame			
AperName	AperType	AperShape	XDetSize	YDetSize	XDetRef	YDetRef	XSciSize	YSciSize	XSciRef	YSciRef
NRS1_FULL_OSS	OSS	QUAD	2048	2048	1024.50	1024.50	2048	2048	1024.50	1024.50
NRS1_FULL	FULLSCA	QUAD	2048	2048	1024.50	1024.50	2048	2048	1024.50	1024.50
NRS2_FULL_OSS	OSS	QUAD	2048	2048	1024.50	1024.50	2048	2048	1024.50	1024.50
NRS2_FULL	FULLSCA	QUAD	2048	2048	1024.50	1024.50	2048	2048	1024.50	1024.50

Figure 10 Basic aperture information placed in the spreadsheet.

Aperte			V-Frame		Frame Relationships					
AperName	XSciScale	YSciScale	V2Ref	V3Ref	V3IdlYAngle	VIdlParity	DetSciYAngle	DetSciParity	V3SciXAngle	V3SciYAngle
NRS1_FULL_OSS	0.10324663	0.10533870	294.054813	-502.901911	139.155450	1	0.00	1	48.133502	139.155450
NRS1_FULL	0.10326748	0.10532422	294.054813	-502.901911	139.155450	-1	0.00	1	48.133502	139.155450
NRS2_FULL_OSS	0.10331174	0.10536197	463.165228	-353.212474	-42.281773	1	0.00	1	-131.149897	-42.281773
NRS2_FULL	0.10331174	0.10536197	463.165228	-353.212474	137.718227	-1	180.00	1	48.850103	137.718227

Figure 11. Scales, positions, and angles are calculated from the distortion coefficient polynomials

Aperture Basic Info						V-Frame		
AperName	AperType	XSciRef	YSciRef	XSciScale	YSciScale	V2Ref	V3Ref	V3IdlYAngle
CLEAR_GWA_OTE	TRANSFORM	1.96614012122000E-01	3.47495883703000E-01	4.26082999999999E+03	-9.10878199999999E+03			
F110W_GWA_OTE	TRANSFORM	1.96614012122000E-01	3.47495883703000E-01	4.26082999999999E+03	-9.10878199999999E+03			
F140X_GWA_OTE	TRANSFORM	1.96614012122000E-01	3.47495883703000E-01	4.26082999999999E+03	-9.10878199999999E+03			
NRS_SKY_OTEIP	TRANSFORM	1.05390000000000E-01	-1.19130000250000E-01	-2.29600000000000E+00	2.29530000000000E+00	-5.18289805611000E-07	-1.92704532397000E-09	2.07500000000000E-01
NRS_CLEAR_OTEIP_MSA_L0	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_CLEAR_OTEIP_MSA_L1	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F070LP_OTEIP_MSA_L0	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F070LP_OTEIP_MSA_L1	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F100LP_OTEIP_MSA_L0	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F100LP_OTEIP_MSA_L1	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F170LP_OTEIP_MSA_L0	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F170LP_OTEIP_MSA_L1	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F290LP_OTEIP_MSA_L0	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F290LP_OTEIP_MSA_L1	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14764658921000E-01	6.05300266496000E-01	5.52684591413000E-06	-3.46028872881000E-04	-4.12970000000000E+01
NRS_F110W_OTEIP_MSA_L0	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14735977446000E-01	6.05268897344000E-01	5.53924093276000E-06	-3.49342978352000E-04	-4.12970000000000E+01
NRS_F110W_OTEIP_MSA_L1	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14735977446000E-01	6.05268897344000E-01	5.53924093276000E-06	-3.49342978352000E-04	-4.12970000000000E+01
NRS_F140X_OTEIP_MSA_L0	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14735977446000E-01	6.05268897344000E-01	5.53924093276000E-06	-3.49342978352000E-04	-4.12970000000000E+01
NRS_F140X_OTEIP_MSA_L1	TRANSFORM	-2.27962000000000E-07	-2.60940000000000E-07	6.14735977446000E-01	6.05268897344000E-01	5.53924093276000E-06	-3.49342978352000E-04	-4.12970000000000E+01

Figure 12. Constant entries in the TRANSFORM rows. The first three rows are the GWA to OTE transforms discussed in sections 2.3.3 and 5.5. The remaining rows contain the field angle to MSA plane transforms. The mapping between the displayed column labels and the NIRSpec meanings is given in Table 5.