JWST TECHNICAL REPORT

Title: NIRISS Commissioning Results: NIS-013(a) – NIRISS-FGS alignment and SIAF Update (NGAS CAR-376, APT 1088)	Doc #: JWST-STScI-008352, SM-12 Date: December 06, 2022 Rev: -
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1 Abstract

This report presents the analysis and results of the commissioning program NIS-013 (NGAS CAR-376, APT 1088). We describe the data and analysis used for updating the SIAF alignments from this commissioning program. We analyzed a total of 8 images (4 primary NIRISS + 4 parallel FGS1 exposures) to derive the SIAF alignment parameters V2Ref, V3Ref, and V3IdlYAngle of the NIRISS detector. These parameters were used to generate the SIAF xml file. The uncertainties of our calibrated parameters based on the 4 independent measurements are well below limits set by the mission requirements.

2 Introduction

The precise locations and orientations of JWST detectors within the focal plane are specified in the Science Instrument Aperture File (SIAF) which is detailed in Cox & Lallo (2017). The contents of SIAF's are separated into two components: the alignment and distortion. For NIRISS, the relevant programs are NIS-011(b) and NIS-013. NIS-011(b) is for the distortion calibration and described in Sohn et al. (2022) in detail. This report presents the analysis and results for the SIAF alignment calibration program NIS-013.

NIS-013 was designed to determine the relative position and orientation of the NIRISS detector in the focal plane of JWST with nominal wavefront quality. The end product of this calibration program is a set of SIAF alignment parameters: V2Ref and V3Ref, the telescope (V2, V3) coordinate of the NIRISS reference point; and V3IdlYAngle, the position angle of NIRISS detector's Y axis relative to V3 measured about the reference point. These SIAF parameters have been pre-determined from ground tests before launch (a.k.a. pre-flight SIAF), but are required to be calibrated on orbit. In this report, we present analysis and results of this calibration.

3 Description of Data

For our SIAF alignment calibration program, we targeted fields within the LMC calibration field. The LMC calibration field catalog is characterized by a ~5×5 arcmin^2 field observed with HST, and a ~12 ×12 arcmin^2 field that encompasses the HST field observed with the HAWK-I camera onboard the Very Large Telescope (VLT). The smaller HST field is used for distortion calibrations (see Sohn et al. 2022 for details) while the larger HAWK-I field is used for SIAF alignments which was designed to fit observations with any JWST science instrument as primary and FGS1 or FGS2 as parallel. The original version of the HAWK-I catalog was constructed by Libralato et al. (2014), and was later tied into the Gaia DR2 astrometric reference frame by Sahlmann (2017, 2019) in preparation for the SIAF alignment calibrations of JWST science instruments. The telescope pointings for APT program 1088 (NIS-13) were specifically chosen such that FGS1, FGS2, and NIRISS field of views (FoVs) remain within the HAWK-I catalog at any given JWST roll angle. Figure 1 shows the actual observational footprint of program 1088 observation 1.

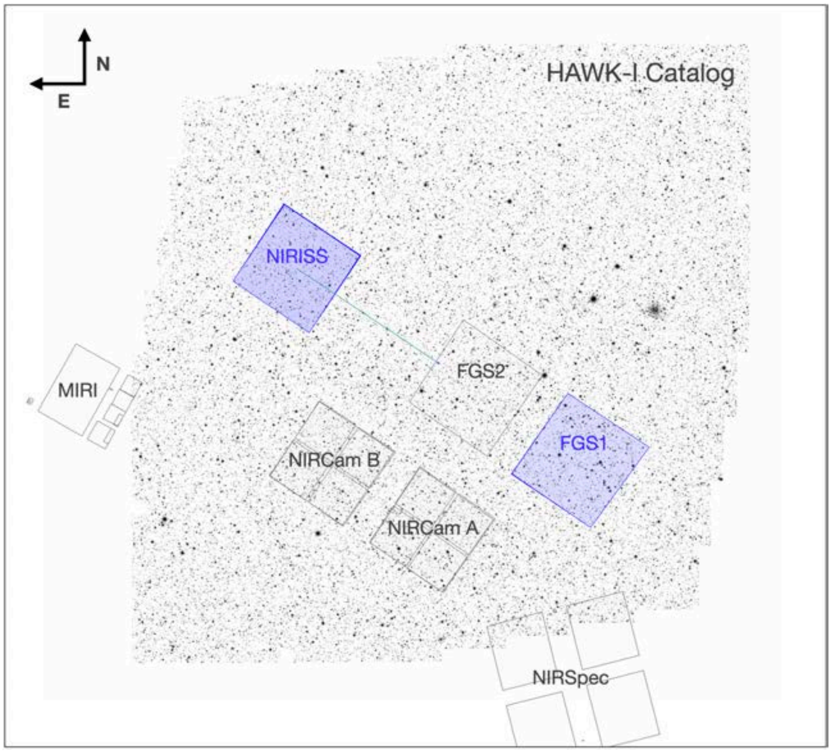

Figure 1. Observational footprints of the images used for the FGS1-NIRISS alignment calibration marked in blue overlaid on the HAWK-I catalog. Footprints for other instruments and FGS2 are labeled in black and were not part of this observation. The observed PA_V3 (position angle of the V3 axis about North around the boresight) was 145.4 deg.

NIS-013 observations were carried out on May 7, 2022, about after the OTE Commissioning has been completed and telescope has mostly reached thermal stability. There were three observations associated with program 1088. The third observation was used for the filter-to-filter offset measurements as described in Goudfrooij et al. (2022). The first observation consists of four dithered full-frame NIRISS F150W and FGS1 imaging while FGS2 was guiding. The second observation was similar to the first one, but the roles of FGS1 and FGS2 were reversed. For the FGS1-NIRISS alignment, we only used the 8 images (4 NIRISS and 4 FGS1) taken in the first observation. Each NIRISS (FGS1) exposure was obtained with 5 (4) groups and 3 (3) integrations. There was a total of four dithered exposures. Figure 1 shows the primary NIRISS and parallel FGS1 images for the first dithered exposure of program 1088 observation 1.

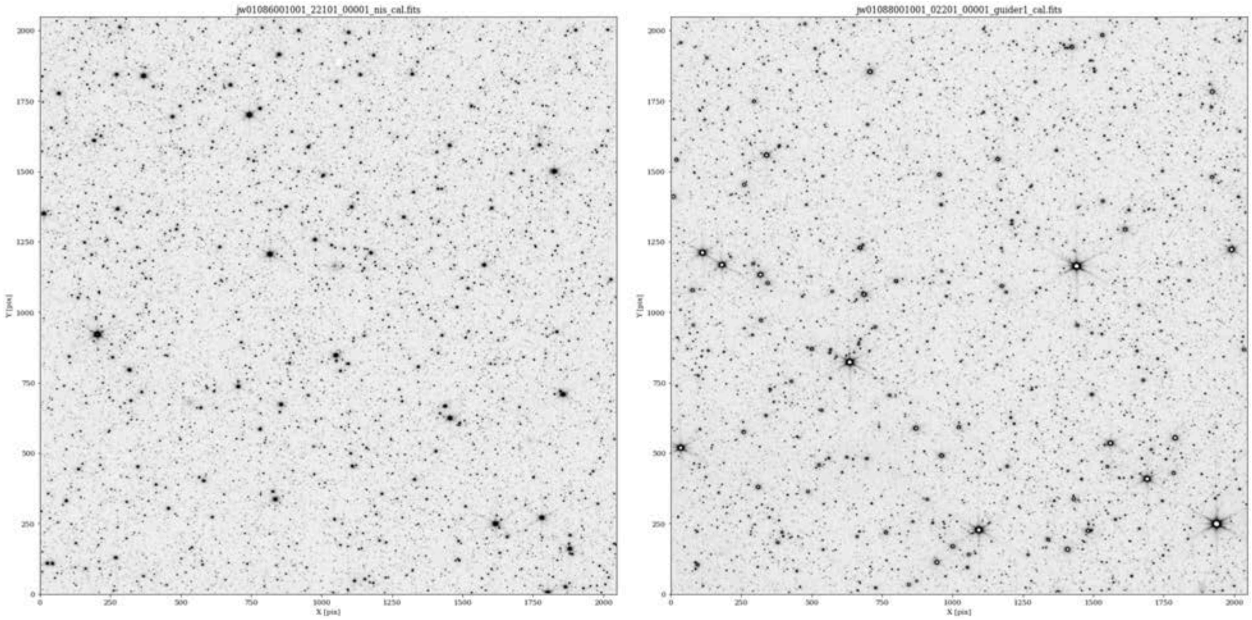

Figure 2. Example NIRISS (left) and FGS1 (right) images from the first dithered exposure of program 1088 observation 1.

4 Analysis Methods

For the analysis, we used the `jwst_fpa.py` python script which is part of JWST Focal Plane Alignment package (GitHub repository: https://github.com/tonysohn/jwst_fpa). This adopts the methodology introduced in Sahlmann et al. (2019) to determine the alignment of a given aperture/instrument (NIS_CEN/NIRISS) relative to a reference aperture/instrument (FGS1_FULL/FGS1). The script starts by going through the source detection, positional measurement, and crossmatching with the HAWK-I reference catalog. These processes are largely identical to those described in Sohn et al. (2022) except that we use the HAWK-I instead of the HST catalog.

With the crossmatched catalog in hand, we go through the initial attitude refinement stage. This is necessary for the accurate transformation of the reference catalog's (RA, Dec) coordinate to the telescope (V2, V3) coordinates. The attitude parameters (RA_V1, DEC_V1, PA_V3) recorded in the FITS image headers[1] are from the commanded pointing and therefore can be offset by up to 0.19 arcsec (Rigby et al. 2022) which is insufficient for our SIAF alignment calibration. We update the telescope attitude using FGS1 observations as summarized below.

- The FGS1 science coordinates $(Xsci, Ysci)_{obs}$ of calibration stars are transformed to telescope coordinates $(V2, V3)_{obs}$. For this transformation, on-flight version of FGS1 distortion coefficients were used since they were available through the FGS-11 program at the time of NIS-013 calibration. The astrometric reference catalog's sky coordinates (RA, Dec) of the crossmatched entries are transformed to $(V2, V3)_{ref}$ coordinates using

[1] The corresponding metadata information for the data model are `model.meta.pointing.ra_v1`, `model.meta.pointing.dec_v1`, `model.meta.pointing.pa_v3`, respectively.

the FITS header (RA_V1, DEC_V1, PA_V3) using *pysiaf*.

- We fit a 1st-order bivariate polynomial (which includes offset, scale, and skew terms) to map $(V2, V3)_{ref}$ versus $(V2, V3)_{obs}$. The linear offset and the Y-rotation terms of this polynomial solution are used to correct the (RA_V1, DEC_V1, PA_V3).

- The corrected attitude from the step above is now used for transforming astrometric reference catalog's (RA, Dec) to a new set of $(V2, V3)_{ref}$ coordinates. The polynomial fit is carried out again using the new $(V2, V3)_{ref}$ versus $(V2, V3)_{obs}$.

- Repeat the steps above until convergence is reached for the (RA_V1, DEC_V1, PA_V3) parameters. The convergence criterion is met when the difference between the new and the previous iteration's parameters is smaller than *f* times the parameter uncertainty, where *f* is typically found to be in the range 0.01 to 0.03 (corresponding to 1-3%).

Once we have the refined attitude, we proceed to the determination of FGS1-NIRISS alignment parameters as follows.

- The NIRISS $(Xsci, Ysci)_{obs}$ is converted to $(V2, V3)_{obs}$ using the SIAF distortion coefficients updated during NIS-011(b) (Sohn et al. 2022) + the pre-flight SIAF alignments.

- (RA, Dec) coordinates from the HAWK-I catalog for the corresponding stars are converted to $(V2, V3)_{ref}$ using the refined attitude parameters.

- A 1st-order bivariate polynomial is used to map the two sets of telescope coordinates from above. The resulting offset and Y-rotation terms are applied to the current (V2Ref, V3Ref, V3IdlYAngle) of the NIS_CEN aperture.

- Repeat the steps above until (V2Ref, V3Ref, V3IdlYAngle) converge. The convergence criteria are as same as described above.

With the updated SIAF alignment parameters, we now proceed to the next step which is to use the $(V2, V3)_{obs}$ of *both* FGS1 and NIRISS to further refine the attitude. Since this covers a larger area on the focal plane with more data points, the attitude, especially the PA_V3, is better constrained than using only the FGS1 observations. Then, we use this improved attitude to re-determine the (V2Ref, V3Ref, V3IdlYAngle) for the NIS_CEN aperture as outlined above. These entire steps are iterated until convergence is reached.

We applied the same analysis methods to all 4 dithered pairs of FGS1+NIRISS images for the calibration. Results from these 4 independent calibrations were then averaged to determine the final values of V2Ref, V3Ref, and V3IdlYAngle.

5 Results

Once the `jwst_fpa.py` script runs through the entire process, it displays a series of diagnostic images that illustrate the results of the focal plane alignment process. Figure 3 shows an example of the alignment results for the first exposures on the JWST focal plane.

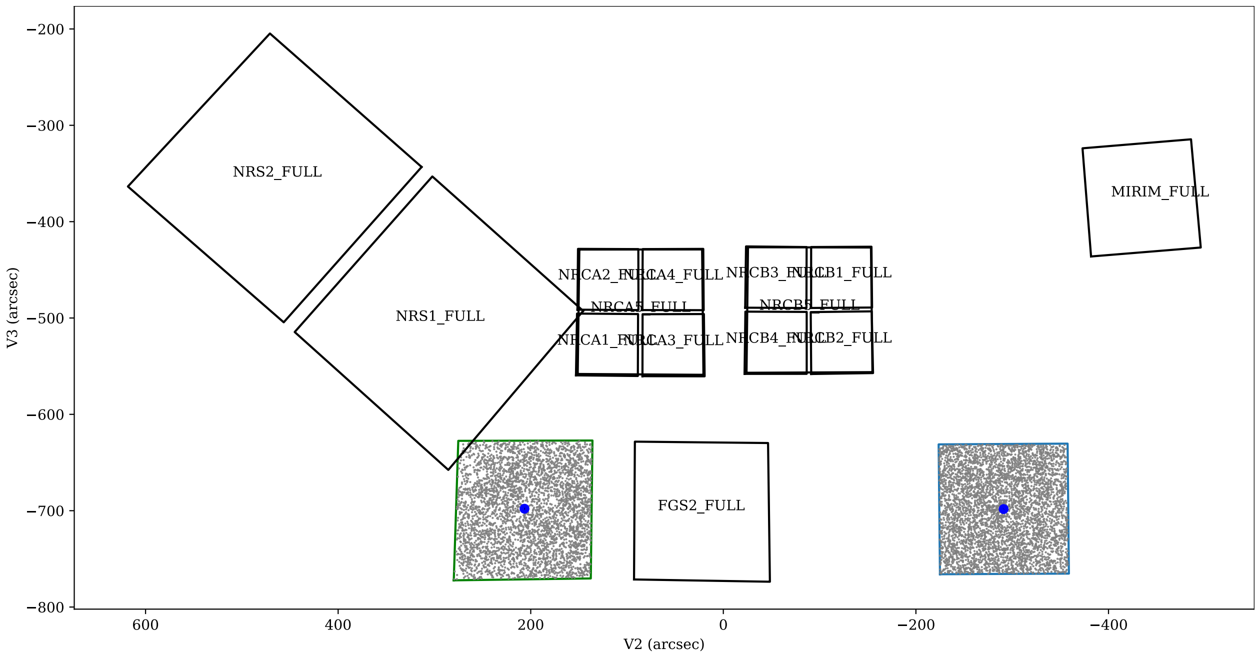

Figure 3. A direct output plot from jwst_fpa.py. FGS1-NIRISS alignment results for the first FGS1 and NIRISS exposures displayed on the JWST focal plane. Gray dots in the FGS1 and NIRISS fields indicate the stars used for this calibration and blue dots show the calibrated location of (V2Ref, V3Ref) for each detector.

Figure 4 shows the V2Ref, V3Ref, and V3IdlYAngle determined for each dither position along with the average of the 4 measurements adopted as the final results.

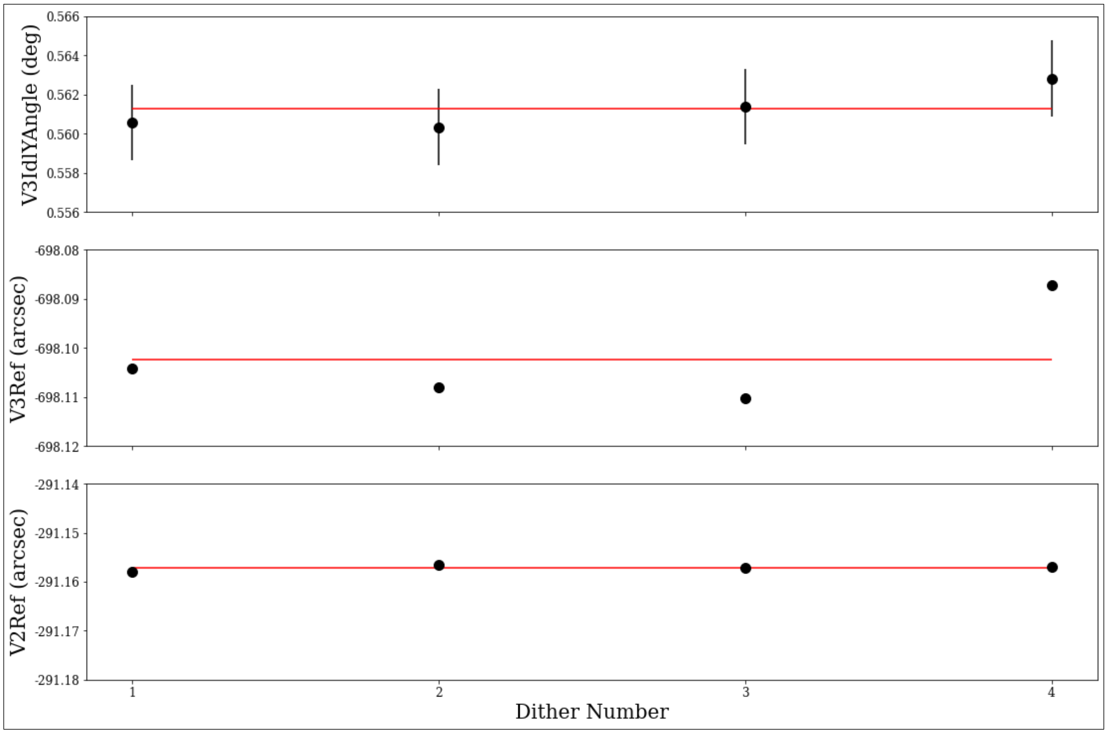

Figure 4. From bottom to top, V2Ref, V3Ref, and V3IdlYAngle measured from each dither pointing. Associate errors are also plotted as vertical bars – for V2Ref, V3Ref, the error bars are equal to or smaller than the data points. Red horizontal line in each panel indicates the average of the 4 data points.

The SIAF requires two parameters V3SciXAngle and V3SciYAngle in addition to the V2Ref, V3Ref, and V3IdlYAngle. These define the X and Y axes of the detector in the science coordinate frame, and can be calculated from the calibrated parameters as follows for NIRISS:

$$V3IdlSciYAngle = V3IdlYAngle$$

$$V3IdlSciXAngle = V3SciYAngle + \arctan\left(\frac{-A_{10}}{B_{10}}\right)$$

where A_{10} and B_{10} are from the distortion coefficients as in Sohn et al. (2022). The resulting SIAF alignment ASCII text file is shown in Figure 5.

```
# NIRISS alignment parameter reference file for SIAF
#
# This file contains the focal plane alignment parameters calibrated during FGS-SI alignment program NIS-13.
#
# Generated 2022-05-12T00:00:00.000 utc
# tsohn
#
                    AperName ,      V3IdlYAngle ,         V3SciXAngle ,          V3SciYAngle ,    V2Ref ,    V3Ref
                     NIS_CEN , 0.56126716610545 , -89.70138692875433 ,     0.56126716610545 , -291.157 , -698.102
                 NIS_CEN_OSS , 0.56126716610545 ,  90.29861307124567 , -179.43873283389456 , -291.157 , -698.102
```

Figure 5. SIAF alignment results in ASCII text file format. This file gets input into the pysiaf's *generate_niriss.py* script for generating the SIAF xml file.

The mission requirements based on Lallo (2010) are such that the FGS-to-SI *alignment* calibration should be accurate at the level of 100 mas or less, and the relative FGS-to-SI *orientation* should have an accuracy of better than 10 arcsec. The rms uncertainties based on our 4 independent measurements are σ(V2Ref) = 0.49 mas, σ(V3Ref) = 9.06 mas, and σ(V3IdlYAngle) = 3.48 arcsec. We therefore conclude that our SIAF calibration results meet the mission requirements. The SIAF parameters from this program was included in the PRDOPSSOC-048 (CR# 5403) delivery which was installed on May 17, 2022.

6 References

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