Nancy Grace Roman Space Telescope (Roman) Technical Report

Title: Astrometry with Roman and Its Relationship to Science Data Products		Doc #: Roman-STScI-000243, SC-01 Date: April 2, 2021 Rev: -
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1 Abstract

The major surveys involved with the Roman mission will expect exquisite precision, in both the resolution and absolute location, of astronomical sources in the fields of regard. While the Roman vehicle does not guarantee that the pointing aperture reference pixel will be exactly aligned with the requested pointing coordinates, it is expected to be within a reasonable tolerance in order to achieve the science goals of the mission. It is important to understand the relationship between the vehicle pointing used during science observations, how that pointing translates to the astronomical scene that is recorded, and how the chain of related coordinate systems is traversed. The Roman telescope is employing a novel guiding system, different than what is used for Hubble or James Webb, for both imaging and spectroscopic observations. In this memo we will outline how astrometry is tied to the world coordinate system that is applied to the resulting science observation datasets. We will focus on the major components of this relationship to encourage greater familiarity with its overall application, while not diving into the details that differentiate its use for imaging versus spectroscopic data analysis.

2 Determination of the Absolute Pointing

2.1 Guide Stars

The Roman ground system is tasked with providing a Guide Star Catalog that will have at least a 95% probability of providing guide stars that meet WFI guiding specifications for all observing modes, on any fixed target for any valid attitude within the field of regard (SOC-267[15]). The stars used for guiding will have a celestial positional accuracy of about 60 milliarcseconds or better (SOC-268[15]). The goal is to find stars that are isolated by at least 10 arcseconds, from all other stars, that are at least as bright as 2 magnitudes fainter than the guide star itself. This isolation distance allows the on-board acquisition algorithm to more easily verify that it has found a sufficient number of the provided guide stars to determine the pointing error. However, if guide stars are not available to meet those specifications, the flight software is still expected to function within requirements. The purpose of the magnitude floor is to help the onboard algorithm better reject background stars in areas where the guide star catalog may not go sufficiently deep, for example, in the galactic bulge[8].

According to an ESA's report on Gaia Early DR3[1]: "The Gaia EDR3 catalogue is essentially complete between G=12 and G=17". The transformation between Gaia and Roman magnitudes should take into account the color of the stars but, as an estimate[2], G=17 corresponds to H_{AB}~14.8, i.e., 2.2 mag brighter than the guide-star faint limit of H_{AB}=17[9]. The faintest reliable magnitude for guiding in imaging mode is likely closer to H_{AB}=16.5 with most of the imaging elements. Note that the adopted magnitude zero-point estimate of ~2.2 mag between Gaia's G and H_{AB} magnitudes is based on a direct comparison between Gaia stars, 2MASS stars, and the HST catalog of the Sagittarius window (GO-13057, PI: Sahu). Stars in common belong to the upper Disk main sequence and the Bulge red giant branch, which are both roughly vertical on a color-magnitude diagram based on either m_{F606W}-H_{2MASS} or G-H_{2MASS}. The adopted photometric zero point between H_{2MASS} and H_{AB} of 1.354 mag comes from Table 2 of Cohen et al (2003)[13]. See WFIRST-STScI-TR1702[2] for more details.

If Gaia's end-of-mission catalog turns out to be complete down to H_{AB}=17, then there is no reason to look for other options, since Gaia's astrometric quality over the entire sky is unmatched. The Gaia catalog will also provide proper motions, which enable use of its astrometric position measurements several years from their nominal epoch. The Guide Star Request and Selection Process Technical Report[12] discusses the need to keep the guide star catalog used with Roman up-to-date with Gaia releases.

2.2 Vehicle Pointing

The spacecraft will slew towards its commanded pointing under the Attitude Control System (ACS), which will use advanced star trackers in order to determine the spacecraft pointing during the slew. The coarse pointing quality under ACS is required to be better than 3.5 arcsec (MRD-393[16]) in order to support initial guide star acquisition; the fine pointing accuracy is required to be better than 640 mas per coordinate and 87 arcsec in roll (MRD-32[16]). All requirements are 1-sigma. A virtual windowing pattern will be used to find the guide stars if the initial pointing is outside the extended guide windows.

2.3 Guiding Windows located on the WFI Detectors

The Wide Field Instrument will be used for guiding all exposures for the observatory, during both WFI and CGI science observations. In order to accomplish this, guide windows, subarray locations available on each of the WFI detectors, will be defined and the pixels they contain will be read out at a faster rate than the rest of the detector. The readout rate for the windows, as well as the entire detector, depends on the size of the guide window itself and will vary between 4 Hz and 6 Hz for the different guiding modes. There may additionally be multiple guide star acquisitions within a single visit; this differs from JWST and HST. The guide window data will be important for Point-Spread Function (PSF) and astrometry reconstruction in direct images.

The guide-window data themselves can also provide high-rate information on image jitter, which does affect the PSF, and may potentially be used for weak lensing, microlensing, and astrometry analyses.

The guide-window data will be downlinked from the telescope and may be used during science data processing of the observations themselves. Specifically, the final corner locations of the guide-windows themselves will be extracted and noted in the science data frames. The final window locations are only determined during the telescope pointing process, and can in principle change during an exposure. Knowing and marking the locations of these guide windows in the datasets will be important for downstream calibration processing, as the noise properties of the image are affected by the location of the guide windows and their faster readout. The size of the guide window itself depends upon the observation mode and changes between different guiding modes.

In order to ensure uniformity of readout timing, there will always be a guide window somewhere within each detector, and all guide windows will be read out during every exposure; however, only designated guide windows will be used for actual guiding. The guide window data themselves will be treated similarly to the full frame science data, in that not all readouts from the detector will be transmitted to the ground. Instead, frames resulting from onboard combination, referred to as resultant frames, will be packaged together to form the integrated data set for each exposure. The instructions that determine how the guide window data are combined onboard the spacecraft will be contained in specific guide-window MultiAccum tables that are referenced by the flight software and known to the ground system and proposing observers. Only resultant frames are used in the onboard attitude calculation and correction loop, as discussed below.

The guide-window locations can change between guide-window cycles at up to 6 Hz, but not within one cycle. For the first set of guide-window resultant frames, the guide-window location will not change across all the frames that compose the resultant image. However, for the following guide window cycle, the position could change, although changes of greater than 1 pixel are expected to be rare in this guide mode. For guide windows, the resultant guide-window frame contains the x and y start and stop positions of the guide-window corners.

In order to support Fine Guidance System (FGS) analysis on the ground, the guide windows for a visit will be in separate files from the science file so that they can be pulled from the archive on demand. The Planning and Scheduling Subsystem (PSS) at the SOC will also use the data for the purpose of troubleshooting failed guiding attempts as well as post-pipeline analysis of the guiding. The FGS software currently uses the center of the WFI detector, (0,0), as the origin for the position of the guide window and the origin for the calculated centroids.

2.4 Guide Star Centroids Calculated by the On-board Flight Software

Roman Flight Software (FSW) uses the resultant guide-window frames to compute a centroid for the guide star within the guide-window, after correcting for any detector orientation flips that may be needed due to the orientation of the Sensor Chip Assembly (SCA) in the Focal Plane Assembly (FPA). For WFI Imaging Mode (WIM), the first moment is calculated, before using a Discrete Fourier transform, followed by a correction for pixelation effects based on the filter in use. This centroid is used to check the alignment between the star tracker and the FPA for alignment-error analysis. A subset of the centroid data that are computed onboard will be transmitted to the ground system for reference and will be included as part of the guiding data that are made available.

3 Science Team Use of Guiding Data

The guide window and centroid data may be important for PSF reconstruction and astrometry in direct images. First-cut information can be obtained from the centroid data (after pairing to the image data). Improved centroid determination may be possible after the fact using the guide window data frames, and taking advantage of information that may not be available to the on-board algorithm, such as source color and image-specific PSF data. We expect that most science analyses will use the effective PSF (ePSF), which is an empirically determined PSF that includes the optical PSF, pixelization and other detector artifacts, image jitter, and any other effect that would impact observed images of point sources. For regular science data, the PSF is effectively sampled only at each resultant frame, separated by 3 seconds or more depending on the exact readout time for the frame and resultant frame combination, and thus will be affected by jitter on time scales up to several tens of seconds.

In contrast, the ePSF applicable to the analysis of guide window data will only contain jitter on sub-second time scales, and thus it is expected to be somewhat sharper than the regular science ePSF. At this point, it is hard to quantify the systematic uncertainties of using the ePSFs constructed from science images to fit guide stars in the fast reads of the guide window data with the purpose of obtaining precise centroids. Nevertheless, science-data ePSFs could still in principle be used with some success on the fast reads of the guide window to provide an external estimate of jitter effects, by treating each guide-star read as a speckle image. This jitter estimate could provide a fair representation of the actual jitter in an image and can be compared to other estimates, e.g., from telemetry.

The science teams will need all available guiding data to help with ePSF determination, as there will likely not be enough bright stars in a typical High Latitude Imaging Survey exposure to fully characterize the ePSF directly. Science Teams are planning to use a combination of image data, observatory telemetry, and high-fidelity jitter information to determine the position- and color-dependent ePSF for each image, which will then be used in further science analyses.

For spectroscopic observations, scientists and the SSC will need to know which edges of the dispersed spectrum for the guide star were used to calculate the centroid during observations. While the blue edge is sharper and will be used for guiding most exposures, depending on the field, there might not be an acceptable blue edge to use for some SCAs. In these cases, the red edge will be used instead. The full science frame may also be used by SSC or science teams, for improving pointing and wavelength knowledge for the spectroscopy data after SOC processing, but a comparison to the guide-window data is still important for refining information about spectroscopy guiding and wavelength locations.

Using an effective minimum exposure time of 3 full frame times (four reads including the zero read), the hard saturation limit – i.e., the brightness of a star that just hits full-well saturation in the central pixel at the minimum exposure time – is typically H_{AB}~15.2. Such a star will have a Poisson S/N of over 350, with 128,000 electrons collected in the central pixel at the minimum exposure time. The central pixel of an H_{AB}=17 star, which we take as the faint guide-star limit in imaging, will have a Poisson S/N over 140, with 20,000 electrons collected in each guide star frame. However, it is possible that guide star pixels will suffer from additional noise, possibly start-up noise that occurs when the readout switches between full frame and guide window. To date, this extra noise has not yet been fully characterized. Based on HST experience and assuming comparable ePSF quality, we expect that the positions of bright stars in Level 2 (L2) images can be measured with a precision of about 0.01 pixel (or better) per star in each coordinate. This applies to guide stars (per guide frame), as long as the extra background in guide star pixels does not exceed about 100 electrons per pixel in each frame. If the extra background is larger, the precision of individual guide star measurements, even with an appropriate ePSF, will likely degrade; for an additional background of 1000 e^-/pixel, we estimate a precision of about 0.05 pixels per coordinate per measured frame.

4 Determination and Use of the Geometric Distortion Solution

For various reasons, such as camera optics, alignment errors, filter irregularities, non-flat detectors, and manufacturing defects, the mapping of the square array of square pixels of a detector onto the tangent-plane projection of the sky requires a nonlinear transformation. Positions measured within the pixel grid need to be corrected for geometric distortion before they can be accurately compared with other positions in the same image or compared with positions measured in other images.

4.1 Determining the Distortion Correction for WFI

The distortion-correction process will employ a two-step hybrid system. Initially, the distortion of each SCA will be solved independently on a tangent plane whose projection point is the central pixel of the SCA. Subsequently, projections and de-projections on to the celestial sphere will enable proper positioning of the pixels in each SCA relative to those of other SCAs, thus providing a global (meta) solution for the entire WFI. This is a work in progress, with a first technical study based on the Gaia catalog as an absolute reference frame published in 2018[3].

For the first step, the general idea is to solve for the geometric distortion of a SCA using a set of polynomial coefficients and a look-up table of residuals for each optical element (filter). To mitigate out-of-plane distortion, the projection point should be chosen as the central pixel position of an SCA. Experience with other instruments suggests that a polynomial solution can correct most of the geometric distortion, leaving (at most) residuals of the order of a few tenths of a pixel (usually a few hundredths). In general, many optical systems are affected by pin cushion or barrel distortion, both of which can be well approximated by third-order polynomials. This suggests that a third-order polynomial might be appropriate for the WFI, but there are instances in which higher-order polynomials are used (e.g., the geometric-distortion solution of the ACS/WFC of HST uses a 4th-order polynomial). It seems unlikely that orders higher than 5th will be needed.

The residuals that are left after applying a polynomial solution are usually due to imperfections in the filter element, in the chip manufacturing process (e.g., lithographic patterns), in the readout electronics (e.g., hysteresis effects between the amplifiers), or any combinations of the above. These systematic residuals are generally mitigated using filter-dependent look-up tables of residuals that can be 1D (e.g., WFPC2) or 2D (e.g., WFC3/UVIS). The size of the look-up table should be dictated by the general shape and size of the residuals. For instance, if only hysteresis effects are present, the look-up table can be as small as a 1-dimensional table of 32 elements (one element per amplifier). If complex lithographic patterns are present, the look-up table can end up being a two-dimensional table of many elements on a side, possibly as large as 100x100 elements (i.e., sampling every 40 pixels or so) or even more.

Due to the large field of view of the WFI, projection effects are not negligible, and it seems more appropriate to provide a global (meta) distortion solution of the WFI using spherical coordinates, even though the internal distortion correction for each SCA may be initially obtained in a local tangent plane projection for computational simplicity. Using a set of reference stars in each SCA (likely from the Gaia catalog), in combination with a set of large dithers (ideally from corner to corner of the entire WFI), it will be possible to precisely map the distortion-corrected pixels of the SCAs from their tangent-plane projections on to the celestial sphere, thus enabling the construction of a meta-solution for the full-frame WFI in terms of spherical angles. This meta-solution is independent on the actual pointing of the telescope on the celestial sphere, and it assumes that the relative angles between the pixels of each SCA are conserved. Rotations of the meta-solution on the sphere will account for different telescope roll angles and pointings, and align the metaframe to the V2,V3 or RA,DEC coordinate systems.

The single-SCA geometric-distortion solution can be represented as metadata (polynomial coefficients and look-up table of residuals) in the ASDF images files, as well as a set (one per filter element) of 36, 4088x4088, 32-bit arrays (2 for each SCA, one for the X correction and one for the Y correction), in which every array element maps the X or Y correction of each SCA pixel. The meta-solution can be expressed in terms of spherical projections of the tangent-plane-defined single SCA solutions, and a set of angles between the spherically-transformed central pixel locations of each SCA.

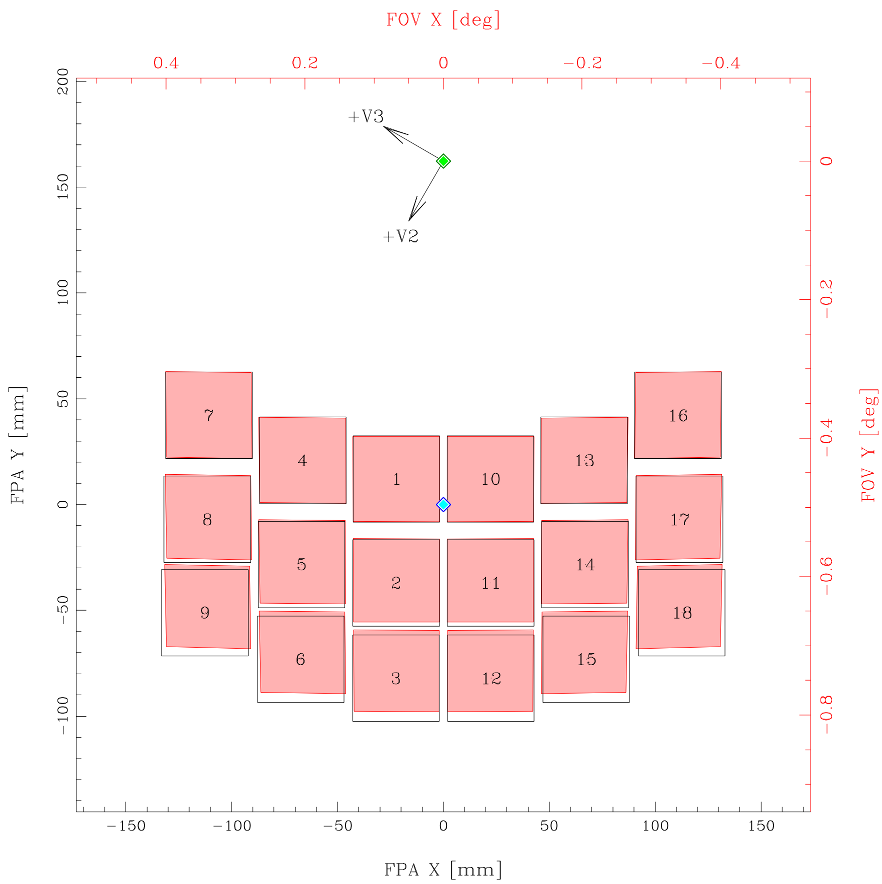

Figure 1: Black squares represent the 18 SCAs of the WFI on the focal plane, in its native coordinate system (FPA), and in units of mm. The reference point of the FPA system is marked by a blue diamond. The V2,V3 system is centered on the telescope optical axis (green diamond) and is defined as having its V3 axis normal to the sunshade. The field angle between the origins of the FPA and the V2,V3 systems is 0.496 degrees. The red-shaded regions represent the distortion-corrected SCAs in the FOV coordinate system, in units of degrees, as projected on the tangent plane of the focal plane using the FPA origin as projection point.

4.2 Use of the distortion models within DMS and PSS

The distortion solution for each SCA is used in both the PSS and Data Management Subsystem (DMS), but at different levels of precision. The distortion parameters stored as part of the Science Instrument Aperture File (SIAF), which itself is stored in the Project Reference Database System (PRDS), usually contains compressed parametric forms, and ignores wavelength dependence. The SIAF information is sufficient for pointing stability and planning. Official reference positions and angles relative to V3 position angle, for all defined apertures, are also maintained in the SIAF. More information about the SIAF file and its relationship to the vehicle is in Section 6 along with more details on the implementation of the WCS.

On the other hand, DMS processing employs the full parametrization of the distortion solution during calibration, and stores that information into the World Coordinate System (WCS) in the resulting science data products at Level 2. This level of accuracy is required in science analysis, and in order to meet the astrometry accuracy requirements listed in Section 5.

5 Determination of Astrometry Solutions

Each image has an initial astrometric determination based on the commanded pointing. On the basis of requirement MRD-32[16], this astrometric information has a minimum accuracy of 640 mas RMS, with a rotation error of 87 arcseconds RMS. In practice, it is expected to be significantly better, possibly around 0.1-0.2 arcsec. The absolute astrometry of each image can then be improved in two different ways. The first is to use the actual measured positions of each of the guide stars, applying the full geometric correction (the Pointing Control System uses a lower accuracy solution), and perform a full focal plane alignment on the basis of their positions. In analogy with HST-related work, this process is called an "a priori" (before the fact) astrometric refinement, as it uses only guide-star related information. The second is to use point sources measured from the image itself, and perform a high accuracy alignment using their catalog values; as for HST, this method is called "a posteriori" (after the fact), as it can only be adopted after the full image data are obtained.

For the a posteriori solution, typically thousands of Gaia sources will be present in each exposure, though sources may be much fainter than guide stars. Even in the sparsest regions of the sky, e.g., around the North Galactic Pole, it has been estimated[2] that about 450 Gaia DR1 sources will be within a full-frame WFI exposure. A query of the EDR3 catalog shows that the density of such sources is predicted to be similar.

The pipeline could in principle extract sources from each Level 2 image, match them to the Gaia catalog, and redetermine the image alignment with higher precision than obtained directly from the guide stars. This could entail on-the-fly update of the alignment information. If this approach is implemented, we should consider: i) whether the sources used for the alignment are recorded by the pipeline; ii) whether the original ("a priori") alignment is also stored in the image metadata, and iii) whether we need tools to update alignment information if reference catalogs change (e.g., new Gaia data release). Ideally, this process would be carried out before the Level 2 data product is delivered, so that the updated alignment is included in the Level 2 metadata in the Archive.

5.1 Error budgets and Estimated Accuracy

5.1.1 Geometric-distortion correction

Assuming Gaia's end-of-mission astrometric errors (positional errors plus proper motion errors), it has been shown[3] that the distortion-solution precision that can be reached using Gaia alone, as an absolute reference frame, is at best 0.03 pixel (3.3 mas). A work-in-progress technical report[17] is investigating the feasibility of employing a combination of Gaia positions to define the initial reference system, and subsequent improvements of the reference system itself through an auto-calibration of the distortion solution (by iterating between solving for the geometric distortion of the SCAs and improving the positions of the reference sources). Preliminary results show that single SCA geometric-distortion residuals are of the order of just a few millipixel (a few tenths of milliarcsec), thus implying that the precision of the distortion solution should be much higher than the precision with which source centroids are measured (i.e., 0.01 pixel).

5.1.2 Guide Star Centroids Using the effective PSF (ePSF)

While error budget estimates for the a-priori and a-posteriori methods have been previously obtained[2], those estimates are based on expected Gaia's end-of-mission errors assuming a nominal Gaia mission lifetime of 5 years and the contents of Gaia Data Release 1. The Gaia mission has now been officially extended to 31 December 2022, with indicative extension to 31 December 2025. In the following, we will use updated figures from the official Gaia website[10] for both the original mission lifetime of 5 years and for the extended Gaia mission (10 years); see also Figures 3 and 4. The guide-window magnitude range, in Gaia magnitudes, is assumed here to be $13.1<G<19.1$, but note that only stars fainter than $G\sim17.3$ (i.e., $H_{AB}\sim15$) are not hard-saturated in L2 images. The position of stars brighter than G~17.3 can be measured on the fast reads of the guide windows using PSF fitting, albeit at a lower precision due to the uncertainties in the shape of the PSF in these fast reads. For simplicity, here we assume that PSF fitting will offer the same precision on the fast reads as on the L2 images, which is 0.01 pixel for the bright limit, and 0.05 pixel for the faint limit. All estimates refer to the start of the Roman mission, assumed here to be 2025.

- Ideal case of 18 guide stars. For the nominal Gaia mission we estimate 0.26–1.60 mas error per coordinate, where the minimum and maximum values assume stars all at the hard-saturation and at the faint guide-star limits, respectively. For the extended Gaia mission the range becomes 0.26–1.36 mas.
- Worst case of only 4 guide stars: 0.56-3.38 mas per coordinate (0.56-2.89 mas for the extended Gaia mission).
- Representative case of 8 guide stars, all with middle-of-the-range magnitude: 0.80 mas for both nominal and extended Gaia missions.

We remind the reader that, although here we are using $H_{AB}=17$ as the faint guide-star limit, the faintest reliable magnitude for guiding in imaging mode is likely closer to $H_{AB}=16.5$.

5.1.3 A posteriori absolute astrometry method using Gaia sources in an image

Let us assume 450 Gaia sources per exposure as a lower limit, a median over the sky of 1,800 sources per WFI exposure, a maximum of around 50,000 sources in very dense stellar regions like the Sagittarius Window[2]. Let the suitable Gaia sources be in the range $17.3<G<20.7$, i.e., between hard-saturation and the Gaia faint limit. Centroiding errors vary according to the S/N of sources in the WFI exposures. If PSF fitting is used, extended sources will be affected by larger centroiding errors than stars at the same magnitude level. In the following, we consider centroiding errors of 0.01 pixel for a $G=17.3$ source, and of 0.15 pixel for a $G=20.7$ source. With these numbers, we can estimate the following errors on absolute astrometry:

- Ideal case of dense stellar field populated by bright sources: 0.006 [0.005] mas, where the first number refers to the nominal Gaia mission, and the number in brackets refers to the extended Gaia mission.
- Worst case of 450 sources (expected WFI stellar density near the North Galactic Pole), all at the Gaia faint limit: 1.53 [0.90] mas.
- Representative case of 1800 sources with middle-of-the-range magnitude 0.16 [0.14] mas.

In both the a-priori and a-posteriori methods, there is marginal difference between using extended or nominal Gaia mission expected errors at the bright limit, since the error budget is dominated by centroid errors. On the other hand, at the faint limit Gaia errors become relevant, and the improvements due to the extended Gaia mission are significant.

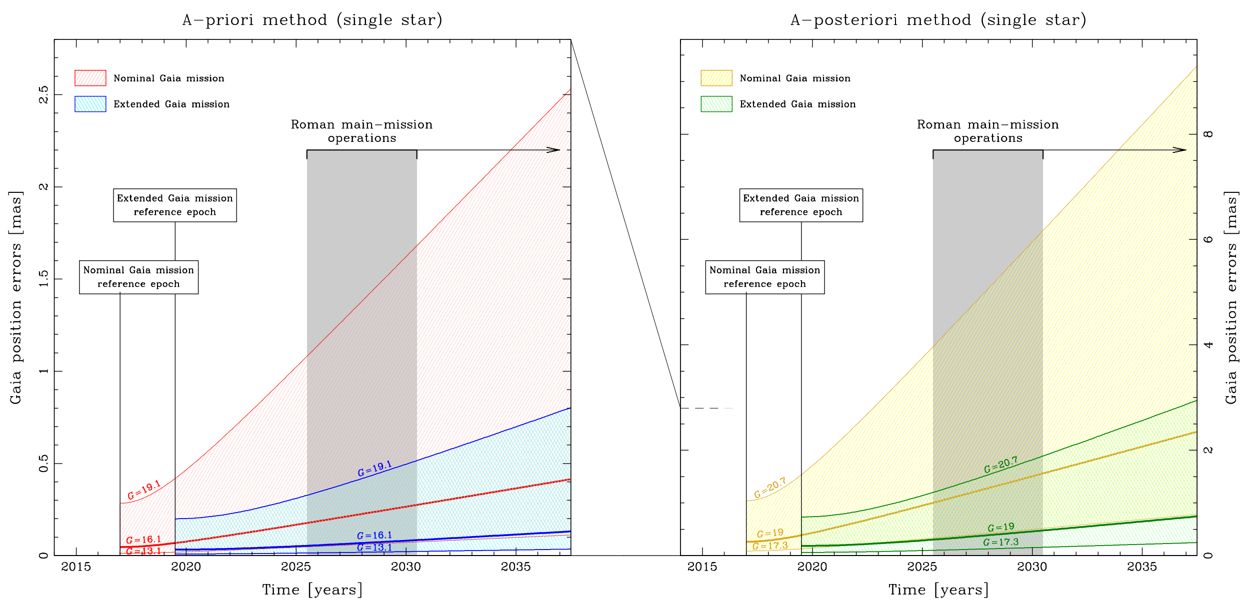

Figure 2: These panels show predicted Gaia-only, end-of-mission absolute astrometric errors as a function of year of observation, for both the nominal Gaia mission of 5 years, and the extended Gaia mission of 10 years. The left panel considers guide stars within the magnitude range $13.1<G<19.1$[2]. Extrapolations from the nominal Gaia mission are in red, those from the extended mission in blue. Bright and faint magnitude limits, as well as the track for a representative star of average magnitude, are shown as continuous lines. The right panel is similar but for the a-posteriori method, for which the usable Gaia magnitude range is $17.3<G<20.7$. In this case, the nominal Gaia mission extrapolation region is in yellow, and that of the extended mission is in green.

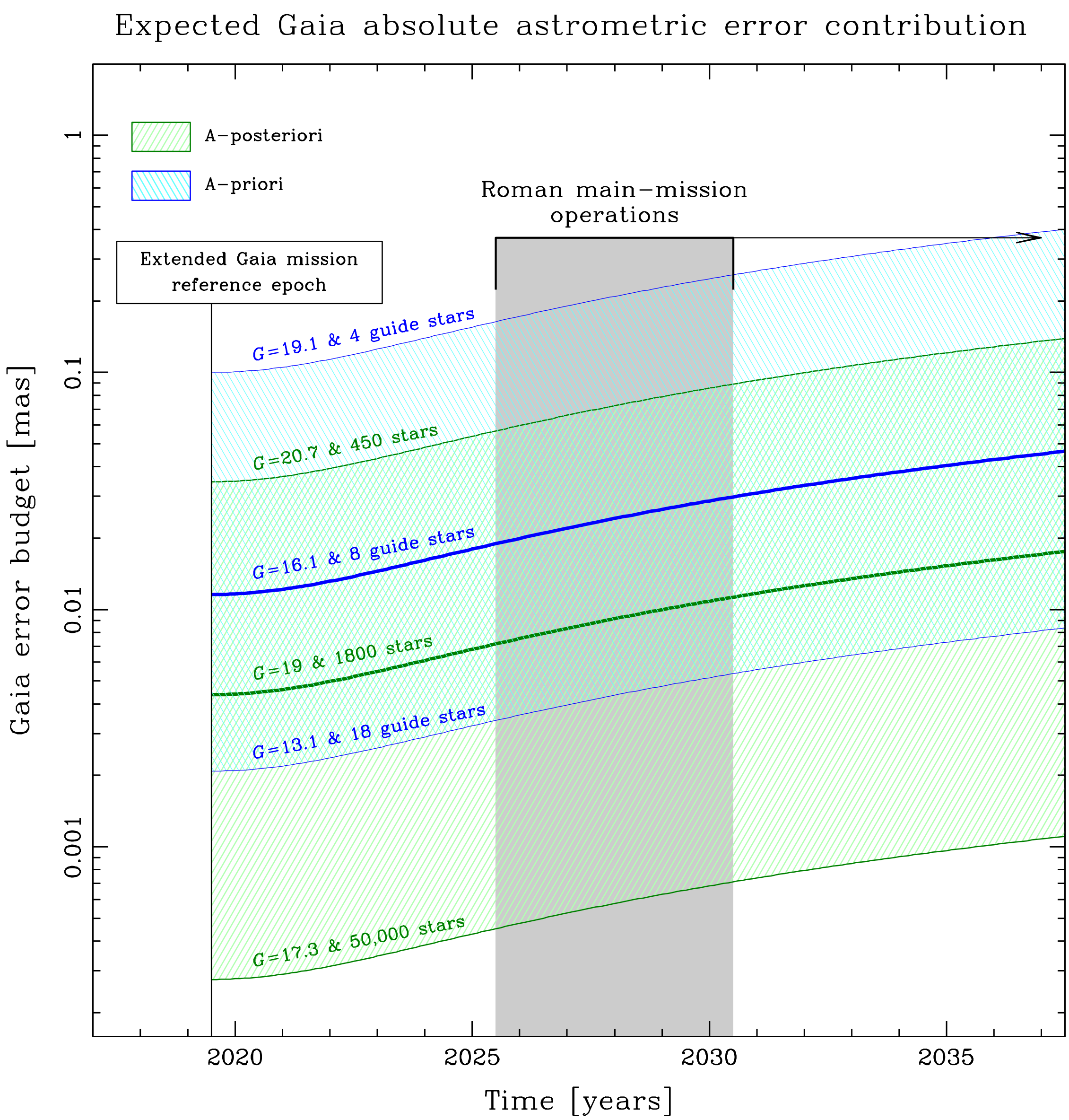

Figure 3: Total astrometric error contribution of Gaia stars to the a-priori (blue) and a-posteriori (green) methods, spanning worst-case, likely, and best-case scenarios for each method. For the a priori method, the best case is 18 guide stars all at the bright end; the worst case is only 4 guide stars at the nominal faint limit, and the intermediate representative (thick blue line) uses 8 guide stars (which should always be available[8]) in the middle of the magnitude range. For the a-posteriori method, the number of Gaia stars available for astrometric matching in a single exposure ranges from 50000 at the WFI saturation limit (expected for the Sagittarius Window in the Galactic bulge[2]) to 450 at the Gaia faint limit (expected at the North Galactic Pole); the representative case (thick green line) uses the median number (1800) of Gaia stars per WFI field of view over the sky, at an intermediate magnitude. Note that the extreme cases have been designed to illustrate the possible range of accuracies, and are not especially realistic; for example, a more realistic worst case considers the typical density of Gaia eDR3 stars around the

South Galactic Pole. We find an average of 454 stars per WFI pointing with a median magnitude G=19.53; this in turn corresponds to a Gaia error budget of 0.021 mas in 2025.5, and 0.034 mas in 2030.5.

5.1.4 Science Requirements Related to Astrometry

The science requirements related to Astrometry are also detailed in RST-SYS-REQ-0020C[14], but for clarity we include a summary of their current text in Table 1 along with related commentary.

Table 1: SRD Requirements Overview[14]

SRD Requirement	Description	Comment
HLIS 2.1.1	Roman shall be capable of producing mosaic images of the HLIS fields using data in each filter, and using coordinates tied to the astrometric frame defined by the ICRF.	
HLIS 2.1.10	Roman shall provide HLSS science data records with relative position measurement uncertainties less than 3.4” over the entire survey area.	This means 3.4" (about 31 WFI pixels) over 1 degree (or over about 32700 WFI pixels), i.e., a deviation of no more than 0.095 % with respect to a "perfect" geometric-distortion solution.
HLIS 2.2.5	Roman shall be capable of providing HLIS calibrated images with the astrometric solution in the WFI images having a relative error (offset between two images of the same galaxy or star, possibly taken at different times during the survey) of < 1.3mas.	1.3 mas corresponds to about 0.012 WFI pixels.
HLIS 2.2.6	Roman shall be capable of providing HLIS calibrated images with the astrometric solution in the WFI images having an absolute error, relative to the astrometric frame defined by the ICRF of: < 26 mas RMS per component for log10 l = 1.5—2.0 < 11 mas RMS per component for log10 l = 2.0—2.5 < 5.1 mas RMS per component for log10 l = 2.5—3.0 < 2.2 mas RMS per component for log10 l = 3.0—3.5.	The science result is sensitive to different size distortion correction errors on different angular scales. If the expected absolute astrometric uncertainty is less than 2.2 mas for every pixel, then all the parts of this requirement are satisfied. The quality of the geometric-distortion solution will be characterized by a single astrometric error (at most 2 errors, one for the X direction and one of Y direction) for the entire WFI. Of course, positions of fainter sources are generally characterized by larger measurement errors.
SN 2.1.1	Roman shall be capable of producing mosaic images of the SN fields in each filter at each epoch of observation, using coordinates tied to the astrometric frame defined by the International Celestial Reference Frame (ICRF).	
EML 2.1.6	Roman shall be capable of providing science data records with relative astrometric measurements having a systematic precision of ≤100 μas over each microlensing season, for sources imaged on the same detector in at least two passbands.	One microlensing season implies 5952 exposures of the same field (15 min cadence over 62 days). If proper motions are taken into account and Poisson noise is the major error contribution, assuming that well-exposed stars

SRD Requirement	Description	Comment
		have a single-exposure positional error of 0.01 pixel, averaging over a season brings: $0.01/\sqrt{(5952)}$ pixel = 0.13 millipixel = 14.3 microarcsec.
EML 2.2.3	Roman shall be capable of providing calibrated data records with relative astrometric measurements having a statistical precision of ≤1 mas per measurement for a star of HAB=21.4 in at least two passbands.	A somewhat conservative estimate of the precision with which the relative position of a relatively bright and isolated star can be measured is 0.01 pixel (i.e., 1.1 mas).
GO 2.1.1	Roman shall be able to produce mosaic images of the General Observer (GO) imaging fields in each filter at each epoch of observation, using coordinates tied to the astrometric frame defined by the International Celestial Reference Frame (ICRF).	
GO 2.2.6	Roman shall be able to provide GO calibrated images with the astrometric solution in the WFI images having a known relative uncertainty (offset between two images of the same galaxy or star, possibly taken at different times during the survey).	Here the goal for the relative uncertainty of the astrometric solution of multiple images of a given field is < 5.5 mas, i.e., 0.05 pixel.
Regarding HLIS 2.1.1, HLIS 2.1.6, HLIS 2.2.6, SN 2.1.1, GO 2.1.1 requirements: the Gaia catalog is already defined on the ICRF. If Gaia stars are used as guide stars, these requirements are automatically met.		

We expect to reach a distortion-solution precision of the order of a few millipixels (a few tenths of milliarcsec). This level of precision will satisfy requirements HLIS 2.1.10, HLIS 2.2.5, EML 2.2.3, and GO 2.2.6.

Regarding the HLIS 2.2.6 requirement, in Section 5.1.2 we showed that the expected absolute astrometric error using 18 guide stars ranges from 0.26 to 1.60 mas. When only 4 guide stars are used, these values become 0.56-3.38 mas. These values assume a nominal Gaia mission lifetime. When the extended Gaia mission is considered, the upper value for 4 guide stars decreases to 2.89 mas. In both cases, the upper limits exceed the most demanding absolute astrometry requirement of 2.2 mas.

At this time, we cannot yet provide estimates of ePSF-based centroid errors using guide windows, or centroid errors using on-board software.

We conclude that, using the much more plentiful fainter Gaia sources that are too faint to be used as guide stars, but that still have high S/N in typical WFI exposures, the estimated absolute astrometric precision improves to the range 0.006-1.53 mas for the nominal Gaia mission, and to the range 0.005-0.90 for the extended mission. In both cases, even the most demanding astrometry requirement of HLIS 2.2.6 requirements is met.

6 Coordinate Reference Frames and Transformations

6.1 Science Instrument Aperture File (SIAF)

The SIAF contains characteristics of the Roman science instruments, expressed in multiple coordinate systems, along with parameters used in the transformation between these systems. These values are used by DMS during science product generation, including metadata population, to help build the pointing and aperture information for the exposure that is used to populate the WCS information for the file. See Figure 1 for a graphical representation of the detector layout in relation to the telescope system.

6.2 Schemas Used with Transforms and Coordinate Frames

ASDF has the capability to validate that a file is complaint with pre-defined rules. This is done with the help of YAML files, called “schemas”, that are associated with the data files. Many transforms and coordinate-frame schemas are already available in ASDF. Schemas for reference files should be written to represent the specific distortions that are part of that optical path. **Error! Reference source not found.** is a file listing for an example schema file that validates the transform file that takes data points from the V2-V3 telescope frame to the sky. The ASDF file that contains the model components is shown in Figure 5.

```yaml
%YAML 1.1
---
$schema: "http://stsci.edu/schemas/yaml-schema/draft-01"
id: "http://stsci.edu/schemas/asdf/transform/rotate_sequence_3d-1.0.0"
tag: "tag:stsci.edu:asdf/transform/rotate_sequence_3d-1.0.0"
title: >
 Rotation in 3D space.
description: |
 Rotation in 3D space by arbitrary number of angles about
 arbitrary order of "x", "y", "z" axes.

examples:
 -
   - A sequence of rotation around 5 axes..
   - |
    !transform/rotate_sequence_3d-1.0.0
      angles: [-0.0193, -0.1432, -0.04, -65.60, 273.089]
      axes_order: zyxyz
      rotation_type: cartesian

allOf:
 - $ref: "transform-1.2.0"
 - type: object
   properties:
    angles:
      type: array
      items:
       anyOf:
       - $ref: "../unit/quantity-1.1.0"
       - type: number
      description: |
       The angles of rotation in units of deg.
   axes_order:
    description: |
      A sequence of "x", "y" or "z" characters representing an axis of rotation.
      The number of characters must equal the number of angles.
      For the JWST V23 to sky transform the axes are zyxyz.
    type: string
   rotation_type:
          description: |
      The type of rotation class to initialize
    type: str
    enum: [spherical, cartesian]
   required: [angles, axes_order, rotation_type]
...
```


Figure 4 Schema of the transform from the V2V3 JWST telescope system to sky(ICRS)

```
#ASDF 1.0.0
#ASDF_STANDARD 1.0.0
%YAML 1.1
%TAG ! tag:stsci.edu:asdf/
--- !core/asdf-1.0.0
asdf_library: !core/software-1.0.0 {author: Space Telescope Science Institute, homepage:
'http://github.com/spacetelescope/asdf', name: asdf, version: 1.2.2.dev891}
model:
- !transform/rotate_sequence_3d-1.0.0
   angles: [-0.0193, -0.1432, -0.04, -65.60, 273.089]
   axes_order: zyxyz
   rotation_type: cartesian
…
```


Figure 5 Example ASDF file that conforms to schema in Figure 4

6.3 Velocity Aberration

Velocity aberration needs to be taken into account for observatory pointing in order to sufficiently locate the prescribed observation field of interest within the guide windows on the WFI. Differential velocity aberration, for the guide stars that have been chosen for the observation, are computed on the ground. The absolute velocity correction and corrections to the initial pointing are calculated by flight software during acquisition of the guide stars. These corrections are specific to the reference point used for observatory pointing, along the bore-sight of the telescope and coincident with the center of the WFI focal plane. For science frames returned to the ground, the differential velocity aberration across the field of view needs to be computed for each SCA, accounting for the nominal placement of the detector in the spacecraft frame.

For distances up to 100 arcsec from the WFI FOV reference point, using a constant scale, compared to calculating the offset for each point exactly, gives deviations in the micro-arcsec range. At 1000 arcsec, the deviations are in the milli-arcsec range. The deviations vary as the cube of the distance. The WFI platescale is 0.11 arseconds per pixel. Using the footprint of the WFI FPA, the long side is roughly 6*4096 pixels across (plus gaps between detectors), which yields a radial distance from the center of the WFI FOV of about 1351 arcseconds. When applying the distortion solution using Gaia level accuracies for source catalogs, it may make sense to use the full differential velocity aberration correction including both scale and shift. Corrections such as this are trivial to apply and account for in the resulting ASDF file created by the science calibration software. The correction would be part of the chain of corrections stored in the WCS object.

6.4 Implementation Tools

The tools used to implement the astrometric solutions are publicly available open source software and include astropy[7] core libraries and affiliated packages. The Generalized World Coordinate System[4] (`gwcs`) is the library that will be used for managing the WCS of Roman data. Transforms will be implemented using `astropy.modeling`[5]. There are many pre-defined transforms currently in the package and new ones can be added as needed. Coordinate frames will be implemented using `astropy.coordinates`[6].

Figure 6 details an imaging WCS, mapping pixel coordinates on a frame, called “detector” to celestial coordinates on a frame named “world”. It is constructed using the `gwcs` software. Multiple simple analytic transforms are combined to form the full mapping from pixels to celestial coordinates. Using “ | ” for composition and “&” for a join operator, as well as the regular arithmetic operators, `astropy.modeling` provides a flexible way to combine models and create a total transform which is easy to evaluate. If the individual transforms have analytical inverses, they are already predefined, although there is a mechanism to overwrite the predefined ones. In the example the individual models are listed and indexed. The line starting with “Expression” shows the operators used to combine the individual transforms.

```
<WCS(output_frame=world, input_frame=detector, forward_transform=
Model: CompoundModel
Inputs: ('x0', 'x1')
Outputs: ('lon', 'lat')
Model set size: 1
Expression: [0] & [1] | [2] | [3] & [4] | [5] | [6] & [7] | [8] & [9] | [10] & [11] | [12] | [13] | [14]
Components:
   [0]: <Shift(offset=-1024.5, name='offset_x')>

   [1]: <Shift(offset=-1024.5, name='offset_y')>

   [2]: <Mapping((0, 1, 0, 1), name='mapping1')>

   [3]: <Polynomial2D(5, c0_0=-0., c1_0=0.06277675, c2_0=0.00000012, c3_0=0., c4_0=0., c5_0=0., c0_1=0., c0_2=-
0.0000001, c0_3=-0., c0_4=-0., c0_5=0., c1_1=-0.00000072, c1_2=0., c1_3=-0., c1_4=0., c2_1=-0., c2_2=0., c2_3=0.,
c3_1=-0., c3_2=0., c4_1=0., name='polynomial_x')>

   [4]: <Polynomial2D(5, c0_0=0., c1_0=-0.00009103, c2_0=0.00000031, c3_0=-0., c4_0=0., c5_0=0., c0_1=0.06307627,
c0_2=-0.00000042, c0_3=0., c0_4=-0., c0_5=0., c1_1=0.00000023, c1_2=-0., c1_3=0., c1_4=0., c2_1=0., c2_2=-0., c2_3=0.,
c3_1=0., c3_2=0., c4_1=0., name='polynomial_y')>

   [5]: <Mapping((0, 1, 0, 1), name='mapping2')>

   [6]: <Polynomial2D(1, c0_0=0., c1_0=-0.99999917, c0_1=-0.0012889, name='linear_x')>

   [7]: <Polynomial2D(1, c0_0=0., c1_0=-0.00128895, c0_1=0.99999917, name='linear_y')>

   [8]: <Shift(offset=86.039011, name='shift_v2ref')>

   [9]: <Shift(offset=-493.385704, name='shift_v3ref')>

   [10]: <Scale(factor=0.00027778, name='units_x')>

   [11]: <Scale(factor=0.00027778, name='units_y')>

   [12]: <SphericalToCartesian(name='spherical2cartesian')>

   [13]: <RotationSequence3D(angles=[  0.02391763,   0.13700764, 359.92586311, -71.99550858,  -5.86893417],
name='rotations')>
```

Figure 6: Example Imaging WCS object as it would be displayed in a python session

7 Astrometric Information used in Science Data Products

Appendix A contains a description of the Roman data levels, which include the science data products that will be available to the community.

The table below contains a summary of information about where the metadata related to WCS come from within the SOC systems.

Item	Description	Origin	Use
Science aperture name	Name of the science aperture in use for the observation.	SIAF, PSS	Correlate the telescope pointing with the aperture reference information.
Science aperture location	The pixel location, including detector, for the science aperture in use. Telescope reference frames used.	SIAF	Assignment of the reference right ascension and declination to the specified pixel. Roman doesn't guarantee that we will get the aperture reference pixel exactly at the requested pixel for the pointing, but it should be close, within a tolerance that is science dependent. This is very different than HST or JWST.
Vehicle attitude	The orientation of the vehicle in space. The attitude in the telemetry is the commanded attitude and other information in the telemetry must be folded in to determine the actual vehicle pointing.	Calibrated Engineering Data	Used to populate pointing information for the WCS. Barycentric.
Vehicle velocity	The velocity of the spacecraft.	Calibrated Engineering Data	The spacecraft velocity perpendicular to the boresight imparts positional aberration which may be correct for as part of the WCS transforms in the resulting data. Barycentric.
RA, DEC of target	The right ascension and declination of the target that is placed at the reference aperture position	SIAF, PSS	The pixel location specified in the SIAF for the aperture in use is tied to the RA,DEC specified for the observation.
Full parametric distortion information	The geometric optical distortion caused by the optical assembly of telescope. The highest order solution necessary for correcting science data is specified.	CRDS	Anything that feeds into the distortion correction is stored in ASDF as models or tables. This becomes part of the full WCS model in resulting science data.
Distortion used for pointing	The geometric optical distortion caused by the optical assembly of the telescope.	SIAF	The lowest order solution needed to point the telescope is used.

Item	Description	Origin	Use
Ephemeris Data	The position and velocity data for the telescope. Barycentric and Heliocentric times are computed during exposure processing.	Delivered by Flight Dynamics to the SOC	DMS processing needs to understand where the spacecraft was, so we would use the predicted ephemeris until the definitive ephemeris is available. There is not currently enough information to determine whether data reprocessing would have to occur when the definitive ephemeris is available.
Guide window centroid	The RMS of the location of the guide star currently being used in a particular detector to inform guiding.	Calibrated Engineering Data	This provides stability information to the ACS, and may provide jitter and pointing information that be used in post-processing to inform the PSF.

7.1 World Coordinate System (WCS) Implementation in the Science Calibration Pipeline

WCS is implemented per SCA. The distortion is saved in files in ASDF format, which are kept in the Calibration Reference Data System (CRDS). The pipeline matches specified keywords in the observation with keywords known by CRDS to pick the reference file that matches the observation parameters and dates. The distortion reference files represent the transform from the science frame to the telescope system, V2V3. If necessary, additional reference files may be created and used to represent additional tabular corrections or filter offsets.

7.2 Representation of Astrometric Information in WFI Level 2 Data

A typical WCS for an imaging observation includes at least three coordinate frames and the transforms between them:

```
  From        Transform
 --------    ----------------
 detector    detector_to_v2v3
   v2v3        v2v3_to_sky
  world           None
```

The coordinate reference systems in use by SIAF and WCS include:

- Detector (pixel) - A coordinate frame associated with each SCA.
- Science (Sci) - Similar to Detector but may be rotated or flipped.
- Ideal (Idl): Distortion corrected to a tangent plane projection, in arcsec. This exists in the SIAF but is not used in the WCS transforms.
- Telescope (V2, V3): Spherical coordinate system, tied to the telescope orientation, measured in arcsec that maps to the sky. Coordinates are Euler angles.

- World (ICRS): Spherical world coordinate system describing the right ascension and declination. This has a one-to-one mapping with the Telescope (V2, V3) coordinates given a Roman attitude matrix describing the pointing of the telescope.

The following keywords from JWST are used to describe the pointing and the transformation between the V2V3 system and the celestial frame. Roman will need to use similar information.

V2_REF (in arcsec)
V3_REF (in arcsec)
RA_REF (in degrees)
DEC_REF (in degrees)
ROLL_REF (in degrees)

These quantities fully define the attitude matrix describing the pointing of the telescope. Note: this is based on JWST coordinate frames and transforms.

There is a potential need for non-contiguous transforms (e.g., lithographic defects; not implemented for now). The `gwcs` library provides the mechanism and models to represent non-contiguous WCSs, not limited to lookup tables. It also provides a mechanism for using non-coordinate inputs to the WCS, like spectral order. Any effects that are determined post-launch to affect the astrometry of sources in a field can be added to the `gwcs` chain of models that describe the transform between the sky and detector. This can be done as a general update if it is added to the science calibration pipeline, or by end users who desire to modify the full chain of models themselves.

JWST is currently planning to save an estimated SIP solution in the Level 2 data based on the more precise `gwcs` model chain. This is planned, of course for the un-resampled FITS files and does not make sense for ASDF files.

8 Open Questions and Conclusions

This memo collected relevant information on the process and expected quality of the determination of absolute astrometry for WFI images. However, some open questions remain, regarding both elements for which we do not have full data yet, especially concerning detector, instrument, and telescope performance, and some decisions on processing that remain open at this time. These include the following:

1. We have implicitly assumed that the focal plane is mechanically stable, i.e., the relative positions of the SCAs with respect to one another remain constant, except for global distortion terms due to the telescope OTA and the orientation of the focal plane assembly. Since the detectors will be hard-mounted on a common rigid substrate, this assumption seems reasonable at this time. However, it will likely have to be verified in ground tests and – presumably with higher accuracy – in orbit. Possible variations would be incorporated into the geometric distortion description and can be readily handled in the format we adopt, but would potentially increase uncertainties in the geometric distortion itself and require more frequent calibrations.

2. The quality of on-orbit guide star centroiding is expected to satisfy the requirements on guiding performance, but we do not have a full characterization of its precision at the level relevant for astrometric registration. It is likely that additional processing of guide window data will yield a higher precision of the so-called "a priori" registration.
3. The ultimate astrometric quality that can be achieved with the "a priori" method is not known at this time, as the electronic and PSF characteristics of guide window data have not been characterized yet. More information is expected from tests at the DCL, especially after tests begin with flight electronics in early 2021, but a full characterization of the electronic noise components will probably only take place during Instrument Thermal Vacuum in late 2022. Jitter comparison between guide window images and full-frame science images will only be reliably obtained in orbit. Therefore, we cannot accurately estimate the final accuracy of the a priori astrometry registration based on guide star information only.
4. The best astrometric registration will be obtained from the "a posteriori" method, in which bright sources are measured within the full-frame images and cross-correlated with high precision astrometry. Thanks to the WFI large field of view, there will be many Gaia stars in essentially every image. The a posteriori registration could be carried out either at L2 or at L3.
    a) In the L2 a posteriori characterization, the source identification and cross-matching happens independently for each exposure, ideally as part of the L1 → L2 calibration pipeline (although it could also be a separate post-pipeline process). As a result, each L2 image will have an accurate astrometric calibration directly out of the pipeline, and be archived directly with such information. Depending on the quality of the astrometry, this step will obviate any need for relative registration of L2 images prior to L2 → L3 processing (such as `tweakshifts`), and will make images with high quality astrometry available to all users straight out of the Archive. Processing like this is not currently implemented for JWST.
    b) In the L3 a posteriori characterization, L2 images will undergo relative registration prior to L2 → L3 processing. After the L3 product is obtained, it is processed to obtain L4 data, such as source catalogs. Source catalogs would then be matched to external catalogs to obtain an improved image registration, which can subsequently be used to update the astrometry of the corresponding L3 product. This method is close to that used in the JWST pipeline, however the improved astrometry is not propagated back to the component L2 products.
    c) L2 characterization results in better archival data, simpler L2 → L3 processing, and broad availability of high-quality astrometry for all follow-up research. L3 characterization is closer to the currently planned JWST process. A decision between these two approaches should be made soon.

We would like to add that PSF fitting in Level 3 images has lower precision than in Level 2 images, in particular in the presence of large dithers. The reason is that an L3 image is a combination of several L2 images, each with its own specific jitter effects that are included in the ePSF. The combination itself could discard different pixels from the L2 images and use only a subset for the final result. This creates a situation in which the pixels of an L3 star can come from different combinations of L2 images, potentially leading to significantly different, and unpredictable, stellar shapes that do not resemble any ePSF from any single L2 image. If dithers are present, errors in the geometric-distortion solution and transformation to the world coordinate system will also be important. Indeed, all of the discussion in Section 5 is based on L2 measurements alone.

5. Astrometric registration of spectroscopic data will be the purview of the SSC. We understand that an early step of their planned spectroscopy pipeline involves using spectroscopic calibration information to reconstruct the relative astrometry of dispersed data, and further refinements occur during the processing. It is unclear how the updated astrometry will be made available to users for related level 2 products.
6. It is to be expected that the astrometric registration of WFI data products will change during the mission. Examples include the use of additional data for large surveys, improvements in the geometric distortion, propagation of L3 astrometry to L2 if the L3 a posteriori characterization is used, and propagation of improved spectroscopic astrometry after SSC processing. Mechanisms to update astrometry information for L1 through L4 data products, possibly through updates to the relevant metadata, WCS objects, or thorough databases to be interrogated at time of reprocessing, should be considered and applied as appropriate for schedule, cost, and implementation needs.
7. Although not directly related to the absolute astrometry of Roman images, the quality of position measurements for sources in L4 products depends strongly on the method used to determine the centroid. For point sources, the best quality is obtained via PSF fitting using a color- and time-dependent ePSF. It is unclear at this stage what centroiding method will be used for pipeline-generated catalogs; having high quality point source astrometry would greatly facilitate large-scale research work, such as characterizing the structure of the Milky Way, finding unusual objects such as high-velocity stars, stars stripped out from geometrically distant subsystems, members of streams, and other work that relies on L4 data.

High precision astrometry is critical to the Roman science mission, as reflected in the relevant requirements captured in the Science Requirements Document. In addition, high-quality astrometry enables a broad range of scientific investigations, and it facilitates data processing and interpretation (cross-matching, follow-up observations, etc). Thanks to the on-detector guiding used for WFI and to the large size of the WFI field of view, together with the availability of extremely accurate astrometry catalogs over the whole sky, achieving sub-mas astrometry, unprecedented for a general astrophysics mission of this scale, is eminently feasible for WFI images.

However, some important choices need to be made on both data processing and handling of astrometric information in the Archive. Specifically, the choice between L2 and L3 implementation of a posteriori astrometry will have significant impact on both pipeline design and astrometric quality for L2 products. The implementation of astrometric data updates, and the choice of algorithms for point-source centroiding in pipeline-generated catalogs, will impact the data processing design. We recommend that these choices be made as soon as practical, in communication with stakeholders in so far as possible.

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10 Appendix A: Roman Data Level Description

10.1 Level 0: Raw Data

Level 0 data is identical with raw packetized telemetry as transmitted from the observatory and received at the ground stations. They are in the same binary format as stored on the Roman Solid-State Recorder.

10.2 Level 1: Formatted Data

Level 1 data products are in the form of uncalibrated individual exposures consisting of raw pixel information formatted into the shape of the detectors and ready for input into the science calibration pipeline.

10.3 Level 2: Pixel Calibrated Data

Level 2 data products have the same shape and pixelation as level 1 products, but have been calibrated to correct for instrument artifacts, with slope fitting, outlier rejection, and other procedures to obtain a true mapping of the scene flux. Calibrated exposures have appropriate astrometric and geometric distortion information attached, and with the exception of grism data, are in units that have known scaling with flux.

10.4 Level 3: Resampled Data

Level 3 data products are groups of calibrated exposures (level 2 products) resampled to a regularized grid, removing the geometric distortion of the original pixels. A common grid can be used for multiple exposures, thus permitting their weighted combination. Level 3 products can be updated as more data are taken.

10.5 Level 4: Derived Data

Level 4 products are usually focused on sources rather than pixels or celestial coordinates. These are most often in the form of object catalogs derived from any collection of lower-level products. These data can contain traditional catalog data (such as positional, size, and shape information) or complex data such as extracted spectra or postage-stamp images of the relevant source from all contributing images.

10.6 Level 5: Community Contributed Science Products

Community Contributed Products encompass any data that is returned to the SOC for archival storage by contributing scientists or groups. It may include data described as any combination of the available Level 2 through 4 products, or a new form that is derived from them. Acceptance and storage of these products is contingent on vetting of their content and data volume limitations.

11 Acronym List

Acronym	Meaning
ACS	Attitude Control System
ACS/WFC	Wide Field Channel of the Advanced Camera for Surveys
ASDF	Advanced Scientific Data Format
CGI	CoronaGraphic Imager
DCL	Detector Characterization Lab
DEC	Declination
DMS	Data Management Subsystem
DR1	Gaia Data Release 1
DR3	Gaia Data Release 3
EDR3	Gaia Early Data Release 3
EML	Exoplanet MicroLensing survey
ePSF	effective Point Spread Function

ESA	European Space Agency
FGS	Flight Guidance System
FITS	Flexible Image Transport System
FPA	Focal Plane Assembly
FOV	Field of View
FSW	Flight SoftWare
GO	General Observer
GSC	Guide Star Catalog
gwcs	Generalized World Coordinate System
HLIS	High Latitude Imaging Survey
HST	Hubble Space Telescope
JWST	James Webb Space Telescope
L1	Level 1 data
L2	Level 2 data
L3	Level 3 data
L4	Level 4 data
MRD	Mission Requirements Document
OTA	Optical Telescope Assembly
PRDS	Project Reference Database System
PSF	Point Spread Function
PSS	Planning and Scheduling Subsystem
RA	Right Ascension
RMS	Root Mean Square
SCA	Sensor Chip Assembly
SIAF	Science Instrument Aperture File
SIP	Simple Imaging Polynomial
SOC	Science Operations Center for Roman
SN	Super Nova
S/N	Signal to Noise
SRD	Science Requirements Document
SSC	Science Support Center for Roman
WCS	World Coordinate System
WFC3/UVIS	Ultraviolet-VISible channel of the Wide Field Camera 3
WFI	Wide Field Imager
WFPC2	Wide Field and Planetary Camera 2
WIM	WFI Imaging Mode