

STIS Coordinate System Orientation and Transformations

George Hartig, Ellyne Kinney, Phil Hodge, Matt Lallo, and Ron Downes
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ABSTRACT

This report presents the definitions and relationships between the various coordinate frames used with STIS. An appendix addresses understanding orientation of slits and images on the sky.

1. Introduction

This report addresses the transformations required by various parts of the ground and flights software between the different coordinate systems used for STIS operations. These coordinates consist of:

- the User system (AXIS1, AXIS2), also known as the IRAF, Image, or SIAS frame
- the Detector system (X_d, Y_d), also referred to as the flight software (FSW) or commanding frame
- the Readout system (X_r, Y_r)
- Vehicle system (V_2, V_3)
- The SICS system (X_{sics}, Y_{sics}), which in the case of STIS is also the POS TARG system (see appendix)

For an additional discussion of STIS apertures and coordinate systems, please see ISR OSG-003: *STIS Focal Plane Part I. Aperture Metrology & the SIAF.DAT file* and also OPR 29753: *Opus Pipeline-STIS World Coordinate System*.

2. Why are There Two CCD Coordinate Systems?

There are two coordinate systems because the desired user coordinate system and the detector coordinate system are not the same. If we employed the detector coordinate system for users, several unsavory things would happen:

- the orientation of user's STIS data would differ from CCD to MAMA observations
 - the dispersion axis and the CCD serial directions would be counter-intuitive along Y
- Therefore, we have elected to separate the detector and user coordinate systems.

3. What are the Implications of Separating the Coordinate Systems?

Two systems impacted by the separation of the User and Detector Coordinate Systems, requiring transformations between the systems, are:

1. TRANS/Commanding - Users specify parameters in the User Coordinate System through the proposal instructions and RPS2, and TRANS must convert them to the Detector Coordinate System for Commanding
2. OPUS - OPUS must unpack the data and organize it so that it corresponds to the User Coordinate System. Keyword values received from telemetry in the Detector Coordinate System must be transformed into the User Coordinate System header keywords defined for the science data.

4. Frame Definitions

4.1 User Frame

The User coordinate system (see Figure 1) is the coordinate system GOs will use to specify the portion of the detector (CCD or MAMA) to be read out when a subarray is commanded, and is the coordinate system that the user will receive their data in following generic conversion in OPUS. All science header keywords will refer to this system. The User coordinate system is defined with User X (AXIS1) roughly parallel to the dispersion in the direction of increasing wavelength and running from 1 to 1062 (CCD) or 1 to 1024 (low-res for the MAMA) in each axis. The exceptions to this rule are the MAMA cross-dispersion modes for which wavelength runs parallel to AXIS2 (X140M and X140H) or anti-parallel to AXIS2 (X230M and X230H). The User Y (AXIS2) runs approximately along the slit. The images are meant to be displayed with AXIS1 horizontal, increasing to the right, and AXIS2 vertical, increasing upward (origin at the lower left corner). The coordinate value is 1.0 at the center of the first pixel. The User coordinates have opposite parity to celestial N-E and V2-V3. If User Y (AXIS2) is oriented directly North, the User X (AXIS1) increases to the West. The units are in pixels.

4.2 Detector Frame

The Detector coordinate system is the coordinate system used by Commanding and the Flight Software. It is used by Commanding to specify the readout of a portion of the detector when a subarray is commanded, and is used by the Flight Software for CCD target acquisitions. The detector frame for the CCD runs from 0 to 1061 (AXIS1) and 0 to

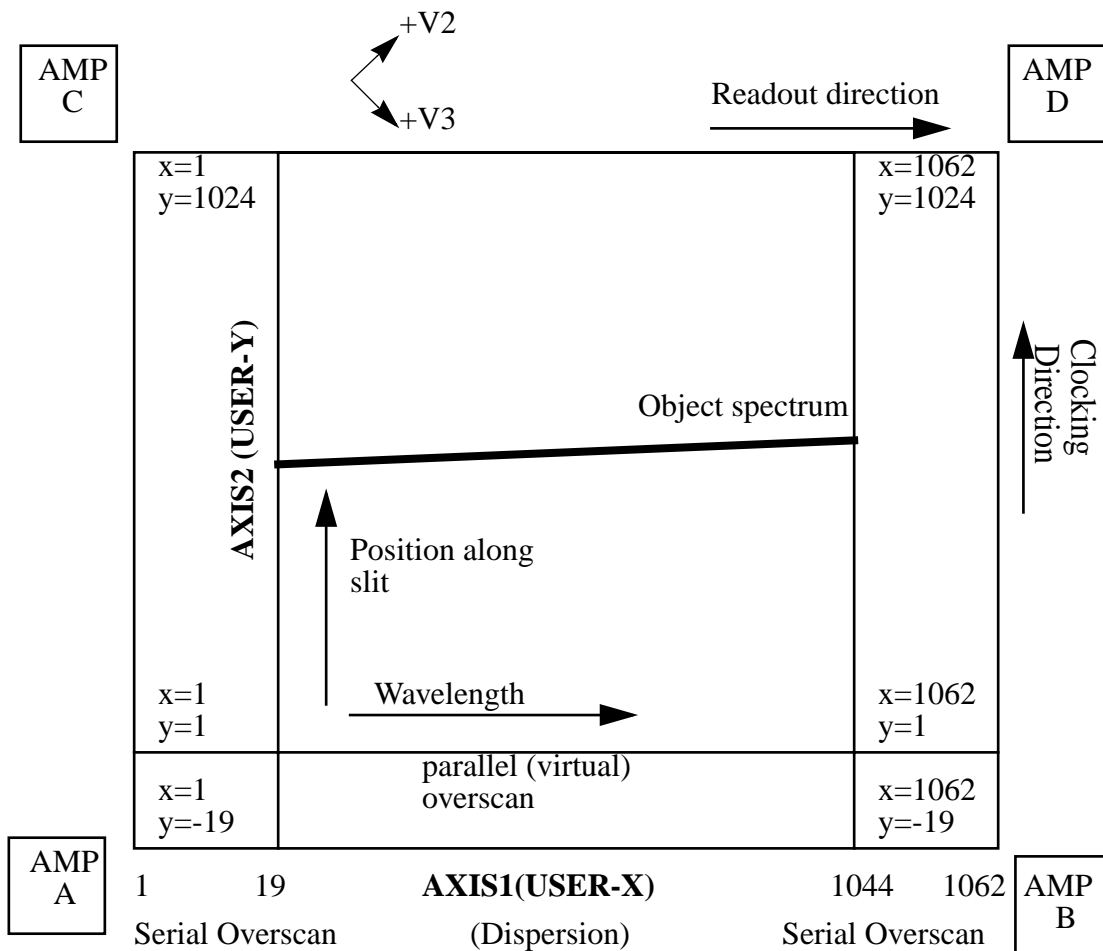


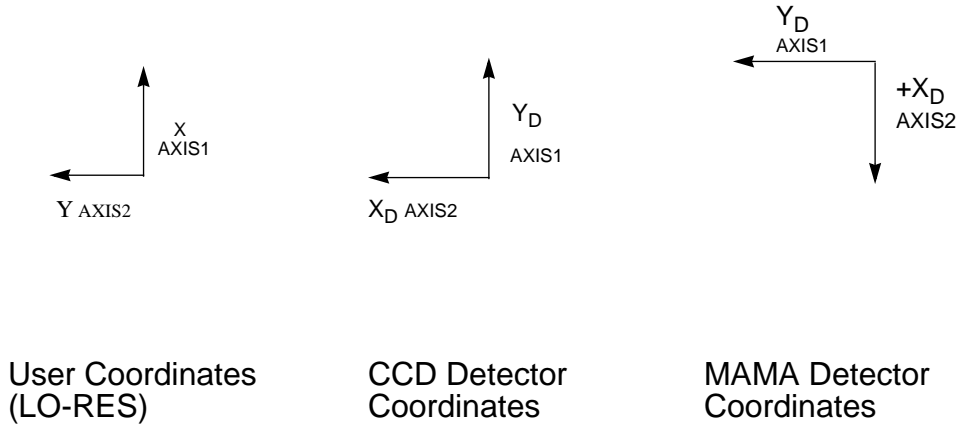
Figure 1 (for Amp D)

1023 (AXIS2; excluding the virtual overscan), while for the MAMAs, it runs from 0 to 2047 (high-res pixels; both AXIS1 and AXIS2). Figure 2 shows the orientation of these frames.

4.3 Readout Frame

The Readout frame is defined as the zero-indexed frame in which consecutive words in the first line of science data from the raw, packetized data stream produced by the STIS ground system are assigned to increasing pixel numbers in the X (row) direction, corre-

Figure 2: User and Detector Frames



View Toward -Z (looking at the sky in the +V1, with the detectors projected)

sponding to Y (column) = 0, with subsequent rows being filled in the same direction (starting at $X=0$) after the previous row is filled. For the CCD, X_r is always parallel to the serial readout register and runs from 0 to 1061 for full frame, unbinned images, while Y_r runs from 0 to 1043, where the final 20 rows are the virtual overscan region. Full-frame, unbinned MAMA readouts extend from 0 to 2047 in both axes. The orientation of the Readout frame is the same for both MAMA detectors, but depends on the selected readout amplifier for the CCD. Figure 2 shows the orientation of these frames, where the superscripts on the CCD Readout frame axis identifiers refer to the readout amplifier.

4.4 Vehicle Frame

The Vehicle frame is that defined in ICD-02. STIS resides in Bay 1, such that its apertures lie nominally on the +V2/+V3 bisector at a radius of 304.3 arcsec. The V system is right-handed, with V1 pointing in the telescope look direction. Figure 3 shows the orientation of these frames.

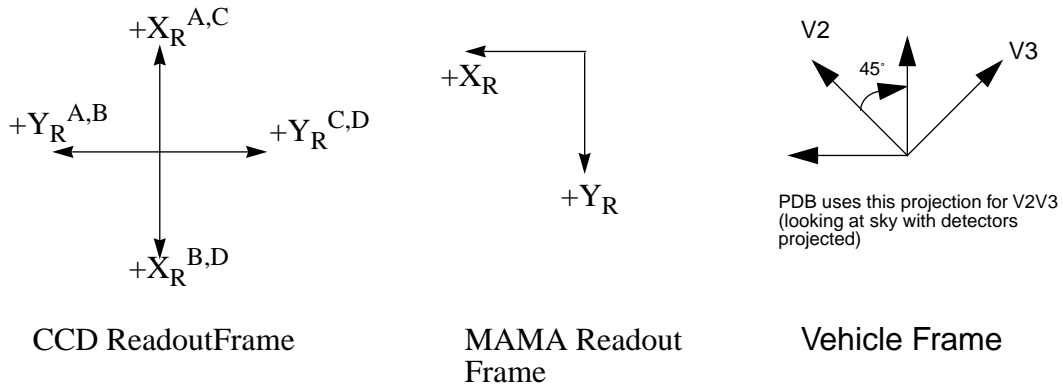
5. Coordinate Transformations

Using the information displayed above, we can derive the required transformations.

User to Detector: These transformations are required by TRANS to convert subarray parameters specified in User coordinates into Detector coordinates. Since the FSW adapts the CCD readout timing pattern according to the selected amplifier, there is no amplifier dependence.

CCD	$X_d = \text{AXIS2} - 1$	$Y_d = \text{AXIS1} - 1$
MAMA	$X_d = 2046 - (\text{AXIS1}-1) \times 2$	$Y_d = (\text{AXIS2}-1) \times 2$

Figure 3: Readout and Vehicle Frames



View Toward -Z (looking at the sky in the +V1, with the detectors projected)

Detector to User: These transformations are required by Generic Conversion to populate the science data headers with appropriate User frame values for subarray size and location. Also, the locations resulting from target acquisition are be transformed to the user frame.

CCD	$AXIS1 = Y_d + 1$	$AXIS2 = X_d + 1$
MAMA	$AXIS1 = 1024 - \text{INTEGER}(X_d/2)$	$AXIS2 = \text{INTEGER}(Y_d/2) + 1$

Readout to User: These transformations are required by Generic Conversion to re-orient the images into the User frame.

CCD Amp A	no transformation required
CCD Amp B	flip about Y_r axis ($X_r \implies -AXIS1$)
CCD Amp C	flip about X_r axis ($Y_r \implies -AXIS2$)
CCD Amp D	rotate 180° ($X_r \implies -AXIS1$ and $Y_r \implies -AXIS2$)
MAMA	rotate 90° CCW ($X_r \implies AXIS2$, $Y_r \implies -AXIS1$)

The IRAF LTV_i and LTM_{i,j} keywords give a linear mapping from a "reference coordinate system" to the pixel coordinate system of an image. These two coordinate systems are oriented the same way; they can differ in scale due to binning, and they can differ in zero point due to overscan regions (for the CCD) or the use of a subarray. For the CCD, the reference coordinate system is that of an unbinned, full-frame image after the BLEV-CORR step of calibration. (This is in amp A orientation, even though amp D is used for

readout.) For the MAMAs, the reference coordinate system is that of a lowres, full-frame image.

The reference coordinates system just described is the system in which pixel positions are given in all STIS reference tables, e.g. the locations of bad pixels in the BPIXTAB. This system is the same orientation and scale as the User coordinates defined earlier. For the MAMA detectors the origins are the same as well. For the CCD, the origin of the User coordinates is the first pixel of the physical overscan region near amp A. If a point on the CCD detector has reference coordinates (Xref,Yref), the User coordinates and image pixel coordinates of that point would be:

User Coordinates	
AXIS1 = Xref + 19	AXIS2 = Yref
Image pixel coordinate	
X = Xref * LTM1_1 + LTV1	Y = Yref * LTM2_2 + LTV2

The IRAF convention for pixel numbers is used here. The first pixel is number one, and the pixel number is an integer at the center of the pixel. The first pixel runs from 0.5 to 1.5. LTMi_i is the reference pixel size in units of the image pixel size in the axis i (1 or 2) direction. LTMi_i is positive for STIS images, raw or calibrated. In principle, there could be LTM1_2 and LTM2_1 as well, but these skew terms are zero for STIS images. LTVi is the location, in the image pixel coordinate system, of pixel zero of the reference coordinate system, for axis i. "Pixel zero" in this context does not mean the first pixel using zero indexing; it means the location one pixel to the left of (or below) the first pixel in the image.

Detector to Vehicle: These transformations are required by the FSW to convert pointing offsets into the Vehicle frame to initiate small angle maneuvers.

$$\Delta V_2 = PS \times (\Delta X_d \times \cos(\theta) + \Delta Y_d \times \sin(\theta))$$

$$\Delta V_3 = PS \times (-\Delta X_d \times \sin(\theta) + \Delta Y_d \times \cos(\theta))$$

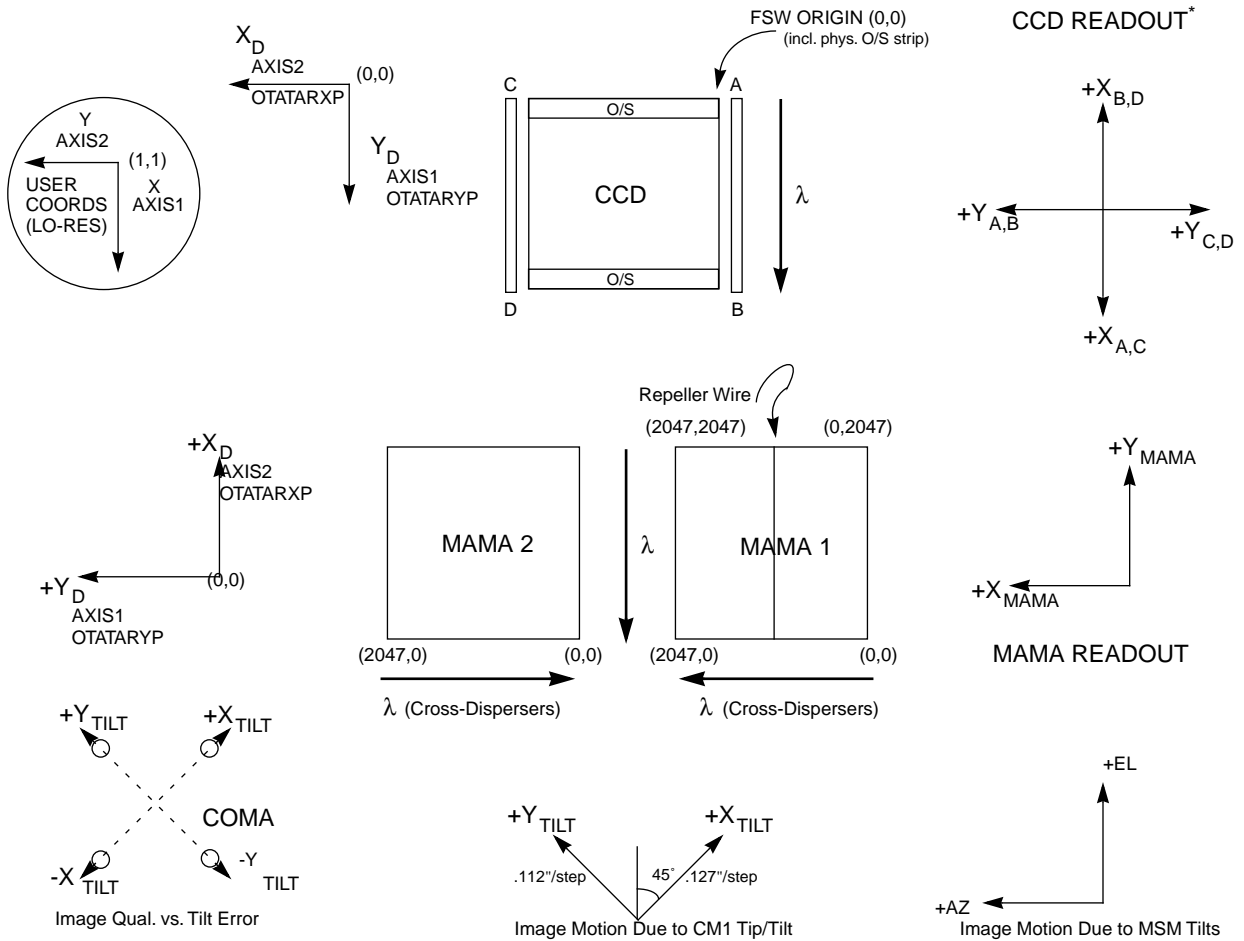
where

$$\theta(\text{nominal}) = 135^\circ \text{ (MAMA) or } 45^\circ \text{ (CCD)}$$

$$PS \text{ (arcsec/pixel)} = 0.0246 \text{ (MAMA) or } 0.0508 \text{ (CCD)}$$

Appendix A - Useful Figures

VIEW TOWARD +Z (-V1) (NO OPTICAL PROJECTIONS)



<p>Physical (no optical projections) Slit Orientations</p> <p>AP 54-56 (CCD filters) Slit 50</p>		<p>Axis1 Axis2 POS TARG</p> <p>Long Slits (34-39)</p>		<table border="1"> <tr> <td>3</td> <td>2</td> </tr> <tr> <td>4</td> <td>1</td> </tr> </table> <p>Quad ND Filter</p>		3	2	4	1	<p>11650.843 steps/deg Motion of slits with positive slit wheel rotation</p> <p>Slits FP Slits</p>	
3	2										
4	1										
<p>OPTICAL X-FORM's:</p> <ul style="list-style-type: none"> • ALL OPTICAL MODES INVERT SLIT IMAGE AT DETECTOR • CORRECTOR SYSTEM (CM1 & CM2) INVERTS • OTA INVERTS 				<p>STIS In Bay 1 (GHRs):</p>							

* 20 ROWS OF VIRTUAL O/S APPENDED TO END OF FULL-FORMAT CCD READOUTS

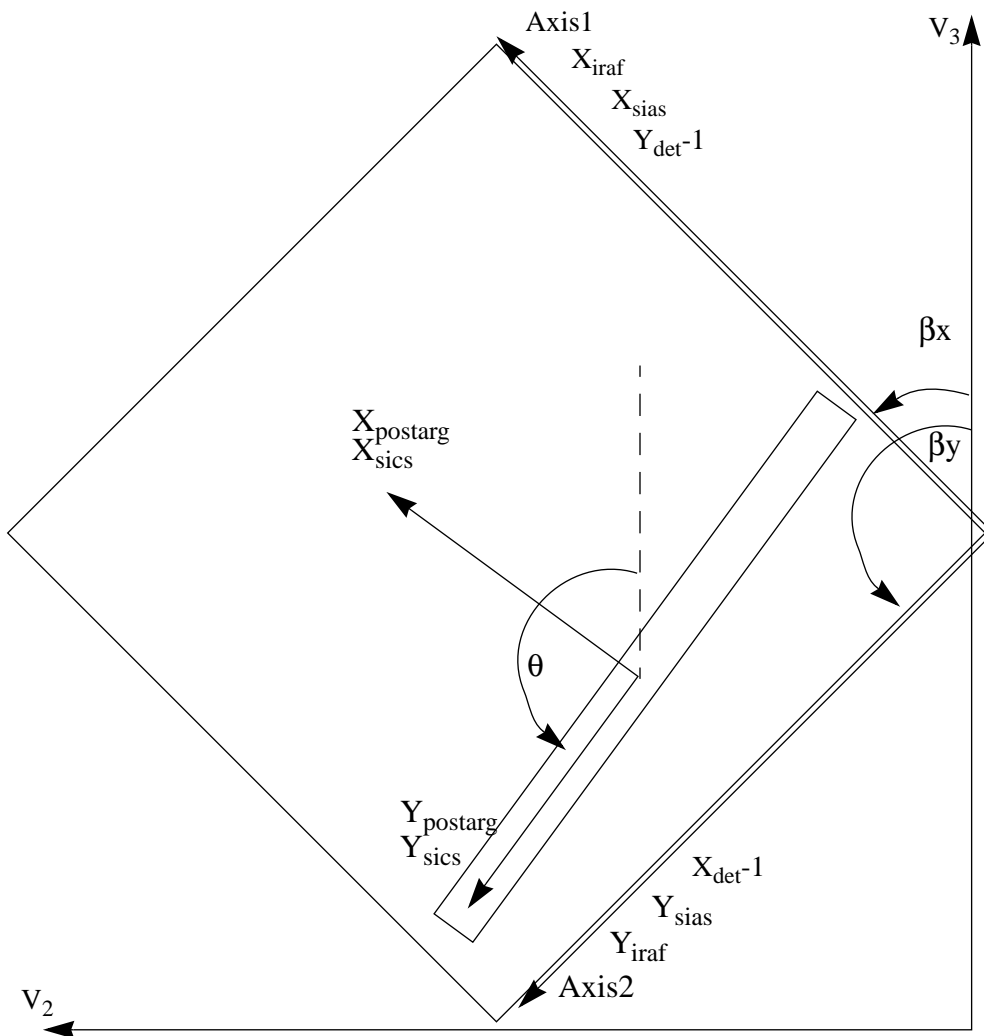
Appendix B - STIS Images

This appendix provides information on PDB SIAF aperture values and roll angles to assist in predicting or interpreting positions and orientations of a STIS image on the sky. Involved in this will be the USER or SIAS frame mentioned earlier, as well as the special aperture-specific SICS frame. The SIAS and SICS names, as well as the angle definitions used below, are SIAF file designations. For the definitions of the SIAF parameters see ICD 26 Part 3 Rev.D (June 1989) *SOGS to PDB ICD*. For a brief on-line discussion of applying SIAF values and for a current listing of some of those values, see:

www.stsci.edu/ftp/instrument_news/Observatory/siaf.html

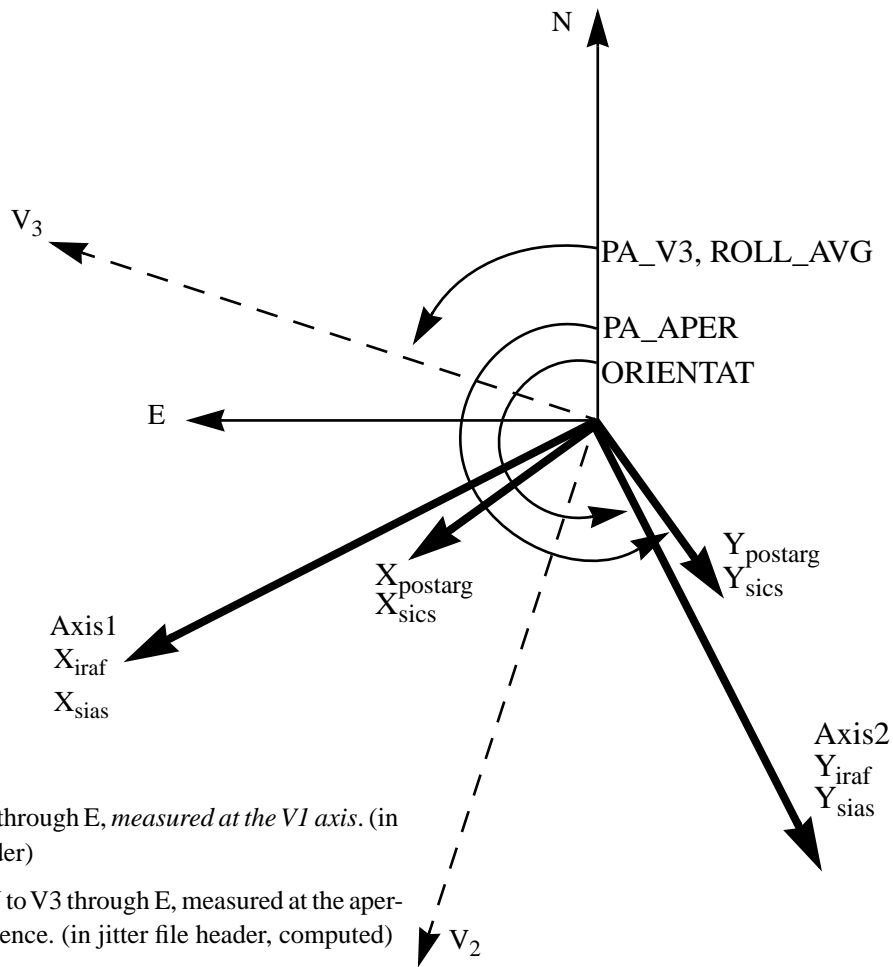
The following diagram illustrates the relation of the SIAS and SICS frames to the vehicle frame V_2, V_3 , and defines some relevant angles.

SIAS in pixels & aligned with the detector.
SICS in arcseconds & aligned with the slit.



The SICS and SIAS axes are practically always aligned ($\text{SIAF } \theta = \text{SIAF } \beta_y$). For STIS there are some exceptions where they can be different by up to ~ 1.5 degrees, such as for the long slits with offset occulting bars. The fact that the targetable reference point is offset in these slits means that when the slit wheel centers this point on the detector, the slit's axes are not quite aligned with the detectors axes. This difference could be important if planning an observation and computing a roll that will result in precise slit orientation on the sky, and for this sort of application the SIAF θ value should be used in the calculation.

The following diagram defines some angles relating North to the vehicle and STIS frames.



PA_V3: N to V3 through E, measured at the V1 axis. (in SPT header)

ROLL_AVG: N to V3 through E, measured at the aperture reference. (in jitter file header, computed)

PA_APER: N to Y axis of aperture (SICS) through E, measured at the aperture reference. (in science header)

ORIENTAT: N to AXIS2 (Y_{SIAS}) through E, measured at the aperture reference. (in science header)

To convert X,Y shifts in STIS images to ΔV_2 , ΔV_3 neglecting distortion, the following transformations are needed:

$$\Delta V_2 = PS * (\Delta X_{\text{iraf}} * \sin(\beta_x) + \Delta Y_{\text{iraf}} * \sin(\beta_y))$$

$$\Delta V_3 = PS * (\Delta X_{\text{iraf}} * \cos(\beta_x) + \Delta Y_{\text{iraf}} * \cos(\beta_y))$$

or:

$$\Delta V_2 = PS * (\Delta X_{\text{det}} * \sin(\beta_y) + \Delta Y_{\text{det}} * \sin(\beta_x))$$

$$\Delta V_3 = PS * (\Delta X_{\text{det}} * \cos(\beta_y) + \Delta Y_{\text{det}} * \cos(\beta_x))$$

where PS (arcsec/pixel) = 0.0246 (MAMA) or 0.0508 (CCD) and the beta angles can be obtained from the above-mentioned URL.

Note that since the STIS axes are orthogonal, the beta angles are always 90 degrees apart, and so the equations can be re-expressed using only one angle.

To convert from ΔV_2 , ΔV_3 to $\Delta\alpha$, $\Delta\delta$, the following transformations are needed:

$$\Delta\alpha \cos\delta = \Delta V_2 * \cos(\text{roll_avg}) + \Delta V_3 * \sin(\text{roll_avg})$$

$$\Delta\delta = -\Delta V_2 * \sin(\text{roll_avg}) + \Delta V_3 * \cos(\text{roll_avg}).$$

The jitter file computed roll_avg keyword is used here since, unlike PA_V3, it is computed at the aperture reference.

As an example, the slew from the 52X0.2 aperture ($\delta = -69^\circ$) to the F28X50LP aperture is:

	X_{det}	Y_{det}
52X0.2	515.670	535.900
F28X50LP	515.670	534.384
refraction correction		+1.269
motion	0.0	+2.785

This results in a slew of $V_2 = 0.1''$ and $V_3 = 0.1''$, and a slew of $\alpha = +0.082s$ and $\delta = +0.138''$.

Similarly, the ORIENTAT angle can be used to transform directly from XY deltas to RA, Dec deltas. Note however ORIENTAT only represents the commanded angle and is not a measured value.