ASTRO-E2 MEMO #2004-06

Title: Definitions of the Coordinate System for the Astro-E2 Event

Category: Software

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Definitions of the Coordinate System for the Astro-E2 Event Files

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Astro-E2 Software Team

In this memo, we define the Astro-E coordinate systems to be used in the XIS/XRS/HXD event files.

1 Definition of the Coordinates

The following coordinates are defined to describe event locations in the telemetry, on the detector, or on the sky. All the coordinates are written in the Astro-E2 event files.

- RAW coordinates:
  Original digitized values in the telemetry to identify pixels of the events. May not reflect physical locations of the pixels on the sensor. For example, XIS RAW X and Y coordinates will have values from 0 to 255 on each Segment[1]. For XRS, the pixel ID, from 0 to 31, will represent the RAW coordinates.

- ACT coordinates:
  ACT is defined only for XIS. The ACT X and Y values are defined to represent actual pixel locations in the CCD chips. ACT XY will take 0 to 1023 to denote the 1024×1024 pixels in the chip. The XIS RAW to ACT conversion depends on the observation modes (such as Window Options) and will require housekeeping information. The XIS ACT coordinates is defined by looking-down the sensors.

- DET coordinates:
  Physical positions of the pixels *within* each sensor. Misalignments between the sensors are *not* taken into account. The DETX/Y coordinates are defined by looking up the sensor, such that the satellite +Y direction[2] becomes the -DETY direction (the same as ASCA convention).

  The DET X and Y values take 1 to 256 for XRS, and 1 to 1024 for XIS. For XRS, the DET X/Y represents position of the center of each XRS pixel in the same unit as that of XIS when projected on the sky (i.e., the difference of the focal length of the XRT is taken into account).

- FOC coordinates:
  Focal plane coordinate common to all the sensors. The unit is the same as that of DET. Misalignments between the sensors *are* taken into account so that the FOC images of different sensors (both XRS and XIS) can be superposed. FOC is calculated from DET by linear transformation to represent the instrumental misalignment, i.e., the offset and the rotation angle. Information of these misalignments is written in the teldef files.

- SKY coordinates:
  Positions of the events on the sky in the same unit as FOC. The conversion from FOC to SKY is made using the satellite attitude in the attitude file and the alignment matrix (3×3) written in the teldef file. For each XIS event, the equatorial coordinates of the pixel center projected on a tangential plane are given[3]. For each XRS event, the equatorial coordinates of the *pixel center* as well as the roll angle of the pixel are given. The roll angle is necessary since the XRS pixel size is finite.

In this scheme, it is important that the conversion from RAW to DET does *not* depend on the misalignments between the sensors. Therefore, DET XY, as well as RAW XY, can be written in the event FITS files without having the calibration information. The DET to FOC conversion requires information of the misalignment between the sensors. The same routines/functions can be used for FOC to SKY conversions for different sensors not depending on the individual characteristics.

[1] Each of the four XIS sensors has a single CCD chip, and a single chip is divided into four Segment.
[2] Satellite Z-axis points the telescope direction, and +Y direction is toward the solar paddle.
[3] There are several projection methods, such as -TAN, -SIN, -ARC and -STG.
See `http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps` for detail. The tangential projection (-TAN) is widely used, and will be adopted for Astro-E2 event files too.

2 Implementation to the FITS Event Files

2.1 Names of the Columns

	XIS	XRS	HXD
SENSOR	SENSOR	–	SENSOR
RAW	SEGMENT, RAWX, RAWY	PIXEL	–
ACT	ACTX, ACTY	–	–
DET	DETX, DETY	DETX, DETY	–
FOC	FOCX, FOCY	FOCX, FOCY	–
SKY	X, Y	X, Y, ROLL	–

2.2 Type and Range of the Columns

2.2.1 XIS

	Type	Minimum	Maximum	Origin	Size of the Pixel
SENSOR	Integer	0	3	–	–
SEGMENT	Integer	0	3	–	–
RAWX/Y	Integer	0	255/1023	–	–
ACTX/Y	Integer	0	1023	–	0.024 mm
DETX/Y	Integer	1	1024	512.5	0.024 mm
FOCX/Y	Integer	(1	1536)[a]	768.5	0.024 mm
X/Y	Integer	(1	1536)[a]	768.5	0.024 mm

[a]: Default image region. The X and Y values can be outside of the region.

The DETXY pixel sizes correspond to the physical pixel size of the XIS CCD. The XY pixel size corresponds to the angular size of a single XIS CCD pixel. To allow rotation of the image and some shift of the pointing direction during the observation, the XY range is taken slightly bigger than $\sqrt{2} \times 1024$.

2.2.2 XRS

	Type	Minimum	Maximum	Origin	Size of the Pixel
PIXEL	Integer	0	31	–	–
DETX/Y	Integer	1	256	128.5	0.02274 mm
FOCX/Y	Integer	1	1536[a]	768.5	0.02274 mm
X/Y	Integer	(1	1536)[a]	768.5	0.02274 mm
ROLL	Real	0.0	360.0[b]	–	–

[a]: Default image region. The X and Y Values can be outside of the region.
[b]: An angle of FOCY-axis from north (usually SKYY-axis) when projected on the sky, measured to the counter clockwise direction in degree.

To make the comparison of the XRS and XIS images easier, the same pixel sizes are used for the both sensors for FOCX/Y and X/Y, and the XRS DETXY pixel size is defined as (XIS pixel size) × (XRS focal length) / (XIS focal length).

2.2.3 HXD

	Type	Minimum	Maximum	Origin	Size of the Pixel
SENSOR	Integer	0	15	–	–

HXD is not an imaging instrument and will not have coordinate columns. The average pointing direction may be written in the event FITS file header.

3 Calibration Information Required for Coordinate Transformation

One teldef file is prepared for XRS, and total 4 files for XIS sensors. In the primary header of each teldef file, alignment information of the individual sensor (DET→FOC and FOC→SKY) is written. They are mainteined under the calibration database (caldb).