ASTRO-E2 MEMO #2005-09

Title: How to calculate the coordinate keywords for Astro-E2 event file

Category: Software

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How to calculate the coordinate keywords for Astro-E2 event file

version 4.0 Ken Ebisawa (2005-06-18)

1 Definition of the keywords

All the extensions in the Astro-E2 event files and HK files with the keyword TELESCOP='Astro-E2' should have the following coordinate keywords: [1].

```
RA_OBJ  =                       / Planned target RA (deg)
DEC_OBJ =                       / Planned target DEC (deg)
RA_NOM  =                       / Nominal satellite pointing RA (deg)
DEC_NOM =                       / Nominal satellite pointing DEC (deg)
PA_NOM  =                       / Nominal position angle from North to DETY (deg)
MEAN_EA1=                       / Mean of the 1st ZYZ-Euler angles (deg)
MEAN_EA2=                       / Mean of the 2nd ZYZ-Euler angles (deg)
MEAN_EA3=                       / Mean of the 3rd ZYZ-Euler angles (deg)
```

In addition, event and HK files for XRS, XIS and HXD have the following keywords:[2]

```
RA_PNT  =                       / Average optical axis location RA (deg)
DEC_PNT =                       / Average optical axis location DEC (deg)
```

These keywords are put in the First Fits File (FFF) header by mk1stfits with *blank* values. Actual values are calculated and filled in the pipe-line processing. Precise meanings of these keywords are the following:

- RA_OBJ, DEC_OBJ

  This is the sky position of the observing target (J2000; same for all the other RA and DEC values). In the case of the point source observation, most likely the point source position. However, in general, this is the target position Guest Observers specified, and put in the proposal and satellite operation database.

  In practice, these values are already in the attitude file. In the pipe-line processing, `aeaspect` will copy RA_OBJ and DEC_OBJ and $OBJECT$ values from the attitude file to event and HK FFFs.

  RA_OBJ and DEC_OBJ values should be the same for all the files in the same sequence.

- RA_NOM, DEC_NOM, PA_NOM

[1] Hence, Primary which does not have TELSCOP keyword does not have these coordinate keywords.

[2] In other words, only common HK files, in which optical axis is not defined, do not have the RA_PNT and DEC_PNT.

These keywords tell the nominal pointing position and position angle (*roll angle*) of the satellite. We may take into account the mis-alignment between the satellite Z-axis and the mean position of the five telescopes.

In Astro-E2, we define FOC (focal plane) coordinate on which different instrument images match each other. In definition, (RA_NOM, DEC_NOM) should agree with the position of the FOCXY (focal plane) origin on the sky, assuming the average attitude.

Position angle is defined as the angle measured from sky North to DETY axis when the detector image is projected on the sky. This is the same definition as used in the ROLL column of the XRS event file [3].

RA_NOM, DEC_NOM are used as the reference point to calculate the projected sky coordinates for each XRS and XIS event.

RA_NOM, DEC_NOM and PA_NOM should be the same for all the files in the same sequence.

Having the identical RA_NOM and DEC_NOM (as well as the same sky pixel scale) makes the sky image comparison easier between different instruments.

- $MEAN\_EA1, MEAN\_EA2, MEAN\_EA3$

  These are the mean satellite Euler angles (defined as Z-Y-Z) averaged over the attitude file. Since these values are directly calculated from the attitude file (see below), *these values are the same for different instruments.*

  $MEAN\_EA1, MEAN\_EA2, MEAN\_EA3$ may be useful to get to know correspondence between the DET image and sky positions. For example, `xrsqlp` will draw average coordinate grids on the DET image using these values.

- RA_PNT, DEC_PNT

  This is the average optical axis location on the sky, converted from the optical axis location on the detector, taking account of the instrument mis-alignments. RA_PNT and DEC_PNT are useful for observers to know how far the main target is from the optical axis, but may not be used for serious data analysis.

  Naturally RA_PNT and DEC_PNT can be different for different instruments, reflecting the instrument mis-alignment.

2 Tasks

2.1 aeaspect

2.1.1 Input parameters

`aeaspect` is an Astro-E2 specific ftool. This tool has the following parameters:

[3] See, e.g., figure 2.5 of the "The Astro-E2 Technical Description" (`http://heasarc.gsfc.nasa.gov/docs/astroe/prop_tools/astroe2_td/node5.html#fig:xrsarray`).

```
     attitude = ae19990922_0800_2210.att    input attitude file
     filelist = none                        file name or @filelist to modify FITS keywords
     leapfile = leapsec.fits                location of leap-seconds file
   xrs_teldef = xrs_teldef_2005-05-25.fits  location of XRS teldef file
   hxd_teldef = hxd_teldef_1999-12-29.fits  location of HXD teldef file
  xis0_teldef = xis0_teldef_2005-05-25.fits location of XIS0 teldef file
  xis1_teldef = xis1_teldef_2005-05-25.fits location of XIS1 teldef file
  xis2_teldef = xis2_teldef_2005-05-25.fits location of XIS2 teldef file
  xis3_teldef = xis3_teldef_2005-05-25.fits location of XIS3 teldef file
  (sample_sec = 60.0)                       sampling time in second (s)
(offset_tolerance = 2.0)                    offset angle tolerance (arcmin)
(roll_tolerance = 1.0)                      roll angle tolerance (degree)
   (num_split = 4)                          number of splitting time intervals
(adopt_median = yes)                        adopt median instead of average
  (update_obj = yes)                        update OBJECT/RA_OBJ/DEC_OBJ keywords
  (update_nom = yes)                        update RA_NOM/DEC_NOM/PA_NOM keywords
  (update_pnt = yes)                        update RA_PNT/DEC_PNT keywords
   (update_ea = yes)                        update MEAN_EA1/MEAN_EA2/MEAN_EA3 keywords
 (anl_verbose = 0)                          ANL verbose level (-1:full, 0:minimum)
 (anl_profile = no)                         Enable ANL module profiling
   (num_event = -1)                         number of event (-1=all,0=exit)
  (event_freq = 1000)                       Event number printout frequency
        (mode = ql)                         Mode
```

2.1.2 Main function

Main function of `aeaspect` is to read the attitude file from the `attitude` parameter, and fill the coordinate keyword values indicated above in the FITS file specified with `filelist` (or all the FITS files specified in the list as file.list). If extension is explicitly specified (like '[2]'), only the keywords in that extension are updated. Otherwise, all the extensions having the TELESCOP and INSTRUME keywords are modified.

$OBJECT$, RA_OBJ, DEC_OBJ (entire lines including comments) are copied from the attitude file if update_obj=yes. To calculate RA_PNT and DEC_PNT, optical axis locations on the detector coordinates are required, which are taken from the instrument teldef files. for $MEAN\_EA1$, $MEAN\_EA1$, $MEAN\_EA3$, the numerical values are written down to 12th digit below the decimal point. For other values (except RA_OBJ and DEC_OBJ which are copied from the attitude file), values are written down to 4th digits below the decimal point.

2.1.3 Example

Here is an example of the coordinate keywords calculated with `aeaspect`:

```
OBJECT  = 'LOCKMAN_HOLE'       / Name of object
RA_OBJ  =              163.4312 / Source RA (deg)
DEC_OBJ =               57.5920 / Source DEC (deg)
RA_NOM  =              162.8028 / nominal satellite pointing direction R.A.(deg)
DEC_NOM =               57.4208 / nominal satellite pointing direction DEC.(deg)
PA_NOM  =            -265.9997 / nominal position angle from north to DETY(deg)
MEAN_EA1=     162.802781082675 / mean of the 1st ZYZ-Euler angle (deg)
```

```
MEAN_EA2=      32.579216022868 / mean of the 2nd ZYZ-Euler angle (deg)
MEAN_EA3=      -4.000269070742 / mean of the 3rd ZYZ-Euler angle (deg)
RA_PNT  =             162.8028 / average optical axis location R.A.(deg)
DEC_PNT =              57.4208 / average optical axis location DEC.(deg)
```

Note, in the example above, not only values but also comments of RA_OBJ and DEC_OBJ are copied from the input attitude file, for which an ASCA attitude file was used. Consequently, these comments are overwritten. In the Astro-E2 attitude file, the same comments for RA_OBJ and DEC_OBJ as those in FFF (see page 1) should be written in the header.

The attitude file and teldef file used are written in the header.

```
ATT_FILE= 'ae19990922_0800_2210.att' / name of the satellite attitude file
TELDEF  = 'xrs_teldef_2005-05-25.fits' / name of the telescope definition file
```

In addition, the following HISTORY keywords are written:

```
HISTORY ------------------------------------------
HISTORY  aeaspect version 1.3 at 2005-06-14T19:24:33
HISTORY ------------------------------------------
HISTORY   attitude='../test/ae19990922_0800_2210.att'
HISTORY   leapfile='../test/leapsec.fits'
HISTORY   sample_sec=60.000
HISTORY   adopt_median=yes
HISTORY   update_obj=yes, update_nom=yes, update_pnt=yes, update_ea=yes
HISTORY
HISTORY Sample Time : 60.0 s   Number of Accept / Sample : 3359 / 3359
HISTORY TIME START STOP TELAPSE (s) :  -8683199.3  -8481703.9    201495.4
HISTORY START DATE TIME in UTC (MJD): 1999-09-22 12:00:00 (51443.50000839)
HISTORY STOP  DATE TIME in UTC (MJD): 1999-09-24 19:58:16 (51445.83213107)
HISTORY
HISTORY Mean satellite Euler angles :  162.804319   32.579952   -4.002507
HISTORY
HISTORY                                    RA          DEC      SUN ANGLE
HISTORY
HISTORY Mean Sun position     (deg) :  180.178554   -0.078059
HISTORY Mean aberration    (arcsec) :  -33.324632   -0.346884
HISTORY
HISTORY Mean satellite X-axis (deg) :  158.057511  -32.490694   38.544755
HISTORY Mean satellite Y-axis (deg) :  249.430052   -2.154009   69.263717
HISTORY Mean satellite Z-axis (deg) :  162.804319   57.420048   59.152195
HISTORY
HISTORY                   RA(deg)     DEC(deg)    ROLL(deg) OFFSET(arcmin)
HISTORY
HISTORY Median          162.804319   57.420048 -265.997493
HISTORY Average         162.807884   57.418934 -265.990251
HISTORY Minimum         162.533402   56.562184 -266.416168
```

```
HISTORY Maximum         165.894395   57.518541 -260.559000  113.347292
HISTORY Sigma (RMS)       0.110218    0.030035    0.192335    4.020585
HISTORY
```

2.1.4 Update attitude file header

The following keywords, which are common to all the instruments, are also copied to the attitude file header.

```
RA_NOM  =             162.8028 / nominal satellite pointing direction R.A.(deg)
DEC_NOM =              57.4208 / nominal satellite pointing direction DEC.(deg)
PA_NOM  =            -265.9997 / nominal position angle from north to DETY(deg)
MEAN_EA1=     162.802781082675 / mean of the 1st ZYZ-Euler angle (deg)
MEAN_EA2=      32.579216022868 / mean of the 2nd ZYZ-Euler angle (deg)
MEAN_EA3=      -4.000269070742 / mean of the 3rd ZYZ-Euler angle (deg)
```

These values are used, for example, `aemkehk` to calculate the instantaneous offset of the attitudes from the nominal attitude. The instantaneous offset will be put in the filter file.

2.1.5 Algorithm to calculate the mean attitude

There are two methods to calculate nominal attitudes depending on adopt_median=yes or no.

Whichever method, aeaspect first calculates the pointing vector and roll angle (as well as Euler angles) for every "sample_sec". If adopt_median=yes, *median* of these values are taken.

If adopt_median=no, *average* of the pointing direction and roll angle are calculated. If the maximum off-set and maximum roll difference from the average are less than offset_tolerance and roll_tolreance, respectively, we take this average attitude. If either exceeds the tolerance, the observation is split into num_split segments. For each time segment, aeaspect calculates the maximum offset and maxim roll, then takes the segment where offsets are the smallest.

2.2 xrscoord, xiscoord

These tools calculate sky X and Y position of each XRS or XIS event from DETX and DETY (via FOCXY – *focal plane* XY) using attitude file. There is a parameter "pointing" which takes the value either ATT, KEY or USER. If pointing=KEY (this will be the case in the pipe-line processing), the sky reference position is taken from *RA_NOM* and *DEC_NOM* keywords.

In addition, xrscoord and xiscoord calculate OPTIC* keyword values in the FOC and SKY coordinates, which are optical axis location *in pixel* in FOC or SKY coordinates. (Optical axis location in the DET coordinate is defined in the teldef file).

2.3 aecoordcalc

This is an ftool to carry out *Astro-E2* coordinate conversion using teldef file for given Euler angles. Inputs are teldef file, Euler angles, one of the RAW, DET, FOC or SKY values, or J2000 or Galactic coordinates, and the reference RA an DEC values (CRVAL1 and CRVAL2). Then, all these coordinate values are output, and also put in the parameter file. This ftool can be a convenient user tool, but currently not planned to be used in the pipe-line processing.

2.4 aemkehk

This is an Astro-E2 specific ftool to read attitude and orbital file, and output the "Extended HK (EHK)" file. The EHK file is used as an input for "makefilter" to create a filter file with orbit and attitude information.

Attitude file is also an input of `aemkehk`. The RA_NOM, DEC_NOM and PA_NOM in the attitude file header are used to calculate the following values in the aemkehk output file.

```
TTYPE10 = 'DLT_RA  '           / difference from mean RA. (arcmin)
TFORM10 = '1E      '           / data format of field: 4-byte REAL
TUNIT10 = 'arcmin  '           / physical unit of field
TTYPE11 = 'DLT_DEC '           / difference from mean DEC. (arcmin)
TFORM11 = '1E      '           / data format of field: 4-byte REAL
TUNIT11 = 'arcmin  '           / physical unit of field
TTYPE12 = 'DLT_ROLL'           / difference from mean roll angle (deg)
TFORM12 = '1E      '           / data format of field: 4-byte REAL
TUNIT12 = 'deg     '           / physical unit of field
TTYPE13 = 'ANG_DIST'           / distance from mean pointing pos (arcmin)
TFORM13 = '1E      '           / data format of field: 4-byte REAL
TUNIT13 = 'arcmin  '           / physical unit of field
```

3 Implementation in the Processing

We will use `aeaspect` to calculate RA_OBJ, DEC_OBJ, RA_NOM, DEC_NOM, PA_NOM, $MEAN\_EA1$, $MEAN\_EA2$, $MEAN\_EA3$, RA_PNT and DEC_PNT (Figure 1).

`xrscoord` and `xiscoord` are used respectively for XRS and XIS (Figure 2). Pointing=KEY is adopted so that the same RA_NOM and DEC_NOM values are used for XRS and XIS. OPTIC* keyword values are calculated by `xrscoord` and `xiscoord`.

Note that those coordinate keywords calculated by `aeaspect` *are never changed by downstream processing.* These coordinate keywords are considered to be intrinsic to particular attitude, teldef file and FFF, and should not be affected by later processing (e.g., change of the GTI).

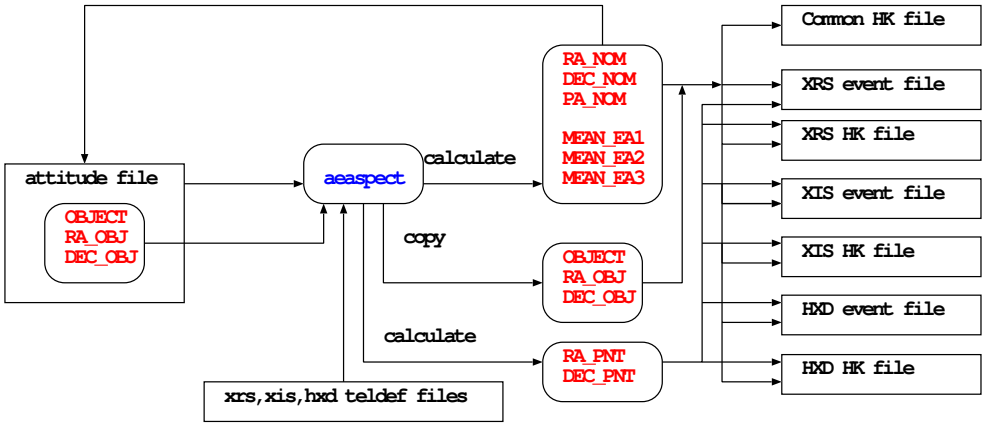

Figure 1: Functionality of "aeaspect".

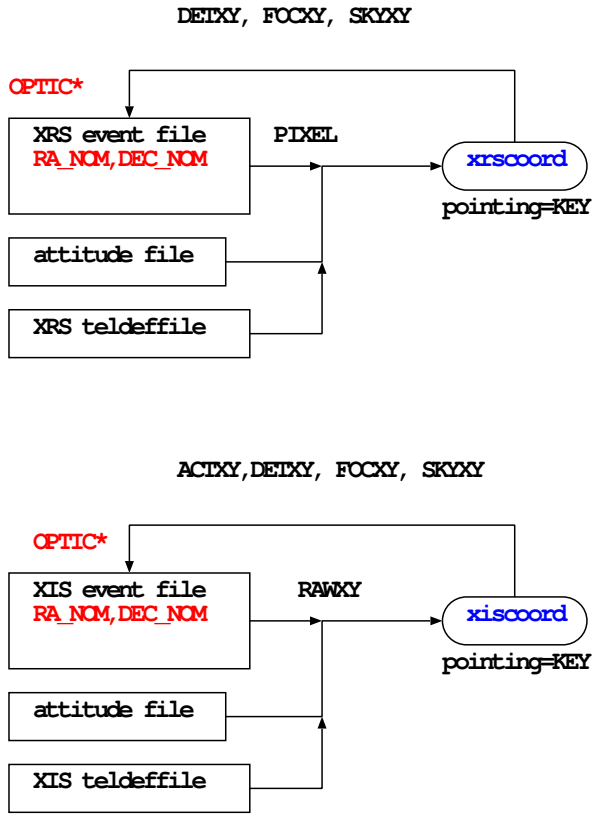

Figure 2: Functionality of "xrscoord" and "xiscoord".