EUV IMAGING SPECTROMETER
Hinode

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EIS POINTING

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1 Overview

Each EIS FITS file contains pointing information, both in the headers and for each exposure as columns in the binary tables. Actual pointing details for a particular FITS file are provided by methods for the EIS_DATA object. Because both spacecraft pointing data and a full understanding of the offsets between EIS and the spacecraft are required, accurately computing these quantities has been challenging. The purpose of this document is to outline in detail the information that goes into computing the pointing numbers.

2 Computing Solar Locations from EIS and Hinode data

Pointing information is used in two places in the EIS software. In the planning software, knowledge of all the offsets that define the relationship between the spacecraft pointing and EIS pointing is necessary to translate the selected x and y positions on the Sun into fine mirror positions and start positions along the slit. In the FITS file generation software, spacecraft pointing information is combined with the same offset information to calculate the location on the Sun of each position along an EIS slit for each exposure. This information is then used to determine keyword values in the FITS headers. In an ideal world these two tasks should use the same offset information to go from planned solar location to instrument pointing parameters and from returned instrument pointing parameters and spacecraft pointing data to actual solar location. In practice, this has not been the case for all EIS FITS files. Note that all pointing values refer to data in the He II 256 Å line. Additional corrections in solar y-positions are necessary for other wavelengths.

Reconstructing the solar location of any EIS exposure requires spacecraft attitude information, the EIS fine mirror position at the time of the exposure, and the offsets in x and y between the spacecraft pointing and EIS.

2.1 Hinode AOCS Data

Pointing information from the Hinode Attitude and Orbit Control System (AOCS) is provided in the HK2 housekeeping data packets. The combination of the UFSS and gyro data results in three parameters provided in the HK2 files at each PACKET_EDITION_TIME:

HK2_ATT_X N/S position, with larger numbers increasingly south

HK2_ATT_Y E/W position, with larger numbers increasingly east

HK2_ATT_Z Rotation around Z

Data in the files are provided at 2 s intervals. The EIS data reformatting system produces HK2 FITS files, which are located in $HINODE/eis/status/YYYY/MM/DD directories at ISAS and NRL. The 24-bit words for each quantity require a little manipulation to recover the position in arcsec. A second set of HK2 FITS files, which are in a more convenient format are also available. These are located in $HINODE/cmn/HK2/YYYY_MM directories at ISAS and NRL. The IDL function hinode_get_att.pro uses these files to return the the times and the associated X and Y attitude information converted to arcsec and corrected so that standard solar sign conventions apply. Note, however, that HK2_ATT_X refers to the N/S direction and HK2_ATT_Y refers to the E/W direction. Each EIS FITS file contains columns in the binary table listing the HK2_ATT_X (YCEN_TI1) and HK2_ATT_Y (XCEN_TI1) values at the start time for each exposure. These numbers have the correct solar sign convention.

A slightly different system for computing the pointing was used early in the mission—up until 2006 December 4. Calling EIS_MKFITS or EIS_FIX_POINTING with /noaocs will invoke software for generating files using the earlier algorithm (see the CONSTRUCT_XYPOS method in the EIS_SPCD object for details). However, this software has not been extensively debugged. Pointing information in files created before 2006 December 4 should be viewed with some caution.

How accurate are the positions provided in the HK2 files? Firm numbers are difficult to find. Once a set of offsets is agreed upon for EIS, it should be possible to compare EIS rasters with EIT images and obtain an observational picture of this value.

While the location on the Sun may be uncertain, fluctuations around that location can be measured with considerable accuracy. The UFSS signals have random noise with a 3σ value of only 0.3 arcsec. Thus, this data can be used to compute the spacecraft jitter as observations are made and corrections can then be made when the data are processed. As discussed below, the EIS_DATA object methods that return pointing information treat the spacecraft x- and y-pointing data differently, but jitter in both directions is possible to extract using these methods. Note that the UFSS signal does not include the EIS-induced jitter, which is significantly larger. The EIS jitter is similar to that observed with XRT, and John Mariska has revised the routine XRT_JITTER to compute the expected EIS jitter. The routine EIS_JITTER is in the EIS SSW distribution. The usefullness of EIS_JITTER is discussed further in §3.

2.2 EIS Coarse and Fine Mirror Positions and Slit Windows

The EIS potential field of view is defined in the y-direction by the 1024 arcsec slit height and in the x-direction by the available range of the coarse and fine mirror mechanisms. Coarse mirror motion is provided by a ball screw and linear bearing arrangement, which can move in step sizes of approximately 0.30 arcsec on the Sun. This mechanism has a range of more than ±2750 steps, leading to a range on the Sun of ±825 arcsec. During instrument development, the intention was to use this capability to offset EIS from the spacecraft pointing allowing studies of different regions than SOT might be interested in. In practice, however, the mechanism has only been used once on 2007 Jan 22 to bring the center of the EIS field of view closer to the center of the SOT field of view. At this time, it is does not appear likely that the coarse mirror position will be changed again. Home position for this mirror is defined as the position it was located at early in the mission and has a value of 43703L. The position after the move is 47659L, and the x-position shift that resulted has been determined to be 130 arcsec.

The EIS fine mirror mechanism uses a piezoelectric transducer (PZT) actuator and a flex-pivot arrangement to tilt the mirror, changing the solar position on the slit. This mechanism moves the mirror in 0.1248 arcsec steps (which need to be multiplied by two to get the image motion on the Sun) to position one of the EIS slits anywhere in the available field of view and to raster the Sun. The nominal useful range of the mirror is from 600 to 3000. Thus the center of the potential EIS field of view in x is at position 1800. The center of the potential EIS field of view in y is position 512 on each slit. Increasing numbers for the fine mirror position move the slit east on the Sun. All offsets from the spacecraft (and from XRT and SOT) are relative to the center of the potential EIS field of view at a fine mirror position of 1800 and a slit location of 512.

2.3 EIS Offsets

Offsets between the center of the potential EIS field of view and the Hinode pointing were measured early in the mission and after the coarse mirror move on 2007 Jan 22. The approach taken in the EIS FITS file generation software is to use the values from early in the mission and then apply a second offset based on the new position determined after the coarse mirror move. For FITS files generated up until (TBD), this second correction only changes the solar x-offset. The solar y-offset also changed when the coarse mirror was moved. This may account for some disagreements between pointing in the EIS FITS file headers and pointing determined from comparing EIS rasters with data from other spacecraft.

The x- and y-offset values carried in the cal_response.txt file are -129.6 and -36.3, respectively. Correcting for the coarse mirror move, adds 130.0 arcsec to the x-offset value, resulting in a new x-offset of $+0.4$ arcsec. The planning software was updated after the coarse mirror move and now uses x- and y-offset values of 0.0 and 50.0, respectively. Assuming a different sign convention, the x-offset values agree and the y-offset values differ by 13.7 arcsec. This was an inconsistency between the pointing information used by the planning software and that used by the FITS file generation and reading software. This inconsistency was corrected in (TBD) July 2010.

There is also an offset between the 1 arcsec slit and the 2 arcsec slit. The 2 arcsec slit image center lies 8 arcsec west of the position of the centers of the 1 arcsec slit and the 40 arcsec slot. This is accounted for in the planning software and also, as of 25 Feb 2010, in the FITS file generation software.

2.4 Computing Pointing for EIS FITS Files

Table 1 summarizes the parameters that go into computing the EIS pointing for the FITS headers and for returning pointing information when the appropriate EIS_DATA, EIS_CAL, and EIS_SPCD object methods are called. In principle, roll information is also needed to compute the pointing, and the equations used in the EIS_SPCD object methods include terms for that correction. In practice, these numbers do not appear to be important and the basic pointing equations for each EIS exposure as currently implemented simplify to

$$x = att_x + \mathit{off}_x + (fm_h - fm_{pos}) \cdot 2 \cdot fm_{ss} + (cm_{pos} - cm_h) \cdot cm_{ss} \tag{1}$$

and

$$y_i = att_y[0] + \mathit{off}_y - y_h + y_{start} + i \ , \tag{2}$$

where fm_{pos} is the position of the fine mirror for the exposure, cm_{pos} is the position of the coarse mirror for the exposure, y_{start} is the pixel value of the lowest y-pixel in the exposure window, and i indexes the pixels in the window along the slit from the start value.

In the solar x-position calculation, the value of the spacecraft x-position at the beginning of each exposure is used. The EIS_DATA object method that returns the solar y-positions along the y-direction of the exposure window, however, uses just the spacecraft solar y-position for the first exposure. This means that the spacecraft x-jitter (and tracking) is already included in the x-positions, but that additional processing is needed to plot the effect of the spacecraft y-jitter on

Table 1: Pointing Data

Name	Meaning	Units
Data from Hinode HK2 files		
hk_{time}	Time of AOCS measurement	s since 1-Jan-2000 UT
att_x	Hinode x-position	Solar coordinates arcsec N/S direction
att_y	Hinode y-position	Solar coordinages arcsec E/W direction
Data from $SSW/hinode/eis/response/cal_response.txt		
fm_{ss}	EIS fine mirror step size	0.1248 arcsec
fm_h	EIS fine mirror home position	1800
cm_{ss}	EIS coarse mirror step size	0.032862 arcsec
cm_h	EIS coarse mirror home position	43703L
y_h	Reference position for EIS slits	CCD y-pixel 512
off_x	x-offset from Hinode pointing to ref_x	-129.6
off_y	y-offset from Hinode pointing to reg_y	-36.3
Data from other sources		
$slit_{off}$	Offset between 1 and 2 arcsec slits	2 arcsec slit is 8 arcsec west

the sequence of exposures. Note that this is a very small effect, and the y-jitter information is available in the EIS_DATA object through the GETYCEN method which returns the spacecraft y as a function of time.

The att_x and att_y values are available every 2 s during the exposure. In the EIS FITS generation software, the spacecraft pointing information is interpolated to the exposure start time. Thus, as the spacecraft pointing fluctuates this should be reflected in the positions recorded in the FITS file. Since EIS exposure times are usually much longer than 2 s, the recorded position could be different from some kind of a mean position computed over the length of the exposure. Hinode spacecraft pointing data suggest that the jitter over an exposure will be 2-3 arcsec at most.

Key pointing information about each EIS raster or sit-and-stare observation is contained in the FITS headers. These values are important for establishing the location of the EIS observation on the Sun to facilitate approximate alignment with images from other data sources. Table 2 lists the important FITS header keywords for pointing. While all the pointing information in the headers should be recoverable from the detailed data in the file itself, it is important that the numbers be useful without the file having to be read.

For any given observation, Hinode is either at a fixed pointing with the Sun rotating beneath the EIS slit, or using rotation compensation with the spacecraft location being automatically adjusted to follow the same solar location. When rotation compensation is used—normally the case—this means that as a sequence of exposures takes place the coordinates that define the boundaries of the region to be observed are changing. The pointing data in the FITS file contain the instantaneous solar position at the time the exposure was initiated. Since a time is available in the file for each exposure, everything inside the file is internally consistent. The FITS headers, however, do not include the time of each exposure, and thus the pointing keywords should be tied to a time that is also provided in the header. The best time to use is the one contained in the DATE_OBS

Table 2: FITS Pointing-Associated Header Keywords

Keyword	Meaning
DATE_OBS	Start date and time of first exposure
XCEN	Center of the raster in solar x
YCEN	Center of the raster in solar y
CRPIX1	Reference pixel in solar x (currently listed as 1)
CRPIX2	Reference pixel in solar y (currently listed as 512)
CRVAL1	Solar coordinate value of CRPIX1
CRVAL2	Solar coordiante value of CRPIX2
CDELT1	Pixel size in solar x (depends on slit and scan step size)
CDELT2	Pixel size in solar y (equivalent to the y-step size in arcsec)
FOVX	Field of view in solar x in arcsec
FOVY	Field of view in solar y in arcsec

keywordthe start time of the raster. This means that all the pointing data in the FITS headers need to be positions at that time.

The XCEN and YCEN keywords were previously computed by taking the median of the pointing values for all the exposures. This helped take care of the problem of computing the center of a raster with many missing exposures, but it was not clear what time to associate with the positions. A better approach, implemented since 25 Feb 210, is to let the first exposure in the observation define the SW boundary of the box that the raster defines on the Sun (EIS scans from west to east), and then use the difference in fine mirror steps between that exposure and the last exposure in the raster and the height of the observing window in y to define the NE boundary of the box at the same time. With this data, the center of the raster box at the time specified by DATE_OBS is computed and XCEN and YCEN would be consistent with DATE_OBS. The same data is also be used to compute the remaining pointing quantities in the header, assuring that they are all consistent. Note that XCEN and YCEN are the position of the center of the raster, but at time DATE_OBS.

In the FITS standard, the keywords CRPIXn, CRVALn, and CRDELTn define a coordinate system reference pixel, the coordinate system value at the reference pixel, and the coordinate increment along each coordinate axis. These values should be consistent with the values in the XCEN and YCEN keywords, and in practice often use the XCEN and YCEN location as the reference value. The other common choice is one corner of the raster image. There is generally a simple relationship between these keywords and XCEN and YCEN. For example, if the location of SW corner of the image is used (first exposure, bottom of y-window), then, assuming all the exposures are in a raster,

$$\mathrm{XCEN} = \mathrm{CRVAL1} + \mathrm{CDELT1} * [(nexp + 1)/2 - \mathrm{CRPIX1}] \tag{3}$$

and a similar expression for YCEN. Note that in the FITS standard, numbering of pixels in an image starts at 1.

Previously In EIS FITS files, CDELT1 and CDELT2 had the correct absolute values. CRVAL1 and CRVAL2 contained the Hinode spacecraft pointing at the time of the first exposure, and CRPIX1 and CRPIX2 were 1 and 512, respectively.

Currently (as of 25 Feb 2010) these quantities are set so that CRPIX1 and CRPIX2 are 1 and 1, CRVAL1 and CRVAL2 are set to the coordinates of the SW corner of the EIS raster, i.e., use the first exposure information, and CDELT1 is set to the negative of the spatial step size in solar x between exposures (or the slit width for a sit-and-stare observation) and CDELT2 to 1.0. The negative value indicates that increasing exposures move the coordinates to the east. Selecting the information from the first exposure assures that the positions are correct for the time in the DATE_OBS keyword.

The FOVX and FOVY keywords could contain either the field-of-view of the EIS raster as planned or as executed. If data loss takes place, or an observation is terminated early for some reason, those values could differ. Though the actual observed values may be the best choice, currently the planned size of the raster is written to the FITS header.

The pointing information described above is accesible through EIS_DATA methods. XPOS gives the x coordinate for each slit position (including jitter and tracking) and YPOS gives the position for each pixel in y, in this case the jitter is not included as explained above. Somewhat counterintuitively, the XCEN and YCEN methods do **not** return the raster center coordinates but rather the home position of the fine mirror in x, including telescope tracking and jitter, and the middle of the physical slit in y including jitter. The XCEN and YCEN values at the center of the raster described above can be recovered by calling the GETINFO method, GETINFO('XCEN') or GETINFO('YCEN') or computed from the algorithm given above.

2.5 Comparison of EIS Rasters with EIT Images

Harry Warren has done a careful coalignment of an EIS raster observed in He II 256 Å (eis_l0_20071211_002416.fits.gz) with EIT He II 304 Å images taken at a nearby time. Using the current EIS offset values, the XCEN and YCEN values in the FITS file, and assuming that the XCEN and YCEN positions are for the time of the middle of the raster, he finds that agreement with the EIT pointing data requires that offsets in solar x- and y-positions of 5.3 and -24.0 need to be added to the values in the FITS header to agree with the EIT data. If instead we modify the XCEN and YCEN values to be the coordinates of the center of the raster at the time in DATE_OBS, then the corrections are -0.6 and -24.0. Including the proposed -13.7 arcsec correction that is required to make the XCEN and YCEN values consistent with the planning software reduces the difference 10.3 arcsec. If Fe XII data are used instead the required offsets are within about an arcsec of these numbers, if the offset between the EIS CCDs is taken into account.

3 EIS Pointing Fluctuations

Hinode undergoes temperature fluctuations as it orbits the earth. These produce small changes in the relationship between the EIS solar pointing and the solar pointing defined by the spacecraft Sun sensors. Early in the mission, comparisons of EIS slot images with XRT images showed that to first order EIS and XRT had the same orbital pointing fluctuations, and some EIS data users began to use the routine XRT_JITTER to account for pointing fluctuations in EIS data files. Since XRT data were not always available, this resulted in interpolations occasionally having to be made to fill

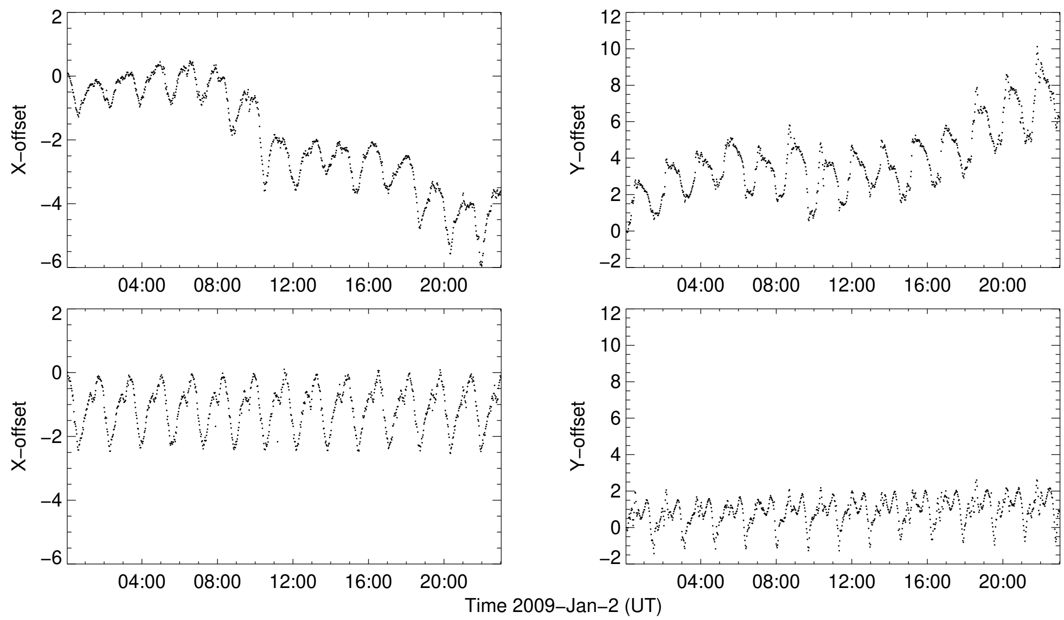

Figure 1: EIS pointing variations over a 24 hr period. The top two panels show pointing variations determined by co-aligning the EIS slot data. The bottom two panels show the output of EIS_JITTER

time gaps in the time series used by XRT_JITTER. To remove that problem, John Mariska created a new procedure, EIS_JITTER, to use EIS time series along with the XRT jitter information to produce correction array for the EIS pointing.

While EIS_JITTER does provide a useful first estimate of the pointing variations in a series of EIS observations, it is not perfect. Figure 1 highlights the differences. The top panels show the EIS pointing fluctuations computed by co-aligning a 24 hr set of EIS slot images. The bottom panels show the output of EIS_JITTER. To first order, the general orbital variations are captured by EIS_JITTER. Occasional larger changes, however, are missed.