EUV IMAGING SPECTROMETER
Hinode

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The EIS Slit Tilts

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1 Introduction

The EIS 1″ and 2″ slits are both tilted relative to the axes of the EIS CCDs, resulting in measured line centroids varying systematically with Y-position. The tilts of both slits are in the same direction, shifting line centroids to higher pixel numbers for increasing Y-position, i.e., lines become increasingly blue-shifted towards the top of the CCDs. The tilt of the 2″ slit is larger than for the 1″ slit.

This document presents measurements of the slit tilts for the EIS 1″ and 2″ slits. The full height of the CCD is used to measure the tilts and the following sections present the observing study used for the measurements, the analysis method and the results.

2 The CALIB_SLIT_SLOT study

The EIS planning software allows an exposure to be positioned anywhere in the Y-direction of the 1024-pixel high CCD (except the very bottom pixel). However the software also restricts any single exposure to be 512 pixels high, thus the full height of the CCD can only be observed by using two separate exposures. A study, CALIB_SLIT_SLOT, was designed to obtain narrow rasters using the 40″, 1″ and 2″ slits and taking the full 512 pixel height in Y. It was intended to be run twice, the first covering the top half of the CCD (Y-pixels 512 to 1023) and the second covering the bottom half (Y-pixels 1 to 512). In addition to measuring the slit tilt, this raster was also intended to be used for measuring the instrumental widths of the 1″ and 2″ slits, and for checking the absolute intensity calibration of the 1″, 2″ and 40″ slits.

CALIB_SLIT_SLOT (ID 352) consists of three different rasters, each of which takes the maximum number of pixels in the Y direction (512). The first is a raster with the 40″ slit which has three scan positions separated by 32″ and an exposure time of 20 s. The second raster is obtained with the 1″ slit, has 15 scan positions and a 40 s exposure time. The third raster uses the 2″ slit, has 15 scan positions and a 20 s exposure time. The two narrow slit rasters use the same line list, consisting of the three core lines, Fe VIII λ185.21, Fe XII λ193.51, Fe XIII $\lambda\lambda$202.04, 203.82, Si VII λ275.35 and Fe XV λ284.16. Only Fe XII λ193.51 and Fe XII λ195.12 are considered in this document.

The dates on which CALIB_SLIT_SLOT observed both the top and bottom of the CCD are given in Table 1. For the period Nov.–Dec. 2009 the study was run in quiet off-limb regions above the equator.

Table 1: CALIB_SLIT_SLOT runs.

Date	Location	Comment
5-Nov-2009	East limb	
13-Nov-2009	East limb	AR loops in north of raster?
19-Nov-2009	West limb	
26-Nov-2009	East limb	
11-Dec-2009	West limb	

3 Analysis method

Each of the narrow slit rasters consists of 15 exposures and the method used here is:

1. Match exposure i from the top half of the CCD with the corresponding exposure i for the bottom half of the CCD.
2. For exposures i create a 1D array containing the measured centroids at each Y-pixel position, matched to their Y-pixel numbers.
3. Fit a quadratic function to the variation of centroids with Y to yield coefficients c_1 and c_2 for the linear and quadratic terms, respectively.
4. Average the values of c_1 and c_2 across the 15 exposures to yield the final parameters $\bar{c}_1$ and $\bar{c}_2$.

Step 2 is complicated by the fact that the lower and upper exposures are obtained at different times and so the orbital variation of the line centroids (caused by movement of the grating) gives a wavelength offset between the exposures. This is corrected in a two step process. Firstly the upper and lower 10 pixels of the lower and upper exposures, respectively, are averaged and the difference between them gives a first guess of the exposure offset. Correcting the two centroid arrays for this offset, a first estimate of the quadratic fit function is made. The original centroid arrays for the lower and upper exposures are then corrected for the slit tilt and the average centroids calculated for the lower and upper exposures. The difference between these average centroids is then the second, and final, estimate of the exposure offset. With this offset, the quadratic function is then re-fit to the centroid data, yielding the final fit parameters for the slit tilt.

4 The $1''$ slit tilt

Previous to the present work, the most extensive study of the slit $1''$ slit tilt was by S. Kamio who measured the tilt in a large amount of data from 2006 November to 2007 November. He fitted a straight line to measured Fe XII λ195.12 centroids yielding an average gradient of 1.18×10^{-5} Å pixel^{-1} with a standard deviation of 1.43×10^{-5} Å pixel^{-1}. Looking at plots of the variation of line centroids across the full height of the CCD (Fig. 1) clearly reveals that the slit appears curved on the detector, with the gradient being steepest at low pixel numbers and shallowest at high pixel numbers. Over-plotted on Fig. 1 is the average tilt obtained by S. Kamio which is in quite good agreement with the measurements in the central portion of the CCD, but in poor agreement for the lowest 300 pixels. Note that, for the time period studied by S. Kamio, EIS observations were restricted to Y-pixels 255 to 766.

The method described in the previous section was applied to the CALIB_SLIT_SLOT observations to derive the fit parameters, $\bar{c}_1$ and $\bar{c}_2$, given in Table 2. The lowest 10 pixels were omitted from the fitting process as it was found that the emission line intensities dropped to zero in this region. It is believed that this is because the bottom edge of the slit occurs in this region.

The χ^2 values for the fits to individual exposure data were generally between 0.5 and 0.8, and the standard deviations of the residuals (between the fits and data) were around 1.2 to 2.0 mÅ. A sharp drop in the measured centroids of about 2 mÅ at the highest pixels (typically pixels >

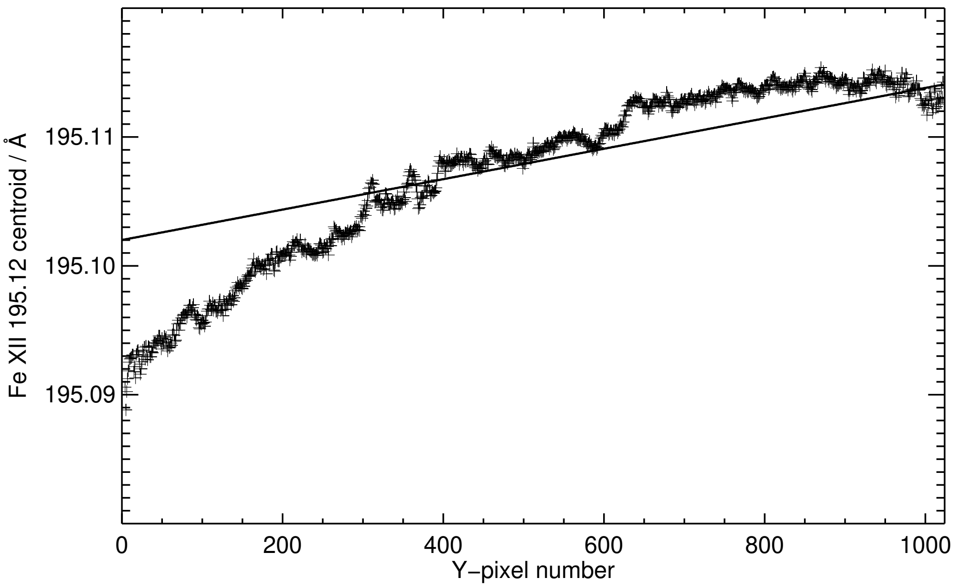

Figure 1: The crosses show measured centroids from the 2009 November 5 data-set for the 1″ slit rasters. The centroids have been aveaged across the 15 exposures of the raster. The straight line shows the average tilt obtained from the work of S. Kamio.

980) was a common feature of the centroid plots, suggesting this may be a real feature. This region was not omitted from the fits, however.

The average values of the fit parameters shown in Table 2 is given below:

$$
\begin{aligned}
c_1 &= 0.0454 \pm 0.0029 \qquad && \text{mÅ pixel}^{-1} \\
c_2 &= 0.0221 \pm 0.0024 \qquad && \mu\text{Å pixel}^{-2}
\end{aligned}
$$

The variation in the fit parameters shown in Table 2 is larger than the typical error on the fit parameters, and so the uncertainties given above are the standard deviations of the fit parameters.

5 The 2″ slit tilt

The 2″ slit is significantly more tilted than the 1″ slit, with a value of approximately 0.12 mÅ/pixel, corresponding to a shift of around 0.12 Å (5 pixels) from the bottom of the CCD to the top (Fig. 2). The slit also shows some curvature as can be seen in Fig. 2. The 2″ slit tilt was previously derived by S. Kamio using the same method as for the 1″ slit and an average gradient of 1.09×10^{-4} Å pixel^{-1} was found, with a standard deviation of 1.03×10^{-5} Å pixel^{-1}. This tilt is over-plotted on Fig. 2 as a straight line and it is seen to be in good agreement with the observations for the upper 600 pixels of the CCD, but not for the lower 400 pixels.

The method described in the Sect. 3 was applied to the CALIB_SLIT_SLOT observations to derive the fit parameters, $\bar{c}_1$ and $\bar{c}_2$, given in Table 3.

The scatter in the derived parameter values is larger than the 1σ error bars, so we take the mean

Table 2: Fit parameters for the 1″ slit data.

Data-set	Line	$\bar{c}_1$ mÅ/pix	σ_1 mÅ/pix	$\bar{c}_2$ μÅ/pix^2	σ_2 μÅ/pix^2
5-Nov-2009	195.1	0.0447	0.0015	-0.0227	0.0009
	193.5	0.0415	0.0019	-0.0196	0.0012
19-Nov-2009	195.1	0.0480	0.0016	-0.0229	0.0016
	193.5	0.0454	0.0010	-0.0218	0.0012
26-Nov-2009	195.1	0.0506	0.0022	-0.0270	0.0017
	193.5	0.0430	0.0015	-0.0196	0.0011
11-Dec-2009	195.1	0.0458	0.0016	-0.0222	0.0011
	193.5	0.0439	0.0015	-0.0207	0.0012

Table 3: Fit parameters for the 2″ slit data.

Data-set	Line	$\bar{c}_1$ mÅ/pix	σ_1 mÅ/pix	$\bar{c}_2$ μÅ/pix^2	σ_2 μÅ/pix^2
5-Nov-2009	195.1	0.1418	0.0013	-0.0221	0.0010
	193.5	0.1402	0.0018	-0.0198	0.0015
13-Nov-2009*	195.1	0.1407	0.0014	-0.0194	0.0009
	193.5	0.1377	0.0026	-0.0170	0.0018
19-Nov-2009	195.1	0.1428	0.0015	-0.0215	0.0010
	193.5	0.1403	0.0014	-0.0188	0.0010
26-Nov-2009	195.1	0.1462	0.0022	-0.0245	0.0014
	193.5	0.1378	0.0019	-0.0165	0.0011
11-Dec-2009	195.1	0.1423	0.0020	-0.0211	0.0017
	193.5	0.1408	0.0021	-0.0196	0.0013

* Data contains significant AR component.

of the parameters and set the error to be the standard deviation of the of parameters. (The 13-Nov-2009 data-set is ignored, however.) This gives the final parameters for the 2″ slit tilt:

$$
\begin{aligned}
c_1 &= 0.1415 \pm 0.0024 \qquad && \text{mÅ pixel}^{-1} \\
c_2 &= 0.0205 \pm 0.0024 \qquad && \mu\text{Å pixel}^{-2}
\end{aligned}
$$

The error bars can be used to derive the uncertainty on the slit tilt correction. Consider the case where the pixel 0 is used as a reference (e.g., a quiet Sun region) and we want to derive the tilt correction for pixel 500. The above parameters lead to a correction of 0.0656 Å with an uncertainty of 0.0013 Å. For the λ195.12 line this corresponds to a correction of 100.8 km s^{-1} with an uncertainty of 2.0 km s^{-1}.

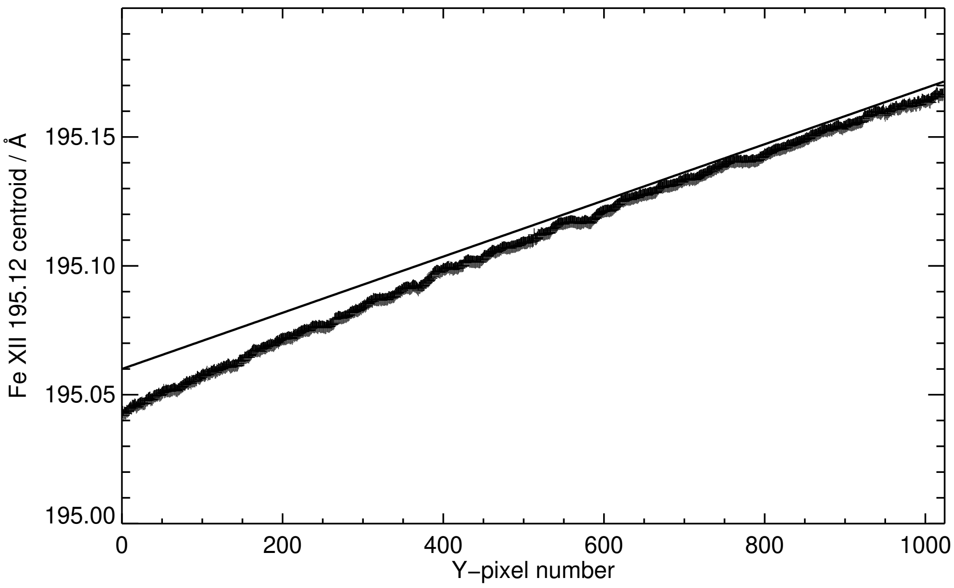

Figure 2: The crosses show measured centroids from the 2009 November 5 data-set for the 2″ slit rasters. The centroids have been aveaged across the 15 exposures of the raster. The straight line shows the average tilt obtained from the work of S. Kamio.

6 Summary

Quadratic fit parameters for the shape of the EIS narrow slits on the EIS SW detector have been derived using the Fe XII λ193.51 and λ195.12 lines. The error bars on the parameters enable the user to estimate the uncertainty introduced by correcting for the slit tilt, although this is $\leq$2 km s^{-1} for λ195.12.

This document considers only the strong Fe XII lines observed on the SW detector. It is likely that the tilts will be different for the LW detector (although the curvature should be the same) however the data-sets considered here are not suitable for the LW detector.

A Detailed method

An example of the IDL commands used to fit the CALIB_SLIT_SLOT data and derive the fit parameters is given below.

For the upper half of the CCD:

```
list=eis_day_files('2009-12-11',time='08:06',/lev)
offset=eis_slit_tilt_array(15,512,1,0)
wd=eis_getwindata(list[1],195.12,/refill)
eis_wvl_select,wd,offset,wvl_select
eis_auto_fit_new,wd,up_fit_195,offset=offset,wvl_select=wvl_select
eis_fit_viewer_new,wd,up_fit_195
```

For the lower half of the CCD:

```
list=eis_day_files('2009-12-11',time='08:24',/lev)
offset=eis_slit_tilt_array(15,512,1,0)
wd=eis_getwindata(list[1],195.12,/refill)
eis_wvl_select,wd,offset,wvl_select
eis_auto_fit_new,wd,lo_fit_195,offset=offset,wvl_select=wvl_select
eis_fit_viewer_new,wd,lo_fit_195

save,file='dec11_s0_fe12_195.save',lo_fit_195,up_fit_195
```

Finally, to derive the fit parameters:

```
calib_slit_slot_s2,lo_fit_195,up_fit_195
```

For each data-set the fit structures are saved, as indicated above, also the calib_slit_slot routine creates a postscript file showing the residuals from each exposure.

Some additional points to note about the analysis:

- The /refill option was used with eis_getwindata which replaces missing pixels with interpolated intensity values. See EIS software note No. 6 for more details.
- The λ193.51 line is affected by dust for a portion of the slit height. By studying the dusty pixel map in SSW it was determined that the dust affects Y-pixels 566 to 579 and so these were removed from the analysis.
- Both the λ193.51 and λ195.12 wavelength windows contain additional lines. The pixel locations of these lines were omitted from the fit. The de-selection of these pixels is performed with the routine eis_wvl_select.