EUV IMAGING SPECTROMETER

Hinode

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EIS Point Spread Function

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1 Overview

The present EIS note describes the current understanding about spatial resolution in the EIS instrument based on a preliminary analysis. The note is simply informative and describes the work that has been done to characterize the Point Spread Function. There is, therefore, no specific software in the EIS SolarSoft distribution addressing this topic.

2 Previous work

Korendyke et al. (2006) reports a pre-launch spatial resolution of $\sim 2''$ as measured from EUV emission from a Penning discharge lamp. They used lines Mg III and Ne III lines in the 171–200 Å range and He II and Ne III in the 251–284 Å. Young et al. (2013) cites a $3''$–$4''$ estimated value from studies of transition region brightenings discussed on the EIS Wiki[1]. Here, we revisit this topic and report our findings of small intensity features and a comparison of EIS raster images to AIA/SDO and TRACE images.

3 Transition region brightenings

The response of the instrument to a point source results in the point spread function (PSF). As there is no lamp on board EIS to perform this calibration on orbit, to study the PSF we have to rely in a natural point source. We know from higher resolution instruments that there are features on the Sun at smaller scales than the pre-flight resolution estimate of $2''$ ($\sim$1450 km), so we can work with the hypothesis that EIS observes small features that act as point sources for the instrument. The dimensions of the resulting image will give us clues about the optical performance.

In Figure 1 we show slot images for the smallest features that we could find. On the left, there is an active region point-like brightening particularly prominent in transition region lines such as Mg VI 269.0 Å and Si VII 275.3 Å. The feature also has a coronal counterpart in lines such as Fe XI 180.4 Å (not shown here). To characterize its dimensions we fit a Gaussian function to the well resolved cross-section along the Solar X direction. The result is a full-width-half (FWHM) of 3 pixels in both spectral lines, that is $3''$. This sets an upper limit to the spatial resolution of the instrument in that direction expressed in terms of the PSF. Along the Solar Y direction the structure is larger, around 6 pixels. An elliptical PSF is a possibility and we have, for that purpose, fitted a 2D Gaussian for the stronger Si VII case. This possibility is discussed further in Section 5. In this case we can not rule out that the source is extended along that direction and the asymmetry is just a consequence of the asymmetric extension. For that reason, we show in the same figure a different transition brightening, a weaker one, that suggests that indeed EIS can image smaller features, in this particular case a 3.5 pixels FWHM. We should point out that the uncertainties in those fitted widths can be of the order of a pixel.

[1] http://solarb.mssl.ucl.ac.uk:8080/eiswiki

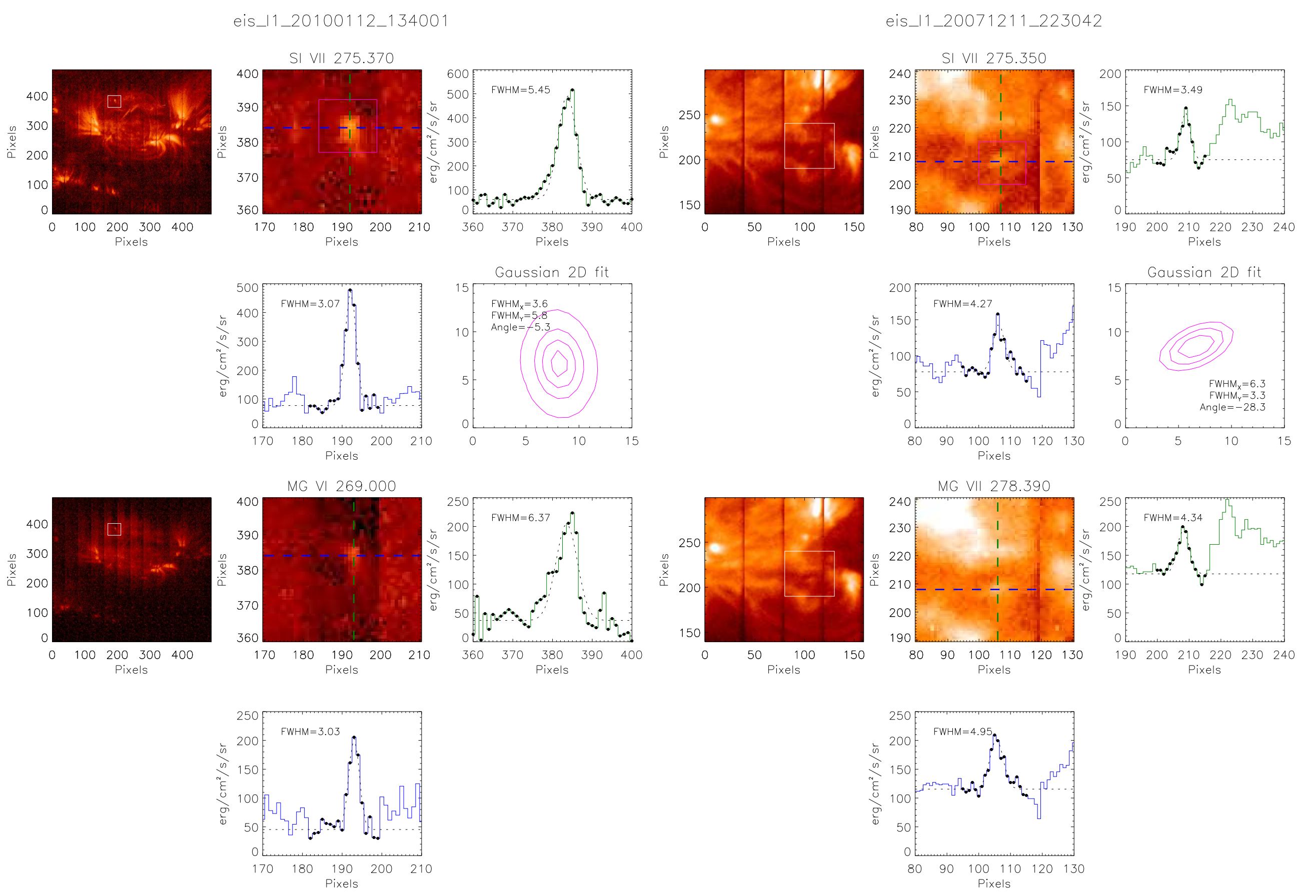

Figure 1: Transition region brightenings observed with the 40″ slit on Jan 12, 2010 (left set of panels) and December 11, 2007 (right panels). Shown here are images for two spectral lines, a close-up, cross-sections along Solar X (in blue) and Solar Y (in green) and Gaussian fits. The fits only include the points along the structure and the background (filled circles). A 2D Gaussian fit for the Si VII line is shown in pink.

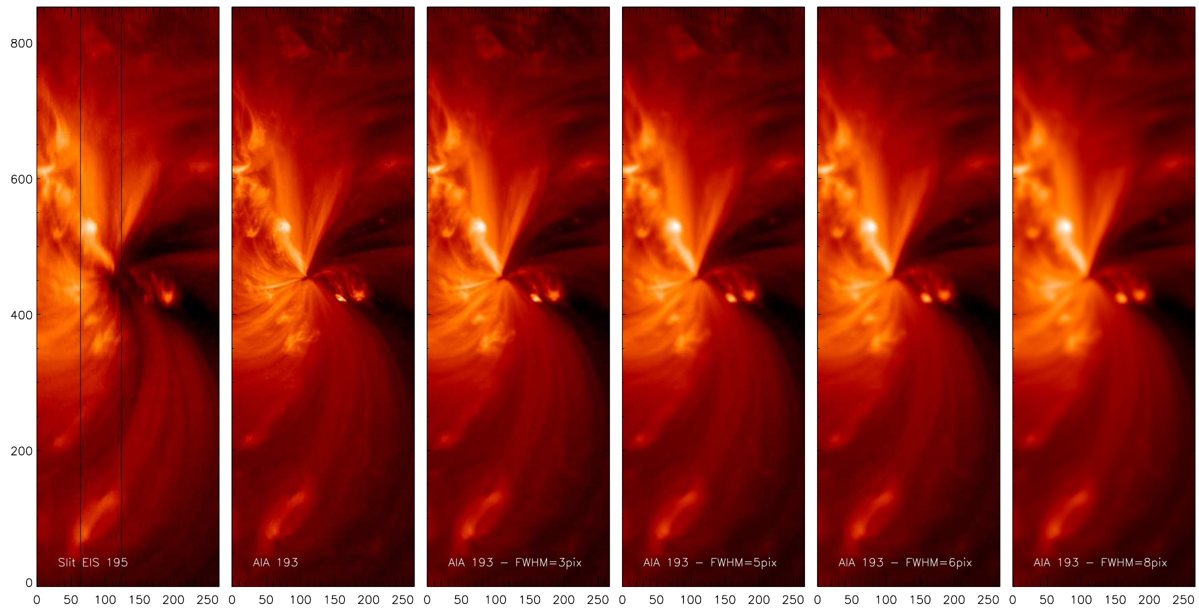

Figure 2: Comparison of an EIS raster (`eis_l0_20100802_105102.fits`) in 195.119 Å to a composite AIA image made out of a sequence of AIA 193 Å images that mimics the EIS scanning. Several degraded versions of the AIA composite are shown, each convolved by a Gaussian filter with different FWHM as labeled.

4 AIA comparisons

In this section we proceed with an alternative approach to understand the EIS performance by comparing it to other instruments that observe the same source at the same wavelength, but higher resolution. That is the case for AIA/SDO with a plate scale of 0.6″ per pixel and a FWHM PSF of ∼1.2″ (Grigis et al., 2012).

In Figure 2 we compare an EIS Fe XII 195.119 Å raster to an AIA composite image made of portions of several 193″ images at different times to mimic the EIS scanning along the Solar X direction. Taking the AIA composite image as the 'true' scale for the natural source, we convolve the image with several Gaussians of different FWHM in AIA pixels to infer the effect of the EIS PSF. We find that a PSF with a FWHM of 5–6 pixels (∼3–3.6″) returns the closest match to the EIS raster, in line with the results obtained in the transition region brightenings analysis. The comparison between an EIS 40″ slot image (Figure 3) and a single AIA image is consistent with this value.

Finally, we also compare an EIS raster to an image from the TRACE instrument with a pixel scale of 0.5″ per pixel. Figure 4 shows a comparison between EIS Fe X 184.5 Å and TRACE 171 Å. The best match in this particular case is around 4 FWHM pixels, that is ∼2″. We have looked at the Solar Y dimensions of some of the small features in the raster and found a range of sizes of 2.5″– 4 ″, with the smaller fit 2.5±1.42 pixels (H.P. Warren, private communication).

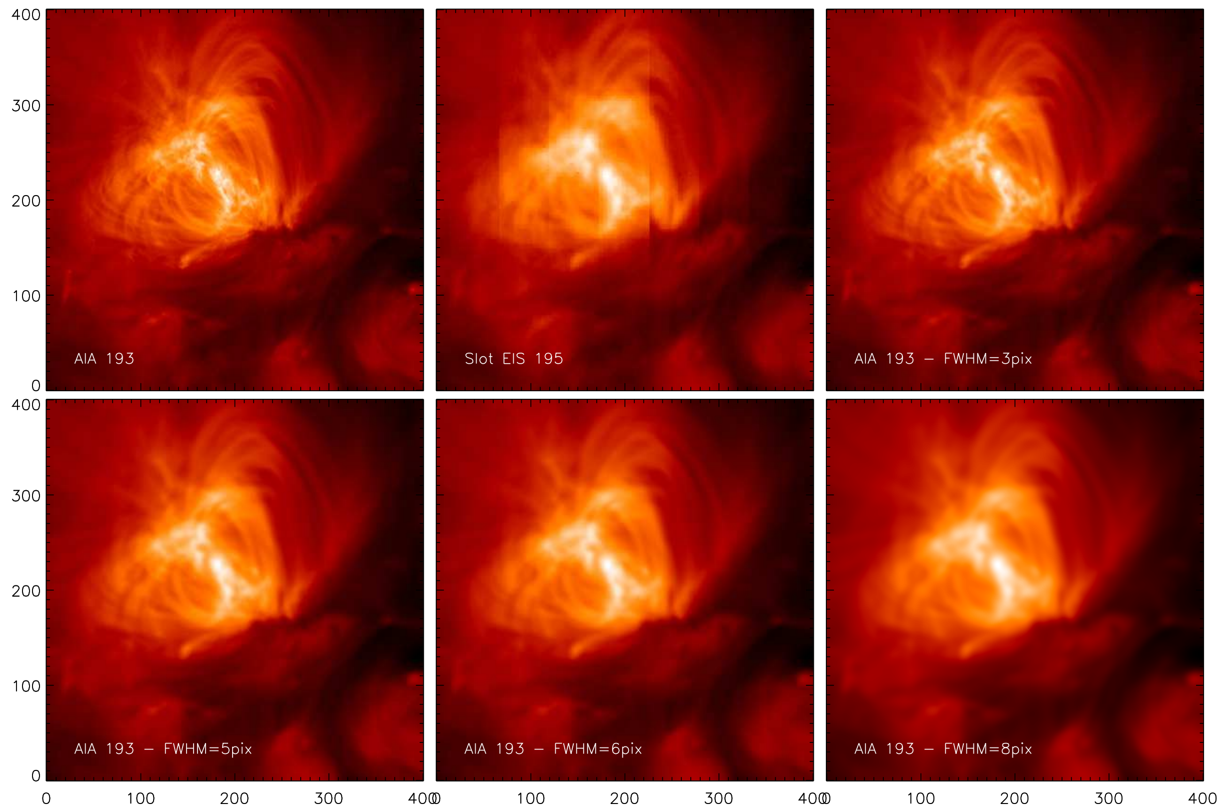

Figure 3: Comparison of an EIS slot raster (`eis_l0_20100618_111034`) in 195.119 Å to an AIA 193 Å image convolved with different Gaussian PSF values.

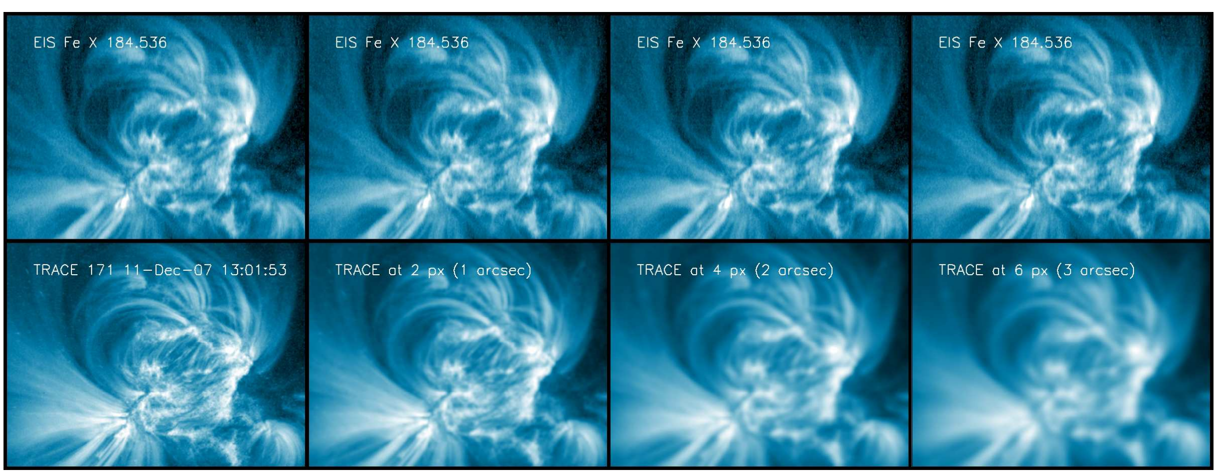

Figure 4: Comparison of an EIS Fe X 184.5 Å raster (`eis_l0_20071211_102542`)to a TRACE 171 Å image convolved with different PSF values.

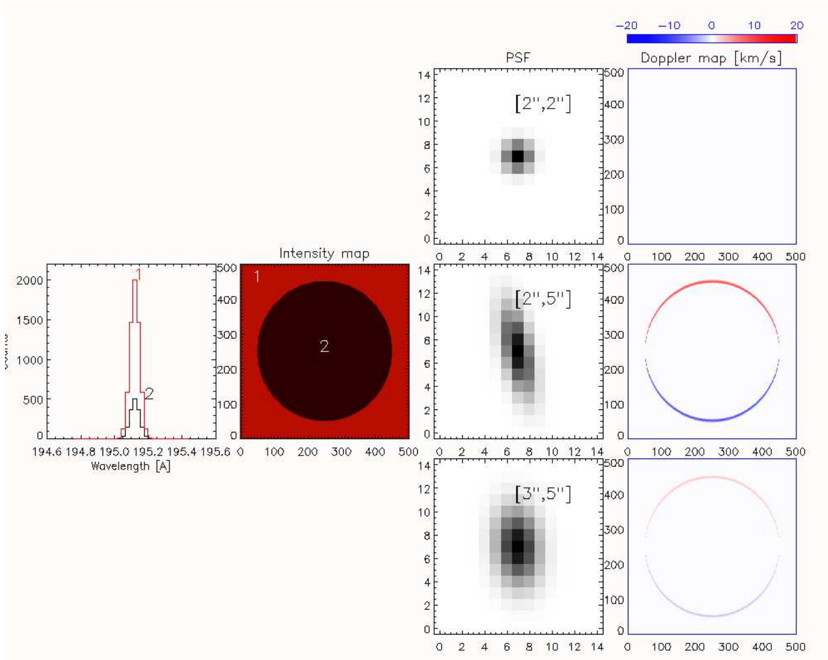

Figure 5: Simulation of the effect of an elliptical PSF to the Doppler shift measurement in the 195.119 Å line. From left to right: spectral profiles for the two different source regions, intensity map at peak spectral intensity, PSF used in the convolution and Doppler map after single Gaussian fit to the line profiles.

5 Asymmetry

As discussed in Section 3, it is possible that the EIS PSF is asymmetric. Figure 1 shows that an asymmetric 2D Gaussian can fit the spatial distribution of the intensity of a point source candidate. In that particular example, we find some degree of inclination. This is relevant because an inclination in the elliptical spot image formed on the detector can lead to systematic Doppler shift signatures. The slot data, nevertheless, needs to be treated with care because the image on the detector mixes spatial and spectral information. Any flows on the source can broaden the image in the spectral direction. A bi-directional flow could produce an inclination on the detector if the red and blue components of the flow are at different Y-positions.

There are, however, other indications for an elliptical PSF from narrow slit scans. Appendix B in Young et al. (2012) discusses "Offsets between intensity and velocity structures in EIS data" and argues that an elliptical inclined PSF would explain characteristic Doppler signatures in certain EIS datasets. In particular, regions with strong gradients such as the solar limb or coronal bright points within a coronal hole. The effect of an elliptical and inclined PSF is simulated in Figure 5. It shows the effect for a disk surrounded by brighter emission, analogue to the observation of a coronal hole against the limb brightening in a coronal line. The source consists of two regions (1 and 2) with two characteristic spectral profiles (left panel in the figure). In the experiment, we convolve their signal with a symmetric ($2'' \times 2''$) and an asymmetric inclined ($2'' \times 5''$) Gaussian profile. We also include a case that is very similar to the PSF numbers found earlier in the fit to a transition region brightening. After the convolution, we fit the spectra of every pixel with a single Gaussian profile and display the Doppler shift displacements. The figure demonstrates that an inclined PSF can introduce systematic features at reasonable velocity amplitudes where there are gradients. The redshifted rim at the North pole limb has been reported by Tian et al. (2010) from an EIS raster. We have found this feature in other datasets, but we should note that it is not present in every EIS raster of the poles.

6 Conclusion

The current preliminary analysis of EIS data is consistent with a PSF with a FWHM of $\sim$3 pixels ($3''$). There are indications that the PSF may be elliptical in shape and inclined with respect to the slit. Users are encouraged to look for the effect in their data and report their findings to the EIS team.

References

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