Overview of EIS Performance

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Abstract. The Hinode EUV Imaging Spectrometer (EIS) is a high-sensitivity spectrometer to observe the solar transition region and corona in two extreme-ultraviolet wavelength bands of 166-211 and 245-291 Å. Hinode was successfully launched on 2006 Sep 23 06:36 JST and EIS has produced high-quality EUV spectra since the First Light Operation on 2006 Oct 28. We report the on-orbit EIS performance after the launch in this short paper.

1. Introduction

EIS was first proposed by T. Watanabe in 1993 during a meeting for the future Japanese solar spacecraft mission, SOLAR-B, after Yohkoh (SOLAR-A). The first proposed SOLAR-B mission payloads consisted of an optical telescope that can resolve magnetic elements on the photosphere and a coronal imager with a higher spatial resolution than Yohkoh soft X-ray telescope. The proposed EUV spectrometer was a 4 m long three-reflection spectrometer that observed an EUV wavelength band of 250–290 Å and did not have a scanning mechanism. The uniqueness of the spectrometer was to cover the temperature range of 4.7 to 7.3 in Log T with a single CCD detector. From the throughput estimation for typical targets on the Sun, and from the consideration of the EUV instrument performance on the Solar and Heliospheric Observatory (SOHO), the spectrometer design was modified into a two-reflection system with a scanning primary mirror when the proposal to ISAS was prepared in 1995. By reducing the number of reflections into two an order of magnitude improvement in effective area was expected. The instrument has been realized by the international participation of UK and US institutes that have extensive heritage in EUV instrumentation and calibration. The EIS development team has been led by UCL’s Mullard Space Science Laboratory in the UK with a major contribution from the Naval Research Laboratory in the US. Eight institutes from four countries (Japan, UK, US, and Norway) were finally involved in the EIS development. The EIS overall instrumental description is summarized in Culhane et al. (2007). In this short paper we briefly report the EIS on-orbit performance.

2. EIS Optics and Pre-flight Performance

The optical layout of EIS is shown in Figure 1. The spectrometer has two spectral bands in the extreme-ultraviolet range, 166.3–211.9 Å and 245.8–291.4 Å according to the laboratory calibration (Lang et al. 2006). The telescope consists of a single offset parabola as a primary mirror and the EUV image of
the Sun on the focal plane is diffracted and refocused on two back-illuminated CCDs with a toroidal concave grating. Both primary mirror and grating surfaces are segmented into two semi-lunar surfaces and each segment is coated with an optimized multilayer coating of Mo/Si for each EIS band. A thin 1500 Å Al filter stops the transmission of visible radiation from the Sun at the entrance section in the spectrometer. A redundant Al filter of the same thickness is placed near the focal plane for accidental failures of the pre-filters. Four types of slits are available at the focal plane of the primary mirror and each has a different width: 1″, 2″, 40″, and 266″. These slits are parallel to the solar north-south direction. The former two are used for the line profile spectroscopy and the latter two are for velocity-convolved imaging observations. A rotating shutter controls exposure durations. Raster scanning capability is achieved by rotating the primary mirror with a piezoelectric drive. A lateral movement of the primary mirror by a stepper motor provides the change of the EIS field of view in an east-west direction. The spectral resolution of EIS before the launch was measured in a laboratory experiment and the full width at half maximum of line profiles was 47 (58) mÅ at 187 (268) Å in the EIS short (long) wavelength band (Korendyke et al. 2006). The left panel of Figure 2 shows the final configuration of EIS before installing the rocket fairing and the right panel illustrates the on-orbit configuration of Hinode.

3. Launch to EIS Start-up Operation

SOLAR-B (Kosugi et al. 2007) was launched on 2006 Sep 23 at 6:36 JST and the spacecraft was renamed Hinode (sunrise) by the late Professor Kosugi just after the success of the launch. EIS was launched such that the slit of 1″ width was set on the focal plane with the open position for the shutter. The EIS survival heaters, which are set near the optical components, were turned on 135 min after the launch. During the orbit control for entering a Sun synchronous polar orbit, EIS was in the survival mode, in which the survival heaters near the optics were only working in the spectrometer and the temperatures of the spectrometer was about -20 deg C. The EIS Instrument Control Unit (ICU) was turned on on
2006 Oct 16 and the instrument checkout was performed by Oct 21 in a limited number of real-time uplink contacts. Following two door deployment operations at the end of 2006 Oct, the EIS First Light operation was immediately executed on 2006 Oct 28. The checkout of mechanisms was completed after the First Light Operations. Everything was perfect in the EIS startup operation.

Figure 2. Left: The final configuration of the SOLAR-B spacecraft just before installing the rocket fairing to the 3rd stage rocket and Right: artist’s illustration of on-orbit spacecraft configuration.

4. On-Orbit Performance in Commissioning/Initial Observations

Figure 3 shows solar EUV spectra observed with the 1″ width slit that are mapped to a whole CCD area covering 1024″ along the slit. When wide slits are used, velocity-convolved images are mapped on to the CCDs as shown in Figure 4. This type of observation utilizing all CCD areas is only possible in an engineering sequence at this time, and the observing area within the central 512″ spatial part can be selected by the EIS planning software. The baseline telemetry allocation to EIS is about 50 kbps average and it can be changed by a decision of the Hinode operation team. Since the data volume of whole CCD pixel area is huge, small-size rectangular spectral windows are normally used to reduce the telemetry to the ground. Up to 25 spectral windows are available. The data compression is used to reduce the data volume further. Although the efficiency of compression depends on the amount of information in the data, the EIS spectra are reduced to 35–40% by DPCM loss-less compression and to 13–18 % by JPEG Q = 95 lossy compression.

2-D information is obtained when the EIS scanning mechanism is used. The top panels in Figure 5 show assembled EIS raster scan data of each line intensity with 1″ width slit and 1″ scanning step. The same region was observed with SOHO CDS. The CDS raster scanning data are shown in the bottom panels of Figure 5 for comparison with the EIS imaging performance. It is found that 2″–3″ imaging performance is provided in EIS raster scan observations.

The on-orbit wavelength determination of EIS has been reported in Brown et al. (2007). EIS in orbit is observing the Sun in 166–211 and 245–291 Å with a dispersion of 0.0223 Å per CCD pixel. Spectral lines on the CCD are tilted to the vertical direction of the CCD. This implies that the absolute wavelength slightly changes along the spatial direction in the raw data.
Figure 3. Solar EUV spectra in EIS (a) short and (b) long wavelength bands with 1″ width slit obtained on 2006 Nov 4 at 11 UT. (c), (d): Average count rate in an active region (AR10921). (e), (f): Close-up of panels (c) and (d) to display line profiles.

Figure 4. Solar EUV images in two EIS wavelength bands with (a), (b) 266″ width slit and (c), (d) 40″ width slit. These were obtained as a part of the EIS First Light on 2006 Oct 28.
Figure 5. (Top) Raster scanning images of an active region from EIS and (Bottom) those from SOHO CDS.

Figure 6. (Left) Spatially averaged line centre positions as a function of scanning position (= time) showing the artifact in Doppler signal. (Right) Seasonal variation of the spacecraft Doppler velocity to the Sun. These need to be taken out for the EIS Doppler measurements.

As reported in Brown et al. (2007) the observed line centre oscillates in phase with an orbital period of the Sun-synchronous polar orbit. The amplitude of line-centre travel is 1–2 pixels, (left panel in Figure 6) probably due to thermal distortion of the spectrometer. The origin of the oscillating line centre also gradually drifts depending on the spacecraft pointing and depending on the season. The Hinode spacecraft has a Doppler velocity relative to the Sun in its orbital motion, and the relative speed to the Sun changes during the year as shown in the right panel of Figure 6. These effects, tilt of spectral lines, line
centre oscillation in an orbital period, gradual line centre drift, and spacecraft Doppler shift, need to be considered in EIS Doppler measurements.

The line width appears to be slightly broader (10–40 % level increase) than that of the laboratory calibration when temperatures of the peak contribution function of each emission line and nonthermal component in previous measurements are assumed. It is also a function of vertical position on the CCD. The instrumental width in orbit is being investigated by the author through comparison of line widths of visible coronal emission lines that were simultaneously observed at Norikura Solar Observatory of NAOJ.

The angular size of the EIS CCD pixel was calibrated for the Mercury transit that occurred on 2006 Nov 8. The travel path length of Mercury was short in the EIS wide slit observation and the accuracy of the measurement was not good. The estimated pixel scale is $1.002\pm0.016''$ per pixel and is consistent with the expected value of $0.997''$ per pixel that is determined from the focal length of the primary mirror and concave grating. A better value will be obtained from the alignment with other EUV images of a known plate scale. The scanning mirror step is calibrated by aligning the wide slit images of an active region that were obtained in a number of repetitive motions of the scanning mirror back and forth. The adopted value for the scanning step is $0.1201''\pm0.0005''$ rotation per step. For $1''$ width slit 4 steps are normally used for the continuous scanning. It corresponds to $0.961''\pm0.004''$ scanning steps on the Sun. This step size needs to be considered when the EIS raster scan data are aligned with other data.

5. EIS Data Analysis

The EIS data have been opened to everybody since 2007 May 27. The EIS data in FITS format of binary extension are obtained via Hinode data centres over the world. The site of data centre at ISAS/JAXA is http://darts.isas.jaxa.jp/solar/hinode/query/top.do. Fundamental software for EIS data analysis is available in Solar Software (SSW). The software is coded in an object-oriented scheme. Some calibration items are still under way. The information for the EIS data analysis is provided at http://msslxr.mssl.ucl.ac.uk:8080/SolarB/SoftGuides.jsp.

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References