Using Solar-B EIS – lessons from SOHO/CDS

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1. Introduction

CDS and EIS share many similarities, both being EUV imaging spectrometers with similar data formats and software. Telemetry restrictions for both instruments lead to spectral windowing being an important observation constraint, and analysis issues such as cosmic rays and velocity measurement are common. Here some of the experiences learnt from almost 10 years of observations with CDS are presented and their relevance to EIS discussed. In addition, methods of coordinating EIS and CDS are presented, and the benefits of using both instruments together highlighted.

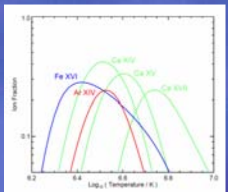


FIGURE 1. Ion fractions for Ar and Ca ions observed by EIS demonstrating that they probe a temperature regime not accessible with the Fe ions. The Ar/Ca ratio will allow the study of the FIP effect in the active corona, while Ar XIV has a density diagnostic in the EIS range.

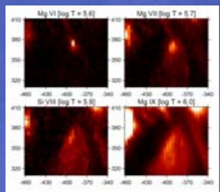


FIGURE 2. CDS images of a fan-shaped coronal loop structure seen in 4 different emission lines. The cool Mg VI and Mg VII ions reveal the loop footpoint. Lines from these ions will also be available to EIS.

2. Designing EIS Studies

The basic observation for EIS will be a *study*, which essentially defines the size of the observation raster and the particular emission lines to be observed. The EIS data rate will not be sufficient to obtain complete EIS spectra at an arbitrary cadence, and so it is necessary to pre-select the emission lines that need to be observed.

2a. Optimising studies

Unlike CDS, the EIS data rate is not fixed and will depend on the other instruments' observing plans. However, it will be convenient to assume a fixed data rate throughout the day on most occasions and so analogies with CDS are applicable.

The key trade-offs that will have to be made are cadence vs. number of spectral lines and/or spatial coverage. CDS studies can be split into 3 basic types:

A. Context raster. Large spatial area with a few strong lines.
B. Diagnostic raster. Small area raster with a large number of lines suitable for detailed plasma diagnostics.
C. Dynamic raster. Small area raster (or sit-and-stare) with a few lines allowing highest possible cadence.

These studies are then combined in sequences usually with the context raster bookending repeats of either of the other types, e.g., ABBBBA, or ACCCA.

A key aim when designing a study it to optimise it to use up as much of the available data rate as possible. When the raster size and exposure time have been decided (based on the type of region to be observed), the number of spectral lines can be set to yield the best possible data rate. *The more lines there are, the more spectroscopy can be done!*

2b. Do not ignore weak emission lines!

A temptation when designing studies is to focus on the strongest lines, but a lot of interesting science is available from other lines. For example, lines of argon, calcium and sulphur are formed at similar temperatures to the strong iron lines, but are generally weaker (e.g., Fig. 1). They are, however, valuable for studies of element abundances (the FIP effect) and they also provide density diagnostics at temperatures not available to the iron ions, such as Ar XIV λ188.0/λ194.4.

EIS covers only a few weak transition region lines, but these will be valuable in certain conditions as can be illustrated from CDS data. Fig. 2 shows CDS images of a coronal loop structure where the footpoint is clearly highlighted in weak emission lines of Mg VI and Mg VII. EIS also sees lines from these ions, and additionally Mg V and Fe VIII.

3. Emission Line Blending

Unexpected line blending can lead to erroneous results. E.g., with CDS large blueshifts in the Fe XVI λ335.40 line were thought to be seen in early data, but they turned out to be due to blending with the weak Mg VIII λ335.25 line in regions with little Fe XVI emission (Fig. 3). Most CDS studies switched to using the unblended but weaker Fe XVI λ360.78 line following this discovery.

If unusual line properties are seen with EIS, CHIANTI synthetic spectra or EIS spectra in different conditions should be consulted for evidence of blending.

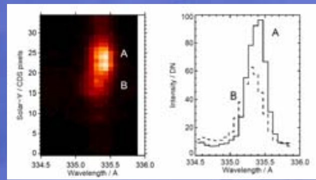
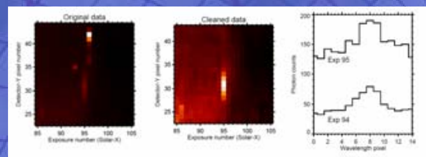


FIGURE 3. Example of a 'false' velocity shift caused by line blending. The left-hand panel shows an individual exposure from CDS in the Fe XVI λ335.40 line, with an apparent blueshift at position B, compared to A. The right-hand panel shows the spectra from these two regions, with a shift of around 0.1 Å (90 km/s) between the two profiles. However the shift is actually caused by a blend with Mg VIII λ335.25 which dominates in cooler regions.

4. Cosmic Rays

These are a common feature of CDS data with around 5 cosmic rays (CRs) appearing on the detector per second. CRs are a more significant analysis problem for spectroscopic data compared to imaging data as they distort line profiles, thus affecting velocity or width measurements. A CR removal method employed for CDS (cds_new_spike) makes use of the full 3D data array (X,Y,λ) to only identify CRs if they are flagged by a median filter applied to individual exposures *and* if the CR is not present in consecutive exposures. Fig. 5 shows one case where cds_new_spike successfully removes real CRs, but leaves behind a genuine small brightening in the data.

FIGURE 5.The left panel shows a sub-image from a CDS raster, with cosmic rays visible. The middle panel shows the image again, but with the CRs removed. The brightening near the middle of the image, however, is real as demonstrated in the spectra in the right panel, where the brightening is seen to be due to a strongly enhanced continuum.



5. Velocity Analysis

Neither CDS or EIS have an onboard wavelength calibration lamp, so the wavelength scale can only be fixed using the measured solar spectra. A common method with CDS is to average spectra over the whole raster and assume this sets the zero point.

CDS is at the L1 point with a constant illumination from the Sun, and so the wavelength scale is very stable with time. However variations in the optical bench temperature in the early phase of the mission led to shifts in the average centroids of emission lines (Fig. 6).

EIS is in a Sun-synchronous orbit with varying illumination from the Earth, and it will be important to monitor average properties of strong emission line profiles on orbital timescales (100 mins) as well as over longer periods (days, months).

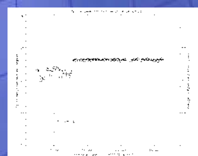


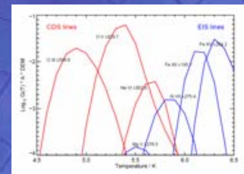
FIGURE 6. An illustration of thermal effects affecting wavelength calibration. Here the average centroid of the O V λ629.7 line is shown over a 50 day period, revealing the dependence on the optical bench temperature.

6. Intensity Calibration

An accurate intensity calibration was not available in the early months of the CDS mission, but a *relative* intensity calibration curve was derived in a straightforward manner by studying line ratios that are insensitive to the plasma conditions. This will be a valuable method for confirming the laboratory calibration of EIS in orbit.

CDS itself has been well-calibrated using both pre-launch lab data and post-launch comparison with SUMER and rocket spectra. There is direct overlap in wavelength coverage between EIS and CDS and so joint calibration observations on monthly timescales would be valuable for confirming the EIS calibration.

FIGURE 7.Contribution functions, G(T), multiplied by abundances and active region DEM values for seven key emission lines observed by SOHO/CDS and Solar-B/EIS, demonstrating the improved transition region coverage offered by CDS.



Combining EIS and CDS Observations

1. Contribution of CDS to EIS Science

The key contribution CDS can make to EIS is the ability to observe several strong transition region lines formed over the range 5.0 ≤ log T ≤ 5.8, where EIS has limited sensitivity. In particular the O V λ629.7 (log T = 5.4) is a very strong line that has been widely used in studies of transient events. Figure 7 demonstrates the relative strengths of key EIS and CDS lines as a function of temperature. Transition region lines are valuable for tracing energy flow between the photosphere (observed by SOT) and the corona (observed by XRT & EIS). Co-aligning CDS and EIS data can be performed by using coronal lines, e.g., Mg X λ624.94 with Fe XII λ195.12, or Si XII λ520.67 with Fe XV λ284.16.

2. Modes of Operation

There are 3 modes of operation for both EIS and CDS

A. raster over a spatial region using a narrow slit
B. keep the slit fixed, and perform repeated exposures at a fixed location (sit-and-stare)
C. use a wide slit (slot) to obtain monochromatic images at a fixed spatial location at high cadence

Mode A is the most common for CDS, and probably also with EIS. However both instruments operating in this mode may not be the best way of utilising the two spectrometers together as their slits will rarely observe the same location at the same time. A better use, particularly for studying dynamic phenomena, could be the following:

Either, CDS should perform sit-and-stare studies, while EIS performs spatial rasters. *Or*, EIS perform sit-and-stare studies while CDS rasters.

This way the spatially-limited, but high time cadence sit-and-stare data can be put in context with dynamics in a larger surrounding region.

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