Doing science with IRIS - experience learned from Hinode/EIS

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Abstract

IRIS will be the fourth in a sequence of solar ultraviolet spectrometers, following on from CDS and SUMER on SOHO and Hinode/EIS. The experience gained from these missions will be valuable for ensuring that high quality science results emerge from IRIS right from the beginning of the mission. This presentation will summarize the experience gained from over five years of Hinode/EIS operations and science, and identify where that experience may benefit the IRIS team. EIS and IRIS combined give superb coverage of all layers of the solar atmosphere, and excellent science can be expected from using both instruments.

1. Instrument Comparison

EIS and IRIS are similar in that they principally return 2D exposures with spatial information along one axis and wavelength along the other, with 2D images built up through rastering (Figure 1). The instrument designs, however, are quite different.

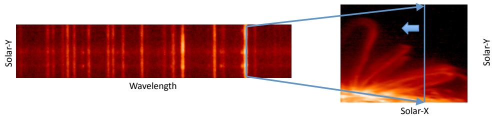

Figure 1: illustration of how rastering works. Consecutive slit images from individual exposures (left) are combined to yield a 2D image by stepping the slit across the Sun.

EIS is a relatively simple instrument - a fact necessitated by the low number of photons in the EUV - with only a single mirror. By contrast the IRIS spectrometers make use of five different mirrors in each channel. The table below compares properties of the instruments.

Component	EIS	IRIS
Telescope	Off-axis parabola	Cassegrain (primary & secondary mirrors)
Slit	Rectangular hole	Aluminium mask placed on a prism
Spectrometer	Single grating	Grating and three mirrors
Detectors	Back-thinned CCDs	Back-thinned CCDs

2. Technical Issues

Interpretation of modern solar UV spectrometer data can be strongly influenced by technical issues related to the optical components of the instrument, and even the satellite itself. The high quality and sensitivity of current generation optical components actually makes these technical issues *more* apparent in the data, but also allows them to be taken care of through software fixes.

A number of examples were found for EIS and are summarized in the table below. Examples are also shown in Figures 3 and 4. Similar instrumental effects may be found for IRIS.

Problem	Effect	Solution	Problem for IRIS?
Mis-alignment between slit and grating (grating tilt)	Dispersion direction is not perpendicular to slit direction (Figure 3).	Use compact spatial feature observed at different wavelengths to measure spectrum tilt on detector.	Likely
Mis-alignment between slit and detector (slit tilt)	Slit image is found to be tilted on detector (Figure 3).	Measure line centroid as function of slit position averaged over time (above limb quiet Sun?).	Likely
Thermal effect: grating wobble	Spectrum oscillates in the dispersion direction by 10's of km/s.	Measure average line centroid (along slit) as a function of time.	Unlikely
CCD spatial offset in Y direction	Spatial features in different detectors are offset in Y direction.	Use lines from different CCDs that are formed at similar temperatures to align detector images.	Likely
Distorted PSF	Can lead to false Doppler shifts (Figure 4).	Check Doppler velocities near compact bright points – are there systematic velocity patterns?	Likely
Satellite jitter	Pointings may not be reproducible: "wobbly" raster movies.	None.	Possibly (due to polar orbit)

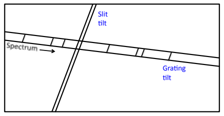

Figure 2: Schematic showing how the spectrum on the detector is affected by slit tilt and grating tilt.

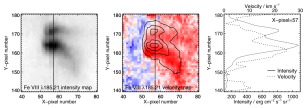

Figure 3: Example from EIS showing how a distorted PSF can introduce false Doppler shifts. Two bright loop footpoints (left panel) show redshifts (middle), but the Y-positions of the redshifts are offset from the intensity peaks.

3. Observing Constraints

Data rate

An individual EIS exposure generates about 9 Mbits of data and, given an average daily data allocation of 700 Mbits, this means only a small fraction of the spectral and spatial information is usually downloaded. Generally this means that only 5-20 spectral lines are observed rather than the entire spectrum.

The IRIS data rate is planned to be much higher than that for EIS (700 kbits/s compared to 8 kbits/s), but the shorter exposure times (1-2 s compared to 30-60 s) and higher spatial resolution (0.3" compared to 2-3") mean IRIS observers will need to make similar compromises. The best observing sequences thus need a careful balance between the number of lines to observe, field-of-view selection, exposure time and cadence.

Cadence

The small field-of-view afforded by a narrow observing slit means that time resolution is often a problem for spectrometers. IRIS has a cadence of at best 0.5 s compared to 2 s for EIS, but the narrower slit of 0.3" compared to 1" will slow down IRIS when rastering the same area.

Observing methods employed by EIS users to improve raster cadence and data usage include

- Sparse rasters (step size is larger than slit width).
- Sit-and-stare rasters (fixed position).
- Event triggers, whereby a high cadence raster sequence is triggered by a brightening (e.g., flare).

Context imaging

For dynamic phenomena, placing a narrow slit image in the context of the surrounding structures of the observing region can be difficult. For EIS, *context rasters* have been important. These are large area, quick rasters obtained with the EIS slot (40" slit) prior to the smaller field-of-view narrow slit rasters. The launch of AIA has also been extremely valuable, with guaranteed high cadence images in several filters.

IRIS has a fixed slit size, and so context rasters are not possible. It does have a separate slit-jaw camera, however, which will obtain images simultaneous with the spectroscopic data. The camera will not be able to take images in the hotter lines, however, (Si IV, O IV, Fe XII, Fe XXI) and so AIA images will be important for placing these lines in context.

4. Communication With Users: Documentation

The complexity of spectroscopic data, coupled with the potential technical issues described in Section 2, mean that it is crucial for the success of a spectroscopic mission to provide good communications and documentation for the user community.

Different approaches were attempted with the SOHO/CDS and Hinode/EIS instrument, and five examples are given in the table below.

Type	Explanation	Comments
Mailing list	Can be used for team announcements and also for users to submit questions.	Quickest form of communication between team and users; risk of e-mail overload.
Analysis Guide	A single document that describes the data and software.	Usually the responsibility of one individual so updates may not be regular.
Software Notes	Documents focused on individual components of data and software.	Can be maintained by the appropriate experts on the team.
Wiki	A web-page that is editable by the team and users.	Can be kept up-to-date easily; results may be chaotic.
Tutorial	A step-by-step guide for basic analysis procedures.	A good starting point for beginners.

For SOHO/CDS, the instrument team prepared many "Software Notes" describing different features of the instrument, the software and data. For Hinode/EIS, the team set up a wiki to which anybody could contribute. The aim was for EIS users to submit data analysis questions that would be answered by team members, and for team members to submit information about EIS that they felt was appropriate for users.

The wiki was successful in the first year or two of the EIS mission, but non-team member questions tailed off after this period. After four years, much of the accumulated information relating to the instrument and data analysis methods were formally written up as EIS Software Notes and distributed through Solarsoft.

A data analysis guide and tutorials are still available on the wiki, however, and the wiki format makes these documents easy to modify by any member of the team.

Recommendation: a web-based wiki is valuable for communicating to the user community, especially for "fast-changing" information in the early days of the mission. More formal "Software Notes" are valuable for providing authoritative information on well-established features of the instrument or data.

5. Combining EIS and IRIS Observations

EIS and IRIS combined give superb coverage of all layers of the solar atmosphere, and excellent science can be expected from using both instruments. This section gives information about coordination and diagnostic opportunities.

Coordination

IRIS is expected to observe the Sun 24 hours/day, while EIS typically can only observe for about 4-8 hours each day. Therefore serendipitous joint observations will be uncommon. Campaigns (HOPs) are the recommended route for scientists to meet specific science objectives. An important aspect will be for the EIS Chief Observer and the IRIS operations scientist to communicate with each other in terms of pointing, timing and types of study.

Co-alignment

The two instruments can be directly co-aligned by using the Fe XII λ1349 (IRIS) and Fe XII λ195 (EIS) emission lines which should show the same spatial features.

The situation is complicated by the fact that the spatial scales are mis-matched (1" for EIS compared to 0.3" for IRIS) and both instruments will likely be rastering, leading to time-dependent effects. The best option may thus be to co-align the images against AIA.

Diagnostic opportunities

The table below gives example IRIS and EIS line lists that, when combined, give almost complete coverage from the photosphere to the flaring corona, and also include three density diagnostic pairs at different temperatures.

IRIS		EIS	
Line	Log (T/K)	Line	Log (T/K)
O I λ1355.6	3.8	O IV λ279.93	5.2
C II λ1334.5	4.3	Mg VII λ278.39, λ280.72	5.8
Si IV λ1393.8	4.8	Fe XI λ256.92	6.1
O IV λ1399.78, λ1401.16	5.2	Fe XIV λ274.20, λ264.79	6.3
Fe XII λ1349.4	6.2	Fe XVI λ262.99	6.4
Fe XXI λ1354.1	7.0	Fe XVII λ254.85	6.7
		Fe XXIII λ263.78	7.1
		Fe XXIV λ255.11	7.2

Two unique diagnostics are available from O IV and Fe XII and are shown in Figure 4. Both are strongly temperature sensitive; O IV λ279.93/λ1401.16 has little density sensitivity, but Fe XII λ195.12/λ1349.40 has some density sensitivity. Fe XII has excellent density diagnostics in the EIS bandpasses and so the density can be independently determined.

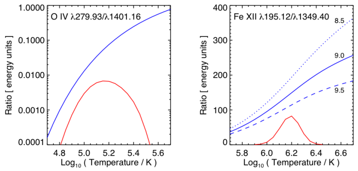

Figure 4: Theoretical variation of two diagnostic ratios of O IV and Fe XII, obtained from CHIANTI 6. The blue lines show the ratio curves, the red lines show the ionization fraction curves of the two ions. For each blue line in the Fe XII plot the logarithm of the density is indicated.