SOLAR-B EIS - The case for two CCDs

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This paper explores the case for two CCD detectors in the Solar-B EUV Imaging Spectrometer (EIS).

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The Scientific Advantages for two detectors are detailed, followed by an exploration of the technical issues involved, including cost and risk. This is followed by a detailed description of the relationship between cost and quality for the EEV's CCDs.

There then follows an argument, based on misalignment build up, for having 1024-pixel CCDs (as opposed to the baseline 512). This requirement is under trade-off study. Other ways of mitigating the problem could potentially be found which do not impact the CCD choice in the same way.

Scientific Advantages of two CCDs

The UK-US-Japan EIS teams have carried out comprehensive science studies on the technically feasible wavelength ranges (http://www.mssl.ucl.ac.uk/Solar-B/doclist.html). Following this it was recognised that having only one wavelength range reduced the quality of the science return substantially (e.g. if the flare lines are not strong, then it is impossible to study flare initialisation which is one of the goals of solar-B). Consequently, it was decided that it is necessary to have two wavelength ranges (SW 170-210 Å and LW 240-290 Å). An investigation was made into the feasibility of locating these two wavelength ranges on one CCD, or of providing a two gratings focussed on to a single detector. It was confirmed that the former would lead to unacceptable confusion of the spectral profiles and that the latter would be unacceptably costly and risk-prone for our partners at NRL.

 In order to achieve the two wavelength ranges and the highest quality science, it is vital to have two CCDs.

The scientific basis for the two wavelength ranges is described below:

SW (170-210 Å)

1) Strong flare lines: one of the main scientific goals for solar B is searching for reconnection inflow and outflow. In order to do this, it will be necessary to have very strong high temperature lines (e.g. Fe XXII, Fe XXIII, and Fe XXIV). These Fe lines are available in the SW range.

2) Diagnostics: The SW range has a wide range of good density diagnostics covering from Log Ne=8-12, but a limited temperature coverage.

LW (240-290 Å)

1) Co-alignment: aligning the datasets from the three instruments onboard solar B is crucial for obtaining maximum science output. As with the Yohkoh spacecraft, the solar B instruments will work together as an observatory, with all instrument team having access to

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all other datasets. For coalignment purposes, it is necessary to have a chromospheric emission line. In the LW range there is a strong He II emission line, which can be coaligned with the white light emission from XRT and the SOT.

2) Diagnostics: The LW range has a wide range of temperature lines from Log T=4.7 to 6.4, but a limited density coverage.

Both ranges

Each wavelength range has its own particular strengths. Using both ranges together is vital in order to obtain good coalignment, alongwith strong flare emission lines. Two important factors for using both wavelength ranges are detailed below;

1) Flare trigger: As stated before, understanding flares is an important scientific aim of the mission. In order to ensure that EIS is pointing at the flaring region, we intend to develop a flare trigger. It is important to use a diagnostic that triggers the instrument as early in the event as possible. To do this, we will use the Fe XXIV lines (there are two strong lines - one in each wavelength range). The emission from Fe XXIV starts to increase before the flare proper begins. Also, it is important to correlate increases in intensity between the two wavelength ranges to avoid false flare flags.

2) With the wide range of temperature and density measurements that will be available from using both wavelength ranges simultaneously, a detailed understanding of the temperature and density structure of flares, active regions and quiet Sun will be possible. This is pivotal in enabling us to understand the physical processes operating in all of these regions.

Technical Issues

For each option, we consider:

- Feasibility / Complexity

- Risk

- Power constraints

- Cadence

- Cost

1. Baseline option – One CCD

- The limiting size factor is probably fitting the electronics onto the FPA. Size of the FPA should be ~ 160mm x 80mm x 3mm, plus camera box of ~ 166m x 86mm x 110mm (overall thickness 3mm) - could this give a problem to match onto the telescope structure ?

- Complex, but still the simplest option. Main problem is likely to be the reproducibility of the CCD mounting and attaching to the telescope stucture in such a way that it is easy to maintain.

- Lowest risk. Ensuring repeatability of the CCD mounting accuracy is the highest risk and slightly unknown at the moment until tolerances for the optics are established.

- Total power ~ 200mW depending on cadence rate. Small compared to potential Read Out Electronics power consumption (up to 5W)

- 0.6s to readout a "typical" spectrum @ 100khz - readout noise ~ 3e- rms. No of data bits ~ 330k

- Baseline option

2. Two CCDs but sharing the same FPA electronics

- Based around option 1 design. The size of the camera may be driven by the need to mount two CCDs. However, as the size was previously constrained by fitting the electronics onto the FPA, it is possible that the increase in size due to the two CCDs will still not exceed the original design

- Design basically identical to option 1, but added complexity in validating mounting accuracy for two CCDs

- Similar to one CCD but requirements to accurately mount two CCDs could lead to increased development time

- If CCD readouts are multiplexed, then power remains @ ~200mw

- Multiplexing CCDs doubles readout time to 1.2s and doubles total number of bits to about 660k for a "typical" spectrum

- Potential new requirements of : 4 FMs, 3 EMs and 4 mock ups. The increase in number of detectors must be traded off against other factors. Likely that CCD grade may have more single pixel blemishes. If there is a lot of difficulty in ensuring CCD mounting reproducibility, then CCD detector scientist costs could increase by a months additional work or so..

3. Two CCDs with separate electronics

- Essentially no real difference but two separate electronics packages could increase the FPA size to about 160mm x 140mm x 3mm, with the camera "box" about 166mm x146mm x 110mm

- Similar risk to option 2

- On-chip power consumption could be doubled to ~400mw - still small compared with the potential consumption of the ROE

- Read out time ~0.6s for each CCD for 100khz readout rate. Typical number of bits ~ 660k to be downloaded)

- As option 2

Costs of two devices

A number of items will contribute to the overall procurement cost of the CCD (in no particular order):

1. number of CCDs procured;

2. the size of each CCD;

3. the cosmetic yield required (i.e the number of defects and blemishes on the CCD);

4. quality control tests - characterisation of the device. A minimum number of quality control tests must be performed to ensure the device is to the agreed quality. There are a range of tests which can be performed, depending on the extent to which documented performance from EEV is necessary.

The original Rough order of Magnitude quote obtained from EEV (in July 1997) assumed that there would only be one detector at the focal plane. Nevertheless, we have been assured by EEV that it will still be possible to produce the increased number of flight models that we will require, still within the original budget.

However, to remain within the original budget we must be willing to trade off the increase occurring in item 1 with reduced expenditure in items 3-4.

Consequently, we may have to reduce the cosmetic yield for the final flight models. Thus, whilst we would still aim to achieve no column defects (in which a complete line of data is lost) we would have to tolerate an increase in "hot" pixels (for example, from 50 per device to 200 per device). This is the main trade off we are likely to have to adopt.

A second trade off is to reduce the level of testing performed by EEV to support the characterisation of the device (of course, there is a minimum of testing that EEV would always perform to ensure the devices were of sufficient quality).

Thus, the main issues are:

- cost - there should be no increased cost in adopting two CCDs per focal plane;

- risk - there will be a slight reduction in the yield quality of the devices, and hence the image quality. Such a reduction would not seriously compromise the quality of the science available, it would however degrade it to a certain extent.

  The trade-off allowable for this item will be quantified by simulating images of varying cosmetic quality and examining the scientific impacts of slightly lower quality images. In addition, the scope of characterisation of the devices will not be so extensive at EEV, requiring more time to be spent at MSSL. However, this additional work is not expected to amount to a more than an additional month's work or so for the detector scientist.

We have also been assured by EEV that they could also produce sufficient devices of size 1k by 2k pixels (rather than the 512 pixels by 2k pixels currently envisaged – see Misalignment below for the rationale behind the 1k device requirement). However, the additional size of each device would again be achieved by a reduction in items 3 and 4.

Misalignment

(CK, NRL)

This analysis considers the tolerance buildup in EIS with regard to the CCD camera. For this analysis, I'm just concerned with tip/tilt of the various elements. I assume no systemic errors (banana mode, etc.) and no significant physical motion of the CCD camera or slit/slot assembly. Defocus and imaging quality concerns have not been addressed herein.

Since no information on structural stability is available, I'm extrapolating from my experience with the HRTS composite telescope which is pretty stiff.

Error budget

Item (1)

> *tip/tilt deviation of the primary mirror from ideal (errors expressed in solar pointing units)*

- error in transferred alignment to the white light telescope (1 arc-minute)

- error due to cumulative environmental testing/launch (3 arc-minutes)

Item (2)

> *tip/tilt deviation of the grating from ideal (errors expressed in solar pointing units)*

- initial alignment error (1 arc-minute)

- error due to cumulative environmental testing/launch (3 arc-minutes)

Simple addition of these errors gives 8 arc-minutes. RSS of these errors gives 5 arc-minutes.

Since the requirement is roughly for a 4 arc-minute diameter field of view around the white light telescope, both the larger CCD and a coarse pointing drive seem to be required. I've neglected any possible correction in the white light telescope; this would clearly also help matters and give some additional margin.