EUV IMAGING SPECTROMETER

Hinode

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Warm and hot pixels on the EIS CCDs

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1 Introduction

EIS has two 2048x1024 pixel CCDs, one for each of the two wavelength channels. The CCDs were provided by the company e2v and are of device type 42-20.

Prior to launch it was expected that the EIS CCDs would experience hot pixels as these are well known defects where individual pixels on the CCDs have higher than normal rates of charge leakage. These are due to either defects in the silicon, or radiation damage experienced in a space environment (in the case of EIS the most likely radiation damage is due to the SAA — South Atlantic Anomaly, which the Hinode satellite passes through periodically every orbit). The CCD manufacturer e2v provides a criterion to identify hot pixels which is detailed in Section 4.1 below.

A defect that was not expected but identified approximately 9 months into the mission was the accumulation of warm pixels, which are similar to hot pixels but have a lower signal level and are much greater in number. To identify these warm pixels it was found that no formal criterion was available (as for the identification of hot pixels) and so a 'bespoke' criterion was defined, which is detailed in Section 4.2.

The large number of warm pixels on the EIS CCDs represent perhaps the single biggest instrumental issue affecting EIS data analysis. The present Software Note discusses some properties of warm pixels and how they are flagged for data analysis. EIS Software Note 13 discusses how scientists should deal with bad pixels in their data analysis.

2 Properties of hot and warm pixels

When a dark frame is taken with EIS, the majority of pixels in the exposure will have a similar data number (DN) value that represents the sum of the CCD pedestal and the dark current. The warm and hot pixels have DN values enhanced over these typical values and the enhancement appears to behave like the dark current. Fig. 1 shows an observed warm pixel signal as a function of time compared to a neighboring, normal pixel. Two features are apparent:

1. the background warm pixel DN value oscillates in time on the frequency of the Hinode orbit (98 mins);

2. the warm pixel detects a solar signal and this signal is the same intensity as in the normal pixel.

The orbital variation of the warm pixel signal is due to the known variation of the CCD temperature during the orbit and thus demonstrates a link between warm pixels and CCD temperature. The CCD dark current also varies over the orbit.

The fact that a solar signal is still measured in warm and hot pixels suggests that it may be possible to recover the solar signal from these pixels.

3 Long term variation of warm and hot pixel numbers with time

In the following sections we retain text from earlier versions of the document so the reader can see how warm pixel behavior has evolved.

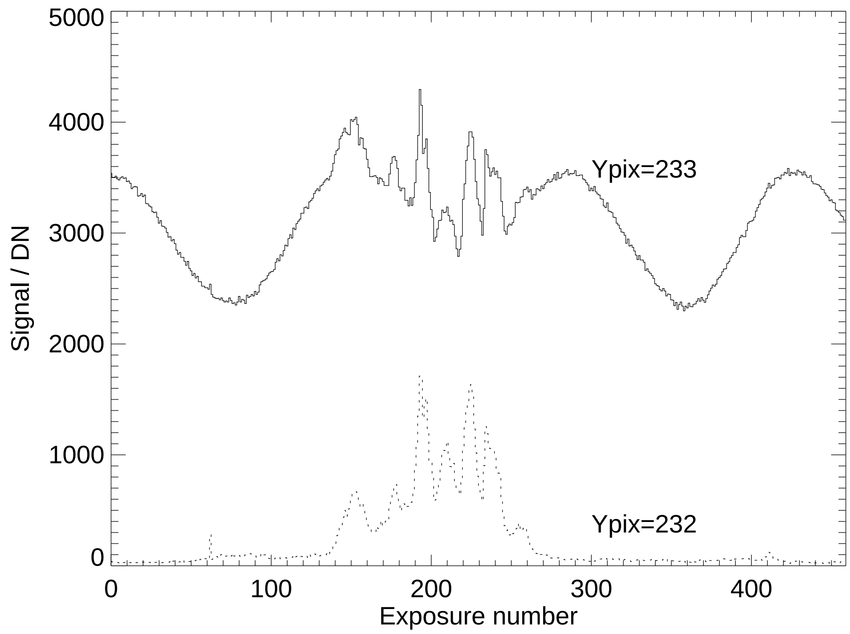

Figure 1: A comparison of the signal in a warm pixel (solid line) and an adjacent normal pixel (dashed line) from a data-set obtained on 2007 December 11. The raster duration was 5 hours 40 minutes.

3.1 Status as of March 2010

A crucial property of the warm and hot pixels on the EIS CCDs is that their numbers are increasing with time. This is not a big problem for hot pixels as there are relatively few of these (around 1% of CCD area as of March 2010), but it is a problem for warm pixels. Each year an additional 4–5% of the detector becomes infected with warm pixels (Fig. 2). As of March 2010 (3.3 years into the mission) around 16% of the EIS CCD pixels are classed as warm pixels. At the current rate of increase the number of warm pixels per each CCD half (512x1024 pixels) will be approximately 31% in February 2013. This value is significant as when a 30% level is reached the line fit parameters will be affected (see EIS Software Note 13) and corrective action will be required (bake-out of the CCDs).

Assuming that there is a steady increase in the number of warm pixels due to radiation damage, the rate of increase (with reference to a threshold) should increase during a warming period and decrease during a cooling period. This is not the case for EIS; during periods of decreasing CCD temperature the warm pixel levels appear to stabilise (Fig. 2). A possible explanation (following consultations with e2v) is that for the EIS CCDs the decrease of warm pixels due to decreasing temperature seems to approximately match the increase due to radiation which gives the impression of stabilisation and not necessarily recovery.

3.2 Status as of December 2019

As described above, the number of warm pixels seemed to show some relation with the CCD temperature. As the mission evolved and the rate of increase of warm pixels slowed, the dependence on CCD temperature became clear, as shown in Figure 3. The CCD temperature is at

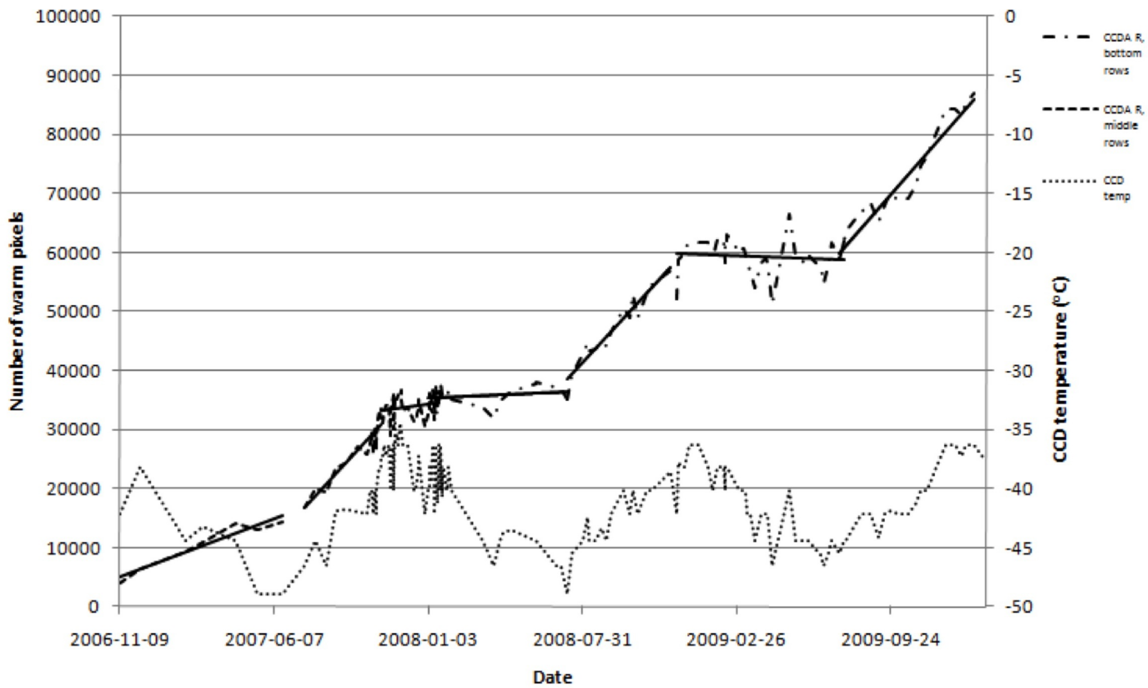

Figure 2: The rate of increase of the warm pixels since launch for the EIS long wavelength CCD (right half, bottom 512 rows).

its hottest during December and January and so the number of warm pixels peaks during this period. A knock-on effect is that data compression works less well during this period, and so EIS Chief Observers need to account for this when preparing their observation plans.

EIS Software Note #13 suggested that warm pixels may significantly impact data analysis if their number reaches 30% of the detector area. Following the peak in the winter of 2015/16 (Figure 3) it was decided to perform the first CCD bakeout for EIS, in the hope this would reduce the number of warm pixels.

The first EIS CCD bakeout (both short and long wavelength CCDs) was performed in February 2016 and lasted three days. This provided encouraging results with a reduction in both the number of hot and warm pixels. The recovery is evident (Figure 3) as following the bakeout the subsequent number of warm pixels at the coldest CCD temperature was significantly lower than the previous years—as shown by the red horizontal line, and also the number of warm pixels at the hottest CCD temperature was significantly lower than previous years—as shown by the red dash horizontal line. A second shorter CCD bakeout (2 days) was performed in August 2017, the purpose of this was to test the new on-board software for bakeout handling (although some hot and warm pixel recovery was seen, this was not as much as the first bakeout—as expected due to the shorter bakeout duration).

The data from the last CCD bakeout (January 2018, duration of just over 3+1/2 days, planned for 5 days) initially indicated some warm pixel recovery but subsequent data showed an increase in the warm pixels. It is presumed that any reduction in the warm pixels initially seen will have been masked by the subsequent increase in warm pixels, which followed during the period that the EIS was switched off for ($\approx$ 4 months).

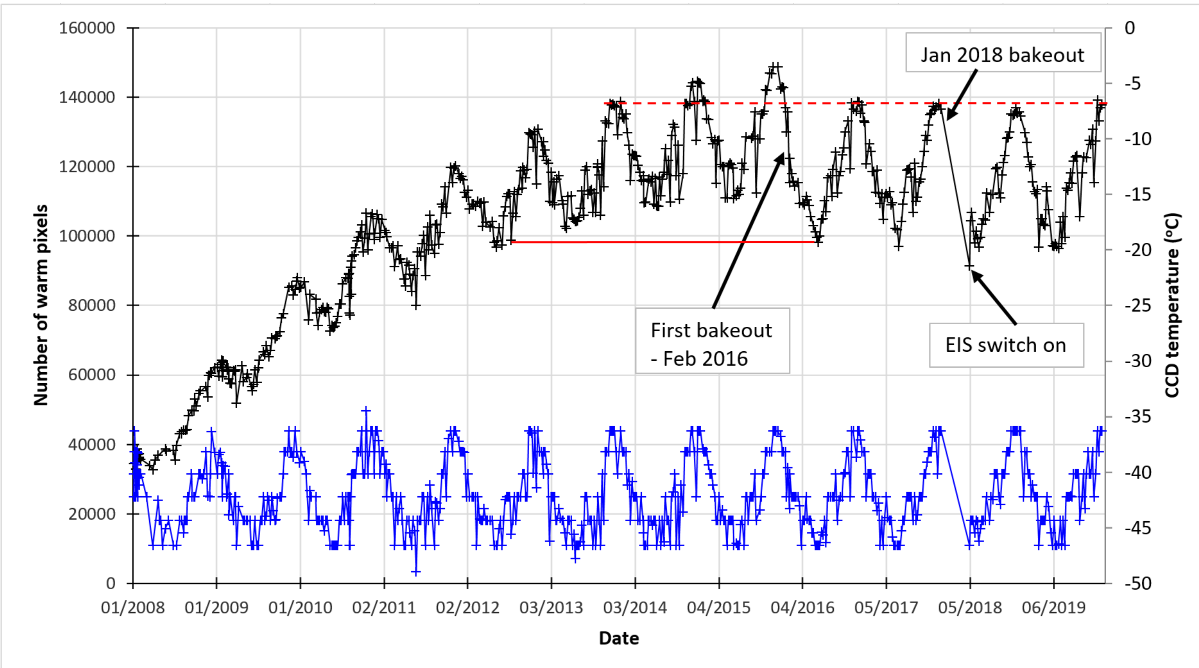

Figure 3: Variation of the number of warm pixels (black) and the CCD temperature (blue) with time, from 2008 January. The red lines are explained in the main text.

As of December 2019 the warm pixels affect 26% of the CCD imaging area, which is the peak for this recent (2019/2020) 'hot' period, this is the same value (26%) for the previous peak in the 2018/2019 'hot' period. For the 2017/2018 hot period the peak was 27%. At their highest level (prior to the first bakeout) the warm pixels accounted for 28% of the imaging pixels (in the 2015/2016 hot period). Note, when a 30% warm pixel level is reached the spectral line fit parameters will be affected (EIS Software Note #13).

4 Hot and warm pixel definitions

4.1 Hot pixels

The hot pixel threshold is based on a criterion set by e2v, which states that any pixel containing more than 25,000 electrons/pixel/second at room temperature is a hot pixel. The threshold is scaled to the EIS temperature using the standard equation

$$\frac{Q_d}{Q_{d0}} = 122\,T^3 \exp(-6400/T) \tag{1}$$

where Q_{d0} is the dark signal at 293 K (e.g., 25000 e^- at 293 K corresponds to 46 e^- at 233 K). Note that, since the hot pixel threshold depends on the CCD temperature, then the number of hot pixels does not vary with CCD temperature. Also, as the hot pixel threshold is expressed as a rate, then the number of hot pixels flagged is independent of the exposure time of the dark frame.

4.2 Warm pixels

Warm pixels are defined to be pixels that lie below the hot pixel threshold (defined above) but above a lower limit threshold that distinguishes them from normal CCD pixels. This lower limit is defined on an ad hoc basis from dark frame exposures taken regularly by the EIS instrument, with the criterion being: *no more than 1 real pixel must be incorrectly categorised as a warm pixel.*

If we assume that the dark current for normal pixels has a standard deviation of σ, then for a CCD image area of 1024×512 pixels (quarter of an EIS CCD), 0.15 pixels lie outside the 5σ range. We thus define warm pixels to be those with DN values above 5σ.

With this criterion, the procedure for producing the dark frame images is:

1. remove any cosmic rays by comparing two consecutive exposures and using the lowest value;
2. subtract the dark current;
3. calculate the standard deviation, σ, of the CCD dark frame exposure;
4. all pixels with DN values greater than 5σ are flagged as warm pixels.

As an example, for a 100 second dark exposure and a CCD temperature of 233 K the hot pixel threshold is 4600 e^- (742 DN) and the warm pixel threshold is 62 e^- (10 DN).

5 Hot and warm pixel maps

Two engineering studies, REGCAL071 and REGCAL072, are run on a weekly basis to obtain dark frames for the top and bottom halves of the EIS CCDs. Warm and hot pixels are identified following the procedure identified above and warm and hot pixel maps are stored in the EIS Solarsoft distribution in the directories:

$SSW/hinode/eis/data/cal/hp [hot pixels]
$SSW/hinode/eis/data/cal/wp [warm pixels]

Each directory contains sub-directories identified by the date on which the REGCAL studies were run. The sub-directories usually contain eight files containing the maps. The two CCDs each have four maps corresponding to the top-left, top-right, bottom-left and bottom-right quadrants of the 2048×1024 pixel CCD. Restoring one of these maps into IDL reveals a 1024×512 array containing 0's and 1's. Pixels marked with 1 are the warm/hot pixels. Note that sometimes due to telemetry data drop-outs not all of the eight maps will be available.

The EIS calibration routine, eis_prep, determines the hot and warm pixel maps that are closest in time to the scientist's observations and applies these maps to flag the pixels as missing pixels (see EIS Software Note 1 for more details).

A hot or warm pixel map for a specific data window of an EIS data-set can be obtained as follows. Consider a data-set with the filename `fname` (can be either a level-0 or level-1 FITS file) that has a data window containing the emission line Fe XII λ195.12. The following commands will create the warm pixel for this window:

```
IDL> data=obj_new('eis_data',fname)
```

```
IDL> cal=data->getcal()
IDL> iwin=data->getwindx(195.12)
IDL> wp=cal->warm_pixels(data,iwin[0])
```

The output array, `wp`, is a two dimensional array of size NW×NY where NW is the number of pixels in the wavelength direction for the λ195.12 data window and NY is the number of pixels in the Y direction for the λ195.12 data window. The array contains 0's and 1's, with a 1 indicating the position of a warm pixel.

The hot pixel map for the data window can be obtained in the same way by substituting `hot_pixels` for `warm_pixels` in the IDL commands given above.

A Document history

Version 3.0, 6-Feb-2020. Added Sect. 3.2