Degradation of the Hinode EIS detectors after 5 years in orbit

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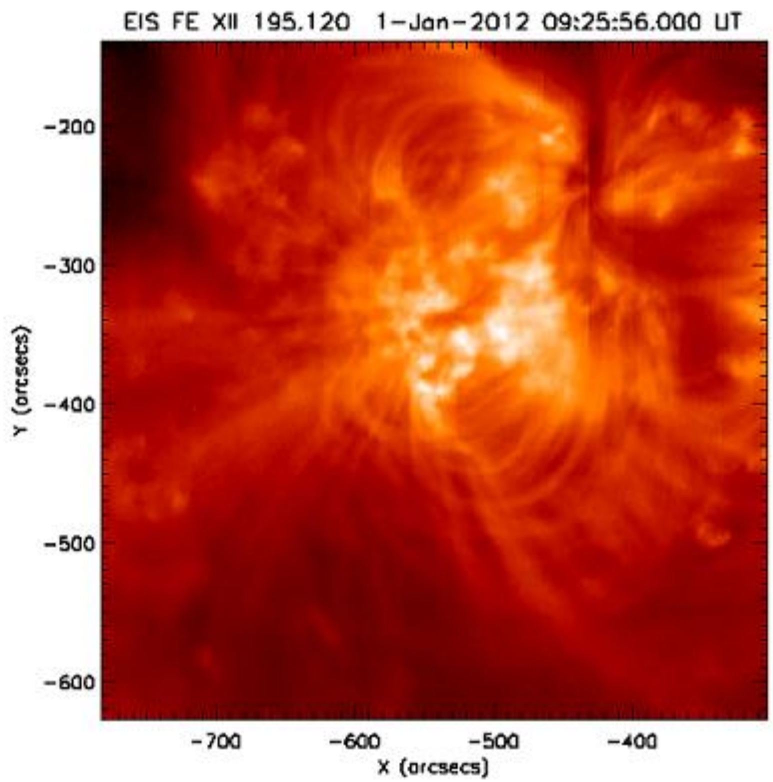
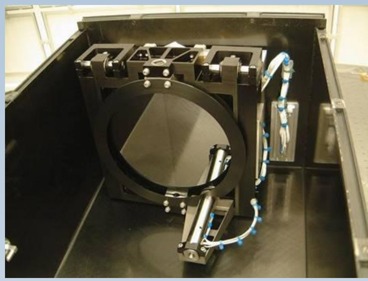


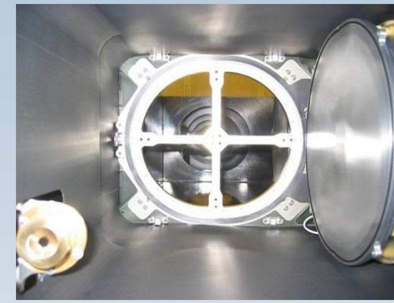
Fe XII 195 Å image of an active region constructed using 40" slot rastering

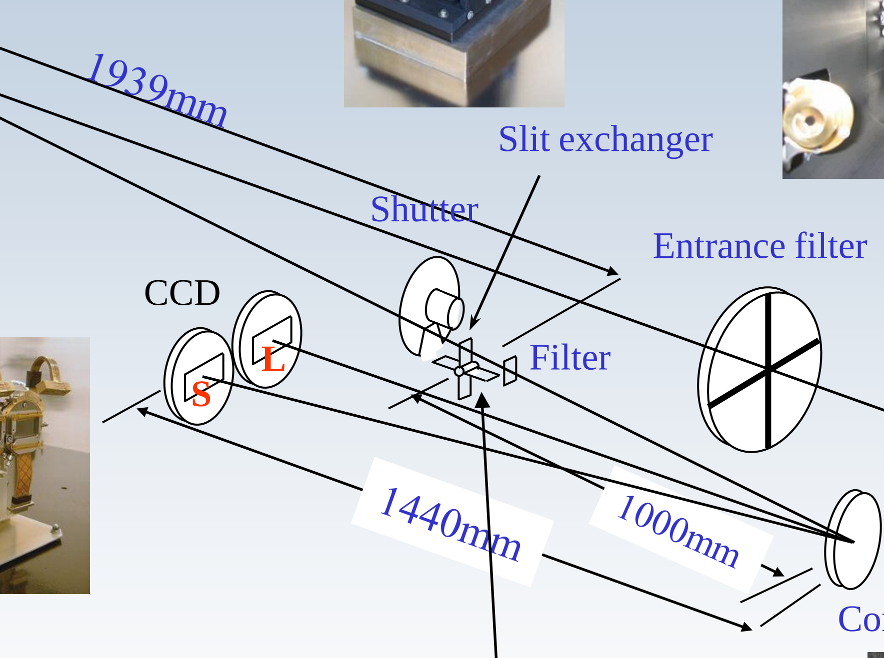
Hinode mission

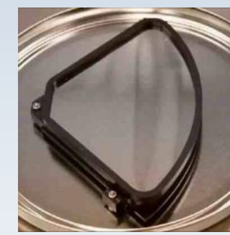
- Japanese satellite with payloads funded by JAXA-ISAS, NASA, ESA and UKSA (previously STFC)
- Launched in September 2006
- Hinode name given post-launch - means Sunrise in Japanese (formerly Solar-B)
- Three solar telescopes: SOT, XRT, EIS
- Hinode is in a sun-synchronous low earth orbit, altitude ~ 600 km
  - the sun is visible 24h/day hence continuously observing
- Hinode orbits the earth in 98 minutes
- Frequent passes through SAA (approx 12 per day)
  - the shortest is ~ 1 minute and the longest ~ 20 minutes
  - science degrades through long passes as the data cannot be completely ‘cleaned up’ (whether EIS observes through the SAA depends on science objectives, e.g. wave detection requires continuous observations)

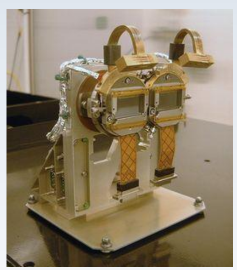
EIS (Extreme-UV Imaging Spectrometer) optical layout









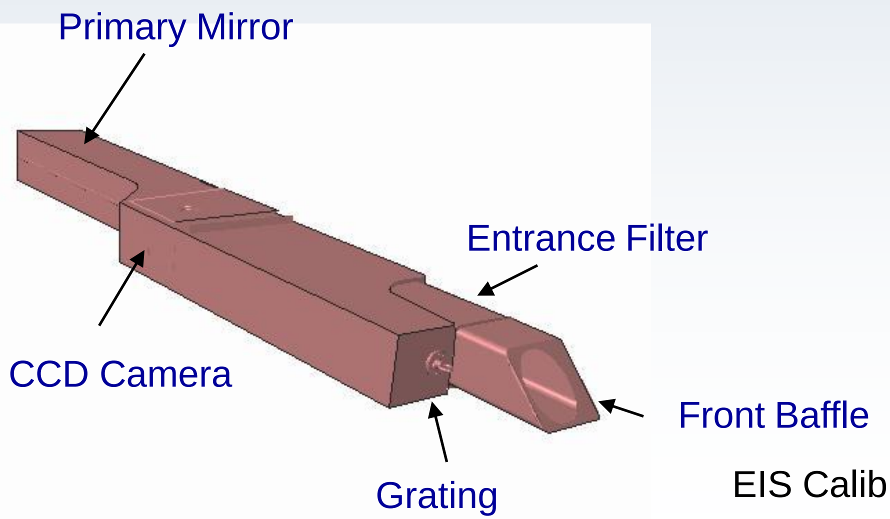


Four positions:
1 and 2 arc sec slits
40 and 266 arc sec slots
- all with 1024 pixels
or 17 arc min height

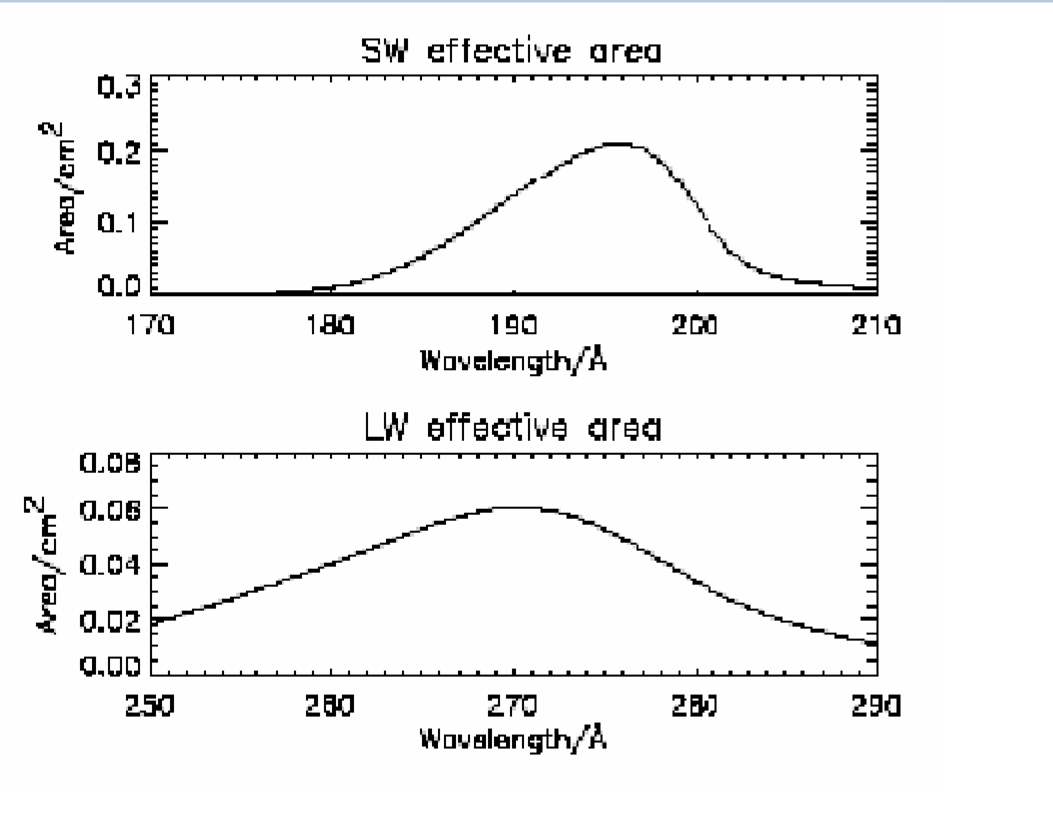
Hinode EIS

EIS detectors

- EIS CCDs:
  - 2 x e2v device type CCD 42-20:
    - CCDA λ range = 250-290 Å
    - CCDB λ range = 170-210 Å
  - Array size = 2048 x 1024 pixels
  - Thinned for back-illumination
  - Pixel size = 13.5 µm x 13.5 µm
  - AIMO (MPP) for low dark current levels
  - On-orbit operating temperature range = ~ -36 to -46 ^{o}C (variation due to perihelion and aphelion)



Instrument throughput



Short and long wavelength effective areas based on measurements of the efficiencies of the individual optical elements (filters, mirror, grating, CCDs)

Large effective area in two EUV bands:

170-210 Å and 250-290 Å

Calibration post-launch

- Following launch :
  - Wavelength calibration – a pixel shift of 8-9 pixels in the spectral direction was observed post-launch when compared with the pre-launch calibration
    - This was attributed to the thermal stability and out-gassing of the instrument (expected behaviour of space instruments)
    - Correction made in the software to accommodate the shift
  - Monitored by identifying the positions of core lines

- Regular calibration studies are run weekly, monthly or quarterly depending on the type of study:
  - e.g. dark exposures, flat-fields, synoptic, QCM, full CCD spectral scans

Hot and warm pixels (introduction)

- Defects in the CCDs where rates of charge leakage are higher due to either defects in the silicon, or radiation damage
  - in the case of EIS the most likely radiation damage is due to the SAA
- Seen as spikes in the data which need to be calibrated out, e.g using eis_prep (IDL routine available in the EIS Solarsoft distribution)
- The positions of the warm and hot pixels are mapped and the information provided to eis_prep
- Hot pixels were expected on the EIS CCDs but not warm pixels (which were identified approx 9 months into the mission)
- Warm pixels have a lower signal level and are much greater in number
  - unfortunately these are a problem as the CCDs are not as cold as predicted (below -50^{o}C)
    - ➢ Hinode XRT has the same type of CCDs as EIS but they run at a much colder temperature (~-80^{o}C) and therefore do not see any warm pixels

Hot and warm pixels (definitions)

- Warm pixels are defined as the pixels which fall into the range bounded by the following lower and upper thresholds:
  - Lower limit threshold (based on 100 sec dark exposures):

    Remove cosmic rays
    Subtract dark current
    Calculate standard deviation (σ) of the dark frame
    Lower threshold = n*σ
    - ➢ Where n = 5 (to prevent more than 1 real pixel being incorrectly categorised as a warm pixel, per exposure)

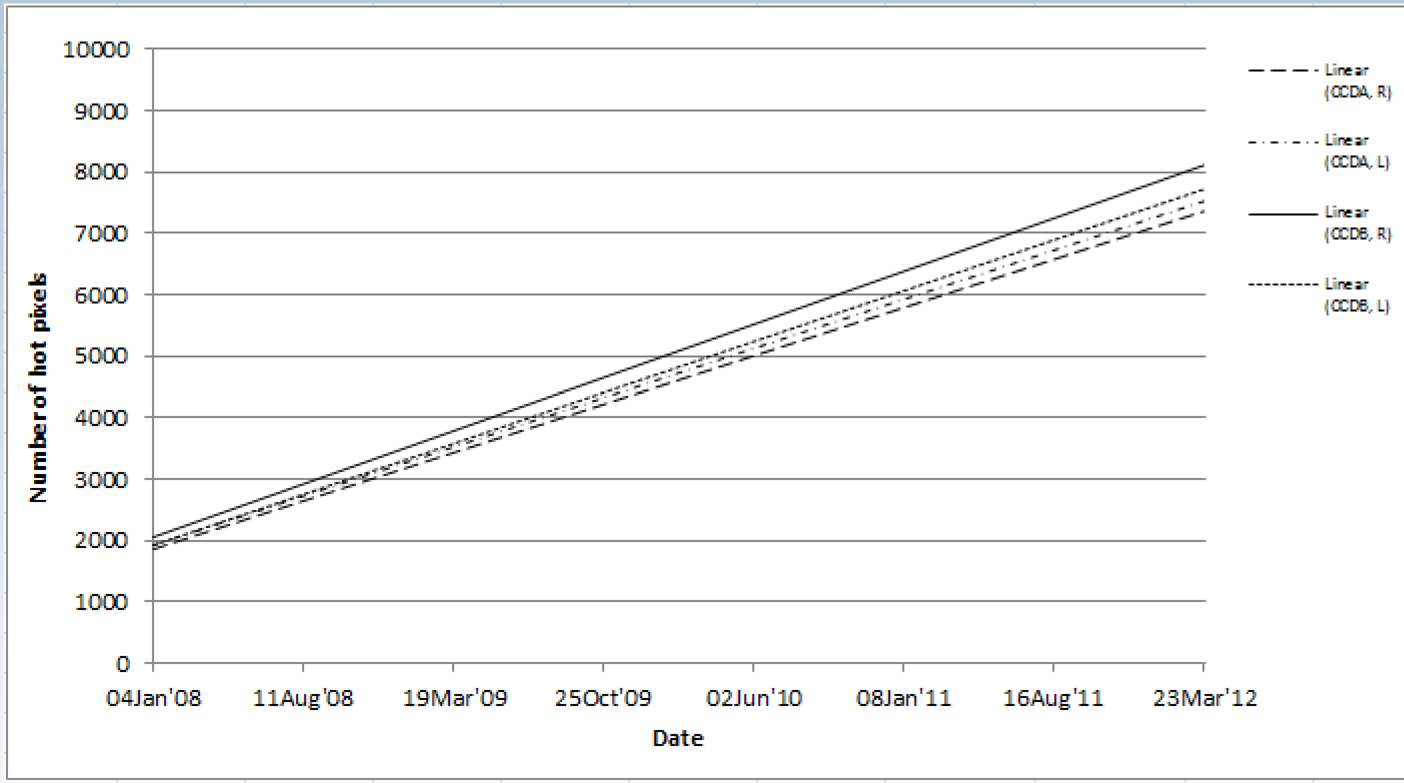
  - Upper limit threshold:

    Set to be the hot pixel threshold

    - ➢ The hot pixel threshold is based on the e2v criterion which states that any pixel containing more than 25,000 electrons/pixel/second at room temperature is a hot pixel (scaled to EIS temp)

Hot pixels

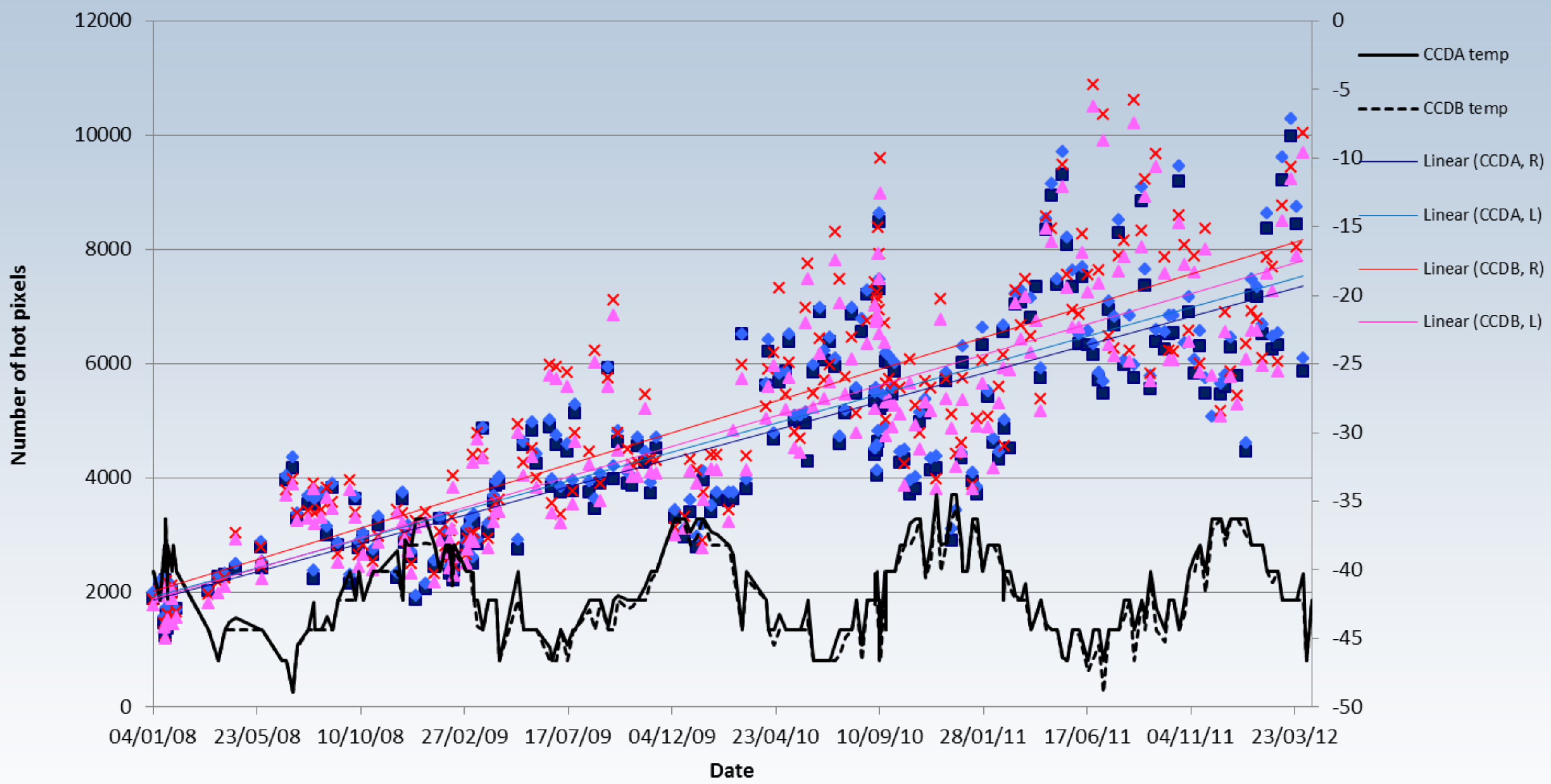
- Follow a linear trend:



Number of hot pixels for the EIS CCDs

- At present the number of hot pixels per each CCD half is approximately 7800 (which is 1.5% of the imaging area)

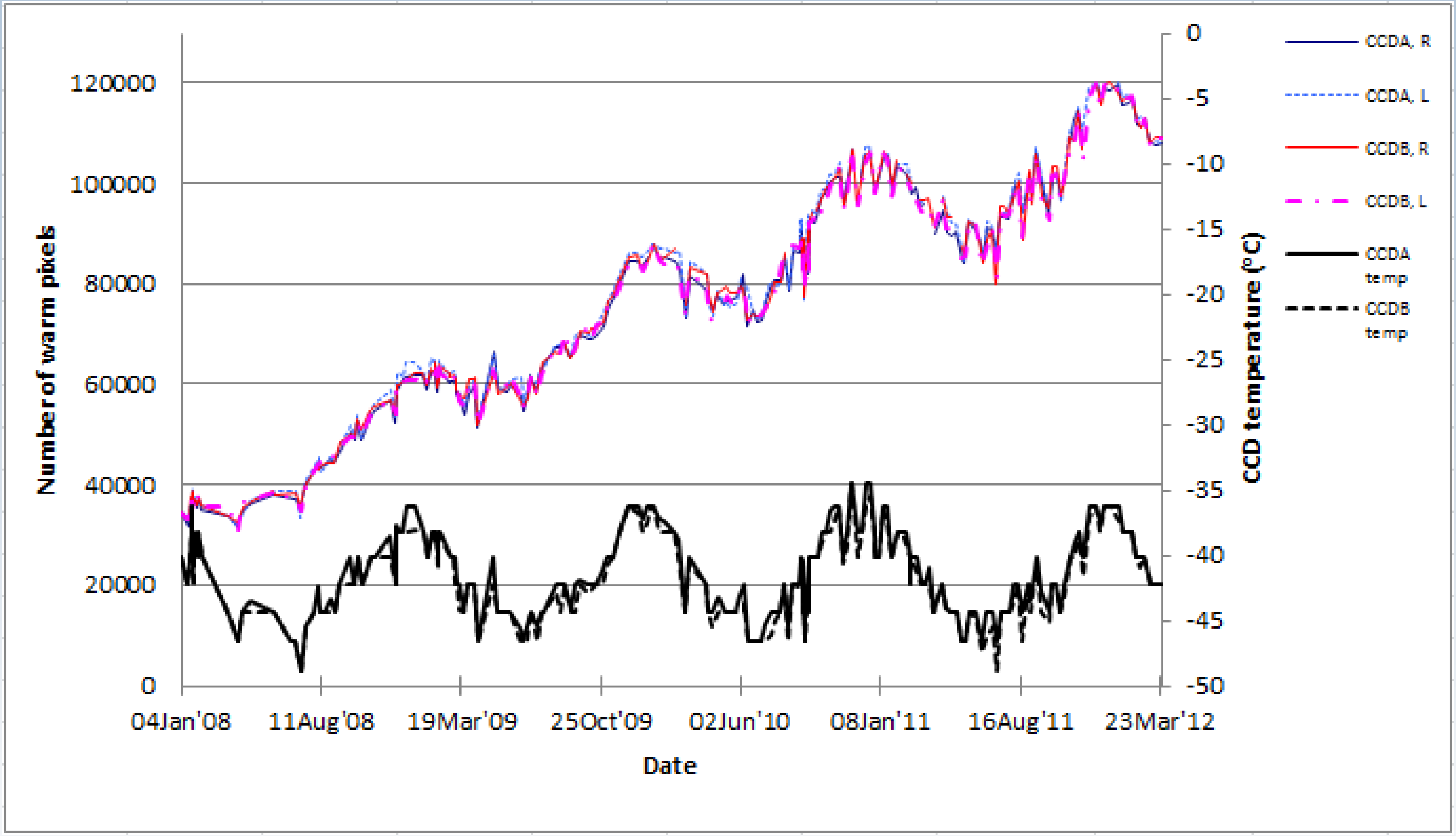
Hot pixels – With actual data



Hinode EIS

EIS Calibration D.Walton L.Bradley

Warm pixels



Number of warm pixels for the EIS CCDs

•The warm pixel trend correlates with the CCD temperatures (annual variations in CCD temp due to aphelion and perihelion)

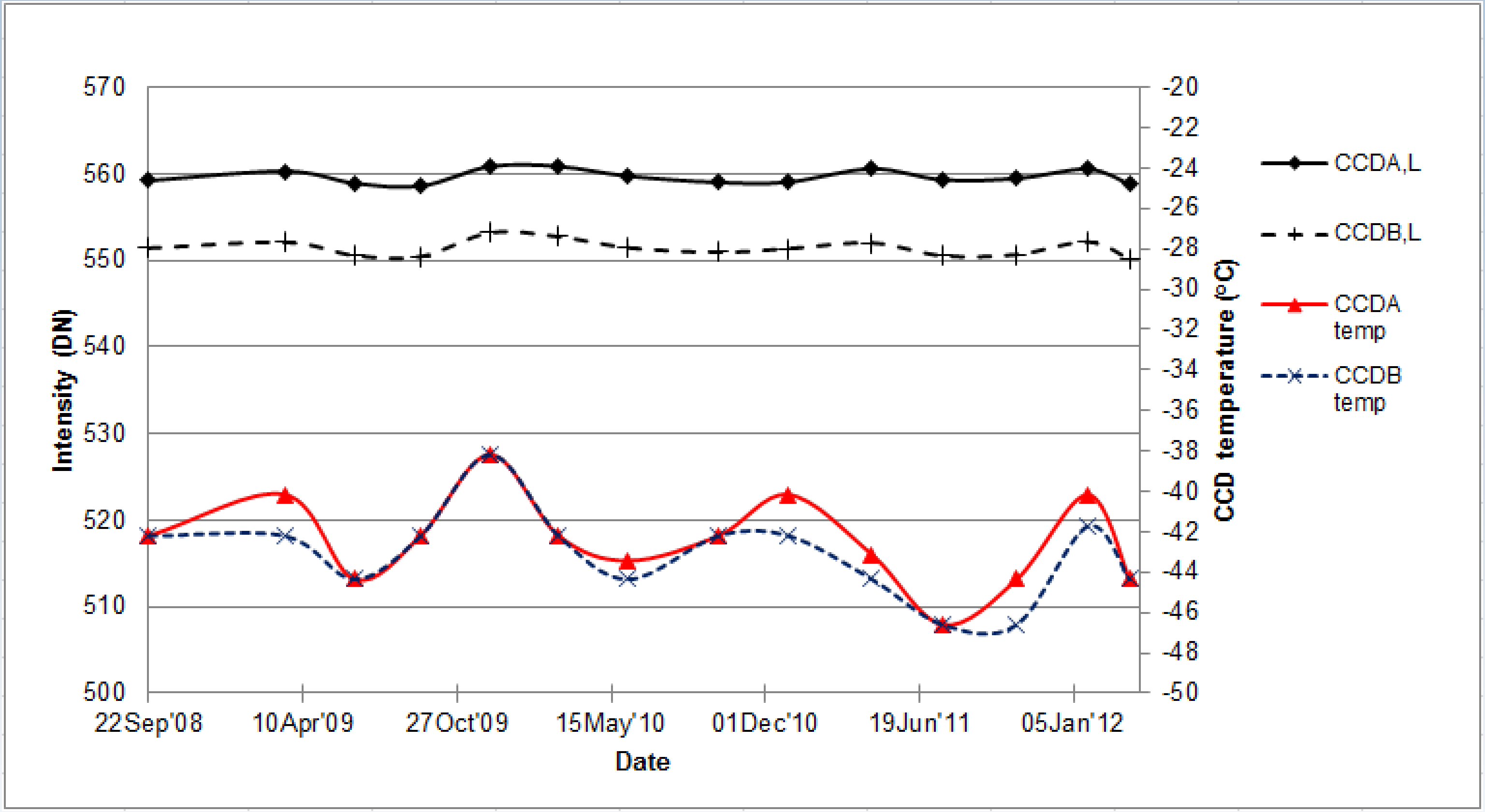
Warm pixels - summary

- As of Mar 2012 the average number of warm pixels per each CCD half is ~108k (which is ~21% of the imaging area).
  - Currently in a decreasing phase
- The number of warm pixels in Dec of each year (hottest point) is increasing by ~16k per year.
  - Based on this assumption the number of warm pixels will be:
  - In Dec 2012: ~136k (26% of the imaging area)
  - In Dec 2013: ~152k (29% of the imaging area)

  (Note: A study performed by P.Young, NRL, found that when a 30% warm pixel level is reached the line fit parameters will be affected)

  - When the number of warm pixels (per each CCD half) reaches 157,286 the 30% level will have been reached
    - The highest number recorded so far was 120,312 on 05 Jan ‘12 (CCDB,L)

Background levels

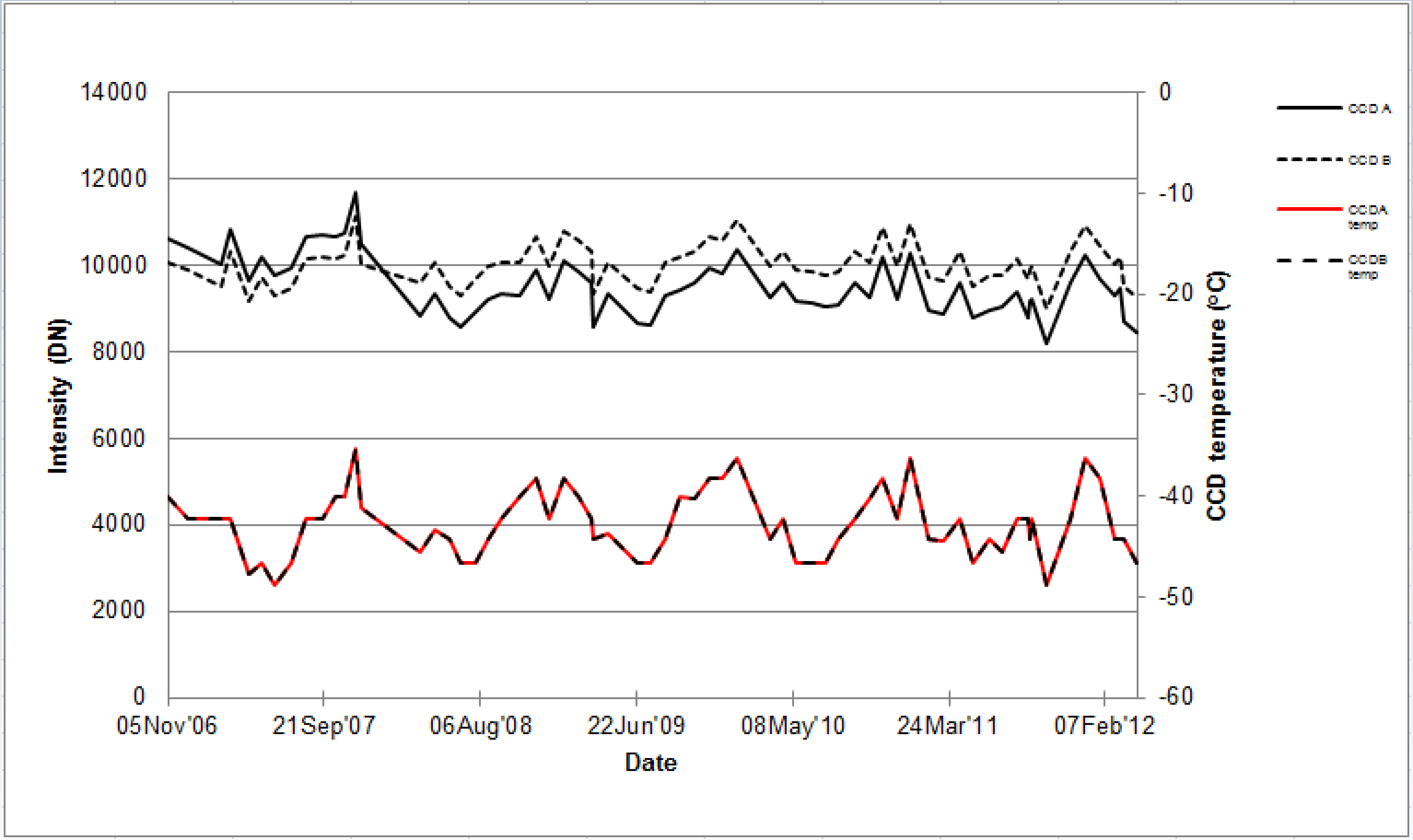


Background levels using 0 second dark exposures (averaged over 450 x 450 pixel area)

- Background levels (ADC offset + dark current) show no significant change over time

Hinode EIS

LED flat field intensity levels

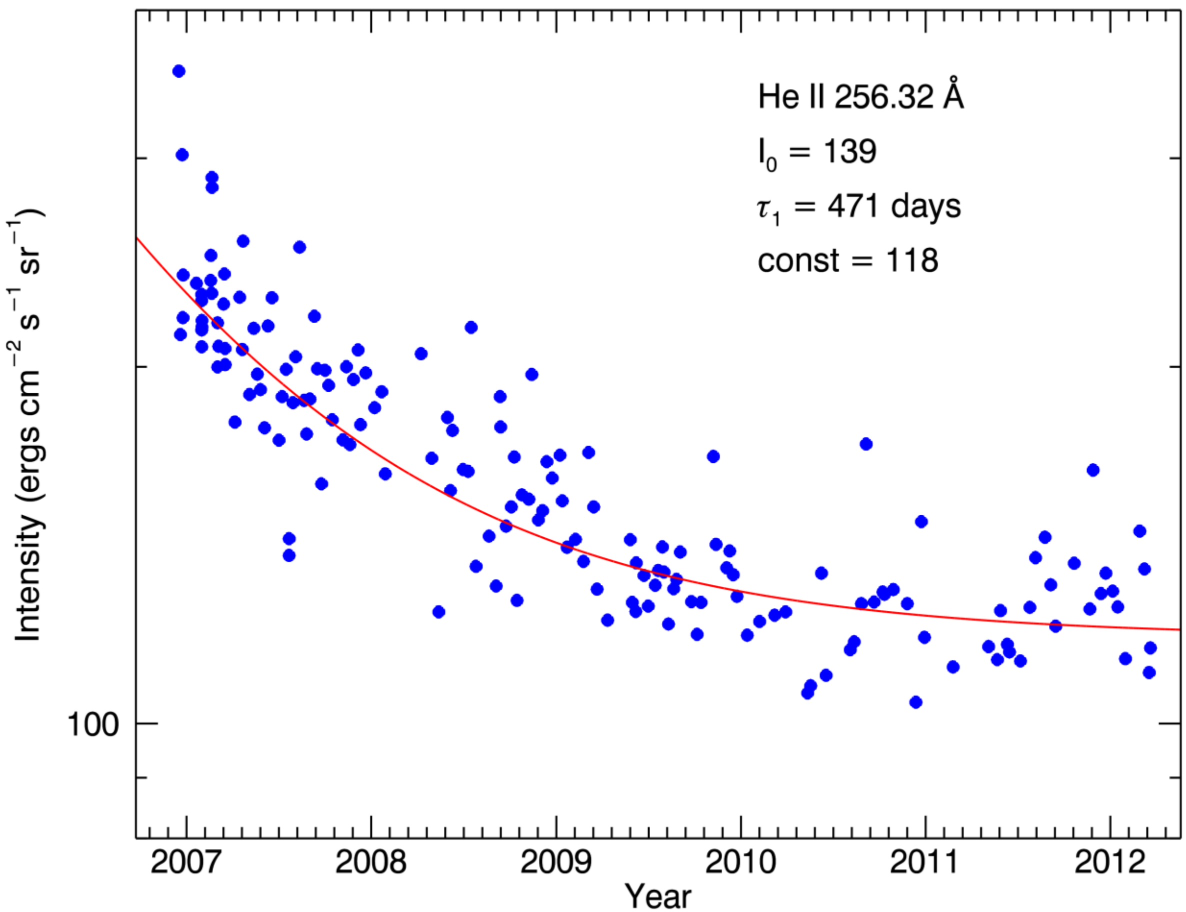


Intensity levels using EIS LEDs (averaged over 450 x 450 pixel area)

- Shows no significant change since launch (up to April 2012)
  - ➢Suggests that contamination is not on the CCDs

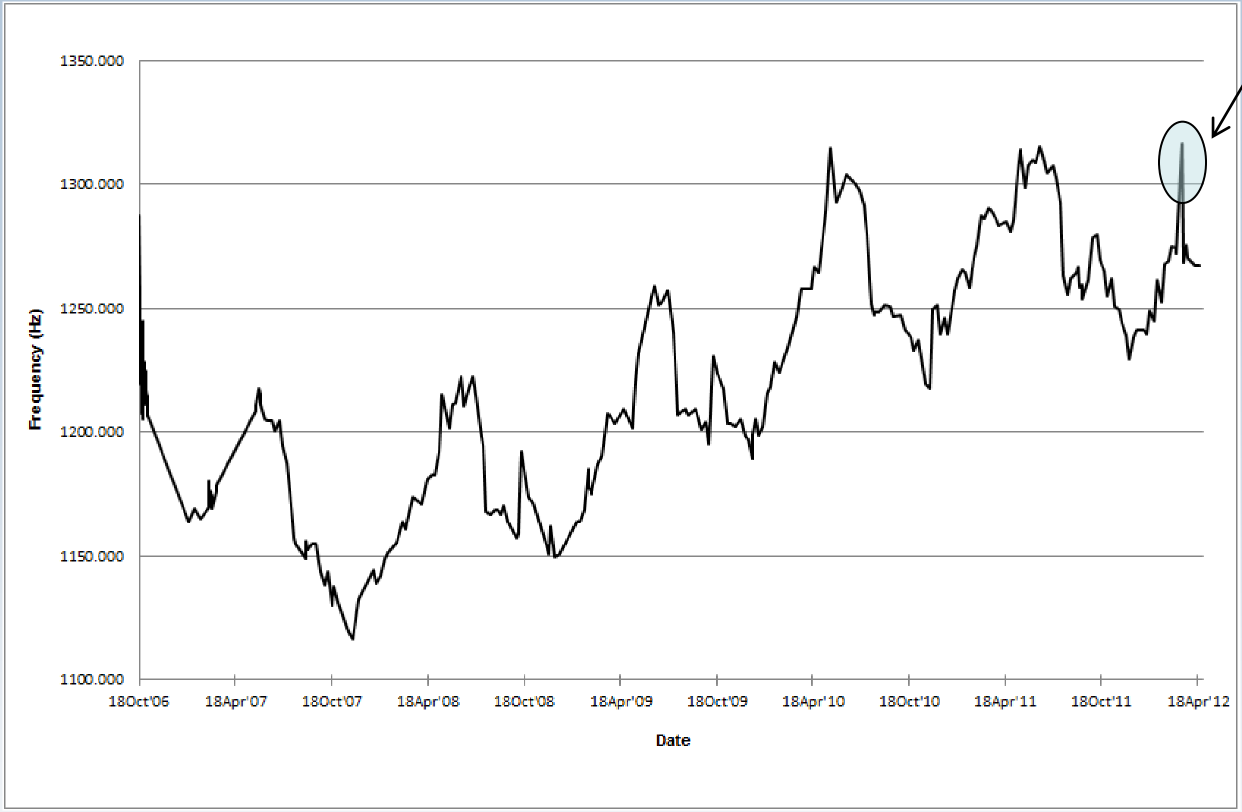
EIS sensitivity update (courtesy J.Mariska, NRL)

- A synoptic observation is run weekly and observes a patch of quiet sun
- Record of He II observations shows that EIS sensitivity decay rate is slowing
- Best fit expression is now an exponential plus a constant
- Not yet clear if some of the flattening is due to solar cycle effects



- The sensitivity decay is due to contamination/degradation of the optical elements – not the CCDs – as shown on previous slide
- The sensitivity changes are factored in the EIS analysis software (eis_prep)

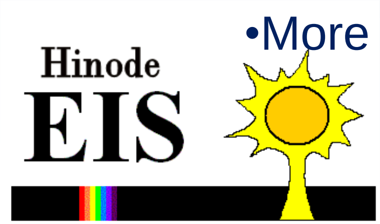
QCM contamination measurement results



Peak is an artifact of recent recovery switch-on (unstable temp.)

EIS QCM2 data from launch (normalised for temp)

- Slight increase year on year; this is to be expected
- 2010 to 2011 saw smaller increase – agrees with sensitivity measurements which show that decay rate is slowing (i.e. less contamination)
- More work to be done in analysing QCM data (e.g. deposition levels)
- *Note: The periodic nature of the mass loading (frequency) is as a result of the annual temperature variations*



CCD bake-out

- The plan so far has been to hold off from doing a CCD bake-out for as long as possible as it presents a risk to the instrument (heaters require a high power mode)
- Discussed at the recent EIS team meeting – bake-out now estimated for Dec 2013 (which will be after 7 years in orbit)
- Initially it was planned to perform a bake-out when the optical performance degraded but the flat-field intensity levels suggest that there is no contamination on the CCDs, therefore a bake-out will not improve optical performance
  - The current driver for a bake-out is the number of warm pixels (not contamination)
  - The warm pixels will compromise the science when a 30% level is reached
  - The warm pixels are also impacting the EIS data compression
    - The effect is that sometimes the EIS allocated telemetry limit is reached as estimates are wrong (data compression degradation)
      - The data compression factors for EIS have been reduced by 10% (5 years into the mission)
        - This reduction is only for the 'hot' season (Oct to April) – when warm pixels are increasing
        - Data compression factors will be returned to nominal in the 'cooler' season (April to Oct) – when warm pixels are decreasing
      - It is hoped that following bake-out the data compression performance will revert to the post-launch level

CCD bakeout

- The amount of warm pixel recovery to expect is unknown but the Hubble Wide Field Camera 3 (e2v CCD type CCD43s; MPP & thinned for backside illumination) have successfully recovered warm pixels:
  - *Performed an experiment where they irradiated their CCD with protons at -84^{o}C (WFC3 operating temp) then warmed to +30^{o}C*
    - *hot pixel annealing began below -40 ^{o}C and the anneal process was largely completed by +20 ^{o}C*
  - *They now perform monthly (on-orbit) anneals (+20 ^{o}C)*
  - *The fact that significant annealing occurs at room temp is not understood since none of the commonly expected defects in Si anneal at such a low temp.*
  - *The hotter the pixel after irradiation the more likely it was to anneal*

➢ *Based on this the EIS team will have to experiment with bake-out temperatures and durations to maximise recovery prospects*

Summary

- The EIS instrument behaviour is nominal for a 5+1/2 year LEO space mission
- The CCDs are sustaining radiation damage as expected
  - Hot pixels were expected but the warm pixels were not
    - This is the result of operating the CCDs at a warmer temperature than anticipated (operating temp = -40 ^{o}C +/- 5 ^{o}C, ideal temp would be < -60 ^{o}C)
- The warm pixels will impact the science operations once their level reaches 30% of the imaging area
  - At present they are mapped and removed via EIS processing software
  - It is hoped that a bake-out (+35 ^{o}C) will recover most of the warm pixels
  - Bake-out is currently planned for the end of next year (2013)
- The data compression performance was impacted when the warm pixels reached a 25% level (5 years into the mission)
  - EIS compression factors are now reduced by 10% during the 'hot' season
- The optical performance degradation is better than expected (compared to similar missions) - it is expected that 1/e will be reached in 7 years
  - ➢ Those involved in the EIS instrument cleanliness are commended!

Hinode EIS