Flares observed by Hinode & SDO during Feb 2011

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1. Introduction

- Active region AR 11158 produced one X flare and several M-flares during 14-18 February 2011.
- Hinode/EIS ran dedicated flare studies, yielding the best set of flare data since 2006.
- This work focuses on a 24 hour period during 15-16 February when seven significant flares occurred (Figure 1).
- The first six flares were all compact flares with no associated eruption; the seventh produced a CME.
- Data from SDO AIA and HMI, and Hinode/EIS are studied.

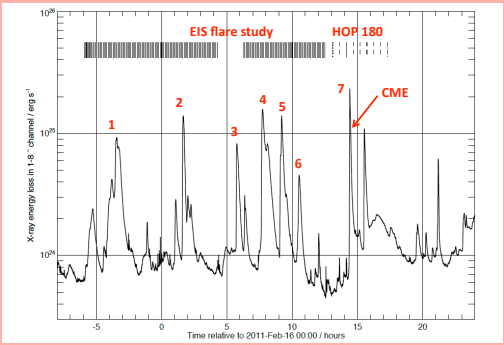

Figure 1. GOES 1-8 Å light curve between 15-Feb 16:00 and 16-Feb 24:00. Seven significant flares are labelled, and the CME associated with flare 7 is indicated. Short vertical lines denote the times when Hinode/EIS was obtaining data. The first two periods correspond to the EIS flare study. The third period corresponds with HOP 180 (not discussed here).

2. Location of flares relative to photosphere

- The active region has four sunspots which we label A-D (from left to right).
- AIA 94 Å channel images from the peak of the flares are compared with the locations of the active region sunspots as seen from HMI (both AIA and HMI images were processed with aia_prep to yield co-aligned images).
- For 6 of the 7 flares the coronal emission is principally located between sunspots A and B (Figure 2).
- For flare 4, there is significant hot emission along the neutral line between sunspots B and C (Figure 2).
- An increase in the magnetic field strength between 2 and 6 UT on 16 February (Figure 3) may be responsible for flares 3-6 which take place between 5 and 11 UT.

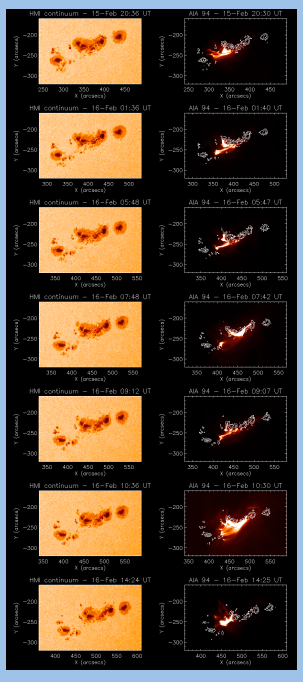

Figure 2. Comparison of photospheric continnuum images (left panels) from HMI with AIA 94 Å channel images (right panels) for each of the seven flares. The contours on the right panel images are from the continuum images in the left panels.

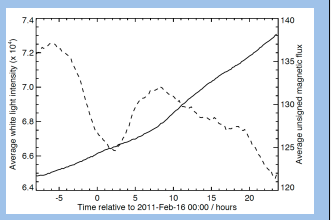

Figure 3. The variation of the average white light intensity and the unsigned magnetic flux during the flaring period. The quantities have been averaged over a box encapsulating the spots, and corrected for the position of the active region on the Sun. Data from HMI.

3. Short-lived hot upflows and flare "knots"

- High velocity blueshifted components of Fe XXIV λ192.04 (20 MK) are measured about 3-4 minutes before the GOES peaks of flares 2, 4, 5 and 6 (Table 1; figure 4); they are only measured in a single raster (duration 5 mins).
- The timings and spatial locations are consistent with the occurrence of compact flare "knots" visible in the AIA 94 Å channel (Figure 5).
- The knots also emit in Fe XIV (2 MK) and so the density can be measured with λ264.79/λ274.20 density diagnostic.
- A cross-section through the knot at 07:40:12 is shown (Figure 6). Densities reach log (N_e/cm^{-3})=10.8, and the plasma column depth is around 10-30 km.
- Flare models suggest hot lines should show large blueshifts at the impulsive phase (Nagai & Emslie 1984), but previous, spatially unresolved observations generally show a dominant rest component (Antonucci et al. 1982).
- The spatially-resolved spectra from EIS show one example of a dominant blueshifted component (Flare 4, Figure 4), but this is a rare occurrence from the five flares considered.

Table 1. Comparison of times for Fe XXIV blueshifts and GOES peaks.

Flare	Time of blueshift	Time of GOES peak
2	01:35:44	01:39:47
4	07:40:12	07:44:05
5	09:03:59	09:06:53
6	10:29:21	10:32:35

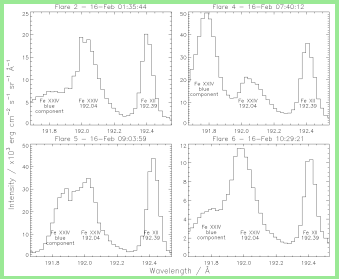

Figure 4. EIS spectra from Flares 2, 4, 5 and 6 showing the Fe XXIV λ192.04 and Fe XII λ192.39 emission lines at individual spatial pixels that display blueshifted components of the Fe XXIV line. 0.2 Å corresponds to 310 km/s, so the components range in velocity from 150 to 500 km/s.

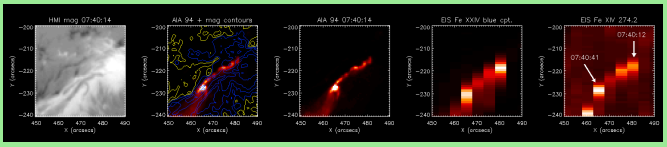

Figure 5. Images from Flare 4 showing flare "knots" in the AIA 94 channel (panels 2 and 3). The HMI magnetogram (panel 1 and contours of panel 2) show knots are close to the neutral line. An image formed in the blue wing of Fe XXIV λ192.04 (panel 4) at about -400 km/s shows good spatial match to the knots. The knots also emit in Fe XIV, allowing density to be estimated. Note that EIS rasters left-to-right with a step size of 5 arcsec for this raster.

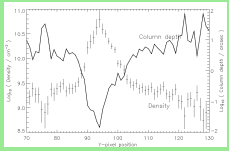

Figure 6. A slice in the Y-direction through the Fe XIV brightening at 07:40:12 UT seen in the fifth panel of Figure 5. The density and column depth were derived using the λ264.79/λ274.20 density diagnostic. These demonstrate that the flare knots are dense and compact, consistent with a location in the chromosphere.

4. Long-lasting 'cool' upflows

- Del Zanna et al.(2011) identified upflows of up to 170 km/s at temperatures 2-3 MK at the footpoints of a flare loop.
- Flare 5 exhibits a similar upflow in Fe XIV lines which occur at a fixed point and last for around 30 mins.
- The blue component can be isolated, and the Fe XIV density diagnostic yields high values of 10^{11} cm^{-3}.
- This component demonstrates that the post-flare loops are continuously filled with plasma from the chromosphere for up to 30 minutes after the flare.

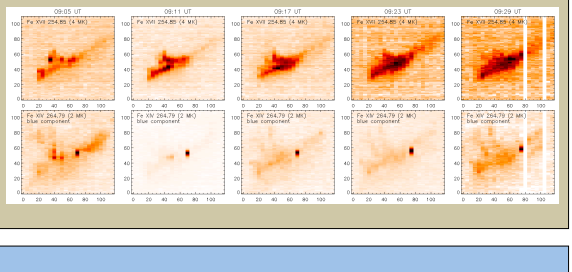

Figure 7. Images from 5 consecutive EIS rasters of flare 5. The upper panels show Fe XVII 254.85 images which display hot post-flare loops. The lower panels show images from the blue wing (-130 km/s) of Fe XIV 264.79 which show a persistent bright spot of emission corresponding to the right-hand footpoints of the hot loops.

5. Summary

- SDO/AIA 94 Å channel (6 MK) images reveal compact (1-4 arcsec) brightenings prior to peak of X-ray emission.
- Hinode/EIS data show strong upflows of 20 MK plasma at locations of brightenings.
- Fe XIV density diagnostic shows high density (10^{11} cm^{-3}) and small emitting size (10's of km) for brightenings.
- Flare no. 5 showed a persistent, high density upflow at the base of a post-flare loop for at least 30 minutes.
- The combination of fast EIS rasters and high cadence imaging from AIA provides excellent opprtunities for flare studies.