RHESSI and IRIS observations of chromospheric evaporation in the 29th March 2014 flare

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Chromospheric evaporation in the standard solar flare model

Energy deposition in the chromosphere leads to heating and overpressure causing plasma to expand upward → EUV / soft X-ray loops
Drivers of chromospheric evaporation

Evaporation can be driven via

a) energy-input by non-thermal electron beam (eg. Fisher 1989)
b) energy input by thermal conduction (Longcope 2014)

It can be (depending on beam energy)

a) “explosive”
b) gentle

Height / Temperature

Fast (>~200 km/s) upflows of hot plasma, downflows of cool plasma → explosive evaporation

Slow (<200 km/s) upflows of hot and cooler plasma → gentle evaporation

→ Relative and absolute velocities can be used to distinguish the two types
Observations of chromospheric evaporation

Indirect observations

Hard X-rays indicate start of energy input

Soft X-rays as signature of evaporated plasma

Consequence of electron beam heating of the chromosphere: Neupert effect (time-integrated HXR flux ~ SXR flux) (e.g., Neupert 1968, Dennis & Zarro 1993, Veronig et al. 2005)
Direct observations

Observations of blue-shifted MK plasma from locations associated with HXR footpoints and flare ribbons

Milligan et al. 2006

And other observations with IRIS (Tian et al. 2015, Young et al. 2015, Brosius et al. 2015, Li 2015, Polito et al. 2016)
Observations of chromospheric evaporation in the March 29th 2014 flare

GOES X1 flare from 29 March 2014 (Kleint et al. 2015, Young et al. 2015, Li et al. 2015 ...)

Two moving flare ribbons
HXR emission for 2 min coinciding with location of ribbons
RHESSI: Location, timing and, amount of energy input

IRIS SJI at 2796 Å
6-12 keV: Coronal source, thermal
30-70 keV: Non-thermal electrons, location of energy deposition
IRIS: Location, timing, and velocity of evaporating plasma

- Use Fe XXI as diagnostic of hot (~10 MK) plasma
- Blue-shifts at location of flare ribbons
Location of upflows relative to HXR source locations

RHESSI SXR source at 6-12 keV

Battaglia et al. 2015

→ Upflows along the flare ribbons
→ Maximum speed ~ 200 km/s
→ Sustained several minutes after HXR
IRIS slit position relative to HXR source

Figure 4. Top left: IRIS 2796 Å images overlaid with 50%, 70%, and 90% contours from RHESSI CLearn images at 6-12 keV (black) and 30-70 keV (colors, 70% contours only). The slit positions are indicated with colored dashed lines. The RHESSI contours show the position of the HXR footpoint for each slit-position in the respective color. Top, other panels: Doppler velocity maps of Fe XXI along the slit for rasters 173 to 176 (indicated by white numbers). Grey areas denote pixels where either no Fe XXI emission was detected or the fit was bad. The contours of the HXR footpoints observed during rasters overlapping in the respective color so of the slit-positions.

Middle and bottom row (from left to right): Individual slit positions relative to HXR footpoint location during rasters no. 173 and 174, overlaid on IRIS 2796 Å and 1400 Å image rasters where no HXR footpoint were observed or no 2796 Å and 1400 Å JI were available are omitted.

4.2. Spatial Association of HXR footpoint emission with Fe XXI blue-shifts

According to the above calculation, the non-thermal power input is big enough to trigger explosive evaporation. According to Fisher (1987), explosive evaporation ceases and becomes gradual once the conductive flux out of the evaporated plasma becomes comparable to the beam flux. The change occurs at temperatures around $\sim 10^{7}$ K over time-scales of a few seconds to a few tens of seconds. In the presented event, the time scale would be of the order of 10 seconds. This scenario could explain blue-shifts that are still observed long after the HXR source since gentle evaporation will continue as long as there is a temperature gradient. Gentle evaporation is further supported by the observed velocities of less than 200 km s$^{-1}$. Thus the observations described in Section 3.1 can be explained with energy input by a non-thermal electron beam resulting in explosive evaporation followed by a transition to gentle evaporation whose signatures are observed once the IRIS slit covers the respective area.

4.3. Co-temporal observation of HXR emission and upflows
We can distinguish 3 cases

1) Upflows observed ~ 30 – 75 s after hard X-rays at a given location
2) Upflows observed co-temporally with hard X-rays but not from same location
3) Upflows not associated with hard X-rays
**Interpretation**

Electron beam driven chromospheric evaporation, transitioned from explosive to gentle and sustained for several minutes (Fischer 1987)

Rationale: Electron energy flux (as found from RHESSI spectrum) \( \sim (2.8-6.6) \times 10^{10} \text{ erg cm}^{-2}\text{s}^{-1} \rightarrow \) would trigger explosive evaporation

**But:** why are there no upflows at the location of HXR where the IRIS slit was co-spatial?

Possible reasons:
- Co-alignment of instruments
- Delayed onset of EUV emission due to ion equilibration time?
- ?

Conductively driven evaporation due to temperature gradient between hot (\( \sim 20 \text{ MK} \)) coronal source and chromosphere

\[
L_{\text{cond}} = 10^{-6} \frac{T^{7/2}}{L_T} \approx 2.2 \times 10^9 \text{ erg cm}^{-2}\text{s}^{-1}
\]
Observations at other temperatures?

Use EIS and other lines observed with IRIS (Polito et al. 2016, Li et al. 2015, Graham & Cauzzi 2015, Tian et al. 2015, ..)

This flare: Li et al. 2015 for selected pixels

We find:

**OIV**: inconclusive, mixed red and blue shifts from location of FeXXI blue-shifts

**SiIV**: red-shifts near leading edge of flare ribbons

**EIS**: line selection sparse. Suggestive of down-flows in FeXVI (2.8 MK) and FeXVII (5.6 MK) near

Conclusion: it is complicated!
Conclusions

- FeXXI is blue-shifted along the flare ribbon in the 29\textsuperscript{th} March 2014 flare
- Location, timing, and energy input calculated from hard X-rays suggests \textit{electron beams as dominant means of energy input during the flare peak}
- Sustained upflows after the X-ray peak and at locations not associated with HXR emission suggest \textit{energy input by thermal conduction as equally important} and (in parts) main driver of chromospheric evaporation