X-ray solar flare loops: temporal variations in length, corpulence, position, temperature and pressure.

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Flare X-ray (>3 keV) emission - corona to chromosphere

13-May-2013

“standard” flare

~3-25 keV
thermal/
non-thermal?
loop-top X-rays

~ > 30 keV
non-thermal footpoint X-rays

RHESSI

X-ray bremsstrahlung
Flare X-ray (>3 keV) emission - coronal X-rays only

- Strong coronal emission
- Bulk of X-ray emission is produced in the coronal loop.
- Non-thermal? loop-top X-rays
- ~3-25 keV

23-Aug-2005

RHESSI

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weak or no footpoint X-rays

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Spatial properties of coronal X-ray sources with energy

Loop Length:

![Image of loop length with energy intervals and fit]

- $L(E) \sim L_{AR} + 1/(2Kn) E^2$

Direction parallel to the guiding B-field.

Acceleration region

$E_2 < E_1$
Spatial properties of coronal X-ray sources with energy

**Loop Width:**

![Image](image.png)

- **23-08-2005 14:27-14:31**
- **Pixon**
- **VIS FWDFIT**
- **17-20 keV**

**Direction:** perpendicular to the guiding B-field.

**E_2 < E_1**

- **W(E) \sim W_0 + D_M E**
- **Presence of magnetic turbulence**
  - (Kontar et al. (2011))

**Acceleration region**

**Chromosphere**
RHESSI and Visibility forward fitting (VIS FWDFIT)

- X-ray visibilities - 2D Fourier components of the X-ray source (Hurford et al. 2002; Schmahl et al. 2007)

\[ V(u, v; \epsilon) = \int_{x}^{y} \int_{y}^{I(x, y; \epsilon)e^{2\pi i(xu+yu)}} dxdy, \]

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We studied 3 M-class events observed by Xu et al. (2008) and Kontar et al. (2011), concentrating on loop changes with time instead of energy:

1. 23rd August 2005
2. 14th/15th April 2002
3. 21st May 2004
Fig. 1. Flare 6 on 28th August 1995: Source changes in time at selected energies of 65.26 keV (left), 68.26 keV (middle), and 62.85 keV (right). The green source plots a Clean image at a selected time of 14:05:55 for each energy range allowing the overall shape of the source to be compared with that of the VIS FWDFIT contours (size) and correspondingly coloured asterisks (source centroid position).

Fig. 2. As Figure 1 but for Flare 6 on 26th April 1995.

Fig. 3. As Figure 1 but for Flare 0 on 21st May 1995. Note that this flare has been studied using different energy ranges of 6.26 keV (left), 62.85 keV (middle), and 85.28 keV (right) events using only Clean and Pixon to confirm the loop shape of each coronal source and find the energy ranges over which a coronal source was present in each flare. Once we were confident that our chosen events only had a simple loop shape, we studied each event using VIS FWDFIT. This is important since the coronal source must have a loop-like shape so that VIS FWDFIT can effectively fit a curved elliptical gaussian (loop) to the X-ray visibilities of the event and give realistic estimates with errors of the source parameters. VIS FWDFIT provides us with loop length FWHM (full width half maximum), loop width FWHM, and the yxz centroid position of the loop. It should also be noted that VIS FWDFIT gives the mean position of the loop shape, not the actual loop position.

Flare 1 - 23rd August 2005 event

- **Limb event with coronal emission in the range ~ 10-25 keV.**
- **Imaging time - 14:22:00-14:40:00** in two or four minute intervals.
- **Weak 30-40 keV footpoints emerging at ~14:36:00.**
23-August-2005 flare

The loop length and loop width change with time.

Fig. 5. 23rd August 2005, middle column 14th April 2002 and right column 21st May 2004 (1st row - Lightcurves for each event at each of the selected plotting energies (see each graph legend), 2nd row - changes in loop width with time, 3rd row - changes in loop length with time, 4th row - changes in loop radial position with time, 5th row - changes in emission measure, EM, with time and 6th row - changes in plasma temperature with time. The dashed lines on all plots represent the approximate points of peaks in the lightcurve. For all events, it can be seen that these peaks are points of change in the source width, length and position.

Peak X-rays

Radial distance [arcsec]

Length [arcsec]

Width [arcsec]

Radial distance [arcsec]

Observation Time

14:24 14:28 14:32 14:36 14:40

10-12 keV 12-15 keV 15-20 keV

For the 23rd August 2005 event - Imaging results.
23rd August 2005 event - *Spectroscopy results*

Peak temperature before peak X-rays

3. Inferring other parameters

The estimate of the source volume is very important as it allows many other parameters to be inferred. The plasma pressure $P$ from the Boltzmann constant and finally the energy density $E$ can be obtained via

$$V = \frac{\pi W^2 L}{4}$$

and

$$n = \sqrt{EM/V}$$

where $L$ is the loop length FWHM and $W$ is the loop width FWHM of each source.

An accurate estimate of the source volume is very important as it allows many other parameters to be inferred.

From the width and length parameters we can infer the changes in source volume $V$ at a given time.

Increases or decreases in loop position with time or energy were especially significant for the shape of each of these sources. Only Clean images are shown in this report but both algorithms each of our chosen events using different imaging algorithms - Clean and Pixonz to confirm the loop shape of each event.

The shape of a ring will pull the shape centroid towards the ends of the loop, often masking small increases or decreases in loop position with time or energy.

The coordinates of this were gained by taking the coordinates of the central circular gaussian that VIS FWDFIT uses to create the final loop shape along with a set of other circular gaussians we wish to define as the loop top centroid position, that is, the central position at the top of the loop.

The pressure $P$ is given by the algorithm is the loop shape mean position, not what is usually defined as the mean position of the loop.

Flare 1

23rd August 2005 event - Inferred parameters

Flare 1 - 14:22:00–14:26:00

- Data-background
- Thermal
- Thick target
- Background

The lightcurves for each event (1st row) for each energy range allowing the overall shape of the source to be compared with that of the VIS FWDFIT middle and 8,205 keV.

The green source plots a Clean image at a selected time of 14:22:55.

The inferences are:

- $V = \frac{\pi W^2 L}{4}$
- $n = \sqrt{EM/V}$
- $P = nk_B T$
23rd August 2005 flare - 3 phases:

**Phase 1** - Peak in plasma temperature

**Phase 2** - Peak in X-ray emission and smallest loop width

**Phase 3** - Peak in thermal pressure.
Results summary and other events

We observed two main temporal results for this type of event:

- Contraction and then an expansion of the loop volume before and after the peak in X-ray emission.
- Three temporal phases: peak in plasma temperature, peak in X-ray emission/smallest loop size and peak in thermal pressure.

We see the same results for two other coronal X-ray events.
Fig. 10. Observations of plasma temperature, X-ray emission, loop width and thermal pressure are replotted together for Flares 1 (left), 2 (middle) and 3 (right) at one energy band of 10-20 keV. Shades of orange represent the three phases of the proposed model: 1. the peak in plasma temperature, 2. the peak in X-ray emission, generally coinciding the smallest loop width and 3. the peak in thermal pressure.
Possible explanations and future work?

1. **A reduction in B pressure?** Liu et al. 2009, Gosain 2012 etc.

2. **Thermal conduction → chromospheric evaporation?**

3. **Thermal pressure balances and overcomes the reduction in B pressure?**
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Future studies/common or different trends for all flares?
- New events with SDO data → multiple loops interacting?
- An X-class event showed similar results using Clean (Caspi & Lin 2010).
- What about events with strong coronal emission and footpoints?