CORONAL LOOP INTERACTION OBSERVED AT VISIBLE WAVELENGTHS

R. N. SMARTT\textsuperscript{1}, Z. ZHANG\textsuperscript{2}, I. S. KIM\textsuperscript{3} and K. P. REARDON\textsuperscript{4}

\textsuperscript{1} National Solar Observatory/Sacramento Peak, National Optical Astronomy Observatories,\textsuperscript{*} Sunspot, NM 88349, U. S. A.

\textsuperscript{2} Nanjing University, Nanjing, China

\textsuperscript{3} Sternberg Astronomical Institute, Moscow State University, Russia

\textsuperscript{4} Institute for Astronomy, University of Hawaii
Honolulu, HI 96822, U. S. A.

\textbf{Abstract.} Coronal loops, as recorded in images of the emission from the 5303Å (Fe XIV) and 6374Å (Fe X) lines, display transient, localized brightenings, commonly evident in post-flare loop systems. Such brightenings apparently occur also in quiet coronal loop systems, but only in the lower range of energies that characterize these coronal events. Brightening is observed to occur in regions where two loops come into contact, with resultant heating of the common plasma volume, and subsequent cooling. The observations show systematically that a brightness maximum in the cooler (6374Å) line lags that of the hotter (5303Å) line, as also for H\textalpha{} material relative to the red line, the sequence revealing cooling of the plasma following initial heating. Coalescence is evident in that the brightness can extend away from the overlapping region along the adjacent parts of the loops. Brightenings are found to be a common phenomenon in post-flare loop systems.

\textbf{Key words:} Coronal Loops – Loop Interaction – Magnetic Reconnection

\section{1. Introduction}

Following a limb flare, as observed in green-line (5303Å; FeXIV) and red-line (6374Å; FeX) images, post-flare coronal loops have a complex structure as they rise above the limb, usually with the appearance of an arcade of loops with enhanced tops. Over a period of many hours, the loop system increases systematically in height, some loops fading, while others appear, but with a gradual decrease in brightness and fewer loops, and an overall simpler loop configuration, the system disappearing after roughly 12-15 hours after reaching heights $> 10^5$ km.

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High-quality images (Smartt et al., 1981) of such post-flare loop systems reveal occasional transient brightenings at localized regions (Smartt and Zhang, 1987; Zhang and Smartt, 1991; Smartt et al., 1993). A brightening appears first in images of coronal green-line emission. Brightenings increase systematically in intensity typically over a period of roughly 15 min to a maximum value, and then gradually fade, with a characteristic lifetime $\sim 30$ min. However, occasionally brightenings can remain at a maximum value for many min. Where the loop structure has a simple geometry, such brightenings are seen to occur at the projected intersection of two adjacent loops. In such cases, the brightening shows a slight extension along the loops away from the intersection point, with also some filling in of the space between the loops, revealing coalescence of the local plasma volumes. Estimated energies of these events are found to be similar to a small flare (Smartt and Zhang, 1987).

Following a maximum in brightening in a green-line image, a maximum occurs in the corresponding red-line image at the same location (apart from geometrical changes that occur in the post-flare loop system over the intervening period). A maximum in the red-line image lags a maximum in the green-line image by at least a few min, with a mean of 8.6 min (90 events). Following a maximum in a red-line image brightening, H$\alpha$ reaches a maximum in the vicinity of the brightening volume, with a mean lag relative to the red-line maximum of 9.3 min (90 events). The maxima appearing sequentially in the green-line, red-line and H$\alpha$ images are interpreted as a process of cooling of the plasma, after initial heating due to loop interaction, from the characteristic temperature of the green-line ($\sim 1.9 \times 10^6$K) to that of H$\alpha$ ($\sim 10^4$K). Since red-line emission is not observed at a brightening site prior to a brightening appearing in the green-line image, it appears that the plasma must be heated very rapidly following the onset of the interaction of two loops. If initial heating raises the plasma to a temperature higher than the characteristic temperature of the green-line, appropriate for other coronal lines, it is expected that a brightening will be observed in such higher-temperature lines prior to a maximum occurring in the green-line brightening following plasma cooling.

The observed brightenings are interpreted as loop coalescence with partial magnetic reconnection. An interpretation of the complex plasma processes involved is based on the theory of magnetic field reconnection driven by a ponderomotive force, in which an initial resistive instability turns into an eruptive instability at the onset of reconnection (Li et al., 1994). The predicted time scales for these events are consistent with those observed. Transient brightenings have also been observed with the Soft X-ray Telescope (SXT) of the Yohkoh satellite (Shimizu et al., 1992). At least some of these brightenings appear to have similar characteristics to those described here, but there has not yet been an opportunity to compare data common to the two instruments.
2. Data Review

When brightening occurs at an early stage in a post-flare loop system development, the specific loop system geometry is often not evident, due to the complexity of the total system. Especially in the case of brightenings that occur at a much later stage (after several hours) and where the “plane” of the interacting loops are not highly inclined to the line-of-sight, it is evident that brightenings occur when two loops come into contact at some localized region. On this basis, it is surmised that all, or most, brightenings are due to such types of loop interactions. However, it is obvious that cases can be expected where two loops interact that are close to parallel, and the region of interaction is then much more extended around the arc of the loops. Further, cases are expected where three loops interact simultaneously, especially in the early stage of a very complex post-flare loop development. It has been noted that post-flare loops often display enhanced tops. Detailed examination of these enhanced tops reveals the same characteristics as localized brightenings - small knots of plasma in the tops become bright independently and then fade, in a manner similar to that of other individual loop brightenings. It is suggested that such brightenings in loop tops could be due to localized interaction of a compact arcade system of loops, or loop segments, in close proximity, of a helical loop top. Fig. 1 is an example (15 June, 1980) of a brightening event in green-line emission at the beginning (16:33UT) (a) and maximum (16:55UT) (b) phases. In this case, the geometry of the complex loop system in the vicinity of the site of interaction is not evident. Fig. 2 is an example (7 December, 1981) of another brightening event in green-line emission at the beginning (17:47UT) and maximum (18:01UT) phases. In this case, the geometry is clearly evident on the original negative, that of the intersection of two isolated loops.

![Figure 1. Brightening event in (15 June, 1980) green-line emission at the initial (a) and maximum (b) phases.](image)

Complex Hα loop structures are invariably associated with post-flare loop systems in their early phase of development. Hence, for events that occur in an early phase, changes in the Hα structure associated with the development of a brightening are not readily interpreted, but the association with the brightening is most clearly evident,
usually with a bright knot of material at the interaction site. For events that occur much later in the development of a post-flare loop system, Hα simply appears at the interaction site with only a partial connection between this material and the solar surface.

The number, N, of brightening events recorded per year over an eleven-year period is indicated in Fig. 3. Under excellent observing conditions, and with observations of a post-flare loop system extending over several hours, the probability of detecting one or more events is close to unity. Since the conditions required for coronal observations, such as sky clarity and instrumental performance, are much more critical than for normal synoptic solar observations, the number of events (90) represented in Fig. 1 are far less than the number of post-flare loop systems that could be viewed under ideal conditions from a single site. Nevertheless, the form of the distribution reflects the probability of limb flares as a function of the solar cycle, and the special opportunity of obtaining data around the peak of the cycle.

Figure 3. Number, N, of brightening events recorded as a function of the solar cycle.
Fig. 4 shows the number, \( N \), of brightening events recorded as a function of projected height, \( h \), above the limb, with a mean value \( \sim 3 \times 10^4 \) km, or 42 arcsec. The relatively few observations above \( 4 \times 10^4 \) km reflects: a) the decreasing number of loops as a function of height and hence, the lower probability of a loop interaction, and (possibly), b) the decreasing energy in the loop system as a function of time following a flare, with corresponding reduced intensity that could reduce the probability of detection.

\[ \begin{array}{c}
\hline
h & N \\
\hline
20 & 30 \\
40 & 20 \\
60 & 10 \\
80 & \\
100 \times 10^3 \text{ km} & \\
\hline
\end{array} \]

**Figure 4.** Number, \( N \), of brightening events recorded as a function of projected height, \( h \), above the limb.

Fig. 5a shows the distribution of the lag in time, \( \Delta t \), of the maximum in intensity of a brightening event as recorded in red-line emission following a maximum in intensity as recorded in green-line emission. Times assigned for the start, maximum and end of an event are rough estimates only, since the images of most brightenings are too small on the original negative to allow accurate photometry. Nevertheless, percentages of errors are believed to be relatively small. Fig. 5b is a similar plot that shows the lag in time of the maximum in H\( \alpha \) emission in the vicinity of the interaction site, following the maximum in the red-line emission.
Figure 5. (a) - Number, N, of brightening events as a function of the lag in time, $\Delta t$, of maximum brightness of red-line emission relative to that of green-line emission; (b) - Number, N, of brightening events as a function of the lag in time, $\Delta t$, of the maximum in Hα emission relative to that of red-line emission.

2.1. Video Recording

A 150-minute sequence of a complex post-flare coronal loop system has been digitized and converted to a video format. When this record is played at a fast (300x, or faster) rate, it becomes apparent that, beyond the development of two obvious loop interaction events, as previously described, other features become evident. In particular, one of the brightening events is seen to move downwards suggesting that the two loops involved are changing rapidly in their relative relationship around this maximum emission period (a few minutes), and/or that the mechanisms involved in the emission process might cause, under certain circumstances, the emitting plasma volume to propagate away from the loop crossing region along adjacent parts of the loop legs. The video sequence also reveals several transient loop brightenings at different locations in the loop systems that are relatively weak and therefore not apparent from the examination of single frames. This new evidence supports the view that loop interaction events occur commonly in post-flare loop systems. There is some limited evidence that brightening events occur also in “quiet” coronal loop systems. Such data will be similarly digitized and processed to explore this question further.

3. Conclusion

Data from coronal loop interaction events, as observed in green- and red-coronal line emission, and in Hα, are found to represent a well-defined phenomenon. Specifically, transient brightenings in coronal loop structures are observed first in images of green-line emission, followed by a corresponding enhancement in red-line emission, and subsequently a maximum in Hα at the interaction site. Projected video images of these data confirm that these events occur commonly as a post-flare loop system develops, including a regime of weak brightenings that are not evident in single images.
is a need to compare these data with other coronal data, such as the soft X-ray data from the Yohkoh spacecraft.

References