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LOOP INTERACTION IN THE VISIBLE EMISSION CORONA -- MORPHOLOGICAL DETAILS

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ABSTRACT

Coronagraph observations of two post-flare loop systems, recorded photographically in the emissions of Fe XIV (5303Å) and Fe X (6374Å), show occasional enhancements at the intersections of some loops. The brightness of such enhancements in the green-line gradually increases to a maximum value several times greater than that of the legs of the loops and then declines with a typical lifetime ~ 30-60 minutes. In red-line emission the loop systems are usually very faint, but show the same overall type of enhancement, with a lag in maximum brightness relative to that of the green line ~ 10 minutes. The electron density, derived from the cooling time, is $\sim 10^{12} cm^{-3}$.

I. INTRODUCTION

We discuss here observations of two flare-associated coronal loop systems, as observed in visible coronal emission lines, with emphasis on characteristics of loop interaction processes during the post-flare phase.

Interacting coronal loops have been investigated in relation to flare studies. Machado (1982) has found that most, if not all, X-ray flares originate in two or more intersecting loop structures. Rust and Somov (1984) showed that 3.5 - 11.5 Kev X-ray brightening started near the intersection of two flare loops. They assumed a thermal energy source at the point of intersection of the two loops, with equal conduction of heat flux into each loop. Transient X-ray brightenings of interconnecting loops have been investigated by Spicer and Svestka (1983). They argue that the fast tearing mode or anomalous Joule heating (following inductive changes in the field) could cause the brightenings, the mechanism depending on the loop history. VLA 6-cm observations have provided evidence of interacting loops that trigger flares and the first direct evidence of the coalescence of coronal loops (Kundu *et al.*, 1984; Kundu, 1983, 1985). These radio observations indicate that in the 20 seconds preceding the impulsive peak ($T_b \sim 1.1 \times 10^9 K$), the arcade of loops (burst source) changed and ultimately developed into two strong bipolar regions or a quadrupole structure whose orientations were such that the field lines were opposed to each other near the loop tops.

The above studies are concerned with the large energies associated with flare production, while the events discussed here represent much smaller energies, since they occur in loop systems in the post-flare phase, often several hours after the flare occurrence. However, the basic processes associated with interacting loops that lead to the release of energy appear to be the same in both the high- and the low-energy cases.

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II. OBSERVATIONS

Observations were obtained with the National Solar Observatory/Sacramento Peak 20-cm aperture patrol coronagraph. Coronal images in Fe XIV (5303Å), Fe X (6374.5Å) and images in Hα of the disk and of prominences are recorded sequentially on high-resolution (SO-115), 70-mm film (Smartt *et al.,* 1981). In the normal mode of operation, a set of these four images is recorded in an interval $\lesssim$ 30s, and repeated at 1 minute intervals. Here we describe the loop interaction features observed in the post-flare loop systems of April 28, 1980 and November 14, 1980.

a) Flare-associated loops, April 28, 1980

These data cover the period 1343 to 1652 UT and 2145 to 2345 UT. The loops are located at a latitude $\sim 22^\circ$. At 1531 UT, an obvious bright point in the green-line loops occurs at the projected intersection of two loops. Microdensitometer measurements of this feature reveal that it is equivalent to a coronal brightness $\sim$ 5 times larger than that of the well-defined loop legs. Approximately 15 minutes before, and 15 minutes later, this feature was no brighter than the other parts of the loop tops. At 1531 UT, the same feature can be identified in the red-line image, although far less bright and less extensive than in the green-line image. It reaches maximum brightness at $\sim$ 1541 UT, although still exceedingly faint. Fine, hair-like lines define the point of intersection of the loops. These combined green- and red-line observations suggest that the enhancement is due in part to an increase in temperature, the lag $\sim$ 10 minutes in the red-line maximum relative to that of the green-line being a measure of green- to red-line cooling time. However, since the feature is visible in the red-line image, but with little other associated structure of the whole loop system, it is likely that the integrated path is greater than simply the sum of two loops along the line-of-sight.

At 1931 UT, the green-line loops (Figure 1) have now reached a height $\sim 10^5$ *km*. At this time, there are fewer loops in the system, and due to the inclination of the plane of the loops relative to the line-of-sight, enhancements that occur at loop intersections are now clearly evident. The large X-point enhancement corresponds to a brightness $\sim$ 3 times larger than unenhanced parts of the loops. This enhancement is not confined to the region of intersection, but clearly extends for considerable distances along the loops. For example, the lower right-hand part of the "X" appears to be enhanced for at least 2.5 x 10^3 km from the point of intersection. This type of observation, together with the measured brightness, confirms that such features arise from localized loop interactions.

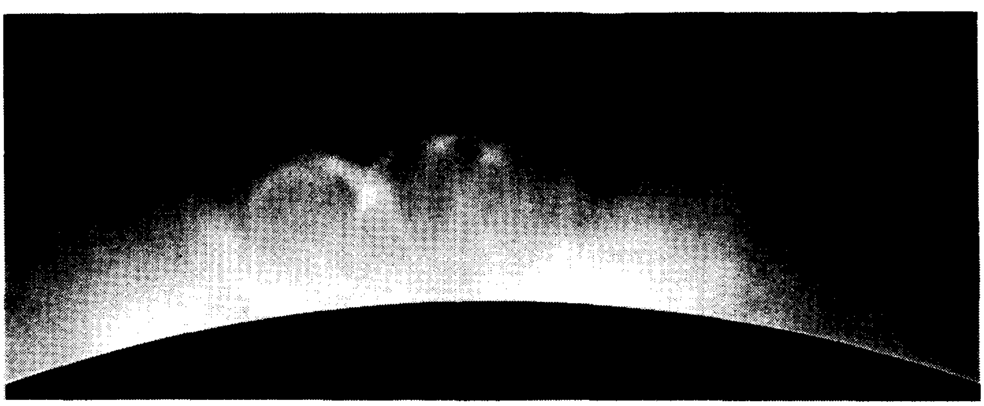

Fig. 1 - Flare associated coronal loops, recorded in Fe XIV (5303Å), on April 28, 1980, at 1932 UT, showing enhancements at loop interactions.

b) Flare-associated loops, November 14, 1980

These loops occurred on the west limb at a latitude of 22° N, the data spanning the interval 1633 - 1808 UT. However, due to a fault in the microprocessor control, data were recorded only at intervals of a few minutes. The most obvious general characteristic of the loops as they appear in the green-line image is the suggestion of two systems of loops, as indicated by the obvious discontinuity in the outline of the loop tops. A bright point occurs at this location, maximum at ~ 1732 UT, as shown in Figure 2.

Fig. 2. Flare-associated coronal loops, recorded in Fe XIV (5303Å) on November 14, 1980, at 1732 UT, showing a bright enhancement at the intersections of two loop systems.

The rise time is estimated to be ~ 25 minutes, while the decay time is ~ 30 minutes. As in the cases discussed above, a similar bright point also becomes evident in the red-line record, reaching a maximum value ~ 10 minutes after the green-line maximum. This lag time estimate is less precise than in the previous cases because of the data gaps. The faint red-line "X" enhancement is notable for its narrow dimensions. The green-line enhancement has an area ~ 4.6 x $10^7 km^2$.

III. ANALYSIS

It was noted in Section II that the maximum brightness in a red-line enhancement at the X-point appears to lag the maximum in the green-line enhancements by about 10 minutes, apparently a measure of the cooling time. Moore et al. (1980) find that radiative cooling dominates conductive cooling when $T < 10^7 K$. The radiative cooling time is given by,

$$\tau_c = \frac{3KT}{\Lambda_\gamma N_e} \qquad (1)$$

where K is the Boltzman constant, T, the plasma temperature before cooling, Λ_λ, the radiative cooling coefficient and N_e, the electron density. If we assume that cooling from maximum green-line emission to maximum red-line emission is due predominantly to radiative cooling, we can estimate a maximum value for the electron density in the region of the enhancement from equation (1). The radiative cooling coefficient has a value of about $10^{-22} erg\ cm^3 s^{-1}$ (Raymond *et al.*, 1976). Then,

$$Ne \lesssim 4.3 \times 10^6\ T/\tau_c,$$

where the unit of τ_c is in minutes.

The appropriate value for T is uncertain, but since red-line emission can be observed faintly at the X-point at the time of maximum green-line emission, we argue that an average value of T in the enhancement cannot be far in excess of the characteristic temperature of the green-line. We therefore take T = 2 x $10^6 K$; then $Ne \lesssim 10^{12} cm^{-3}$.

IV. DISCUSSION

The question arises concerning the morphology of the loop system that leads to the condition required for an X-point brightening. An arcade of loops spanning a field line contains parallel loops with currents having the same sense. Our observations typically show much more complex structure in which parallel loops appear to be the exception. It therefore seems likely that an encounter between two loops that have intersecting planes occurs when the lower loop develops more rapidly than the higher loop, or simply if photospheric motion moves the loop footpoints such that contact occurs. The reason for the relatively short life-times of the enhancements is not obvious.

In summary, we have presented here the first evidence of coronal loop interaction in the post-flare phase as observed in visible coronal lines. Derived electrons densities are found to be roughly an order of magnitude larger than those that characterize the loop system. A definitive analysis of the phenomenon will probably require spectral data of the visible emisison as well as coordinated observations with X-ray, EUV and radio measurements.

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