MORPHOLOGY OF ACTIVE REGION TRANSIENT BRIGHTENINGS WITH THE YOHKOH
SOFT X-RAY TELESCOPE

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ABSTRACT

Frequent transient X-ray brightenings occur in solar active regions. The Yohkoh Soft X-ray Telescope observed 142 transient brightenings during an interval of time in late 1991 October. We classify them in terms of morphology and time evolution: (1) simultaneous multiple loop brightenings are more often seen than brightenings of single and pointlike structures; (2) for multiple-loop brightenings, the loops tend to brighten from their footpoints and/or the apparent contact point in the initial phase of transient brightenings, followed by the brightening of the entire loops; (3) more than one-half of the multiple-loop brightenings have Y-type configurations in which the apparent contact points are located close to their footpoints. Though transient brightenings show great variety in morphology, these results suggest that most of them are due to the magnetic interaction of multiple loops. X-ray emission from the footpoints in the early phase suggests that the hot plasma in the brightening loops comes from chromospheric matter or low-temperature coronal matter present around the bases of the coronal loops prior to the brightening. Enhanced X-ray emission at the contact points implies local plasma heating by magnetic interaction. The predominance of the Y-type configuration suggests that the interaction of coronal loops tends to occur near the footpoints.

Subject headings: Sun: activity — Sun: corona — Sun: flares — Sun: X-rays, gamma rays

1. INTRODUCTION

The Soft X-ray Telescope (SXT) (Tsuneta et al. 1991) aboard the Yohkoh satellite (Ogawara et al. 1991) reveals that active regions show many small flare-like brightenings (Shimizu et al. 1992). The energy involved in a transient brightening is $10^{23} \sim 10^{24}$ ergs, at or below the low end of the subflare energy range (Thomas & Teske 1971). The duration of the transient brightenings is from a few minutes to tens of minutes. Shimizu et al. (1992) have found that intense transient brightenings coincide in time with small soft X-ray enhancements observed with GOES satellites but that SXT images show many faint transient brightenings which are not detectable by GOES. Transient brightenings are observed on average every $\sim 3$ minutes in "active" active regions down to every $\sim 1$ hr in quieter active regions (Shimizu et al. 1992).

In the previous solar maximum, a balloon-borne hard X-ray (above 20 keV) observation with very high sensitivity (detection limit $\sim 10^{-2}$ photons keV$^{-1}$ cm$^{-2}$ s$^{-1}$) discovered "microflares" with nonthermal hard X-ray spectra (Lin et al. 1984). This discovery has led to the speculation that numerous microflares or nanoflares may be a possible source for heating the corona (Lin et al. 1984; Parker 1988), but Hudson (1991) suggests that the existence of the distinct frequency distribution is needed in the nanoflare energy range for coronal heating. Canfield & Metcalf (1987) identified the Hz counterparts of some large microflares observed by Lin et al. (1984) on the basis of their temporal coincidence. Tsuneta & Lemen (1993) pointed out that the microflares observed by Lin et al. (1984) are associated with small soft X-ray enhancements seen in the GOES time profile and suggested that the transient brightenings revealed by SXT are the soft X-ray counterpart of the hard X-ray microflares.

The SXT observation provides a new tool to study the spatial structure of transient brightenings or microflares; high spatial resolution together with the high time cadence enables us to study the time evolution of the transient brightenings. Shimizu et al. (1992) have reported that transient brightenings have a variety of morphology and time evolution. In this paper, we classify transient brightenings in terms of morphology and time evolution. Observation and analysis procedures are presented in § 2 and examples of the transient brightenings are shown in § 3. In § 4 classifications of the transient brightenings are presented, and in § 5 we discuss the interpretation of the classifications.

2. OBSERVATION AND DATA ANALYSIS

2.1. Observation

SXT is a grazing incidence soft X-ray (3 $\sim$ 60 Å) telescope equipped with a 1024 x 1024 charge coupled device (CCD) detector. Two filter wheels and a mechanical shutter are mounted in front of the CCD detector to choose energy band and exposure time. The CCD camera, filter wheels, and shutter
are controlled by onboard microprocessors. SXT provides high-quality images with excellent scattering performance and with high temporal and spatial resolution. For more detailed description, refer to Tsuneta et al. (1991).

The data used in this analysis were taken in the period of 1991 October 24 to 31. Partial CCD images (10’ × 10’ with two different X-ray filters (Al 1265 Å filter, Al/Mg/Mn filter) are available every 128 s. The pixel size of the images is 2.46. The target region is the Active Region NOAA 6891, which is completely covered by the 10’ × 10’ field of view. The exposure durations are controlled by an onboard automatic exposure control logic, so that most of the images are taken with proper exposures without saturating the CCD.

The total observation time in the high telemetry bit-rate per day was about 4 hr in late 1991 October, and the maximum continuous data coverage without interruption was about 30 minutes the situation was greatly improved with the use of NASA’s deep space network to receive the Yohkoh telemetry, starting in 1991 mid-November). The target region showed very high activity with five X-class flares (Solar Geophysical Data) and more than half of the observation time was occupied by major flare observation.

2.2. Data Selection and Data Analysis

The Active Region NOAA 6891, which was located at the disk center on 1991 October 27 was selected for the detailed analysis because it produced many transient brightenings. Images satisfying the following criteria were chosen: (1) the region should be located within 45 heliocentric degrees from the disk center (1991 October 24 to October 31), to avoid foreshortening; (2) images should not be saturated; (3) more than seven sequential images, corresponding to a time coverage of ~15 minutes, should be available to study the time evolution; and (4) images should not contain flares (>C2 GOES classification), because exposure durations suitable for flares bias against seeing fainter brightenings. The total time coverage of all the data selected with the above criteria is about 6.25 hr.

We selected those events that were observed throughout their lifetime and events observed from beginning up to maximum phase, to study the behavior in the growth phase. We selected 142 transient brightenings in total. The number of events is sufficient to classify them statistically in terms of morphology and time evolution. The morphological conclusions come from visual inspection of the images.

3. EXAMPLES OF TRANSIENT BRIGHTENINGS

The excellent spatial resolution of SXT has revealed that active-region transient brightenings show much variety in morphology and evolution. In this section we present some specific examples (Fig. 1a–li [PI 8 and 9]). Here the lifetime of a transient brightening is defined as the duration above half-maximum intensity. The intensities shown below are their total energy fluxes at the SXT focal plane through the Al 1265 Å filter in the unit of ergs s⁻¹. In comparison with the 0.5–4 Å soft X-ray data from the GOES spacecrafts, 5 × 10⁻⁸ and 5 × 10⁻⁵ ergs s⁻¹ roughly correspond to 2 × 10⁻⁹ (~B3 class) and 10⁻⁷ (~B1 class) W m⁻² in the GOES 0.5–4 Å channel, respectively.

3.1. Multiple-Loop Brightening Example 1

The morphological evolution of the first example is presented in Figure 1a. The bright feature appears around 2202 UT on 1991 October 30, i.e., in the second picture. We observed no features relating to this brightening in the image taken about 2 minutes prior to the second picture. The lifetime of the brightening is about 8 minutes and its peak intensity is about 3 × 10⁻⁴ ergs s⁻¹ around 2207 UT.

This transient brightening has two loop structures, which appear to be in contact in the middle. The separate southern footpoints are seen clearly, whereas the northern footpoints are not resolved. The length of each loop is about 3.5 × 10⁶ km, and its width is about 5 × 10⁵ km. Because the entire loops brighten in the second image, we cannot determine where the brightening starts in this case. This implies that the transient brightening has a rapid evolution, less than 2 minutes in the early phase.

3.2. Multiple-Loop Brightening Example 2

This event starts at about 2055 UT on 1991 October 27, peaks in total intensity (2 × 10⁻³ ergs s⁻¹) around 2100 UT, and then slowly fades. It is a relatively large event and is observed by the GOES satellites as a small enhancement above the slowly varying background (about C2 background level at that time) in the 1–8 Å range. Its evolution is shown in Figure 1b. Three loops can be seen clearly, which appear to be close together at the top of the loops. The length of each loop is about 5 × 10⁴ km, and its width is about 5 × 10³ km. The northern loop is the brightest of the three loops. The loops initially brighten from both footpoints and then become filled with X-ray emitting plasma. The top of the loops is the brightest in the peak phase.

Another faint single-loop brightening appears on the north of the brightest loop around 2101:33 UT.

3.3. Multiple-Loop Brightening Example 3

The third example (Fig. 1c) starts to brighten around 2142 UT, 1991 October 25. The apparent contact point of the multiple loops is the brightest. Note that this brightest region is saturated in the second and third pictures. This bright region then extends to the entire loops. The initial brightening at the contact point contrasts sharply with the initial brightening at the footpoints in the previous example. The length of each loop is about 5 × 10⁹ km, and its width is about 5 × 10⁵ km. The lifetime of the brightening is more than 10 minutes with the peak intensity of 3 × 10⁻² ergs s⁻¹ around 2149 UT.

Preexisting loops (first picture) were already present before the onset of the transient brightening, implying that they had relatively higher density or temperature than the prebrightening plasma of the example in Figure 1b. The preexisting bright loops are due to another transient brightening prior to the first picture.

We should note that our video movie of this brightening shows the slow movement of the northern loop toward the direction of the southern loop, giving us the impression that the motion drives the interaction of the two loops.

3.4. Multiple-Loop Brightening Example 4

In Figure 1d the bright feature that can be seen just below center is another transient brightening beginning just prior to the first picture, which is independent of the transient brightening mentioned in this subsection. The brightening of interest starts around 2109 UT on 1991 October 24 and lasts about 8 minutes. Its peak intensity is about 1 × 10⁻³ ergs s⁻¹. This transient brightening can be regarded as consisting of two
Fig. 1.—Evolution of active-region transient brightenings. The size of each image is 205 × 205. North is up and west is to the right. These images are normalized for exposure time and adjusted for the differing filter transmission (Hα 1265 Å and Al/Mg/Mn filters). Panels (a)–(e) show simultaneous brightenings of multiple loops, with the initial brightening of the whole loop (a), at footpoints (b), at the contact point (c), both at the footpoints and at the contact point (d), and at the contact point and a footpoint (e), respectively. Panel (f) is an example of the pointlike brightenings. Panels (g)–(i) show brightenings of the single loops, with the initial brightening of the whole loop (g), at both ends of the loop (h), and at one side of the loop (i), respectively. In (b), the black strip is an artifact.

Shimizu et al. (see 422, 907)
PLATE 9


30-OCT-91


25-OCT-91


30-OCT-91

(h) 20:59:02 21:01:10 21:03:18 21:05:26 21:07:34

24-OCT-91


25-OCT-91

Fig. 1—Continued

SHIMIZU et al. (see 422, 907)
loops, because two separated legs can be seen in the west side. The length of each loop is about $4 \times 10^4$ km, and its width is about $3 \times 10^3$ km.

The contact point of the loops as well as their footpoints are bright in the picture just after its onset. The 2114 UT picture shows that the tops of the loops are brightest in the peak phase.

3.5. Multiple-Loop Brightening Example 5

The example shown in Figure 1e has a complex morphology. The transient brightening of interest is the faint event which starts to brighten in the center of the picture around 2208 UT on 1991 October 30. The bright feature on the top edge of the picture is another transient brightening that occurred just prior to the first picture. The faint looplike feature on the southwest of the first picture is also another transient brightening.

In the third picture we can see a bright core feature and a loop structure which expands from the bright core eastward. Also, a faint loop structure expands from the bright core westward. In the second picture we can observe two faint parallel loops in the location where the brightening feature appears. The faint parallel loops have two slightly enhanced emissions; one is on the location where the bright core feature appears, and the other is on the east side of the brightening loop structure. Thus, this transient brightening may have two loops with unbalanced intensities, and they may brighten from a contact point and one footpoint.

This transient brightening has the length of about $2 \times 10^4$ km and the width of about $2 \times 10^3$ km. Its lifetime is about 4 minutes and its peak intensity is about $2 \times 10^{-4}$ ergs s$^{-1}$.

3.6. Pointlike Brightening Example

The transient brightening presented in Figure 1f is an example of a pointlike brightening. The diameter of this brightening is less than a few pixels. The brightening is seen only in the third picture, and its duration is considerably shorter than other events. The intensity of the brightening is $8 \times 10^{-5}$ ergs s$^{-1}$ in the third picture. A faint feature in the first and second pictures appears to be the remnant feature of another pointlike brightening that occurred prior to the first picture. We have the impression that some pointlike brightenings recur almost in the same location.

3.7. Single-Loop Brightening Example 1

The size of the transient brightening shown in Figure 1g is somewhat larger than those of the pointlike brightenings, such as Figure 1f. This is classified as single-loop brightening due to the elliptical shape. The length of the brightening is about $9 \times 10^3$ km on the major axis and $4 \times 10^3$ km on the minor axis. The brightening is seen only in the third picture with an intensity of $3 \times 10^{-4}$ ergs s$^{-1}$.

3.8. Single-Loop Brightening Example 2

The transient brightening (Fig. 1h) appears near the boundary of a sunspot penumbra located on the west side of the brightening. This has a single-loop structure with length of $2 \times 10^6$ km and width $4 \times 10^3$ km. It starts to brighten from both ends of the loop, followed by the entire loop brightening. The brightening lasts about 5 minutes with the peak intensity of about $3 \times 10^{-4}$ ergs s$^{-1}$.

In the fourth picture, another transient brightening appears on the lower right-hand side. The bright feature on the top edge of the pictures is also another transient brightening that occurred prior to the first picture.

3.9. Single-Loop Brightening Example 3

The transient brightening shown in Figure 1i appears near or at the location where the brightening in Figure 1h has appeared on the previous day. It is also similar to the brightening in Figure 1h in morphology and evolution. However, the X-ray emitting plasma is generated at one end of the loop in the initial phase and then fills up the loop. The length of the loop is about $2 \times 10^6$ km, and its width is about $4 \times 10^3$ km. The peak intensity is about $1 \times 10^{-4}$ ergs s$^{-1}$.

4. CLASSIFICATION OF TRANSIENT BRIGHTENINGS

The previous section shows that soft X-ray images obtained by SXT enable us to study the morphology and evolution of active-region transient brightenings and that they have wide variations in morphology and time evolution. We shall attempt to classify 142 transient brightenings, including the events that are illustrated in the previous section, in terms of morphological and evolutionary characteristics in order to illustrate their common properties. These brightenings are selected with the selection criteria mentioned in § 2.2.

4.1. Single Loop or Multiple Loops

While the three transient brightenings illustrated in § 3 appear to consist of a single loop, five others are simultaneous brightening of multiple loops. Therefore, the sample of transient brightenings are classified into three morphological categories: (1) pointlike brightenings, (2) brightenings of a single loop, and (3) simultaneous brightenings of multiple loops (Table I). Here the multi-loop events are defined as simultaneous brightenings of two or more separate loops, parts of which overlap each other. The pointlike events are defined as circular brightenings with the diameter less than $12^\circ 5$ (5 pixels), and the single-loop events are elongated structures for which only one loop brightens. The examples in Figures 1a–1e are classified as multiple-loop events, whereas the example in Figure 1f is a pointlike event, and the examples in Figures 1g–1i are single-loop events, respectively.

Table 1 shows that 57 events out of 142 samples appeared with multiple loops, 59 events were single loops, and 26 events were pointlike. This result indicates that simultaneous multiple-loop brightenings are seen as often as brightenings of single loops. The number of simultaneous multiple-loop brightenings, however, is less than the sum of single-loop and pointlike brightenings. Note that NOAA 6891 is so bright that bright background structures may obscure some faint transient brightenings.

In simultaneous brightenings of multiple loops, the participating loops have wide variations in morphology. Two brightening examples are shown in Figures 1g–1i. They show different types of brightenings, which are classified as single-loop, multi-loop with balanced intensity, multi-loop with unbalanced intensity, and multi-loop with complicated structures. The classification is based on the intensity and morphology of the brightening features. The table lists the number of events in each category.

<table>
<thead>
<tr>
<th>Morphological Classification of Transient Brightening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification</td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>Total analyzed event</td>
</tr>
<tr>
<td>Point-like event</td>
</tr>
<tr>
<td>Single loop event</td>
</tr>
<tr>
<td>Multiple loop event</td>
</tr>
<tr>
<td>2 loops balanced intensity</td>
</tr>
<tr>
<td>unbalanced intensity</td>
</tr>
<tr>
<td>&gt; 2 loops (complicated)</td>
</tr>
</tbody>
</table>

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ening loops are seen in 86% of the multiple-loop events (Figs. 1a, 1c, 1d, and 1e), and 14% show more than three loops (Fig. 1b). In the events with two brightening loops, more than one-half of them have the loops with similar intensity (Figs. 1a, 1c, and 1d), although some show unbalanced intensity (Fig. 1e).

Figure 2 shows the distribution of the loop length of multiple-loop events, of single-loop events, and pointlike events. The length of the loops in single-loop events is shorter than that of the loops in multiple-loop events. Most of single-loop brightenings are less than 25" long, which corresponds to about 10 CCD pixels.

4.2. Morphological Evolution of Single-Loop Events

In the following two sections, we try to classify transient brightenings in terms of morphological evolution.

Table 2 shows where the loop starts to brighten, i.e., the loop footpoints or the loop top for 59 single-loop events. An event which has its entire loop brightening in the first image is classified as "whole loop brightening." About 70% of single-loop events are classified this way. The temporal resolution of 128 s, however, may not be enough to catch their initial evolution.

It is observed that 30% of single-loop events brighten from parts of the loop; some of them from the top, others from the footpoint(s) of a loop such as Figures 1h and 1i. The number of events which brighten from footpoint(s) is considerably larger than the number of events which brighten from the top. The brightenings at the loop footpoints are a typical feature in the early phase for the single-loop events. This partial brightening either at the footpoints or the top of the loop is followed by the entire loop brightenings. Therefore, it is more likely that the whole-loop brightening cases started at the footpoint(s) or top.

4.3. Morphological Evolution of Multiple-Loop Events

A detailed classification of 57 multiple-loop events is shown in Table 3. Here "contact point" means the place where two loops appear to contact or merge into each other. Events which start to brighten from their contact point, such as Figure 1c, occupy about 18% of multiple-loop brightenings, whereas the events with one footpoint brightening are 4%, and the events with two footpoint brightenings, such as Figure 1b are 21% of the total. About 18% of multiple-loop events appear to brighten both from their contact points and from their footpoints (Fig. 1d).

The events classified as "whole loop brightening," such as Figure 1a, are 32% of multiple-loop events, which is considerably less than that of single-loop events. This may be due to the fact that the size of multiple-loop events is larger than that of single-loop events (see Fig. 2). "Contact or footpoint" in Table 3 means that we cannot decide on the place where the brightening starts, because of the close distance between the contact point and the footpoint. The brightening starts either from the footpoint(s) or the contact point without exception. This result means that the initial brightenings at the footpoint(s) or at the contact points are characteristic of multiple-loop events.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole loop brightening</td>
<td>18</td>
<td>31.6</td>
</tr>
<tr>
<td>From one footpoint to whole</td>
<td>2</td>
<td>3.5</td>
</tr>
<tr>
<td>From two footpoints to whole</td>
<td>12</td>
<td>21.1</td>
</tr>
<tr>
<td>From contact point</td>
<td>10</td>
<td>17.5</td>
</tr>
<tr>
<td>From one footpoint + contact</td>
<td>4</td>
<td>7.0</td>
</tr>
<tr>
<td>From two footpoints + contact</td>
<td>6</td>
<td>10.5</td>
</tr>
<tr>
<td>From one footpoint + (contact or footpoint)</td>
<td>4</td>
<td>7.0</td>
</tr>
<tr>
<td>From contact or footpoint</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>From other except footpoint and contact</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

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TABLE 4
MORPHOLOGICAL CLASSIFICATION OF MULTIPLE-LOOP EVENTS

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>NUMBER</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-type configuration</td>
<td>14</td>
<td>24.6</td>
</tr>
<tr>
<td>Y-type configuration</td>
<td>35</td>
<td>61.4</td>
</tr>
<tr>
<td>I-type configuration</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Others</td>
<td>7</td>
<td>12.3</td>
</tr>
</tbody>
</table>

4.4. Geometrical Configuration of Multiple Loops

Table 4 describes the spatial relationship between two brightening loops for multiple-loop events. Here X-type is the configuration in which the contact point is located near the tops of two loops. Y-type is the configuration in which the contact point is located close to the footpoints of two loops. I-type is the configuration in which two loops are in line with each other and the contact point is located close to their footpoints. The category “others” are complicated brightenings which do not allow us such simple classifications.

More than one-half of the multiple-loop events are classified as Y-type configuration, and one-fourth of them as X-type configuration. The I-type configuration is rare. Since the contact point in a Y-type brightening may be lower in altitude than that of an X-type brightening, this suggests that the interaction between multiple loops may occur more readily in the lower coronal atmosphere than in the higher coronal atmosphere.

5. DISCUSSIONS AND CONCLUSIONS

5.1. Interpretation of Classification Results

The morphological classification of transient brightenings (Table 1) shows that simultaneous brightenings of multiple loops are seen as often as brightenings of a single loop. One may suspect that multiple-loop events are simply time coincident but independent single-loop brightenings. Assuming that two independent single-loop brightenings occur randomly in the active region, we roughly calculated the probability that they should be observed as multiple-like features and found that its probability may be considerably less than 15%. This suggests that most of 57 multiple-loop events (40.2% of 142 events) are due not to chance occurrence of two independent loop brightenings but to the interaction of more than two loops.

On the other hand, are single-loop or pointlike brightenings really a single emitting structure? If so, one-half of the transient brightenings could be explained by single-loop models such as, for example, Uchida & Shibata (1988). Figure 2, however, shows that the size of the loops in single-loop events is smaller than that of the loops in multiple-loop events and that most of single-loop events are less than 25” in length. In addition, because these structures are small, there conceivably still might be small structures that would not have been observed. In this case, the single-loop events could be the multiple-loop brightenings observed as a single loop because of the lack of the spatial resolution. A few single-loop events (loop length > 50”) are larger than the average multiple-loop events and could really be single-loop events, though large single-loop events are rare. Therefore, we can conclude that some of single-loop and pointlike brightenings could have multiple-loop structures on subloop scales and that most of the transient brightenings may consist of multiple loops.

The occurrence of multiple-loop events could be explained either (1) by magnetic interaction (e.g., magnetic reconnection) between the loops or (2) by a common origin that simultaneously affects several loops without mutual interaction. It is difficult, however, for the common origin to cause an enhanced emission just at the contact point of the loops, which is apparently observed in more than 35% of the multiple-loop brightenings. Therefore it is more likely that transient brightenings are due to the magnetic interactions of coronal loops.

The name “transient brightening” does not necessarily imply that there is a preexisting structure but that these events may sometimes be the appearance of new coronal loops resulting from local magnetic reconfiguration of the corona. However, in some cases there is good evidence that a preexisting structure was present, and sometimes, at the resolution of SXT, it appears that the same structure can brighten more than once (e.g., Figs. 1c and 1f).

The statistical investigation of morphological evolution of transient brightenings in their initial phase shows that loops start to brighten from their footpoint(s) and/or their contact points. Note that all the transient brightenings do not usually have initial brightenings both at their footpoints and their contact points. The preexisting loops in the transient brightening presented in Figure 1c imply that the visibility of the brightening at the contact point may be related to higher plasma density or temperature of the prebrightening loops. The visibility of the initial emissions at the footpoint(s) and the contact point may be associated with physical conditions in the loops, such as the plasma density, temperature, and magnetic pressure.

The enhanced emission at the contact point is probably the key that will solve the mechanism of the magnetic interaction of multiple loops. The X-ray enhancement at the contact point may be not be simply due to the summation of the X-ray intensity of the two independent loops. In the second picture of Figure 1d, the X-ray intensities of the northern loop, the southern loop, and the contact point are about $2 \times 10^{-6}$ ergs s$^{-1}$ pixel$^{-1}$, $3 \times 10^{-6}$ ergs s$^{-1}$ pixel$^{-1}$, and $9 \times 10^{-6}$ ergs s$^{-1}$ pixel$^{-1}$, respectively (these intensities are the energy flux at the SXT focal plane through Al 1265 Å filter). This shows that the X-ray enhancement at the contact point is 2 times higher than the sum of the loops, suggesting that the enhanced emission at the contact point is not due to the superposition of the multiple-loop intensities but due to a change of physical conditions with the interaction of multiple loops. In the studies of large flares, Machado et al. (1983) and Poland et al. (1982) give possible evidences for flare triggering by the interaction of two magnetic structures.

Soft X-ray radiation at the footpoints is most likely thermal emission from the hot plasma, because the energy range of the Al 1265 Å filter (0.7 ~ 4 keV) is thermal dominant. This means that the hot plasma is generated around the bases of the coronal loops in the initial phase of transient brightenings; the hot plasma probably comes from the heating of chromospheric matter or low-temperature coronal matter present around the bases of the coronal loops prior to the brightening (Neupert 1968). Suggested sources of the heating of chromospheric matter or low-temperature coronal matter are nonthermal particles (Brown 1971; Hudson 1972) and/or conduction fronts. The Yohkoh observations clearly confirm the particle-driven evaporation picture for some large flares (Sakao et al. 1992; Hudson et al. 1993). Another interesting idea is that chromospheric matter is driven into coronal loops by the twisting up
of a flux tube under the photosphere (Uchida & Shibata 1988). Following the generation of hot plasma at the footpoints, the coronal loops are soon filled with the hot plasma. In case of Figure 1b, the lower limit of the upward velocity of the hot plasma is estimated to be about 400 km s\(^{-1}\). Watanabe et al. (1992) showed one transient brightening which seemed to have a blueshifted component, which is sometimes observed in large flares (e.g., Antonucci et al. 1982; Tanaka et al. 1982), in the S Xv spectra observed with the Yohkoh Bragg Crystal Spectrometer (Culhane et al. 1991), though it is difficult in the S Xv spectra to see the blueshifted component of transient brightenings because of the lack of image-resolved spectroscopy.

The Y-type is the common configuration for multiple-loop events. This result suggests that the magnetic interaction between the associated loops occurs more readily in the lower coronal atmosphere than in the higher coronal atmosphere. This may be due to the difference in the plasma conditions, or to driving by photospheric motions.

5.2. Possible Driving Forces for Multiple-Loop Interaction

We expect there are three types of the force leading to interaction between multiple loops; (1) the attractive force due to the currents (magnetic twists), (2) the vertical force due to the magnetic emergence, and (3) the horizontal force due to the photospheric motion. The magnetic interactions of multiple loops due to the currents and the magnetic emergence have been studied in computer simulations and in laboratory plasmas.

The interacting (coalescence) model of current loops was proposed as an important process for solar flares and X-ray brightening phenomena (Gold & Hoyle 1960) and has been investigated in detail by many theorists using computer simulation (e.g., Tajima, Brunel, & Sakai 1982; for a review see Sakai & Ohsawa 1987) for understanding many characteristics of solar flares, such as their rapid impulsive phase and heating. Two magnetic loops may carry similar twists (currents) due to the twisting motion at the photosphere and so may attract each other. They will have a neutral-sheet configuration at the surface where the two loops merge. Magnetic reconnection during the coalescence of current loops can be classified into six processes, depending on the directions of their currents and the magnetic polarities at their footpoints (Sakai & Koide 1992). A recent laboratory experiment taking into account all three vector components of the magnetic field shows that the direction of the toroidal field plays an important role in merging process and that loops with antiparallel toroidal field merge much faster than those with parallel field (Yamada et al. 1990).

The emerging flux model (Heyvaerts, Priest, & Rust 1977) has also been investigated in detail as another important process for solar flares. A new magnetic flux tube rises and collides with an existing flux tube, creating a current sheet between them. Kawai et al. (1992) carried out a detailed comparison between soft X-ray bright features and Hz features in the emerging flux regions (EFR) and show one example of transient brightenings associated with the new magnetic emergence (see Fig. 1 in Kawai et al. 1992). Recent numerical simulations by Forbes & Priest (1984) and Shibata, Nozawa, & Matsumoto (1992) show that hot plasma can be created by a magnetic reconnection in a neutral sheet between emerging and preexisting coronal magnetic fields.

The interaction mechanism of magnetic loops due to the horizontal motions at the photosphere was presented by Park & Priest (1993, 1988) as a mechanism for the heating of the corona. The horizontal motions at the photosphere move the magnetic loops, because the plasma is frozen with the magnetic fields. Small moving magnetic features are observed near certain sunspots by time series of magnetogram observations (Harvey & Harvey 1973). Moreover, recent high spatial resolution observations in the visible continuum enable measurement of flow patterns on the scale of meso- and supergranulation (Title et al. 1989, 1992) and confirm that regions of convergence of the horizontal flow field are collection basins of the magnetic field (Simon et al. 1988). Thus, the moving magnetic loops due to the horizontal motions may approach each other and thus create a current sheet between them.

The relation between transient brightenings and the driving forces can be clarified by combining soft X-ray images and high spatial resolution Hz, continuum, and magnetogram data.

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