Transient Brightenings in Active Regions Observed by
the Soft X-Ray Telescope on Yohkoh

Toshifumi SHIMIZU* and Saku TSUNETA
Institute of Astronomy, The University of Tokyo, Mitaka, Tokyo 181

Loren W. ACTON and James R. LEMEN
Lockheed Palo Alto Research Laboratory, Palo Alto, CA 94304, U.S.A.

and

YutakaUCHIDA
Department of Astronomy, Faculty of Science, The University of Tokyo, Bunkyo-ku, Tokyo 113

(Received 1992 May 22; accepted 1992 June 8)

Abstract

The Soft X-ray Telescope (SXT) aboard the Yohkoh satellite has revealed that active regions show
many compact loop brightenings which we call “active-region transient brightenings.” The released energy
by an “active-region transient brightening” is considerably less than $10^{29}$ erg, which is the low end of the
subflare energy range. Small soft X-ray enhancements observed by the GOES satellites are identified to
relatively intense “active-region transient brightenings.” The transient brightening occurs on the average
of one every ~ 3 min in “active” active regions and down to one every ~ 1 hr in “quieter” active regions.
This suggests that the transient brightening is a very common phenomenon in active regions and that the
magnetic loops in active regions are far from static.

Key words: Active regions — Magnetic loops — Sun: activity — Sun: X-rays

1. Introduction

The Soft X-ray Telescope (SXT) aboard the Yohkoh satellite (Ogawara et al. 1991) has revealed that active re-
regions show in their cores frequent transient brightenings of compact loops. Figure 1 shows a time sequence of im-
egages of the active region NOAA 6891 during the period of
1814 to 2357 UT on 1991 October 30. The compact loops
are normally faint and obscured by the diffuse component
of active regions. These loops sometimes show transient
brightenings, indicated by the arrows in figure 1; these
brightenings continue over a period of a few minutes to
tens of minutes. These pictures indicate that transient
brightenings are common phenomena in active regions
and that compact bright loops are far from static.

In this Letter we report on initial analysis of these
“active-region transient brightenings,” which can be well
observed by the SXT because of its large dynamic range
and good image cadence.

* Also at Department of Astronomy, Faculty of Science, The
University of Tokyo, Bunkyo-ku, Tokyo 113.
filter) of active regions as the index of activity. This can be derived from a composite whole-sun image. We define the area with pixels exceeding 2,000 DN (Data number, 1 DN = $5.8 \times 10^{-10}$ erg s$^{-1}$ pixel$^{-1}$ at the SXT focal plane) as the area of an active region.

2.3. Definition of Active Region Transient Brightenings

All of the events which vary their brightness in active regions are qualified as being active-region transient brightenings. In these data analyses we select the events which can be observed during most of their lifetimes. We also include the events which were observed at least during their rise phases, since we are mainly interested in the initial phase of transient brightenings for the purpose of finding a clue to the mechanism of their occurrence.

Fig. 1. Sequence of partial frame image (PFI) pictures of NOAA 6891 during the period of 1814 to 2357 UT on 1991 October 30. Although the SXT takes images with excellent time resolution of 128 s in the daytime of the satellite, this figure shows only a subset of images to illustrate the transient brightenings. The arrows indicate intense transient brightenings.
3. Results and Discussions

3.1. Identification of Transient Brightenings with GOES

The active region NOAA 6891 was a complicated active region which appeared on the Sun in late 1991 October. Figures 2a and 2b show sequences of images of the active region during the periods of 1836 to 1906 UT and of 2136 to 2222 UT on 1991 October 30, respectively. Figure 2 shows that compact loops with lengths of a few $10^3$ to $50 \times 10^3$ km suddenly brightened and then faded away here and there in the active region.

The soft X-ray flux monitors aboard the GOES satellites of National Oceanic and Atmospheric Administration (NOAA) continuously observe the total soft X-ray flux (0.5–4 Å and 1–8 Å) from the entire Sun. Figure 3 is an example of GOES time profiles, in which the periods marked by shadows indicate the times when the SXT acquired the PFI images of figure 2. Small soft X-ray enhancements can be seen frequently in the 0.5–4 Å profile.

Five small soft X-ray enhancements can be observed in the GOES profile in the first period, which are indicated by (1)–(5) in figure 3. Number (1) coincides in time with transient brightening (A) observed by the SXT. The small soft X-ray enhancements indicated by (2), (3), (4), and (5) in figure 3 are also accompanied by active-region transient brightenings indicated by (B), (C), (D), and (E) in figure 2a, respectively. In figure 2a it is shown that the SXT can also observe smaller active-region transient brightenings which are not visible above the slowly varying background on the GOES data. These brightenings are indicated by the thin arrows in figure 2.

We confirmed that the small soft X-ray enhancements observed by the GOES satellites were not caused by other phenomena that occurred elsewhere, by using the whole-sun images obtained almost simultaneously with the data of figure 2.

We also compare the transient brightenings observed in figure 2b with the small soft X-ray enhancements shown in the shadowed period on the right-hand side of figure 3. The enhancements indicated by (6), (9), and (10) are accompanied by active-region transient brightenings indicated by (F), (H), and (I), respectively. The small enhancement denoted by (7) cannot be compared with the sequence of images in figure 2b, due to a lack of the data during the period from 2139 to 2156 UT. The SXT also observed faint active-region transient brightenings, such as (G), which cannot be detected by the GOES satellites [see the mark (8) in figure 3].

The small soft X-ray enhancements observed by the GOES satellites have turned out to coincide with “intense” transient brightenings. The SXT images show that many faint transient brightenings, which are not detectable by the GOES satellites, also inject energy and mass into the active-region corona.

3.2. Frequency of Transient Brightening in Active Regions

The active region NOAA 6891, which was discussed in the previous section, was quite energetic and showed many transient brightenings. Transient brightenings were observed on the average of every 2 min 36 s in this active region during the period of 1991 October 24 to October 31.

How frequently can transient brightenings be typically observed on the average in each active region? In figure 4 the frequency of the occurrence of transient brightenings versus the total soft X-ray flux (through Al 1265 Å filter) of active regions is shown. There is a good correlation between the frequency of the transient brightening and the total soft X-ray flux from active regions. We note that the one stray point was estimated from data of only 40 min observation. Transient brightenings were typically observed once every ~3 min in “active” active regions down to once every ~1 hr in “quieter” active regions, which suggests that the active-region transient brightening is quite a common phenomenon in active regions and that the active regions are far from static.

© Astronomical Society of Japan • Provided by the NASA Astrophysics Data System
3.3. Physical Parameters of the Transient Brightening

The temperature and emission measure (EM) of a hot plasma can be estimated from the SXT images by the filter-ratio method (Vaiana et al. 1973; Tsuneta et al. 1991; Hara et al. 1992). Note that the overall wavelength response of the SXT gives weight to higher temperatures in the differential distribution of plasma temperatures (Hara et al. 1992).

Table 2 gives the physical parameters for an event observed on 1991 December 26. Active-region loops with a temperature of about $5.3 \times 10^6$ K was heated to about $7.0 \times 10^6$ K when they brightened. EM ($N_e^2l$) also suddenly increased from about $1.1 \times 10^{28}$ cm$^{-5}$ to about $6.7 \times 10^{28}$ cm$^{-5}$. Assuming that the plasma depth along the line of sight is equal to the width of the bright loops, the electron density increased about a factor of about 2 in the brightening loop. Since plasma motions are inefficient across the magnetic field, the increased plasma maybe inject from the footpoints, i.e., the chromosphere, into the loops. This is actually supported by the observation that such loops typically brighten from their footpoints during the initial phase.

The thermal energy contained in the bright loops is given by

$$E_{th}(\text{erg}) = 3N_e k T V,$$

(1)

where $k$ is the Boltzmann's constant and $V$ is the total volume of the loops. Using the temperature and density derived from the SXT images, we can obtain $4.6 \times 10^{28}$ erg for the thermal energy content, which is one order less than that of a subflare. Since the transient brightenings referred here are relatively intense, we presume that more frequent transient brightenings may release less amount of energy.
3.4. Typical Examples of the Transient Brightening

Active-region transient brightenings have various morphologies as shown in figures 1 and 2. We can classify the active-region transient brightening into two categories: (1) brightening of a single loop; (2) simultaneous brightenings of more than two loops (multiple loops). The transient brightening (E) in figure 2a consists of a single loop. On the other hand, the transient brightening (H) in figure 2b and the brightening that occurs at the lower left-hand side of the frame taken at 2202 UT in figure 2b are simultaneous brightenings of multiple loops. More than half of the events are identified as multiple loop brightenings (Shimizu 1992). Note that we have no direct evidence for the interaction of the associated loops in a multiple-loop brightening, and that they may be caused either by the interaction of associated multiple loops or by a common origin that simultaneously affects several loops.

Active-region transient brightenings also show various morphological evolutions as shown in figure 2. Brightening (H) in figure 2b started both from the footpoints and from the contact point of the loops. Many loops brighten from their footpoints and/or the intersecting point of loops during the initial phase of transient brightenings (Shimizu 1992).

We should point out that some active-region transient brightenings tend to occur recurrently almost at the same locations. In figure 1 we can see a typical example of recurrent brightenings at the upper right-hand side of the frames, which is indicated by thick arrows. In the same place the transient brightening occurred more than five times in six hours. These brightenings may be caused by an interaction between a long loop and a compact loop at the footpoint of the long loop. We can see many other recurrent brightenings in figure 1.

We are grateful to all members of the Yohkoh team for the instrumental developments and daily operations and to H. Hara, H. Hudson and K. Strong for helpful discussions and comments. We are also grateful to the Max '91 for providing us the GOES data used here.
Fig. 3. Time profiles of the GOES X-ray intensity on 1991 October 30. The shadows indicate the times when the SXT acquired the images of figure 2. The upper and lower lines indicate the full-sun soft X-ray flux through 1–8 Å and 0.5–4 Å, respectively. The solid lines are observations by the GOES-7 satellite and the dotted lines by the GOES-8 satellite.

Fig. 4. Occurrence frequency of active-region transient brightenings in active regions, all of which were in the passage on the Sun from 1991 October 3 to November 23. The horizontal axis is the total soft X-ray flux of the active region obtained from full frame image (FFI) data, indicating activity of active region. The vertical axis is the frequency of occurrence of transient brightenings per hour in each active region.
Table 2. Physical parameters of the transient brightening.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>before brightening</th>
<th>during brightening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop length (cm)</td>
<td></td>
<td>3.3 × 10^9</td>
</tr>
<tr>
<td>Loop width (cm)</td>
<td></td>
<td>7.0 × 10^8</td>
</tr>
<tr>
<td>Temperature (K)</td>
<td>5.3 × 10^6</td>
<td>7.0 × 10^6</td>
</tr>
<tr>
<td>EM(N_e l) (cm⁻³)</td>
<td>1.1 × 10^{28}</td>
<td>6.7 × 10^{28}</td>
</tr>
<tr>
<td>Density (cm⁻³)</td>
<td>4.0 × 10^9</td>
<td>9.8 × 10^9</td>
</tr>
<tr>
<td>Total electrons (electrons)</td>
<td>6.5 × 10^{36}</td>
<td>1.6 × 10^{37}</td>
</tr>
<tr>
<td>Thermal energy content (erg)</td>
<td>1.4 × 10^{28}</td>
<td>4.6 × 10^{28}</td>
</tr>
</tbody>
</table>

References


