SPATIAL RELATIONS BETWEEN PREFLARES AND FLARES

FRANTIŠEK FÁRNÍK
Astronomical Institute, 251 65 Ondřejov, Czech Republic
HUGH HUDSON
Institute for Astronomy, University of Hawaii, Honolulu, HI 96822, U.S.A.
and
TETSUYA WATANABE
National Astronomical Observatory, Mitaka, Tokyo 181, Japan

(Received 15 May, 1995; in revised form 20 September, 1995)

Abstract. We have conducted an initial search for discrete preflare brightenings as observed in soft X-radiation by *Yohkoh*. The *Yohkoh* images allow us to identify, to within a few arc seconds, the location of a preflare event relative to the succeeding flare. Our initial motivation in this study was to search for early coronal brightenings leading to flare effects, as had been suggested by earlier studies; thus we concentrated on *Yohkoh* limb events. We find no evidence for such early coronal brightenings. Between 15% and 41% of the 131 suitable events matched our criteria for preflare brightening: the same active region; brightening within one hour of the flare peak; preflare brightness less than 30% of the flare peak. In the great majority of the preflare cases, we found that physically separate nearby structures brightened initially. Often these structures appeared to share a common footpoint location with the flare brightening itself. In a few cases the preflare could have occurred in exactly the same structure as the flare.

1. Introduction

It is well known that some flares (not all but a substantial fraction) are preceded by brightenings observed in optical, radio or X-ray spectral bands. Such a brightening can originate in the same active regions where a flare later appears. Even without spatial resolution to resolve the details of the process there is a general conjecture that the preflare activity is physically connected with the main event and plays an important role in the flare energy build-up. The first study on this topic was published by Bumba and Křivský (1959), who introduced the name 'preflares' for the brightenings. They analyzed 110 events observed in Hα, radio and ionospheric effects (a substitute for direct X-ray observations) and concluded among other things that: the time gap between the preflare and main flare maxima is in the range of 10–50 min, the average duration of the preflares is 5-10 min and the preflare positions are usually not identical with the location of the main flares. The observations suggested that the preflares had their origin in the higher layers of the solar atmosphere relative to the main flares.

Since this first paper appeared not many authors have studied the properties of the preflares in detail, probably due to the lack of high-resolution data in the short-wave (X-ray) region. Results published during the seventies are not very clear and conclusive, see Spangler and Shawhan (1974), Pallavicini *et al.* (1975), Petrasso

Solar Physics **165:** 169–179, 1996.

et al. (1975), Kahler (1979), and Wolfson (1982). Some studies focused on preflare activity as observed in optical data, for example filament activation (Rust, 1975; Rust and Webb, 1977). Much more detailed analysis of small activity prior to main energy release was done in the radio region (interferometer at 17 GHz) by Kai, Nakajima, and Kosugi (1983). These authors showed that 26% of the events studied (97 radio bursts) were preceded by smaller bursts (preflares) with the time interval between the preceding and main bursts being 10–35 min (average 25 min). During the eighties data from the SMM satellite enabled much more detailed analyses of many solar phenomena. Harrison *et al.* (1985) and Simnett and Harrison (1985) studied a few flares with soft X-ray enhancements (precursors) using data from the HXIS instrument. They concluded that these enhancements (we use the name preflares) appeared $\approx$ 20 min prior to the impulsive phase and may be a source of coronal mass ejections. But in the events studied the preflare enhancements were widely separated from the main flares. A summary of preflare activity across the whole electromagnetic spectrum is given by Schmahl *et al.* (1989) in a compilation of papers from three scientific meetings. The authors show that the X-ray precursors (preflares) in the high-resolution X-ray photographs from *Skylab* appear as loops or kernels close to, but not necessarily at, the flare site and that in many cases the preflares are closely associated with activated filaments. Tappin (1991), from a study of HXIS data, concluded that the vast majority of X-ray flares have precursors (preflares) some 10 to 60 min before the flare. This seems to disagree with other studies, including the present one. This discrepancy can have its origin in the very poor spatial resolution of HXIS which did not allow Tappin to distinguish between causally related events and just statistically related ones. Recently, Fárník and Garcia (in Brown *et al.*, 1994) published stereoscopic observations in the soft X-ray region from the GOES and PHOBOS spacecraft (broad-band full-disk data) where two events seem to have preflares high in the corona relative to the main peaks which originated below. This altitude difference was derived using stereoscopy. Unfortunately no image data were available and therefore uncertainty remains whether the two preflares were physically related or were independent events in widely separated regions. The many questions remaining around preflare activity in X-ray region led to the decision to use data from the *Yohkoh* soft X-ray telescope for the following study. Our main goals were: (1) to improve statistical knowledge about flares with preflare activity (as observed in soft X-rays) and about preflare characteristics, and (2) to study the spatial relations between the preflares and the consequent flares, i.e., to decide whether the preflare emission can originate high in the corona, or whether its source is co-spatial with the main flare source.

2. Data Selection and Description

The *Yohkoh* observations are generally focused on flares and the soft X-ray telescope (SXT; see Tsuneta *et al.*, 1991) usually concentrates on the active region with the brightest $40'' \times 40''$ area. If a flare appears in another active region, SXT quickly repoints, but in such a case the preflare history is largely lost. Due to limited capacity of the telemetry system, some weak events stored in the satellite memory can also be overwritten by a stronger event which follows the weak one prior to telemetry transmission. Finally, there is the typical problem of time-series gaps due to the day/night cycle (period $\approx$ 97 min) and the Van Allen belts. Therefore it is not easy to find flares with full preflare histories in the *Yohkoh* data base. We have adopted the following procedure:

(1) All flares observed during the period October 1991–October 1993 close to the solar limb (between 60 and 90 deg west or east) were selected (in fact all events during which *Yohkoh* automatically switched into Flare Mode). We listed 484 of such flares (list No. 1). The reason why we selected flares close to the limb was the possibility that preflares originate higher in the corona than the main events; we wanted to prove or reject this hypothesis.

(2) Out of the list only 307 events were observed without a pointing change, and thus an opportunity for preflare history (list No. 2).

(3) Using GOES plots we selected real flares only (some of the *Yohkoh* flare modes were false alarms, due mostly to radiation-belt remnants). For a few events the GOES data were missing and we had to reject these also. Thus list No. 2 diminished to 131 flares (list No. 3).

(4) At the same time (using GOES plots), flares with preflares were selected from the list No. 3. Here we have to describe our definition of a preflare. Our definition is based on the GOES two-channel plots. We consider an event to be a flare with a preflare provided there is an emission rise above the background level clearly observed during the one-hour period prior to the main peak. This preflare emission must be observed in one of the two GOES channels at least and must be substantially weaker (less than 30%) when compared with the main peak. According these criteria we found 55 events with preflares in list No. 3 (list No. 4).

(5) Finally, some of these events were not completely observed due to satellite night and in those cases we are not able to prove (using *Yohkoh* SXT data) that the 'GOES preflare' is a real preflare and not an independent event from another active region. These cases were also rejected and we continued analyzing the events which were covered (both preflare as well as main flare) by SXT observations. In such a way we found 19 events in which we can confirm preflare occurrence according to our definition. The selected events are listed in Table I together with basic parameters of the events. Four examples of these 19 events are discussed in the following chapter in more detail. The data selection process is described in detail because we would like to give it as guidelines for future studies to help omit some possible biases resulting from selection.

We note that the criteria adopted here aim at the discovery of discrete preflare events, rather than pre-heating in a structure that is about to flare. This distinction is somewhat model-dependent.

TABLE I
Selected events and their basic parameters

	Date	A	B	C	Location
1	1 Nov., 1991	22:37	C7.1	12	S15 W62
2	19 Nov., 1991	9:31	C9.2	17	S15 W65
3	2 Dec., 1991	4:57	M3.5	18	N18 E90
4	16 July, 1992	16:58	M6.9	54	S13 W60
5	17 July, 1992	21:11	C7.3	27	S11 W65
6	11 Aug., 1992	22:27	M1.4	16	N17 E85
7	22 Aug., 1992	14:52	C6.6	13	N16 W68
8	25 Aug., 1992	19:20	C9.0	30, 50[a]	N11 W90
9	8 Sep., 1992	12:07	M2.7	35	S10 W72
10	9 Sep., 1992	2:13	M3.1	14, 40[a]	S10 W75
11	10 Sep., 1992	2:29	C9.5	19	S11 W88
12	12 Oct., 1992	21:53	C2.7	19	S17 W88
13	30 Oct., 1992	8:17	M1.9	34	S26 W61
14	29 Nov., 1992	8:47	C9.5	55	S28 W89
15	17 Jan., 1993	9:45	C1.4	55	S08 W62
16	17 Jan., 1993	14:34	C5.2	18	S10 W66
17	11 Apr., 1993	6:15	C9.7	36	S10 W61
18	26 May, 1993	1:59	C2.7	33	N12 E75
19	23 June, 1993	22:50	C4.0	35	S09 E89

A = approximate time of the main peak maximum (UT).
B = GOES-6 soft X-ray importance.
C = time delay of the main peak relatively to the preflare peak (in min).
[a] Preflare with two pronounced peaks.

3. Discussion of Observation of Selected Events

3.1. 11 August 1992 Event

As we already stressed in the introductory section our first interest was in deciding whether there is any observational evidence supporting the theory that the preflare X-ray emission originates at much higher levels in the solar atmosphere than the main event itself. Our flare of 11 August is a good example to show that this ‘higher level’ scenario may be false. The flare, at M1.4 magnitude, was very close to the solar limb (N17 E85) and any altitude differences would be nicely seen. Figure 1 shows the GOES two channels X-ray time series, the shaded parts marking satellite nights. The SXT observations are represented in Figure 2(a) which describes the flare development. The black contours show the X-ray emission during the first brightening (seen in the harder GOES channel) at 21:48:15 UT. The second peak emission at 22:09:05 UT is shown by white contours, while the main peak is seen as

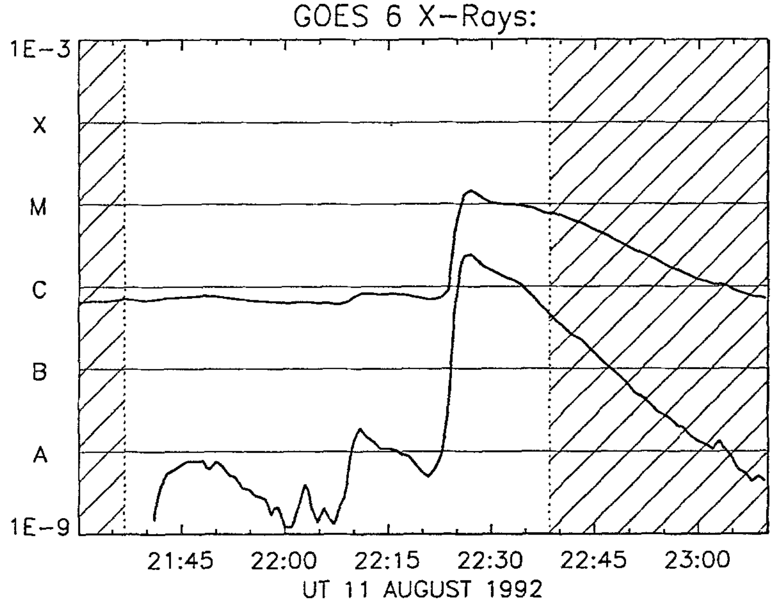

Fig. 1. Plots of GOES soft X-ray data for the August 11, 1992 event. Shaded area shows the *Yohkoh* night intervals.

a gray-scale picture in the background (intensity of individual pixels is proportional to black color) at 22:34:19 UT. We interpret Figure 2(a) as a complex structure of magnetic loops which are schematically drawn in Figure 2(b). The first heating appeared in loop 'A' and the disturbance moved during the preflare process into loop 'B'. Here, the second preflare peak emission originated followed immediately by the main phase emission. During the main phase hot plasma filled loop 'C' as well as loop 'D' and the decay phase emission was mainly seen in the large loop 'D'.

We would like to stress here that our schematical drawings (Figures 2(b), 4(b), 6(b), and 8(b)) represent just our interpretation of the SXT images and that there can be some ambiquity there. We cannot exclude other magnetic configurations by the data we have seen.

3.2. 9 September 1992 Event

An M3.1 flare occurred close to the western limb (S10 W75), so its position again would enable us to see height differences between the flare and preflare sources. Again, no such differences seem to exist. Figure 3 shows the GOES light curves – the preflare emission has two peaks (at 01:33 and at 01:52 UT) which are followed by the main phase. The SXT data are shown in Figure 4(a). Contrary to the previous event (Figure 2(a)) the first preflare peak is displayed as a gray-scale picture (01:26:00 UT), the white contours represent the second preflare peak

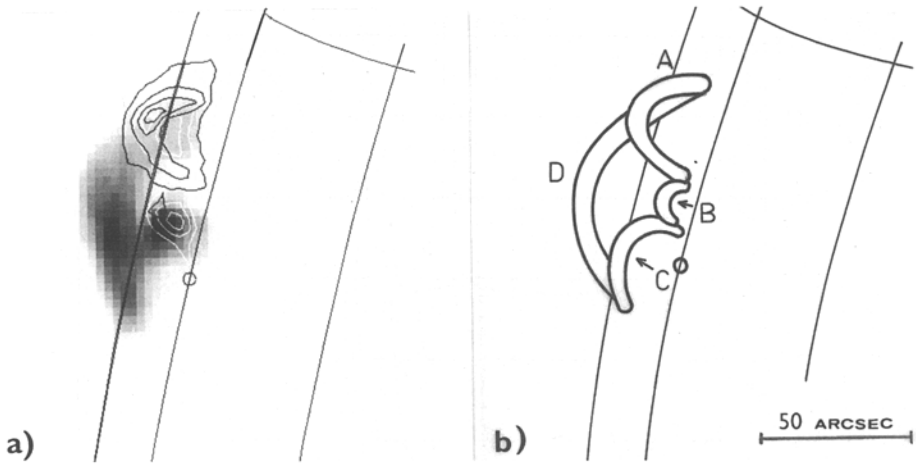

Fig. 2. (a) Superposition of three SXT images at three different times of the August 11, 1992 event. Black contours show the preflare emission at 21:48:15 UT (contour levels are 30, 50, 70, and 90% of maximum flux), white contours at 22:09:05 UT (levels 50, 70, and 90%) and the gray-scale picture with full resolution (2.5 arc sec) shows the emission of the main peak at 22:34:19 UT. The circle is at coordinates N15 E80. Grid separation is 10 deg. (b) Magnetic structure tentatively drawn to fit SXT images for the August 11 event.

emission (at 01:55:38 UT) while the black contours show the main peak emission at 02:12:26 UT. Similarly to the 11 August event we propose the magnetic loop structure drawn in Figure 4(b). The loop 'A' was heated during the initial phase. Later on, the loop 'B' became visible too (second peak of the preflare, see Figure 3) and, finally, the small loop 'C' was the source of the main peak emission.

3.3. 17 January 1993 event

This small, C5.2, event was situated at S10 W66. Its preflare emission was hardly distinguishable above the background level in the GOES softer band while the harder band shows a pronounced brightening, see Figure 5. In Figure 6(a) the preflare emission is represented by the gray-scale picture at the time of its maximum (14:15 UT) and the shape of the main source is shown by white contours describing the situation (14:31 UT). It is clearly seen that the weak preflare brightening and the following flare were situated very close one to another, and part of the main source actually appeared to match the preflare. We propose the tentative magnetic configuration in Figure 6(b). The preflare originated in a very small loop 'A' and initiated the main process in loops 'B' and 'C'. A possible source of energy could be interaction of emerging flux ('A') with pre-existing flux 'B'.

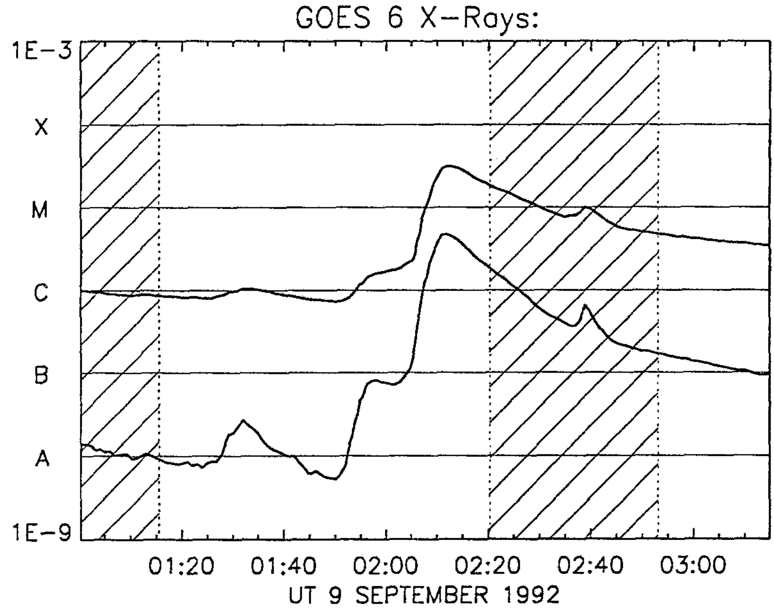

Fig. 3. The same as in Figure 1, but for the September 9, 1992 event.

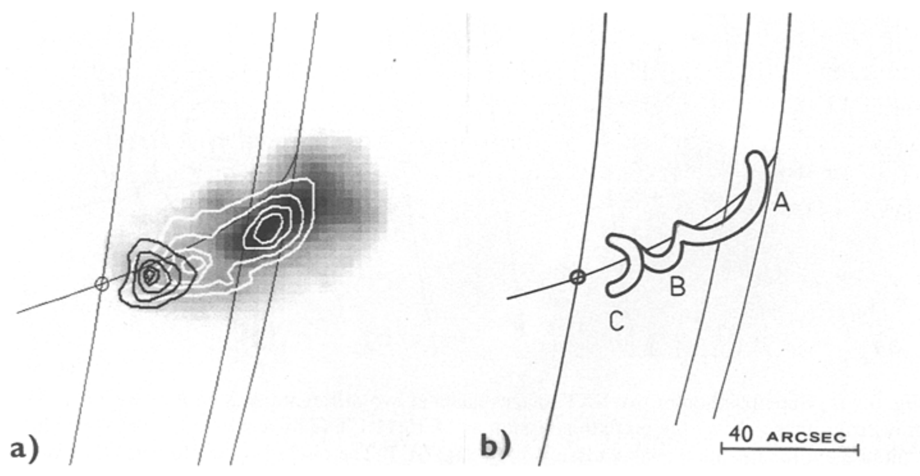

Fig. 4. (a) Similar to Figure 2(a) but for the September 9, 1992 event. Contrary to Figure 2(a) the gray-scale image shows the preflare emission at 01:26:00 UT while the white contours show emission at 01:55:38 UT (levels 40, 60, 80, and 90% of maximum flux) and black contours the main peak emission at 02:12:26 UT (levels 20, 40, 60, 80, and 90%). The circle is at coordinates S10 W70. Grid separation is 10 deg. (b) The same as in Figure 2(b), but for the September 9, 1992 event.

3.4. 11 April 1993 Event

As Figure 7 shows, this event had a relatively long-lasting and clearly visible preflare. The flare itself reached magnitude C9.7 and its coordinates were S10 W61.

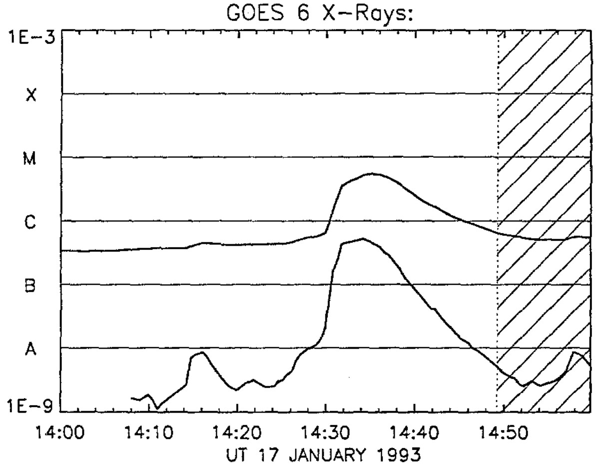

Fig. 5. The same as in Figure 1, but for the January 17, 1993 event.

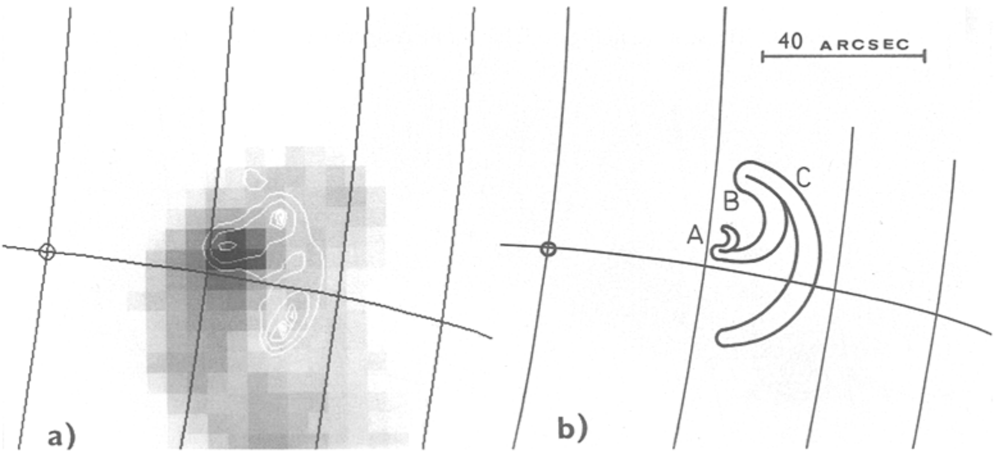

Fig. 6. (a) Superposition of two SXT images taken at two different times on January 17, 1993. The gray-scale image shows the preflare emission at 14:15:11 UT (half-resolution, 5 arc sec) while the contours outline the main peak emission at 14:31:37 UT. The circle is at coordinates S10 W60 and the grid separation is 5 deg. (b) The same as in Figure 2(b), but for the January 17, 1993 event.

The maximum intensity of the preflare was about 36 min prior to the main peak. The magnetic configuration seems to be the most simple among all our studied events, see Figure 8(a) in which the preflare (gray-scale picture) as well as the main peak (white contours) are shown. In this case we suppose again that a small emerging loop 'A' was the source of the preflare brightening. Later, the adjoining larger loop 'B' brightened and became the source of the main peak emission – see Figure 8(b). Interaction between these two loops again could be a possible source

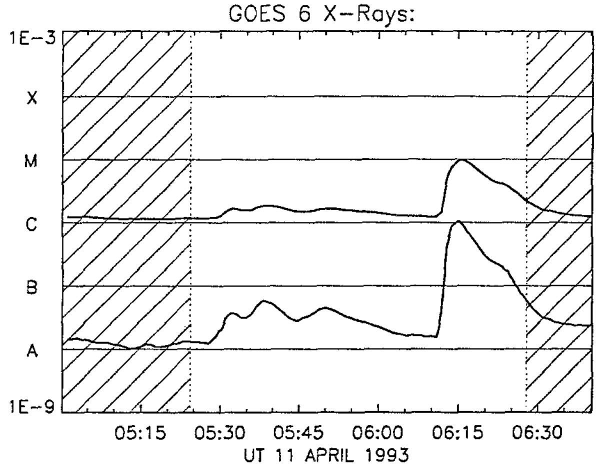

Fig. 7. The same as in Figure 1, but for the April 11, 1993 event.

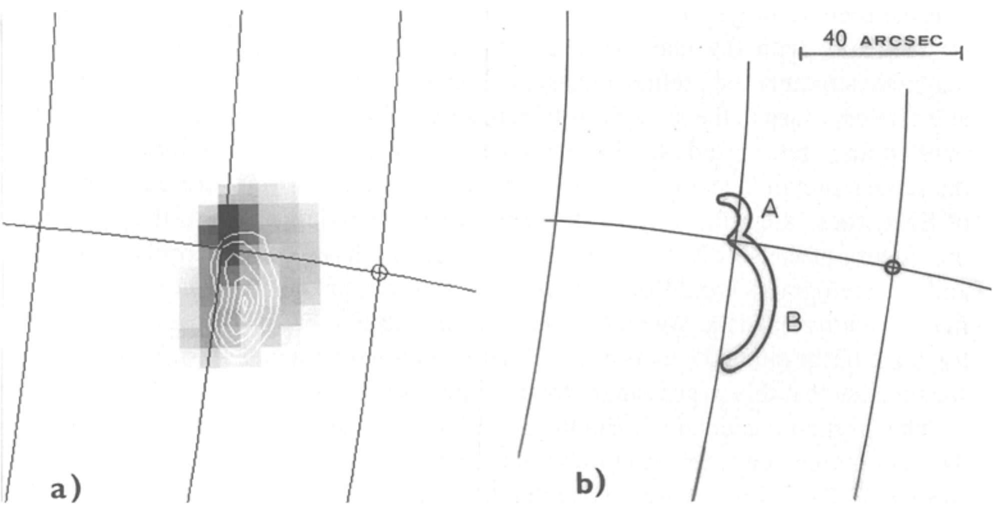

Fig. 8. (a) The same as in Figure 6(a), but for the April 11, 1993 event. The gray-scale image (half-resolution) shows the event at 05:38:24 UT and the contours outline emission at 06:14:32 UT. The circle is at coordinates S10 W65 and the grid separation is 5 deg. (b) The same as in Figure 2(b), but for the April 11, 1993 event.

of flare energy. We realize that our tentative explanation for the source of flare energy has no theoretical support because the proposed geometry of loops is not yet theoretically worked out.

4. Conclusions

Based on our observations we discuss two properties of our studied events: (a) the statistical frequency of the preflare appearance (as observed in soft X-rays), and (b) the spatial relationship between the preflares and the main peaks.

(a) From the lists of events described earlier we estimate that at least 19 out of 131 events involved preflares. The upper limit would be 41 out of 131, from the GOES data alone without consideration of the *Yohkoh* coverage. Thus the preflare fraction lies between 15 and 31%, but certainly larger than 15% because the physical proximity of each of the 19 events could be confirmed with the *Yohkoh* images. Thus our conclusion is basicaly in agreement with results obtained from radio data (see Kai, Nakajima, and Kosugi, 1983).

(b) As for the spatial relation between preflare and main peak sites, we find that our original concept of high-altitude preflares was false. All of the data studied exclude such a possibility. On the contrary, in many events the data look like energy flows into the flare from below – see, for example, Figures 6(a) and 8(a). In these events one cannot exclude the possibility of a small emerging loop interacting with an older and larger one. Generally, the SXT data show (and our figures demonstrate) that the preflare brightening appears in an adjacent loop which may be connected magnetically with the main peak flaring site. In some cases of a very simple magnetic structure the preflare emission appears to come from the identical site, or at least very close to the main flaring loop's footpoint. Ve note that even in cases of overlapping preflare and flare images, we cannot with absolute certainty argue that the same structure became energized twice. Even within the few-arcsec resolution of SXT, there are still foreground/background uncertainties due to the optically thin nature of the soft X-radiation. Ve know that high resolution Hα observations and magnetograms would greatly strengthened our conclusions but we failed to find the additional data. We do not exclude a possibility that such data exist at least for some of the studied events but we focused our main attempt on soft X-rays and we suppose that this paper can motivate more detailed studies in the future.

The original conjecture of Bumba and Křivský regarding the coronal origins of flare energy has not been confirmed in the sense that we have not found discrete coronal preflare events. We note that this does not of course rule out the participation of coronal energy release. The *Yohkoh* soft X-ray observation provide many hints of large-scale reconnection processes, and recently the hard X-ray data also strongly suggest coronal energy release during the impulsive phase of a flare (Masuda *et al.*, 1994).

Finally, we would like to stress that, unfortunately, *Yohkoh* data are not very suitable for studying weak preflare emission because of the observational preference for large events. This is especially a disadvantage for statistical studies. On the other hand, knowing that there are no high-altitude precursors, we are going to extend our analysis to close-to-disk-center flares where we could combine SXT and magnetic field data. *Yohkoh* also is generating a huge data base of microflares, defined here as events below about C2 that do not trigger the flare mode. These events should provide a rich source of statistical information on multiple flaring and on preflare behaviour, at least for the smaller events.

Acknowledgements

F. Fárník acknowledges support from JSPS which made it possible for him to visit ISAS and analyze *Yohkoh* data. At the same time he would like to express his gratitude to all the members of the *Yohkoh* team who helped him to become familiar with the necessary hardware as well as software, in particular to Jim Lemen, Bob Bentley, Mons Morrison, Sam Freeland and Nariaki Nitta. H. Hudson was supported by NASA contract NAS 8–37334.

References

Bumba, V. and Křivský, L.: 1959, *Bull. Astron. Inst. Czech.* **10**, 221.

Brown, J. C., Correia, E., Fárník, F., Garcia, H., Hénoux, J.-C., La Rosa, T. N., Machado, M. E., Nakajima, H., and Priest, E. R.: 1994, *Solar Phys.* **153**, 19.

Harrison, R.A., Waggett, P. W., Bruner, M., Dryer, M., and Simnett, G. M.: 1855, *Solar Phys.* **97**, 387.

Kahler, S. W.: 1979, *Solar Phys.* **62**, 347.

Kai, K., Nakajima, H., and Kosugi, T.: 1983, *Publ. Astron. Soc. Japan* **35**, 285.

Masuda, S., Kosugi, T., Hara, H., Tsuneta, S., and Ogawara, Y.: 1994, *Nature* **371**, 495.

Pallavicini, R., Vaiana, G. S., Kahler, S. W., and Krieger, A. S.: 1975, *Solar Phys.* **45**, 411.

Petrasso, R. D., Kahler, S. W., Krieger, A. S., and Silk, J. K.: 1975, *Astrophys. J.* **199**, L127.

Rust, D. M.: 1975, *Phil. Trans. Roy. Soc. London* **A281**, 427.

Rust, D. M. and Webb, D. F.: 1977, *Solar Phys.* **54**, 403

Schmahl, E. J., Webb, D. F., Woodgate, B., Waggett, P., Bentley, R., Hurford, G., Schadee, A., Schrijver, J., Harrison, R., and Martens, P.: 1989, in M. R. Kundu, B. Woodgate, and E. J. Schmahl (eds.), *Energetic Phenomena on the Sun*, Kluwer Academic Publishers, Dordrecht, Holland, p. 77.

Simnett, G. M. and Harrison, R. A.: 1985, *Solar Phys.* **99**, 291.

Spangler, S. R. and Shawhan, S. D.:1974, *Solar Phys.* **37**, 189.

Tappin, S. J.: 1991, *Astron. Astrophys. Suppl. Ser.* **87**, 277.

Tsuneta, S., Acton, L., Bruner, M., Lemen, J., Brown, W., Caravalho, R., Catura, R., Freeland, S., Jurcevich, B., Morrison, M., Ogawara, Y., Hirayama, T., and Owens, J.: 1991, *Solar Phys.* **136**, 37.

Wolfson, C. J.: 1982, *Solar Phys.* **76**, 377.