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Letter to the Editor

SXR Coronal Flashes

S. Koutchmy[1], **H. Hara**[2], **Y. Suematsu**[2] **and K. Reardon**[3]

[1] Institut d'Astrophysique de Paris, C.N.R.S., 98 bis Bd Arago, F-75014 Paris, France, associated with the Paris VI University
[2] National Astronomical Observatory, Mitaka, 181 Tokyo, Japan
[3] Osservatorio di Capodimonte, via Moiariello 16, I-80131 Napoli, Italy

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Abstract. We provide evidence for the existence of a new type of soft X-ray (SXR) brightening event that we call coronal flashes. The phenomenon was observed on deep time series taken with the SXT of Yohkoh in the north polar coronal hole, near the sunspot minimum. Events last as short as 1.5 mn and the corresponding SXR flux span the range of energies, from single pixel brightenings corresponding to fluxes of about 10^{24} erg but barely surpassing the level of the noise, to higher and more smeared multiple px brightenings still orders of magnitude smaller than the known small SXR bright points and/or transient brightenings. The typical occurrence rate of flashes is 1 event/arcmin^2/5mn with a 1/2 mn integration time. At least part of the coronal flashes are recurrent and some of them could be associated with a SXR jet; it is not clear what is their optical counterpart.

Key words: Solar corona; MHD; SXR; jets; bright points; brightening events; reconnections; magnetic dissipation; nano-flare; flash; flare.

1. Introduction

To understand coronal heating we need a mechanism that maintains the high temperature of the plasma. Also, we must consider the transfer of momentum to produce the fast wind and accelerate it from inside, especially above coronal holes (CH). Dissipation of Alfven waves was proposed for this but no firm observational evidence seems to exist.

Fast, small-scale mechanisms were proposed to provide the necessary energy, based on MHD magnetic- dissipation processes in explosive events (e.g. Dere et al. 1989): frequent UV brightenings (Porter et al. 1984) and more generally, in coronal bright points (BP) Golub et al. 1974 and transient brightenings (TB), Shimizu et al. 1994.

Send offprint requests to: S. Koutchmy

Nano- flares were proposed by Parker, 1988. They seem to be rather ubiquitous and to be due to fast magnetic reconnections occuring in tangential discontinuities (TD) that are not clearly identified in the very inner corona. However, TDs are observed in the white-light (WL) intermediate corona at larger scale, Koutchmy, 1971 and in the solar wind, Neugebauer et al. 1984.

From the analogy with small flares, it is possible that those tiny reconnections preferably produce high energy particles and only a small radiative signature that escapes observations, possibly due to the lack of appropriate methods of observation.

Deep SXT observations performed on Yohkoh near solar minimum provides a good opportunity to observe the tiniest events that can be found in the region of the darkest background of polar CH and evaluate their role.

2. Observations

Two runs were made in Aug 25 and Sept 2, 1995 using the soft X-ray telescope (SXT) aboard Yohkoh (Tsuneta et al. 1991). We wished to look at the SXR signature of WL coronal spikes of the inner corona that were detected during solar total eclipses (Koutchmy and Stellmacher, 1978) and which could be similar to the recently discovered SXR jets (Shibata et al. 1994) seen in active regions. An other possibility was to look at the faintest SXR transient brightenings (TB) similar to those seen by Shimizu et al. 1994.

Two sets of data were obtained in a limited region near the north pole, in the so-called 'partial-frame mode' that takes frames of 256x64 px at the highest possible cadence. Data were collected on Aug. 25, 1995 (92 images of 15 s exposure time and 2 orbits) and on Sept. 2, 1995 (200 images of 30 s exposure time and 5 orbits). Each time several continuous time series were taken at approximately 35 sec intervals with the so-called 'thick filter' (temperature sensitivity near 3 to 5 MK) made of AlMgMn (Yoshida et al. 1995). Here we concentrate on a small part of the selected observations and we look at the smallest events close to the noise level. Using visual correlations of intensities recorded at the size of a single or of several px, we identified many definitely weak events (the px size at full resolution is 2”45). The dark current and the small motions of the satellite were accurately taken into account, as is usually done using the Yohkoh IDL package available at ISAS. Further, to facilitate the search, we use negative display and a high magnification to increase the visibility of the pattern and, surprisingly, we found many real events that appear on at least 3 consecutive frames, without appreciable motion; these events are eventually seen again in the time series, 20 mn and more later. Because they are occuring over a very dark background and because they are so short in time, we call them flashes.

For obvious reasons (on the disk, in active regions, or in quiet regions at solar maximum, the SXR background is considerably brighter on average and such long exposure times could not have been used), these events have presumably not been reported in the litterature (see, e.g. Shimizu, 1995). As an example Figure 1 shows eight consecutive and independant frames taken from the 1st orbit of our best run of sept. 2, 1995. They were taken 32 seconds apart and the exposure time was 30 s.

3. Analysis and results

3.1. Qualitative evaluation

Figure 1 shows different types of event over a short time series of 4.5 mn: a) faint BP (usually of many hours lifetime and extended) or faint TB (usually of several mn duration and extended); b) faint TBs with jets (elongated structure); c) flashes occuring over 1 or more px. These are the smallest real events we can measure on this set of data, and we concentrate on them.

First, note that a rather continuous density distribution of SXR intensities is observed from BP towards flashes and that, 20 to 30 mn later (not shown here), approximately 40% of the flashes could still be identified at the same place. Further, we noticed that over the very dark background of the CH, the noise is due to random events of unknown origin; the shot noise of the true background photons is completely negligible and we took care of the ’hot’ pixels.

From our preliminary calibration based on the comparison with BP, it is clear that we are dealing with Data Numbers (DT) that correspond to single or several photo- electron events per px. In such cases, single px events are easier to identify: the probability of having one of the random noise event overlapping it is limited, and the probability of having such events on 2 (and a fortiori on 3) consecutive frames exactly on the same px is very low. We conclude that when a single px brightening occurs consecutively on 3 or more frames, it must be real. When the event is extended over 2 or more px, we allowed for a small apparent displacement not exceeding half the size of the event. Then the flux is larger and it is easy to identify it on a single frame despite the background noise. However, the recurrence of each event is a more fundamental property of flashes.

In order to evaluate the level of the faintest meaningful events observed with SXT, we compared the pattern on a full-

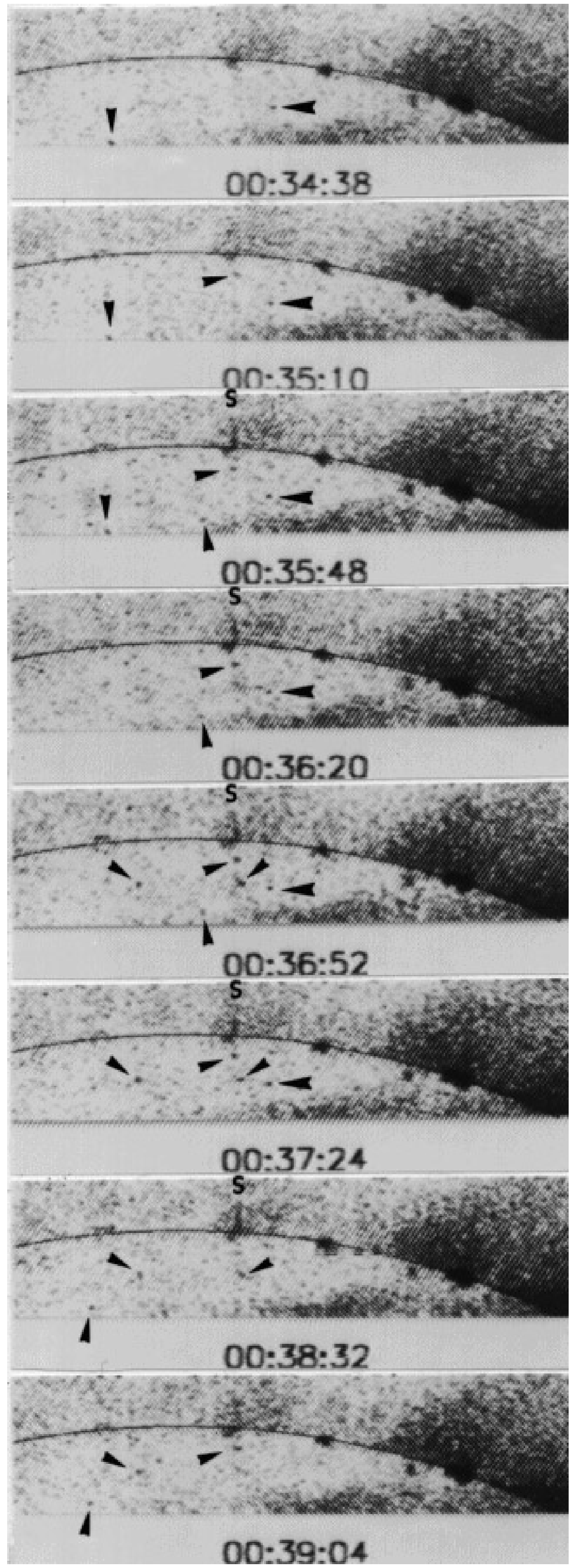

Fig. 1. Mosaic of 8 consecutive frames taken on Sept. 2, 1995 over the N-pole region. Flashes are shown by arrows; s is for a faint jet. On this sequence we counted 20 flashes in 5 mn.

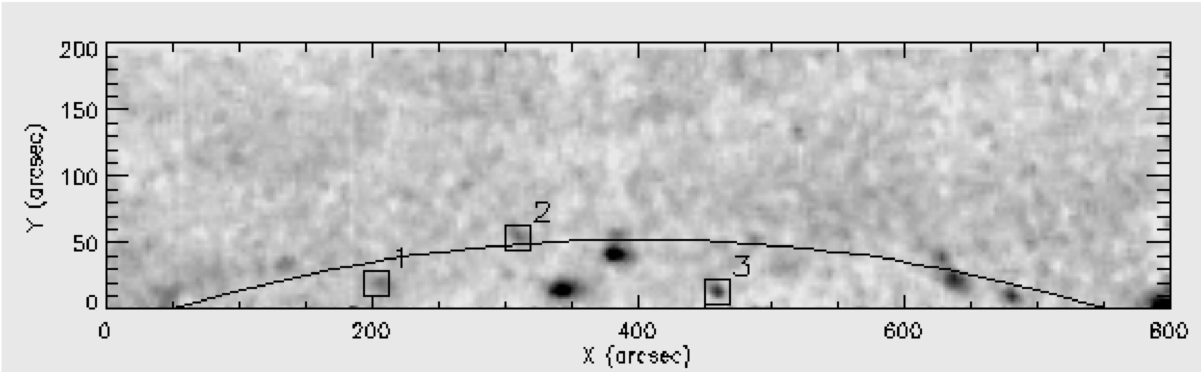

Fig. 2. Integrated frame showing the fov studied on Aug. 25, 1995. The filter and position angle is the same, but the exposure time is 15 s. Note the position of the photospheric limb and boxes with selected events, where the flux is measured, see Fig. 3.

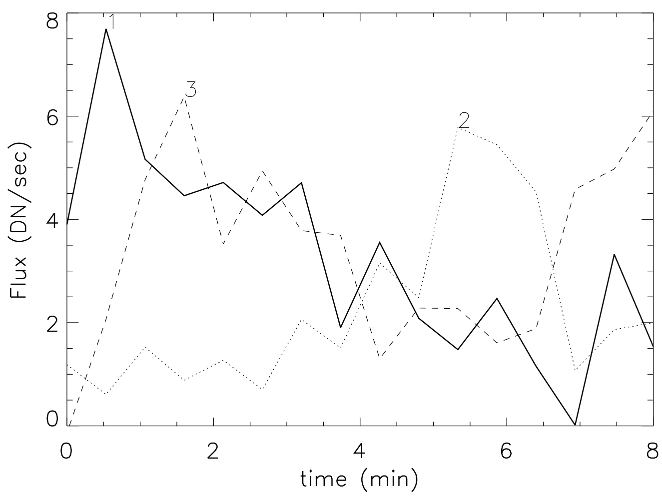

Fig. 3. Light curves of the events shown with boxes on Fig. 2.

frame SXT image (taken from the synoptic program) with a full- frame taken independently in one of the coronal channels of the EIT experiment of the recently launched SOHO mission (data kindly provided by the EIT team for evaluation purpose only). We used a few frames taken on may 26, 1996 almost at the same time for both missions, with standard exposures. After sharpening the images, EIT frames taken using a coronal filter show more small events than the SXT full disk images. Doing a precise spatial correlation on properly scaled copies we convincingly see that rather faint events taken with SXT are real, because they show up on the EIT frame, especially on dark regions of the polar CHs. It is clear that using the time series made of frames taken with longer exposure time, as those analysed in this study, we will see fainter events.

3.2. Quantitative evaluation

Figures 2 and 3 give an elementary but quantitative description of how the flashes look like. These figures were made from images taken during the 1st run of Aug. 25, 1996. Figure 2 shows the fov using an integration of 8 frames. The events which were chosen are shown, as well as the box used to get the DN shown on Fig. 3. Light curves are given in DN/sec; flux is measured when the size of the box which defines the integrated area is rather larger than it could be to optimize the signal/noise ratio (the larger the box, the larger the noise level due to random pulses of the background). Figure 1 shows a larger number of flashes per frame because, the exposure time being twice as long, we detect fainter flashes. Note that the noise did not significantly increase. When a 1/2 mn integration time is used as in Figure 1, we evaluate the typical 'density' of flashes (or occurence rate) seen over a polar region to be of order of: 1 event per arcmn^2 of the solar surface per 5 mn interval (including the faintest flashes).

The average lifetime is 3 to 5 mn although shorter events certainly exist. This number includes the very bright flashes which could be nothing but the faintest TBs discussed by Shimizu, 1995. Going toward the limb and outside, it is difficult to claim any relationship with respect to cos theta. Flashes seem just to cover the solar surface.

4. Discussion

We believe that the flash is a new class of SXR TB for the following reasons:

a– The flux is typically 2 orders of magnitude smaller than the faintest TB reported by Shimizu et al, 1994 and their 'density' or occurence rate at the solar surface is 2 to 3 orders of magnitude larger.

b– Flashes also occur above the limb, although it is difficult to make a clear distinction between off-the-disk flashes and very small jets with apparent motion. This point will be discussed in a forthcoming paper devoted to the study of polar coronal SXR jets.

c– They are significantly smaller in size. Indeed the smallest flashes could be smaller than the px size, as suggested by the dispersion of our measurements of the location of the smallest flashes.

d– Their frequency distribution does not fit with the extrapolated value obtained from the frequency distribution graphs of TB as given in Shimizu, 1995. However, as stated by that author, his graphs show a saturation effect at small values of fluxes, because the overlapping effect due to the background emission does not permit to correctly make the count.

In case we want to propose a 'universal' frequency distribution for flare-like events, it is clear that no saturation effect should occur at any energy level, especially in the range of small energies which is considered here. However, the size of the sites of the flashes is definitely smaller than for a typical bi-polar magnetic region responsible for a BP and/or a TB. It is closer to the size of a magnetic element (e.g. Lorrain and Koutchmy, 1994). Their number 'density' and behavior make these events quite close to the chromospheric spicules (Suematsu et al. 1996) and to impulsive events seen in Halpha above polar CH (Koutchmy and Loucif, 1991). Flashes could be due to a process proposed for nano- flares (e.g. Einaudi and Velli, 1994) or, more likely, could result from reconnection phenomena occuring at lower heights (Yokoyama and Shibata, 1995). In our opinion, it is now urgent to accumulate more observations in possibly other spectral and temporal ranges. Simultaneous observations taken with both SXT of Yohkoh and EIT of Soho would be interesting. WL eclipse observations of spikes (elongated coronal density structure) and plasmoids (small closed magnetic structure) could also be helpful, as well as deep coronal Halpha and He lines observations.

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