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Long duration flares (LDEs) during the minimum of solar activity

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Abstract

During the period of a low solar activity, numerous X-ray flares of the GOES class from A to C are observed. We are searching for a counterpart of the long-duration flares among these low intensity events, i.e., we are looking for flares with decay times longer than 1 h and the GOES classes less than C6. We are using data obtained from the GOES satellites. In the period of time between February 1994 and November 1997 we have found about 250 events fulfilling the criteria mentioned above. We analysed the morphology and physical parameters of these low intensity flares using the *Yohkoh*/SXT images. We have also performed statistical analysis of all the observed events.
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1. Introduction

Long duration events (LDEs) are generally associated with large, high (10^4–10^5 km), long-lasting (several hours) arcades of loops (Kahler, 1977). These arcades are characterised by slow expansion (1–10 km/s). SXR time profiles of LDEs are usually smooth. Hard X-ray emission of LDEs are weaker than in impulsive flares but still clearly observed (Tsuneta et al., 1992; Harra-Murnion et al., 1998). In the previous paper, (Siarkowski et al., 2002) we have identified many very soft, low intensity and long duration flares, using data taken with RF15-I X-ray photometer aboard INTERBALL-Tail satellite from August 1995 to November 1997. In this paper, we extend the former analysis to a period of low activity (February 1994–November 1997). We have identified about 250 LDE events with decay times longer than 1 h and GOES classes less than C6. We used *Yohkoh*/Soft X-ray Telescope (SXT) images to identify structures of these events. Imaging capability of the SXT gives a unique opportunity to study such faint events.

2. Observations and data analysis

We have used GOES data for the identification of an event lasting more than 1 hour and for the determination of its incremental class (flux after background subtraction). From the ratio of the GOES low (1–8 Å) and high (0.5–4 Å) energy channels we have calculated physical parameters of the flares (temperature, emission measure). We have also determined the flare rise time. We have studied the morphology of the analysed events basing on images from the Soft X-ray Telescope (SXT) of the *Yohkoh* satellite. All of the SXT images were taken with the spatial resolution of 2.46 arcsec (one pixel is about 1800 km) or 4.92 arcsec (Tsuneta et al., 1991). For analysis of the GOES data and the preparing *Yohkoh*/SXT images, we have used standard SolarSoft procedures.

3. Results

From February 1994 to November 1997 we have identified about 250 small LDE events with decay times longer than 1 h and GOES classes below C6. We have determined the temperature and emission measure for the 189 events recorded in the high energy channel of GOES.

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The previous results have clearly indicated that the emission measure increases with the flare GOES class. Garcia (1988) has shown this relationship for strong M- and X-class flares, Phillips and Feldman (1995) for flares with GOES class B5 to C2. Using BCS data Feldman et al. (1995b) confirmed this relationship for flares with GOES class greater than C2. Above results were based on the data for all (not only LDE) flares. We confirmed here this relationship for our set of LDEs. These results are presented in Fig. 1 together with lower boundary of the maximum emission measure found by Garcia (1988). This figure shows that small LDEs follow the same relation as large flares. However it should be noticed that some of the above results were obtained using BCS data. These results cannot be so directly compared to results obtained from GOES data.

In Fig. 2 the relationship between the incremental GOES class and the maximum temperature is shown. As expected clear increase of the maximum temperature with the GOES class can be observed. Similar relationship was observed by Garcia (1988), Feldman et al. (1995b, 1996a,b). However it is worth noticing that Phillips and Feldman (1995) did not find such relation for their set of B5-C2 GOES flares.

Feldman et al. (1995b) analysed relationship between emission measure and temperature for flares with GOES class greater than C2 (all flares, not only LDEs). They confirmed that, as expected, the hottest flares have large value of emission measure. However, Phillips and Feldman (1995) analysed the same relationship for flares with GOES class B5-C2 and did not find this correlation to be particularly evident. It was probably due to limited range of emission measure in their data. We present this relationship for our sample of small LDEs in Fig. 3. Similarly to Phillips and Feldman, we also do not see evident correlation. However, there is slight tendency that hottest flares have larger value of emission measure.

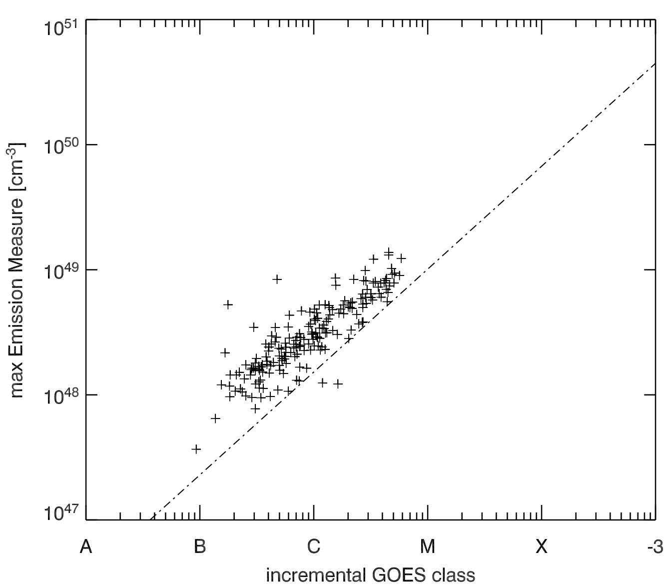

Fig. 1. Maximum emission measure as a function of incremental GOES class for our set of small LDE. Dashed line shows the lower boundary of the distribution found by Garcia (1988) for M- and X-class flares.

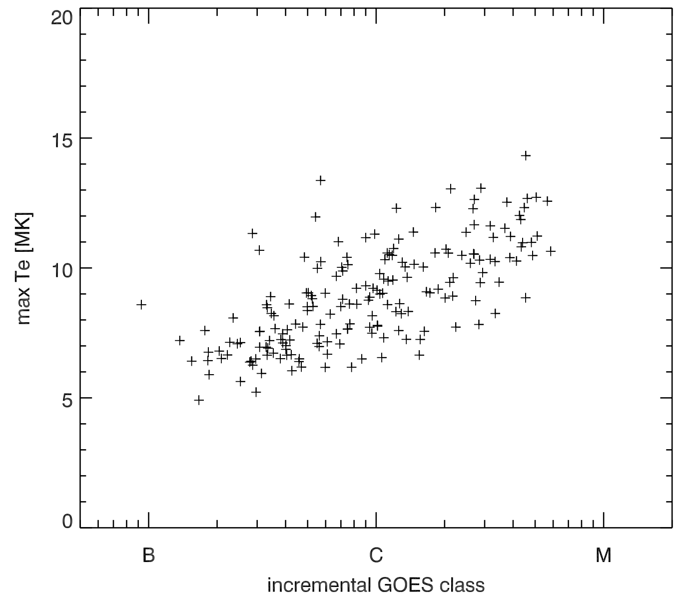

Fig. 2. The relationship between the incremental GOES class of the all analysed flares and the maximum temperature.

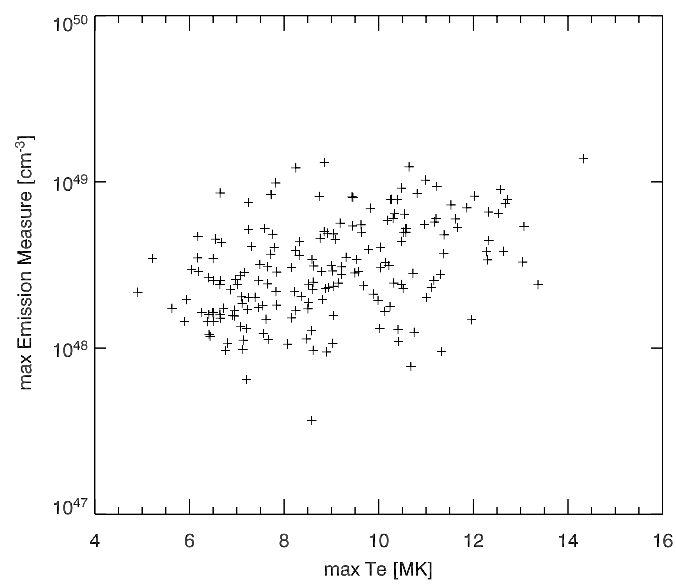

Fig. 3. Maximum emission measure as a function of maximum temperature.

Fig. 4 shows the histogram of the rise time, normalised to the total duration of the flare. We can state that the average rise time of all events is about 15% of their duration time.

The structure of LDE flares is quite complicated and characterized by a large diversity of magnetic loops. Usually these loops form giant arcades associated with filament eruption or coronal mass ejection. According to Feldman et al. (1995a) the most intense emission comes from a small number of loops. The brightest emitting regions are found

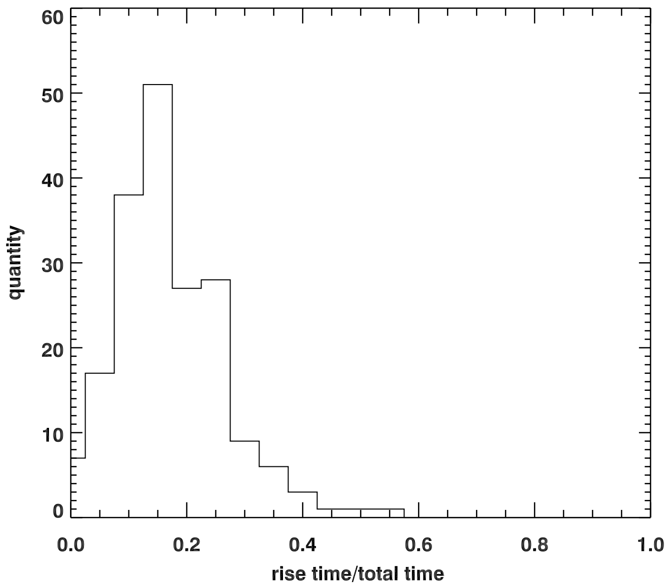

Fig. 4. Histogram of the rise time (normalised to total duration) for all the analysed events.

to be located near the tops of these loops. During the flare evolution usually a few hot and bright kernels of emission develop along the arcade channel (Jakimiec et al., 1997; Kołomański and Jakimiec, 2002). *Yohkoh*/SXT observations revealed numerous examples of the cusp-shaped loops in LDE flares (Tsuneta et al., 1992; Isobe et al., 2002). All these observations indicate that continuous magnetic reconnection and the resultant energy release should occur in the decay phase of LDE (e.g., Harra-Murnion et al., 1998).

In this paper, we analysed the morphology of small LDE flares for 170 out of 189 events for which the SXT images were available. We have found that, similarly to bigger flares there is a large diversity of the morphology of these small events, including single loops (SL), interacting loops (IL), sigmoids (S), arcades (A) and complex system of the loops (CL). We have also identified significant group of events that are behind the limb (BL). The distributions of the observed groups of events are presented in Figs. 5a and b. In Fig. 5c the quantity distribution of the above groups for individual years is shown. We can observe similar distribution in particular years for each group of events. In Fig. 6, we present two characteristic examples of the SXT images for analysed events.

4. Conclusions

From February 1994 to November 1997 we have identified about 250 small LDE events with decay times longer than 1 h and with GOES classes less than C6 observed by SXT. We have used GOES data for identification of these events and for determination of their incremental class. From the ratio of the GOES low and high energy channels we have calculated physical parameters of the flares (temperature, emission measure). We have found the following properties of these flares:

1. Similarly to larger flares there is a clear tendency for the maximum temperature of an event to increase with the soft X-ray intensity given by the incremental GOES class of the event.

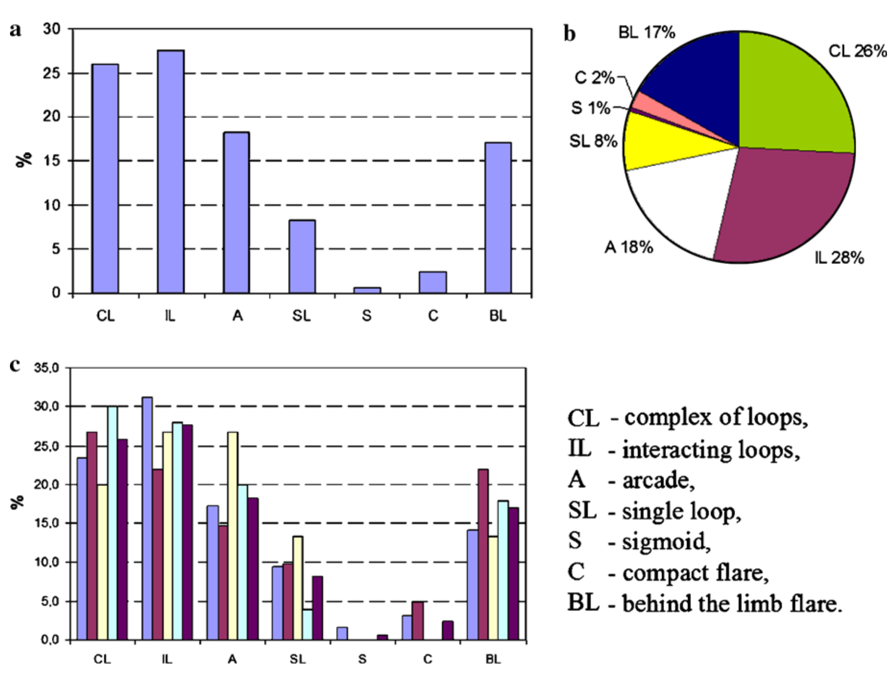

Fig. 5. Statistical distribution of morphological characteristics of all events for which we have SXT images (see text for details).

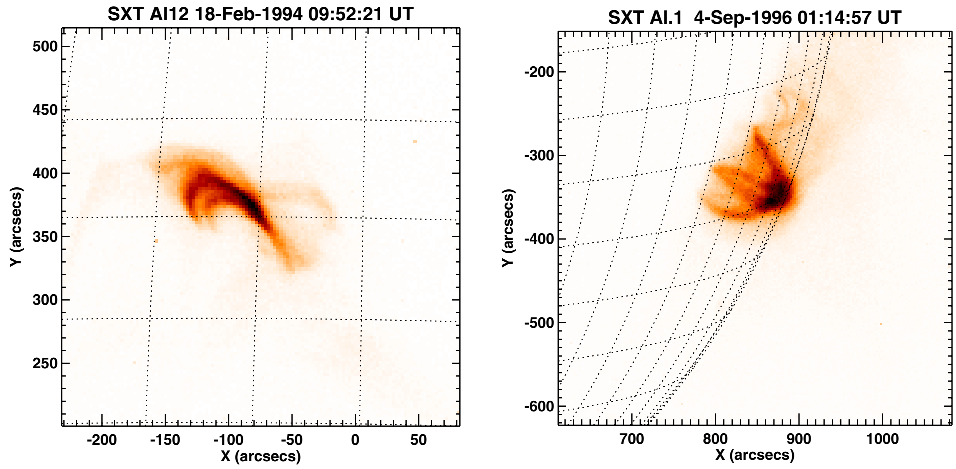

Fig. 6. *Yohkoh*/SXT images. Left: 18 February 1994 flare (an example of interacting loops – IL). Right: 4 September 1996 flare (an example of complex system of loops – CL).

2. There is also a strong correlation between the flare emission measure and the flare class.
3. Generally moderate long duration flares seem to behave like other moderate flares with respect to the T/EM/flare – class statistic.
4. Similarly to Phillips and Feldman (1995) we do not see evidence for a significant correlation between emission measure and temperature for our set of data.
5. The average rise time of all events is less that 15% of their duration time.

We have found that morphology of analysed small LDEs is quite complicated with a large diversity of loops configuration. These structures are however very similar to those observed in large long duration flares.

Acknowledgements

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