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Solar flares with and without SOHO/LASCO coronal mass ejections and type II shocks

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Abstract

We analyse of a set of *radio rich* (accompanied by type IV or II bursts) solar flares and their association with SOHO/LASCO Coronal Mass Ejections in the period 1998–2000. The intensity, impulsiveness and energetics of these events are investigated. We find that, on the average, flares associated both with type IIs and CMEs are more impulsive and more energetic than flares associated with type IIs only (without CME reported), as well as flares accompanied by type IV continua but not type II shocks. From the last two classes, flares with type II bursts (without CMEs reported) are the shortest in duration and the most impulsive.

Keywords: Sun: Coronal mass ejections; Sun: Flares; Sun: Activity; Sun: X-rays

1. Introduction

The association of Coronal Mass Ejections, flares and metric radio bursts of the type II and IV family, remains an open issue. The general idea is that the association probability rises in proportion to flare strength and CME velocity Kahler et al. (1984), yet exceptions abound:

- 40% of the M class flares are not associated with CMEs (Andrews, 2003) while 86% of the CMEs are associated with class C flares (Harrison, 1995).
- 30% of the coronal shocks, corresponding to metric type II bursts, are not associated with CMEs (Kahler et al., 1984; Classen and Aurass, 2002).
- CMEs not associated with type IIs are equally divided in fast ($V_{CME} > 455$ km/s) and slow ($V_{CME} < 455$ km/s) (Sheeley et al., 1984).
- Type II bursts are fairly well associated both with intense and weak HXR bursts (Pearson et al., 1989).

In this report, based on a data set of *radio rich* events, we analyse the intensity, impulsiveness and energetics of the associated GOES SXR bursts in order to explore the nature of flares apparently associated with Coronal Mass Ejections and type II bursts.

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Table 1
Summary of peak and integrated flux for SXR flares

	Peak flux (W/m^2)			Integrated flux (J/m^2)		
	Mean	Min	Max	Mean	Min	Max
Class A	7.2×10^{-5}	4.5×10^{-7}	5.6×10^{-4}	8.8×10^{-2}	2.6×10^{-4}	0.75
Class B	3.2×10^{-6}	7.1×10^{-7}	6.4×10^{-6}	0.5×10^{-2}	0.1×10^{-2}	0.02
Class C	4.4×10^{-6}	7.8×10^{-7}	8.0×10^{-6}	0.7×10^{-2}	0.3×10^{-2}	0.01

Table 2
Duration, rise time and decay time of the SXR flares

	Rise time (s)			Decay time (s)			Dur. (s)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Class A	867.0	240.0	3480.0	1310.0	240.0	4980.0	2177.0	480	5710
Class B	890.2	241.0	2340.0	840.3	216.0	2090.0	1730.5	481	4430
Class C	1488.0	540.0	2280.0	1928.4	540.0	3540.0	3416.4	1080	5760

Table 3
Impulsiveness (Wm^{-2}s^{-1}) of the SXR flares

	Mean	Min	Max
Class A	8.0×10^{-8}	1.9×10^{-9}	4.4×10^{-7}
Class B	6.4×10^{-9}	2.1×10^{-9}	1.2×10^{-8}
Class C	4.5×10^{-9}	5.7×10^{-10}	1.5×10^{-8}

Table 4
Colour temperature and emission measure

	Colour temp. (10^6K)			Emission measure (cm^{-3})		
	Mean	Min	Max	Mean	Min	Max
Class A	15.1	7.2	25.8	4.6×10^{49}	1.6×10^{48}	2.8×10^{50}
Class B	10.1	6.0	26.2	2.0×10^{49}	5.8×10^{49}	8.6×10^{49}
Class C	10.0	5.7	13.2	7.3×10^{49}	5.2×10^{48}	4.4×10^{48}

2. Observational results and analysis

We use a moderate size data set of *radio rich* events, i.e., CMEs and flares accompanied by metric type II or IV bursts, in the 1998–2000 period. The gross spectral characteristics of these events, observed by the radiospectrograph ARTEMIS-IV, and the associated CME and flare parameters are summarised in Caroubalos et al. (2004).

From the 40 events of the original data set we have eliminated all events coinciding with SOHO/LASCO data gaps and those without an SXR flare in *Solar Geophysical Reports*. We also excluded event number 28 (24 March 2000), which coincides with an undocumented data gap in the 23–24 March 2000 period and event number 29 (27 March 2000) in which the CME-flare association is dubious.

The remaining 32 events were divided in thee classes: flares associated with a type II metric burst and a SOHO/LASCO CME (class A, twenty events), flares associated with a type II metric bursts without a SOHO/LASCO CME reported(class B, seven events) and flares with a SOHO/LASCO CME, a type IV burst but without a type II burst (class C, five events).

We remark that the type IV (without type II) continua[1] rate is significantly higher in 1998 (7 out of 16) compared to 1999–2000 (1 out of 16). This is in agreement with statistics that specify the type IV maximum rate of occurrence in 1998 for solar cycle 23 (Georgiou et al., submitted for publication); it may be, also, attributed to the high levels of noise storm activity during 1999–2000 which may have masked faint to medium intensity type IV detection.

The term *SOHO/LASCO CME* is used here to describe events included in the SOHO/LASCO coronagraph event list (Yashiro et al., 2001); although this list includes all well-defined CMEs, it may be incomplete with respect to minor, faint structures leaving the sun.[2] For each class of events we analysed SXR flare data such as:

- Colour temperature and emission measure from the GOES data, following Garcia (1994).
- Impulsiveness, defined as the ratio of Peak flux (1–8 Å GOES channel) to the rise time and representing the average growth rate of the flare (Pearson et al., 1989, also Magdalenic and Vrsnak, 2001; Vrsnak et al., 2001).
- SXR flare characteristics: Peak flux, total integrated flux (1–8 Å GOES channel) and rise time. The decay time was estimated from the GOES (0.5–4 Å channel) data as the interval required for the flux to drop to 25% of the peak value. The event duration was set equal to the sum of rise and decay times.

The results of this analysis, pertaining to the SXR flare characteristics, are summarised in Tables 1–4.

[1] A type IV may be outside the observing range or below the sensitivity threshold of ARTEMIS-IV.

[2] Also SOHO/LASCO may not be capable of observing most slow, narrow and faint Earth directed CMEs.

Furthermore, we examined the relation between flare parameters (rise vs. decay time, temperature vs. emission measure) as well as the relation between CME and type II speed and SXR integrated flux. In Fig. 1, we present scatter plots of CME velocity versus the total integrated flux (1–8 Å GOES channel) of the associated SXR flare (panel A), type II drift velocity versus the total integrated flux (panel B), flare rise versus decay time (panel C) and colour temperature versus emission measure. Certain observational results arise as follows:

- Flares associated with CMEs and type II shocks (class A) are, on the average, more energetic by more than an order of magnitude with respect to flares of the remaining two categories (class B and C); the latter are characterised by almost the same average peak and integrated flux. (cf. Table 1).
- The rise and decay time of class C events exceeds significantly on the average, the rise and decay of classes A and B, yet their ranges overlap. (cf. Table 2, also Kahler et al., 1984 for similar results). The length of the rise phase increases with the length of the decay phase; the correlation is almost the same for all the three event classes (cf. Fig. 1, bottom left, also Kay et al., 2003).
- Flares associated with type II shocks and CMEs are, on the average, more impulsive by an order of magnitude compared to flares with type IIs but without CMEs; these, in turn, are more impulsive than CME-associated flares which have no type II association by a factor of 50%. The ranges overlap, yet the third class appears significantly less impulsive than the first two (cf. Table 3).
- Differences in average emission measure and temperature are not very pronounced among the three classes. Class B and C events have the same average temperature, (10×10^6K) and are clustered in the lower emission measure-temperature range (cf Table 4 and Fig. 1, bottom right). The majority of class A events on the other hand reaches higher temperatures and emission measures than the rest. The correlation of colour temperature–emission measure is consistent with previous results by Kay et al. (2003).
- Type II drift velocities appear all in excess of 400 km/s and uncorrelated with the SXR time integrated flux (cf. Fig. 1A). The scatter in the data points is attributed mostly to the dependence of the type II velocity, mainly, on ambient coronal conditions (cf., for example, Pearson et al., 1989, also Kahler et al., 1984 and Vrsnak et al., 2002).
- CME velocities appear fairly well correlated to the SXR Integrated flux, (cf Fig. 1, top right) the non-type II CMEs (class C) are clustered towards the lower velocity and flux range, yet connected to the rest of the sample. This result is in accordance with the CME velocity versus peak flux correlation reported by Moon et al. (2003); the position of class C events on the velocity-integrated

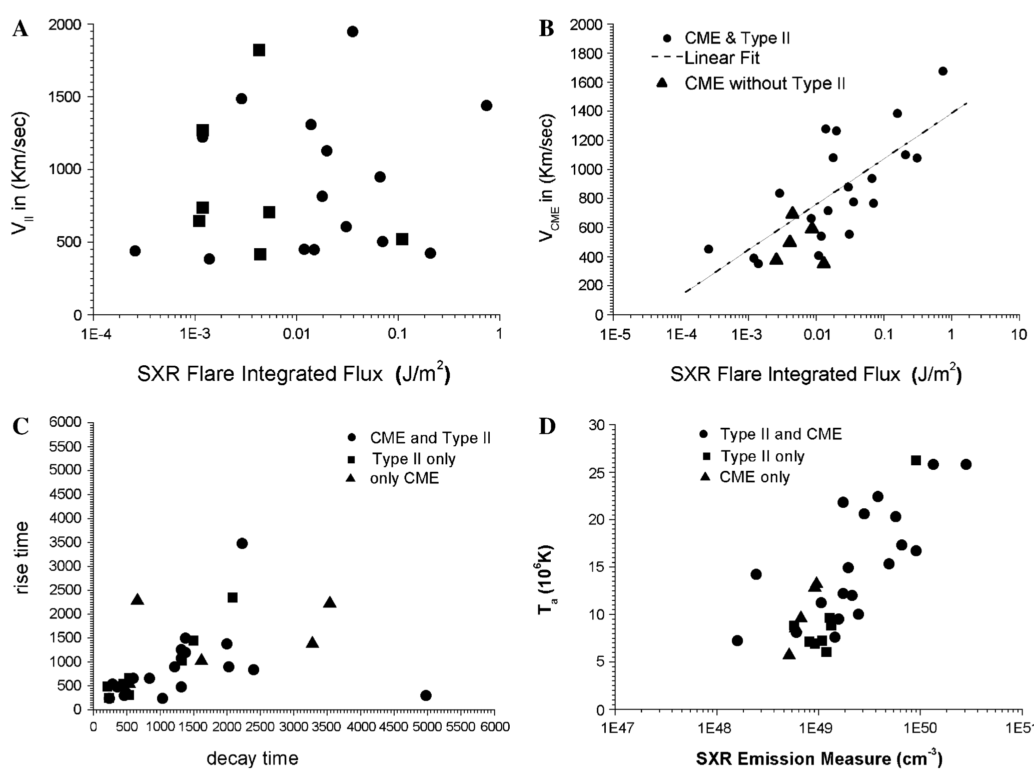

Fig. 1. Type II drift velocities versus integrated SXR flux (A); CME velocities versus integrated SXR flux (B); SXR rise time vs. decay time (C); colour temperature versus emission measure (D); circles correspond to CMEs associated with type II bursts, triangles to CMEs not accompanied by type II, and squares to type II bursts not coincident with CMEs.

flux plane corroborates Sheeley et al. (1984) who state that type II associated CME velocities exceed a threshold of about 400 km/s.

3. Discussion and conclusions

The comparison between soft X-ray characteristics, has pointed to a certain ordering where class A events (type II with CME reported) are more energetic than class B (type II without CME reported) and class C (CME without type II). Furthermore class B events have the shortest duration while class C are the least impulsive. Despite the established trend that the largest flares favour CMEs and that the most impulsive ones are more likely to be associated with the formation of MHD shocks, manifesting themselves as coronal type II bursts, the range of the parameters within our, medium size, sample overlap significantly. Furthermore, some of the low intensity flares in the sample were found associated with CMEs and type II bursts. This implies that certain details of the CME and flare origin, which were not analysed in this work need to be taken into account in future studies. The examination of the magnetic properties of active regions has provided enough candidates such as active region potential magnetic energy (Venkatakrishnan and Ravindra, 2003), sigmoid magnetic structures (Harra, 2002), helicity (Nindos and Zhang, 2002; Van Driel-Gesztelyi et al., 2002) and magnetic shear (Falconer et al., 2003). Although the issue remains open it appears that, in general, flux emergence and changes in the magnetic field topology favour the MHD instabilities which drive energy release manifestations such as flares, CMEs and shocks.

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