Abstract

An analysis is presented of a set of radio rich solar SXR flares, i.e. accompanied by type IV or II metric radio bursts, associated with Coronal Mass Ejections and MHD shocks, recorded as type II events, in the period 1998-2000. The relative size, impulsiveness and energetics of these events are investigated. We find that, on the average, the flares with type II bursts and CMEs are larger, more impulsive and energetic from the flares with type II but without CMEs. The latter are more energetic than flares associated with relatively slow CMEs accompanied by type IV continua but not type II shocks. Although a simple classification may not be readily determined the results imply that associated energetic events originate, more often than not, from sources with characteristics fairly well correlated.

Key words: Sun: Coronal Mass Ejections, Sun: Flares, Sun: Activity, Sun: X-Rays
### Table 1: Summary of Peak & Integrated Flux for SXR Flares.

| Class  | Peak Flux $(W/m^2)$ | Integrated Flux $(J/m^2)$ |
|--------|---------------------|---------------------------|
|        | Mean                | Min          | Max          | Mean                | Min          | Max          |
| Class A| $7.2 \times 10^{-5}$| $4.5 \times 10^{-7}$ | $5.6 \times 10^{-4}$| $8.8 \times 10^{-2}$| $2.6 \times 10^{-4}$| $0.75$       |
| Class B| $2.6 \times 10^{-5}$| $2.1 \times 10^{-6}$ | $1.8 \times 10^{-4}$| $1.8 \times 10^{-2}$| $2.1 \times 10^{-2}$| $0.11$       |
| Class C| $4.4 \times 10^{-6}$| $7.8 \times 10^{-7}$ | $8.0 \times 10^{-6}$| $0.7 \times 10^{-2}$| $0.3 \times 10^{-2}$| $0.01$       |

1 **INTRODUCTION**

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

- 40% of the class M 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 & Aurass, 2002).
- The non-type II associated CMEs are equally divided in fast ($V_{CME} > 455$ Km/sec) and slow ($V_{CME} < 455$ Km/sec) (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 size, impulsiveness and energetics of the associated GOES SXR recordings in order to explore the nature of flares apparently associated with Coronal Mass Ejections and type II bursts.

2 **OBSERVATIONAL RESULTS & ANALYSIS**

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

From the forty events of the original data set data set we have eliminated all events coinciding with LASCO DATA GAPS and those without an SXR flare tabulated in the Solar Geophysical Reports. The remaining thirty three events were partitioned into, twenty ejective flares associated with a type II metric burst (class A throughout the text), eight non-ejective flares associated with a type II metric burst (class B) and five ejective flares without a type II metric burst.
Table 2: Duration, Rise Time & Decay Time of the SXR Flares.

|        | Rise Time (sec) | Decay Time (sec) | Dur. (sec) |
|--------|-----------------|------------------|------------|
|        | Mean    | Min    | Max    | Mean    | Min    | Max    | Mean    | Min    | Max    |
| Class A| 867.0   | 240.0  | 3480.0 | 1304.0  | 240.0  | 4980.0 | 2177.0  | 480    | 5710   |
| Class B| 877.6   | 241.0  | 2340.0 | 864.0   | 216.0  | 2090.0 | 1741.6  | 481    | 4430   |
| Class C| 1488.0  | 540.0  | 2280.0 | 1928.4  | 540.0  | 3540.0 | 3416.4  | 1080   | 5760   |

Table 3: Impulsiveness \((W m^{-2} sec^{-1})\) of the SXR Flares.

|        | Mean    | Min    | Max    |
|--------|---------|--------|--------|
| Class A| 8.0 \(10^{-8}\) | 1.9 \(10^{-9}\) | 4.4 \(10^{-7}\) |
| Class B| 4.0 \(10^{-8}\) | 2.1 \(10^{-9}\) | 2.8 \(10^{-7}\) |
| Class C| 4.5 \(10^{-9}\) | 5.7 \(10^{-10}\) | 1.5 \(10^{-8}\) |

II metric burst (\(class\ C\)). For each class of event we analyse SXR flare data such as:

- Colour Temperature and Emission measure from the GOES measurements, following [Garcia (1994)]
- Impulsiveness, defined as the quotient of Peak Flux (1-8 A GOES channel) over the rise time and representing the average growth rate of the flare [Pearson et al (1989)], albeit for HXR bursts, also [Magdalenic & Vrsnak (2001), Vrsnak et al (2001)].
- SXR flare characteristics: Peak flux, total integrated flux (1-8 A GOES channel) and rise time, which were taken from the Solar Geophysical Data. The decay time was estimated from the GOES (0.5-4 A channel) data as the interval required for the drop of flux 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 to 4. We, furthermore, examine the variations of the flare parameters as well as the CME and Type II kinetics vs SXR integrated flux. In figure 1, we present velocities of CMEs versus the total integrated flux (1-8 A GOES channel) of the associated SXR flare; drift velocities of type II bursts versus the total integrated flux; flare rise time versus decay time and emission measure as a function of colour temperature. Certain observational results arise as follows:

- The ejective flares associated with type II shocks (Class A) are more energetic than non-ejective flares with type II bursts (Class B); these, in turn, are more energetic than ejective flares which are not accompanied by type II events (Class C). Both the average peak flux and the average time integrated SXR flux differ almost by an order of magnitude from a category to
Table 4: Colour Temperature & Emission Measure.

|        | Colour Temp. $(10^6\text{K})$ | Emission Measure $(\text{cm}^{-3})$ |
|--------|-------------------------------|----------------------------------|
|        | 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 $10^{48}$ |

The next, yet their ranges overlap (cf. Table 1).

- The rise and decay time do not differ significantly on the average, while their ranges overlap. The class C events present a higher rise and decay time that the other two categories while duration of Class B events is smaller than the rest (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 in almost the same way for all the three event categories (cf. figure 1, bottom left, also [Kav et al. (2003)]).

- Ejective flares associated with type II shocks (Class A events) overcome on average impulsiveness non-ejective flares with type II bursts (Class B) by a factor 2; these, in turn, overcome the non-type II ejective flares (Class C) by an order of magnitude. The ranges overlap, yet the third category appears significantly less impulsive than the first two (cf. Table 3).

- The three categories, do not differ significantly on the average emission measure and temperature (cf Table). The class B and class C events have the same average temperature, $(10^6\text{K})$ and are clustered in the lower emission measure-temperature range (cf. figure 1, bottom right). The majority of class A events on the other hand reaches higher temperatures and emission measures than the rest. The colour temperature-emission measure relation is consistent with previous results by [Kav et al. (2003)].

- The type II drift velocities appear all in excess of 400 Km/sec and uncorrelated with the SXR time integrated flux (cf. figure 1, top left). There is not any apparent separation between non-eruptive flare associated type II bursts (Class B events, or flare blast originating MHD shocks) and the CME driven shocks (Class A events, or piston driven shocks). 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)]).

- The CME velocities appear fairly well correlated to the SXR Integrated flux, (cf figure 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 flux plane corroborates [Sheeley et al. (1984)] who state that type II associated CME velocities exceed a threshold of about 400 Km/sec.
3 DISCUSSION AND CONCLUSIONS

The comparison between the soft X-ray characteristics, has underlined a certain ordering where Class A events are more energetic than Class B which in turn are more energetic than class C. Further more the Class B events (Type II without CME) have the shortest duration while Class C events (Non-Type II CMEs) are the least impulsive. The ranges of parameters, however, overlap significantly; the least energetic and the flares of low temperature are almost equally divided among the three classes introduced in this report, while the most energetic events are associated with type II shocks and CMEs. The lack of a clear dividing line among classes implies that both CMEs and type IIIs are present in a wide range of SXR flare parameters. The need for a close examination of the less energetic events, almost suggests itself in the hope of a resolution of this uncertainty.
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