Coronal Shocks And Solar Energetic Proton Events

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Abstract

From July 1996 - June 2001, $< 50\%$ of favorably-located metric type II radio bursts had associated solar energetic protons (SEPs). When western hemisphere metric IIs were accompanied by decametric-hectometric (DH; 1-14 MHz) type II emission, their association with ∼20 MeV SEP events was 90% vs. only 25% for metric IIs without a DH counterpart. Overall, 82% (63%) of all SEP events with visible disk origins were associated with metric (DH) type IIs, with percentage associations increasing with SEP event size to 88% (96%), respectively, for ∼20 MeV SEP events with peak intensities $\geq 10^{-1}$ pr cm^{-2} s^{-1} sr^{-1} MeV^{-1}. Our results are consistent with the following (not mutually exclusive) possibilities: (1) large ∼20 MeV SEP events result from strong shocks that can persist well beyond ∼3 R$_\odot$; (2) shock acceleration is most efficient above ∼3 R$_\odot$; (3) shocks that survive to ∼3 R$_\odot$ are more likely to have broad longitudinal extents.

1. Introduction

It is generally accepted that metric type II solar radio bursts are manifestations of shock waves caused by disturbances moving outward through the solar corona with speeds of ∼500-1000 km s^{-1}. Metric type II bursts have typical starting frequencies ∼100 MHz (∼1.5 R$_\odot$) and drift toward the lowest frequencies commonly observable from Earth (∼20 MHz; ∼2.5 R$_\odot$) with a drift rate of ∼0.1-1 MHz s^{-1}. Coronal shock waves are thought to be the principal acceleration mechanism for the largest ("gradual") SEP events observed at 1 AU [7].

While coronal shocks are held to be a necessary condition for large SEP events, metric type II bursts are not a sufficient condition for a SEP event to occur. Kahler [4] found that only about half (31/58) of favorably connected (W10-W85) metric IIs observed from June 1973 through June 1980 were associated with >20 MeV SEP events. We investigate the possibility that the presence or absence of a DH type II burst observed in the 1-14 MHz range (∼10 R$_\odot$ - 3 R$_\odot$) by the WAVES experiment on the Wind spacecraft may distinguish between SEP-associated and non-SEP-associated metric type II bursts (see [2]).

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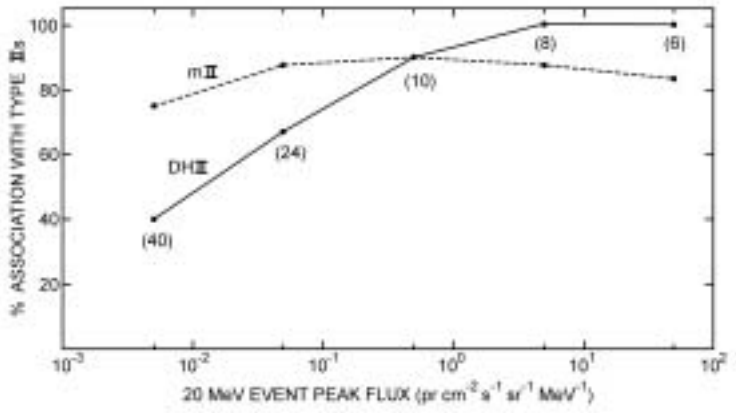

Fig. 1. Percentage association of ∼ 20 MeV SEP events with metric type II (dashed line) and DH type II (solid line) bursts as a function of SEP event peak intensity.

2. Analysis

2.1. Event Associations

Metric type IIs and Hα flares: We began with the list of metric type II bursts reported in Solar-Geophysical Data (SGD) between 01 July 1996 and 30 June 2001. During this period, 447 separate metric type II bursts were reported, of which 57% (253/447) were associated with Hα disk flares.

DH type IIs and Hα flares: For a list of DH type IIs, we used the compilation on the WAVES website, considering only those events with starting frequencies $\geq$ 1 MHz. During the period of interest, 172 independent DH IIs were reported, of which 54% (93/172) were associated with Hα disk flares.

SEP events and Hα flares: To compile a SEP event list, we used 19-22 MeV data from the EPACT investigation on the Wind spacecraft. This channel has a background of ∼2-3 x 10^{-4} pr cm^{-2} s^{-1} sr^{-1} MeV^{-1}. We identified 134 increases of ∼20 MeV protons $\geq 10^{-3}$ pr cm^{-2} s^{-1} sr^{-1} MeV^{-1} during the five year interval and found disk flare associations for 88 of these events.

SEP events with metric and DH type IIs: We find that 82% (72/88) of our SEP events are associated with metric IIs, and 63% (55/88) are associated with DH IIs. 91% (80/88) of SEP events have metric and/or DH type II emission.

In Figure 1 it can be seen that smaller SEP events are more likely to be associated with metric IIs than with DH IIs and that the association of SEP events with DH type IIs increases rapidly with SEP event size. 80% (51/64) of SEP events with ∼20 MeV intensities < 0.1 pr had metric IIs, vs. 88% (21/24) of SEP events with peak intensities $\geq$ this threshold. Corresponding figures for DH type II associations with SEP events are 50% and 96%, while the rates for SEP events with associated metric and/or DH IIs are 88% and 100%.

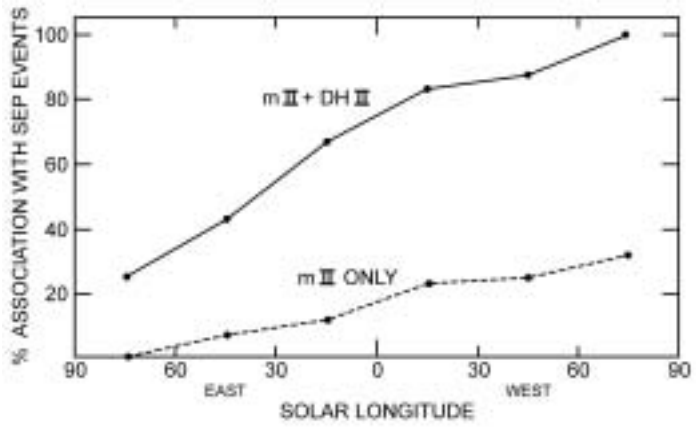

Fig. 2. Percentages of metric type II only (dashed line) and metric II + DH II (solid line) bursts associated with ∼20 MeV SEP events as a function of flare longitude.

Table 1.

WH metric II	SEP Event?		
	Yes	No	Total
w/ DH II	26	3	29
w/o DH II	17	52	69
Total	43	55	98

2.2. Factors affecting metric type II - SEP association

Flare longitude: "SEP visibility functions" for metric only type IIs (dashed line) and metric + DH type IIs (solid line) are shown in Figure 2. To construct these curves, we began with our samples of these two categories of type II bursts and determined their percentage SEP event associations as a function of flare longitude. In the figure it can be seen that SEP visibility for metric + DH type IIs is a factor of three or more times that for metric only IIs at all longitudes.

DH association: The matrix in Table 1 includes only the metric type IIs from western hemisphere sources in Figure 2. Comparing the columns of the matrix confirms Kahler's [4] finding that approximately half of favorably located type II bursts (55/98 = 56%) are not accompanied by SEP events at Earth. Comparing the rows of the matrix indicates that only 30% (29/98) of metric type II bursts have DH counterparts.

The key result of our study is the marked difference in the degree of SEP association between metric IIs with and without DH type IIs. Only 25% (17/69) of western hemisphere metric type IIs without a DH II counterpart are followed by SEPs at Earth vs. 90% (26/29) of metric IIs with associated DH type II bursts.

3. Discussion

Our principal finding is that favorably located metric type II bursts that have a DH counterpart are much more likely to be followed by SEPs than metric IIs that lack such low frequency emission. How do we interpret this result? There are several possibilities, which are not mutually exclusive.

First, the strong/fast shocks that survive into the DH range [6] are also those that are most likely to be efficient proton accelerators (at all heights in the corona) since CME speed is correlated with peak ∼20 MeV SEP intensity [5]. An alternative (or contributing) explanation for the high association between DH type IIs and SEP events is suggested by studies (e.g., [1]) indicating that the Alfvén speed in the corona typically has a peak value around ∼3 $R_\odot$, corresponding to the ∼14 MHz plasma level in the DH range. Above this height, shock acceleration will become more efficient as the Alfvén speed decreases. Support for the viewpoint that shock acceleration of SEPs is most efficient above ∼3 $R_\odot$ comes from persistent evidence for delayed injection onsets of high-energy protons and mildly relativistic electrons [e.g., 3]. A third possible explanation for the link between DH type IIs and SEP events indicated by Table 1 might be that those shocks that survive to greater coronal heights will also span a broader range of longitudes and thus be more likely to reach the magnetic fieldline connected to Earth [8]. This effect is best illustrated by considering eastern hemisphere solar activity: eastern hemisphere metric IIs without accompanying DH type IIs are much less likely to have SEP association (8%; 4/50) than is the case for such events with associated DH type II emission (52%; 12/23).

In sum, the statistics presented here support the view that the solar energetic protons (SEPs) observed near Earth are accelerated at coronal shocks. But not all shocks are "SEP-effective"; only about half of favorably-located metric type IIs are linked to SEPs. The shocks that are strong enough to produce type IIs in the DH range (> 3 $R_\odot$) are the ones most likely to have SEP association.

4. References

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