THE CORRELATION OF CORONAL MASS EJECTIONS WITH ENERGETIC FLARE PROTON EVENTS

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ABSTRACT

E > 4 MeV proton events presumed due to solar flares are compared with coronal mass ejections (CMEs) observed with an orbiting coronagraph. We can associate H alpha flares with 27 of the 50 flare proton events of the study. Each of these 27 flares can then be associated temporally and spatially with a CME, confirming the earlier conclusion, based on Skylab data, that a CME may be a necessary condition for a flare proton event. Peak 4-22 MeV proton fluxes correlate with both the speeds and the angular sizes of the associated CMEs. CMEs of larger angular sizes are more likely to be loops or fans rather than jets or spikes and are more likely to intersect the ecliptic.

1. Introduction

Kahler et al (1978) used Skylab coronagraph data and IMP-7 flare proton events to show that a coronal mass ejection (CME) may be a necessary requirement for the occurrence of a proton event. They concluded that the CME caused a substantial restructuring of the coronal magnetic field and provided access to the interplanetary fields for the energetic protons. They suggested that protons were accelerated in shocks ahead of the CME and that the angular sizes of the observed CMEs could explain the region of fast propagation (Reinhard and Wibberenz, 1974)

Recent studies of proton acceleration assume a shock context (Achterberg and Norman, 1980; Lee and Fisk, 1982). Type II bursts provide evidence of shocks, and the shocks are assumed to be piston-driven by CMEs and to travel ahead of CMEs through the outer corona and into the interplanetary medium (Maxwell and Dryer, 1981). However, protons are sometimes accelerated to energies of tens of MeV in the impulsive phases of gamma-ray flares (Chupp, 1982) before the type II burst onsets. In addition, some shocks could be blast waves rather than piston-driven by CMEs, so a confirmation and extension of the earlier Kahler et al (1978) study is in order to test the picture of proton acceleration in CME-driven shocks.

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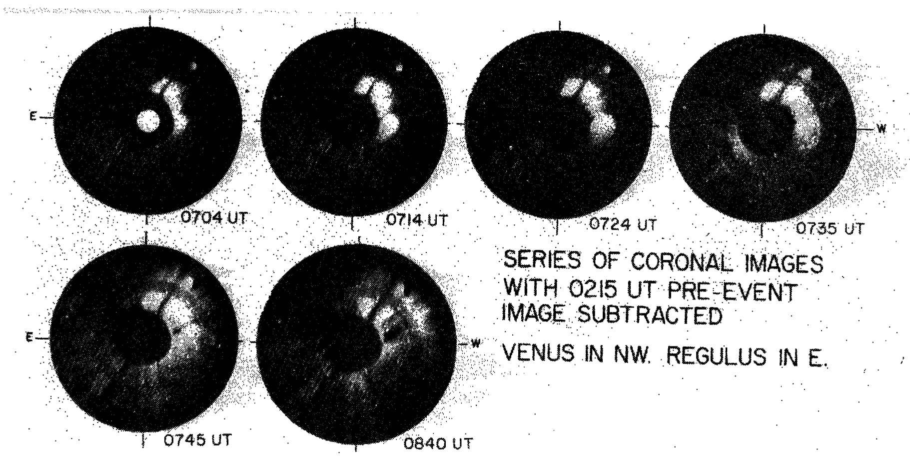
2. Data Analysis and Results

We used data from the GSFC experiments on IMP-8 and ISEE-3 to select E > 4 MeV proton events presumed due to flares. We looked for evidence of velocity dispersion, relatively flat energy spectra, and an absence of magnetic storm sudden commencements to distinguish flare-related proton events from delayed or corotating events. We then looked for H alpha flare associations in Solar-Geophysical Data bulletins, using type II burst reports and GOES soft X-ray plots as corollary data. For each proton event the flare association was classified as probable (Y), possible (P), or no flare (N). The reduced data from the NRL white light coronagraph on the P78-1 spacecraft (Michels et al, 1982) were then searched to find those proton events for which subtracted images had been obtained just prior to or shortly after the proton event onset. During the the period April 1979 through February 1982 50 such events were identified.

The next step was to decide for each proton event whether a CME association was very probable, probable, improbable, or very impro-



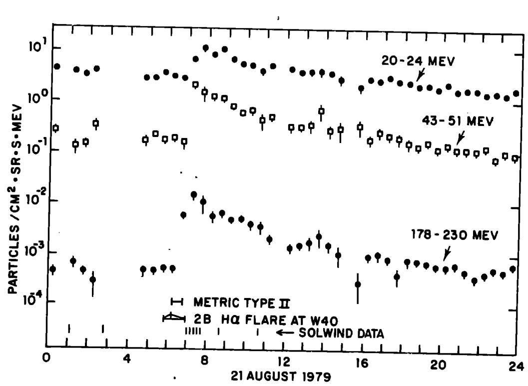


Figure 1a (above): The sequence of subtracted images from the NRL coronograph on 21 August 1979. The 2B flare at N17 W40 gave rise to a spikey fan CME with an angular size of 110° and a measured speed of 690 km s^{-1}.

Figure 1b (left): The proton flux measured in three energy bands on IMP-8 on the same date. The fluxes preceding the event were high due to a proton event beginning 18 August.

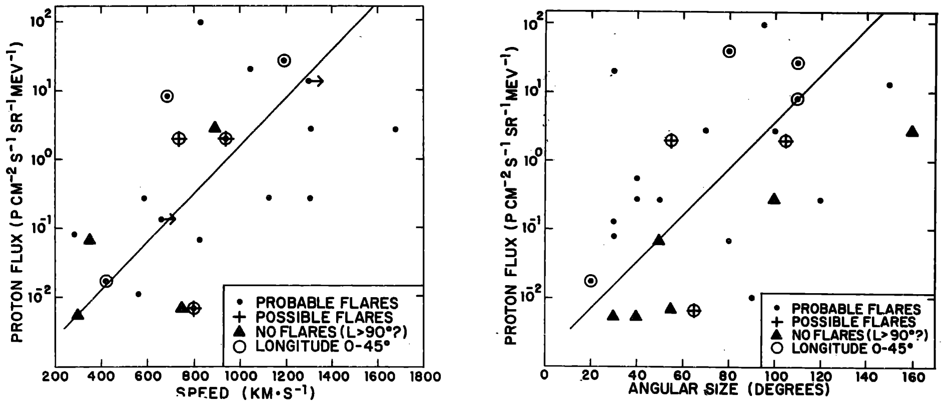


Figure 2. Plots of peak 4-22 MeV proton fluxes against corresponding CME speeds (left) and angular sizes (right). The three classes of flare associations correspond to the Y, P, and N events of Table 1. Speeds are probably underestimated for circled events due to flares at longitudes less than 45°. Solid lines are least squares best fits.

bable. For events with probable or possible flare associations the position and timing of the CME was considered in determining the association. For those with no flare associations we used the rate of rise of the proton flux to establish the appropriate limb as the likely source of the proton flare.

The flare and CME associations of the 50 proton events are shown in Table 1. The important result is that all 27 proton events with good flare associations were probably or very probably associated with CMEs. An example of the latter group is shown in Figure 1. The less likely probable (+) associations were due mostly to coronagraph data gaps precluding observations of the CME passage in the field of view and to CMEs occurring off the appropriate limb but the wrong quadrant, i.e., north rather than south or vice versa. Candidate CMEs thought unlikely to be associated with proton events accounted for the improbable (-) cases. The lack of good flare associations precludes the 5 events in the very improbable (--, no observed CMEs) column from yielding good candidates for a counter example with no associated CME.

Table 1. Proton Event Association

Flare Association[a]	CME Association[b]			
	(--)	(-)	(+)	(++)
Y	0	0	6	21
P	3	3	4	3
N	2	2	6	0

a. Y, probable; P, possible; N, no flare.
b. (--), very improbable; (-), improbable; (+), probable; (++), very probable.

CME angular sizes have been measured, and in most cases the CME speeds in the plane of the sky could be deduced. Figure 2 shows the peak 4-22 MeV proton fluxes against the speeds for the west hemisphere (+) and (++) events of Table 1. The data are characterized by a correlation coefficient of r = 0.56, significant at the 99% confidence level.

Similarly, we have compared the peak proton fluxes with the CME angular sizes with the result shown in Figure 2. The correlation coefficient here, r = 0.49, is also significant at the 99% confidence level, and the least squares best fit is shown.

3. Discussion

The results of this study confirm the earlier conclusion of Kahler et al. (1978) that CMEs may be necessary requirements for interplanetary proton events from flares. In addition, we find the correlations of peak proton fluxes with CME speeds and angular sizes, as shown in Figure 2. The speed correlation may not be surprising, since Gosling et al. (1976) found that faster CMEs were more likely to be associated with type II bursts. Thus, faster CMEs may give rise to faster shocks in which proton acceleration is facilitated.

The reason for the correlation between peak proton fluxes and CME angular sizes is not obvious. If the CME speeds were correlated with angular sizes, then a peak proton flux correlation with one parameter would imply another correlation with the second. However, analysis of the CMEs of Figure 2 shows only a weak correlation between speed and angular size (r = 0.32, significant at the 87% confidence level), suggesting that peak proton fluxes are correlated with the CME angular sizes independently of their speeds. Since larger CMEs are more likely to intersect the ecliptic, in which the energetic protons are observed, that may be the reason for the preferred large angular sizes. A statistical analysis of a larger sample of CMEs shows that those associated with proton events are about equally likely to intersect the ecliptic as they are to exceed 60° in full width. Thus the data do not allow us to decide whether angular size or intersection of the ecliptic is the important factor in the correlation. Several CMEs with proton events clearly avoid the ecliptic however, and one, on 21 May 1980, is confined to within 20° of the south ecliptic pole. If the angular size, rather than the intersection of the ecliptic, is the important factor, it may be that the narrow angle CMEs, the spikes and jets, are not so efficient as the larger loop and fan structures in giving rise to shocks.

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