Proceedings of ICRC 2001: 3443 © Copernicus Gesellschaft 2001

ICRC 2001

A CME Associated with an impulsive SEP event

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Abstract. An impulsive solar energetic particle (SEP) event observed on the *Wind* spacecraft on 2000 May 1 was associated with an impulsive solar active region M1 X-ray flare. The timing and position of a fast (v = 960 km s^{-1}), narrow CME observed in the Lasco coronagraph on $SOHO$ make clear the connection between the CME and the flare and SEP event. Impulsive SEP events have long been associated with impulsive flares, but only gradual SEP events have thus far been found to be associated with CMEs. This is the first clear case of an impulsive SEP event with an associated CME.

1 Introduction

Observations of solar energetic particle (SEP) events observed at 1 AU have established the existence of two classes of SEP events (Reames, 1999). The first class, the longer duration or gradual SEP events, are produced in coronal and interplanetary shocks driven by fast (v $\geq$ 700 km s^{-1}) coronal mass ejections (CMEs) (Kahler, 2001). The second class, the impulsive SEP events, was initially discovered because their high ^{3}He/^{4}He abundance ratios exceed the coronal values by several orders of magnitude. These SEP events, characterized by large enhancements of high-Z elemental abundances and known as Z-rich events, are now understood to be accelerated in impulsive solar flares and released into narrow angular ($\theta \leq 30°$) regions of interplanetary space (Reames, 1999). Good associations of the impulsive SEP events were found with solar kilometric (Reames et al., 1988) and metric (Kahler et al., 1987) type III radio bursts. The acceleration of impulsive SEPs has been modeled by stochastic ion interactions with electromagnetic hydrogen cyclotron waves (Roth and Temerin, 1997) and with cascading Alfven and fast-mode waves (Miller, 2000) generated in the flare impulsive phase.

A basic distinction between the two classes of SEP events is that gradual SEP events are accompanied by CMEs, while the impulsive SEP events have no known CME associations (Reames, 1999). The latter statement is based on a statistical comparison of ^{3}He-rich SEP events with metric type II bursts and CMEs (Kahler et al., 1985). Using 10-hour windows to search for associated CMEs observed with the NRL Solwind coronagraph on the $P78-1$ spacecraft and control periods of 10-hour windows, Kahler et al. (1985) concluded that there was no evidence for an enhanced rate of CME occurrence during the injections of the ^{3}He-rich events.

With the launch of the *SOHO* spacecraft in late 1995 we have had the capability to compare SEP events at 1 AU with CMEs observed by the Lasco coronagraph of $SOHO$. As expected, nearly every gradual SEP event is associated with an observed fast CME. However, we have now observed an impulsive SEP event clearly associated with a CME. We discuss the details of that event, which occurred on 2000 May 1.

2 The Observations

Figure 1 shows time profiles of the 2000 May 1 SEP event from the Energetic Particles: Acceleration, Composition, and Transport (EPACT) experiment (von Rosenvinge et al., 1995) on the *Wind* spacecraft. The event is identified as an impulsive SEP event by its high (> 1) Fe/O and low (~ 10) H/He ratios (Reames, 1999), and also by its duration of ~ 1 day. The distinct intensity increase up to an energy of 20 MeV in H is unusual for an impulsive SEP event. A clear timing dispersion between the profiles of the 2.3 and 20 MeV H indicates that an impulsive injection occurred $\leq$ 1100 UT.

An impulsive M1.1 GOES X-ray flare with an onset at 1016 UT and maximum at 1027 UT is shown in the top of Figure 2. The bottom of the figure shows a height-time profile of gray scale images of coronal white light brightness profiles generated from the Large Angle Spectroscopic Coronagraph (Lasco) (Brueckner et al., 1995) on the *SOHO* spacecraft. The height-time profile consists of sequences of

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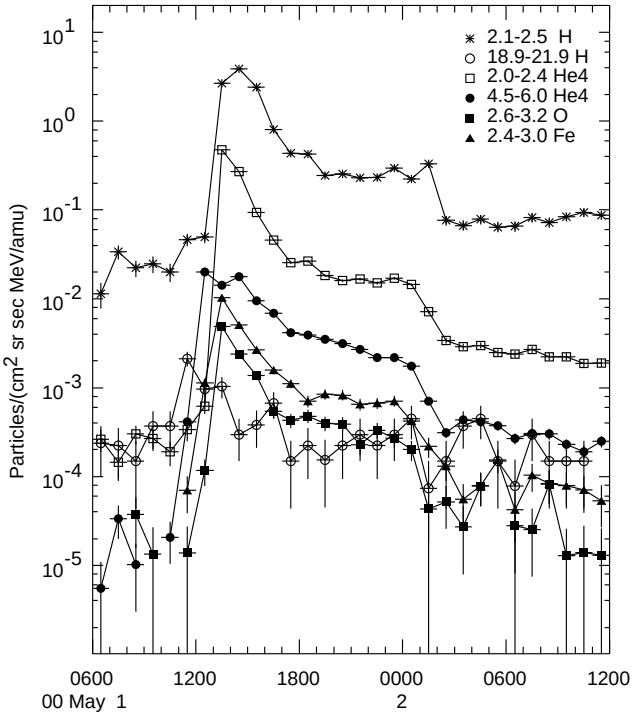

Fig. 1. Intensities of various elemental species versus time for the impulsive flare ejection of 2000 May 1.

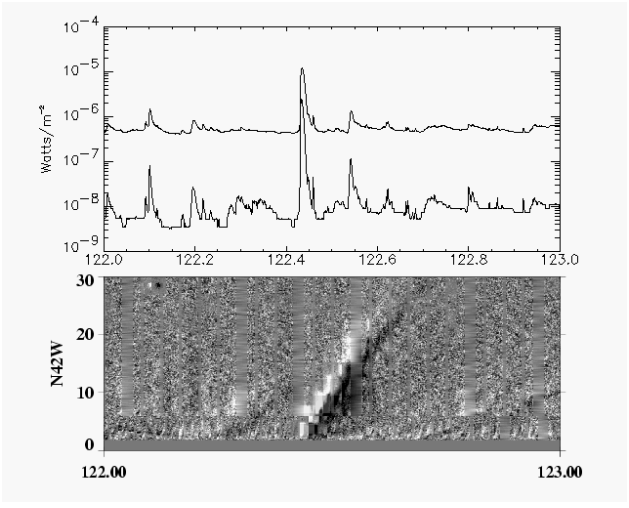

Fig. 2. Top: GOES X-ray flux profiles on 2000 May 1. The M class flare at $\sim$ 1030 UT is associated with the CME and impulsive SEP event. Bottom: Gray scale images of C2 and C3 coronal brightness height-time profiles along a fixed radial direction at ϕ = 312°.

subtracted images from the C2 and C3 coronagraphs along a fixed radial direction at ϕ = 312° using the technique discussed by Sheeley et al. (1999). The figure shows a fast bright CME with a projected onset at $\sim$ 1000 UT and a speed of 960 km s^{-1}.

Subtracted C2 and C3 images of the CME are shown in the bottom of Figure 3. The narrow $\sim$ 20° width of the CME places it in the lower end of the statistical distribution of CME widths (St. Cyr et al., 2000). The top of Figure 3 shows a direct and a subtracted image in the 195 $\AA$ band from the Extreme-ultraviolet Imaging Telescope (EIT) (Delaboudiniere et al., 1995) on the *SOHO* spacecraft. A compact brightening in AR 8971 at approximately N20W54 with a maximum in the 1024 UT image clearly corresponds to the M1 flare in Figure 2. No Hα flare was reported for this event.

The timing and spatial relationships of Figures 1 to 3 show that the May 1 impulsive SEP event was associated with the compact flare and narrow CME observed in the EIT and Lasco images, respectively. This flare was confined to the active region and was associated with a 950 sfu burst at the peak frequency of 8800 MHz and with groups of metric and kilometric type III radio bursts. No type II bursts were reported. The impulsive SEP event follows the accepted paradigm (Reames, 1999) in its association with the impulsive solar flare, but not in its association with the CME.

We have examined other contemporaneous SEP and coronagraph data sets to search for further candidate associations between impulsive SEP events and CMEs. We first compared impulsive SEP events observed by the *ISEE-3* spacecraft with CMEs observed with the Solwind coronagraph. We then compared additional impulsive SEP events observed with the EPACT instrument with Lasco CMEs. A number of additional candidate associations were found, adding further evidence to our finding that in some cases CMEs can be associated with impulsive SEP events.

3 Discussion

While the association of CMEs with impulsive ^{3}He-rich or Fe-rich SEP events appears contrary to the current understanding of impulsive SEP production at the Sun, there are several reasons that this association might have been expected. First, the lack of CME association with impulsive flares and SEP events was not firmly established. The study of Kahler et al. (1985) found no statistical evidence for CME associations with ^{3}He-rich SEP events, but specific flare associations were not used in that study. No cases of clear CME associations with ^{3}He-rich or Fe-rich SEP events were found, but this did not preclude the possibility that future cases might be found.

There has also been increasing evidence that impulsive flares produce faint coronal ejecta. Soft X-ray ejections from compact limb flares at least M2 in size have been observed (Shibata et al., 1995), and the range of velocities of the faint ejections was 50-400 km s^{-1}. In the view of Shibata et al. (1995) the ejecta from compact flares were plasmoids formed in the reconnection region over the flare and threaded by twisted field lines connected to the photosphere. In a recent work Ohyama and Shibata (2000) surveyed *Yohkoh* SXT limb flares and found that 36 to 40 of the 57 flares with good observations during the flare impulsive phases were associated with X-ray plasma ejections. Some X-ray jets are associated with type III radio bursts (Shibata et al., 1996). Raulin et al. (1996) discussed two cases of *Yohkoh* SXT and metric

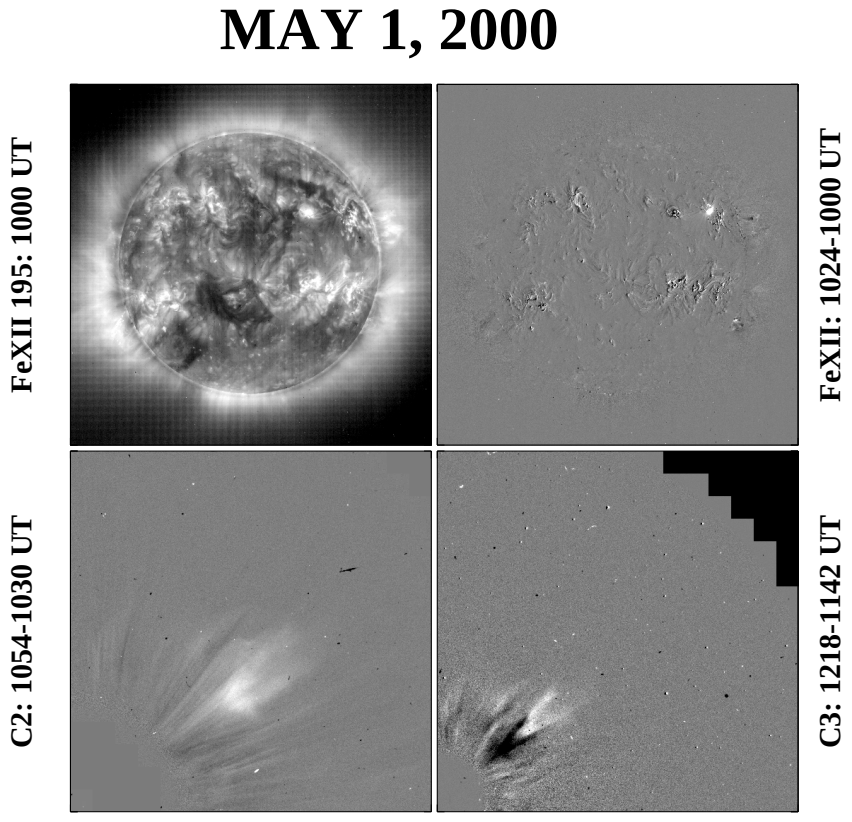

Fig. 3. Top left: Direct EIT 195 $\AA$ image showing the solar disk before the flare. Top right: Subtracted EIT 195 $\AA$ image showing the impulsive flare as a small white feature in the NW quadrant of the disk. Below: subtracted C2 (left) and C3 (right) images showing the CME.

observations showing that the type III burst electrons from active regions propagated along the enhanced density region of the X-ray jets. They associated both the electron acceleration and the jet production with magnetic reconnection. The presence of type III bursts indicates the rapid upward propagation of keV electrons which is possible only along open field lines. In addition, many bright jet-like CMEs observed in the Lasco coronagraph appear to be associated with impulsive flares.

The May 1 impulsive flare appears to be a case in which an associated ejectum was so bright that it was easily visible in the Lasco coronagraph. Besides an intense X-ray burst, the flare was associated with interplanetary SEPs with proton energies extending to 20 MeV and with an intense microwave burst. We have also found several candidate cases of impulsive flare ejecta in the Solwind and Lasco CME images. However, we find that very few of the impulsive SEP events can be associated with CMEs, probably because the ejecta are too faint to be detected or to warrant selection as CMEs in coronagraph observations. The best chance for seeing such events is when very energetic impulsive flares occur near the solar limb. Conversely, we expect that only a few impulsive flares will be favorably located to produce SEP events observable at 1 AU (Reames, 1999).

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