INTERACTING CMEs AND EFFECTS ON THE ACCELERATION AND TRANSPORT OF ENERGETIC SOLAR PARTICLES

Mario Damasso [1] Marco Galliani [2]
[1] General Applied Physics Institute, University of Milan, Italy
[2] Physics Department, University "Roma Tre", Rome, Italy

INTRODUCTION

Fastest and widest CMEs could originate MHD shocks that accelerate solar wind ions and produce the so-called gradual Solar Energetic Particle (SEP) events, very important for space weather purposes. Recently, it has been pointed out that a shock propagating in coronal and IP medium perturbed by preceding palsma emissions could produce SEP events with very high intensities [1, 2]. So, it is interesting to study carefully CMEs interaction - deduced for the first time from the combined analysis of radio spectrograms (decametric-hectometric band) and coronagraph images [3] - to point out the effects induced on acceleration and transport of solar energetic particles. We have studied three interaction events between two CMEs. Each has associated a gradual SEP event, and we have analysed H, He, O and Fe ions to find in their behaviour some characteristics due to interaction. Data interpretation was performed in the framework of the gradual SEP events model [4] based on the resonance mechanisms between energetic protons and Alfvén waves.

THE EVENTS WE HAVE ANALYSED

DATE	FLARE					CME			
	Start	Max	End	Classification (X-ray/optical)	Position on solar disc	First observation in LASCO/C2 fov (UT)	Central position angle	Amplitude (°)	Linear velocity (km/s)
2001/11/22	20:10	20:55	23:52	M1.8 / 2B	02S 06E (AR 9690)	23:30	Halo	360	1443
	21:50	22:15	22:25	C5.8 / 2N	01S 16W (AR 9704)	23:30	Halo	360	1437
	22:32	23:30	00:06	M9.9					

DATE	FLARE					CME			
	Start	Max	End	Classification (X-ray/optical)	Position on solar disc	First observation in LASCO/C2 fov (UT)	Central position angle	Amplitude (°)	Linear velocity (km/s)
2001/04/09	15:20	15:34	16:00	M7.9 / 3B	32S W04 (AR 9415)	15:54	Halo	360	1192
2001/04/10	05:06	05:26	05:42	X2.3 / 3B	02S W09 (AR 9415)	05:30	Halo	360	2411

DATE	FLARE					CME			
	Start	Max	End	Classification (X-ray/optical)	Position on solar disc	First observation in LASCO/C2 fov (UT)	Central position angle	Amplitude (°)	Linear velocity (km/s)
1999/06/04						08:06*	Halo	360	980
	06:06*	07:00*	07:28*	M3.9 / 2B	N17 W88 (AR 8552)	07:26	269	180	2230

* The source region of this CME is in the NNE sector of the solar disc, as inferred from SOHO/EIT and Yohkoh/SXT images
* start, max and end times of the optical flare

In the tables above are showed the solar phenomena associated with the SEP events selected: the CMEs producing the gradual SEP, the ones preceding, the associated flares and the corresponding sources on the solar disc. The CMEs data are from SOHO/LASCO catalog [5].

All the events show a type II radio bursts associated with the second CME (from 14 to 0.5 MHz), with a stucture typical of CMEs interaction in the interplane tary space (radio spectrograms are from Wind/WAVES experiment and are not showed here).

Event n° 1: 2001, November 22

This SEP event (start 23:20 UT) is associated with two IP shocks driven by CMEs from near solar regions and with time difference of only two hours. Intensity-time profiles of abundance ratios (1.3 ÷ 16 MeV/n; fig. 1), normalized to typical coronal values and measured after the 2nd CME, show a short initial suppression in the first energy range: this is not a common behaviour during gradual SEP events associated with a single IP shock. We interprete it as the initial presence of a very hard proton spectrum capable to generate and amplify Alfvén waves resonating (scattering) most with Fe ions.
In fig. 2, single Fe and O fluxes show, at the time of the ICME transit at ~1 AU, the presence of an intense magnetic turbulence in the region between the shocks that is able to trap O ions efficiently: this could explain the high values of the Fe/O ratio just after the initial phase of the event. These interpretations seem to be supported by the quite different behaviour of Fe/O and He/H time profiles, with Fe and He ions with nearly the same rigidity: this is a way to test the role of ion-wave scattering processes.

Fig.1

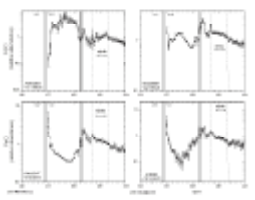


Fig.2

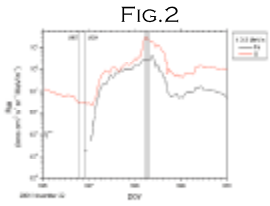


Fig.3

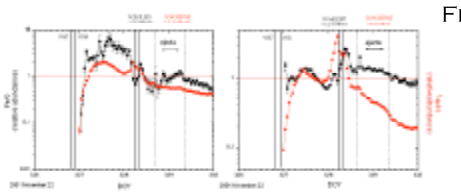


Fig.4

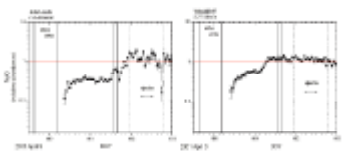


Fig.5

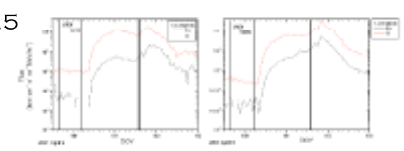
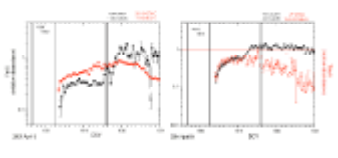


Fig.6



Event n° 2: 2001, April 9-10

This SEP event (start 8:50 UT on april 10) is associated with a CME preceded 14 hours before by a second CME from the same region on the solar disc. It has been yet partially analysed [6]. Fe/O abundances ratios in the first two energy ranges (fig. 4) show anomalous suppressed values
(<1), caused by the Fe fluxes that rise slower than O ones. The proton spectra analysis does not support the idea of high magnetic turbulence in front of the first shock. We suppose there was high turbulence between the two shocks, as the single Fe and O fluxes (fig. 5) and the comparison between Fe/O and He/H profiles (fig. 6) seems to point out.

Fig.7

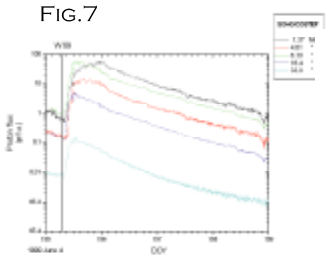


Fig.8

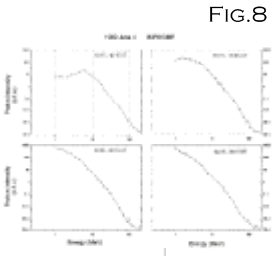
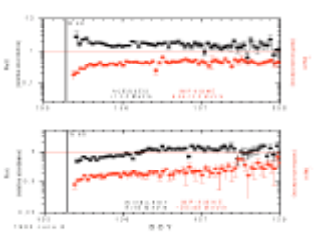


Fig.9



Event n° 3: 1999, June 4

The CMEs originated from distant solar regions but their big amplitudes made possible the interaction. Fig. 7 shows proton fluxes as measured by SOHO/COSTEP experiment. The second CME produced a gradual SEP event typical for a MHD shock originating from the well-connected West solar emisphere. We suppose there is no evidence for properties due to interaction: fluxes seem to be the typical ones produced by a fast and wide CME expanding in the no-perturbed solar wind.
We reach the same conclusion analysing proton energy spectra (fig. 8; data from IMP-8/GME experiment, 2 hours averages): their temporal evolution seems to exclude the presence of high magnetic turbulence due to Alfvén waves, as a consequence of CME interaction. Also the comparison between Fe/O and He/H time profiles (fig. 9) support this idea: they are modulated almost in the same way, indicating no strong variations of magnetic turbulence met by energetic ions during

CONCLUSIONS AND COMMENTS

The November 2001 event seems to produce the effects of a single, very strong shock, possibly due to this type of CME interaction (the number of the shocks, geometry, timing of the plasma emissions). During the april 2001 event the time difference between the two emissions seem to determine an high level of magnetic turbulence in the region between the two shocks. Instead, in the June 1999 event the distance of the sources on the solar disc and the absence of a shock driven by the first CME could explain, in the energetic ions, the lack of particular characteristics due to processes induced by CMEs interaction. To find effects in the acceleration and transport processes of SEP, the study of other well defined CME interactions events could make clear the weight of parameters as the proximity in time and space of two or more shocks and their relative geometry.

References

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[3] Gopalswamy, N., et al., 2001, ApJ, 548, L91
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