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Energetic Particles inside Magnetic Clouds: a tentative search for their origin

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Abstract

During solar activity cycle 21st maximum, the instrumentation aboard ISEE-3 spacecraft observed many energetic particles events, several of them associated with Magnetic Clouds (MCs). In this paper, we focus our study on the December 19th 1980 event, which was related with an MC that showed one of the most intense magnetic field strength ever observed. We have studied the energetic particle (36 keV – 1,6 MeV) spectra and directional distribution evolutions just before, inside and after the MC passage, with the aim of finding the origin of the energetic particles detected inside the MC.

1 Introduction

Since the publication of the paper “The Solar Flare Myth “ by Gosling, the solar cause(s) of Energetic Particle Events in the Interplanetary Medium (IP) has become one of the major issues of discrepancies among the scientific community. Nevertheless, the amount of sights and experimental evidences indicating the fast Coronal Mass Ejections (CMEs) as the main responsible of Energetic Particle Events associated with Interplanetary Travelling Shocks has increased during the last years. It is assumed that the interplanetary counterpart of these CMEs are the Magnetic Clouds (MCs) that are regarded as magnetic structures isolated from the Interplanetary Magnetic Field (IMF) with a local magnetic field topology and plasma signatures well established. The interested reader can find a detailed description of this matter in Cid.et al. 1999. Recently, Cid et al. 1998 have presented an efficient model of MCs that allows, not only their clear identification but the detailed study of their internal structure and the sharp delimitation of their borders. However, what it is not already known is the large-scale structure of the MCs. Nowadays there are two competing models. The first one regards the MCs as closed toroidal like structures completely isolated. The second one assumes that the MCs are loop like structures with their feet anchored at the Sun. In addition to direct measurements of the magnetic field and plasma parameters, several studies (Marsden et, al, 1987, Richardson t al., 1991 and references therein) have been reported in which energetic particles are used as tracers of the large-scale structure of the MCs. Particularly, field-aligned bi-directional flows (BDFs) of solar energetic particles have been attributed to the effects of mirroring in the isolated well-ordered magnetic field characteristic of magnetic clouds. As for the energetic particles accelerated by the shocks associated with MCs, Rodríguez-Pacheco et al. 1997 presented a study of the most intense energetic particle events in the vicinity of the Earth and their possible relationships with MCs. The MCs seem to play a double role. In one hand the plasma that they carry acts as the shock driver, and in the other hand, the volume by they contained seems to be isolated from their magnetic environment. The second role means that downstream the energetic particles accelerated at the shock front and propagating Sunward seem to be not allowed to penetrate inside the cloud. Particularly, the experimental data show particle fluxes decreases as the MCs are convected past the spacecraft detectors. In this study, we have focused our attention in an MC that presented one of the most intense magnetic field strength ever recorded. This MC was related with an interplanetary shock that reaches the spacecraft on 19th December 1980. We have studied the MC local structure using the Model by Cid et at. 1998 mentioned above, and the energetic particle temporal profiles, spectra and directional distributions, with the aim of clarifying the complex relationship between the shock, MC and energetic particles.

2 Instrumentation

The "Low Energy Proton Instrument" (Balogh et al., 1978, van Rooijen et al., 1979) consist of three identical semiconductor telescopes designated T1, T2 and T3, each with a conical field of view of half-angle 16º, and a geometrical factor of 0.05 cm^2 sr. The telescopes are inclined 30º, 60º and 135º respectively to the spacecraft spin axis, which is directed northward perpendicular to the ecliptic plane. This configuration optimizes the angular coverage and, at the same time, avoids direct solar radiation. The energy range of the instrument is divided in eight (E1,...,E8) logarithmically spaced energy channels (E1.....E8) with their lower thresholds at 36, 56, 91, 147, 238, 384, 612 and 1000 keV. The directional information for every energetic channel is obtained in eight equi-angular (45º, except for E8: 90º) azimutal sectors (S1.....S8). From these data, the directional information of the incoming particles is derived. It should be noted that this instrument is not capable of discriminating between protons and heavier ions, so in the following we will refer to protons or particles indiscriminately. Finally, we have to mention that at the moment of writing this contribution only the one hour averages of T2 were available, i.e. only data from the telescope that pointed 30º above the ecliptic plane have been used.

3 Results

3.1 Temporal Profiles: Figure 1 shows the temporal profiles of channels E1 and E8 (first and second curves from the top respectively), and the poloidal and toroidal components of the magnetic field (third and fourth curves respectively). The sharp increase on the intensity of E1 around 05h of doy 354 indicates the shock arrival at the spacecraft (dashed line). The magnetic field components suggest that: a) the MC reach the spacecraft around 13h of the same day (first solid line), i.e. 8 hours later b) the MC center is located around the first hour of doy 355 (dotted line), and c) that the MC leaves the spacecraft around 12h of the same day (last solid line). Several noticeable features can be obtained after a detailed examination of this figure:

1. The MC arrival is well reflected in the energetic particle profiles by sudden decreases, but while these decreases are both of more than one order of magnitude, the lower energy particles seem to be more affected.
2. Despite the decreases mentioned above, the flux level inside the MC is still more than one order of magnitude higher than the background level.
3. Inside the MC the particle fluxes are slightly higher in its first half than in its second one.
4. The MC departure does not produce any remarkable effect on the fluxes.

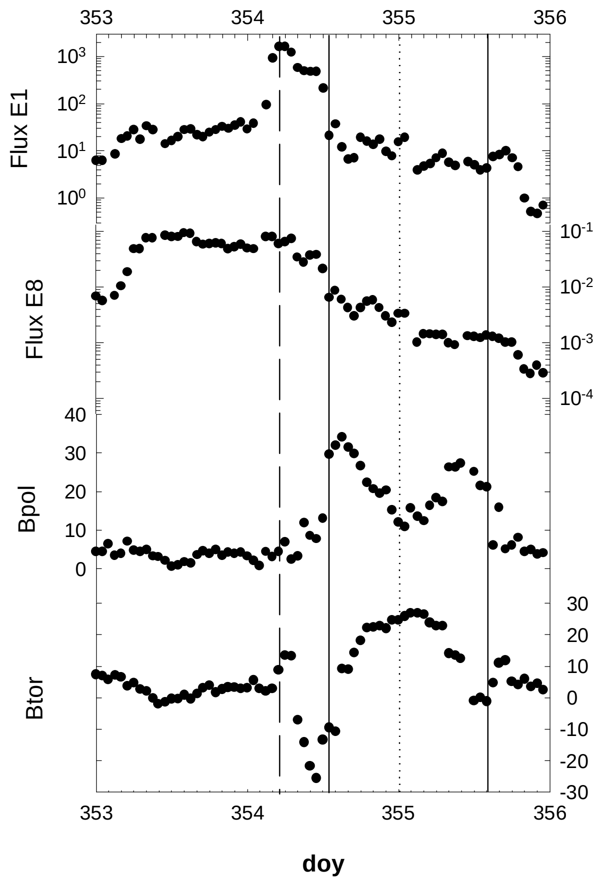

Figure 1: Temporal profiles of channels E1 and E8 compared with the temporal evolution of the poloidal and toroidal components of the magnetic field.

3.2 Spectra: Figure 2 shows the spectra evolution since the time of the shock passage which corresponds with time =0. All the spectra are suitable to a power law fit (i.e. $I \propto E^{-\gamma}$). The exponent's temporal evolution is shown in the bottom panel. As it can be seen, between the arrival times of the shock and the MC, the exponents suffer a smooth decrease, which is stopped through the MC passage. The MC arrival clearly affects the spectrum but its departure does not. The γs maximum value is 3.1 (time 0) and their minimum is 2.2 (time+11). Along the MC, their values show slightly variations that are mainly due to the increases and decreases of the lower energy particle fluxes.

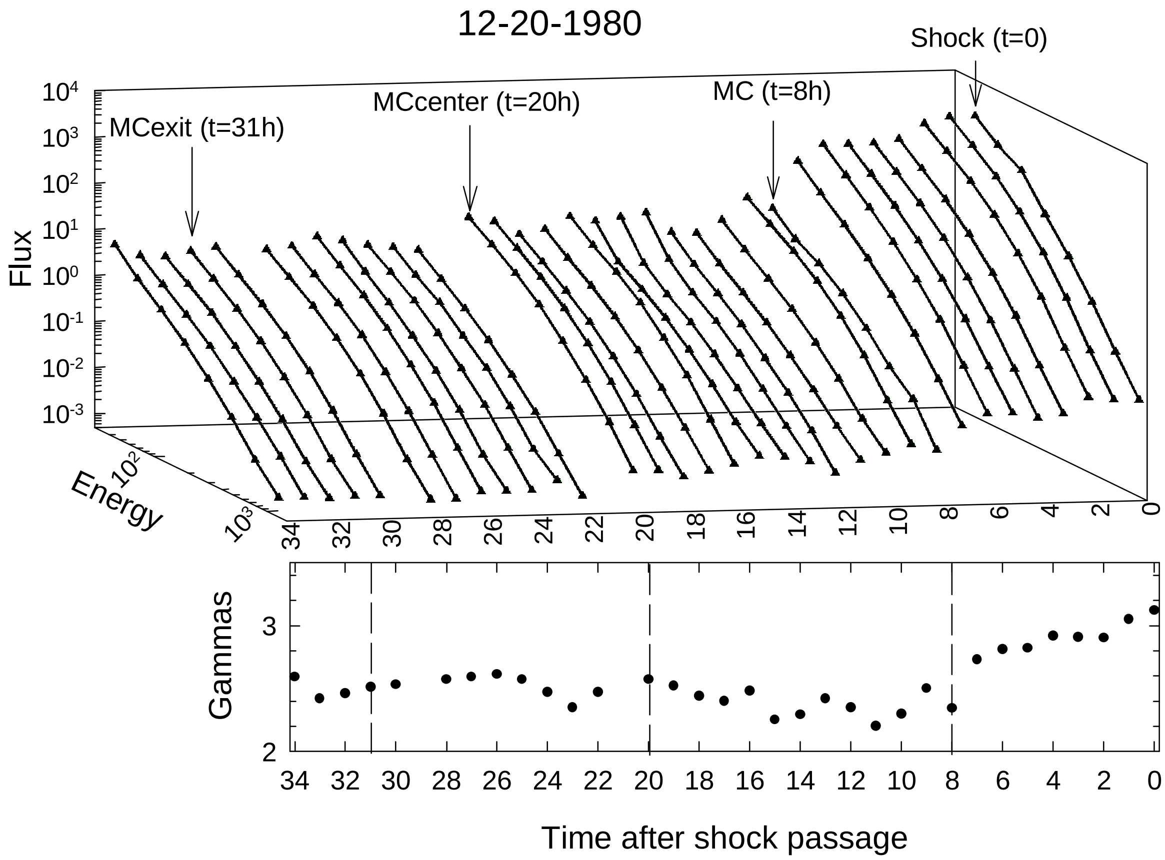

Figure 2: Top: evolution of the energetic particle spectra since the shock passage (t=0). Bottom: evolution of the spectra exponents.

3.3 Anisotropies: Due to the "low-energy" of the particles under consideration, the study of the directional distributions has been made after transforming the energetic particle fluxes to the solar wind frame. This study covers the 44 hours after the time of the shock arrival, so it includes the BDF reported by Mardsden and his collaborators mentioned above. Nevertheless, this BDF is not directly associated with the magnetic structure, because it reaches the spacecraft 8 hours after the MC back border. Anyway, we have centered our attention to the fluxes directional information just before, inside and just after the MC. Despite the fact that the directional fluxes did not show any evident trend along the MC passage, we have to point out several interesting features:

I) While the MC arrival induces dramatic changes on the directional profiles, the variations produced by its departure are smoother.

II) During the first hour of the MC temporal extension, there are particle streamers coming from the inner parts of the MC.

III) We have only find a slightly trace of BDF one hour before the MC center (t+18).

IV) There are periods inside the cloud in which the energetic particles show a completely distinct behavior at low (below 400 keV) and high (above 400 keV) energies. The most significant of them is the period between t+11 and t+14. These differences are much less remarked along the second half of the cloud.

Figure 3 shows the directional fluxes showed by channels E1 (left column) and E7 (right column) during the previous and first hours of the MC (first and second rows respectively), at the time of the BDF mentioned above (third row) and during the last our of the cloud and the first outside it (fourth and fifth row respectively). The Sun is located on the top of each figure. The magnetic field azimut and the flux in the sector with the highest flux are indicated for each interval.

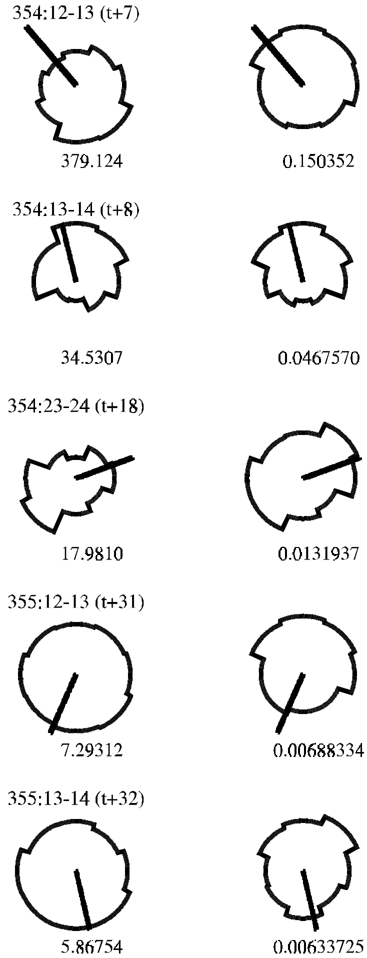

Figure 3: Directional fluxes during some of the intervals discussed in the text.

4 Discussion:

After considering the results previously mentioned, our opinion is that there is not any clear evidence that indicates the source of the energetic particle inside the cloud. Nevertheless, the spectra exponents and their evolution indicate that the particles downstream the shock and inside the cloud have the same source. The temporal profiles spectra and directional distributions suggest a double asymmetry. There seems to be an asymmetry in the behavior of the mentioned properties between the first and second half of the cloud. This asymmetry is also reflected by the toroidal and, mainly, the poloidal components of the magnetic field. This behavior is extreme in the MC borders: while the MC arrival induces dramatic changes in all the studied properties, its departure does not produce any variation. The second asymmetry refers to the studied energetic band (36-1600 keV): inside the cloud it seems to be decouped around 400keV.

References

Balogh, A. Et al., 1978 IEEE Trans. Geosci. Electron., 16(3), 176.

Cid, C., Hidalgo, M. and Viñas, A.F. 1998, ECRS, 191.

Cid, C., Hidalgo, M., Rodríguez-Pacheco,J., Medina,J. and Sequeiros,J., 1999, SH 2.1.19 this volume.

Gosling, J.T., 1993, JGR, 98, 18937.

Marsden, R.G., Sanderson, T.R., Tranquile,C. And Wenzel K.P., 1987, JGR, 92, 11009.

Richardson, I.G., Cane,H.V.and von Rosenvinge T.T., 1991, JGR, 96, 7853.

Rodríguez-Pacheco, J., Cid, C.,Sequeiros, J., del Peral, L., Bronchalo, E.and Medina, J., 1997, ICRC97, SH1-3, 85.

Van Rooijen, J.J. et al., 1979, Space Sci. Instrum., 4, 373.