The influence of the Earth magnetosphere on solar and galactic particle fluxes at 1 AU

E.I. Daibog, Yu.I. Logachev, K. Kecskeméty, M.A. Zeldovich, G.M. Surova

***Abstract*—The temporal behavior of 1-100 MeV proton fluxes is investigated inside and outside the Earth magnetosphere at ~1 AU using measurements on IMP-8 during 1973-2001. On a nearly circular orbit (R≈20-30 R_E) IMP-8 stayed inside the magnetosphere about half of its lifetime. The large amount of data available permitted a statistical study of proton flux variations both for solar energetic particle (SEP) events (490 events) and quiet periods (150 intervals). Distributions of τ values determining the slope of exponential decay $J(t) = J_o \cdot \exp(-t/\tau)$ after solar energetic particle event maximum were obtained. During quiet-time periods the distributions of spectral indices ν and γ of fitting function $J(E_p) = A \cdot E^{-\gamma} + C \cdot E^{\nu}$ as well as τ were compared for different space regions. The orbit was divided into 3 regions: I) from the Earth-Sun line to the entering point to the magnetosphere, II) inside the magnetosphere and III) from the exit point from magnetosphere up to the Earth-Sun line. The distributions of τ, γ and ν were all found to differ in these regions. It is suggested that the "cleanest" observations were made in the region I, where the magnetic field lines pass the Earth magnetosphere without any noticeable distortions, while regions II and III were characterized by strong distortion of the interplanetary magnetic field due to its interaction with the magnetosphere. The results obtained indicate the necessity of considering the influence of the Earth magnetosphere on low energy particle fluxes even beyond 20 R_E.**

1. Introduction

PARTICLE fluxes in the interplanetary space exhibit various spatial structures at different energies. Here we used proton intensity data from IMP-8 (experiment CPME) with energy 0.5-48 MeV in 1973–2001. During this observation interval spanning nearly 3 solar cycles 640 time periods were selected under active and quiet Sun. During quiet time periods the proton energy spectra and spectra of heavier nuclei had minimum at energy E_{min} (for protons E_{min} = 10-30 MeV) [1,2]. The proton spectra were approximated by the function:

$$J(E_p) = A \cdot E^{-\gamma} + C \cdot E^{\nu} \qquad (1)$$

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Figure 1 presents an example of the quiet-time proton spectrum (14-16 May 1976) where one can see the intensity minimum at energy E_{min} dividing the particles of solar and galactic origin. The particles of the left spectral branch with energy $E < E_{min}$ are the solar and heliospheric particles meanwhile the right branch particles ($E > E_{min}$) are the galactic ones. With solar activity increasing E_{min} shifts to higher energies because the number of solar particles increases and number of the galactic ones decreases due to modulation processes. This spectral change was first found for protons [1], further for fluxes of heavier nuclei and more recently for such exotic nuclei as ^{3}He [3].

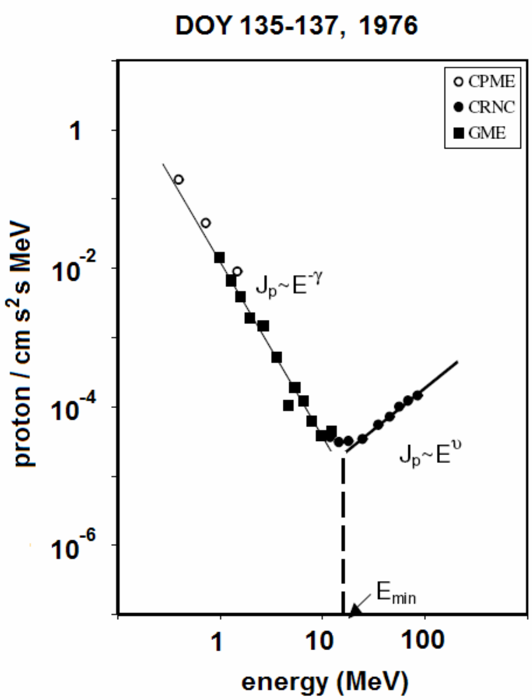

Figure 1. The proton energy spectrum at 1 AU during quiet Sun on 14-16 May 1976 based on CPME, CRNC, and GME data from IMP-8. The spectral parameters are γ = 2.7, ν = 1.3 and E_{min} = 17 MeV.

The features mentioned above are observed under quiet or quasi-steady conditions of the interplanetary magnetic field (IMF). When the IMF is disturbed, the proton fluxes undergo strong spatial and temporal variations. The magnetosphere is a noticeable factor of influence on parameters of interplanetary space (solar wind and IMF). Charged particle fluxes measured near the Earth in different spatial regions are strongly modified by the magnetosphere both inside it and at its boundaries.

Previously we studied particle fluxes under quiet solar conditions and during the decay phase of SEP events. The proton fluxes with energies 1-10 MeV decrease after solar flare often following exponent rule $J(t) = J_o \exp(-t/\tau)$ where τ is the characteristic decay time [4], [5]. The occurrence of such profiles indicates quasi-steady conditions in the interplanetary space and of the magnetic field. Taking this into account one can consider the value of τ for various solar events as a mean parameter for particle fluxes and its variations can be used for estimating the influence of magnetosphere on particle fluxes. Under quiet Sun for this purpose the spectrum parameters γ, ν and E_{min} can serve. Three of the parameters mentioned (τ, γ, and ν) have been used here for the estimation of the influence of magnetosphere on the low-energy particle fluxes.

2. The Orbit of IMP-8

IMP-8 was launched on 26 October 1973 with initial perigee 141,185 km, apogee 288,857 km, inclination 28.7° and rotation period of 12.3 days. Later on the s/c orbit changed to a perigee $\geq$ 20,000 km and inclination up to 50° [6].

Due to this orbit IMP-8 was located inside the Earth magnetosphere almost half of the time. In our investigation each of IMP-8 rotations was divided into three regions: I) – from the Earth-Sun line to the entering point into the magnetosphere, II) – inside the magnetosphere and III) – from the exit point from magnetosphere up to the Earth-Sun line. As the time of the intersection of the Earth-Sun line was not available, we took it as the mean value between the times of exit from and entrance into the magnetosphere. Both time moments in 1973-2002 are available on the website http://nssdcftp.gsfc.nasa.gov/miscellaneous/orbits/imp8/imp8.solarwind. The example of IMP-8 orbit with three selected regions is presented in Figure 2.

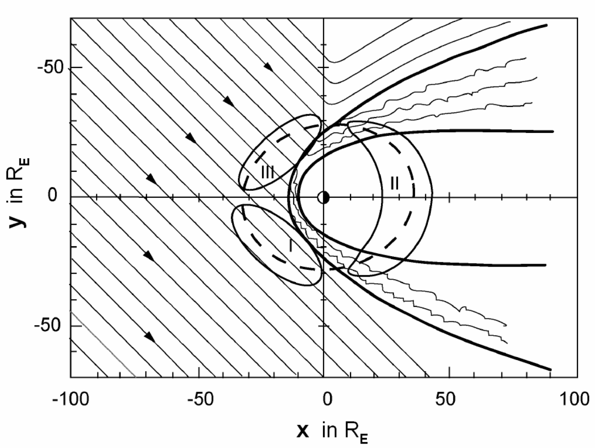

Figure 2. The IMP-8 orbit (dashed oval) projected on the ecliptic plane, solid ovals: 3 selected spatial regions. The nominal IMF is shown by straight lines with arrows. Distances along the x and y axis from the Earth are in R_E.

The regions under consideration were characterized by strong differences in the magnetic field structures. In the absence of strong disturbances in region I the interplanetary magnetic field (it should be noted that for determining τ, ν and γ periods with the field quasi-stable conditions were selected) pass the Earth magnetosphere without interaction. Region II is situated entirely inside the magnetosphere so charged particles entering this region are governed by magnetospheric field. Only a small part of these particles can be captured by the magnetosphere but the dominant part would move out of magnetosphere therefore the particle intensity remains unchanged in comparison with the interplanetary values at 1 AU. It should be taken into account that region II is located at rather far distances from the Earth. As for region III, it is where the strongest interaction occurs between the interplanetary magnetic field and the Earth magnetosphere (see Fig. 2). Therefore just here one can expect the strongest influence of the magnetosphere on charged particle fluxes.

3. Particle Flux Statistics under Quiet Sun and During SEP Events

A. Statistical Properties of Quiet-Time Proton Spectra

Under quiet Sun the interplanetary space has a stationary structure and the particle fluxes of solar origin approach the minimal values remaining nearly constant for time periods of 3 to 15 days. These intervals are optimal for considering the effects of the influence of magnetosphere on the particle fluxes near and inside it. Here the parameters ν and γ were obtained from approximation (1). Due to the short lengths of orbit in regions I and II (about 3 days) and to ensure that entire quiet-time periods be inside one of the three designated orbit regions, the durations of quiet-time periods investigated were limited to 3 days. Longer quiet periods have been investigated separately. When selected periods belonged to two distinct regions, the time of residence in each of them were compared. If their ratio was 1:3 or less, the selected time period was further considered and was attributed to the region with longer part of selected period, otherwise this period was excluded from the investigation. After the selection the total numbers of quiet periods were 150 and 47 in region I, 60 in region II, and 43 in region III, respectively. Figures 3 and 4 present the distributions of ν and γ values for all three spatial regions investigated (I, II, and III). In spite of the relatively weak statistics one can see that these distributions show some difference for different regions. Attention should be paid to the ν distribution in region III characterized by a nearly symmetrical shape, closer to Gaussian than the distributions in regions I and II. It should be noted that the values of ν refer to protons with energies >10-20 MeV whereas the values of γ are determined by proton fluxes with energy <10 MeV (contrary to ν, the γ distribution is the most symmetrical in the region I). At present we have no explanation of the differences observed; obviously, more statistics is needed.

B. Statistical Properties of SEP Event Flux Declines

During the time period investigated (1973 – 2001) more than 600 SEP events of >1 MeV protons were analyzed. The distribution of characteristic decay time τ of proton intensity $J(t) = J_o \exp(-t/\tau)$ have been obtained. The total time of decay was highly variable among various SEP events with values of several hours to >3-5 days or longer. For short decay times it is very difficult to distinguish between exponential decay and the power-law. Therefore we limited to events with decay time ≥12 hours. On the other hand, the selected orbit spatial regions I and II had durations only about 3 days. Therefore events with decay phase >3 days were excluded from the investigation to limit event durations to one selected region (I or II). The periods were selected in the same way as in 3A. After the selection the total number of SEP events was 490, from them 150 in region I, 232 in region II, and 108 in region III. In Figure 3c the distributions of τ for all 3 regions selected are displayed. One can see that for regions I and II the distributions are practically identical and slightly differ from that of region III where the strongest influence of magnetosphere on the interplanetary magnetic field might be expected. However, the τ distributions for regions II and III show an excess of events with high values of τ in comparison with region I. Also worth to note that >1 MeV proton fluxes in region II (located entirely inside the magnetosphere) practically coincide with fluxes well outside the magnetosphere.

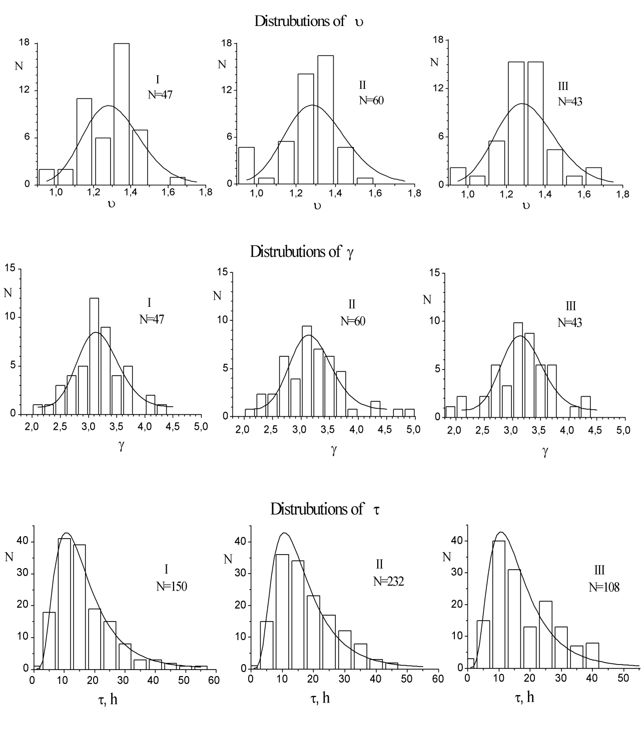

Figure 3. Distributions of proton spectral parameters v, γ and of decay time τ for 3 selected regions of the magnetosphere (I, II, III). For comparison the best-fitting curves for region I in each region are also shown (Gaussian or lognormal approximation).

4. Comparison of Particle Fluxes Measured on IMP-8 and ACE

Another possibility is to study the degree of the influence of Earth magnetosphere on the particle fluxes, by comparing simultaneous measurements on two s/c (for example on IMP-8 and ACE). We used the CPME – IMP-8 1-2 MeV protons and LEMS120 - ACE 1.05-1.89 MeV protons. ACE is orbiting around the Lagrange point L1 at 0.01 AU from the Earth. At such a far distance from the Earth (>200 R_E), apart from upstream events [7], the influence of the magnetosphere on particle fluxes measured by ACE is practically negligible. The next step was to compare the proton time profiles on ACE and IMP-8. Figure 4 presents the decay curves for 3 SEP events registered in regions I, II and III selected along the IMP-8 orbit. The largest difference between proton fluxes at ACE and

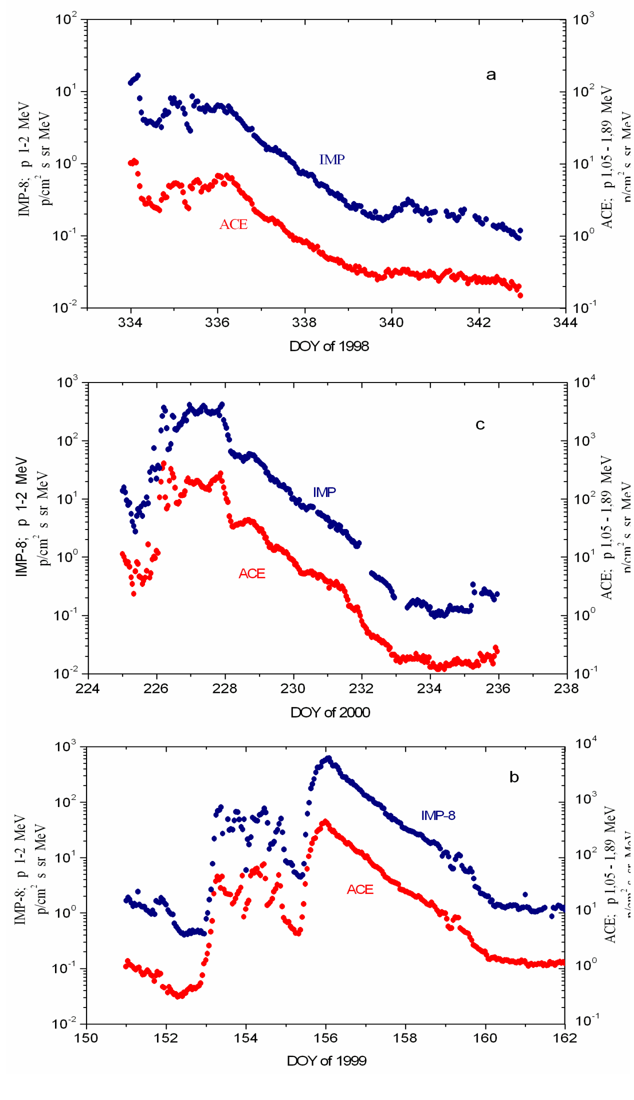

Figure 4. Time profiles of ~1 MeV proton intensities during SEP events in selected regions I, II, III (a, b, c) measured by IMP-8 and on ACE simultaneously. The region III shows the strongest difference between proton fluxes on IMP-8 and ACE.

IMP-8 can be observed in region III where we assume the occurrence of the strongest influence of magnetosphere on charged particles due to stronger interaction of IMF with the bow shock.

5. CONCLUSION

The analysis above suggests that the quasi-steady >1 MeV proton fluxes measured on IMP-8 undergo only a limited influence of the Earth magnetosphere. However, the most significant disturbances in particle fluxes occur during periods when the magnetosphere is strongly disturbed, for example, in magnetic storms. In these cases some peculiarities can appear (predominantly in region III) in proton fluxes different from that in the interplanetary space. This effect is desirable to be taken into account when precise measurements of the ″clean″ particle intensity, i.e. undisturbed by the magnetosphere are needed.

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