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EFFECT OF GEOMAGNETIC STORM ON TRAPPED PROTONS WITH $E_p > 1$ MeV AT ALTITUDES OF 500 km[1]

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The changes in the position of the boundary of trapped protons above 1 MeV during and after a geomagnetic storm ($D_{st} = 172$ nT) at low altitudes are presented. There are found irreversible changes of the proton flux for protons with low equatorial pitch-angles above certain L, depending on energy. The data are interpreted in terms of nonadiabatic effects of particle motion in the dipolar magnetic field.

ВЛИЯНИЕ ГЕОМАГНИТНОЙ БУРИ НА ЗАХВАЧЕННЫЕ ПРОТОНЫ С ЭНЕРГИЕЙ $E_p > 1$ МэВ НА ВЫСОТЕ 500 км

В работе приведены наблюдения изменения положения границы захваченных в геомагнитном поле протонов с энергией свыше 1 МэВ в течение геомагнитной бури и непосредственно после нее ($D_{st} = 172$ nT) на малых высотах. Обнаружены необратимые изменения потока протонов с низкими экваториальными питч-углами свыше определенного L, которое зависит от энергии. Полученные данные можно объяснить при помощи неадиабатических эффектов движения частиц в дипольном магнитном поле.

I. INTRODUCTION

During geomagnetic storms, when the magnetic field strength is depressed, a redistribution of energetic particles trapped by the geomagnetic field takes place. Such changes have been investigated many times. The strongest changes are seen at the "edge" of the radiation belt, where the intensity sharply decreases. The shift of the boundary to lower L has been registered at high altitudes [1].

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In this paper these changes of the proton flux are analysed ($E_p > 1$ MeV) during and after the geomagnetic storm, Oct. 27—28, 1977 at various L shells at low altitudes. This enables to extend the study of the redistribution of the proton population to particles with relatively low equatorial pitch-angles.

II. EXPERIMENT

The satellite Intercosmos-17 was a low altitude ($h \approx 500$ km) polar orbiting satellite ($i = 83.5°$). One of the apparatuses, Pero-3/E, measured the protons at several energy intervals from 1 MeV to >100 MeV. The energy intervals and geometrical factors of the detectors used in this analysis are: $E_p = 1$—6.5 MeV with $G = 0.29$ cm²ster; $E_p = 30$—100 MeV, $E_p > 100$ MeV with $G = 1.53$ cm²ster and $E_p = 10$—30 MeV has geometrical factors $G = 0.92$ cm²ster for 10—30 MeV interval and $G = 0.61$ cm²ster for 16—30 MeV interval, respectively. The two geometrical factors for the last detector are due to partial screening of the detector by solar batteries.

The changes of proton fluxes were analysed on several orbits of the satellite in the interval of Oct. 22—30, 1977, which enabled to compare the intensity of protons at the same points of the L-B coordinate system before, in the main or recovery phases of the storm and also 2 days after reaching the minimum D_{st}. The time intervals of the measurement used as well as the D_{st} variation (minimum $D_{st} = -172$ nT at 05 UT on October 28, 1977) are drawn in Fig. 1.

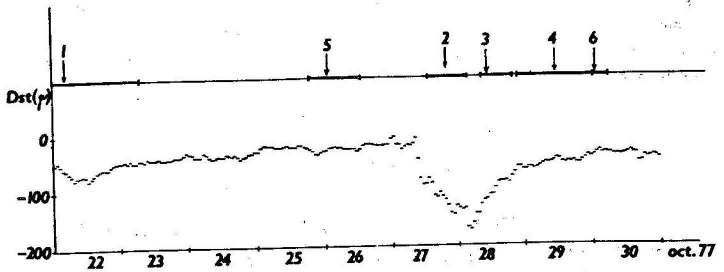
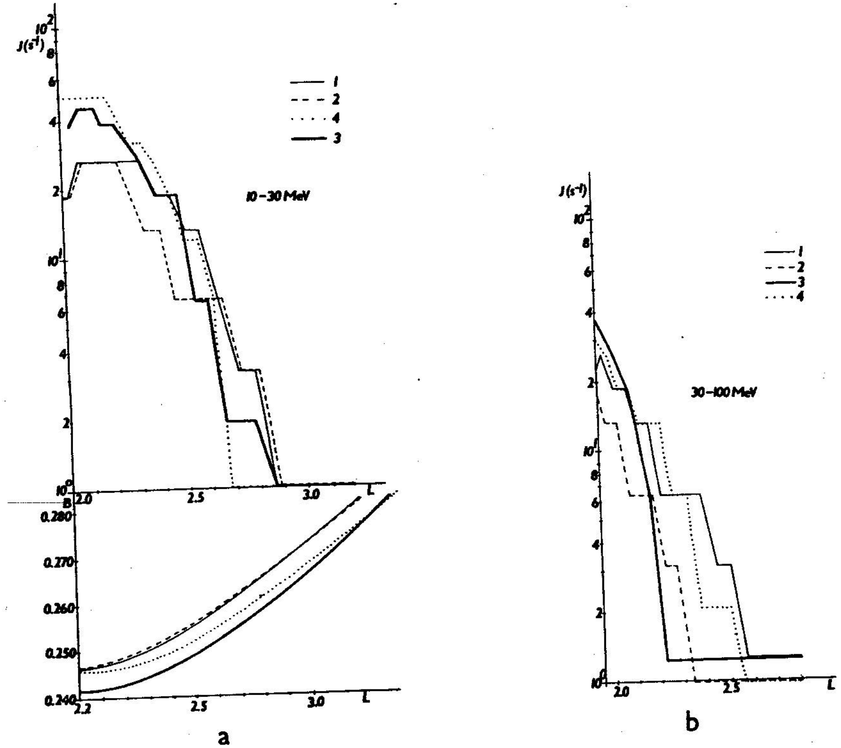


Fig. 1. The values of D_{st} during the analysed period. The thick intervals denote time periods when data are available. By the arrows passes discussed further are depicted.

III. OBSERVATIONS

The profiles of the proton flux with various energies near the trapping boundary, by which we mean the place where the counting rate of the detector drops sharply to 1 s^{-1} for several orbits with near lines in L-B space during the time intervals marked in Fig. 1, are seen in Fig. 2a, b, c, d. The shift of the boundary on the lower L for passing with $D_{st} = -140$ nT is seen (with exception of the 10—30 MeV interval) up to 100 MeV by comparison between curves 1 and 2. The curve 3 (after minimum D_{st}) pronounces a further progress of this shift, which is now significant for all energies studied. Curve 4 corresponds to the time 30 hours after minimum D_{st}.



a

b

Comparison of the proton flux profiles on an orbit before (curve 5) and 2 days after this minimum D_{st} (curve 6), where the satellite passed the given L shell practically at the same B, in Fig. 3, gives evidence of an irreversible decrease of protons near the outer boundary of their registration which persists at a time when the D_{st} reversed to the value before the storm.

In contrast with this is the situation on the lower L shells. The altitude profiles of protons provide a picture of the variations during and after the storms, i.e. the dependencies of the counting rate on B for the given L. An example of such dependencies is drawn in Fig. 4, where we see that at $L=2.3$ and $L=2.4$ a flux of protons where $E_p=10$—30 MeV, which pronounces the decrease during the main phase of the storm and recovers to the former value 2 days after the minimum D_{st}.

The analysis of the available altitude profiles enabled to estimate the boundaries in the L units above which the changes of the proton flux for the given energy interval are irreversible (L_{ir}) as well as L_{rev}, the upper limit of reversible changes are present. These values together with boundaries of proton registration before the storm, L_b, are given in Table 1.

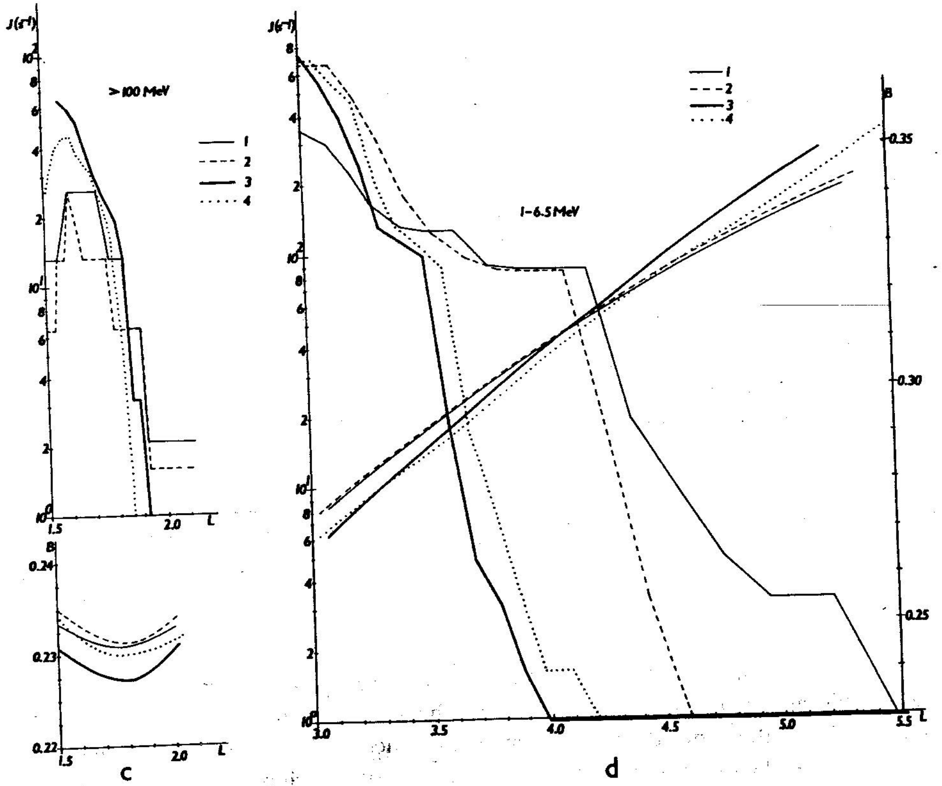


Fig. 2. The profiles of the proton flux near the outer boundary for passings marked in Fig. 1. a) 10—30 MeV (in the bottom part the trajectories are given); b) 30—100 MeV; c) >100 MeV; d) 1—6.5 MeV.

IV. DISCUSSION AND CONCLUSIONS

In papers [2, 3] there were determined the values L_{ir}, L_{rev} in high altitude measurements of protons. In [2] after the storm with $D_{st} \simeq 180$ nT the fluxes of protons $E_p > 40$ MeV were reversible for $L < 2.5$, while for $L \geqslant 2.6$ they were irreversible. The irreversibility of proton intensity ($E_p > 30$ MeV) after the storms with $D_{st} = -206$ nT and 231 nT, respectively, were found at $L > 2.5$ in [3]. The lower values of L obtained in our analysis (for approximately the same energy intervals) where the effect of irreversibility is found, are a natural consequence of the pitch-angle distribution of the trapped particles.

In connection with the development of the mathematical aspect as well as the laboratory investigations, a progress in understanding the non-adiabaticity of the energy proton motion in geomagnetic traps has been obtained in recent years [4—7]. The particle lifetime in the dipolar field is determined by the parameter

$$\chi = \varrho / R_c \qquad (1)$$

where ϱ is the Larmor radius of the particle and R_c is the curvature radius of the

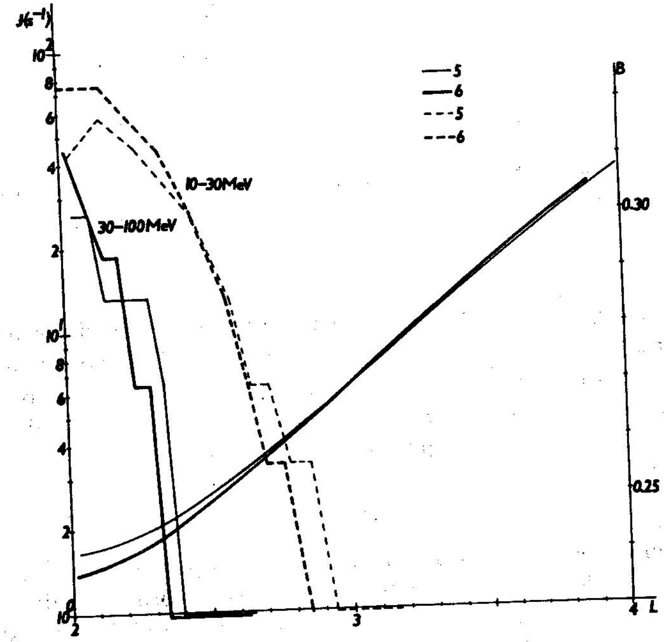


Fig. 3. The profiles of the flux in the passings before and after minimum D_{st}, for which the trajectories are similar.

magnetic field line. The theory gives only enough but not a sufficient condition of stability of $\chi < \chi_c \ll 1$. Here χ_c is the critical value of χ above which the adiabatic motion need not to be satisfied. If this condition is not valid, the instability of the motion connected with irreversible changes of the magnetic moment in the

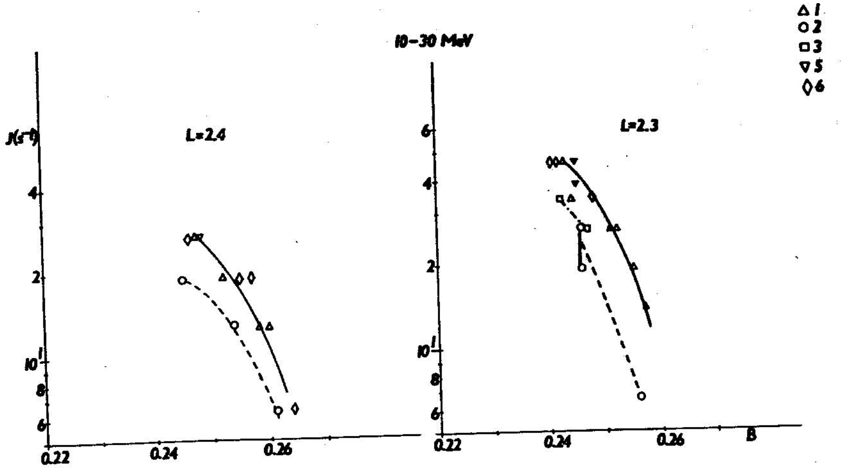


Fig. 4. The altitude profiles showing the reversible changes of fluxes for $L=2.3$ and 2.4 and $E=10$—30 MeV.

manyfold reflection at the mirror points, arises. For the proton with impulse p given in MeV/c the value of χ is [5]

$$\chi_L = 5.04\times10^{-5}\,L^2pc\,. \tag{2}$$

This means that for a proton with a given energy the stable trapping is possible up to the upper L_{krit}. During the geomagnetic storm due to the depression of B the value of χ increases, which leads to the decrease of the lifetime of particles. According to [8] the relative increase of χ when the disturbance has the value D_{st} for particles with low equatorial pitch-angles given is

$$\chi_2/\chi_1 = 1 + 4.8\times10^{-5}\,D_{st}L^3 \tag{3}$$

where D_{st} is measured in nT and χ_1 is given by (2). The second term in (3) is twice lower for equatorially mirroring particles. For the given storm the ratio (3) is 2.02 for $L=5$, 1.66 for $L=3$ and 1.07 for $L=2$. If the "boundary" L_b is an estimate of L_{krit}, then the relatively highest change of χ for a given energy must be just below L_b. When we suppose further that the protons are firmly trapped up to the L_{krit}, then at the time of the maximum depression of B the new L'_{krit} should be shifted so that

$$L_{krit}^{2} = L_{krit}'^{2}(1 + 4.8\times10^{-5}\,D_{st}L_{krit}'^{3})\,. \tag{4}$$

It is interesting to note that if we take a rough estimation using $E=E_{min}$ for each energy interval and take $L_{krit}=L_b$ and $L'_{krit}=L_{ir}$, then equation (4) is fulfilled satisfactorily within experimental errors (unequal geometrical factors of the detectors, not precisely determined value of L_{ir}). In other words, for a given energy interval the particles are found to be firmly trapped after the storm only up to the shell, at which the value of χ at the time of minimum D_{st} did not exceed the critical value χ_c obtained during the time interval before the storm.

Table 1

Energy interval [MeV]	L_b	L_{rev}	L_{ir}
1—6.5	5.0	3.8	4.0
10—30	2.9	2.65	2.7
30—100	2.5	2.30	2.35
>100	1.92		1.85

The value χ_c estimated in this way increases with energy and using the threshold energies it is changed by factor 1.50 beginning from 1 MeV to 100 MeV. This dependence may be, however, masked by the fact that at a constant altitude at a different L we detect the trapped particles with eqatorial pitch-angles α, $\arcsin\alpha=\sqrt{L^3/0.312\,B_{500}}$ and the critical value χ may depend on α too.

Concluding we can say that protons with energies above 1 MeV trapped in the geomagnetic field manifest after a moderate geomagnetic storm irreversible changes of their flux not only at high altitudes, but changes are detected also for particles with low equatorial pitch-angles ($\alpha \lesssim 18°$) and these changes near the boundary of the trapping may be interpreted in terms of nonadiabatic effects of proton motion in a dipolar field.

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