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STUDY OF FAST CHARGED PARTICLES WITH A CERENKOV DETECTOR ON THE KOSMOS-900 ORBITER

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Experimental data, for the period from April 30, 1977 to October 10, 1979, on the spatial distribution of secondary electrons with energy greater than 15 MeV and protons with energy greater than 400 MeV at an altitude of ∿500 km as well as data on the fluxes of relativistic electrons with energy exceeding 15 MeV, arising in the decay phase of magnetic storms and trapped in the outer radiation belt, are presented. The results of measurements of solar cosmic rays (SCR) in the vent on November 22, 1977 are discussed.

1. Introduction

One goal of the experiment on the KOSMOS-900 orbiter was to study the high-energy component of secondary radiation observed near the earth. In addition to this, information about events associated with the penetration of SCR into the earth's magnetosphere and injection of high-energy electrons into the outer radiation belt was obtained.

2. Apparatus

The radiator in the Cerenkov counter was a plexiglass sphere 30 cm in diameter, coated on the outside with a white, dull paint. The geometric factor of the counter in the first channel of the apparatus equalled 7100 $cm^2 \cdot sr$. The apparatus is described in detail in [1].

3. Planetary Distribution of Secondary Charged Particles

The study of the spatial distribution of secondary charged particles is very important for resolving the question of the mechanism of their formation and lifetime. The results of such an investigation are presented in [2], where the dependence of the counting rates for the primary channel of the apparatus, recording electrons with $E_e > 15$ MeV and protons with $E_p > 400$ MeV, on the geographic longitude for different L shells in the northern hemisphere are presented. The information was obtained during a geomagnetically quiet period.

The longitudinal dependence obtained for $L \geq 1.5$ has two maxima at longitudes of 90-100° and 240-260°. At $L = 1.1$ the counting rate is almost independent of the longitude.

The results of the measurements also show that the magnitude of the counting rate on a fixed L shell depends on the strength of the geomagnetic field B. As B increases the counting rate increases, unlike the intensity of the charged particles in the earth's radiation belts.

If the contribution of the primary cosmic rays to the overall counting rate and the dependence of their intensity on the longitude, associated with the changes in the threshold cutoff rigidity of the geomagnetic field for given L are taken into account, then we obtain for the ratio of the intensity of the secondary radiation at the maximum of the longitudinal

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dependence of the intensity to the minimum the values $\sim$1.2, 1.5, and 1.3 for L = 1.5, 2, and 4, respectively.

In the southern hemisphere the intensity of the secondary radiation in the range of longitudes 60-300° is virtually independent of the longitude.

If it is assumed that the secondary radiation is isotropic, and the geometric screening of the primary cosmic rays by the earth is taken into account, then for the absolute intensity we obtain the values $\sim 200\ m^{-2}\cdot sec^{-1}\cdot sr^{-1}$ for L = 1.1 and $\sim 300\text{-}400\ m^{-2}\cdot sec^{-1}\cdot sr^{-1}$ for L = 2.

Our data and the results of [3, 4] lead to the conclusion that the secondary radiation consists primarily of electrons with energy greater than 70 MeV, while for energies ranging from 15 to 70 MeV the electron intensity is insignificant. The longitudinal distribution of the excess radiation is independent of the local time, indicating that the spatial character of the longitudinal dependence is associated with the magnetic field strength.

The latitude dependence of the counting rate in the first channel of the apparatus contains a region of high intensity for L = 3.5-4.5 as compared with higher latitudes; this is probably attributable to the characteristic features of the penetration of primary particles into the magnetosphere and to the dynamics of the albedo particles.

4. Nonstationary Belt of Electrons with Energy Exceeding 15 MeV

During the course of the experiment there were four periods during which events associated with magnetic storms were recorded. Similar information was obtained in three periods. The events were detected according to an increase in the counting rate in the first channel of the apparatus on the magnetic shells L = 3.2-4.1 in the region of the south Atlantic (Brazil) anomaly at latitudes ranging from 80° WL to 35° EL. The magnitudes of these increases were 1.5-2 times greater than the background values from galactic cosmic rays. The events occurred in April of 1977, September-October 1977, and January and September-October 1978. An increase in intensity was observed in a narrow interval of values of L (the half-width of the intensity distribution ΔL did not exceed 0.3). The intensity at the maximum of the distribution depended on the magnetic field strength at the point where the maximum was recorded and increased as the magnetic field strength decreased, indicating that the apparatus recorded trapped radiation. The small-half width of the intensity distribution (in geometric space 100-150 km) supports the fact that a belt of trapped electrons with energy $E_e > 15$ MeV was detected.

In April 1977 the strongest magnetic storm with a sudden onset occurred on April 7, 1977 at 18.45 UT [5]. The maximum value of the indices D_{st} and K_p equalled 110 nT and 7, respectively. The first peak in the electron flux of magnitude $I = 2.6\ cm^{-2}\cdot sec^{-1}$ was recorded on April 11, 1977 at 22.06 UT. The delay time in the appearance of the electron fluxes relative to SC equalled $\sim$4.5 days. During April 12 and 13, 1977 the flux decreased to values of $I = 0.54\ cm^{-2}\cdot sec^{-1}$. The local time during the measurements equalled 21 h, 30 min.

In January 1978 a strong disturbance of the magnetic field [6] ($D_{st} = -129$ nT, $K_p = 7$) was observed on January 3, 1978. The first electron fluxes were recorded on January 9, 1978 at 0.38 UT, i.e., with respect to SC the delay equalled $\sim$5 days. The fluxes were recorded on January 9, 10, and 11, 1978. The magnitude of the recorded fluxes varied from $0.5\ cm^{-2}\cdot sec^{-1}$ to $2.7\ cm^{-2}\cdot sec^{-1}$.

The strongest magnetic disturbance, amongst the disturbances which we observed, with maximum change in the index $D_{st} = -240$ nT occurred in September-October. The event occurred on September 29, 1978 at 3.01 UT [7]. The first maximum of the flux was recorded by our apparatus approximately six days after the onset of SC, i.e., October 4, 1978 at 23.57 UT. For October 4, 5, 6, and 9, 1978 belts with a rise of up to $1.6\ cm^{-2}\cdot sec^{-1}$ were detected eleven times.

Fluxes of electrons with $E_e > 15$ MeV, recorded in April 1977 and January and October 1978, varied in time in a quite complicated manner. Flux variations with a period of 1-2 days were observed. The total lifetime of the electron belts, associated with each disturbance of the magnetosphere at altitudes of $\sim$500 km, was of the order of 1 week.

For three periods when electron fluxes were observed, the maximum values of the index D_{st} equalled -110, -129, and -240 nT, while the delay time in the appearance of accelerated electrons equalled 4.5, 5, and 6 days, respectively. As one can see, the delay time increases as D_{st} increases, and in addition the dependence of the delay time on D_{st} is nearly logarithmic. This dependence can be understood based on the results of [8], where it is pointed out that accelerated electrons with lower energies always appear when a definite state of the magnetosphere during the restoration phase is reached. At the same time the magnetosphere returns to its undisturbed state exponentially in time. The results obtained show that D_{st} increases the values of L at which the maxima of the electron fluxes are observed decrease. Our values of L follow well the curve $L_{max} = f(D_{st\ max})$ presented in [8] for low-energy electrons. In [9, 10] it was concluded that this is evidence for the fact that the recorded electron fluxes originate from diffusion. The results obtained prove that in the magnetosphere electrons can be accelerated up to energies exceeding 15 MeV. Diffusion electrons with energy greater than 30 MeV were virtually not observed in the experiment. Our conclusion that the position of the maximum intensity of electrons injected during magnetic storms is independent of their energy is very important for understanding acceleration processes in the magnetosphere, just like the determination of the maximum energy up to which the magnetosphere can accelerate electrons.

In conclusion it should be noted that no fluxes of accelerated electrons with $E_e > 15$ MeV were observed in all magnetic storms for which we have data. This concerns, in particular, the magnetic storm with $D_{st} = -98$ nT, which occurred on November 25, 1977 after the burst of SCR on November 22, 1977. Our data for November 30 and December 1, 2, and 4-6, i.e., during the period when the appearance of accelerated electrons could be expected, do not show that the counting rate increases as the shells L = 3-4 are crossed. It is interesting to note that in all cases when electron fluxes were observed the maximum solar-wind velocity reached values of ~ 750 km$\cdot$sec^{-1}. In the event of November 25, 1977 the solar-wind velocity did not exceed ~ 550 km$\cdot$sec^{-1}. The results of investigations of fluxes of electrons with energy ~ 1.5 MeV on a geostationary satellite are presented in [11], and it is pointed out that the solar-wind velocity is correlated with the intensity of the accelerated electrons. In our case the condition for generation of high-energy electrons is apparently the combination of a strong magnetic disturbance ($|D_{st}| > 100$ nT) and a high solar-wind velocity ($v > 550$ km$\cdot$sec^{-1}).

5. Penetration of Solar Protons into the Earth's Magnetosphere

A solar flare of magnitude 2B with heliographic coordinates of 23° N and 40° W was recorded on November 22, 1977 at 9.45 UT. An increase in the intensity of cosmic rays were recorded on the orbiter [12-14] and observed at many stations with neutron monitors with a cutoff rigidity of less than 5 GV. The recording of cosmic rays by neutron monitors started at 10.10-10.15 UT; the maximum intensity was observed at 10.33-10.50 UT. Our apparatus started to record an increase in the intensity of cosmic rays at 10.30 UT. We obtained continuous data from 14.10 UT on November 21 up to 11.45 UT on November 22, 1977. The device recorded an elevated intensity, associated with the penetration of SCR into the magnetosphere, from 10.30 to 11.45 UT. The maximum increase in the SCR flux relative to the preflare level in the first channel equalled 600%. The apparatus recorded primarily solar protons; the contribution from electrons could not have exceeded 4% [15]. The intensity of particles with $Z \geqslant 2$, recorded in one of the channels, during the flare was approximately 200 times lower than the proton intensity.

For the flight through the northern and southern hemispheres the maxima in the intensity observed at 10.35 and 11.40 UT on the magnetic shell with L = 3.6 are a characteristic feature of the intensity distribution. The exomagnetospheric orbiter data [16] and the neutron-monitor data mentioned above do not show such a time dependence, which leads us to the conclusion that the observed phenomenon has a spatial character. The detection of maxima in the latitude dependence of the data from the network of neutron monitors supports this conclusion [17]. These intensity maxima are obviously associated with the penetration of SCR into the magnetosphere. The burst of SCR occurred when the interplanetary space was not disturbed by prior events, which excluded superposition effects. The coordinates of the flare were favorable for observing the anisotropic stage of the rise in SCR, since the mean line of the interplanetary magnetic field from the region of the flare passed near the earth. This facilitated the "direct" arrival of the particles along the line of force. Data from the KOSMOS-900 orbiter encompassed the period of the flare up to 11.45 UT, i.e., primarily the anisotropic stage in the rise of the SCR flux near its maximum, which makes it possible to evaluate the magnitude of the anisotropy of the SCR flux during the flare. An accurate analysis requires knowledge of the asymptotic directions of arrival of the particles along the entire trajectory of the orbiter taking into account the local time. For this, the results of [18], where the burst of SCR on November 18, 1968 is analyzed, can be employed. The conditions for the propagation and detection of SCR on November 22, 1977 were analogous to this case. Generalizing our data and the data of [18] it may be concluded that on the evening side of the earth at high latitudes of the northern hemisphere the device recorded primarily particles moving in the direction of the sun, while for the flight through the same region on the morning side primarily particles moving away from the sun were recorded. The difference, observed in these regions, in the intensities can be explained by the presence of a positive anisotropy of the SCR flux. According to the KOSMOS-900 data the ratio of the particle fluxes moving away from the sun to the fluxes moving toward the sun equalled ~ 6. The neutron monitor data give a value of ~ 4. Our data, obtained at high latitudes, lead to the conclusion that the anisotropy of SCR decreases with time, and remains positive in so doing.

The form of the energy spectrum of the detected particles in the range of rigidities 1-4 GV can be evaluated from the changes in the geomagnetic cutoff rigidity accompanying the motion of the orbiter. For the time interval 10.31-10.53 UT the value ~ 2.4 was obtained for the magnitude of the index γ of the integrated spectrum, while for subsequent periods (10.54-10.58, 11.21-11.25, 11.40-11.44 UT) the magnitude of γ equalled, on the average, 4.1, 4.3, and 4.2, respectively. The value of γ increased as the rigidity increased, reaching 5.2 for a rigidity greater than 3 GV.

Detailed analysis of our distributions of the SCR intensity in a flare reveals small peaks of the intensity, following one another regularly with time intervals of ~ 120 sec throughout the entire period of detection of the flare. It is possible that here either modulation of the particle flux at the source or the conditions of propagation of the particles in the interplanetary space or in the magnetosphere are manifested. Two-minute pulsations of the radio emission from the sun at a frequency of 202 MHz were also observed at this time [19].

Thus the experiment on the KOSMOS-900 orbiter significantly increased the understanding of the characteristic features of the penetration of SCR into the magnetosphere and the acceleration of electrons during magnetic disturbances, and gave detailed information about the spatial distribution of hard secondary electrons near the earth.

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