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High Energy Electrons at Altitudes 500 km Near the Equator*

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Abstract. Measurements provided by a high-energy electron spectrometer on board a low altitude polar orbiting satellite allowed the determination of fluxes of electrons with energy above 100 MeV which were stably trapped or quasi-trapped in the radiation belt at L = 1.13–1.16. Relatively high fluxes of trapped electrons at minimum-B-equator are reported, $(18{,}200 \pm 2{,}000)\ \mathrm{m^{-2} \cdot s^{-1} \cdot sr^{-1}}$ and $(10{,}400 \pm 1{,}500)\ \mathrm{m^{-2} \cdot s^{-1} \cdot sr^{-1}}$ for >100 MeV and >300 MeV, respectively. The sharp increase of the electron flux with decreasing B in the region, where stably trapped particles are detected, corresponds to pitch angle distribution at the equator of the form $J(\Theta) \sim \sin^n \Theta$, where $n = 65 \pm 15$. The shape of the pitch angle distribution, together with relatively high fluxes of electrons, supports the assumption that they are generated due to the decay of particles produced in interaction of high energy protons trapped in the inner radiation belt with the residual atmosphere.

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Key words: High energy electrons – Radiation belt of Earth – Intercosmos 17 satellite

Introduction

Although the characteristics of electrons with energies up to several MeV trapped in the Earth's radiation belt at low altitudes have been studied for many years (for instance Imhof and Smith, 1965), the picture of electron population at higher energies is not so complete to date.

The existence of a radiation belt composed of electrons with energies above 100 MeV was suggested by Grigorov (1977). Further, the measurements on board Cosmos 490 and Salyut 6 confirmed this assumption (Basilova et al., 1978; Basilova et al., 1982a, b, c; Galper et al., 1981).

This paper follows the works mentioned above and extends the analysis of high energy electrons in the equatorial region using the experimental material obtained during measurements by the apparatus SEZ-10 on board Intercosmos-17 satellite.

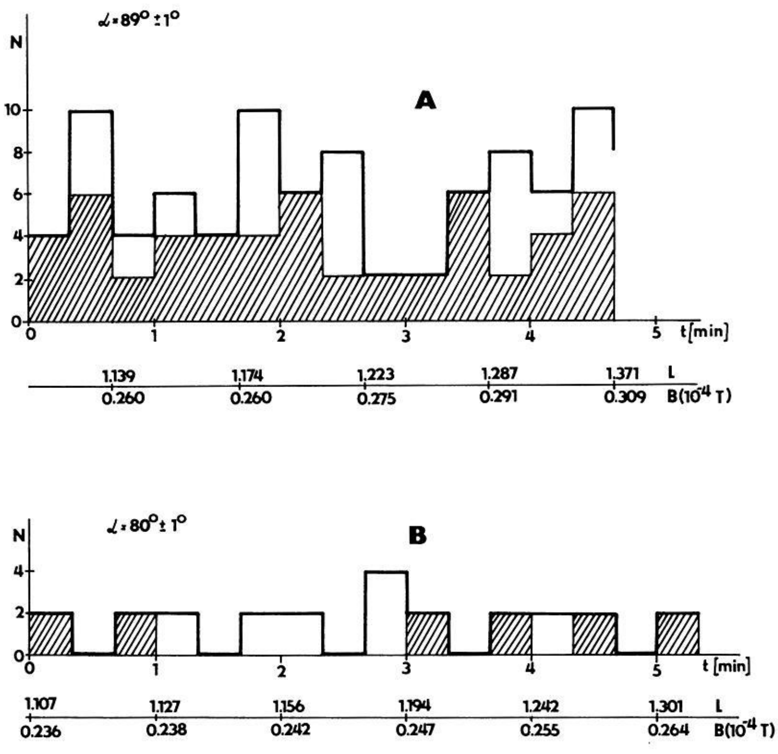

Fig. 1a and b. Number of counts of the telescope without the lead filter (*full line*) and with the filter (*thin line*) corresponding to the electrons $E_e > 100$ MeV plus relativistic protons and relativistic protons, respectively. Accumulation is taken for 20 s because of low statistics:
a region with $B = (0.285 \pm 0.035) \cdot 10^{-4}$ T $\alpha = 89° \pm 1°$
b region with $B = (0.241 \pm 0.005) \cdot 10^{-4}$ T $\alpha = 80° \pm 1°$

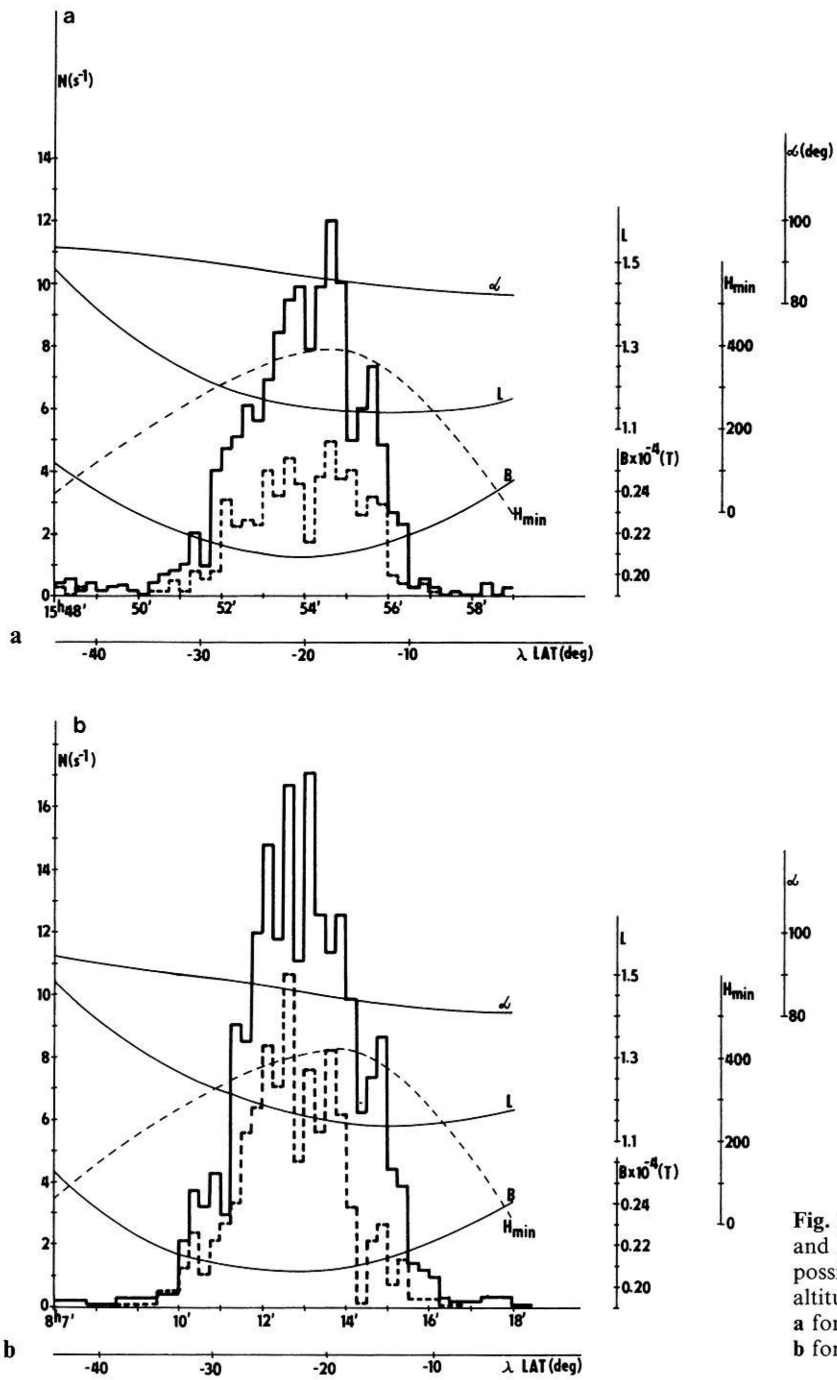

Fig. 2a and b. Registration of $\geqq 100$ MeV electrons (——) and $\geqq 300$ MeV (---) for passes when data recording was possible with 0.3 s resolution. Given are L, B, minimum altitude of mirror points H_{min} and pitch angle α.
a for 13. Dec. 1977, 15.48–16.00 UT
b for 17. Jan 1978, 08.07–08.18 UT

Experiment

The satellite Intercosmos-17 had a circular orbit with altitude 500 km and inclination 83.5°. The apparatus SEZ-10 placed on board the satellite was a spectrometer for electrons with energies 0.1–300 GeV. The detector consists of two telescopes, one of them under a lead filter with a thickness corresponding to 3 radiation length units. Electrons impacting on the filter produce electron-photon cascade and are not registered in the detector of singly charged particles. The flux of electrons is determined as the difference of counting rates between the telescope without the lead filter and the one with it. The filter changed its position periodically above the two telescopes.

The telescopes consist of scintillators, a Cherenkov detector and an energy detector of the sandwich type combined of lead and scintillator sheets – the shower calorimeter. The telescope without the filter measures the flux of electrons and protons, the telescope with the filter detects the slightly attenuated flux of protons. The attenuation coefficient $K = 0.93 \pm 0.02$ was obtained experimentally in calibration by the beam of protons with energy 1.24 GeV. It is supposed that K is independent of proton energy. The detector of energy has 8 intergral energy levels with threshold energies 0.1, 0.3, 1, 3, 10, 30, 100 and 300 GeV, respectively. A more detailed description of the apparatus is presented in (Grigorov et al., 1978).

The opening angle of the telescope was 22° and the

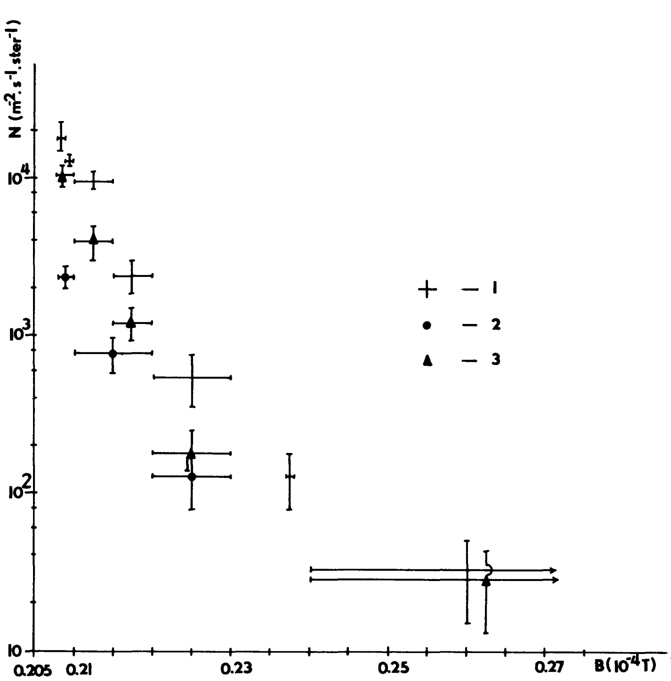

Fig. 3. Dependence of counting rate of electron detectors on B for the interval $L=1.13$–1.16.
1. – $E_e > 100$ MeV and $\alpha = 87° \pm 3°$
2. – $E_e > 100$ MeV and $\alpha = 81° \pm 1°$
3. – $E_e > 300$ MeV and $\alpha = 87° \pm 3°$

geometrical factor of the detector was 7 $cm^2 \cdot sr$. The axis of the telescope was oriented perpendicularly to the orbital plane. This fact allowed the determination of the flux of particles with relatively high pitch angles. For given L, the value of the angle α between the axis of the detector and local $\vec{B}$ depends on the longitude. For our analysis, where $L<1.4$, the value of α, computed from the knowledge of B components and orientation of the detector, had a minimum value of 65°.

Observations

Individual passes of the satellite through the low latitude region can give the picture of the electron fluxes which are stably trapped or quasi-trapped in the radiation belt. Boundaries of trapping, quasi-trapping and albedo particles are given as lines in the L–B plane or L-α_{min} plane, where α_{min} denotes the pitch angle of the particles at the peak of the given field line. By the term "trapped" for given L we mean particles for which the line of mirror points is not lower than 60 km above the Earth (Basilova et al., 1982a) at any longitude. Albedo particles have a maximum altitude of their mirror points at 60 km. Particles for which B is between the values of boundaries described, are quasi-trapped.

Here we are analyzing fragments of orbits, through the region $L=1.10$–1.40. Two examples of recording of the counting rate are given in Fig. 1. In the basic telemetry regime they are accumulated counts in 5 s intervals in both telescopes, with and without the lead filter. The fragments of the orbit correspond to that part of L–B plane where stable trapping is not possible and only quasi-trapped and/or albedo particles can be registered here. More clearly, the geomagnetic field model IGRF 1975 gives, for the altitude 500 km and for $L=1.15$, the region of stable trapping defined above in $B<0.233 \cdot 10^{-4}$ T and for $L=1.30$ $B<0.248 \cdot 10^{-4}$ T. The given L shell reaches the satellite at higher B on the top pass of Fig. 1 than on the bottom one. The difference is in the orientation of the detector. For the upper part of Fig. 1 α changes its value from 90.9°–88.9° while at the lower part $\alpha=80.0°$–81.4°. The comparison of the two passes shows the dependence of the flux of quasi-trapped electrons on angle α.

Because of the relatively low counting rate corresponding to the flux of electrons $E_e>100$ MeV in the quasi-trapping region, the detailed analysis of the flux profile in narrow L intervals is impossible. Coming to the region of lower B, where stably trapped particles may also be present, the flux of electrons increases. The basic telemetry regime is able to measure reliably only up to 6 counts per s, and this makes a limit for using this regime only up to approximately $H_{min}=100$ km for orientations of the detector with angle $\alpha=90 \pm 6°$.

Several orbits through the region of low B (for L up to $L=1.16$, practically to minimum-B-equator) in the Brazil magnetic anomaly were examined carefully, especially those with an alternative telemetry regime, when counts are accumulated in 0.3 s intervals. The profiles of electron fluxes with $E_e>100$ MeV and $E_e>300$ MeV, respectively, obtained in two passes through the region with low B are presented in Fig. 2a, b. The flux increases sharply at $B<0.21 \times 10^{-4}$ T in comparison with that of quasi-trapped electrons.

Combination of the two telemetry regimes gives the possibility of obtaining the altitude profile, i.e. the dependence of electron flux on B for a given L. We have chosen the interval $L=1.13$–1.16, because at these L we can measure, at altitude 500 km, particles practically at the minimum B value. On the other hand we must take a finite width ΔL because of low statistics.

Compilation of the data obtained from 23 passes of the L region mentioned above at various longitudes and in two α intervals, for 5 s recordings, together with passes of the satellite through the low B region in the Brazil magnetic anomaly, for 0.3 s recordings, is presented on Fig. 3.

A very sharp dependence of the flux on B up to 0.24×10^{-4} T is seen. Fitting the data for $\alpha=90 \pm 6°$ as $B^{-n/2}$ we obtain the value of $n=65 \pm 15$. From that we can estimate the pitch angle distribution at the equator as $\sin^n \Theta$, where Θ is the equatorial pitch angle of the particles. In the stably trapping region the strong pitch angle dependence may also be deduced from the significant change of flux with angle α.

Discussion and Conclusion

Analysis of 23 passes of the satellite Intercosmos-17 through the near-equatorial region allowed the determination, for $L=1.13$–1.16, of fluxes of quasi-trapped, as well as of stably trapped electrons. Typical values of the quasi-trapped electron flux are, for $\alpha=90 \pm 6°$, 33 ± 24 $m^{-2} \cdot s^{-1} \cdot sr^{-1}$ and 27 ± 23 $m^{-2} \cdot s^{-1} \cdot sr^{-1}$ for >100 and >300 MeV respectively (see the values centered near $B=0.26 \cdot 10^{-4}$ T in Fig. 3). No significant dependence on B was obtained for quasi-trapped particles.

A sharp increase of flux, for $\alpha=90 \pm 6$, consistent with $B^{-n/2}$, where $n=65 \pm 15$, is seen for a decrease of B under the limit of stable trapping. The highest fluxes registered were (18,200 ± 2,000) $m^{-2} \cdot s^{-1} \cdot sr^{-1}$ and (10,400 ± 1,500) $m^{-2} \cdot s^{-1} \cdot sr^{-1}$ for > 100 MeV and > 300 MeV, respectively. They were detected for $L = 1.15$ and $H_{min} = 420$ km.

Clear dependence of the electron flux on pitch angle is detected for the stably trapped particles.

The high fluxes of electrons registered here and the shape of their pitch angle distribution, with the high energy protons at the lower edge of the radiation belt, (Fischer et al., 1977) are difficult to explain only as a result of an interaction of primary cosmic rays with the atmosphere of the Earth, as was suggested for fluxes of electrons registered under the radiation belts. It is possible that the source of relatively high fluxes of energetic electrons is the interaction of high energy protons ($E > 1$ GeV) of the inner radiation belt with the residual atmosphere. Preliminary estimates show that the results of measurements presented here are not in contradiction with this assumption.

Further progress in understanding production and loss mechanisms for the high energy electron component in the equatorial region needs to extend the statistics of passes of the satellite through the low latitudinal region as well as careful estimation of electron production due $\mu \rightarrow e$ decay of charged pions created by high energy protons from inner radiation belt in interaction with the atmosphere. Spectral characteristics as well as more detailed pitch angle distributions of electrons for various L in comparison with high energy proton spectra given for instance by Hovestadt et al. (1972) and Valot and Engelmann (1973) are needed.

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