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SUMMARY

The results of investigations are communicated of the spectrum of protons in the inner radiation belt with the aid of AES "KOSMOS-137" on shells with L = 1.2 — 1.7, alongside with the spatial distribution of protons in the energy range 0.8 — 1000 Mev and in the plane of the geomagnetic equator.

Comparison is made of the results obtained with those of other authors.

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As a result of a large number of works, devoted to the study of the inner radiation belt, sufficiently clear representations have by now been obtained in regard to basic processes leading to its formation, and the spatial distribution, as well as spectra of protons, trapped by the Earth's magnetic field.

At the same time, studies of proton spectra in the inner radiation belt still offer interest at this time, since neither the range of spectrum's energy nor the measurements made corresponded to the entire region of space, but only to parts of it.

For a multilateral investigation of the inner belt one must cover the energy range from $E_p \sim 1$ Mev to $E_p \sim 1000$ Mev, while measurement of spectra must be conducted in the region $L \sim 1.1$ to $L \sim 2.5$ in both the equatorial plane and at high latitudes through the values $B/B_{equ} \sim 5$ (L and B being the McIlwain parameters). (refer to [1]).

(*) ISSLEDOVANIYE SPEKTROV PROTONOV VNUTRENNEGO RADIATSIONNOGO POYASA NA SPUTNIKE "KOSMOS-137".

The above requirements are difficult to combine in a single experiment. Thus, for example, the application of nuclear emulsions allows us to obtain a detailed information on proton spectra in the region 20 — 700 Mev [2], but, because of the impossibility to separate the registered events in time, they usually are conducted over trajectories that, as far as possible, are localized in L, B-space [3]. Satellites with 15,000 km apogee do satisfy the requirement of radiation belt studies at $L = 1.5 - 2.5$ in the equatorial plane, but do not — for $L < 1.5$ and at high values of B. In short, they do not allow the tracking of proton spectra at low altitudes.

Sufficiently detailed experimental investigations of proton spectra were conducted in works [2, 3] with the application of the method of nuclear emulsions in the 10 — 200 Mev energy range with the aid of silicon detectors [4], and by measurements at low altitudes in two energy ranges, i. e., 5 — 20 Mev and 60 — 120 Mev [5].

The most complete data on spatial and energy distributions of protons of the inner radiation belt are brought out in the work [6], where information is available on spectra of protons with energies from 1 to 60 Mev for $L = 1.6$ to 2.4.

A series of detectors were installed on AES "KOSMOS-137", launched on 21 December 1966 into orbit with apogee $\sim$ 1700 km and perigee $\sim$ 220 km with $\sim 49°$ inclination to equatorial plane. These detectors permitted to measure the spectra of protons in the 0.8 — 1000 Mev range for parameter L values from 1.1 to $\sim$ 2.0 and B from 0.10 to 0.5. The measurements in question were conducted with the aid of three types of detectors:

1) surface-barrier-type silicon detectors with thickness of sensitive region of 30 mm allowed us to register protons in the 0.8 — 7 Mev range, practically without electron background [7].

2) a combined spectrometer of protons [8], which allowed us to measure a background-or num-free registration of protons in five energy ranges: $E_p > 2$ Mev, $E_p > 22$ Mev, $E_p > 27$ Mev, $E_p > 40$ Mev.

The spectrometer consisted of a silicon diffusion-drift (Li) detector with sensitive region thickness $\sim$ 1.5 mm, separating over dE/dx only protons with energy $E_p = 2 - 200$ Mev and switched on coincidences with it of detector E, realized on a scintillation counter with CsI crystal. A special α-compoound Po^{210} , yielding only several tens of pulses per second at photomultiplier output, registered over a separate channel, was applied on the CsI crystal.

The threshold of discrimination of pulses from the control α-compound was installed in such a way that the variation of FEU or of amplification circuits and pulse discrimination from the photomultiplier by ±20% yield a variation by several factors in the rate of control readout. Since all the amplification and pulse discrimination circuits were realized according to analogous diagrams, the readout stability along the control channel characterized the temporal stability of the entire spectrometer.

In the course of about 100 days of flight the number of pulses from the control α-compound, measured in the regions of the geomagnetic equator and at low heights, did not vary by more than 30%; this points to a high stability of the entire routing. During the first 8 days of flight, according to whose data the spectra of protons were constructed, the stability was still higher.

3) A Čerenkov detector permitted the registrations of protons with energies $E_p > 600$ Mev, $E_p > 800$ Mev, $E_p > 1000$ Mev. Electrons with energies $E_e > 7$ Mev, $E_e > 12$ Mev and $E_e > 15$ Mev could respectively be measured along the same channels. From the analysis of the Cerenkov detector it follows that protons were registered practically everywhere, with the exception of shells with $L \sim 2.8$, where a small peak ($\sim 20 - 40\%$ of the absolute intensity), due, in our opinion, to electrons with energy $E_e > 7$ Mev, was recorded.

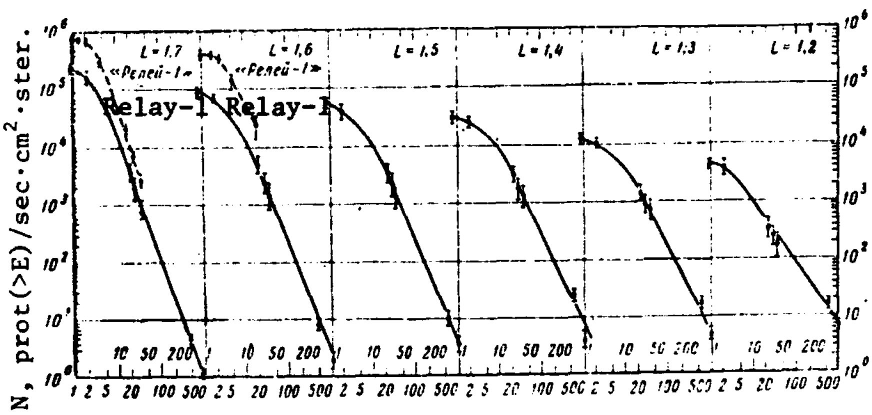
The radiator of the Čerenkov detector was made of organic glass in the shape of a cylinder with 7 by 7 size. The detector was practically isotropic. The information along the second threshold was arriving with great gaps; it will not be considered in the present work.

In this way, there was a possibility to measure of integral spectra in an energy range from ~ 1 to 1000 Mev at 7 points.

The satellite rotation took place at a rate of about 1 rpm and the averaging of information arriving from the detectors (1 to 2 readouts per minute) was within approximately the same time interval. For the facility of comparison with

with other works our results were converted to flows on 1 sterad; however, one should note that these data are averaged by all pitch-angles.

The entire aggregate of the obtained results was processed as follows. The graphs of counting rate dependence on time were tied to L by which of the enumerated detectors and to B-coordinates computed with a precision to 1% along the satellite's flight path. The moments of time when L assumed the values of 1.2, 1.3, 1.4 etc. and up to 1.7 were fixed. The counting rates I and the values of B were determined at the same moments of time. Dependences $I = f(B)$ at $L = const$ were constructed for each of the fixed L-shell, these dependences being the curves of intensity variations along the chosen field line. When constructing these dependences we utilized the data of the first 8 days of flight ($\sim$ 80 orbits). Since the selected values of L were attained 2 to 4 times on each orbit, each of the constructed curves contained no less than 100 – 200 points which fitted sufficiently well the curve determined by the method of the least root-mean-square deflection. Subsequently, background subtraction and intensity conversion were performed, taking into account the geometric factor of each of the detectors.



Energies of protons, Mev

Fig.1. Integral spectrum of protons in the plane of the magnetic equator

It should be noted that in the given experiment, the values of L in the equatorial plane reached $L \leqslant 3$. In order to obtain the values of intensities in equatorial region for greater values of L, extrapolation was applied along the field line B_{equ} according to the same law of intensity variations, as in the sector close to B_{min} on the given line of force. Such extrapolations were performed for the values $L = 1.4 - 1.7$, where it was required to extrapolate from

$B_{equ}/B = 1.3 - 1.2$ to $B/B_{equ} = 1$, i.e., in the latitude interval < 20° from the geomagnetic equator.

The errors in the determination of intensities were summed up from the spread linked with the effects of orientation, from extrapolation errors and imprecisions in the determination of the geometrical factor. The aggregate maximum error did not, as a rule, exceed 2 and was mainly determined by the spread of initial data by intensities on account of different satellite orientation relative to the line of force at times, when readings were taken down.

The spectra of protons for the chosen value of L were constructed according to the obtained values of $I_{equ\ i}(i = 1 - 7)$. Moreover, there was a possibility of constructing spectra for $B/B_{equ} > 1$ also.

For energies $E_p > 0.8$ Mev, the first point was obtained from the readings of the detector which registered not all particles with energies greater than the above assigned, but only in the range from 0.8 to 7 Mev. The conducted calculations show that the contribution of particles with energies $E_p > 7$ Mev was insignificant and did not exceed 15%.

The integral spectra of protons in the plane of the geomagnetic equator for various L-shells are plotted in Figure 1 according to data of "Kosmos-137". For comparison, we brought out in the same figure the spectra on L = 1.6 and 1.7 obtained on AES "Relay-1" [6] (1963). It may be seen from the comparison that the shape of the spectrum and its inclination in the range from 2 to 40 Mev agree well with one another. The departures in the absolute values, constituting ~ 4, may be explained as follows. As noted by the authors of [6], what was measured aboard AES "Relay-1" was actually the flux of particles in pitch-angle interval $90 \pm 10°$ ($I_{90 \pm 10°}$) i. e. the maximum possible flux at the given point, while in the "Kosmos-137" experiment the latter was measured in the $0 \div 180°$ ($I_{0 \div 180°}$) pitch-angle interval. The numerical calculations for the angular distribution of particles $dN = A \sin^8\theta d\theta$, measured in the work [6], yield
which is in good agreement with the results obtained. In the energy range $E_p <$ < 2 Mev the spectra obtained on Kosmos-137, are somewhat steeper, but the discrepanies are not so essential if we take into account the errors due to experiments shown in the figure.

As L decreases, a tendency could be clearly seen to the decrease in inclination of curves which are well approximated by the expression $N(>E) = AE^{-n}$ over the ranges 20 – 1000 Mev. This results is in agreement with those obtained in the work [5], where the authors indicate that at values of L from 1.2 to 1.4 the inclination does not practically vary in the portion of the spectrum from ∿ 10 to ∿ 100 Mev, and then it sharply increases for L > 1.4. It should be noted that, because of the absence of points with energies $E_p > 5 - 10$ Mev and $E_p > 100 - 200$ Mev, we did not succeed in taking down a detailed picture of the shape of the spectrum, and the availibility of these additional points may lead to spectrum approximation by expressions of the type $N(>E) = Ae^{(-E\ E_0)}$.

From the consideration of spectra on all L it follows also that the increase of spectrum inclinations takes place mainly at the expense of sharp rise in the number of particles with energies $E_p < 20$ Mev. Whatever the law of proton spectrum approximation, one may obviously separate 2 portions on the spectrum with entirely different character: the portion with $E_p < 20$ Mev and that with $E_p >$ > 20 Mev. The form of the spectrum notably differs over these portions and serves as an indication on the different nature of mechanisms responsible for the injection of protons and their losses in these two energy ranges.

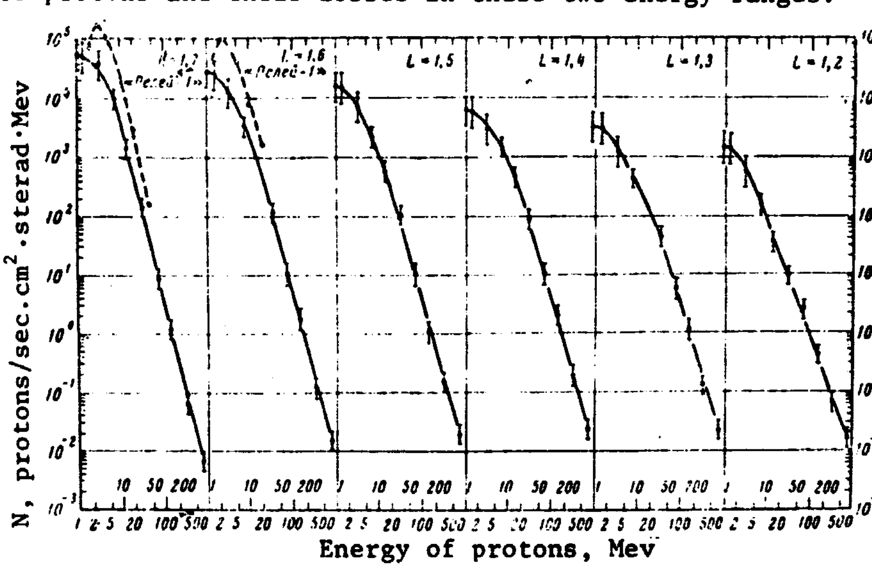


Fig.2. Differential spectra of protons in the magnetic equator plane

Spectra of protons, obtained by differentiation of the spectra brought out in Fig.1 are plotted in Figure 2. For the sake of comparison the differential spectra of work [6] are also given in Figure 2.

In the 2 — 40 Mev energy range a good agreement is observed with the data of AES "Relay-1". The difference in the absolute intensities on the coefficient $\sim$ 4 is explained in the same manner as for the integral spectra. In the 1 — 2 Mev region there are discrepancies, somewhat beyond the limits of the experiment error; they are quite significant in this energy range. We consider that a certain increase in the number of protons with energies $\sim$ 1 Mev is still present, and this increase may be explained by the change in the conditions of low-energy protons' absorption in the atmosphere. In 1963 the atmosphere density at great heights was close to maximum value for the period of the solar cycle, and by 1967 it decreased substantially and was close to minimum, which should have been particularly manifest in the ionization losses for protons with energy of $\sim$ $\sim$ 1 Mev.

Figure 3 (next page) illustrates the distributions of protons of various energies in the plane of the magnetic equator obtained after the data of AES "KOSMOS-137", "ELEKTRON" series and also after the data of "EXPORER-15" and "RELAY-1". The data of "KOSMOS-137" are in good agreement with those of AES "EXPLORER-15" and "RELAY-1", which, for the sake of comparison with the former were reduced by a factor of 4. A somewhat greater discrepancy exists between our own results and the data of satellites of the "Elektron" series. Fig.3 points to the high stability of spatial distribution of protons of the inner radiation belt in the equatorial plane over the period 1962 - 1967.

The dependence of the position of various energy protons' maxima in the equatorial plane is represented in Figure 4 (page 9), where the data obtained on AES "Explorer-12" [9], "Explorer-15" [10], "Relay-1" [6], "Kosmos-137" and 1964-45A" [11] are all indicated.

The position of maxima L_{max} as a function of energy E of protons is sufficiently well described by the expression $L_{max} \sim E^{-1/7}$ for energies from 0.3 to $\sim$ 30 Mev. It should be noted that the theoretical work [12], in which it was assumed that the atmosphere density for $L < 3.5$ varies as L^{-4}, gives the dependence for L_{max} in the form $L_{max} \sim E^{-1/5}$, while the work [13], in the assumption of constant density of the atmosphere gives a dependence $L_{max} \sim E^{-3/16}$. For energy higher than 30 Mev, the experimentally measured dependence is approximated by the expression $L_{max} \sim E^{-1/15}$, which is substantially different from the law

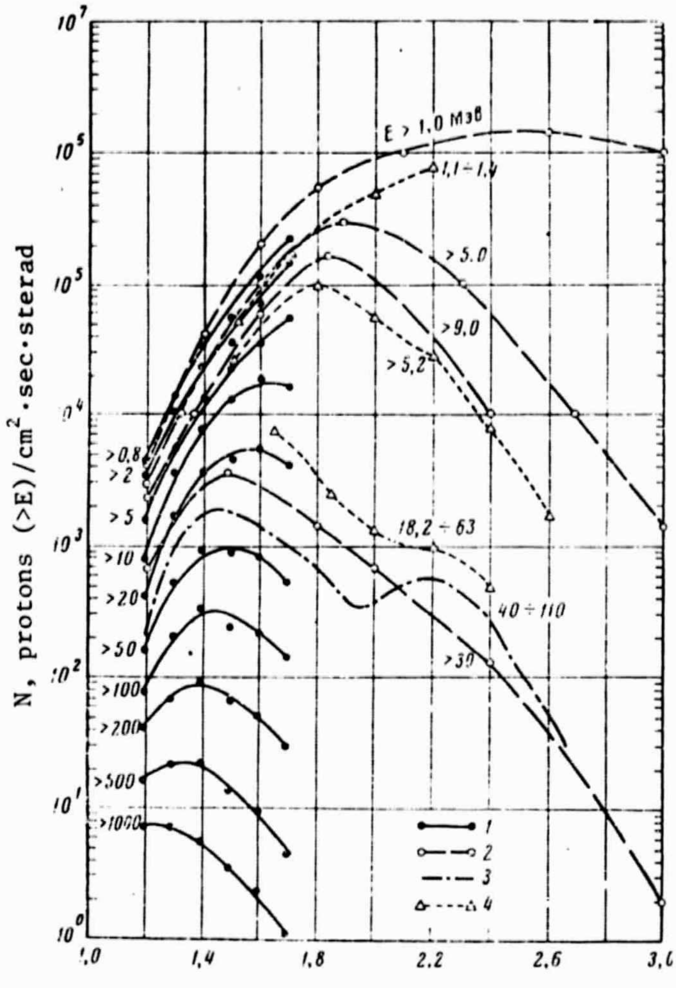


Fig. 3

Distribution of protons of various energies in the plane of the magnetic equator

1) AES "KOSMOS-137" (1966); 2) AES "ELEKTRON" (1964); 3) AES "EXPLORER-15 (1962); 4) AES "RELAY-1" (1963)

$L_{max} \sim E^{-1/7}$. This points to the fact that albedo neutron disintegration by cosmic rays begins to take plave for energies > 30 Mev, while the main source of protons through energies of 30 Mev is the transfer from magnetosphere boundary [13].

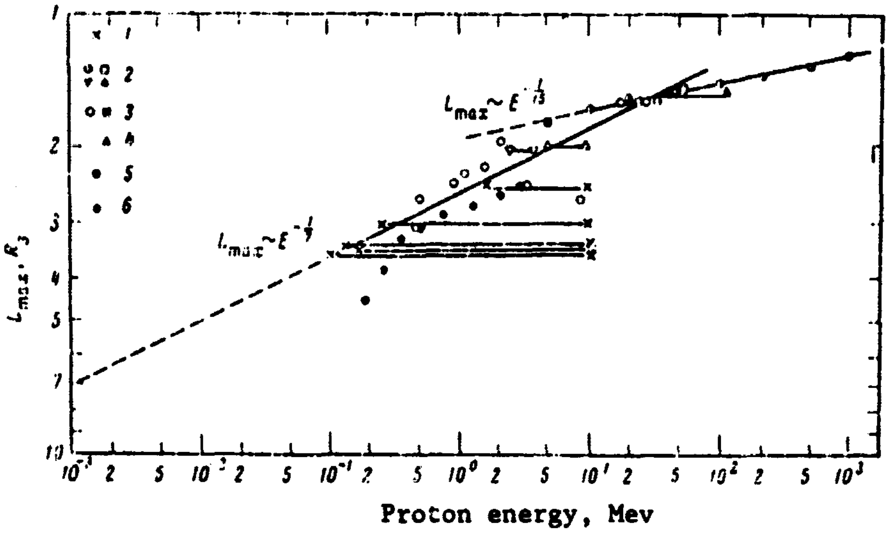


Fig.4. Dependence of maximum position of various-energy proton distribution on E_p in the magnetic equator plane:

1)Explorer-12, Explorer-14, Explorer-15; 2) Telstar-1; Relay-1; 3) Relay-1, OGO; 4) Explorer-15; 5) Kosmos-137; 6) '1964-45A'.

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T H E E N D

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