Time evolution of the secondary cosmic radiation during the magnetic storm of 20 August 1979

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(Submitted 18 January 1982)

Pis'ma Zh. Eksp. Teor. Fiz. **35**, No. 6, 254–258 (20 March 1982)

Approximately periodic variations were detected in the electron, proton, and γ intensities by the Nataliya-1 gamma telescope during a flight on a high-altitude balloon at 46 °N. The periods of these variations were ~1, 10, and 30 min. Sharp surges in the intensities of these components were detected simultaneously. The time evolution of these events and their relationship to processes in the disturbed magnetosphere are discussed.

PACS numbers: 94.30.Lr, 94.30.Wb

The Nataliya-1 gamma telescope measured the intensities of γ rays with energies >5 MeV, of electrons with energies >20 MeV, and of protons with energies greater than 100 MeV and greater than 500 MeV during a flight on a high-altitude balloon in August 1979. The measurement latitude corresponded to 46 °N, and the measurement altitude corresponded to a residual atmosphere of 7 g/cm^2.

The Nataliya-1 gamma telescope is described in detail in Ref. 1. During the flight on 20 August 1979, the telescope was operated in two modes to detect γ rays. The corresponding detection criteria can be written

$$M1 = \overline{\left(\sum_{i=1}^{5} A_i + \bar{\check{C}} A_6 \right)} (S_{12} \cdot S_{34} \cdot S_{56}),$$

$$M2 = M1 \cdot \check{C},$$

where $S_{12} = C1 + C2; S_{34} = C3 + C4; S_{56} = C5 + C6$; A_i are the anticoincidence counters; $i = 1, 2, \ldots, 6$; the C_j are proportional counters; $j = 1, 2, \ldots, 6$; and $\check{C}$ is the Čerenkov counter. The operating mode was switched during the flight at intervals averaging 8 min.

The charged component of the cosmic radiation was measured in three channels while the γ measurements were being taken, and the number of times the gamma telescope was triggered during the readout of information from the spark chambers was also measured.

The count rates in the various channels are determined by the following particles.

Channel $I1$: $A_1 \cdot A_6$ coincidences distinguish electrons with $E_e > 20$ MeV and protons with $E_p > 100$ MeV which come from above and below.

Channel $I2$: $A_1 \cdot A_6 \cdot \check{C}$ coincidences distinguish electrons with $E_e > 20$ MeV and protons with $E_p > 100$ MeV which are coming from above.

Channel $I3$: The count rate here is determined by the fluxes of electrons with

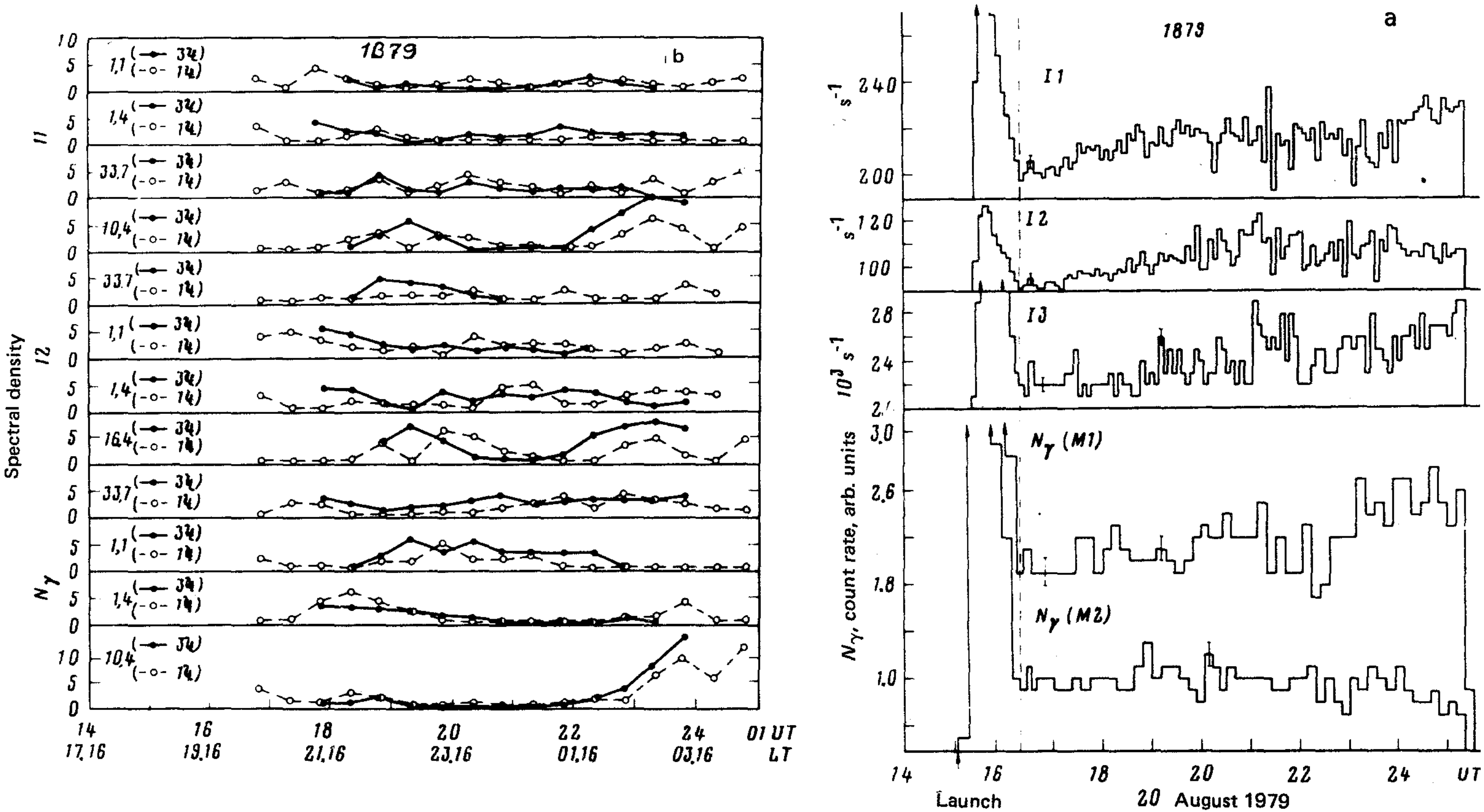

FIG. 1. a—Time evolution of the count rate in channels $I1$, $I2$, $I3$, and $I4$ (N_γ); b—dynamics of the spectral density of the approximately periodic variations with periods of 1.1, 1.4, 10.4, and 33.7 min in channels $I1$, $I2$, and $I4$ (N_γ).

$E_e > 1.5$ MeV and protons with $E_p > 12$ MeV across the surface of the counters A_i, $i = 1, 2, \ldots, 6$.

Channel $I4$: This channel stores the γ events over the time interval of about 2 s after each operation of the instrument.

Figure 1a shows the time dependence of the count rates in all four channels for the flight of 20 August 1979.

The results describe an increase in the count rate in channels $I1$, $I2$, and $I3$ during the flight of 20 August. Against the background of a smooth increase in the count rates in the channels there are some sharp surges. The flight altitude remained constant at 7.0 ± 0.3 g/cm^2 on the plateau, and the cutoff rigidity did not change (during the flight, the balloon moved 15 km from its launch point).

No systematic changes in the characteristics of the instrument were noted.

We believe that this intensity increase is associated with the active phase of the magnetic storm of 19-21 August 1979 (Ref. 4).

The geomagnetic-activity indices for 20 August according to the magnetic stations at Moscow, Tbilisi, and Dnepropetrovsk were $\Sigma K = 33, 36$, and 46, respectively. The magnetogram reveals a sharp decrease (–180 γ) in the horizontal component of the magnetic field (H) for Moscow at 17.00 UT, a recovery, and then, at 21.00, a new change, of +60 γ.

The intensity data from all the channels were analyzed for (temporally) periodic variations by a method similar to that of Refs. 2 and 3. All the data were summed over 30-s or 20-s intervals, depending on whether 3-h or 1-h fragments of the entire recording were to be analyzed. The resulting values were subjected to a low-frequency filtering and used to determine the spectral density J_K, as for an ordinary discrete Fourier transformation. The method of Ref. 2 was used to evaluate the reliability of the results. The search for periodic variations was carried out over the frequency interval from 1.2×10^{-4} to 1.6×10^{-2} Hz.

For a more detailed analysis of the dynamics of the variations we selected certain periods for which the spectral density exceeded the value of 3 continuously for more than 2.5 h for two or more channels. These periods turned out to be 1.1, 1.4, 10.4, and 33 min. The dynamics of the amplitudes of the variations for these periods can be seen in Fig. 1b, which shows the spectral density for these periods for time intervals of 3 h or 1 h; the entire recording time is then spanned through a systematic shift of 0.5 h.

The reliability is particularly high for the period of 10.4 min, and we will analyze in detail the behavior of the variations with this period. For the 10.4-min period there may be a correlation with the time evolution of the horizontal component of the geomagnetic field during the main phase of the magnetic storm for the channels $I1$, $I2$, and $I3$. A repeated increase in the spectral density for variations with the same period of 10.4 min can be seen in channel $I4$ and again in channels $I1$ and $I2$.

It is reasonable to suggest that the variations for 18–20 UT can be explained by the precipitation of protons with $E_p > 500$ MeV. Quantitative estimates yield identical values for the additional variable flux with a period of 10.4 min in channels $I1$ and $I2$ [$\sim 10^2$ particles/(m$^2 \cdot$ s $\cdot$ sr)]. The absence of variations with this period in the γ channel in this case implies that the variable component consists not of electrons with $E_e > 20$ MeV but instead protons (for the most part). The behavior of the count rate from channel *I3* is consistent with this suggestion.

The variations with the same period, which can be seen beginning at 22.00 UT and which reach a maximum intensity at 24.00 UT, are probably caused by a periodic precipitation of electrons, since the same variations are seen in the channel *I4* (the γ channel). Here we are taking into account the fact that γ rays with $E_\gamma > 5$ MeV in the upper atmosphere are produced by electron bremsstrahlung.

Under magnetically quiet conditions, the total electron flux at the geomagnetic latitude 46 °N consists of electrons of the re-entrant albedo and secondary electrons which are produced in the residual atmosphere (7 g/cm^2 for the present measurement) by the primary cosmic rays. In the case of a magnetic disturbance, there is an additional source of electrons: the precipitation of "quasitrapped" electrons.[5,6]

The distinction of two time intervals in the appearance of variations with the period of 10.4 min–the first appearance at 18.00-21.00 UT (21.00-24.00 LT) and a second at 23.00-24.00 UT (02.00-04.00 LT), associated with protons and electrons, respectively–is consistent with the hypothesis of a spatial separation of precipitation regions. The time

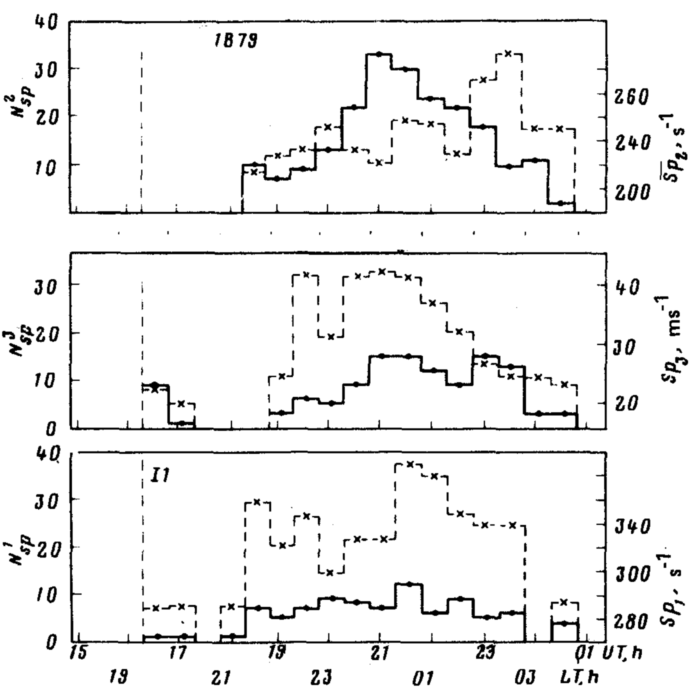

FIG. 2. Solid histogram–Time evolution of the frequency at which surges are detected in the charge-particle intensity; dashed histogram–average amplitude of these surges. Here N^1_{Sp}, N^2_{Sp}, and N^3_{Sp} are the frequencies of the surges in the count rates in channels *I1*, *I2*, and *I3*, respectively; Sp_1, Sp_2, and Sp_3 are the amplitudes of the surges in the count rates in channels *I1*, *I2*, and *I3*.

sequence of the detected events is then caused by the rotation of the earth. Note should also be taken of the symmetry of the variation regions with respect to the midnight meridian.

The most important of the other variations detected on this flight have periods ~30 min and 60-90 s. This set of periods (60-90 s, 10 min, and 30 min) is frequently observed during or after magnetic storms[11,12] in the magnetosphere.

According to Siscoe's model[13] the period of 10.4 min corresponds to Pc6 variations and has a maximum amplitude in the plasma sheet; i.e., it should be most noticeable at low latitudes. The results we are reporting here apparently constitute the first observation of a pulsed precipitation of electrons with $E_e > 20$ MeV at middle latitudes. Martin *et al.*[8,9] have reported observations of the precipitation of electrons with $E_e > 7.5$ MeV at the Brazilian anomaly with a preferential period of 25-30 min, according to preliminary data. Interestingly, the precipitation was also preceded by a magnetic disturbance.

The characteristic period of the variations (10.4 min) is approximately equal to that observed in the magnetosphere after a magnetic disturbance in Ref. 10, so that we are inclined to believe that the observed pulsed precipitation of electrons results from the excitation of resonant standing waves in the magnetosphere, which casue a pitch-angle scattering of quasitrapped electrons into the loss cone.

In the same flight we observed intense, brief surges (lasting $\leqslant 5$ s) in the count rates in channels $I1$, $I2$, and $I3$. The time at which these surges appeared was related to the crossing of the midnight meridian. Figure 2 shows the time dependence of the frequency at which these surges appeared. The ratio of the intensity in a surge to the average intensity is 3-6. The maximum in the frequency in which these surges are detected is shifted into the morning sector. The duration of these surges and the localization near the midnight meridian suggest that they are related to an acceleration of an impulsive, explosive nature.

Both the pulsed acceleration and the approximately periodic precipitation of particles are apparently caused by the disturbance of the magnetosphere.

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Translated by Dave Parsons
Edited by S. J. Amoretty