Fluxes of anomalous cosmic rays near the earth at the end of the 22nd solar cycle

N. L. Grigorov, D. A. Zhuravlev, M. A. Kondrat'eva, M. I. Panasyuk, and Ch. A. Tret'yakova

Scientific-Research Institute of Nuclear Physics, M. V. Lomonosov Moscow State University, 119899 Moscow, Russia

(Submitted 22 December 1994)
Pis'ma Zh. Eksp. Teor. Fiz. **61**, No. 2, 79–82 (25 January 1995)

Results found from the exposure of solid-state track detectors on earth satellites in 1993–1994 are reported. At the end of the 22nd solar activity cycle, long before the next expected minimum of solar activity, fluxes of ions of anomalous cosmic rays appeared near the earth. These fluxes continue to exist stably. They are comparable in magnitude to the fluxes observed in 1987, at the time of the last minimum. The characteristics of these fluxes are similar to those found in 1987. They indicate that a Van Allen belt has formed in the earth's magnetosphere from ions of the anomalous component of galactic cosmic rays.

In 1984–1991 we carried out some experiments to detect nuclei with atomic numbers $Z \geqslant 6$ and energies of 5–20 MeV/nucleon on some of the Kosmos satellites.[1] Among the sources of the heavy ions were ions of the anomalous component of the galactic cosmic rays, which had been discovered[2] in 1974. At that time, it was hypothesized that these particles originate from neutral atoms of the interstellar medium.[3] This hypothesis is based on the assumption that the ions of the anomalous component are singly charged. This assumption was later confirmed experimentally.[4]

The fluxes of anomalous ions differ from the fluxes of solar and galactic ions in both charge composition and energy spectrum. The temporal variations in the magnitude of the anomalous-ion fluxes are similar to those in the fluxes of ordinary galactic cosmic rays: They are determined by solar modulations during the eleven-year solar activity cycle and reach a maximum size at solar minimum.

The ions were detected in our experiments by solid-state track detectors consisting of stacks of several layers of Kodak CN-85 cellulose nitrate with a total thickness of 500–700 μm and an area of 25–50 cm^2. These stacks made it possible to identify nuclei with atomic numbers $Z \geqslant 6$ which were stopped in the detector and also to determine their energy. The thickness of the stacks and the exposure conditions limited the energy interval to 5–20 MeV/nucleon. After the exposure, the detector layers were subjected to chemical processing—an etching—and then examined under a microscope. The purposes of this examination were to find tracks from nuclei and to measure the characteristics of the tracks in order to determine the charge and energy of the particles. The detectors were exposed on satellites with an orbital inclination of 62–82° at altitudes of 200–400 km. Triaxial stabilization of the satellites during the flight made it possible to determine the direction in which the particles arrived from the surrounding space. The brevity of the

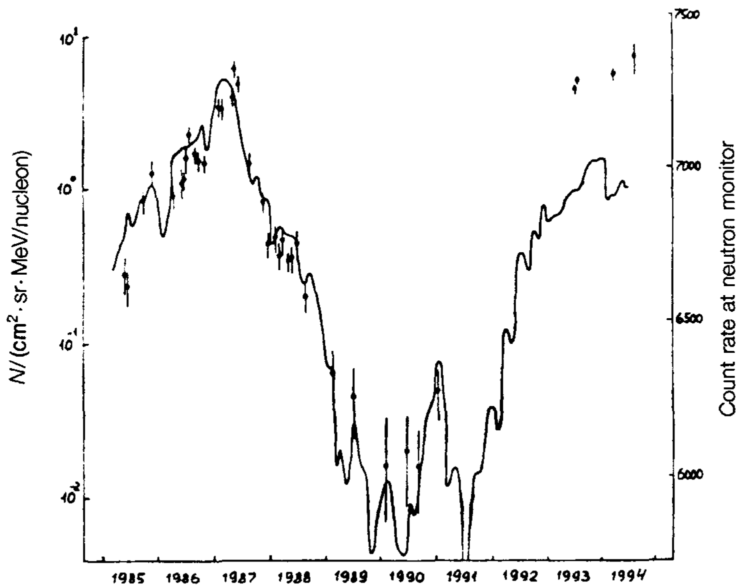

FIG. 1. Temporal variations in the magnitude of the flux of heavy ions with an energy of 10 MeV/nucleon (the points; ordinate scale at the left) and of the count rate of the Deep River neutron monitor (curve; ordinate scale at right).

exposures (14 days in most cases) made it possible to distinguish periods in which solar cosmic rays were detected during solar proton events and also periods of quiet sun, during which the detectors detected ions of the anomalous component.

Over the years 1984–1990 we were able to carry out several exposures per year during quiet solar periods. We were thus able to determine the time evolution of the flux of anomalous ions over the 22nd solar cycle. It can be seen from Fig. 1 that the fluxes of the anomalous-component ions reached a maximum in 1987, at solar minimum, and then began to fall off. By the end of 1990, the magnitude of these fluxes had decreased by almost two orders of magnitude. In other words, the anomalous component essentially disappeared from space near the earth. Unfortunately, for reasons beyond our control, the experiments were interrupted in 1991. It became possible to resume the measurements only in mid-1993. In 1993–1994, there were four exposures of detectors, which coincided in time with periods of a quiet sun.

The results of these exposures turned out to be slightly unexpected, in the sense that the anomalous-component fluxes found by our detectors were very large. The next solar minimum, of the following (23rd) cycle, was not expected before 1995–1996. Although neutron monitors detected a significant increase in the intensity of galactic cosmic rays as early as 1992 (Ref. 5), and although ions of the anomalous component were observed[6] even in June of 1992 on the U.S. satellite SAMPEX, the fact that the anomalous-component fluxes in mid-1993 were of the same magnitude as during the minimum in 1987 is a nontrivial result. In the last cycle (the 22nd; Fig. 1) and in the one before that

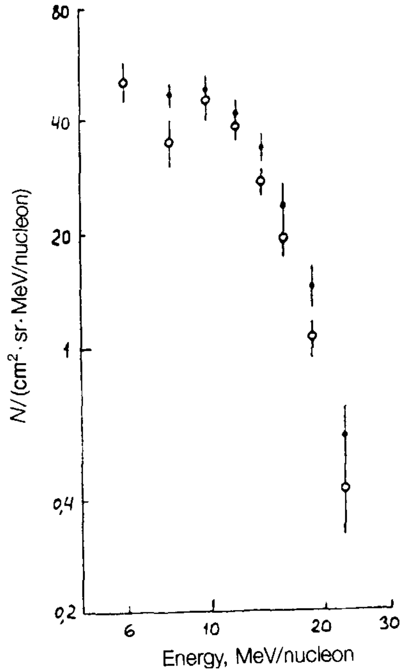

FIG. 2. Energy spectra of ions with $Z \geqslant 6$ detected in 1993 (filled circles) and 1987 (open circles).

(the 21st; Ref. 7), a correlation had been observed between the fluxes of anomalous component and the galactic cosmic rays. Now, as can be seen from Fig. 1, this correlation is disrupted: The fluxes of galactic cosmic rays in 1993–1994 reached a magnitude only at the level of 1985–1986, while the fluxes of the anomalous component exceeded the 1987 level—the level at the minimum of the 22nd solar cycle. This phenomenon has yet to be explained, although some hypotheses have been offered.[6]

Otherwise, the characteristics of the fluxes of the anomalous component detected by the detectors in 1993 did not differ from those observed in 1987. Figure 2 shows the energy spectra of the ions detected in 1987 and 1993. We see that these spectra are similar. The charge composition of the ion flux in 1993 was characterized by C/O= 0.009 $\pm$0.003 and N/O=0.091$\pm$0.010. In 1987, these ratios were C/O=0.03$\pm$0.01 and N/O =0.12$\pm$0.04 (Ref. 1).

Moreover, there were essentially no changes in the angular distributions of the ions detected by the detectors. Figure 3 shows azimuthal distributions of the tracks in the stacks exposed in 1987 and 1993. As we have shown previously,[8] the sharp anisotropy in the angular distributions of the anomalous ions detected can be explained on the basis that, being singly charged, these ions penetrate deep into the earth's magnetosphere, where they lose their electrons and are trapped by the geomagnetic field, forming a Van Allen belt. The anisotropic angular distribution observed in the last exposures thus indicates that a Van Allen belt of ions of the anomalous component of the galactic cosmic rays reappeared in the earth's magnetosphere in 1993–1994 and continues to exist stably. The same conclusion was reached by some U.S. researchers after an analysis of experi-

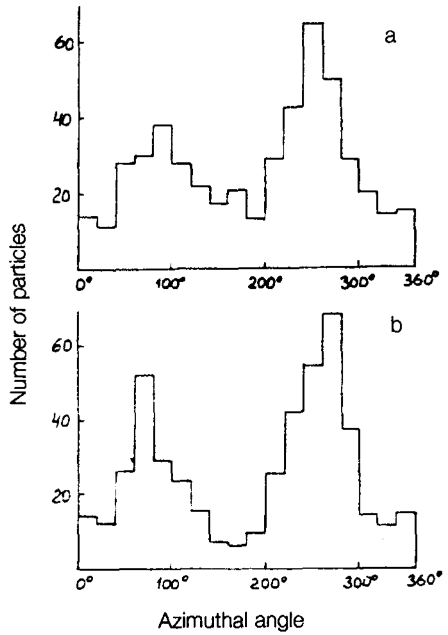

FIG. 3. Distribution with respect to azimuthal angle of tracks from ions. a—Detected in 1993; b—in 1987.

mental data from electronic apparatus carried on the SAMPEX satellite.[9]

[1]N. L. Grigorov *et al.*, Preprint NIIYaF MGU-88-48-69, Moscow, 1988.
[2]F. B. McDonald *et al.*, Astrophys. J. Lett. **187**, L105 (1974).
[3]L. A. Fisk *et al.*, Astrophys. J. Lett. **190**, L35 (1974).
[4]N. L. Grigorov *et al.*, Izv. Akad. Nauk SSSR, Ser. Fiz. **55**, 2017 (1991).
[5]Solar Geophys. Data, N601, Part 1, 113 (1994).
[6]R. A. Mewaldt *et al.*, *Proc. 23rd ICRC* (Calgary, Canada, 1993), Vol. 3, p. 404.
[7]R. A. Mewaldt, *Proc. 22nd ICRC* (Adelaide, Australia, 1990), Vol. 6, p. 161.
[8]N. L. Grigorov *et al.*, Kosm. Issled. **31**, 91 (1993).
[9]J. R. Cummings *et al.*, *Proc. 23rd ICRC* (Calgary, Canada, 1993), Vol. 3, p. 428.

Translated by D. Parsons