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Abstract

Full Text

GEOPHYSICS

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VARIATIONS OF COSMIC RAYS

ACCORDING TO DATA FROM THE ZOND-3 AND VENERA-2 STATIONS

At the end of 1965 and the beginning of 1966, two stations, Venera-2 and Zond-3, were simultaneously in flight in interplanetary space in the USSR program. During its motion the Zond-3 station was moving away from the Sun, while the Venera-2 station at the same time was approaching the Sun. Projections of the trajectories of the stations onto the plane of the ecliptic are shown in Fig. 1. Simultaneous measurement of the intensity at stations moving in different directions makes it possible in the best way to take account of temporal variations in cosmic-ray intensity and to find the dependence of this quantity on distance from the Sun, i.e., to determine their radial gradient. Estimates of the radial gradient have been given earlier ([1]-[3]).

Fig. 1. Projections of the trajectories of the interplanetary stations Venera-2 and Zond-3 onto the plane of the ecliptic. Lines from the Sun show the shape of the corpuscular-flow lines at a radial velocity of 300 km/sec

Figure 2 gives the results of registration of cosmic-ray intensity by STS-5 gas-discharge counters installed on the Venera-2 and Zond-3 stations for the period from 14 XI 1965 to 21 I 1966. At the Venera-2 station, the data were averaged over 4-hour intervals, except for the interval 19–26 XII 1965, for which there is only a mean value for the whole interval. For this time the data from the Zond-3 station are available mainly only in the form of mean values over large time intervals (5–7 days and more). Figure 2 also gives 4-hour values of the

Fig. 2. Cosmic-ray intensity recorded at the Venera-2 and Zond-3 stations and by a neutron monitor on Earth (Deep River)

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counting rate of the neutron monitor at Deep River. From this figure it is seen that the intensity variations in different regions of interplanetary space have not only different amplitudes but also are not simultaneous, which is especially clearly seen from the times at which the characteristic changes in intensity arise.

Therefore, to determine the radial gradient of cosmic-ray intensity, two intervals were selected, at the beginning and at the end of the joint flight of the Venera-2 and Zond-3 stations, characterized by a relatively quiet state of cosmic-ray intensity. At the beginning of the flight an interval t_1, from 15 to 20 XI 1965, was chosen; at the end of the flight an interval t_2, from 4 to 11 I 1966. The mean values of the intensities over these time intervals are known with good accuracy, reaching 0.02%.

However, since the intensity variations in the regions of the Venera-2 and Zond-3 stations are different, from the readings of the counter of the Venera-2 station the dispersions of the 4-hour intensity values were determined, and these were taken as the measurement error.

As a result, for these time intervals the following values of the mean counting rates of the counters of the Zond-3 and Venera-2 stations, located at mean distances R from the Sun, were obtained: $N_{\text{Zond-3}}(t_1, R_1) = 26.38 \pm 0.015$; $N_{\text{Zond-3}}(t_2, R_2) = 26.31 \pm 0.03$; $N_{\text{Venera-2}}(t_1, R_3) = 26.17 \pm 0.015$; $N_{\text{Venera-2}}(t_2, R_4) = 25.95 \pm 0.03$, where $R_1 = 182 \cdot 10^6$ km, $R_2 = 192 \cdot 10^6$ km, $R_3 = 148 \cdot 10^6$ km, $R_4 = 134 \cdot 10^6$ km. From these data, the value of the radial gradient was obtained as $\delta = (3.1 \pm 0.4)\%$ per 1 AU.

Fig. 2. Cosmic-ray intensity recorded at the Venera-2 and Zond-3 stations and by a neutron monitor on Earth (Deep River)

The time shift of the characteristic features of the behavior of cosmic-ray intensity for different regions of the solar system may be due to the displacement in space of magnetic inhomogeneities that promote or hinder the entry into a given point of particles of primary cosmic radiation. It is natural to assume that the speed of displacement of these inhomogeneities is close to the speed of the solar wind, i.e., is about 300 km/sec. During the joint flight of the Venera-2 and Zond-3 stations, the difference in the distances from the stations' locations to the Sun varied from 30 to $65 \cdot 10^6$ km. This means that at the Zond-3 station the characteristic changes in intensity should have been observed 1–2 days after analogous changes at the Venera-2 station.

For comparison of the readings of the counters of the Venera-2 and Zond-3 stations, Fig. 3 gives the mean intensity values recorded at the Venera-2 and

Zond-3 stations in identical and coincident time intervals (see Fig. 3a), as well as shifted (see Fig. 3b) by the time $\Delta t = \Delta l / V$, where Δl is the difference in the distances from the Sun for the positions of the Zond-3 and Venera-2 stations at a given moment of time, and V is the solar-wind speed, equal to 300 km/sec. If one assumes that such a shift leads to a more correct account of temporal variations, and calculates the cosmic-ray gradient on the basis of the intensity values obtained after the shift and a change in the length of the averaging intervals, then for the gradient we find the value $\delta = 5\%$ per 1 AU. As is seen from Fig. 3b, there is an irre-

regularity of the radial gradient, which may be associated with a change in the character and magnitude of Forbush effects at different distances from the Sun. Therefore it is possible that the radial gradient obtained is due to Forbush effects.

During the flight of the Venera-2 station, two Forbush decreases in cosmic-ray intensity occurred (see Fig. 2). In addition to the absence of simultaneity of this effect noted above, the different character of its development is clearly seen. At the Venera-2 station the Forbush effect sets in very rapidly; the sharp decrease in intensity occurs in a time of less than 4 hours on 31 XII 1965 and about 8 hours on 18 I 1966. The neutron monitor on the Earth during both Forbush effects shows a considerably slower decrease, amounting to 2–3 days, i.e., 10 times slower than at the Venera-2 station. The gradual onset of the Forbush effect on the Earth can be explained either by the influence of the Earth' s magnetosphere, or by the fact that particles with larger momenta are recorded on the Earth than at the Venera-2 station.

Fig. 3. Values of the counting rates averaged over several days for the Venera-2 and Zond-3 stations during their joint flight: **a** –averaging over identical time intervals; **b** –averaging for the Venera-2 station over time intervals shifted relative to the Zond-3 station.

Radial gradient of protons with energies 1–5 MeV. The *n*-*p* detectors installed on the Zond-3, Venera-2, and Venera-3 stations, which are sensitive to protons with energies of 1–5 MeV, in addition to sharp increases in counting rate, detected a very stable and rather time-constant background, approximately 10 times greater than the possible background of high-energy particles.

Figure 4 presents the mean daily readings of the proton detectors of the Venera-4 and Zond-3 stations.

Fig. 4. Dependence of the intensity of protons of 1–5 MeV on distance from the Sun. The points correspond to the mean daily intensity for quiet days (days when bursts of 1–5 MeV protons were observed are excluded).

The time periods corresponding to the sharp increases (bursts) have been excluded. It is seen from the figure that the proton intensity increases strongly with increasing distance from the Sun. When the distance from the Sun changes from $130 \cdot 10^6$ to $190 \cdot 10^6$ km, the intensity of this, apparently isotropic, proton radiation of 1-5 MeV increased by a factor of 5. The portion of the simultaneous variation at the Zond-3 and Venera-2 stations at different distances from the Sun excludes the temporal character of this phenomenon. As follows from Fig. 4, an especially rapid increase begins at distances of $160 \cdot 10^6$ km.

Naturally, one may suppose that these protons[1] are of solar origin. But then it is rather difficult to imagine an increase in their intensity with increasing distance from the Sun. Nevertheless, one can propose certain mechanisms that qualitatively explain the increase in intensity with distance from the source, if one takes into account that the discussion concerns the intensity outside the channels along which particles are ejected from the Sun.

A sharp increase in the intensity at distances $\geqslant 1.4$ AU indicates that the accumulation of protons traveling along magnetic channels beyond the Earth' s orbit occurs at a relatively small distance from the Sun, say $1.5 \div 2$ AU; i.e., it must be assumed that at these distances the field of the magnetic tubes loses its orderliness and the motion of the protons acquires a chaotic, possibly diffusive, character. Some of the particles of this proton belt leave the Solar System, while some diffuse toward the center.

To explain the gradient, one could use Parker' s theory, which predicts a gradient of galactic cosmic rays, but with the source not at infinity, but in the form of a ring located in the 1965 period in the region of Mars' s orbit. The magnitude of the intensity gradient of $1 \div 5$ MeV protons between the orbits of Venus and Earth is 100% per 1 AU, i.e., 30 times greater than the possible gradient of galactic cosmic rays. This difference is apparently entirely explained by the difference in particle energy. It is possible, however, that the application of Parker' s diffusion theory to explain the gradient in the region of the Earth' s orbit, where the magnetic field has a quasi-regular character, is not legitimate.

However, in the presence of a regular radial field, particles arriving from outside may be pushed out by the propagation from the Sun of magnetic disturbances and shock waves. But one may assume that the motion of protons in the region of the Earth' s orbit occurs in a completely ordered way, with conservation of magnetic moment. In this case it is difficult to expect a gradient of galactic cosmic rays. But for protons of solar origin the following mechanism is possible.

Protons of $1 \div 5$ MeV, which are often accelerated on the Sun (see (4)), are carried out along field lines to great distances from the Sun, where the magnetic field is strongly weakened and loses its regular character, and therefore there the pitch angle of the particles may change in connection with nonconservation of the magnetic moment. When the pitch angle becomes greater than 90°, reverse motion of the particles into the central regions of the Solar System begins. If it is assumed that the pitch angle mainly changes by small angles, then for this reason the maximum for the returning particles should occur at a pitch angle equal to 90°. Subsequently the particles may undergo oscillations, being

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[1] J. A. Simpson, C. Y. Fan, P. Meyer, *J. Phys. Soc. Japan*, **17**, Suppl. A-2, Part 2, 505 (1962).

reflected in the inner parts of the Solar System as from a magnetic bottle and scattering at large distances from the Sun.

Particles whose pitch angle is close to 90° will easily undergo such oscillations, since at large distances from the Sun they need to change their pitch angle only by a small amount. In contrast, particles with small pitch angles will either leave the Solar System or return back to the central regions of the Solar System with a pitch angle close to 90°.

The mechanism considered should lead to the presence of a large radial gradient of $1 \div 5$ MeV protons.

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Note: Figure translations are in progress. See original paper for figures.

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