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Abstract

Full Text

GEOPHYSICS

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MEASUREMENTS DURING THE FLIGHT OF THE VENERA-2, VENERA-3, AND ZOND-3 STATIONS OF PROTONS OF SOLAR ORIGIN WITH ENERGY 1–5 MeV

During the flight of the interplanetary automatic stations Zond-3, Venera-2, and Venera-3, 6 cases of significant increases in the counting rates of the proton detectors installed on these stations were recorded. Three of them were recorded by the Zond-3 station, two by the Venera-2 station, and one by all three stations.

Fig. 1. Increase in the flux of low-energy protons on 29 VII and 16–17 VIII 1965.

The semiconductor surface-barrier proton detectors had an area of about 0.2 cm^2 with an n-p junction thickness of 35 μ. On the side of free space, within a solid angle of $\sim$ 1 steradian, the detector was shielded by aluminum foil 2 mg/cm^2 thick. On the other sides the shielding exceeded 1 g/cm^2 of aluminum. The detectors were adjusted to register protons with energies from 1 to 5 MeV. The direction of the axis of the entrance window made an angle of $90 \pm 10°$ with the direction toward the Sun. Information was read out once every 4 hours and corresponded to the number of counter pulses integrated over this time. The range of measured intensity corresponded to an average counting rate from $1.1 \cdot 10^{-3}$ to 1.1 pulses/sec.

Figs. 1–3 show 4 cases of a significant increase in the intensity of 1–5 MeV protons. In addition to the readings of the proton detector and the Geiger counter of the interplanetary stations, the figures present 4-hour data from the neutron monitor (Deep River) and data for the K_p-index of magnetic disturbance on

Fig. 2

Figure 2: Fig. 2

Earth.

Fig. 1 shows the first two cases, which occurred on 29 VII and 16–17 VIII 1965. In both cases the burst of 1–5 MeV protons occurred

against the background of a small Forbush effect, as is evident from the decrease in the counting rate of the Geiger counter of the Zond-3 station and of the neutron monitor on Earth. Apparently, during the increase in the intensity of protons of 1–5 MeV, the Earth and the Zond-3 station were in a corpuscular stream.

On 29.VII, two days after the Earth first entered the corpuscular stream and then the Zond-3 station did, there occurred a considerable increase in the flux of protons of 1–5 MeV, which lasted approximately one day.

Fig. 2. Same as in Fig. 1, for 4.X.1965.

On 16–17.VIII the proton enhancement was apparently caused by an active region on the Sun with coordinates 25 N, 90 W (on 16.VIII.1965). Assuming the motion of solar protons along the lines of force of the magnetic field, i.e., along an Archimedean spiral, we obtain for the velocity of the corpuscular stream 220 km/sec. This value is small, but in what follows we shall again arrive at similarly small values for the stream velocities.

Figure 2 presents the picture of the third increase in the flux of low-energy protons, accompanied by an increase in the flux of penetrating protons ($E_p > 40$ MeV), recorded by the Geiger counter.

As is seen from Fig. 2, the character of the enhancement of 1–5 MeV protons has a very complex form. This enhancement began as early as the end of September and continued until 8.X.1965. On the Sun an active region appeared as early as 26.IX (20 N, 90 E, 07 h 15 m U.T.) and existed until 8.X.1965 (22 N, 76 W, 07 h 35 m U.T.). In such an active region, during the indicated period, there was observed one flare of class 2+, 6 flares of class 2, 12 flares of class 1, and many still smaller ones. In addition, in another active region, which on 4.X.1965 had coordinates 22 S, 29 W, a class 2 flare was observed at 9 h 35 m U.T. However, calculations showed that these active regions cannot be associated with the appearance of 1–5 MeV protons moving along an Archimedean spiral corresponding to a radial plasma velocity of 200–400 km/sec. It is possible that other regions on the Sun were responsible for the appearance of the protons.

Figure 3 gives data on the increase in the intensity of 1–5 MeV protons on 27.XI.1965, recorded on three interplanetary stations: Venera-2, Venera-3, and Zond-3. The distance between the Venera-2 and Venera-3 stations at that time was 10^6 km. The observed displacement of the maximum of the increase in

Fig. 3

Figure 3: Fig. 3

proton intensity at the Venera-3 station in comparison with the Venera-2 station can be explained by the fact that the rotation period of the Venera-3 station considerably exceeded the averaging interval of the data, which could have led to some modulation of the counting rate of the Venera-3 station detector and to a displacement of the maximum. The rotation period of the Venera-2 and Zond-3 stations was much shorter than the averaging time. Po-

therefore no additional modulation due to rotation should be expected for the Venera-2 and Zond-3 stations. During this increase in intensity (see Fig. 1 of paper (4)), the Venera-2 and Zond-3 stations were positioned so that the corpuscular stream first swept past the Venera-2 station, and then the Zond-3 station, at a stream velocity of less than 350 km/sec.

Analysis of Fig. 3 reveals the following features: 1) the delay of the steep front of the flare of 1–5 MeV protons on November 27, 1965, on Zond-3 in comparison with Venera-2 is ~ 20 h, while the delay of characteristic details of cosmic-ray variations, according to the Geiger counter data, on November 26, 1965, on Zond-3 is ~ 30 h in comparison with the corresponding details on Venera-2; 2) the time interval between two increases in intensity according to the Geiger counter readings on the Venera-2 station (November 23 and 25, 1965) is ~ 35 h, while for the corresponding increases on the Zond-3 station (November 23–24 and 26, 1965) it is ~ 50 h; 3) on the Zond-3 station, the flare of 1–5 MeV protons on November 28, 1965, begins gradually, and its beginning coincides with the beginning (though sharper) of the flare on Venera-2; 4) on November 24, 1965, there was a small flare on Venera-2 and, practically simultaneously, a longer-lasting and very intense flare on Zond-3*.

Fig. 3. Same as in Fig. 1, for November 27, 1965.

From the observed features one can form the following picture of the course of the process of acceleration and propagation of 1–5 MeV protons in interplanetary space. These protons are accelerated on the Sun and move without hindrance along magnetic-field lines curved into an Archimedean spiral. On November 24, 1965, along the field lines passing through Venera-2 there was a very weak proton flux, whereas along the field line passing through Zond-3 the flux had a very considerable intensity. On November 26, 1965, along the field line passing through Venera-2 and Venera-3, an intense particle flux arose. At the same time, a considerably weaker flux arose along the field line passing through Zond-3. This flare lasted more than a day, and the sharp increase on Zond-3 on November 27, 1965, may be interpreted as the arrival at Zond-3 of a field line richly populated with protons and causing, on November 26, 1965, a sharp increase at Venera-2 and Venera-3. This leads to a corpuscular-stream velocity of 220 km/sec. The width of the streams populated with 1–5 MeV protons is

$3 \cdot 10^{12}$ cm.

Let us suppose that the minimum of cosmic-ray intensity recorded by the counter on Venera-2 and Venera-3 on November 24, 1965, was caused by the corpuscular stream. Then, from the delay time (~ 24 h) of the mini-

* There are some doubts as to the reliability of the measurements during the flare of October 24, 1965, on Zond-3.

the intensity minimum on Zond-3 relative to Venera-2 and Venera-3, it follows that the mean velocity of this stream is 200 km/sec. At the same time, from the fact that the width of this minimum on Zond-3 is greater than on Venera-2 and Venera-3, it follows that the velocity of the stream decreases with time from 290 to 190 km/sec for a stream width of $\sim 10^{13}$ cm. Such low velocities of plasma motion have not yet been observed by direct methods. It should be noted, however, that the stream velocities obtained here and above are determined from the pitch of the assumed Archimedean spiral. But the structure of the magnetic field need not correspond exactly to such a picture. It is possible that the shape of the spiral is distorted owing to nonuniform injection of plasma by the given active region on the Sun, as well as to the interaction of magnetic flux tubes from neighboring regions. Nor can one exclude the possibility that, as the plasma moves away from the Sun, its velocity deviates from the radial direction, tending to orient itself along the magnetic field. In this case the pitch of the spiral will continuously decrease with distance from the Sun, and also with time after the onset of the flare. Such a picture explains the experimental data on the delay rather well, without leading to anomalous plasma velocities of ~ 200 km/sec, and allowing velocities of 300 km/sec and even more, which have repeatedly been found by direct measurements.

These data show that the Sun not only generates high-energy protons, detected in balloon flights ([1]), but more often protons of lower energies, $1 \div 5$ MeV. The propagation of high-energy protons in interplanetary space (near the maximum of solar activity) occurs by diffusion ([1]). The time dependence of the intensity of $1 \div 5$ MeV protons, as follows from Figs. 1–3, has an entirely different character, sometimes not at all resembling diffusion. Therefore there is hardly any doubt that, at least near the minimum of solar activity, the propagation of $1 \div 5$ MeV protons in interplanetary space occurs along lines of force, i.e., in a manner sharply different from diffusion ([2]).

If the corpuscular stream has a magnetic field whose lines of force abut on an active region on the Sun, then low-energy protons generated in this active region move freely along the spiral along the lines of force of the magnetic field. Thus the corpuscular stream creates a kind of tunnel through which protons of comparatively low energies can leave the Sun and reach regions located at considerable distances from the Sun.

This assumption is confirmed by experimental data obtained by Simpson in 1964 on the satellite Explorer-18 ([3]). On this satellite an increase in the intensity of low-energy protons was recorded regularly every 27 days during several successive rotations of the Sun, which indicates the continuous outflow of these protons from one active region of the Sun within the corpuscular stream.

Nevertheless, apparently more often the outflow of protons continues for less than one solar rotation. Thus, active regions do not generate protons all the time, or the conditions for the escape of protons from the Sun are not present all the time, but periodically, and sometimes for a long time, an active region becomes a source of low-energy protons.

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