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Abstract

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GEOPHYSICS

**V. V. BEZRUKIKH, K. I. GRINGAUZ, L. S. MUSATOV,
R. E. RYBCHINSKY, M. Z. KHOKHLOV**

INVESTIGATIONS OF SOLAR-PLASMA FLOWS

ON THE INTERPLANETARY STATION ZOND-2

(Presented by Academician A. L. Mints on 11 V 1965)

Among the reports published to date that relate to direct observations of solar-plasma flows in interplanetary space on the spacecraft Luna-2 ⁽¹⁾ and Luna-3 ⁽²⁾ in 1959, Venera-1 ^(2,3) and Explorer-10 ⁽⁴⁾ in 1961, Mariner-2 ^(5,6), Mars-1 ⁽⁷⁾ in 1962, and Explorer-18 ⁽⁸⁾ in 1963–1964, the longest period is covered by measurements carried out by K. Snyder and M. Neugebauer by means of an electrostatic analyzer on Mariner-2, which lasted almost continuously for 4 months. The authors ^(5,6) showed the presence of a good correlation between the velocities of solar-plasma flows and Kp -indices characterizing geomagnetic disturbances. However, in ^(5,6) it is pointed out that there is no satisfactory correlation between the magnitudes of solar-plasma flows and Kp -indices (with the reservation that this conclusion is preliminary). The results of our experiments speak in favor of the existence of such a correlation.

On the interplanetary station Zond-2, launched on 30 XI 1964, several charged-particle traps were installed, intended for measuring charged-particle flows near the Earth and for determining the magnitudes of solar-plasma flows and their energy spectra.

In the present communication, preliminary data are given from measurements carried out on the Zond-2 station by means of a modulation trap and one of the integral charged-particle traps during the first half of December 1964.

In the design of the integral trap, in comparison with three-electrode traps with constant potentials on the electrodes installed on other Soviet space rockets ^(2,7), certain changes were introduced. With its help it was possible to record

Fig. 1

Figure 1: Fig. 1

electron flows with energy > 70 eV and flows of positive ions with energy > 50 eV. More strictly speaking, in this way only differences of these flows could be recorded. However, on individual sections of the trajectory the experimental data clearly make it possible to identify those regions where flows of charged particles of one sign predominate.

The modulation trap installed on the Zond-2 station differed from the same type of trap installed on the Mars-1 station ⁽⁷⁾ by a somewhat larger size. The design of the trap is close to the design used by Bridge et al. on Explorer-10 (1961) ⁽⁴⁾. The voltage on the modulation grid was supplied in the form of the sum of two voltages—a constant one, which successively assumed 8 values from ~ 230 to ~ 3200 V, and an alternating voltage of rectangular form with a full amplitude of ~ 450 V (modulation frequency ~ 1000 Hz). The diagram of the trap and the voltage diagram are shown in Fig. 1. A system of shielding grids separates the modulation grid from the collector. Emission of electrons from the collec-

was suppressed by means of an additional grid near the collector, which had a potential of -70 V relative to the body of the station. The alternating component of the collector current, proportional to the magnitude of the flux of positive particles in the corresponding energy interval, was recorded by a resonant amplifier tuned to the modulation frequency. The instrument could record, in each energy interval of width ~ 450 eV, fluxes of positive ions ranging from $\sim 1 \cdot 10^7$ to $\sim 2.5 \cdot 10^9$ $\text{cm}^{-2} \cdot \text{s}^{-1}$. The total flux of positive ions with energies < 3600 eV is approximately equal to the sum of the fluxes recorded in all energy intervals. The time required to determine one spectrum (i.e., successive measurements in 8 intervals) was 4 min. In addition, a dc amplifier (for positive and negative currents) was included in the collector circuit of the modulation trap; with its aid it was possible to estimate the magnitude of the flux of positive ions with energies exceeding 3600 eV, and also to record electron fluxes with energies > 70 eV.

Fig. 1

With the aid of modulation and integral traps for charged particles, during a number of communication sessions with the Zond-2 station, measurements were made of the fluxes of solar-wind protons and of their energy spectra. The basic position of the modulation trap is the position in which its axis is oriented toward the Sun. When the trap axis deviated from this direction, corrections were introduced into the measured quantities, based on a study of the angular characteristics of the trap in the laboratory.

As an example of the measurement results, Fig. 2 gives a series of solar-wind spectra obtained during the measurement sessions of 5 XII 1964, when Zond-2

was at a distance of $\sim 1.7 \cdot 10^6$ km from the Earth.

The values of the fluxes of positive ions in the energy range up to 900 eV are comparatively small ($\sim (3 \div 7) \cdot 10^7 \text{ cm}^{-2} \cdot \text{s}^{-1}$). It should be noted that the day 5 XII 1964 was an exceptionally quiet day magnetically (for example, according to data from the observatory at Coimbra, the sum of the three-hour K -indices for 5 XII 1964 was $\Sigma K = 2$).

As in the previous experiments on Venera-1 in 1961 (3) and on Mars-1 in 1962, the measurements showed that an increase in geomagnetic disturbances is associated with an increase in the intensity of solar-plasma fluxes. Thus, on 7 XII 1964, when according to data from the same observatory $\Sigma K = 18$, during the measurement session at 21 h a flux was recorded whose intensity exceeded $\sim 1.5 \cdot 10^9 \text{ cm}^{-2} \cdot \text{s}^{-1}$. In the following days the flux intensity again decreased to a level of $\sim 10^8 \text{ cm}^{-2} \cdot \text{s}^{-1}$. In this connection it should be noted that on 7 XII 1965 the only magnetic storm in December with a sudden commencement at 10^h30^m was observed.

The relative positions of the Zond-2 station and the Earth on 7 XII 1964 were such that the solar-plasma fluxes first interacted with the Earth, and then, with a delay of approximately 40 ÷ 120 min (depending on the assumption about the direction of motion of the flux front), with the interplanetary station. Thus, our observations apparently refer to a time roughly 10 h after the passage of the flux front responsible for the sudden commencement of the storm on 7 XII 1964.

Fig. 2

It should be noted that during strong geomagnetic disturbances, streams of solar plasma of $\sim 10^9 \text{ cm}^{-2} \cdot \text{s}^{-1}$ were also observed at the Mars-1 station (for example, on 22 XI 1962 at 9 h 40 min and on 30 XI 1962 at 10 h).

Despite the fact that the total duration of our observations of solar-plasma streams is considerably shorter than the duration of the observations carried out on Mariner-2 (5,6), the observational data from 1959 on Luna-3 (2), from 1961 on Venera-1 (3), from 1962 on Mars-1, and from 1964 on Zond-2 make it possible to say that a correlation exists between the magnitudes of the solar-plasma streams and the Kp -indices. In particular, geomagnetic storms corresponding to $Kp \geq 5$ are caused by streams of solar plasma of $\sim 10^9 \text{ protons} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$, considerably (by an order of magnitude) exceeding

the magnitudes of the fluxes during magnetically quiet periods. It may be noted that even 10 hours after the sudden onset of the magnetic storm on 7 XII 1964, the magnitude of the solar-plasma flux still exceeded by 10–15 times the magnitude of the flux before the onset of the storm. At the same time, from data obtained on Mariner 2 (5), it follows that in an analogous situation, after the passage of the shock front associated with the onset of a magnetic storm (see the storm of 7 X 1962), the plasma flux fell comparatively rapidly (within ~ 5 hours) to the level that had existed before the storm.

Thus, with regard to the connection between the magnitudes of solar-plasma fluxes and geomagnetic disturbances, the data obtained as a result of our experiments and in the experiments on Mariner 2 differ from one another.

It may be assumed that the uncertainty of the data on the correlation between Kp -indices and the magnitudes of solar-plasma fluxes, noted in (⁵, ⁶), is connected with the peculiarities of the method of observation and interpretation of the primary experimental data obtained on Mariner 2. Measurements with the electrostatic analyzer used on Mariner 2 made it possible to determine plasma velocities with great accuracy; however, in order to determine the total flux the authors (⁵, ⁶) had to make assumptions in the form of the energy spectrum of the protons, which may lead to uncertainty in estimates of the flux magnitudes. On the other hand, charged-particle traps make it possible to determine directly the magnitude of the flux of positive ions.

The data presented indicate the need for further study of correlation dependences between the characteristics of geomagnetic disturbances and the characteristics of solar-plasma fluxes.

Radiotechnical Institute
Academy of Sciences of the USSR

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