# SOLAR WIND AND MAGNETOSHEATH OBSERVATIONS AT EARTH DURING AUGUST 1972

O. L. VAISBERG and G. N. ZASTENKER
*Space Research Institute, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.*

**Abstract.** Experimental data of Prognoz, Prognoz-2 and HEOS-2 on interplanetary plasma and magnetosheath plasma in the period of unusual solar activity in August 1972 are considered. All measurements showed the extremal plasma properties with strong variations. Attempt is made to identify the structure according to near-Earth observations. The positions of the magnetopause and bow shock suffered significant variations during this time interval.

## 1. Introduction

Measurements of interplanetary plasma parameters near the Earth during the unique helio- and geophysical events of August 1972 represent significant interest, first of all because the strongest interplanetary disturbances were among the major manifestations of violent solar activity observed up to that time.

In addition, the results of these measurements are important for their contribution to the understanding of many unusual magnetospheric and ionospheric phenomena that took place during this time, as well as phenomena observed on the surface of the Earth (McKinnon, 1972; Coffey, 1973).

## 2. Spacecraft and Instrumentation

Detailed near-Earth solar wind plasma measurements during the period under discussion were performed only on Prognoz and Prognoz-2 (Temny *et al.*, 1974; Bezrukikh *et al.*, 1974; Bezrukikh *et al.*, 1975; Zastenker *et al.*, 1976; Cambou *et al.*, 1975) and HEOS-2 (Report ESRO, 1973; Cattaneo *et al.*, 1974; Grunwaldt, 1975). Results of observations on IMP and Vela satellites are not published in this writing and are unknown to the authors.

The Prognoz satellites had high-eccentric orbits with apogee 200 000 km, perigee 1000 km and inclination 65° (Temny, 1974), so they spent most of the orbital period (equal to 96 h) in interplanetary space. In August 1972 the projection of the axis of apsides of Prognoz-2 was in the dayside sector, directed approximately toward the Sun. The projection of Prognoz's line of apsides was in the morning sector at an angle of $\sim 90°$ relative to the Sunward direction.

These satellites were spin-stabilized with axes of rotations directed approximately towards the Sun.

Several instruments for plasma measurements were on board these satellites. The narrow-angle energy-mass-analyser RIP-803 (Vaisberg *et al.*, 1971) and electrostatic

*Space Science Reviews* **19** (1976) 687–702. *All Rights Reserved*
*Copyright © 1976 by D. Reidel Publishing Company, Dordrecht-Holland*

analyser RIP-804 (Zurina *et al.*, 1971) were on Prognoz. The first one was utilized for separate measurements of ion components (protons, $\alpha$-particles and ions with $m/q \simeq 4$). The second one was used for more detailed measurements of ion energy spectra. Both analysers were oriented in the Sunward direction and had an angle of view of 4°–8°; energy range upper limit, 4 KeV for protons and 16 KeV for $\alpha$-particles. The identical energy-mass-analyser RIP-803 and double electrostatic analyser CALIPSO (Cambou *et al.*, 1975) were on board the Prognoz-2 satellite. The CALIPSO-spectrometer was used for simultaneous measurement of electron and ion energy spectra in the energy range from 0.4 to 20 KeV with 15 energy steps and a somewhat wider angle of view of about 12°. The satellite's telemetry frame provided the measurement of energy spectra in 11-min time intervals.

Also installed on the two satellites were the different wide-angle Faraday-cup-type detectors (traps) (Bezrukikh *et al.*, 1974). Among them were an integral trap with angle of view ~150° for the measurements of difference between total ion flux and flux of electrons with energy > 70 eV as well as a differential trap for the measurement of ion energy distribution in the range up to 4 KeV with low energy resolution and angle of view about 90°. The time resolution of these measurements was 5.5 min.

The HEOS-2 satellite had a more elongated elliptical orbit with the height of apogee of 240 000 km and with the perigee height of about 1000 km (Report ESRO, 1973). It was launched for the study of interplanetary space and of the polar magnetosphere and had an inclination of about 90°. Two plasma experiments were performed on this satellite: S-202 (Coletti, 1971) and S-210 (Waard *et al.*, 1970). In the S-202 experiment, simultaneous measurements of electron and ion fluxes, with low energy resolution in the energy range up to 4 KeV, were made by an electrostatic analyser with several collectors.

An energy-spectrometer with a wide energy range, from 0.1 to 45 KeV, was used in the S-210 experiment. This instrument had an energy resolution of ~10%, an angle of view equal to 45° × 25°, and a time resolution of about 4 min. Information on angular distributions of particle flux was obtained on this rotating satellite.

## 3. General Behaviour of Parameters

Interpretation of the measurements by each of the above-mentioned instruments performed during the unusual and complicated events of August 1972, meets with some difficulties and is not very reliable, due to limitations of sensitivity, direction characteristics and energy range. Yet the intercomparison and analysis of the entire stock of obtained data allows one to construct a reasonably reliable picture of the various physical events.

Behaviour of the basic solar wind parameters: velocity, number density and ion temperature, was obtained first for some time intervals in August according to CALIPSO (Cambou *et al.*, 1975) and ion trap measurements (Bezrukikh *et al.*, 1975).

During a great part of the period under study, the velocity of solar plasma was

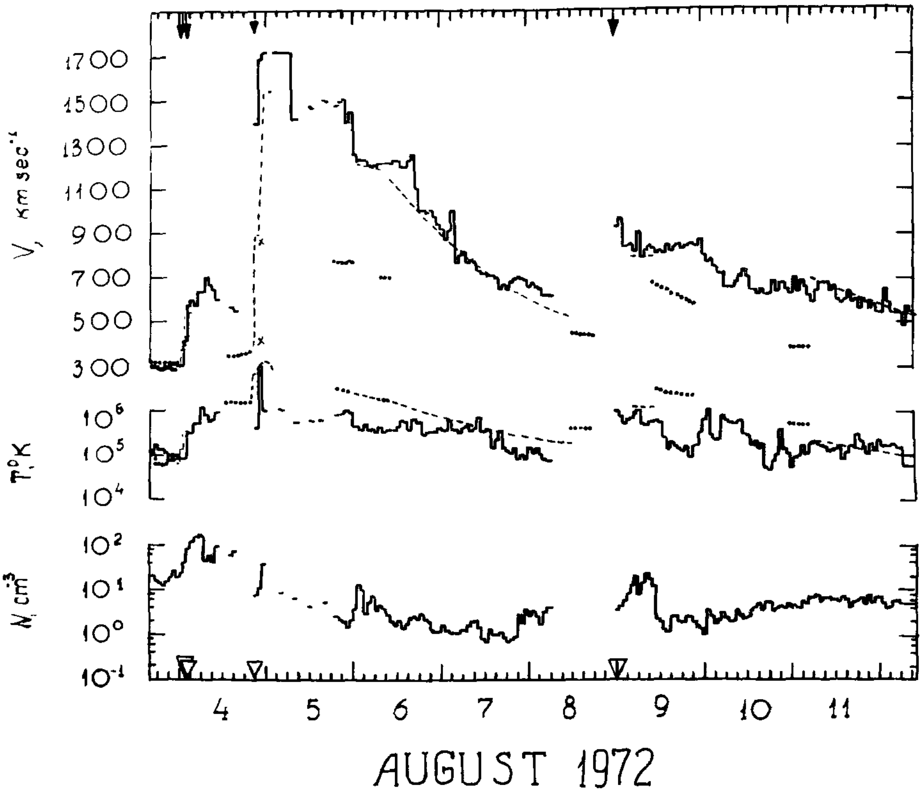


Fig. 1. Hourly-averaged values of plasma velocity, temperature and ion number density. Thick line—solar wind measurements on Prognoz-satellites; dashed line—HEOS-2 solar wind measurements; dotted line—magnetosheath measurements on HEOS-2; crosses—measurement of velocity and temperature in the magnetosheath on Explorer 45 satellite. The sharp jumps of plasma parameters are marked by arrows; the triangles depict the SCs.

beyond the upper limit of all Prognoz instrumentation except for the CALIPSO spectrometer. So the plasma velocity and ion temperature were obtained essentially according to the CALIPSO data, and the total number flux was obtained from data of the integral traps.

On Figure 1 (taken from Zastenker *et al.*, 1976) 1-h averaged solar wind parameters are given, as obtained from joint processing of all plasma instrumentations data on two Prognoz satellites. Data gaps on 4 and 8 August are due to magnetosphere crossings by these two satellites. On the same figure some solar wind and magnetosheath plasma parameters are given, as obtained on the HEOS-2 (Grunwaldt, 1975) and (one point) Explorer 45 (Fritz *et al.*, 1974) satellites. Very good time-sequence correspondence of the plasma parameters' behaviour and a reasonably good accord of observed values are seen, despite some schematic character of the data of Grunwaldt (1975).

It is seen, from Figure 1, that this time interval is characterized by sharp jumps of plasma velocity, temperature and number density, and by the increase of these parameters to very high, extremal values.

The most dramatic change of parameters took place on 4 August. In the beginning of that day, the solar wind velocity and temperature were close to usual undisturbed values, and only the number density was somewhat increased.

Then, during a few hours, the rise of velocity, temperature and number density was observed. Very high number density was observed, up to $\sim 150\ \mathrm{cm}^{-3}$. Between 06 and 09 UT on 4 August the rise changed to a slow decrease of all parameters. Yet, at the end of that day, the sharp rise of velocity and ion temperature up to very high values occurred. Such high values have never before been observed during more than a decade of direct interplanetary measurements, i.e., almost a total cycle of solar activity.

The number density quickly dropped to a very low level, $\lesssim 1\ \mathrm{cm}^{-3}$, and then reached usual values ($\sim 5\ \mathrm{cm}^{-3}$) on several days. The solar wind velocity slowly decreased during a few days. This behaviour of parameters (fast drop of number density with slow decrease of velocity) appears to be specific for the solar wind during disturbances associated with strong flares (Dryer, 1974, 1975). The fast, but relatively moderate magnitude rise of these parameters at the end of the 8 and at the beginning of the 9 of August changed this smooth variation. Then the picture repeated in basic details: the sharp drop of number density with subsequent recovering and slow decrease of velocity down to $\sim 550\ \mathrm{km\ s}^{-1}$ on 12 August were observed.

Intercomparison of plasma behaviour with geomagnetic observations (see Figure 1) shows that sharp jumps of plasma parameters (marked by arrows) coincide with sudden commencements (SC). In the early papers (McKinnon, 1972; Coffey, 1973) and then later with more foundations (Cambou *et al.*, 1975; Zastenker *et al.*, 1976; Dryer, 1975; Dryer *et al.*, 1974) these moments were interpreted as arrivals of four interplanetary shocks at the Earth, and the associations between each of the strong flares and the shocks have been supposed. Detailed descriptions of the observed events are given below.

## 4. Structure of Disturbances

### A. THE BEGINNING OF 4 AUGUST

Solar wind parameters for this period were given in Temny *et al.* (1974). Some additional data are in the papers by Bezrukikh *et al.* (1974), Bezrukikh *et al.* (1975), Zastenker *et al.* (1976) and Cattaneo *et al.* (1974).

Figure 2 shows the velocity and temperature of proton and $\alpha$-components of the solar wind (according to measurements of RIP-803 and RIP-804) on the Prognoz satellite (Temny *et al.*, 1974) and proton number density (according to measurements with the ion traps (Bezrukikh *et al.*, 1974)). The undisturbed solar wind had the velocity of $\sim 350\ \mathrm{km\ s}^{-1}$, proton number density of $\sim 20\ \mathrm{cm}^{-3}$, proton temperature $(5\ \text{to}\ 15) \times 10^4$ K and $\alpha$-particles temperature $(4\ \text{to}\ 13) \times 10^5$ K. The first jump of plasma parameters was observed on Prognoz and Prognoz-2 at 0116–0118 UT (the

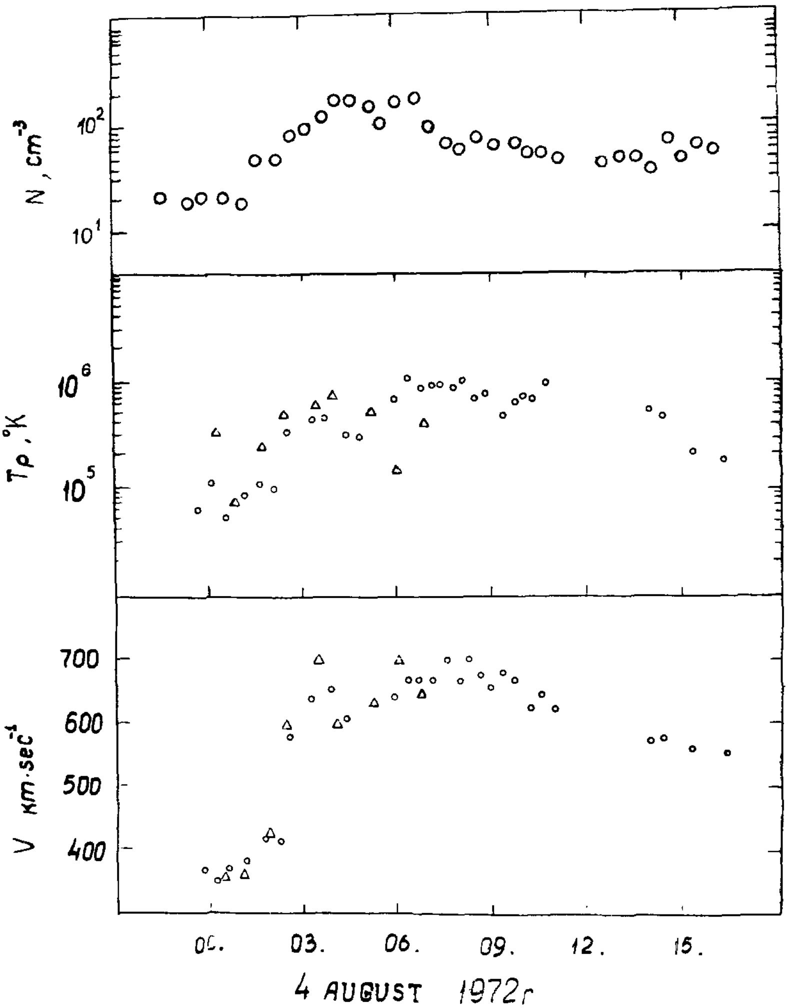


Fig. 2. Time profile of solar wind parameters upon arrival of 1st and 2nd interplanetary shocks. Open dots show the proton parameters; triangles—the same for $\alpha$-particles.

uncertainty of time scale is about 1 min). According to data of the S-202 experiment on the HEOS-2 satellite, solar wind observations began at 0120 UT and before this time the satellite was in magnetosheath (Cattaneo *et al.*, 1974). The velocity and temperature increase were moderate (velocity – up to $\sim 450$ km s$^{-1}$ and proton temperature – up to $1 \times 10^5$ K). The proton number density that was high before the disturbance rose to $\sim 50$ cm$^{-3}$. Table I, taken from Zastenker *et al.* (1976), shows the jumps of solar wind parameters for this and subsequent disturbances defined by the data of all instrumentation on Prognoz and Prognoz-2.

The event was quite surely identified as the arrival at the Earth of an interplanetary shock from the first major solar flare which began at 0316 UT on 2 August (Temny

TABLE I

Plasma changes across the August 1972 interplanetary shock waves

| No. | Day of August | Time (UT) | Solar wind parameters | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $V_1$ (km s$^{-1}$) | $V_2$ (km s$^{-1}$) | $T_1$ (°K) | $T_2$ (°K) | $n_1$ (cm$^{-3}$) | $n_2$ (cm$^{-3}$) |
| 1 | 4 | 0118 | 336 | 434 | $8.5\times10^4$ | $1.3\times10^5$ | 18 | 50 |
| 2 | 4 | 0220 | 418 | 580 | $1.7\times10^5$ | $6.8\times10^5$ | 43 | 78 |
| 3 | 4 | 2054 | — | 1200 | — | $10^5$–$10^6$ | — | 5 |
| 4 | 8 | 2352 | 700 | 900 | $2\times10^5$ | $7.10^5$ | $\sim2$ | $\sim4$ |

*et al.*, 1974; Zastenker *et al.*, 1976; Cambou *et al.*, 1975; Dryer, 1975; Dryer *et al.*, 1974).

After an hour, at 0220 UT, the second and stronger jump of solar wind parameters was observed on the Prognoz satellites (see Figure 2 and Table I). As a result of this shock wave, the velocity and proton temperature rose considerably. The jump of velocity from $\sim$400 km s$^{-1}$ to $\sim$600 km s$^{-1}$ was seen also on HEOS-2 (Cattaneo *et al.*, 1974). According to the interpretation of Cambou *et al.* (1975), Zastenker *et al.* (1976), Dryer (1975) and Dryer *et al.* (1974), this interplanetary shock arrived at the Earth from the second strong flare which occurred at 1958 UT on 2 August. Between 0220 UT and 2054 UT on 4 August no significant disturbance had been observed. The disturbance at 2054 was connected to the third flare (Zastenker *et al.*, 1976).

Comparison of the observations of the first and second shocks on the Sun (as Type II radio bursts) and at different space probes (Dryer *et al.*, 1974; Zastenker *et al.*, 1976) shows that the average velocity of the second shock was considerably higher than the first one. They must have met, therefore, at 0.1 AU beyond the Earth's orbit (Zastenker *et al.*, 1976).

As seen from Figures 1 and 2 the velocity of the solar wind continued to increase after these shocks and reached $\sim$700 km s$^{-1}$ at 0900 UT. The proton temperature rose to $\sim 10^6$ K, and the number density exceeded 100 cm$^{-3}$. Then the values of all three parameters began to diminish slowly.

Figure 2 also shows the parameters of the $\alpha$-component (Temny *et al.*, 1974). From 0100 through 0700 on 4 August the velocity of the $\alpha$-component is equal to the proton velocity within 5% uncertainty. The temperature of $\alpha$-particles is about four times the proton temperature between 0100 and 0300 UT, and in the region of maximum velocity this factor grows to 10. Then the $\alpha$-particle temperature follows the decrease of proton temperature. It seems that there is no evidence of an increase of helium content in the interval 0100–0700 UT. After 0700 UT the rise of background of the RIP-803 detector, due to arrival of a strong flux of protons with $E > 30$ MeV from the flare of 4 August, prevented the further registration of $\alpha$-particles by this instrument.

B. THE END OF 4 AND BEGINNING OF 5 AUGUST

The most interesting, albeit complicated, event occurred between the end of 4 and beginning of 5 of August. Detailed descriptions of plasma properties are given in Report ESRO (1973), Cattaneo *et al.* (1974), Cambou *et al.* (1975) and Grunwaldt (1975). The measurements of the CALIPSO spectrometer on Prognoz-2 (Cambou *et*

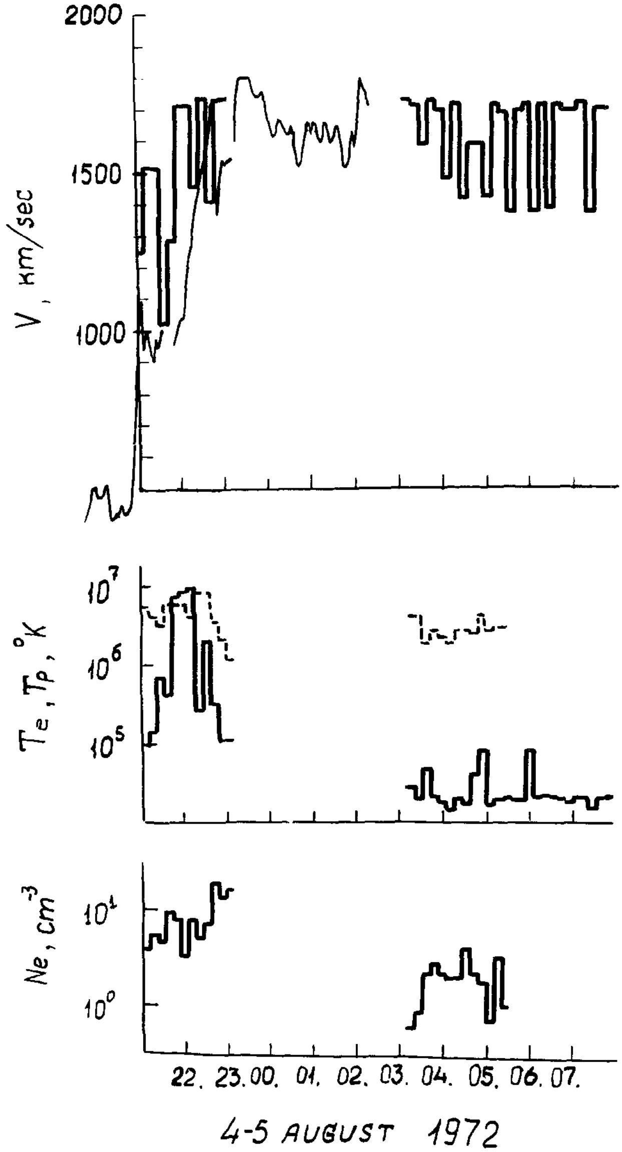


Fig. 3. Solar wind parameters for period of observations of the third interplanetary shock. Thick and dashed lines show the measurements on Prognoz-2 (dashed line is the electron temperature); thin line—HEOS-2 measurements.

*al.*, 1975) and the magnetospheric spectrometer of S-210 experiment on HEOS-2 (Grunwaldt, 1975) are given on Figure 3. As mentioned above, the plasma velocity was so high that the particles energy was beyond the range of most instrumentation. The velocity could be measured only by the CALIPSO spectrometer (with a range up to 20 KeV) and the magnetospheric spectrometer S-210 (with range 45 KeV). Data of these two instrumentations are in satisfactory agreement.

Before 2054 UT on 4 August both Prognoz satellites (Bezrukikh *et al.*, 1975; Cambou *et al.*, 1975) and HEOS-2 (Cattaneo *et al.*, 1974; Grunwaldt, 1975) were in the magnetosheath. According to HEOS-2 data at 2000 UT, the plasma flux velocity was 400–500 km $s^{-1}$, proton temperature about $3 \times 10^6$ K, and number density $\sim 1$ $cm^{-3}$. At 2054 UT the magnetosphere was compressed due to the sharp increase of solar wind presure and Prognoz-2 and HEOS-2 found themselves in the solar wind (Cambou *et al.*, 1975; Cattaneo *et al.*, 1974; Grunwaldt, 1975). Both instruments showed the solar wind velocity in excess of1000 km $s^{-1}$ (see Figure 3 and Table I). These observations provided the basic argument for the interpretation of this event as the arrival of an interplanetary shock wave from the third and very strong solar flare which began at 0621 UT on 4 August (Cambou *et al.*, 1975; Dryer *et al.*, 1974; Zastenker *et al.*, 1976). If this moment were to be attributed to arrival of the shock from the second flare, as it was supposed in McKinnon (1972) and Coffey (1973), the average velocity of the shock would have had to be 850 km $s^{-1}$, i.e., less than the observed plasma velocity. Such attribution, made before the availability of the data just discussed, is clearly impossible.

Following the shock arrival and continuing to 2240 UT, the solar wind velocity continued to rise (also, there is some discrepancy between the results of two spectrometers) to $\sim 1700$ km $s^{-1}$, and the proton temperature rose to $10^7$ K (see Figure 3). The electron temperature also was very high, and the number density was near normal level ($\sim 10$ $cm^{-3}$).

About 2240 UT on all three satellites, denser ($N \gtrsim 30$ $cm^{-3}$) and colder plasma was observed. It was supposed, in Cambou *et al.* (1975), that the plasma piston arrived between 2240 and 2311 UT. The average velocity of this piston, generated by the solar flare of 0621 UT on 4 August, would be very high – more than 2000 km $s^{-1}$.

Between 2311 UT on 4 August and 0250 UT on 5 August the signal of CALIPSO dropped below the instrumental threshold. This signal drop-out could be due to several possibilities: it could (i) be connected with a subsequent increase of velocity (not confirmed by HEOS-2 data), or (ii) with a decrease of ion temperature so that this instrument did not register any more of the low energy tail of more monoenergetic flux. Furthermore, it could be not excluded that (iii) the plasma flow direction was deviated more than 20°–30° from the anti-Sunward direction. At approximately 0200 UT on 5 August, the HEOS-2 satellite entered the magnetosheath and, until 6 August, did not register the solar wind.

An unusual plasma structural formation was observed by Prognoz-2 instrumentation from 0250 UT to 0520 UT on 5 August. As shown by Cambou *et al.* (1975)

during this time interval, the electron temperature increased enormously, and the ion number flux dropped strongly while the velocity of plasma remained very high, $\geq 1700$ km $s^{-1}$. According to numerous observations at this time (see, for example, Cambou *et al.*, 1975; Blokh *et al.*, 1974; and Lanzerotti *et al.*, 1974) a sharp rise, a levelling-off or plateau, and then a sudden decrease of the flux of energetic particles (from 1 to 500 MeV) were observed. The magnetic field intensity was also lower during this interval compared to that in the surrounding plasma. It was supposed in Cambou

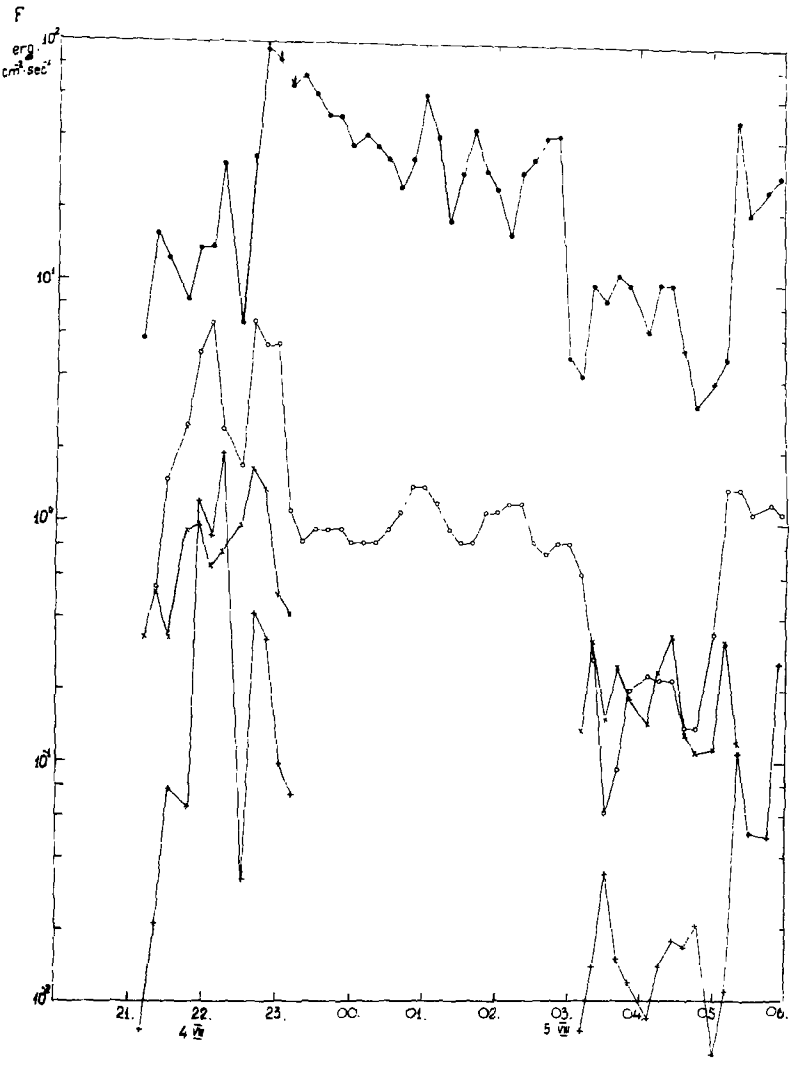


Fig. 4. Energy flux of solar wind upon arrival of the third shock. Designations: points—kinetic energy flux; open dots—magnetic energy flux; straight crosses—protons thermal energy flux; oblique crosses—electron's thermal energy flux.

*et al.* (1975) that these data could be considered as observations of a closed plasma formation with trapped or guided energetic particles.

It seems interesting to consider the unusual interplanetary plasma from the point of view of an energy balance. Estimations of kinetic energy flux ($Nm_pV^3/2$, where $m_p$ is the mass of a proton), of proton thermal energy flux ($NkT_pV$), of electron thermal energy flux ($NkT_eV$), and of interplanetary magnetic field energy flux ($B^2V/8\Pi$) are shown on Figure 4 as observed by the Prognoz satellites (Cambou *et al.*, 1975).

Most evident is the very high kinetic energy flux which reached about 100 erg cm$^2$ s$^{-1}$ at 2300 UT on 4 August. This value is about two orders of magnitude higher than the energy flux usually observed in the solar wind disturbances caused by interplanetary shocks (Dryer *et al.*, 1975). The highest kinetic energy flux was observed during the time interval that was tentatively connected to arrival of the plasma piston. The magnetic energy flux and thermal energy flux were also considerably higher than values usually observed in similar cases. Another peculiarity of this event is the high relative value of magnetic energy to kinetic energy flux for some time intervals. For example, at about 2200 UT and at ~2300 UT on 4 August, the magnetic energy flux reached 20–50% of the kinetic value. At the same time the thermal energy of electrons was, as a rule, higher than the thermal energy of protons and, in fact, even approached the magnetic energy.

A very interesting behaviour of the total energy values was observed during the previously mentioned interval of about 0300–0500 UT on 5 August. Both magnetic and kinetic energy fluxes dropped by a factor of 5–10 within this time interval. Yet, a significant gap was observed: the magnetic energy began to drop by 5–10 min later, and rose by 5–10 min earlier, than the kinetic energy flux. This circumstance could be considered as evidence of a current system on the boundary of a closed plasma configuration. At the same time the change of energetic particle flux occurred simultaneously with the change of magnetic field, as may be seen from the observations of Lanzerotti *et al.* (1974).

It is possible to note the high degree of correlation between the changes of magnetic and kinetic energies during all phases of this event (Figure 4).

### C. THE END OF THE 8 AND BEGINNING OF 9 AUGUST

The detailed picture of interplanetary plasma behaviour upon arrival of the interplanetary shock from the fourth strong flare (beginning at 1509 UT on 7 August) is shown on Figure 5 according to Prognoz-2 measurements. As in other cases, the solar wind velocity was determined from CALIPSO data (Cambou *et al.*, 1975) and number density was calculated from this velocity and total number flux measured by the ion integral traps (Bezrukikh *et al.*, 1975). Prognoz-2 entered the interplanetary medium at 2326 UT on 8 August shortly before arrival of the disturbance. As seen from Figure 5 the velocity was quite high at this time (~600 km s$^{-1}$), and the number density was low (~2–3 cm$^{-3}$). This low number density appears to be connected to rarefaction of interplanetary plasma after the passages of the three previously-discussed

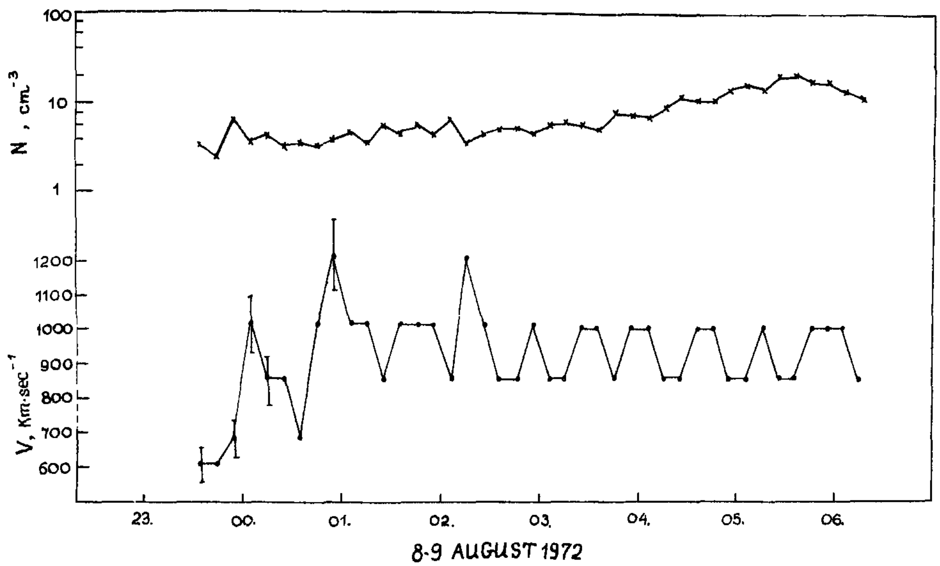


Fig. 5. Time profiles of velocity and number density of plasma upon arrival of the fourth interplanetary shock. Bars show the errors of velocity determination.

interplanetary shocks. At 2352 UT on 8 August simultaneously with SC observation (McKinnon, 1972; Coffey, 1973), the sharp jump of solar wind velocity occurred accompanied by a minor increase of number density (see Table I). At about 0030 UT on 9 August, the velocity decreased and then sharply increased. A second SC observed at several observatories at 0036 UT (McKinnon, 1972; Coffey, 1973) could be connected to this velocity increase. During the following 6 h the solar wind velocity varied between 900 and 1000 km $s^{-1}$, and the number density increased gradually to $\sim$20 $cm^{-3}$ and then began to decrease. These data apparently do not reveal with confidence the plasma piston. According to data of Figure 1 and Figure 5 it is supposed that plasma piston was observed between 0400 and 1000 UT on 9 August.

Comparative consideration of plasma measurements performed at different heliocentric distances gave the possibility to study the motion of the interplanetary shocks from the third and fourth flares (Zastenker *et al.*, 1976). Most remarkable is the average velocity of the shock wave from the 3rd flare – 2850 km $s^{-1}$. Another peculiarity is the detection of these two shocks at the Earth prior to their arrival at Pioneer 9 which was at a heliocentric distance of 0.8 AU at another heliographic longitude ($\sim$48°E). The time delay between the Earth's and Pioneer 9 observations was 2 h for the third flare and 7 h for the fourth. This apparently shows the significant nonsphericity of these interplanetary shocks. This deviation from near-spherical shape may be the cause of the significant difference between the post-shock solar wind parameters near the Earth and Pioneer 9 and Pioneer 10 observations. Thus, while the near-Earth maximum plasma velocity exceeded 1700 km $s^{-1}$, the velocity was not higher than 990 km $s^{-1}$ according to Pioneer 9 hourly-averaged measurements and not higher than 690 km $s^{-1}$ according to Pioneer 10 data (Zastenker *et al.*, 1976; Dryer, 1975). It is interesting to remind the reader that, relative to the Earth, the third flare occurred close to central meridian (E09), and the fourth flare was in the western hemisphere of the Sun (W39) while Pioneer 9 and Pioneer 10 were situated at approximately 45° to the east from the Sun–Earth line (McKinnon, 1972; Coffey, 1973). The analysis of these shocks' trajectories showed that the value of their deceleration was small (Zastenker *et al.*, 1976), thereby supporting the hypothesis on their piston-driven nature.

## 5. Magnetopause and Magnetosheath

Data on magnetosheath plasma for this time interval are scarce. Some results of measurements on HEOS-2 (Grunwaldt, 1975) and Explorer 45 (Fritz *et al.*, 1974) are shown on Figure 1. The jumps of solar wind parameters during crossings of the bow shock were approximately the same as for normal conditions. But the positions

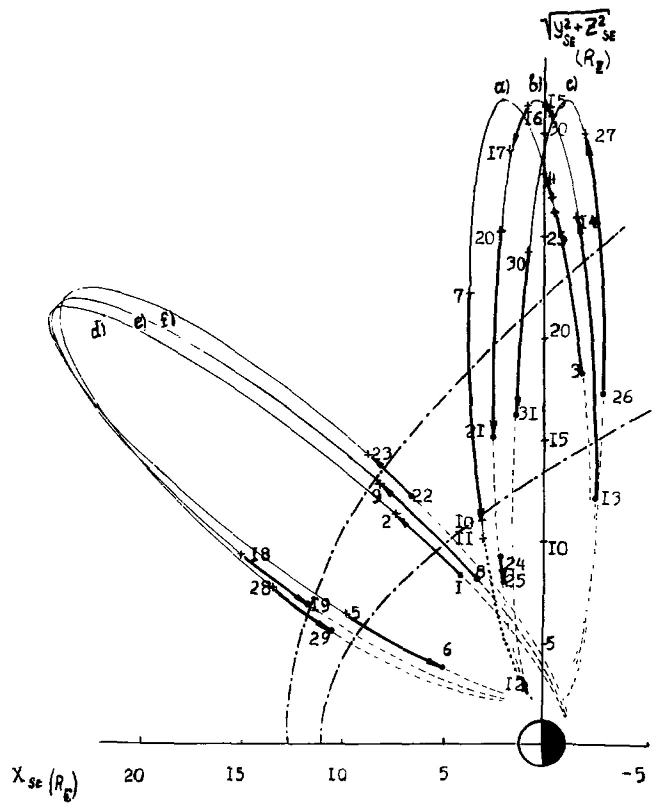

Fig. 6. Prognoz (a, b, c) and Prognoz-2 (d, e, f) trajectories for time interval under discussion. Points—magnetopause crossings; crosses—bow shock crossings; thick lines—parts of trajectories in the magnetosheath; dashed lines—magnetospheric parts of trajectories. Table II gives the moments corresponding to each of the enumerated points. Dashed-dotted lines—average bow shock and magnetopause positions according to Prognoz measurements.

TABLE II

Prognoz and Prognoz-2 crossings of the Earth's bow shock and magnetopause (see Figure 6)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Day of Aug. | 31.VII | 31.VII | 1 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 |
| Time UT | 1551 | 1848 | 1528 | 0728 | 0714 | 1025 | 1049 | 1631 | 2054 | 2240 | 2317 | 0353 |
| No. | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Day of Aug. | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 8 | 9 |
| Time UT | 1046 | 0348 | 2107 | 1017 | 2103 | 0300 | 0635 | 0648 | 1951 | 2046 | 2326 | 0035 |
| No. | 25 | 26 | 27 | 28 | 29 | 30 | 31 | | | | | |
| Day of Aug. | 9 | 9 | 10 | 12 | 12 | 12 | 12 | | | | | |
| Time UT | 0123 | 1622 | 1543 | 0549 | 0842 | 0940 | 1954 | | | | | |

of the bow shock and magnetopause differed significantly from their mean values (Temny *et al.*, 1974; Bezrukikh *et al.*, 1975; Cattaneo *et al.*, 1974; Grunwaldt, 1975; Fritz *et al.*, 1974).

Prognoz satellites crossed the magnetopause twice per 4 days and HEOS-2 crossed it twice in 5 days. Drawn according to Temny *et al.* (1974) and Bezrukikh *et al.* (1975), Figure 6 shows, in solar-ecliptic coordinates, the trajectories of the Prognoz

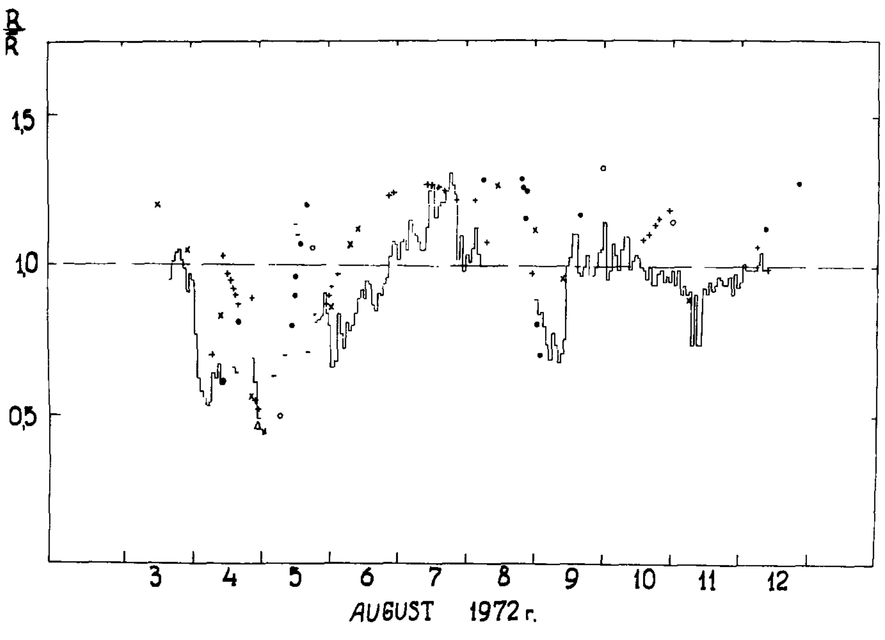


Fig. 7. Magnetopause and bow shock position during the time interval under consideration. Points—magnetopause from Prognoz and Prognoz-2 data; open dots—the same according to HEOS-2 data; triangle—the same according to Explorer 45 data; straight crosses—bow shock from Prognoz and Prognoz-2 data; oblique crosses—the same according to HEOS-2 measurements. The solid and dashed lines show the normalized equilibrium positions of boundaries calculated by measured solar wind ram pressure.

and Prognoz-2 satellites for three consecutive revolutions with crossings of bow shock and magnetopause appropriately marked. The Universal Time for every crossing is shown in Table II. Thick parts of the orbital traces in Figure 6 correspond to magnetosheath plasma observations, and dashed thin lines are the magnetospheric parts of the orbits. Mean positions of the bow shock and magnetopause, according to Prognoz data (Vaisberg *et al.*, 1974; Gringauz *et al.*, 1974), are shown for comparison.

Figure 7 shows the positions of the bow shock and magnetopause for the period under discussion as observed by Prognoz and other satellites. The ratio of $R/\bar{R}$ is plotted versus time where $R$ is the observed geocentric distance of each crossing, and $\bar{R}$ is the mean value of this distance in the same direction (on the same radius-vector). These observations are compared with the values of $R/\bar{R}$ calculated by the use of the observed solar wind parameters (see Figure 1) under an assumption of gas-dynamic equilibrium (Binsack and Vasyliunas, 1968):

$$R/\bar{R} = (\overline{NV}^2/NV^2)^{1/6}$$

where $\overline{NV}^2$ is the mean solar wind pressure.

Comparing the calculated and measured positions of boundaries, it is necessary to remember that, when the solar wind pressure changes considerably and the magnetopause is displaced significantly, the observed boundary crossing corresponds, not to an equilibrium position, but to the position of the satellite at the time of the boundary's passing-by. Besides, due to small inertia of these boundaries, their positions are determined (probably during not more than a few minutes) by more-or-less small-scale variations of solar wind pressure rather than hourly-means of its values. So the calculated and measured positions, as well as those positions measured by different satellites, have to coincide only in the sense of tendency and the moments of crossings.

Consider from this point of view the succession of observations shown on Figures 6 and 7. The ram pressure increase upon arrival of the first and second interplanetary shocks (mainly due to increases of number density) forced the bow shock to approach the Earth (at 0714 UT on 4 August), and then the magnetopause moved inward once more (at 1025 UT on 4 August). Strongly differing from this coordinated behaviour is the observation of the bow shock in the morning sector of the magnetosphere at 1049 UT on 4 August. Indicated thereby (Dryer, 1973) is a highly-deformed transient bow shock position associated with a flattened magnetopause.

At 2240 UT on 4 August the solar wind pressure reached very high values and compression of magnetosphere was so high that the solar wind was observed for 37 min on Prognoz which was, prior to this time, well inside the magnetosheath (see points 10 and 11 on Figure 6). As seen from Figure 7 this position of the bow shock corresponds to compression of the magnetosphere by a factor of 2. The observations are in good accord with simultaneous data of the plasma spectrometer on Explorer 45 ($S^3$) which registered the magnetosheath plasma at 5.2 $R_E$ (Fritz *et al.*, 1974). This shows that the magnetopause was closer to Earth than 5.2 $R_E$ (shown by the triangle on Figure 7).

In the course of 6–8 August the number density of the solar wind dropped to very low levels (Figure 1). Correspondingly, the magnetopause and bow shock were displaced by 20–30% from their mean positions and rendered significant variations.

Before the arrival of the fourth interplanetary shock at the Earth, the Prognoz-2 satellite was in the solar wind, and Prognoz was inside the magnetosphere. Yet at 0035 UT on 9 August, Prognoz registered at 9.5 $R_E$ the inward motion of magnetopause; subsequently, the satellite was in the magnetosheath for a duration of 50 min (points 24 and 25 on Figure 6). This observation shows the diminution of the magnetosphere by $\sim$30%. Apparently this compression was connected to the second solar wind velocity jump accompanying the shock from the fourth strong flare (see Figure 5).

The positions of the boundaries during 10–12 August were quite remote from the Earth in accordance with the very low number density at this period of time.

Summarizing, it is possible to say that positions of the boundaries during the period under discussion rendered strong variation in satisfactory agreement with observed variations of the solar wind ram pressure. The results of Prognoz, HEOS-2 and Explorer 45 satellites are in good accord.

The part of the inbound orbit of Prognoz from 2317 UT on 4 August to 0358 UT on 5 August draws one's attention (from point 11 to point 12 of Figure 6). Up to point 12, which is very close to the Earth (at 2.3 $R_E$), magnetosheath-type of broad ion spectra were observed. It was not possible to identify the magnetopause position from these data. It is possible to suggest that Prognoz was crossing the dayside polar caps which can be strongly displaced under the influence of solar wind disturbances similar to that found in the strong magnetic storm of 1 November, 1968 in Russel *et al.* (1971).

## 6. Conclusion

Measurements of plasma properties made on near-Earth satellites during the August 1972 events show that the interplanetary medium displayed a complicated structure. Unusual plasma formations and many discontinuities have been observed. Interplanetary plasma parameters varied over a very wide range (number density and ion temperature – more than two orders of magnitude, plasma velocity – not less than by a factor of 5) and sometimes reached extreme values.

Strong, sharp increases in the solar wind plasma parameters, which were connected with arrivals of the interplanetary shocks from the four major flares during 2–7 August, were alternated by periods of slower restoration of the normal level. These events led to many significant consequences in near-Earth space (see McKinnon, 1972; Coffey, 1973). Among these consequences were strong changes of dimensions of the magnetosphere – from compression by a factor of 2 to significant inflation, especially in the morning sector.

## Acknowledgements

The authors are greateful to F. Cambou and C. d'Uston (CESR, Toulouse), H. Rosenbauer and H. Grunwaldt (Max-Planck-Institute, Munich), Sh. Sh. Dolginov and E. G. Eroshenko (IZMIRAN, Moscow), G. Moreno (Laboratorio Plasma Spazio, Rome) for kindly providing their data (often in advance of publication) on magnetic field and plasma measurements during the period under discussion. We would also like to thank our colleagues, especially V. V. Temnyi, and also M. Z. Khokhlov and A. A. Zertzalov for their assistance and useful discussion of the manuscript.

We would like to express our gratitude to M. Dryer for helpful discussion and assistance in evaluating this paper.

## References

Bezrukikh, V. V., Beljashin, A. P. *i dr.*: 1974, *Geomagnetism i Aeronomija* **14**, 399.

Bezrukikh, V. V., Gringauz, K. I., Zastenker, G. N., and Khokhlov, M. Z.: 1975, *Kosmich. Issledov.* **13**, 342.

Binsack, H. M. and Vasyliunas, V. M.: 1968, *J. Geophys. Res.* **73**, 429.

Blokh, G. M., Volodichev, N. N. *i dr.*: 1974, *Geomagnetism i Aeronomija* **14**, 725.

Cambou, F., Vaisberg, O. L., Espagne, H., Temnyi, V. V., d'Uston, C., Zastenker, G. N., Zertzalov, A. A., and Khokhlov, M. Z.: 1975, *Space Res. XV*, 461.

Cattaneo, M. B., Cerulli-Irelli, P., Diodato, L., Egidi, A., Moreno, G., and Hedgecock, P.: 1974, in D. E. Page (ed.), *Correlated Interplanetary and Magnetospheric Observations*, D. Reidel, Dordrecht, Holland, p. 555.

Coffey, H. E. (ed.): 1973, Collected Data Reports on August 1972 Solar-Terrestrial Events, *Report UAG-28*, WDC-A for STP, NOAA, July.

Coletti, A.: 1971, Laboratorio Plasma Spazio Internal Note LPS-71-18.

Dryer, M.: 1973, *Radio Sci.* **8**, 893.

Dryer, M.: 1974, *Space Sci. Rev.* **15**, 403.

Dryer, M., Eviatar, A., Frohlich, A., Jacobs, A., Joseph, J., and Weber, E. J.: 1974, in G. Newkirk (ed.), Coronal Disturbances, *IAU Symp.* **57**, 377.

Dryer, M.: 1975, *Space Sci. Rev.* **17**, 277.

Dryer, M., Smith, Z. K., Unti, T., Mihalov, J. D., Smith, B. F., Wolfe, J. H., Colburn, D. S., and Sonett, Ch. P.: 1975, *J. Geophys. Res.* **80**, 3225.

Fritz, T. A., Smith, P. H., Williams, D. J., Hoffman, R. A., and Cahill, L. J.: 1974, in D. E. Page (ed.), *Correlated Interplanetary and Magnetospheric Observations*, D. Reidel, Dordrecht, Holland, p. 485.

Gringauz, K. I., Zastenker, G. N., and Khokhlov, M. Z.: 1974, *Kosmich. Issledov.* **12**, 899.

Grunwaldt, H.: 1975, Ph.D. Thesis, Max-Planck-Institute.

Lanzerotti, L. J. and Maclennan, C. J.: 1974, in D. E. Page (ed.), *Correlated Interplanetary and Magnetospheric Observations*, D. Reidel, Dordrecht, Holland, p. 587.

McKinnon J. A.: 1972, *August 1972 Solar Activity and Related Geophysical Effects*, Ed. US Dept. of Comm., NOAA, Dec.

Russel, C. T., Chappel, C. R., Montgomery, T. D., Neugebauer, M., and Scarf, F. L.: 1971, *J. Geophys. Res.* **76**, 6743.

Report ESRO, XVI COSPAR Meeting, Konstanz, Germany, 1973.

Temnyi, V. V., Zertzalov, A. A., Vaisberg, O. L., and Berezin, Yu. E.: 1974, *Kosmich. Issledov.* **12**, 74.

Vaisberg, O. L., Polenov, B. V., and Khasanov, B. I.: 1971, in *Jadernoe priborostroenie*, No. 14, Atomisdat, Moscow, p. 97.

Vaisberg, O. L., Zertzalov, A. A., Temnyi, V. V., and Berezin, Yu. E.: 1974, *Kosmich. Issledov.* **12**, 80.

Waard, J., Kooter, C. J., and Summerhill, S.: 1970, ESRO TN-104 (ESTEC).

Zastenker, G. N., Vaisberg, O. L., Cambou, F., Temnyi, V. V., and Khokhlov, M. Z.: 1976, *Space Res. XVI* (in press).

Zurina, L. S., Oldecop, L. G., Polenov, B. V., and Khasanov, B. I.: 1971, *Pribori i tekhnika experimenta* **2**, 46.