Cosmic Research, Vol. 36, No. 1, 1998, pp. 93–102. Translated from Kosmicheskie Issledovaniya, Vol. 36, No. 1, 1998, pp. 98–107.

The DOK-2 Experiment to Study Energetic Particles by the *Tail Probe* and *Auroral Probe* Satellites in the INTERBALL Project

V. N. Lutsenko*, K. Kudela, and E. T. Sarris*****

**Space Research Institute, Russian Academy of Sciences, Profsoyuznaya 84/32, Moscow, 117810 Russia*

***Institute of the Experimental Physics, SAN, Košice, Slovakia*

****The Demokritos University, Xanthi, Greece*

Received July 10, 1997

Abstract—The instrumentation and technique of the DOK-2 experiments for studying energetic particles in the Earth's magnetosphere are briefly described. The experiments are carried out onboard the *Tail Probe* and *Auroral Probe* as a part of the INTERBALL project. A large body of data on the characteristics of energetic electrons (27–400 keV) and protons (20–800 keV) within various parts of the magnetosphere have been obtained since the beginning of the experiment. Due to the high energy and time resolution of the DOK-2 equipment, effects never observed before have been discovered, for example, monoenergetic proton beams. Examples of the data obtained in the course of the experiment in the magnetotail, magnetosheath, and upstream of the bow shock are given.

INTRODUCTION

Particles with energies of tens and hundreds of keV, which represent the suprathermal part of the magnetospheric plasma, are produced as a result of particle acceleration within various parts of the magnetosphere and play a significant role in the dynamics of magnetospheric processes. A study of these particles is an obligatory part of all satellite programs to study the near-Earth space. The INTERBALL project provides a unique opportunity to study the physical processes in the terrestrial magnetosphere and at its boundaries due to the launch of a group of spacecraft: two principal satellites (the *Tail Probe* and *Auroral Probe*) and a sub-satellite of the *Tail Probe*, the *MAGION-4*. The *Tail Probe* was launched on August 3, 1995, to an orbit with an apogee of 200000 km, a period of 4 days, and an inclination of 62.8°. The *Auroral Probe* was launched on August 29, 1996, and had the same inclination, an apogee of 20000 km, and a period of 6 h. The *Tail Probe* crosses the magnetotail during three months every year and makes it possible to study the processes in the plasma and neutral sheets of the tail and in its northern lobe. During the rest of time, the *Tail Probe* can study the processes at the magnetospheric boundaries: at the magnetopause, in the magnetosheath, and at the bow shock. The *Auroral Probe* makes measurements over the northern polar cap and auroral zone possible, which are both topologically related to the tail. Two DOK-2 experiments on the exploration of energetic particles at both probes and a reduced version (DOK-2C) at the sub-satellite were planned. These experiments are aimed at studying energetic ions and electrons in an energy range from about 20 to 400–800 keV. This is the most important range for studying active processes in the magnetotail and at the magnetosphere boundaries, in particular, the particle acceleration processes. There have already been some publications where the DOK-2 data are analyzed jointly with the data of other experiments of the INTERBALL project [1–6]; however, so far, there have been no publications specially dedicated to the DOK-2 experiment.

The main parameters of the equipment, the measurement technique, and the experiment status as of June 1997 are described below. Without aiming at a detailed analysis and interpretation of specific results of the measurements, we present below some examples of the data on energetic particles, which have been measured in various parts of the magnetosphere, and demonstrate the opportunities for its study opened up by the DOK-2 experiments within the INTERBALL project.

THE DOK-2 SPECTROMETER

Two pairs of telescopes for energetic particles with passively cooled and completely biased surface-barrier silicon detectors are used in the DOK-2 spectrometers. The cooling of the detectors and charge-sensitive pre-amplifiers down to −10 ... –20°C makes it possible to reduce their noise levels and increase the energy resolution. One telescope (1*e*, 2*e*) in each pair has in front of its 0.3 mm thick detector a foil, which absorbs protons with the energy of $E < 400$ keV; thus, the telescope measures the electron spectrum in the range of 27–400 keV. The second telescope (1*p*, 2*p*) in each

Particle energy values for the *TP*-parameters in keV

Telescope	*Tail Probe*			*Auroral Probe*		
	*TP*1	*TP*2	*TP*3	*TP*1	*TP*2	*TP*3
1*e*	28–32	44–53	79–98	26–29	39–46	71–89
2*e*	27–31	42–51	76–95	25–28	38–45	68–85
1*p*	22–29	47–61	102–133	18–24	39–50	84–109
2*p*	21–28	46–60	102–133	20–26	43–57	98–129

pair has a magnet in front of its detector 0.15 mm thick. The magnet deflects electrons with the energy of $E < 1500$ keV, and the telescope measures the energy spectrum of all ions (actually protons) in the range of 20–800 keV. The complete angular apertures and geometric factors of the electron and proton telescopes are 27° and 12.5°, and 0.066 and 0.015 cm^2 sr, respectively. The particle flux angular distribution is measured in some operation modes using the spacecraft rotation, with a period of 2 min around the axis directed to the Sun (the φ angle), and mechanical scanning of the second pair of the telescopes in the plane containing the satellite rotation axis (the angle $\theta = 45°–180°$). In this way, the three-dimensional distribution function of the particles is measured during every two-minute rotation period. In the main (monitoring) operational mode, the second pair of telescopes is in a fixed position, which makes it possible to obtain more restricted information on the particle angular distribution.

The analog electronics for each detector consists of a charge-sensitive pre-amplifier, a pulse-shaping amplifier, and a logarithmic amplitude-digital converter with 56–57 channels (amplitude analyzer). The pulse amplitude is proportional to the particle energy release in the detector. The basis for the generation of the output information is "elementary measurement" (EM): one complete 56–57-channel spectrum per second for each of the four detectors. These data may be obtained only in the direct transmission mode (DT) of the DOK-2 instrument. Because of the limited capacity of the onboard memory unit (MU), in the modes with data storage, two complementary types of output information are formed from the EMs:

(1) Full spectra, accumulated over the time from 1 to 1464 s, depending on the particle flux intensity.

(2) Three parameters of the time profiles (*TP*) for each detector. The parameters are the number of pulses in three narrow energy intervals accumulated during the time from 1 to 260 s. This time is determined by a special algorithm, which provides information compression by a factor of 10–100, conserving the ability to record statistically significant one-second variations of the flux. The energy values for the *TP* parameters are shown in the table. In the monitoring mode, the *TP*s are measured with a variable temporal step. In the fast and DT modes, a constant step of 1 s is used. The change from the monitoring to fast modes and back is done automatically, depending on the characteristics of the particle flux measured.

The DOK-2C device, a reduced version of the DOK-2, is installed onboard the subsatellite. Its detector scheme is similar to that of DOK-2, except for the ability to scan. The amplitude analyzers have eight channels in the same energy range as in DOK-2. The device data are transmitted in the DT mode by a separate telemetry system (STO) with a time step of 0.4 s. This information is received in the Czech Republic.

The complete description of the DOK-2 equipment is presented in [7]. We note only that the main advantage and difference of this instrument from the devices used before is its ability to measure electron and proton spectra with high energy and time resolution.

THE BEGINNING OF OPERATION AND STATUS OF THE DOK-2 EXPERIMENT

The DOK-2 spectrometer at the *Tail Probe* was switched on 5 h after the satellite launch, and it has been operating continuously since that time (October 1997), being switched off only for 2–4 h within the radiation belts once in every revolution period of the satellite (equal to four days). After intense use of the mechanical scanning during the first three months of operation, the telescopes of the second group have been fixed since November 1, 1995, at an angle of 62° to the satellite axis X directed to the Sun. The noise level of the detectors was low during the entire period and provided high energy resolution of 5–6 keV and 7–9 keV for the detectors of the electron and proton telescopes, respectively.

The DOK-2 spectrometer on the *Auroral Probe* was also switched on 5 h after the satellite launch on August 29, 1996. The device testing was carried out on September 3, 1996, and regular operation started on September 15, 1996, continuing up to the present time. The DOK-2 quota in the onboard MU of the telemetry system (about 10 Mbit) makes it possible to conduct continuous measurements during about half of the two-day operation cycle. After the use of the scanning operation mode during the initial period, the second group of telescopes were oriented at an angle of 79° to the satellite axis X. As in the case of the *Tail Probe*, the noise level for all four detectors was 5–8 keV.

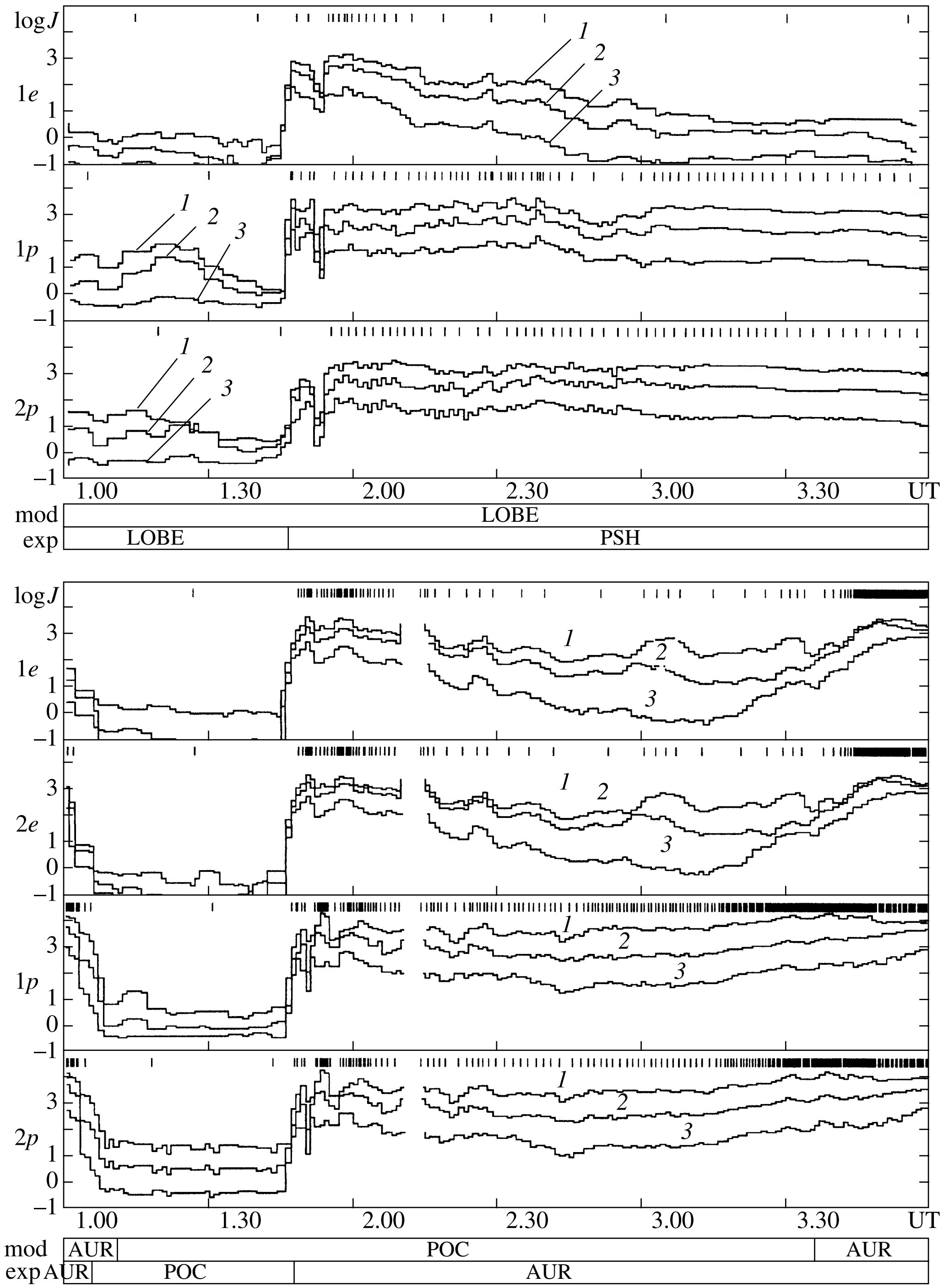

Fig. 1. An example of the substorm onset at 01:46 UT on December 11, 1996, recorded simultaneously at the *Tail Probe* (top) and *Auroral Probe* (bottom). The temporal behavior of the *TP*-parameters for DOK-2 (1 min averages) is presented. The telescopes are denoted on the left-hand side of each panel; the numerals at the curves correspond to the *TP*-parameters. The vertical dashes at the top edge of each panel mark the time of the end of the corresponding spectrum measurement. Below the DOK-2 data, the region identifications according to the model (mod) and the plasma experiment data (exp) are indicated.

The preliminary processing of the telemetry information for the DOK-2 experiments is carried out in the Space Research Institute (SRI) of Russian Academy of Sciences. The physical analysis is being performed jointly by the SRI, the Institute of Experimental Physics (IEP) of the Slovakian Academy of Sciences, and the Demokritos University (Xanthi, Greece).

The DOK-2C instrumentation on board the *MAGION-4* sub-satellite also operated normally. The processing of the information is being carried out in the IEP (Košice, Slovakia).

SIMULTANEOUS MEASUREMENTS ONBOARD THE *TAIL PROBE* AND *AURORAL PROBE* DURING THE ONSET OF THE GEOMAGNETIC SUBSTORM OF DECEMBER 11, 1996

The opportunity to conduct simultaneous measurements with similar equipment both in the magnetotail at distances up to 20–27 R_E (R_E is the Earth's radius) and in the polar cap or auroral zone at distances of about 3 R_E is one of the important features of the INTERBALL project.

Such an opportunity arose for the first time in November 1996–January 1997, when the *Tail Probe* spent a long period in the magnetotail at distances of 10–27 R_E. The period of December 10–13, 1996, was characterized by increased magnetospheric activity. At 01:00 UT on December 11, 1996, the *Tail Probe* was at the point with the coordinates $X_{GSM} = -26.63$, $Y_{GSM} = 7.83$, $Z_{GSM} = 3.03$ (in the R_E units), ILAT = 74.4°, and MLT = 17.0 h, the values corresponding to the northern lobe of the tail. Here and below, the coordinates and physical region boundaries calculated by V.I. Prokhorenko with the use of the Tsyganenko model [8] are used. The following designations of the physical regions are used in the figures: LOBE is the tail lobe, PSH is the plasma sheet of the tail, AUR is the auroral zone, and POC is the polar cap. The distance to the neutral sheet was 6.22 R_E, and the plasma sheet thickness was 3.57 R_E. The *Auroral Probe* was over the polar cap in the point with the coordinates $X_{GSM} = -2.26$, $Y_{GSM} = 0.58$, $Z_{GSM} = 2.41$, ILAT = 80.47°, MLT = 21.0 h. Here, ILAT is the invariant geomagnetic latitude, and MLT is the local geomagnetic time of the base of the geomagnetic field line where the spacecraft is located. According to the Tsyganenko model, there was no direct magnetic connection between both satellites.

Figure 1 shows the *TP*s of the DOK-2 instruments onboard the *Tail Probe* and *Auroral Probe* from 01:00 UT to 04:00 UT on December 11, 1996. Here and below, the intensity J is expressed in (s cm^2 sr keV)$^{-1}$ units. A sharp increase in proton and electron fluxes occurred at 01:46 UT simultaneously (within several seconds) at both probes. The similarity of the electron flux temporal profiles demonstrate that this is no random coincidence. According to the ELECTRON, PROMICS, and CORALL (*Tail Probe*), and ION (*Auroral Probe*) devices, plasma fluxes typical for the tail plasma sheet and auroral zone appear at the same time at both satellites.

Figure 1 shows the boundaries of the physical regions according to the model (mod) and the above plasma experiments (exp). The images of the auroral oval in the UV range obtained during the same time onboard the *POLAR* satellite [9] show the increased luminosity of the nightside auroral zone, its splitting, and the shift in the direction of the magnetic pole. The measurements of the interplanetary magnetic field onboard the *WIND* spacecraft [9] at a distance of 74.5 R_E upstream from the solar wind show that the B_z-component changed its sign at 01:30 UT and took a stable positive value. This change of sign should have reached the Earth 12.5 min later ($V_x = 630$ km/s), that is, at 01:43 UT, immediately prior to the onset of the event recorded at both INTERBALL satellites.

It is known that positive B_z leads to the reconnection of the field lines of the interplanetary magnetic field and the magnetic field at the tail poleward boundary, and to their shift downstream. The tail "erosion" should lead to an expansion of the plasma sheet and to a shift of its boundary and the boundary of the conjugated part of the auroral zone. Apparently, we observed this very phenomenon on December 11, 1996. The detailed analysis of these data is still in progress.

THE PITCH-ANGLE DISTRIBUTIONS OF ENERGETIC PARTICLES IN THE TAIL PLASMA SHEET: THE DIFFERENCE IN THE ELECTRON AND PROTON DISTRIBUTIONS

It has been mentioned above that DOK-2 makes it possible to obtain angular and pitch-angle distributions using the satellite rotation with a period of 2 min around the X axis and scanning of the second group of the telescopes (2e, 2p) in the plane containing this axis. When there is no scanning, these telescopes are directed at the angle of 62° (45° during the first months of the flight) and also make it possible to obtain information on the pitch-angle distributions, except for cases when the magnetic field direction coincides with the X axis. An example of such information is shown in Fig. 2. The measurements were conducted at 19:00–19:30 UT on January 16, 1996, in the plasma sheet of the magnetotail. The *Tail Probe* was at the point with the GSM coordinates $X = -8.89$, $Y = 9.73$, and $Z = -0.77$. According to the Tsyganenko model, this point is located at the flank of the plasma sheet in the vicinity of the neutral sheet. The top panel of Fig. 2 shows the *TP*-parameters of the 2p and 2e telescopes ($\theta = 62°$). The middle panel shows the pitch-angle variations, and the bottom panel shows three components of the magnetic field in the GSM system. The magnetic field changed slightly from 19:00 UT to 19:23 UT. After that moment, strong variations of the B_x and B_y components began, B_x crossing the zero line.

Three features in the particle angular distribution may be noted.

1. Whereas the *TP*-parameters for the proton telescope are very weakly (if at all) modulated by the satellite rotation, there is a deep (up to 200 times) spin modulation for electrons.

2. The modulation is well pronounced for the high-energy particles (76–95 keV), less pronounced for the

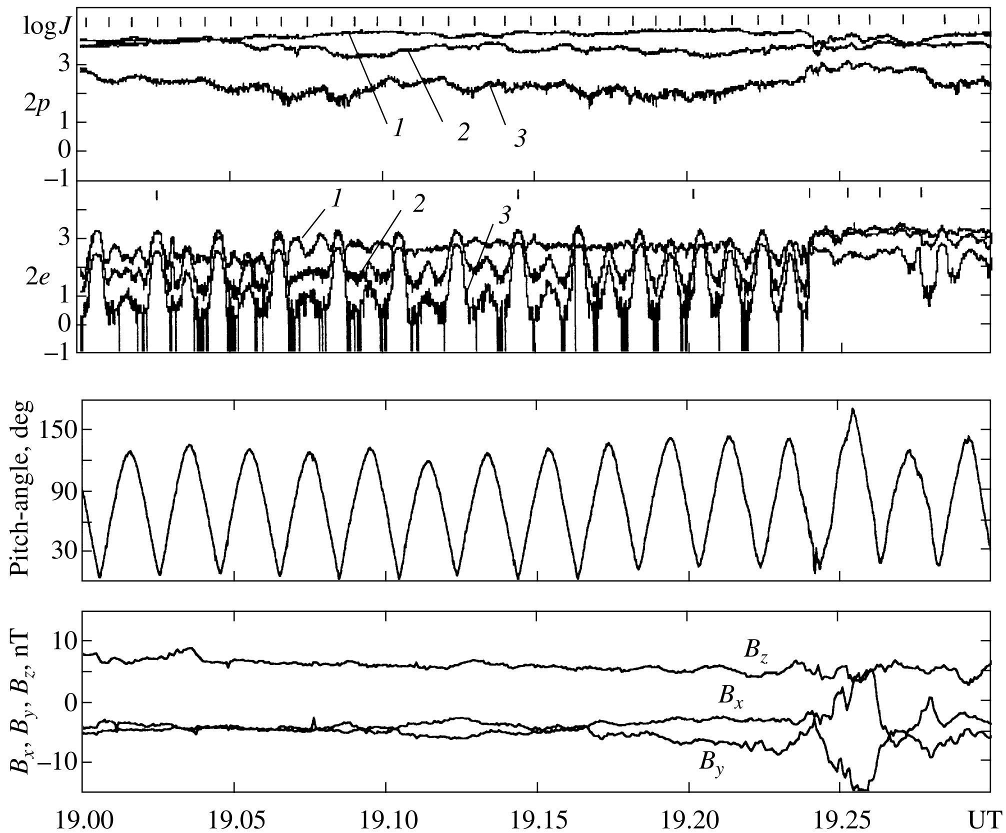

Fig. 2. Differences in spin-modulation of protons and electrons with different energies in the plasma sheet of the magnetospheric tail on January 16, 1996 (the *Tail Probe*, $X_{GSM} = -8.89$, $Y_{GSM} = 9.73$, $Z_{GSM} = -0.77\ R_E$). On the top, the *TP*-parameters of the 2*e* and 2*p* (θ = 62°) telescopes are shown. As in Fig. 1, the numerals *1*, *2*, and *3* denote the *TP*-parameters. The particle pitch-angle variations are shown in the middle. Three geomagnetic field components (GSM) are shown at the bottom.

moderate-energy particles (42–51 keV), and very weak for the low-energy particles (27–31 keV).

3. The main maximum of the electron flux is regularly observed at pitch angles close to 0°. A maximum that is lower in magnitude exists under pitch angles of about 135°–150°. This second maximum is gradually growing, reaching the main one at 19:20 UT.

Evidently, there is a two-direction flux of high-energy electrons, that is, constant along the magnetic field and gradually growing opposite to the field. The lower the energy, the more isotropic the electron flux.

OBSERVATION OF THE SPATIAL DISPERSION IN THE ELECTRON AND PROTON SPECTRA AT THE AURORAL ZONE BOUNDARY

The high energy and time resolution of the DOK-2 made it possible to detect and study fairly fine dispersion effects in the electron and proton spectra observed under the transition from the polar cap to the auroral zone (during the inbound leg of the orbit in the morning sector of the magnetic local time (MLT)). These effects are smooth continuous shifts of some details in the spectra (peaks and "waves") toward lower energies.

Figures 3–6 show examples of the DOK-2 data obtained (*Auroral Probe*) at 10:20–14:20 UT on October 6, 1996, in the polar cap and auroral zone. In the middle of this interval, the *Auroral Probe* was at the point with coordinates $X_{GSM} = 0.34$, $Y_{GSM} = -1.42$, $Z_{GSM} = 3.74$, ILAT = 79.4°, MLT = 7.1 h. Figure 3 shows the *TP*-parameters during 3 h. The strong modulation of the *TP*-parameters for the 2*p* telescope with the period of 2 min in the 11:00–12:10 UT interval is accounted for by the detection of light reflected from the Earth. The positions of the physical regions according to the model are shown at the bottom. As in Fig. 1, the vertical dashes at the top edge of each panel indicate the end of the spectrum measurement interval. Figure 4 shows the sequences of the spectra for the electron telescopes. The corresponding time intervals are marked in Fig. 3 by the black bars. The characteristic "waves" of maxima and minima are smoothly shifted in the direction of lower energies. The proton spectra (see Fig. 5) are even more interesting in character, having two narrow ($\Delta E/E \sim 25\%$) peaks

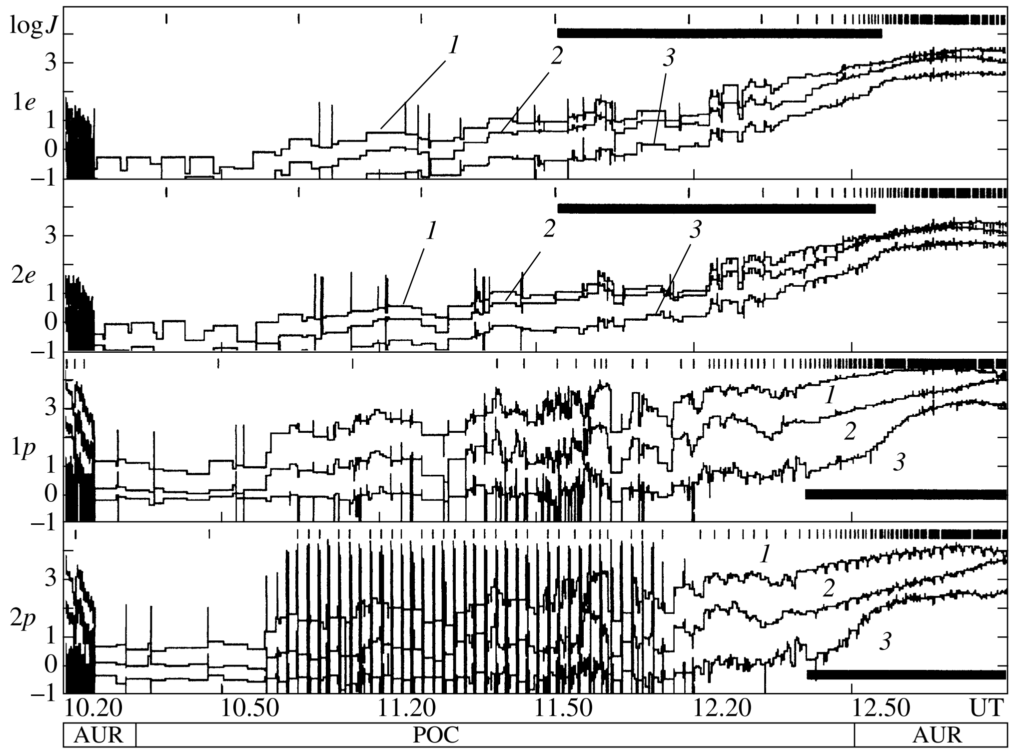

Fig. 3. The temporal variations of the electron and proton fluxes during the *Auroral Probe* crossing of the polar cap and auroral zone at 10:20–13:50 UT on October 6, 1996. Black stripes indicate the time intervals that correspond to the spectrum sequences shown in Figs. 4 and 6. The short periodical (T = 2 min) increases of the count rate of the 2p telescope from 11:00 to 12:10 UT are caused by the detection of light reflected by the Earth. The model boundaries of the physical regions are indicated at the bottom.

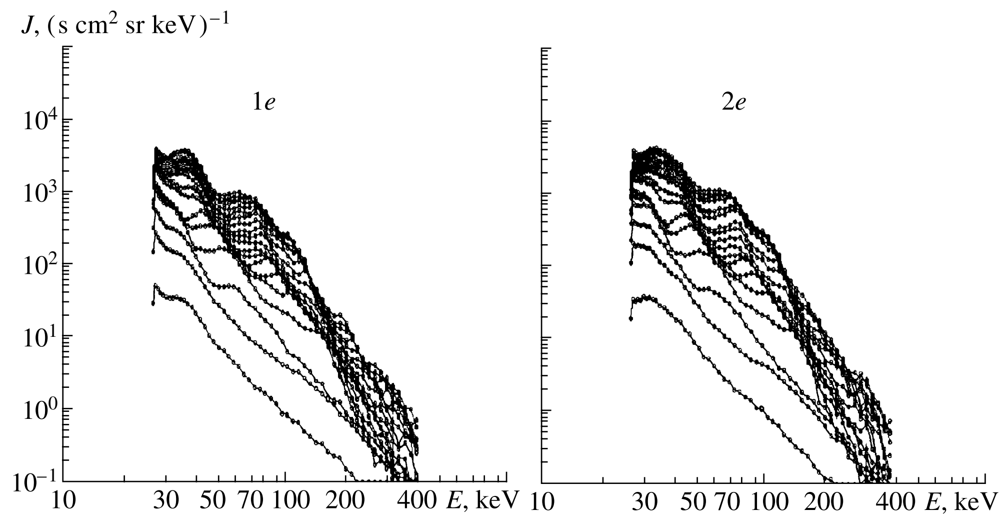

Fig. 4. Sequences of 20 electron spectra during the *Auroral Probe* passage from the polar cap to the auroral zone at about 12:19 UT on October 6, 1996. The corresponding time intervals are marked by black stripe in Fig. 3.

with the energies of E and $2E$ above the background of the smooth power spectrum. The E value decreases gradually from about 190 to about 90 keV (Fig. 6). The entire process takes about 20 minutes both for the protons and electrons, which evidently testifies to a spatial nature of the dispersion. The example shown of the energetic particle dispersion is not the only one. Analysis and interpretation of the above spectra are in progress.

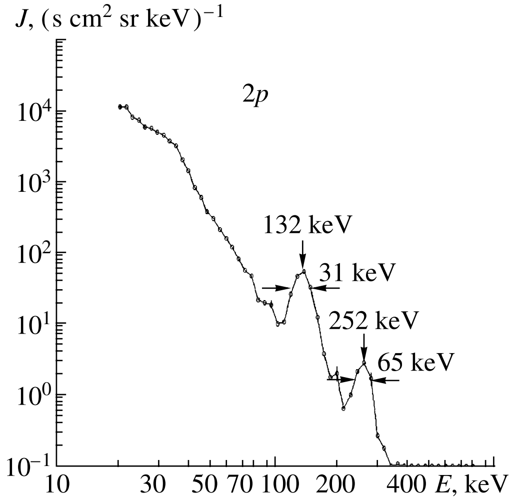

Fig. 5. The proton spectrum with narrow lines at the polar cap–auroral zone boundary at 12:49 UT on October 6, 1996 (*Auroral Probe*).

NEW DATA FOR THE MAGNETOSHEATH: PEAKS AT HIGH ENERGIES IN THE PROTON SPECTRA

The DOK-2 measurements have shown that the energy spectra of protons in the magnetosheath have a power law form with variations related to magnetic field fluctuations. However, sometimes at the flanks of the magnetosheath, during several minutes, we observed spectra that, besides the power law continuum, contained a high-energy peak (100–400 keV and higher). This was always observed for the $2p$ telescope ($\theta = 62°$) and never for the $1p$ ($\theta = 180°$) telescope. In the top panel of Fig. 7, the *TP*-parameters for an event occurring in the magnetosheath at 05:50 UT on July 10, 1995, are shown. The *Tail Probe* was at that moment located at the point with coordinates $X_{GSE} = 6.48$, $Y_{GSE} = -14.75$ ($Y_{GSM} = -13.88$), and $Z_{GSE} = -0.27$ ($Z_{GSM} = 5.01$). According to the model, this point corresponds to the magnetosheath. The variations of the relative distance between the lines of three *TP*-parameters suggest strong variations of the spectrum slope in the 20–130 keV range; however, they do not provide information on the entire spectrum. Below in Fig. 7, the proton spectrum of the $1p$ telescope obtained for the whole interval and four sequential spectra of the $2p$ telescope are shown. The numerals and dashes in the top figure indicate the time interval of these spectra measurements. The power law component of the spectra has in the beginning an unusually low value of the power exponent ($\gamma = -2.17$). The maximum of the peak, which appears in the $2p$-spectrum beginning from No. 1, shifts from about 240 to about 700 keV. Analysis of the *TP*-parameters shows that the peak appeared even earlier, at about 05:49.40 UT in the 100–130 keV range. The process duration was about 4 min. The interplanetary magnetic field data [9] (the *IMP-8*, *GEOTAIL*, and *WIND* spacecraft) show that a sharp turn of the field vector occurred at 05:46 UT, and the B_z component, which before that had a value of about –4 nT, came close to zero. The most probable cause of the occurrence of the high-energy peaks is particle leakage from the magnetosphere under some kind of special conditions occurring as a result of the change of the interplanetary field direction.

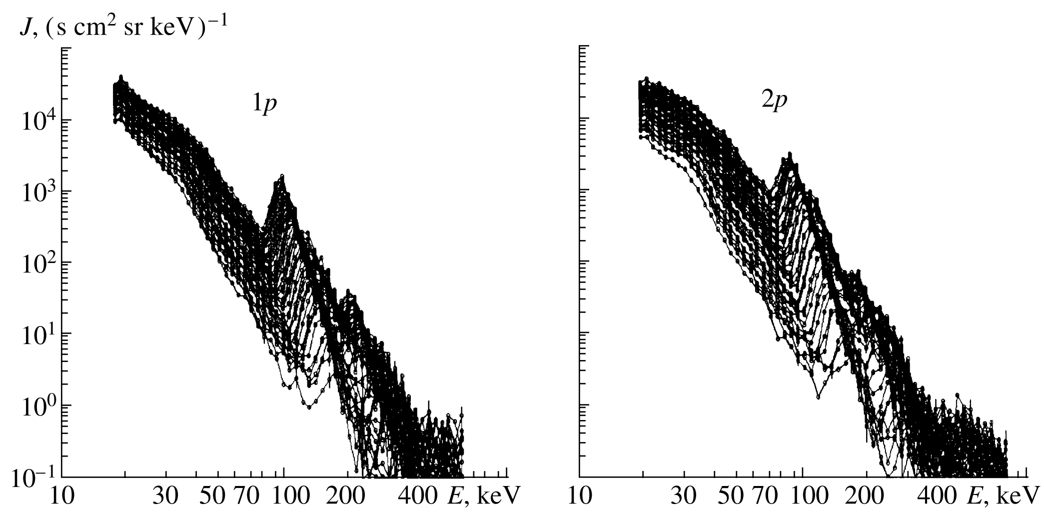

Fig. 6. Sequences of 60 proton spectra, one of which is presented in Fig. 5, at the *Auroral Probe* passage from the polar cap to the auroral zone at about 13:00 UT on October 6, 1996. The smooth shift of the peaks toward lower energies is clearly seen. The corresponding time intervals are marked by black stripes in Fig. 3.

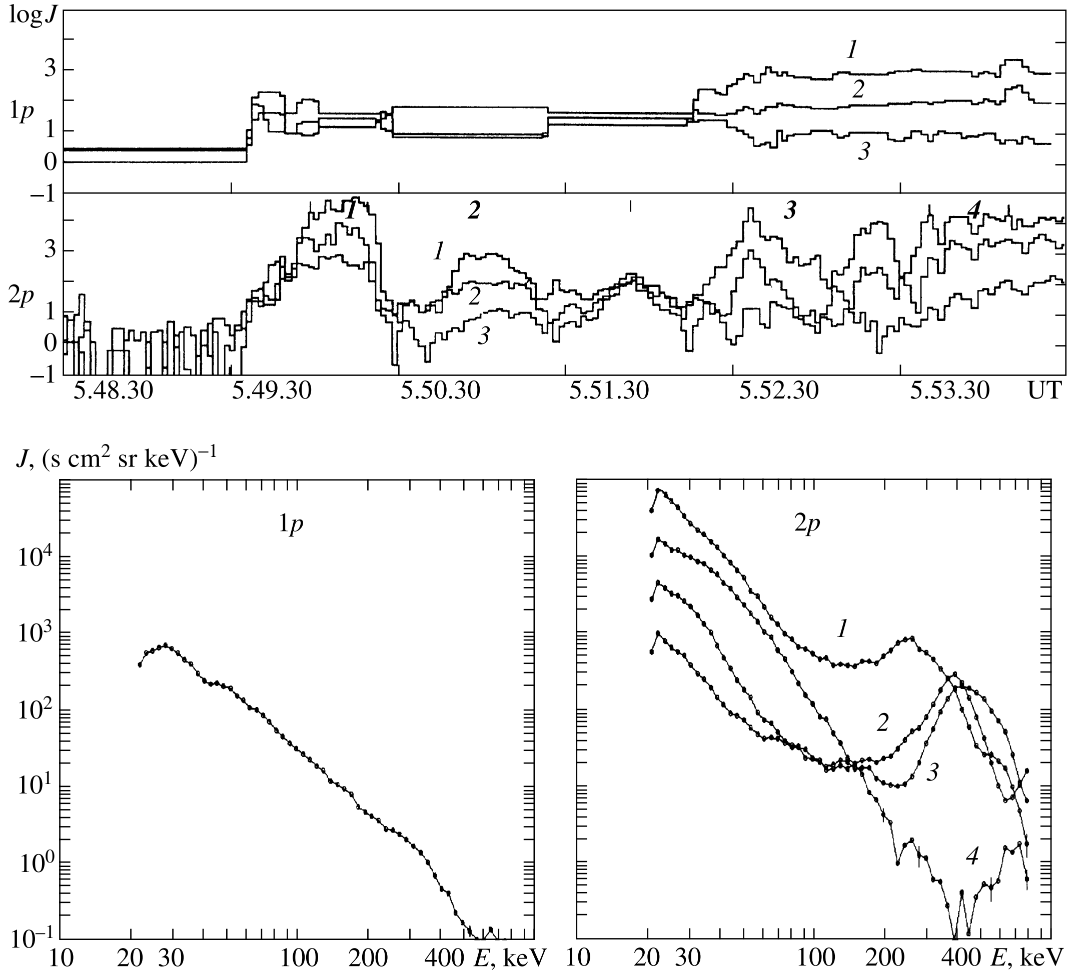

Fig. 7. The peaks of high-energy protons in the magnetosheath at 05:50 UT on August 10, 1995 (*Tail Probe*). The temporal variations of the proton telescope parameters are shown on the top. The 1*p* telescope spectrum for the entire time interval is shown at the bottom on the left-hand side. The sequence of the 2*p* telescope spectra is shown on the right-hand side. The spectrum numbers correspond to the numbers of the time intervals denoted by numerals in the top panel.

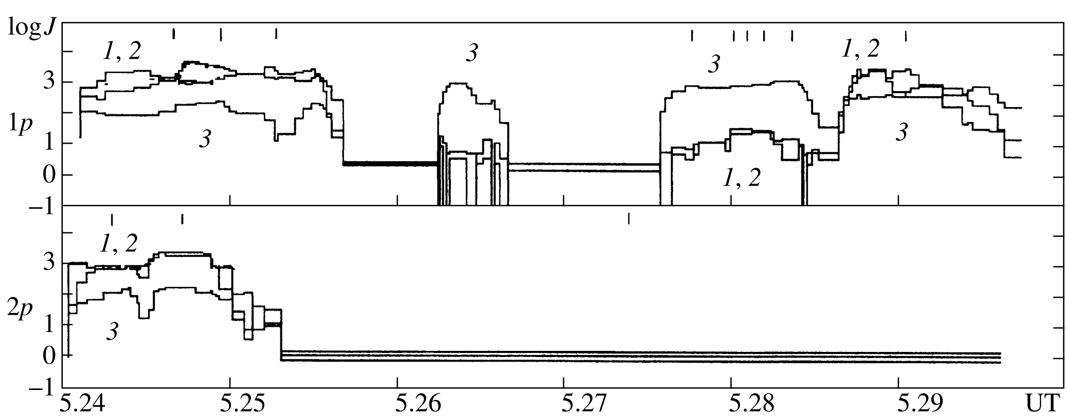

Fig. 8. The temporal variations in the proton intensities in the interplanetary space in front of the bow shock at 05:24–05:30 UT on April 20, 1996. Seen in the middle are two time intervals of about 20 and 60 seconds' duration, where the intensity of the high-energy parameter *TP*3 exceeds the intensities of *TP*1 and *TP*2 parameters by more than two orders of magnitude.

NEW DATA IN THE REGION IN FRONT OF THE BOW SHOCK. MONOENERGETIC PROTON BEAMS

The region in front of the Earth's bow shock is another region where unusual spectra with peaks were observed. Figures 8–10 show two examples of such spectra (this time, for the 1*p* telescope).

The first event took place at 05:28 UT on April 20, 1996. The *Tail Probe* was at the point with the GSE coordinates $X = 18.37$, $Y = 12.60$, $Z = -0.80$. Figure 8 shows the *TP*-parameters for the proton telescopes. One can see from Fig. 8 that, in the time intervals 05:26.16–05:26.41 UT and 05:27.35–05:28.29 UT, the intensity of the high energy parameter *TP*3 exceeds the *TP*1 and *TP*2 intensities by more than two orders of magnitude. The total spectrum of the 1*p* detector is shown in Fig. 9. The very intense and narrow peak with $E_{max} = 94.5$ keV and the full width at half-maximum (FWHM) of 21.8 keV dominates in the spectrum. The proper FWHM of the proton peak is 20.3 keV, if the detector resolution equal to 8 keV is subtracted. Four such peaks with a stable maximum position were observed during about 20 seconds.

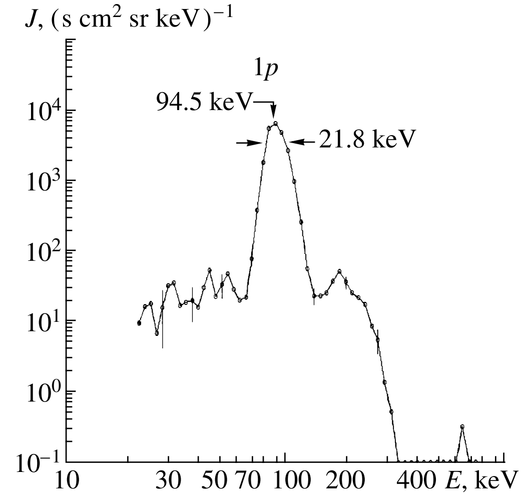

Fig. 9. The narrow intense line with $E_{max} = 94.5$ keV and the FWHM of 21.8 keV dominating in the proton spectrum of the 1*p* telescope at 05:28.06 UT on April 20, 1996 (*Tail Probe*).

Figure 10 shows the second example, the event at 15:00 UT on April 23, 1996, when the spacecraft was at the point with the GSE coordinates $X = 23.10$, $Y = 13.15$, and $Z = 2.55$. The peak with $E_{max} = 38.5$ keV and the FWHM of 9.4 keV dominates in the spectrum of the 1*p* detector. Four similar spectra with E_{max} changing from 40.2 to 35.5 keV were observed during 28 s. The energy resolution of the 1*p* detector was at that time 8.14 keV. This means that the proper FWHM of the proton peak did not exceed 4.7 keV, that is, we have an almost monoenergetic line.

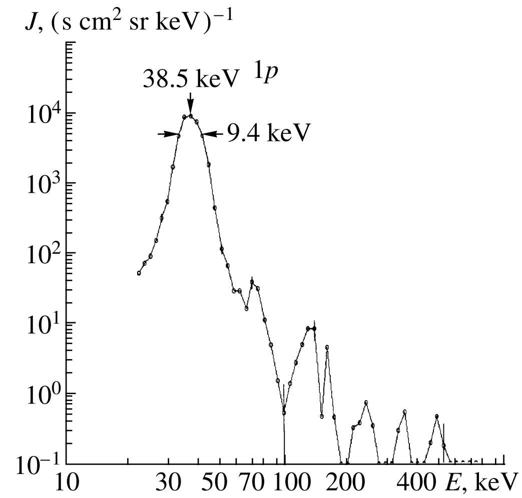

Fig. 10. Monoenergetic protons in front of the bow shock at 15:00.05 UT on April 23, 1996 (*Tail Probe*).

In both cases, the spectra of the 2*p* detector showed a low intensity and the absence of peaks. This demonstrates that the protons are coming from the bow shock. The onboard magnetometer data show that the spacecraft might have had a magnetic connection with the bow shock. One can see from Figs. 9 and 10 that the proton flux was very intense and reached 10^4 (cm^2 s sr keV)$^{-1}$. The energy flux corresponding to the spectrum in Fig. 10 is 1.4×10^7 keV cm^{-2} s^{-1}, a value that is comparable with the solar wind energy flux. The energy density was 0.4 keV cm^{-3}. It van be mentioned that the magnetic field energy density at that time was only 0.09 keV cm^{-3}. The electron fluxes were negligible in both cases.

Three possible sources of energetic protons in front of the Earth's bow shock have been discussed in the literature: acceleration under the gradient drift at a quasi-perpendicular shock [10], Fermi acceleration in front of a quasi-parallel shock [11], and leakage from the magnetosphere [12] (also for a quasi-parallel shock). None of these mechanisms can account for such high intensity and the monoenergetic character of the proton beam. Evidently, this problem requires further study.

CONCLUSION

The DOK-2 experiments at the INTERBALL 1 and 2 spacecraft are still continuing successfully. A lot of data on various parts of the terrestrial magnetosphere have already been obtained. Because of the high energy and time resolution of the DOK-2 equipment, new facts concerning energetic particles in the magnetospheric plasma are being revealed and will need further study and explanation.

ACKNOWLEDGMENTS

We thank the staff of the magnetic measurement group for the magnetic field data and V.I. Prokhorenko for the calculations of orbits and physical region boundaries. The work was supported by INTAS (project nos. 93-2031 and 96-2346) and the Slovakian Academy of Sciences (grant no. 1353).

REFERENCES

1. Sandahl, I., Lundin, R., Yamauchi, M., *et al.*, Cusp and Boundary Layer Observations by Interball (Report at COSPAR, 1996), *Adv. Space Res.* (in press).
2. Savin, S.P., Borodkova, N.L., Budnik, E.Yu., *et al.*, Interball Case Magnetotail Study, COSPAR, 1996.
3. Sandahl, I., Pulkkinen, T., Budnik, E.Yu., *et al.*, Interball Substorm Observations: Christmas for Space Scientists, in *Proc. 3rd Int. Conf. on Substorms, Versailles, France, May 13–17*, 1996.
4. Savin, S.P., Borodkova, N.L., Budnik, E.Yu., *et al.*, First Interball Results in Magnetotail Boundary Study, in *XXVth General Assembly of URSI, Lille, France, August 28–September 5,* 1996.
5. Lutsenko, V.N., Kudela, K., and Sarris, E.T., Electron and Ion Spectra Shape in the Geotail Plasma Sheet, in *Chapman Conference on "The Earth's Magnetotail: New Perspectives," Kanazawa, Japan, November 5–9,* 1996.
6. Taktakishvili, A.L., Zelenyi, L.M., Lutsenko, V.N., and Kudela, K., On the Spectra of Energetic Particles in the Earth's Magnetotail, *Kosm. Issled.* (in press).
7. Lutsenko, V.N., Rojko, J., Kudela, K., *et al.*, Energetic Particle Experiment DOK-2 (INTERBALL Project), in *INTERBALL: Mission and Payload*, RSA-IKI-CNES, 1995, p. 249.
8. Tsyganenko, N.A., Global Quantitative Models of the Geomagnetic Field in the Cislunar Magnetosphere for Different Disturbance Levels, *Planet. Space Sci.,* 1987, vol. 35, pp. 1347–1358.
9. CDA Web, ISTP Key Parameters.
10. Decker, R.B., Computer Modeling of Test Particle Acceleration at Oblique Shocks, *Space Sci. Rev.*, 1988, vol. 48, pp. 195–262.
11. Lee, M.A., Coupled Hydrodynamic Wave Excitation and Ion Acceleration Upstream of the Earth's Bow Shock, *J. Geophys. Res.*, 1982, vol. 87, p. 5063.
12. Kudela, K., Sibeck, D.G., Belian, R.D., *et al.*, Possible Leakage of Energetic Particles from the Magnetosphere into the Upstream Region on June 7, 1985, *J. Geophys. Res.*, 1990, vol. 95, pp. 20825–20832.