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DISPERSION STRUCTURES IN THE ENERGETIC ION AND ELECTRON SPECTRA IN THE AURORAL REGIONS: THEIR NATURE, PROPERTIES AND IMPLICATION.

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ABSTRACT

In DOK-2 experiments onboard Interball 1,2 (Lutsenko at al., 1998) we observed ~200 dispersion structures in energetic ion and electron spectra in the auroral zones of the Earth's magnetosphere at ILAT=67-74° (L=6.5-13.2). Some detailed analysis results for ~ 40 of these dispersion events are given. Their main characteristics show that we have deal with particles, which were injected momentary onto closed magnetic field lines from the plasma sheet and experienced a gradient-curvature drift. In some cases we observed ions from one injection making several turns around the Earth, which allowed us to find accurate values of drift periods in the real magnetic field. Due to high energy and time resolutions of DOK-2 the dispersion structure analysis may give a drift start time T_o with an accuracy of tens of seconds and an estimation of the acceleration process duration which was ~1 min. The time T_o was compared with the time history of UVI brightening in the auroral oval. The comparison can help to determine the moment of a large-scale particle acceleration in the chain of events accompanying substorm development. For several substorms source energetic particle spectra were reconstructed from our dispersion event data.

NEW RESULTS OF DISPERSION EVENT DATA ANALYSIS

Dispersion effects in energetic particle fluxes were already subjects of study in several experiments on the geostationary orbit (Belian, et al., 1984, Birn at al., 1996), in the cusp vicinity (Karra and Fritz, 1999) and by simulation (Lin at al., 1998). They were particle intensity increases arising first in higher energy channels and then in lower ones. Due to much higher energy resolution of the DOK-2 instruments (56 logarithmically spaced energy channels in 20-800 keV range) these structures look like narrow peaks in energy spectra (relative FWHM ~20%) moving gradually to low energies. Examples of the dispersion events studied in the DOK-2 experiment and their interpretation as a result of a gradient-curvature drift were already published elsewhere (Lutsenko at al., 2000). Figure 1 presents one more example of spectrograms for one simple event on June 28, 1997 02:10-02:40 UT (Auroral Probe). The field line foot for the spacecraft position had coordinates fLAT=64.94-61.64° (ILAT=70.08-67.18°), fMLT=8.46-9.08 h. Two upper spectrograms correspond to ion telescopes directed at 180 and 79° to spacecraft spin axis (see Lutsenko et al., 1998). In our previous work (Lutsenko at al., 2000) we showed that two parallel dispersion lines in such spectrograms with a constant energy ratio of $E_2/E_1=2$ correspond to protons (lower) and alpha particles (upper). One broader dispersion structure is seen in the electron spectrogram (below). Figure 2 shows one partial spectrum for the 1p-telescope. It gives impression on the instrument resolution and the peak energy determination accuracy. The inverse E vs. time plots for all these species are shown in Figure 3. A linear fitting of the data allows to determine the time of the drift motion start T_0.

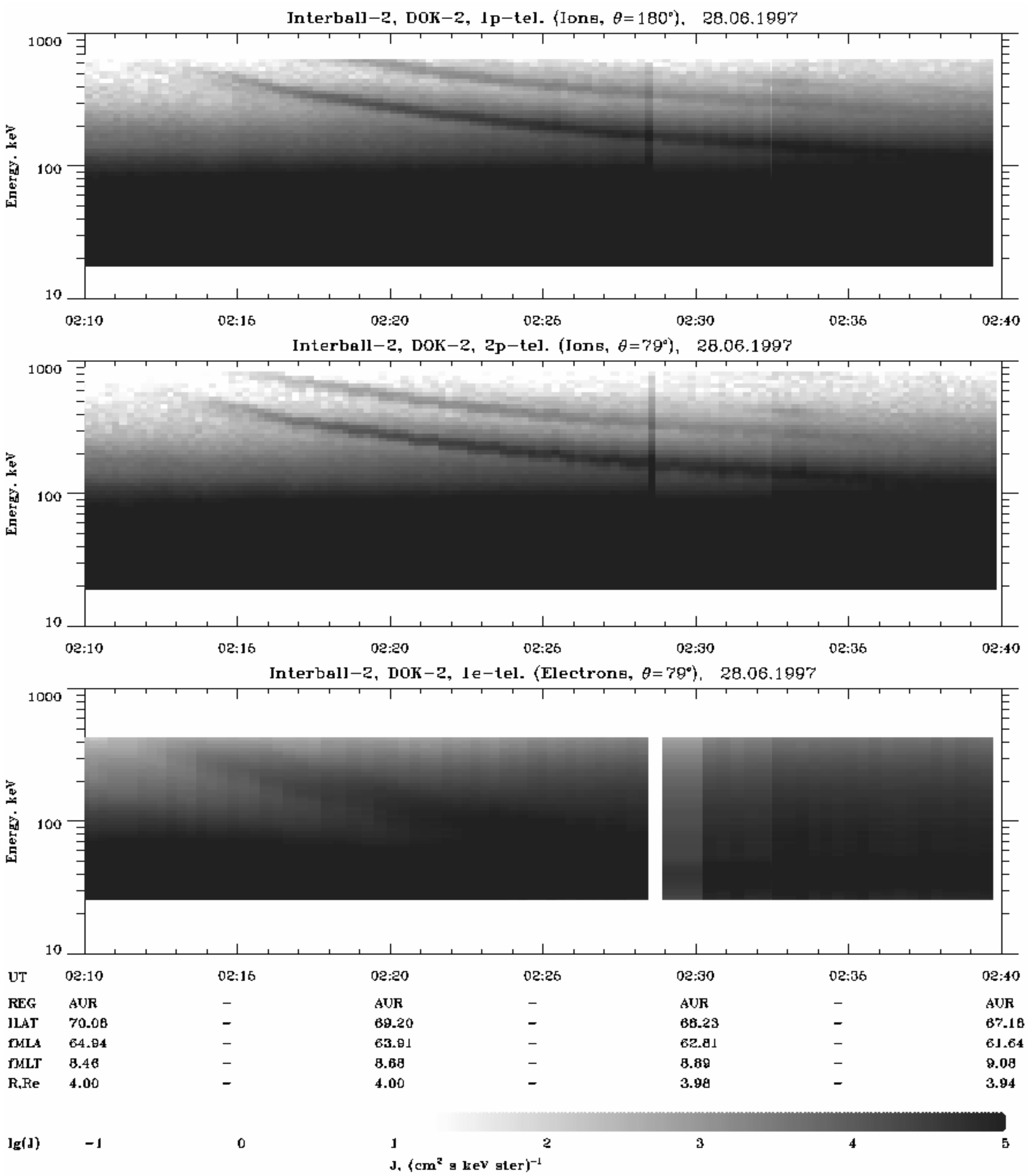

Fig. 1. Example of dispersion event on June 28, 1997 (Auroral Probe). Two upper panels show spectrograms for two ion telescopes (108° and 79° to spin axis, the lower one – for electron telescope (79°).

The sketch in Figure 4a illustrates our idea on the dispersion event origin. Particles accelerated momentary at some point in the plasma sheet move earthward to a closed field line region where at time $T=T_0$ and longitude $\varphi=\varphi_0$ they start a gradient-curvature drift (see e.g. Roederer, 1970). The propagation time to this point is determined by the particles velocity and for several hundreds keV ions should not exceed 1 min. Then ions and electrons drift in opposite direction and encounter the spacecraft located at the angle φ_1 at the time T_1. In dipolar magnetic field the bounce averaged angular drift velocity is constant and equal according to Roederer (1970):

$$\frac{d\varphi}{dt} = \left(\frac{3R_E \cdot L \cdot g(\alpha_o)}{k_0}\right) \cdot \left(\frac{m_0 c^2 \cdot \gamma \cdot \beta^2}{2q}\right) = \left(\frac{3R_E \cdot L \cdot g(\alpha_o)}{k_0}\right) \cdot \left(\frac{E}{q} \cdot \frac{(E + 2m_0c^2)}{2 \cdot (E + m_0c^2)}\right)$$

The expression in the 1-st parentheses gives the dependence of dφ/dt on the Earth's magnetic dipolar moment k_0, L-parameter and equatorial pitch angle α_0. For $40° \le \alpha_0 \le 90°$ $g(\alpha_0) \approx 0.70 + 0.30 \sin \alpha_0$.

The expression in the 2-nd parentheses gives the dependence of dφ/dt on particle parameters. For ions in DOK-2 range (20-800 keV) it can be reduced to E/q. For electrons (E=25-400 keV) a full relativistic expression should be used. It can be expected that this dependence of the drift velocity on particle parameters will be conserved in the real magnetic field where the drift velocity should be some function of φ: f(φ) (maximum velocity at midnight, minimum at noon). Here dφ/dt=f(φ)·E/q or dφ/f(φ)=E/q·dt. After integration along the particle drift path we can found: $F(\varphi_1)$-$F(\varphi_0)$=E/q·(T_1-T_0), where F(φ) is some function which depends on the magnetic field structure. So in the real magnetic field as in the dipolar one,

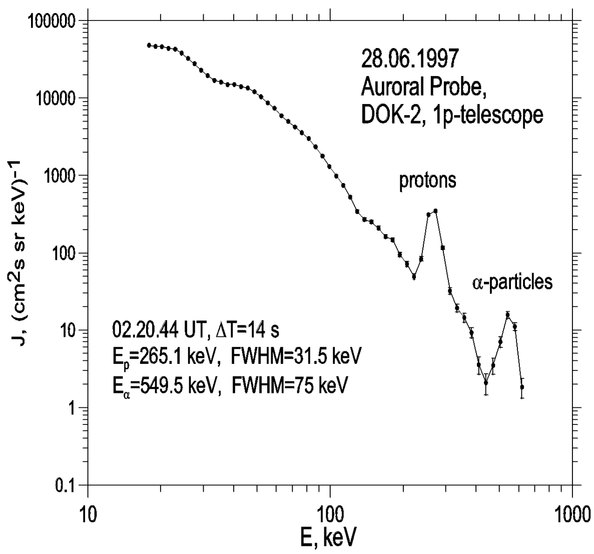

Fig. 2. One partial ion spectrum from the upper spectrogram on figure 1.

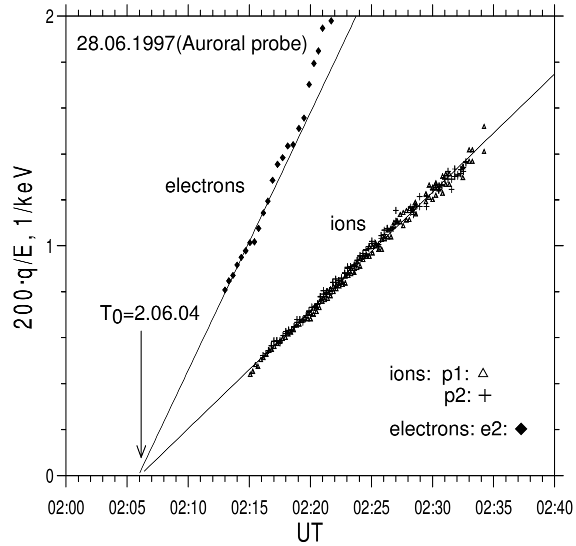

Fig. 3. Method of determination of the injection time T_0.

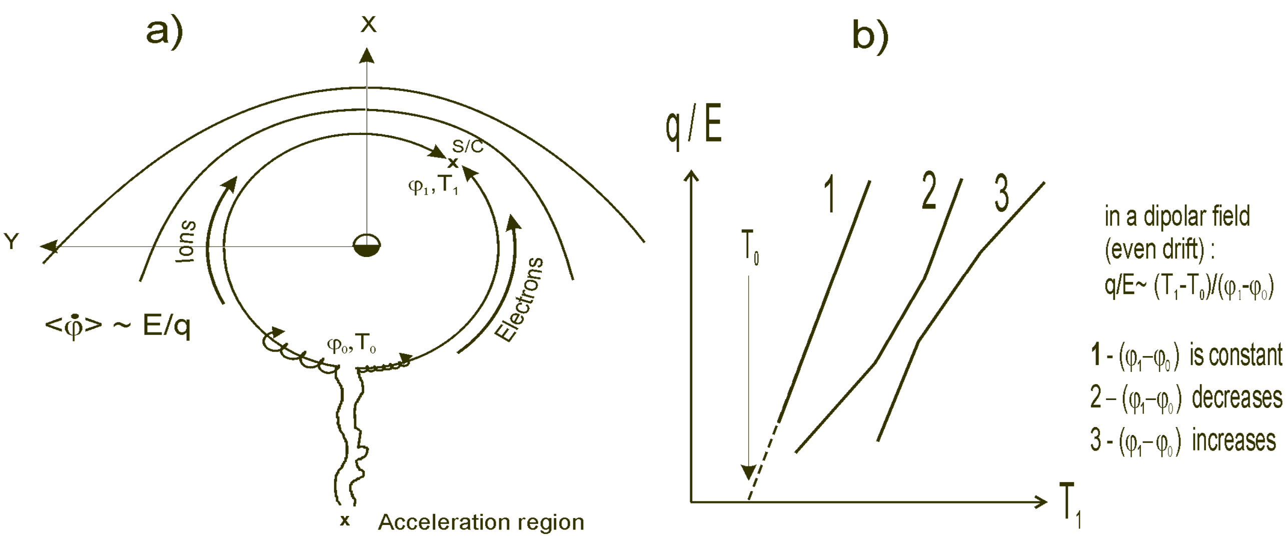

Fig. 4. (a) –Sketch illustrating the dispersion events origin, (b) – Three types of q/E vs. time dependence.

if the observation site φ_1 is a constant during particles drift, we should expect a linear dependence of q/E on T: $q/E=(T_1-T_0)/(F(\varphi_1)-F(\varphi_0))$. The graphs in figure 4b show how this dependence changed when the observation site φ_1 changes. In most cases studied in DOK-2 experiment the change of the spacecraft's φ_1 during the event is small in comparison with the particles drift path length $\varphi_1-\varphi_0$ and the dependence mentioned was very close to linear. The T_0 values were determined usually using data for protons, α-particles and electrons and the scattering of results for different species was tens of seconds. As was mentioned the time of drift start T_0 may differ from the acceleration time not more than ~1 min.

In figure 5 we compare the development of two substorms on 13.02.1997 as seen by the Polar UV imager (above) and T_0 determined from DOK-2 data for these events (below). The Polar UVI data (P.I. George Parks) were taken from movies prepared in Applied Physics Laboratory, John Hopkins University (http://sd-www.jhuapl.edu/Aurora/polar_movies/UVI_polar_movies.html). The left UVI panels correspond to the first appearance of brightening, the right ones – to its maximum. It can be seen that T_0 is 1.5-3 min after the first signatures of aurora and is ~5 min before it's maximum.

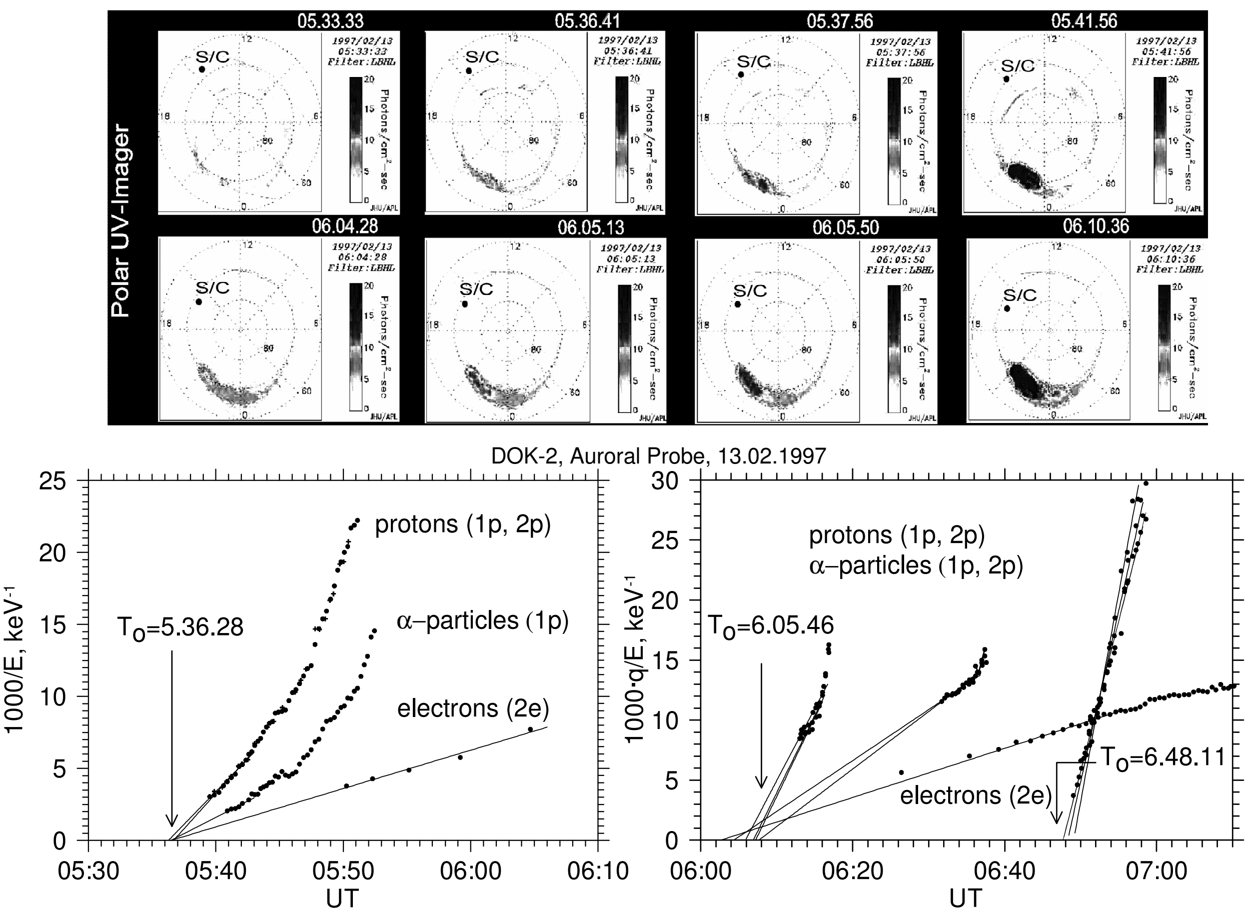

Fig. 5. Development of two substorms on 13.02.1997 as seen by Polar UV imager (above) and T_0 determination from DOK-2 data for these events (below).

In several cases we observed 2-3 proton dispersion structures with different energy change velocities which gave the same value of T_0 (one is shown in Figure 5). They correspond to ions from the same injection observed after several turns around the Earth. Here we can find values of the drift period for different ion energies in the real magnetic field. One good example of such an event is given in figure 6. The time intervals between neighbouring lines at any value of q/E should be equal and should give a drift period T_d. In this case T_{11}=15.33 min, T_{12}=15.52 min for E= 480 keV and T_{21} =20.48 min, T_{22} =21.12 min for E= 356.5 keV. The L- value of the spacecraft position varied from 9.81 to 6.73 during these measurements so ions were injected on a broad range of L-shells. The estimation for the dipolar field model (see Roederer, 1970) give 9.67 min (L=9.81) and 14.1 min (L=6.73) for E=480 keV. For E=356 keV the periods should be 13 min (L=9.81) and 18.97 min (L=6.73). So the dipolar field model predictions are too rough. We found the following expression for drift period in the real magnetic field for L=6.7-9.8:

$$T_d(E)=7.46\cdot10^3\cdot(E/q)^{-1}\ \text{min.}$$

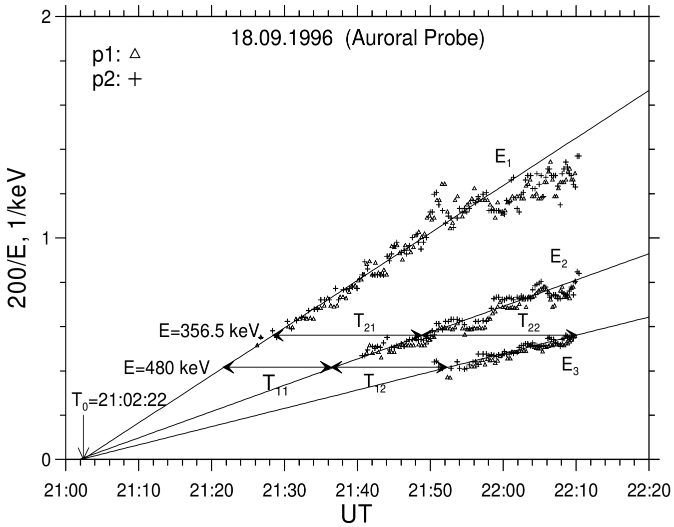

Fig. 6. Inverse E plot for protons in the dispersion event on September 18, 1996.

The width at half maximum of peaks in dispersion event energetic spectra depends on several factors. These are a detector resolution, a spectrum accumulation time, a spread of T_0 and φ_0 values due to the irregular particles motion in the highly turbulent plasma sheet, and an acceleration process duration. Taking into account first two known factors and the measured value of dE/dT we estimated the sum of last two factors. For the event on June 28, 1997 (Figure 1) at E=420 keV we have: the measured FWHM=69 keV, the detector energy resolution of 8 keV, the dE/dT=0.77 keV/s, and the accumulation time of 13 s. For the sum of the acceleration process duration and the spread of T_0 and φ_0 we obtained 79 s. So the acceleration duration should not exceed this value.

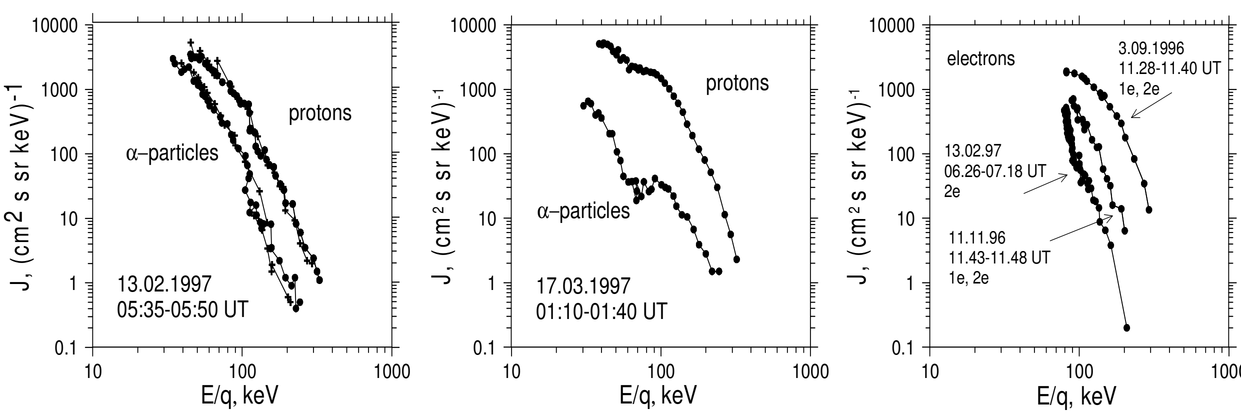

Fig. 7. Ion and electron source spectra constructed from dispersion events data.

The dispersion peaks in spectra are essentially samples of the source spectrum at different energies. We reconstructed the source ion and electron spectra for several events with good resolved peaks. Some of them are shown in figure 7. Unfortunately we did not found a spectrum measured with comparable resolution at the same time in the plasma sheet close to the source to compare with reconstructed spectra. In figure 7 we use the value E/q instead of E. The shapes of proton and α-particle spectra are very similar in this scale. The peculiarity in both spectra at 100 keV/q in the central panel may be due to a particle momentary loss in some place on the drift pass because both species at equal E/q should be in this place at the same time.

CONCLUSIONS

Some results of the analysis of high-resolution energetic particle data for dispersion events in auroral zone were given. It was shown that these data allow to find many characteristics of the large-scale particle acceleration in substorms: the time and duration of the process, energetic spectra for protons, α-particles and electrons for a particular event so as characteristics of gradient-curvature drift of particles in the outer magnetosphere. What is important, this information can be obtained by measurements far from the acceleration site located in the plasma sheet and tens of minutes after the acceleration ends.

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