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Plasmapause Dynamics during Magnetic Storms as Observed by the Auroral Probe/Alpha 3 Experiment

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Abstract. Some examples of distributions $n(L)$, $T_i(L)$, and $T_e(L)$ measured in the outer plasmasphere during geomagnetically quiet and disturbed periods aboard Auroral Probe of the INTERBALL mission are presented. Dependencies of the plasmapause position on time for different geomagnetic activity levels are considered. Data on plasmapause dynamics during magnetic storms were also obtained. It turned out that in all considered cases the plasmapause started to move towards the Earth before the main phase of the magnetic storm and possibly just after sudden commencement. In some cases during magnetically quiet periods plasmapause may be asymmetric in noon-midnight direction. Asymmetry value may reach 1.3L.

1 Instrumentation and data processing

The Tail and Auroral Probes of the INTERBALL mission were equipped with the identical Alpha 3 instruments which provided energy spectra measurements of cold ion fluxes in the range 0 – 25.5 eV. Below the data obtained with the Auroral Probe will be considered. This satellite was launched into an orbit with the apogee of ~ 20000 km, the inclination to the equatorial plane of 65°and rotation period of 6 hours. The Alpha 3 instrument consists of two plane wide angle plasma analyzers: a modulation analyzer and an analyzer with retarding potential. The instrument was installed in the dark part of the spacecraft surface and oriented in the anti-sunward direction. Each spectrum was measured during 2 s, but the intervals between spectra varied from 15 s to 260 s. Detailed description of the instrument was given by Bezrukikh et al. (1998). The data obtained are influenced neither by fluxes of ions of energies higher than 25.5 eV nor by secondary electrons. Here the spectra measured by the modulation analyzer aboard the Auroral probe inside the plasmasphere will be discussed.

The parameters of plasmaspheric cold ions: density n and temperature T_i, as well as the value of the spacecraft potential Φ_0, were obtained via fitting the experimental spectra by the calculated spectra. Each part of the ion energy spectrum is determined by a definite parameter. The slope of the spectrum on the right hand side is described by the temperature, Φ_0 determines the position of spectrum maximum and D is referred to the spectrum slope on the low energy edge. Ion density n is a linear parameter and is easily determined from ion flux magnitudes.

2 Results of observations and discussion

Figs. 1a-c present distributions of ion density $n(L)$ and temperature $T_i(L)$ and spacecraft potential $\Phi_0(L)$ reduced from the spectra measured aboard the Auroral probe in the daytime magnetosphere sector on September 9, 21, and 27, 1996 for different geomagnetic activity levels. The sums of K_p-indices for the corresponding previous days were 12.0, 32.3, and 22.7, respectively. It is well known that low energy plasma measurements inside the plasmasphere depend strongly on the potential of the spacecraft. The bottom curves in Fig. 1a-c show that for the cases in question the spacecraft potential varies from –0.65 V on L = 2 up to 0 V in plasmasphere regions where the ion density is >10 cm^{-3}. These potential variations are in reasonable agreement with a large number of measurements on different spacecraft (see Whipple, 1981). In cases b and c (Fig. 1) abrupt density decrease occurs when the spacecraft potential is close to 0 V. Nevertheless the abrupt ion density decrease at L>2.7 which is considered as the plasmapause crossing cannot be explained by Φ_0 increasing since even an overestimated value of Φ_0 = +0.5 V (in comparison to the results of measurements) would not decrease the density value more than by 2.7 times for ion temperature T_i = 5000 K.

Distributions of cold plasma density in the night, dawn, and day time plasmasphere sectors were studied quite carefully by ground-based (Carpenter 1966) and satellite in situ measurements (Gringauz and Bezrukikh, 1976, Harris et al. 1970, Horwitz et al. 1984, Comfort 1986) and radio

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sounding observations (Decreau et al. 1978, Carpenter and Anderson, 1992). Density distributions in the region of the evening bulge seem to be known less reliably as there are not so many measurements in this region and physical processes are very complicated there (Carpenter et al. 1993). *n(L)* profiles observed on September 9, 21, and 27 aboard the Auroral probe (Fig. 1) are in good agreement with ISEE-1/whistler data obtained by Carpenter and Anderson (1992.).

The study of the plasmasphere thermal structure began aboard the Prognoz satellites (Bezrukikh and Gringauz, 1976). However, the most reliable and complete set of data on T_i distributions inside the plasmasphere and close to the plasmapause were obtained by ISEE and DE-1 satellites (Comfort *et al.* 1985, Comfort 1986). $T_i(L)$ distributions measured on board the Auroral probe (Fig. 1) well correspond to the DE-1 ion temperature measurements.

Until recently the amount of data on electron temperature inside the plasmasphere was rather limited (Freeman *et al.* 1970; Decreau et al. 1978). For instance, in the experiment of Decreau et al. (1978) plasma frequency and Debye length were measured permitting to determine electron density and electron temperature. According to Decreau et al. (1978) during quiet periods at geocentric distances 4 $R_E < R < 7$ R_E (R_E – Earth radii) the electron temperature T_e varies from 3000 K to 50000 K. Regular measurements of T_e in the upper ionosphere and in the plasmasphere were performed by the EXOS-D satellite in 1989 – 1994 (Balan et al., 1996). Aboard the Auroral probe the electron temperature was measured in the experiment KM-7 (Afonin *et al.*, 1998).

The electron temperature can be estimated from ion measurements of the modulation analyzer aboard the Auroral probe by fitting the *D* value, in cases when the angle between the normal to the analyzer aperture and the spacecraft flight direction was less than 75° and $e\Phi_0 > kT_i$ (*e* is electron charge). Values of T_e determined from D length (assuming it is equal to the Debye length) are shown in the top panel of Fig. 1a. Distribution $T_e(L)$ in Fig. 1a shows that T_i and T_e are in right relation ($T_e > T_i$, everywhere in the region where T_e was determined). The presented values of T_e vary in the range (7-9)·10^3 K when 2.2 <L<2.7 and T_e > 20000K for L>3.1 and correspond to the results of Decreau et al. (1978) and to the results of Balan et al. (1996) for low L-values. The values of electron temperatures simultaneously measured by the KM-7 instrument (Afonin, 1998) were 2000 – 3000 K, that is significantly less than the T_e and even the T_i values measured by the Alpha 3 instrument. This contradiction is likely to be the consequence of the underestimation of T_e values provided by KM-7 inside the plasmasphere (Afonin et al., 1998).

It is well known that plasmapause position is highly variable with the level of geomagnetic activity. In the sixties and seventies empirical relations for the dependence of the plasmapause position on the K_p-index were deduced (e.g. see Carpenter, 1963; Binsack, 1967; Bezrukikh, 1970; Chappel et al., 1970)). Some of the authors considered the distance to the plasmapause versus maximum K_p value in the preceding 24 hours (e.g. Carpenter, 1967; Gringauz and Bezrukikh, 1976), and recently Carpenter and Anderson (1992) analyzed this dependence using the maximum value of K_p in the preceding 12 hours. Chappel et al. (1971) and Decreau et al. (1982) statistically analyzed the data obtained with the satellites OGO-5 and GEOS and concluded that the dimensions of the plasmasphere first contract in the nighttime sector and then this contraction extends to other sectors of the plasmasphere with a velocity close to the velocity of cold plasma corotation. These results made an impression about considerable inertness of the plasmapause dynamics.

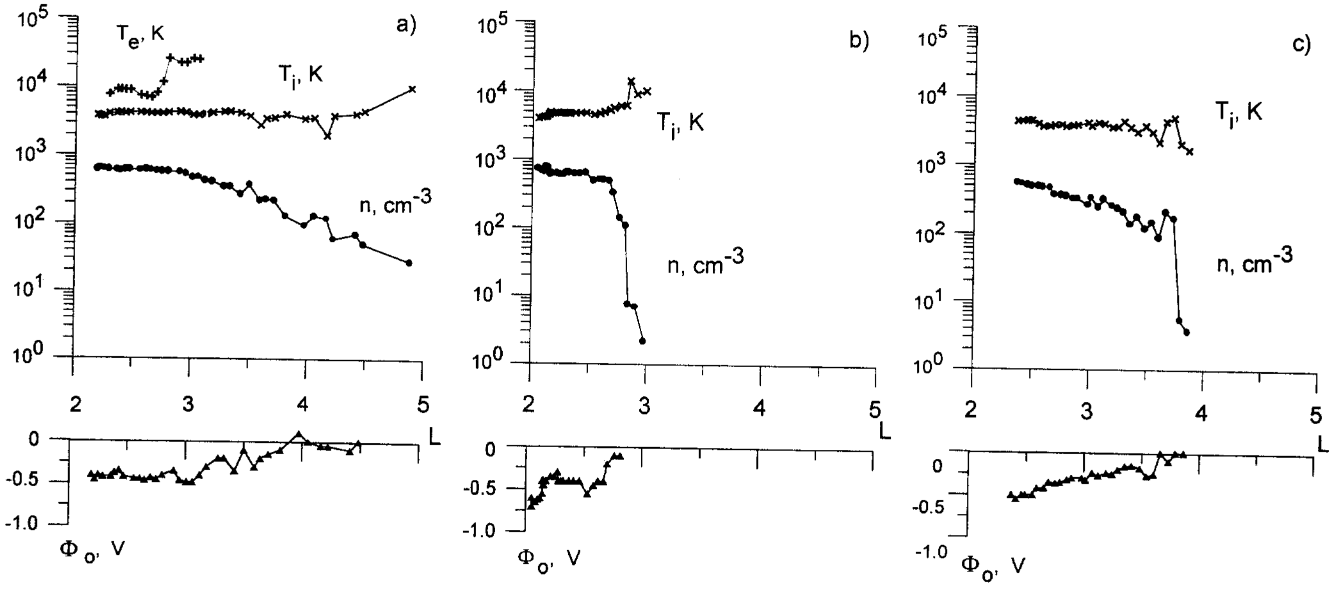

Fig. 1. Distributions of $T_i(L)$, $T_e(L)$, $n(L)$, $\Phi_0(L)$ in the plasmasphere measured a) Sept. 9, 1996 (13.02 - 13.50 UT, 12.13 - 13.05 MLT, $\Sigma K_p = 12.0$) after continuos quiet period, b) Sept. 21, 1996 (09.09 - 09.41 UT, 11.60 - 12.40 MLT, $\Sigma K_p = 32.3$) immediately after two successive magnetic storms, c) Sept. 27, 1996 (21.11 - 21.45 UT, 10.1 - 11.2 MLT, $\Sigma K_p = 22.7$) during quiet period.

The Alpha 3 instrument aboard the Auroral probe provides a rare if not a unique possibility to follow the plasmapause dynamics far from the base of geomagnetic field lines in real time every 6 hours. Fig. 2 presents an example of the dependence of the plasmapause position on geomagnetic activity as it was observed by the Alpha 3 instrument on board the Auroral probe. In the top panel the plasmapause position dynamics versus time is shown for the day side (open circles) and night side (filled circles) magnetosphere sectors on October15-30, 1996. The bottom curve shows daily sums of K_p (ΣK_p) for the same period. General anticorrelation of the plasmapause position with ΣK_p is obvious from the presented data. It is seen also that the plasmapause moves faster towards the Earth during the increase of geomagnetic activity (17-21 October.1996 in Fig.2) than it moves away from the Earth during geomagnetic activity decrease (21-28 October.1996). This fact is likely to be connected with the long duration of the refilling processes of geomagnetic field tubes.

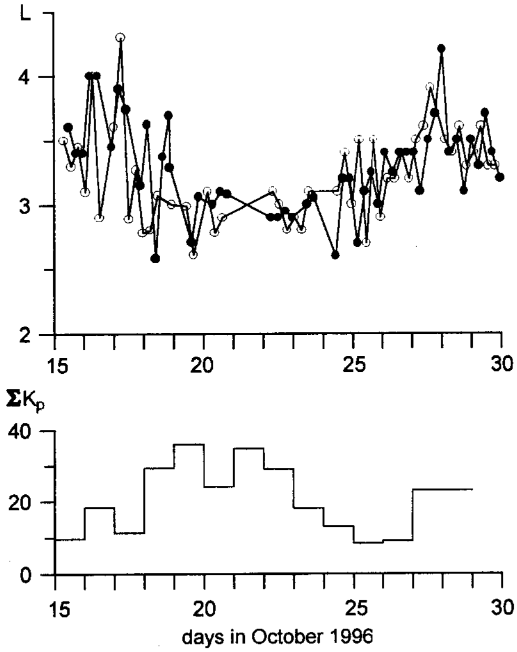

Fig.2 Plasmapause position on the day side (open circles) and night side (filled circles) as a function of time. In the bottom daily sums of K_p index are drawn for reference.

Figs. 3a-3c show some examples of the plasmapause dynamics connected with geomagnetic storms on October 18, 1996, February 28, 1997, and September 3, 1997. In the top panels the plasmapause position versus time is shown. Fig 3a presents the plasmapause dynamics on the day side (open circles) and night side (filled circles) of the magnetosphere on October 16 – 21, 1996. Fig. 3b gives plasmapause dynamics on the prenoon and noon sides on February 22 – Mars 5,1997 and fig.3c - on the postmidnight side of the magnetosphere on September 1 – 6, 1997. Kp-indices are shown in the middle panels and Dst variations at the bottom of Figs. 3a-3c. Fig. 3 demonstrates that the diminishing of the plasmasphere in different MLT sectors (except the dusk sector) during geomagnetic storms occurs almost simultaneously with small time delay relative to the maximum of the storm main phase. Pay attention to the short time interval in Fig.3b when plasmapause approaches 2L. Corcuff and Delaroshe, (1964) also reported on the

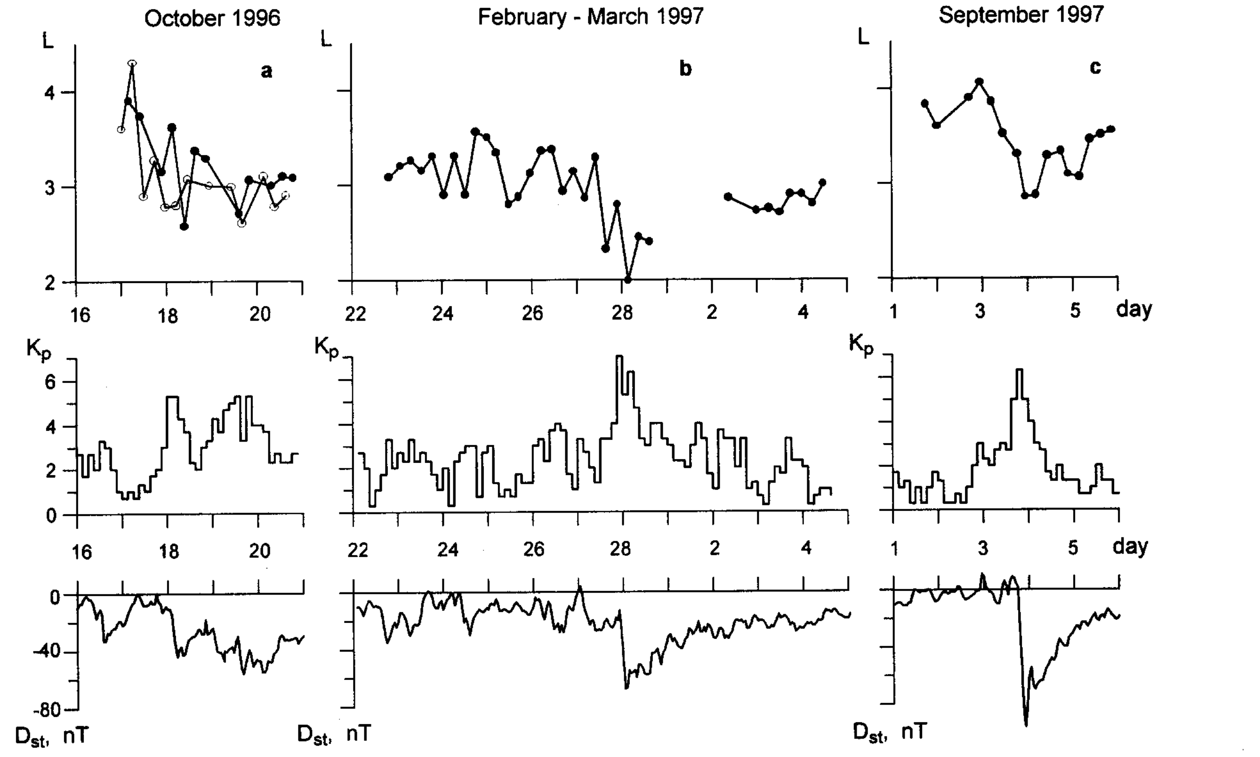

Fig.3 Top panels - plasmapause possition (L – shell) variations as a function of time for three magnetic storms. a – plasmapause dynamics on the day (open circles) and night (filled circles) sides; b - plasmapause dynamics on prenoon and noon sides; c - on postmidnight side of the magnetosphere. Middle and bottom panels – K_p and D_{st} indices variations, respectively.

observation of the plasmapause very close to the Earth (2.0L), and marked that it may be even closer.

Fig. 4 shows plasmapause position variation during the transition from geomagnetically quiet period of September 4 - 10, 1996 to moderately disturbed period of September 10 - 14, 1996. Contrary to the previous example Fig. 4 demonstrates the existence of asymmetry in the day - night direction in the plasmapause position observed sometimes during long quiet periods. Earlier such an asymmetry was observed by Gringauz and Bezrukikh (1976), but no confirmation was found in the data of Carpenter and Anderson (1992).

4 Conclusions

The examples of the plasmapause dynamics considered above permit us to conclude that

- on the night, dawn, and day sides the plasmapause begins to move toward the Earth long before the main phase of the geomagnetic storm, maybe just after storm sudden commencement;

It is likely the inconsistency of the data of the Auroral probe/Alpha 3 experiment with the results obtained by Chappel et al. (1971) and Decreau et al. (1986) is connected with essentially different geomagnetic conditions during these measurements.

- the plasmapause approaches the location nearest to the Earth at the main phase of the geomagnetic storm;
- sometimes plasmapause can move toward the Earth to a distance of 2L for a short time; reverse motion of the plasmapause starts with the beginning of the geomagnetic storm recovery phase.

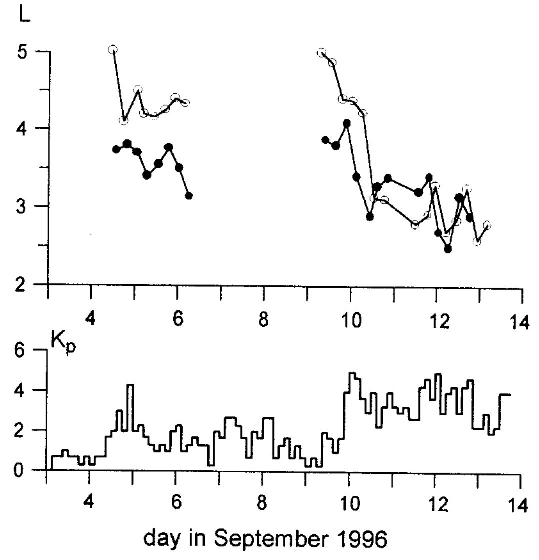

Fig. 4 Noon (open circles) - midnight (filled circles) asymmetry of the plasmapause position in magnetically quiet geophysical conditions.

- At least a sporadic existence of the plasmasphere asymmetry in the noon - midnight direction was confirmed for low geomagnetic activity level.

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