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Asymmetry of the Earth's plasmasphere in the direction noon–midnight from Prognoz and Prognoz-2 data

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Abstract—The asymmetry of the Earth's plasmasphere in the direction noon–midnight is revealed. It decreases under strong geomagnetic disturbances. The possible causes of it are discussed.

1. Introduction

The first information on daily variations of altitude of the Earth's plasmasphere boundary (plasmapause) obtained was from ground observations of whistlers giving information on the plasmapause position in the plane of the geomagnetic equator (Carpenter, 1966). The important feature of these variations is the increase of the plasmapause altitude at evening hours ('bulge'). *In situ* measurements of the ion density aboard satellites, in particular Electron-2 and 4 (Bezrukikh (1970)) and OGO-5 (Chappell *et al.*, 1970a, 1970b, 1970c, 1971, Chappell (1972)) confirmed the increase of the plasmapause altitude in the evening hours and from the OGO-5 data this bulge on average is symmetrical relative to the meridian 0600–1800 LT (Chappell *et al.*, 1970c).

The existence of the asymmetry of the plasmasphere in the direction dawn–dusk can be satisfactory explained on the assumption that the plasmapause should be an equipotential surface and, therefore, its shape is defined by the configuration of large-scale electric fields in the magnetosphere. In the equatorial plane the plasma convection, as was proposed by a number of authors, creates a homogeneous electric field across the magnetosphere which is directed from dawn to dusk. The superposition of this field with the radial electric field relative to the Earth, which is accounted for by the near-Earth plasma corotation, leads to the shape of the outer equipotential being elongated in the dawn–dusk direction, close in shape and size to that observed by means of whistlers and satellites, Nishida (1966), Brice (1967), Kavanagh *et al.* (1968).

It may be mentioned that as long ago as 1968 Axford noted that this conception is oversimplified (Axford, 1969).

Wolf (1970) outlined that the magnetospheric convection should greatly depend on the conductivity distribution in the ionosphere. In Wolf (1970), calculations are presented of equipotentials in the magnetospheric equatorial plane under different assumptions on the conductivity distribution in the ionosphere. The number of calculated versions in Wolf (1970) was large but unfortunately the author did not recommend any of these as a preferable one. One could conclude, however, that the difference of day and night ionospheric conductivity can lead to plasmapause asymmetry in the direction day–night.

Chappell *et al.* (1971) considered a number of peculiarities of the daytime plasmasphere from measurements on the OGO-5 satellite, however, among these peculiarities, the asymmetry of the plasmasphere relative to the meridian 0600–1800 LT (i.e. in the direction noon–midnight) is not noted and Chappell (1972) only discussed the possibility of such an asymmetry, which is considered to result from 'troughs' in ion density profiles arising in periods of changes in geomagnetic activity.

Plasmaspheric measurements of the ion density $n_i(L)$ conducted by means of charged particle traps aboard satellites Prognoz and Prognoz-2 showed that the plasmaspheric boundary near noon is located, especially in relatively geomagnetic-quiet periods, at higher L-shells than that near the midnight and that the value of this asymmetry is sometimes comparable with the well-known plasmaspheric bulge in the dusk sector of the magnetosphere. The purpose of the present paper is a brief description of these measurements and results.

2. Results of Measurements

Prognoz and Prognoz-2 satellites were launched on 14 April 1972 and 29 June 1972 respectively into orbits with initial parameters:

Satellite	Apogee, 10^3 km	Perigee, km	Inclination	Period, h
Prognoz	200.9	940	65°	97.0
Prognoz-2	201.0	557	65°	96.9

Both satellites were oriented to the Sun.

On each of the satellites identical sets of charged particle traps were installed which included, in particular, two hemispherical traps with outer grids at the electrical potential of the body of the satellite. The aim was to measure plasmaspheric ion characteristics, BEZRUKIKH *et al.* (1974). One of these traps was oriented to the Sun, another one was located at the shaded part of the satellite and oriented in the antisolar direction. Problems of the data processing technique are considered elsewhere. The estimated measurement error can reach a factor of 2.

Each satellite during each revolution around the Earth intersected the plasmasphere four times at different altitudes. To illustrate this the projection of the near-Earth part of a 'Prognoz' satellite orbit into the XZ-plane in solar ecliptic coordinates on 28 May 1972 is shown in Fig. 1. In the present paper the data on intersections of the plasmapause at high altitudes ($h > 10{,}000$ km, points of 'a' and 'd' types in Fig. 1) only are used. The analysis of the data corresponding to low altitudes (points of 'b' and 'c' types in Fig. 1) will be published elsewhere.

In Figs. 2–4 ion density altitude profiles $n_i(h)$ are presented from the measurement data.

To make easier the comparison with earlier published results on n_i measurements (for example, in CHAPPELL *et al.*, 1970b, 1970c, 1971; CHAPPELL, 1972) besides altitudes h, values of corresponding L-coordinates are presented along the abscissa axis. The left parts of the graphs correspond to inbound passes of satellites, the right parts to outbound ones. In each graph the universal time UT and local time LT are shown which correspond to two above-mentioned intersections of the plasmaspheric boundary. The satellite passes the part of orbit under consideration, from first entering the plasmasphere to last going out of it, during 3–5 hr

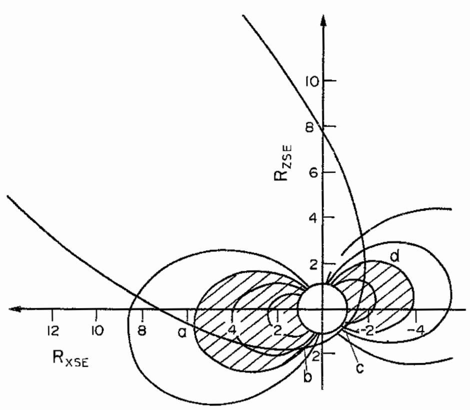

Fig. 1

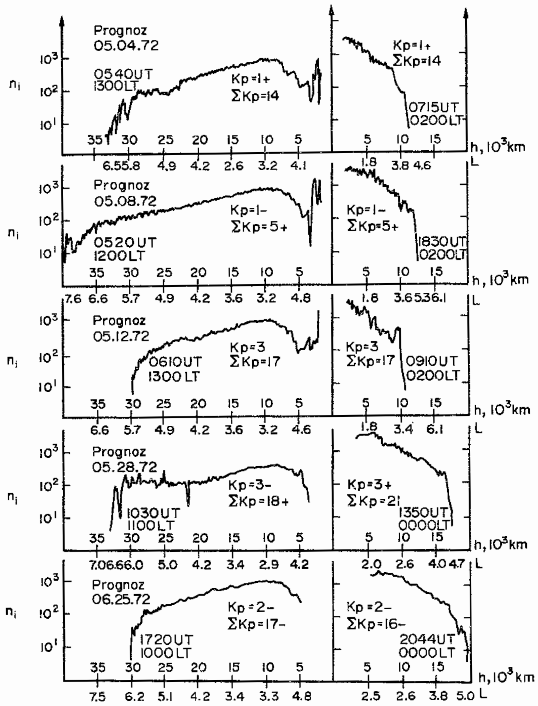

Fig. 2

and the local time changes by 10–14 hr. Besides, in the left part of each of the $n_i(L)$-distributions the K_p-values are shown corresponding to the satellite entry to the plasmasphere at the inbound pass and the sum of K_p-indices during the 24 hr preceding to the entry to the plasmasphere. In the right part are shown the K_p-values corresponding to the satellite going out of the plasmasphere and the sum of K_p-indices during the 24 hr preceding to the satellite going out of the plasmasphere.

In Fig. 2, a number of $n_i(L)$-profiles is presented which were obtained from the Prognoz satellite in magnetic-quiet and moderately magnetic-disturbed periods (during the measurements $K_p \leqslant 3$, the sum of K_p for the day preceding the going out of the satellite from the plasmasphere $\sum K_p \leqslant 21$). The local time at the moment of the satellite entering the plasmasphere at the inbound pass is 1000–1400 LT and at the exit from the plasmasphere is 2200–0200 LT. In Fig. 3, similar data are presented from Prognoz-2 satellite. During the exit from the plasmasphere at the outbound pass in this group of the data the local time corresponds to 2300–0400 LT. On each pair of graphs presented in Figs. 2 and 3 one can see essential differences between $n_i(L)$-profiles obtained near the local noon and local midnight.

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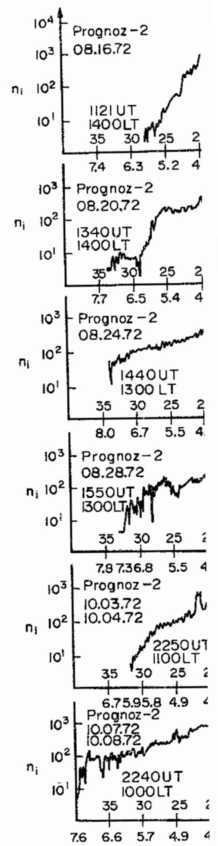

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First of all the L-value at the dayside part of the plasmapause is considerably higher than that at the nightside part (this difference is not less than one unit of L and in most cases it is significantly higher). Besides, on graphs $n_i(L)$ in Figs. 2 and 3 corresponding to the dayside plasmasphere a more gradual decrease of n_i is typical compared to abrupt falls of n_i near the night boundary of the plasmasphere. In some cases (for example, Fig. 2a, b; Fig. 3e, f) the decrease of n_i at the dayside part is followed by marked variations of n_i—values (at

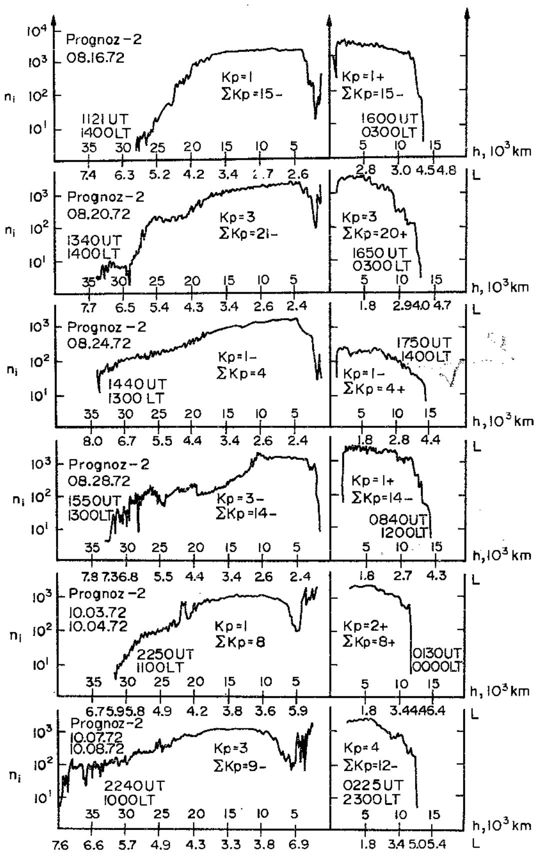

Fig. 3

$n_i < 10^2\ \mathrm{cm}^{-3}$) which are not observed at the nightside part. In Fig. 4, also corresponding to quiet geomagnetic conditions, one can compare $n_i(L)$-profiles for 1500–1600 LT to the dawn ones (0400–0600 LT). One can see that at afternoon hours both considerable stretching of the plasmasphere and comparatively slow decrease of n_i are retained whereas in the morning and night sectors a distinct plasmapause is observed which is located at comparatively low L-values.

In Fig. 5, $n_i(L)$-profiles are shown corresponding to magnetic disturbed conditions. From the graphs

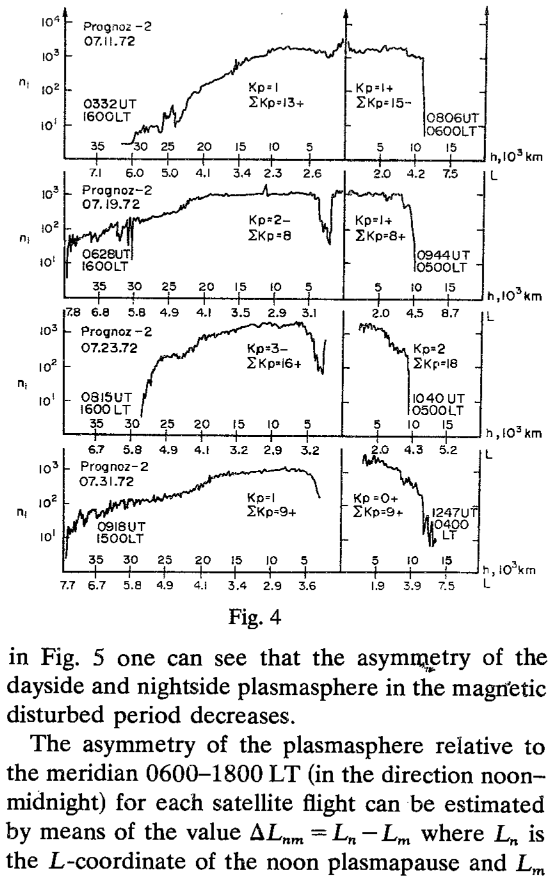

Fig. 4

in Fig. 5 one can see that the asymmetry of the dayside and nightside plasmasphere in the magnetic disturbed period decreases.

The asymmetry of the plasmasphere relative to the meridian 0600–1800 LT (in the direction noon–midnight) for each satellite flight can be estimated by means of the value $\Delta L_{nm} = L_n - L_m$ where L_n is the L-coordinate of the noon plasmapause and L_m is that of the midnight plasmapause. From the Prognoz and Prognoz-2 data corresponding to quiet and moderately disturbed conditions the average value $\Delta L_{nm} = 1.6$, and during strong disturbances this value can fall almost to zero.

Let us note that according to data from the same

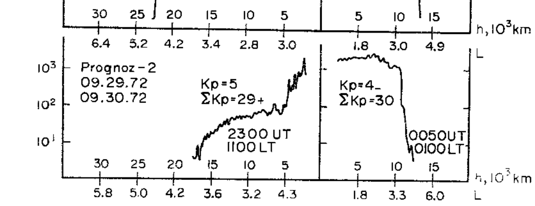

Fig. 5

satellites under quiet conditions the asymmetry of the plasmasphere relative to the meridian 0600–1800 LT (in the direction dawn–dusk) is on average $\Delta L_{dd} = 2.5$ (the number of data obtained from these satellites during disturbances is not enough to make any conclusions).

So the measurements described reveal the asymmetry of the plasmapause in the direction noon–midnight under magneto-quiet conditions, and this asymmetry is somewhat less on average than that in the dawn–dusk direction, but it is nevertheless considerable. This asymmetry decreases with the growth of the geomagnetic disturbances.

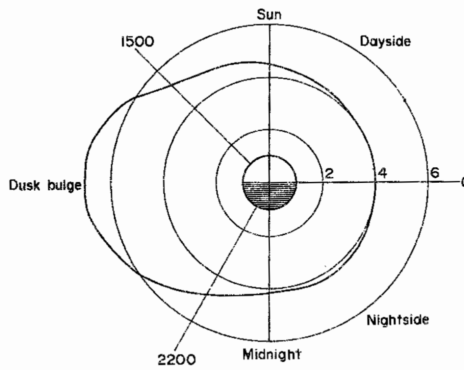

Fig. 6. (CHAPPEL *et al.*, 1971).

3. DISCUSSION

It is necessary to compare the above data with those earlier published. Differences of plasmapause height at noon and midnight are not noted in the results obtained from whistler observations (CARPENTER, 1966; CARPENTER and PARK, 1973). Reasons for this need to be analyzed.

Peculiarities of the dayside plasmapause are considered in the special paper by CHAPPELL *et al.* (1971) based on results of direct measurements from the OGO-5 satellite and also in a review by CHAPPELL (1972). The comparison of the data presented in these papers with those described is most interesting. The results obtained from Prognoz and Prognoz-2 satellites confirm the existence of a number of peculiarities of the dayside plasmapause outlined in the paper by CHAPPELL *et al.* (1971). Among them there is the more gradual decrease of n_i with the increase of L than that at the nightside sector (one can agree that one reason for this is the existence of plasma fluxes from the dayside ionosphere moving up along magnetic field tubes, PARK (1970), EVANS (1971), BANKS *et al.* (1971). In our data as well as in the paper by CHAPPELL *et al.* (1971), in a number of cases at $L > 6$ oscillatory variations of n_i are observed during the decrease of n_i and this variation is explained in the paper by CHAPPELL *et al.* (1971) by processes causing the departure of the cold plasma from the dayside plasmasphere.

The consideration of separate $n_i(L)$-profiles presented in papers by CHAPPELL *et al.* (1970a, b, c, 1971) CHAPPELL (1972) shows that according to the data of these profiles the altitude (L-coordinate) of the dayside plasmapause often markedly exceeded the altitude of the nightside plasmapause (see, for example, Fig. 5c CHAPPELL *et al.*, 1971b), where left graphs correspond to afternoon hours and right ones to night hours; the latter is not noted in the paper by CHAPPELL *et al.* (1970b), but follows from the paper by CHAPPELL *et al.* (1970a). However, as was noted, on the curve of averaged diurnal variations of the plasmapause L-coordinate, presented in the paper by CHAPPELL *et al.* (1971) and CHAPPELL (1972) and reproduced in Fig. 6, the asymmetry in the direction noon–midnight is very low ($\Delta L_{nm} \sim 0.5$) and CHAPPELL *et al.* (1971) did not pay any attention to it. From Prognoz and Prognoz-2 data this asymmetry, as one can see from the above-given data, is considerably higher (in any case under magnetic quiet conditions).

The considered effect could be overlooked by the authors of papers by CHAPPELL *et al.* (1971) and CHAPPELL (1972), if geomagnetic disturbances, during which the noon–midnight asymmetry of the plasmapause decreases occupied a considerable part of the period of OGO-5 measurements, the data of which were used to determine the 'average' plasmapause (one should bear in mind that in 1968–1969—the period of observations by OGO-5—the solar activity was maximum).

It should be noted that in the review by CHAPPELL (1972), devoted to the morphology and dynamics of the plasmasphere from the data of direct measurements, in the section where large-scale 'troughs' of charged particle concentration in $n_i(L)$-profiles were considered, Chappell gave two possible sketches of changes of the size and shape of the plasmasphere under variable geomagnetic conditions including the formation of asymmetry in the noon–midnight direction. The sketches are reproduced in Fig. 7: the case (a) corresponds to the increase of the geomagnetic activity ($\Delta L_{nm} > 0$), the case (b) to the decrease of the activity ($\Delta L_{nm} < 0$).

The results of measurements from Prognoz and

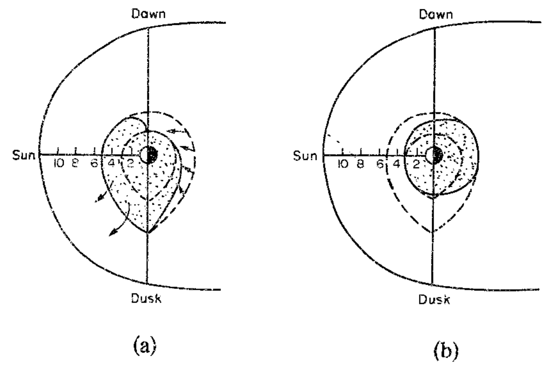

Fig. 7. (Chappel, 1972).

Prognoz-2, including the noon–midnight asymmetry of the plasmapause, do not coincide with the sketches in Fig. 7. The highest values of ΔL_{nm} are obtained during prolonged magnetic quiet periods when the sum of K_p-indices both for 24 hr preceding to measurements $(\sum K_p)_1$ and for 24 hr after measurements $(\sum K_p)_2$ changed very little and were low.

So, for example, on 24 August 1972, $\Delta L_{nm} = 3.4$, $(\sum K_p)_1 = 4$, $(\sum K_p)_2 = 6_+$; on 28 August 1972, $\Delta L_{nm} = 3$, $(\sum K_p)_1 = 15$; $(\sum K_p)_2 = 16_+$; on 7 November, 1972, $\Delta L_{nm} = 3$, $(\sum K_p)_1 = 9_-$, $(\sum K_p)_2 = 10_+$.

So a considerably higher altitude of the plasmapause at noon hours compared to that at midnight hours is the typical feature of the quiet magnetosphere but not of disturbed one.

We consider that the plasmaspheric asymmetry relative to the dawn–dusk meridian from the point of view of existing conceptions on magnetosphere–ionosphere interactions is quite natural and its study is important for the improving of our knowledge of the magnetospheric convection, i.e. large-scale electric fields in the magnetosphere.

One can note at least three reasons for this asymmetry.

(1) A general asymmetry of dayside and nightside magnetosphere and, in particular, of electric fields at the subsolar part of the magnetosphere and at its nightside part. As the convective flux of the plasma moving in the direction to the Sun from the magnetospheric tail and approaching the subsolar part of the magnetopause has inevitably to change direction and a velocity component perpendicular to the Sun–Earth line should arise, a component of the convection electric field normal to the magnetopause should arise at the dayside magnetosphere in the equatorial plane. Such an electric field component should create a difference in the shape of the dayside and nightside plasmapause (if we consider it as an equipotential surface).

(2) The higher conductivity of the dayside ionosphere at the foot of the magnetospheric field tubes creates a shorting effect which reduces the potential difference across the equatorial plane of the magnetosphere, the velocity of the plasma convection and the transverse electric field compared to those at the nightside magnetosphere where magnetic force tubes link the nightside ionosphere with low conductivity. This also causes the difference in the shape of the dayside and nightside plasmapause and a larger electric field at the nightside corresponding to the equipotential plasmapause which is closer to the Earth.

(3) Along the magnetic field tubes, connected to the dayside ionosphere, the proton fluxes go up and fill the plasmasphere and along night field tubes the fluxes of plasmaspheric protons go down. The latter support the existence of the nightside ionosphere after the cessation of the ionizing solar radiation. These processes slow down the decrease of n_i near the plasmasphere boundary at the dayside and accelerate it at the nightside.

4. CONCLUSIONS

Measurements of the ion concentration in the plasmasphere by means of Prognoz and Prognoz-2 satellites showed that near noon the plasmapause is placed at higher L-shells than near midnight. For magnetic-quiet and moderately disturbed periods the noon–midnight asymmetry ΔL_{nm} on average is 1.6; under strong geomagnetic disturbances this asymmetry decreases or almost disappears.

Reasons for this difference in positions of the dayside and nightside plasmapause can be connected to differences in the direction of the convective plasma motion at dayside and nightside magnetosphere, slowing down of the magnetospheric plasma convection at the dayside magnetosphere accounted for the high conductivity of the dayside ionosphere and the existence of plasma fluxes, going up along field tubes from the dayside ionosphere and going down from the plasmasphere into the ionosphere in the night.

Models of the distribution of large-scale electric fields in the quiet magnetosphere have to satisfy the condition of the existence of the asymmetrical (in the direction day–night) equipotential surface—the plasmapause, having the geometry corresponding to the measured data.

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