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STRUCTURE AND PROPERTIES OF THE EARTH'S PLASMASPHERE

K. I. Gringauz

Space Research Institute, Academy of Sciences of the U.S.S.R., Profsoiuznaia ul. 82/34, Moscow, U.S.S.R.

ABSTRACT

The widely used concept of the plasmapause as the last closed electric field equipotential in the equatorial plane of the magnetosphere is oversimplified. The field aligned plasma motions are of substantial importance in the plasmapause formation and should be taken into account. Distributions of the main plasma parameters measured from the Prognoz-5 satellite are presented. The diurnal variations of the plasmapause height and the plasmasphere thermal properties are discussed.

INTRODUCTION

It is a commonly expressed opinion that the shape of the plasmapause in the equatorial plane is completely determined by the superposition of two independent electric fields in this plane (one of which is caused by magnetospheric convection and the other - by plasma corotation with the Earth). This point of view (which assumed the additivity of these electric fields and does not take into account the finite ionospheric transverse conductivity as well as the presence of gravitational and centrifugal forces affecting the ions) leads to the conclusion that the plasmapause is symmetric with respect to the dawn-dusk meridian but is elongated in the dusk sector (the "tear-drop model") /1/, /2/, /3/.

This concept seemed to be confirmed by the OGO-5 experimental data /4/, but nevertheless is oversimplified and cannot explain other experimental results. Measurements made by the Prognoz-1 and -2 satellites /5/ revealed that considerable asymmetries of the plasmapause in the noon-midnight direction are frequently observed, and this has been confirmed in a number of publications (e.g. /6/, /7/, /8/). These asymmetries of the equatorial plasmapause were also often observed by the Prognoz-5 satellite /9/, i.e., they exist in different phases of the solar cycle. Any adequate theory of plasmapause formation should naturally explain both the dawn-dusk and the noon-midnight asymmetry.

Actually, the location and shape of the plasmapause are determined not only by the magnetospheric electric field distribution at the time of observation but in addition by the variation of the ionosphere (being the source of plasmaspheric particles), and by the processes of filling and depleting the outer flux tubes in the plasmasphere. Efforts are being made at present to develop such models. For example, Lemaire has developed a model of plasmapause formation in which due account is taken of gravitational and centrifugal forces acting upon cold plasmaspheric ions and the resulting plasma motion along the geomagnetic field, and of the empirical McIlwain model of electric and magnetic fields /10/. The calculated equatorial plasmapauses then exhibited the above two types of asymmetry.

Finally, in trying to determine large-scale electric fields in the magnetosphere from the plasmapause location one should keep in mind the frequently occurring large density inhomogeneities which can lead to an error in determining the plasmapause position from a satellite.

Fifteen years ago Carpenter et al., after comparing satellite and ground-based data emphasized "The results presented above may be deceptive in their simplicity. Data not presented here indicate that the plasmapause is extremely complex, with regions of irregular behaviour, periods of rapid expansion or compression, and variations in details of the plasma profile at the boundary" /11/. The whistler data of Park and Carpenter /12/ and the Prognoz-5 satellite data obtained in 1977 completely confirm these plasmapause characteristics. Therefore, when trying to use the meausred plasmapause position to determine the convection electric fields (for example, /13/), one should be very careful.

The present review is an attempt to summarize the available data on the plasmasphere including, in particular, its thermal properties and shape, the latter being of special interest for this meeting.

Chemical and Charge Composition of Ions in the Plasmasphere

The study of the ion mass and charge composition of the plasmasphere is important for interpreting the results of simple probe measurements (e.g., those using retarding-potential analyzers) and for assessing the possible presence of ions pertaining only to the plasmasphere so that their detection in other magnetospheric regions can uniquely indicate their plasmaspheric origin. The initial mass-spectrometric measurements of ions in the plasmasphere from the OGO-3 satellite showed that 0.99 n_i (n_i is the total ion number density) are protons while 0.01 n_i are He^+ ions /14/. OGO-5 measurements first revealed O^+ ions ($\sim$0.001 n_i) /15/. The ion spectrum became richer in composition with increasing mass-spectrometer sensitivity. GEOS-1 data (during the IMS period) first recorded the presence of O^{2+} ions, and it was shown that the $n_{O^{2+}}/n_{O^+}$ ratio can reach 1 near the equator at L $\sim$ 3, whereas in the F-region ionosphere at mid-latitudes $n_{O^{2+}}/n_{O^+}$ is $\sim$0.003. It was shown in Ref./16/ that neither photoionization of O^+ ions at high altitudes by solar UV, nor impact ionization of O^+ ions can explain so high a value of the $n_{O^{2+}}/n_{O^+}$ ratio. Instead it was shown that with reasonable assumptions concerning the T_i distribution along the L = 3 flux tube for equinox conditions one can explain the measured $n_{O^{2+}}/n_{O^+}$ values by thermal diffusion.

The number density of He^+ ions according to GEOS-1 data was approximately one order of magnitude higher than the results of earlier measurements, reaching $\sim$0.1 n_i /17/. According to DE-1 satellite data, the n_{He^+}/n_{H^+} ratio in the outer plasmasphere exceeds by several times the corresponding value obtained from the GEOS-1 satellite /18/. Thus, from recent data we cannot consider He^+ to be a minor constituent, and the plasma should therefore more properly be regarded as consisting of two important components.

The question as to why the He^+ abundance increases in the plasmasphere according to recent measurements as compared with the OGO data was not discussed in /17/ and /18/ (whether it is related to the measurement methods or reflects some considerable temporal variations in the He^+ number density).

Measurements from the DE-1 satellite detected for the first time N^+ and N^{2+} ions. The fluxes of N^+ are 0.05-0.01 of the O^+ fluxes and those of N^{2+} are 0.05-0.1 of the N^+ fluxes /19/. N^+ ions were not distinguished from O^+ in earlier measurements due to the insufficient mass resolution of the instruments used.

Since O^{++} and He^+ ions are present in small amounts in the terrestrial atmosphere and are practically absent in the solar wind, the considerable amounts measured in the magnetosphere, outside the plasmasphere, could be an argument in favor of their plasmaspheric origin and be useful in studying plasma circulation in the magnetosphere.

Ion Number Density and Temperature Distribution in the Plasmasphere from Prognoz-5 Data

At the Conference on fundamental magnetospheric processes near the plasmapause held in Huntsville, USA, in October 1983, much attention was paid to the definition of the "plasmapause", as the report /20/ shows. This name was given by Carpenter /21/ to the outer boundary of the comparatively dense plasma region surrounding the earth and was related to an abrupt decrease in the plasma number density. As mentioned above, however, Carpenter also emphasized the complex and inhomogeneous structure and variability of the plasmasphere in general, and of the plasmapause, in particular. It was already noted in the sixties that the plasmapause is characterized not only by considerable gradients of the plasma number density, but by other phenomena as well (for instance, the spikes of electron heating of electrons at the plasmapause /23/). Data from the Soviet Elektron-4 satellite showed that a gradual decrease in the plasma number density is also sometimes observed /24/. Therefore, the problem of plasmapause definition is sometimes rather complicated. Judging from Green and Horowitz's report on the Huntsville Conference /20/ (Soviet scientists did not take part) the problem of the plasmapause shape (its local time dependence of the plasmapause L-value, L_{pp}) was not discussed at the conference. Meanwhile there is no generally-accepted opinion about this problem in spite of its importance for the plasma circulation in the magnetosphere. Fig.1 presents the average plasmapause position, (a) from whistler measurements /21/; (b) from OGO-5 ion mass spectrometer data /4/; and (c) from ion trap data from the Prognoz satellite series (for small K_p) /25/. In figures 1(a) and 1(b) the noon and midnight L_{pp} values are seen to be almost identical, while in Fig.1(c) they are substantially different, and in addition to an evening "bulge" there is also one at noon.

We will now discuss some plasmasphere measurements from the Prognoz-5 satellite. The satellites of the Prognoz series (up to Prognoz-8) were launched into practically identical orbits with an apogee of $\sim$31 Earth radii, an inclination to the equator of $\sim$65°, and

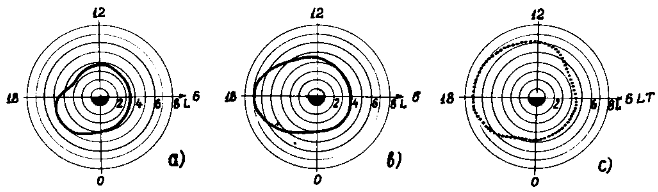

Fig. 1. Equatorial cross-sections of the plasmapause: (a) - average position according to whistler data /21/; (b) - average position according to OGO-5 data /4/; (c) - positions for K_p = 1-2 according to Prognoz-1 and Prognoz-2 data /25/.

an orbital period of ∿4 days. Figure 2 shows the near-earth part of a typical orbit of one of these satellites projected onto the solar-ecliptic X,Z-plane, during the early part of the mission. For a comparatively short time (∿3 h) the satellite intersects the same L-shells at different altitudes and latitudes and makes it possible to estimate the parameters of the plasmaspheric pl:sma in different parts of the same L-shell.

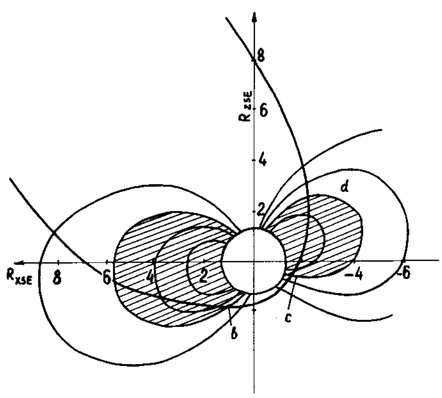

Fig. 2. Projection of the Prognoz-1,2 and Prognoz-5 near-earth parts of orbits onto the X,Z-plane in solar-ecliptic coordinates.

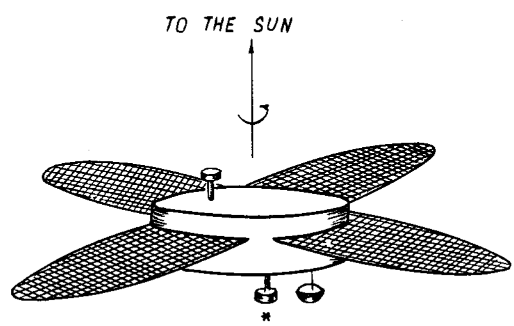

Fig. 3. Ion retarding-potential analyzer location on board the Prognoz-5 spacecraft (asterisk).

Fig. 3 shows the position of the Prognoz-5 retarding potential ion analyzer. It is shown by the asterisk and is located on the shaded part of the satellite which rotates about an axis oriented sunward. The analyzer aperture is perpendicular to this axis.

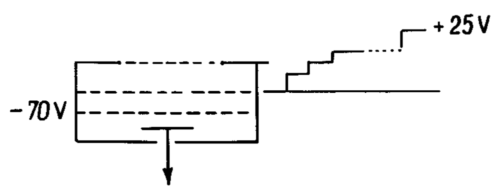

Fig. 4. Flat ion-retarding-potential analyzer on board Prognoz-5.

Fig. 4 is a sketch of the analyzer. The outer grid is at the satellite potential; on the middle analyzing grid the potential varies relative to the satellite from 0 to 25 V, while on the last grid there is a constant potential of 70 V which prevents photoelectrons from the satellite sheath from reaching the analyzer collector.

Processing of the retardation curves (ion probe characteristics) was performed as follows. The current intensity measured in the ϕ = 25 V step was first subtracted from the other measured currents (i.e., the effect of ion fluxes with E > 25 eV and of electrons with E > 70 eV corresponding to the voltage - 70 V on the supressor grid of the analyzer were removed). The slope of the retardation curve when plotted on a semilogarithmic scale gives T_i, with smaller slopes giving larger T_i according to Langmuir theory. The presence of two linear parts of the retardation curve was interpreted as being due to He^+ ions. Data processing was performed assuming a Maxwellian ion velocity distribution. When the retardation curve showed a single linear part, all the ions were taken to be protons and the least-squares method was used to select an analytical expression including the satellite velocity (known), the ion number density n_i, their temperature T_i and the satellite potential ϕ_s, such that the theoretical curve and experimental data best coincided. Plasma drift can only shift the retardation curve but does not change its slope, and ions with $E > 25$ eV contribute to the collector current in a way which does not vary with the retarding potential, and hence does not affect the T_i determination.

As a result of processing each retardation curve, values of n_i and T_i are obtained characterizing the proton component of the plasma. One retardation curve is measured in 80 s, which corresponds to an orbital path length of ∿300 km at altitudes of ∿15,000 km and ∿700 km near to perigee.

Since the acceptance cone of the ion analyzer is wide (a cone with vertex angle ±40°), the pitch-angles of ions cannot be measured. Anisotropic ion fluxes can, however, be detected by the analyzer within the limits of this acceptance cone. If the anisotropic ion fluxes are comparable with the isotropic fluxes and the energy of the former is $E < 25$ eV, then they also will be analysed over energy, changing the shape of the retardation curve and causing nonlinearities in portions of the retardation curve plotted on a semilogarithmic scale. In this case the number density and energy of these ions can be roughly estimated by approximating the nonlinear portions of the retardation curves by linear ones. This fact should be kept in mind when comparing the retarding-potential analyzer results with later measurements made near the plasmapause by more sophisticated, narrow-angle instruments which allow measurements of the ion pitch angle to be made.

Bezrukikh and Gringauz in 1976 /26/ found from Prognoz-1 and -2 satellite data that there are two zones in the plasmasphere: a stable, cold zone at $L < 3$ where $T_i < 0.8$ eV (i.e., T_i values are relatively close to ionospheric temperatures) and an outer "hot" variable zone at $L > 3$ where $0{,}9$ eV $< T_i <$ ∿ 20 eV. Separation of the whole plasmasphere (not only in the equatorial plane) into cold and hot zones became possible in 1976 only by using Prognoz data from different latitude regions on the same L-shells. Gringauz (1983) noted that it is reasonable to change the term "hot zone" for the term "warm zone".

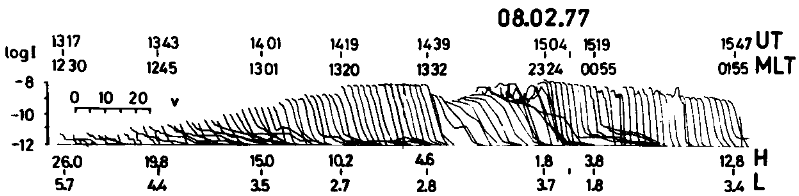

Fig. 5. Composite of the ion retardation curves for the near-earth section of a Prognoz-5 orbit.

Fig. 5 presents a retardation curve composite (using a semilogarithmic scale) which was obtained on 8.02.1977 during a passage of the Prognoz-5 satellite through the plasmasphere. This figure illustrates the variations in slope of the linear portions of the retardation curves (the steeper is the slope, the lower is T_i), the presence of the cold and warm zones, and also the presence of parts of the trajectory (in the outer zone) where the retardation curves have more than one linear portion which indicates the existence of a multi-component plasma.

In Figures 6-10 we will now examine some typical n_i (L, H) and T_i (L, H) profiles obtained from the Prognoz-5 data. Each of these figures shows a pair of n_i and T_i distributions. The left hand distribution corresponds to the inbound part of the orbit and also, in most cases, to daytime whereas the right hand distribution corresponds to an outbound trajectory and, generally, to night-time. The horizontal axis indicates the L-parameter and altitude H above the Earth's surface, while the maximum K_p index for the preceding day (K_{pm}) and the sum of K_p for the preceding day (ΣK_p) together with the D_{st} index of the time of measurement are given at the top of the figures.

Fig. 6 gives results obtained on 3.01.1977. The plasmapause is distinctly seen both in the day-time and night-time n_i distribution. Inhomogeneities of n_i in the night-time plasmasphere are more intense than in the day-time. There is a considerable noon-midnight asymmetry of the plasmapause, and the night-time n_i-profile is steeper than the day-time profile. The warm zone is observed only in the night-time plasmasphere, while $T_i < 10^4$ K everywhere in the day-time plasmasphere.

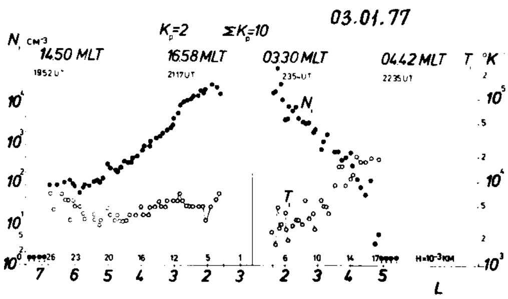

Fig. 6. Distribution of n_i (L, H) and T_i (L, H) from Prognoz-5 data on 3.01.1977.

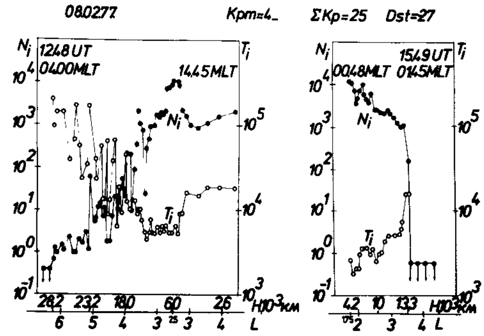

Fig. 7. The same as Figure 6 but on 8.02.1977.

Fig. 7 (08.02.1977): the values of n_i and T_i in the morning and day-time plasmasphere at L > 3 are rather inhomogeneous during the whole satellite passage; in the night-time plasmasphere the inhomogeneities are less intense. The night-time plasmapause is well-pronounced whereas the morning n_i-profile is characterized by a gradual but oscillating decrease of n_i, and the plasmapause can be defined only as the point where n_i reaches a minimum corresponding to the instrument sensitivity. The noon-midnight asymmetry is considerable, and while the warm zone is present both at night and in the day, the day-time and morning values of T_i are significantly higher than at night.

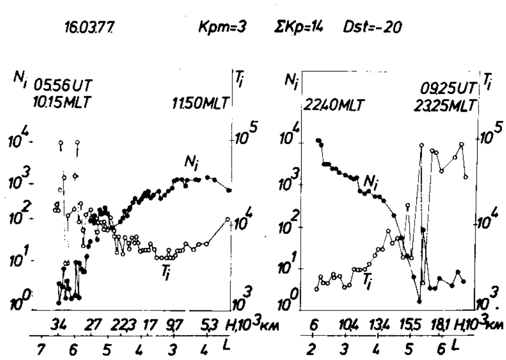

Fig. 8. The same as Figure 6 but on 16.03.1977.

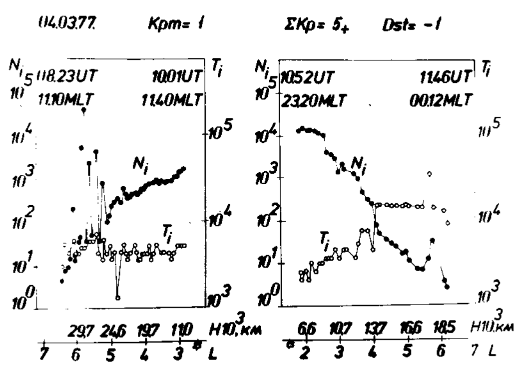

Fig. 9. The same as Figure 6 but on 4.03.1977.

Fig. 8 (16.03.1977): the plasmapause is determined without difficulty both in the day and nightside passes, but the plasmaspere is inhomogeneous, the n_i and T_i inhomogeneities being especially large near the plasmapause. A noon-midnight asymmetry is present, the nightside n_i profile being steeper than the dayside profile. The warm zone is present in both cases.

A case where a well-pronounced noon-midnight plasmapause asymmetry is absent during quiet geomagnetic conditions is shown in Fig. 9. In spite of the low magnetic disturbance during the measurement interval and the extremely quiet geomagnetic prehistory (ΣK_p = 5+), very large n_i inhomogeneities were observed (reaching several orders of magnitude) in the noon plasmasphere resulting in difficulties in determining the plasmapause location at L $\sim$ 3÷6, $T_i > 10^4$K. In the midnight region a gradual decrease in n_i is observed from L $\sim$ 2.5 to L$\sim$5.5 with comparatively small n_i inhomogeneities. The warm zone ($T_i > 10^4$K) is observed at L > 4 in the night-time plasmasphere only. The plasmapause location determination is just as difficult as in the case of the dayside.

Fig. 10 (29.11.1976): the inbound part of the satellite orbit in this case crossed the evening and midnight region of the plasmasphere (LT - 17.05 to 02.30). The decrease of n_i with increasing altitude and L-parameter is gradual; n_i inhomogeneities are comparatively small; the plasmapause is difficult to determine; the plasmasphere boundary could, apparently, be identified as the region of the minimum measured n_i values. In the morning-noon sector of the plasmasphere, the picture is similar. An asymmetry of the plasmasphere is not observed. The warm zone is present only for large L (L > 5.5).

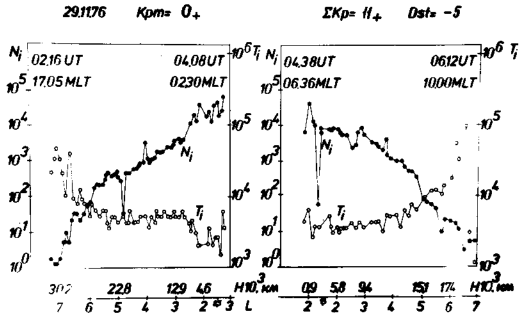

Fig. 10. The same as Figure 6 but on 29.11.1976.

The typical examples discussed above, taken together with all the other data obtained from the Prognoz-5 satellite allow us to draw the following conclusions:

1. The plasmasphere is often inhomogeneous in terms of its plasma number density and proton temperature, especially in the plasmapause region.

2. A noon-midnight asymmetry in the plasmapause occurs generally (but not always) during periods of low and moderate magnetic disturbance.

3. The day-time $n_i(L)$ profile is in most cases less steep than the night-time profile.

4. A well-pronounced plasmapause, being a region where the plasma number density decreases rapidly can be observed either on both day and night sides of the plasmasphere, or only on one or other of them, or it may be absent over the whole plasmasphere (i.e., the plasma number density decrease with increasing L can sometimes be gradual).

5. The inner plasmasphere zone (L < 3) is as a rule cold (T_i < 8·10³K). In the outer part of the plasmasphere, warm plasma can present on both day and night sides, (T_i > 8·10³K) or it may be present only at the night or the day side of the plasmasphere, or, rarely, it may be absent on both sides.

The above features of the plasmasphere and the plasmapause mean that one should be very careful in trying to determine specific characteristics of the plasma circulation in the magnetosphere based on the shape and the location of the plasmapause.

Comparison of Prognoz-5 Results with the Results of other Satellites

Noon-midnight asymmetry of the plasmasphere. This feature of the plasmasphere having been described by Gringauz and Bezrukikh (1976) /5/ was confirmed by Maynard and Grebowsky (1977) /8/ who analysed Explorer 45 electric field double - probe data, by Carpenter (1978) /6/ who used wistler data, and by Decreau et al. from the data of an active wave experiment on GEOS-1 (mutual impedance method) /7/. Recently the difference in the properties of the noon and midnight plasmasphere was confirmed by another active wave experiment (relaxation sounder) on the GEOS-2 spacecraft in 1979 (Higgel and Lei, 1984) /27/. Fig. 11 shows the electron number density n_e measured by this geostationary satellite at different local times in the range 0.1 < n_e < 100 cm⁻³. The distance of every point from the center of the diagram indicates n_e. As seen from the diagram n_e values at noon are substantially higher and more stable than the values near midnight, and this fits in well with the Prognoz-5 results.

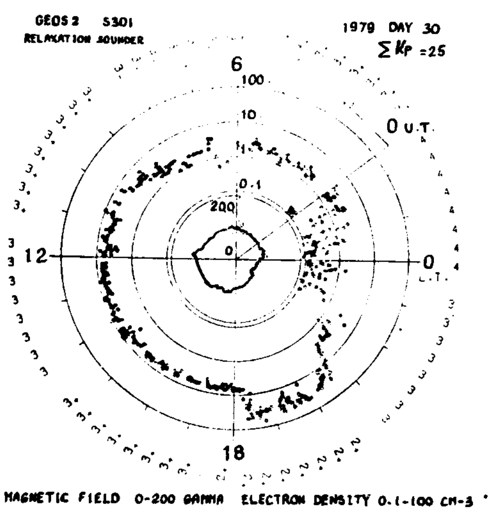

Fig. 11. Polar diagram of n_e (MLT) from GEOS-2 data on 30.01.1979 /27/.

The data of Prognoz-5 (1977) and GEOS-2 (1979) are in agreement with the Prognoz-1,2 (1972) data (Fig. 12). All these data together indicate that the noon-midnight plasmapause asymmetry is observed at all phases of the solar cycle. The question of the diurnal variation of plasmapause altitude seems not to have been discussed in recent papers by American authors, nor at the Huntsrille Conference /20/, in spite of its evident importance for plasmasphere physics and for the magnetospheric plasma circulation problem.

Warm zone in the plasmasphere. The only data on the charged particle temperature in the plasmasphere up to 1976 were the T_i estimates based on the Soviet Luna-2 rocket measurements /28/ and the T_i and T_e data from OGO-5 (Serbu and Maier /29/), the latter being per-

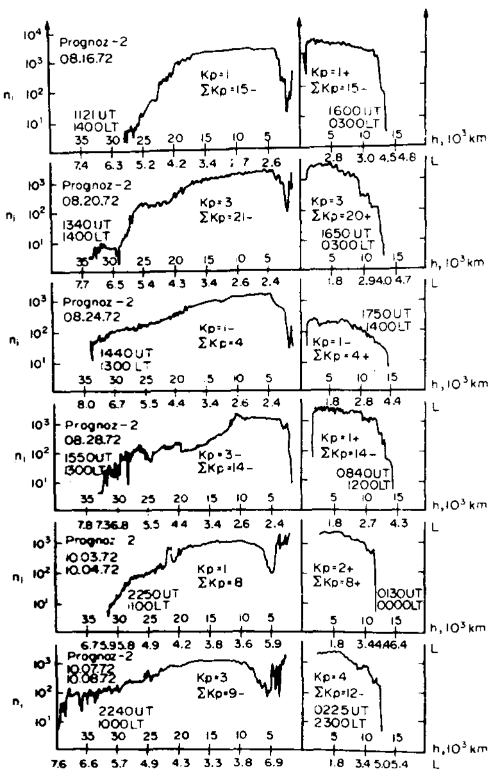

Fig. 12. **Distributions of n_i (L, H) from Prognoz-2 data /5/.**

formed at small inclinations to the equatorial plane. Bezrukikh and Gringauz /27/ presented data on T_i for various latitude regimes and showed that at L < 3, T_i < $8\cdot10^3$K not only near the geomagnetic equator but also over the whole plasmasphere. They suggested that the plasmasphere should be considered as consisting of both "cold" (T_i < $8\cdot10^3$K) and "hot" (L > 3, $T_i \sim 10^4-2\cdot10^5$K) zones. It is more reasonable, however, to call the latter the "warm" rather than the "hot" plasmaspheric zone /9/.

A great number of experimental data were published after 1976 indicating that for L > 3, $T_i \sim$ 1 to 20 eV. Most of these publications are related to the near-equatorial region - the data being obtained from ATS-6, GEOS-1,2, ISEE-1, and the SCATHA satellite /30/, /31/, /7/, /17/, /32/, /33/. The only satellite (besides those of the Prognoz series) performing measurements well away from the equatorial plane is the Dynamic Explorer-1 satellite /34/, /18/. All these results, without exception, confirm the presence of the warm zone in the plasmasphere (the Prognoz-5 data presented above indicate, however, that the whole plasmasphere is sometimes cold, <1 eV).

According to DE-1 data (for L > 3) on 14.10.1981 at L $\sim$ 3.1, isotropic protons were observed with $T_H^+ \sim$ 2 to 2.2 eV and with $n_{H^+} \sim$ 200 to 500 cm^{-3}, while He^+ ions were observed with the same temperature but with number densities $n_{He^+} \sim$(140-165) cm^{-3}. Moreover, the same satellite measured anisotropic protons H^+ with a temperature of 10 eV and a number density 2 to 5 cm^{-3} and He^+ ions with $T_i \sim$ 10 eV and $n_{He^+} \sim$ 2 to 3 cm^{-3} /33/.

Several minutes after DE-1 encounted the plasmapause (L $\sim$ 3.5) the number density of isotropic H^+ ions decreased to 130-160 cm^{-3} (at the same temperature $\sim$2 eV). The number density and energy of the anisotropic H^+ ions increased respectively up to 4 cm^{-3} and 15 eV. Without discussing in detail here methodological questions, it is reasonable, however, to emphasize that in the first case the Prognoz-5 retarding-potential analyzer could not observe the high temperature anisotropic component of the plasma but might give the common temperature $T_i \sim$ 2.2 eV, while in the second case (if the anisotropic fluxes penetrated into the analyzer) an increase of T_i should be measured.

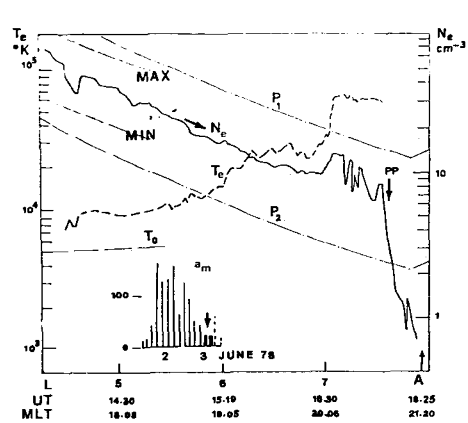

Fig. 13. Distributions of n_e(L) and T_e(L) from HEOS-1 data on 2-3.06.1978 /7/.

The DE-1 plasma measurements thus confirm the concept of cold and warm zones in the plasmasphere(and also contain information on the composition and detailed structure of the "warm" zone). In some DE-1 energy-spectrograms /34/, the "warm" zone of the plasmasphere can be visually distinguished from the cold zone.

Fig. 13 presents an example of the n_e(L) and T_e(L) distribution in the outer zone of the plasmasphere obtained by the mutual impedance method from GEOS-1 /7/. As seen from the figure, T_e at L > 5 considerably exceeds T_e in the ionosphere and, as the authors indicated, the observed T_e variations with L correspond qualitatively to the results reported by Bezrukikh and Gringauz /26/. It should be noted, however, that T_e values are lower than simultaneous T_i values following the results of /26/, /18/ and /33/.

It is noteworthy that T_e and T_i temperatures in the plasmasphere were first measured simultaneously on OGO-5 by Serbu and Meier /29/. The mechanism of plasma heating occurring in the warm zone appears to be more effective for ions than for electrons.

Plasmasphere and Magnetospheric Plasma Circulation

Up to now the concept has been widely used that the plasmapause is the most external closed electric equipotential surface in near-earth space which bounds the convection "forbidden-zone" of cold magnetospheric plasma. According to /1/, /2/ this region has a "tear-drop" shape symmetric with respect to the dawn-dusk meridian (i.e., without a noon-midnight asymmetry) and is determined only by the homogeneous convection electric field (directed from dawn to dusk) superimposed on the radial electric field of cold plasma corotation with the Earth. Factors such as the effects of the non-uniform transverse conductivity of the ionosphere on the potential distribution in the equatorial plane, the processes of plasma exchange between the plasmasphere and the ionosphere and mechanical forces (gravitational and centrifugal) acting on ions were not taken into account in this model.

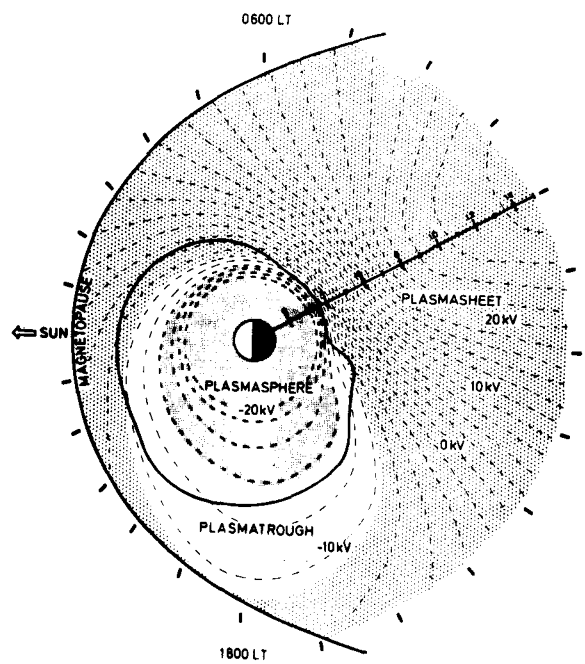

Fig. 14. Example of Lemaire's calculations of the plasmapause /10/.

This model became commonly used since with reasonable assumptions about the dawn-dusk convection electric field ∿0.5 mV/m it resulted in an acceptable altitude of the plasmapause in the equatorial plane and explained its dusk bulge. Nevertheless, this concept of plasmapause formation is clearly over-simplified for the above reasons and is unacceptable if for no other reason than it cannot explain the noon-midnight plasmapause asymmetry which, as we have seen, is a commonly observed feature of the plasmapause. Space restriction does not allow us to describe here the theoretical works concerning the formation of the plasmapause. I would like, however, to mention Lemaire's work beginning in 1975 /10/. Lemaire used empirical McIlwain models of the electric and magnetic fields and took into account mechanical forces acting on the ions. It should be noted that according to Lemaire, the plasmapause is not the last closed electric equipotential but is determined by the combined effect of both electromagnetic and mechanical forces acting on ions which together determine the formation of the plasmaspheric boundary (plasmapause). Fig. 14 shows the results of one of Lemaire's calculations; the plasmapause has both dawn-dusk and noon-midnight asymmetry. Since any theory should be checked by its correspondence to experimental data, it seems to me that more attention should be paid to Lemaire's work than has been paid up to now.

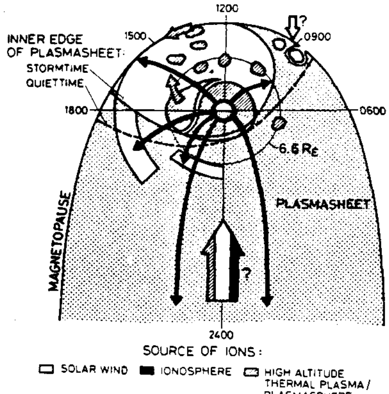

Fig. 15. Large-scale magnetospheric circulation according to Balsiger /35/.

Finally, in the plasmasphere there are also O^{++} and He^{+} ions. Their relative number densities as compared with another ions exceed substantially their relative abundance in the ionosphere and they are absent in the solar wind. Considerable fluxes of these ions have been measured in the plasma sheet and ring current (Balsiger, /35/). This validates the assumption of the plasmaspheric origin of these ions and leads to the important possibility of observing the processes which accelerate these ions and their flow paths in the magnetosphere using ion energy-mass-spectrometers. Fig. 15 shows a possible pattern of magnetospheric convection taking into account the partially plasmaspheric origin of the magnetospheric plasma sheet /35/.

SOME CONCLUSIONS

1. There is no commonly accepted theory of the plasmapause formation, which can explain peculiarities of the shape and time behavior of the plasmapause.

2. The plasmapause (and the plasmasphere) is inhomogeneous plasma region, very variable. The dayside plasmapause is often less steep than nightside and often is difficult to define its position.

3. The midday-midnight asymmetry of the plasmapause does exist often but not always.

4. The heated (warm) zone of the plasmasphere outside $L \sim 3$ is almost always observed at night but more rarely at midday. The inner plasmasphere ($L < 3$) is always cold ($T_i < 0.8$ eV).

5. There are not clear reasons of large differences in He^+ content in the plasmasphere between OGO-3,4 data,on one side, and GEOS-1,2 and DE-1 data, on the other side. Peculiarities of chemical composition of the plasmasphere can be used for the study of plasma circulation in the magnetosphere.

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