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ON THE FORMATION OF THE NIGHTSIDE IONOSPHERIC BULGE IN THE VENUS WAKE

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RESUMEN

Se presenta un estudio de la distribución de la posición de la ionosfera del planeta Venus conforme a las observaciones hechas en el experimento de medición de temperatura de electrones con la sonda Pionero Venus. Los resultados de este estudio son examinados en conexión con la geometría de la prominencia ionosférica nocturna de ese planeta. Se demuestra que la evidencia experimental indica que además de mostrar alturas decrecientes con latitud, la prominencia se presenta menos frecuentemente a altas latitudes. Este resultado es consistente con las predicciones del modelo viscoso y la penetración de partículas del viento solar hacia la umbra planetaria por el terminador polar.

ABSTRACT

A study of the distribution of ionopause crossings obtained from the Pioneer Venus electron temperature probe measurements is presented and its results discussed in connection with the configuration of the nightside ionospheric bulge. It is shown that the available experimental evidence indicates that in addition to showing decreasing heights with increasing latitude, the bulge of the nightside ionopause is also less frequently formed at high latitudes. This result is consistent with the predictions of the viscous entry model and the penetration of ionosheath fluxes into the umbra through the polar terminator.

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INTRODUCTION

The observation of a prominent nightside ionospheric bulge in the Venus nightside ionopause as reported by Brace *et al.* (1979, 1980) has revealed a strong dynamic interaction between the shocked solar wind and the ionospheric plasma. Even though the measured positions of the nightside ionopause is indicative of highly variable conditions which include sudden changes in height and the observation of complex layer and cloud-like structures, there seems to exist a general coherent pattern controlling its overall configuration. Thus, the reported bulge (or region of increased ionopause height) appears to be more prominent and better defined at low than at high latitudes. In addition, the phenomenon exhibits an apparent approximate symmetry with respect to the midnight plane.

When the ionopause height is plotted as a function of the solar zenith angle, an initial increase in height is seen at about 130^o and 110^o (for the outbound and inbound crossings, respectively) and a subsequent decrease to very low altitudes at larger angles. Brace *et al.* (1980) have indicated that this seeming behavior is the result of an intrinsic bias imposed by the geometric restrictions of the Pioneer-Venus orbit which cannot intersect high altitude positions of the ionopause in the deep regions of the umbra. In fact, when the data are plotted in terms of the local solar time (LST), the bulge is distributed uniformly across the entire nightside, 2 to 3 hours behind the planetary terminator.

The existence of a well-defined ionospheric boundary above the nightside hemisphere is suggestive of particle fluxes streaming within the umbra outside of an effective ionospheric obstacle. The fact that such a boundary may extend to very high altitudes can, in addition, be interpreted as indicating a pronounced downstream elongation of the nightside ionosphere by the external streaming fluxes. A configuration consistent with this behaviour was recently presented by Pérez-de-Tejada (1980) in terms of a viscous flow interaction between the ionosheath flow and the local plasma near the polar terminator (defined with respect to the plane formed by the Sun-Venus axis and the direction of the interplanetary magnetic field). According to this model the interplanetary magnetic field piled up in front of the dayside ionosphere prevents the direct contact between both plasmas across the entire cross section of the ionospheric obstacle. Near the polar regions, however, the enhancement of interplanetary magnetic fluxes is expected to be significantly less effective and thus should permit the onset of the proposed viscous interaction.

A most important consequence of this configuration is the fact that the entry of the ionosheath flow into the wake should be controlled primarily by the conditions present at the polar regions. Thus, the magnitude and the latitudinal distribution of the enhanced magnetic fluxes outside the dayside ionosphere directly determine the extent of the region where the viscous interaction takes place and in turn affect the resulting latitudinal distribution of the outward bulge of the ionopause in the nightside.

We should note in this regard that the more effective accumulation of the interplanetary magnetic field lines at low latitudes also implies a harder and better developed downstream extension of the dayside ionopause at these latitudes. The configuration of the boundary near the polar regions should, on the other hand, be more dependent on the time varying conditions affecting the interaction process near the terminator. Thus, the cavity formed by the draped interplanetary magnetic field around the ionospheric obstacle (as shown in figure 1 of Pérez-de-Tejada, 1980) should, in general, be more easily deformable at high latitudes and exhibit a tendency to flatten out in the direction perpendicular to the solar wind velocity and magnetic vectors. It follows from these considerations that the observation of the ionospheric bulge in the near wake should exhibit a preferred rate of occurrence at low latitudes and that in a proportionately larger number of cases the high latitude ionopause should exhibit non-bulge conditions as a result of the more frequent collapse of the cavity at those latitudes. This condition should exist downstream from the planetary terminator and affect possible assymetries of the dayside ionospheric obstacle. Such assymetries have, in fact, been predicted by Cloutier and Daniell (1974) in studies of differences in the efficiency of the convective V x B electric field impressed upon the ionosphere by the flowing solar wind.

The purpose of the present paper is to analize the ionopause observations of Brace *et al.* (1979) and to show how they may be consistent with the process of solar wind interaction with the Venus ionosphere as described by Pérez-de-Tejada (1980). A similar treatment has also been proposed by Gombosi *et al.* (1980) in terms of diffusion processes forced on the ionosheath flow by small-scale fluctuations of the magnetic field near the ionopause. In that study, as well as in the viscous flow model, it is assumed that the entry of the solar wind plasma into the umbra behind the terminator results from strong wave-particle interactions which control the motion of the particles throughout the region of interaction.

ANALYSIS OF THE PIONEER VENUS MEASUREMENTS

A direct test on the suggested preferred occurrence of the bulge at low magnetic latitudes can be carried out by examining the distribution of ionopause crossings in the nightside hemisphere as reported by Brace *et al.* (1980). The Pioneer-Venus data are particularly suitable to investigate this question as the spatial position of the spacecraft's orbit allows consecutive measurements of the high and low latitude ionopause in each pass. The latitude and local solar time of over 300 ionopause crossings obtained during the first 304 passes of the Pioneer-Venus orbites between LST = 16 hrs and LST = 8 hrs across the entire nightside hemisphere is presented in Figure 1. These observations include some measurements made upstream from the terminator and thus expose the relative increase in ionopause altitude and latitude from the dayside to the nightside as detected in the inbound and outbound transversals. The vertical scale in the right hand side gives the approximate height of the ionopause crossings which is uniquely related to the local latitude of the observations (see, for example, figure 3 in Brace *et al.* 1980).

Aside of the fact that a number of points do show the overall tendency for the ionopause to rise at night in both the inbound and outbound crossings, it is notable that in many cases the nighttime ionopause exhibits a comparable or even lower height than the dayside crossings. The position of these points does not necessarily imply, however, the collapse of the nightside cavity since the spread of the dayside crossings suggests that in many instances a small size (dayside) ionospheric obstacle could induce a small nighttime bulge. In order to assess the contribution of this latter possibility it is useful to examine statistically the relative position of the nightside crossings with respect to that of the dayside points.

The total population of points within and outside the bulge along latitudinal bands 10° thick drawn across Figure 1 is shown in Table 1. The bulge has been selected as that region between LST = 20 hrs and LST = 4 hrs which includes the large majority of the height-increased crossings detected. By independently calculat-

λ	INBOUND		OUTBOUND	
	Outside	Inside	Outside	Inside
0-10°			12	4
10-20°			46	9
20-30°	–	2	32	24
30-20°	2	5	–	15
40-50°	27	11	–	15
50-60°	41	32		
60-70°	10	23		

Table 1.- Population of ionopause crossings inside and outside the bulge region (between LST = 20 hrs and LST = 4 hrs) for selected latitude bends.

ing (for the regions within and outside the bulge) the relative fraction of the population of each latitudinal band with respect to the total number of points in each of these two regions it is possible to compare both distributions despite the different sampling available for the dayside and nightside hours. Figure 2 shows the resulting frequency distributions obtained in this way for the inbound and outbound

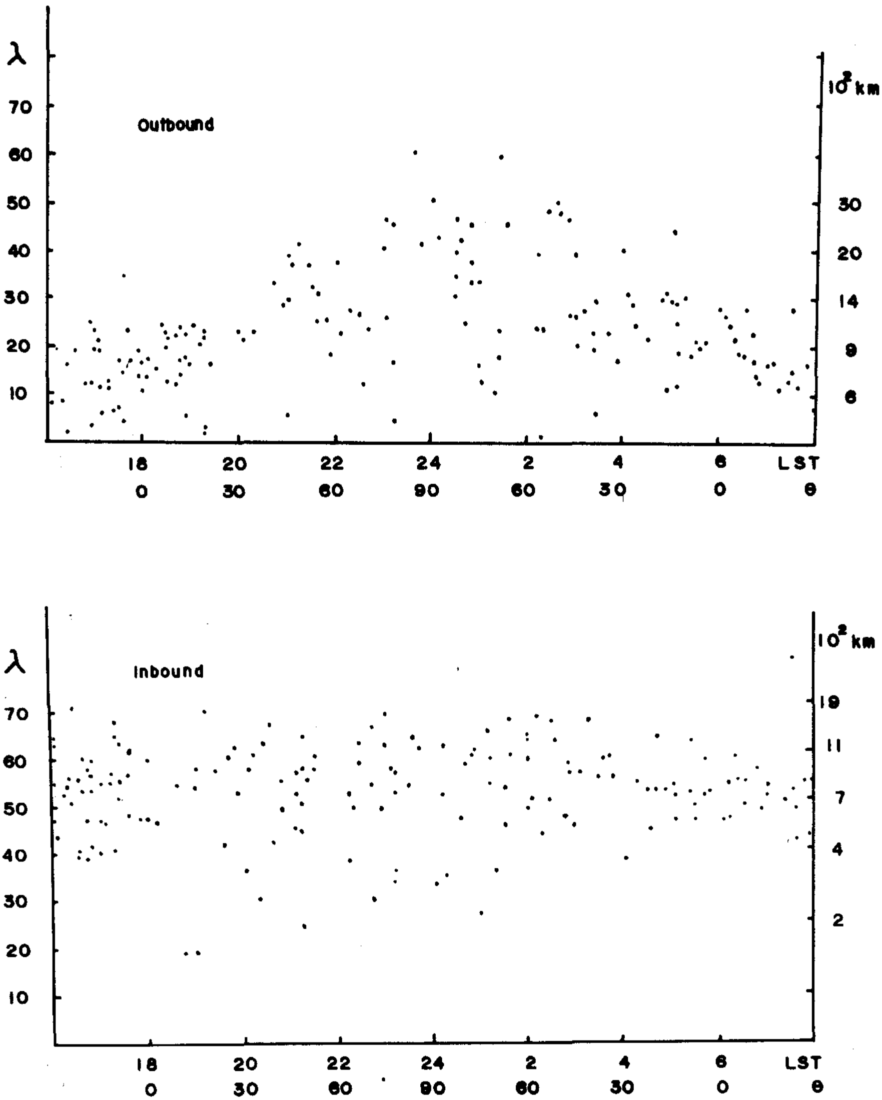

Fig. 1. Position of the Venus ionopause as detected in the inbound and outbound passes of the Pioneer-Venus orbiter between LST = 16 hrs and LST = 8 hrs.

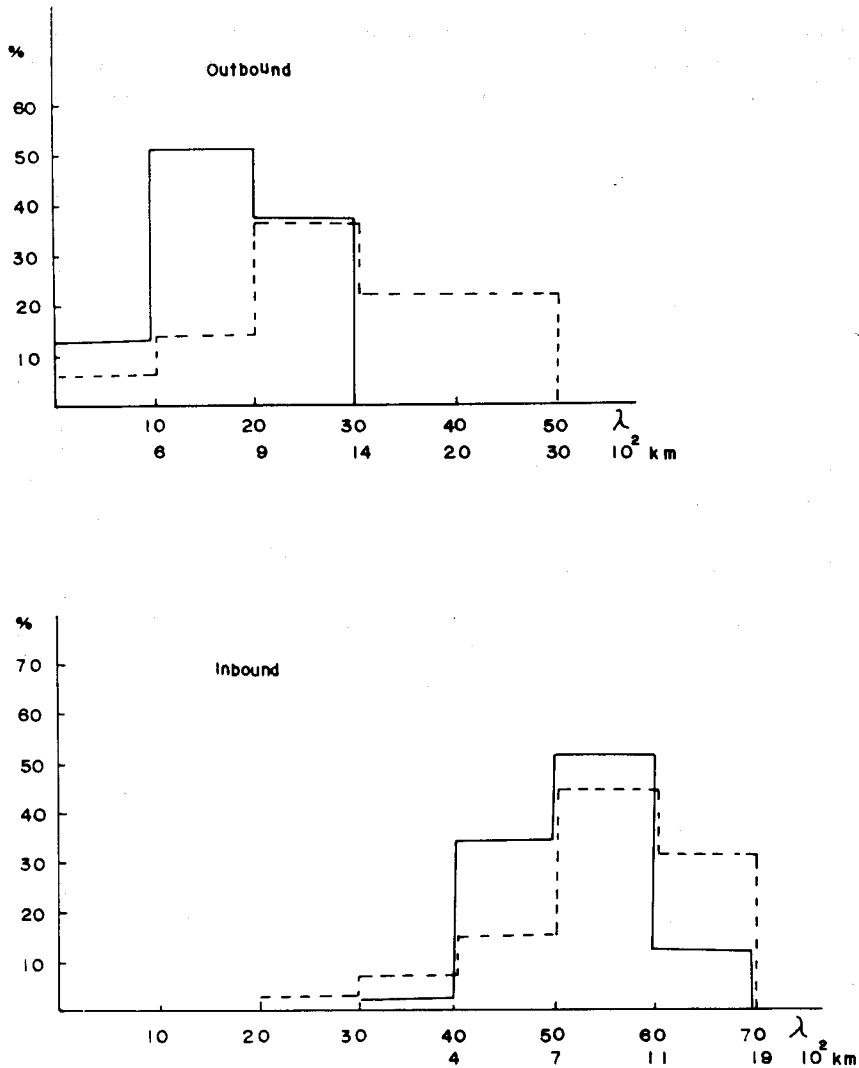

Fig. 2 Frequency distribution of the ionopause crossings shown in Figure 1 for the regions within (dashed lines) and outside (solid lines) the bulge (between LST = 22 hrs and LST = 4 hrs.)

crossings. The most notable result of this analysis is the distinct upward shift of the nightside ionopause in the outbound crossings with respect to the dayside ionopause distribution. This feature, which is not as notable in the inbound crossings reflects an abundance of low latitude crossings exhibiting a high altitude nighttime ionopause. This result refers to the number of cases where this occurs and is unrelated to the magnitude of the observations themselves. Thus, we note that at the heights where the dayside ionopause is more frequently seen (700 - 1100 km and 600 - 900 km for the inbound and outbound crossings, respectively) the nightside ionopause occurs more frequently in the inbound crossings (44 %) than in the outbound crossings (14%). This means that it is far more probable for the ionopause to keep the same height range (that is, non-bulge conditions) in the inbound crossings than in the outbound ones. At the same time, we note that in the low height tail of the distributions, the altitude of the ionopause is seen to decrease more frequently at night in the inbound crossings than in the outbound ones. A simpler and less approximate way of analyzing the data can also be performed, in Figure 2, by assigning the non-bulge distributions to a single latitudinal bin and examining the bulge distribution with respect to this bin. We note first, that the outbound and inbound nonbulge ionopause crossings can be assumed to occur almost entirely at 10-30° λ and 40-60° λ, respectively (85 % and 87 % of all cases actually occur within these bins). An analysis of the nighttime ionopause distributions with respect to these latitudinal bins indicates that, in the outbound crossings, 50 % of all cases occur within and 44 % above the bin. In the inbound crossings, 59 % of all cases occur within the bin and 31 % above the corresponding bin. These numbers suggest, again, that the nightside ionopause height increases more frequently at low latitudes. Conversely, there is a preference for the high-latitude crossings to remain in the same altitude range in the nighttime hours.

The suggested more frequent deformation of the magnetic cavity near the polar regions may also be partly responsible for the reductions of ionopause height seen in the outbound (low latitude) crossings. It is interesting to note, however, that the large majority of the ionopause crossings of the low-height tail of the outbound bulge distribution of Figure 2 are observed within ± 3 hours of the midnight plane and that only a few points are actually detected near the boundary of the cavity at these latitudes. This configuration is again indicative of a harder and less deformable low-latitude boundary of the magnetic cavity and of the presence of ionosheath fluxes admitted preferably at high latitudes. We should note, in addition, that since the geometry of the Pioneer-Venus trajectory favors the detection of low-latitude ionopause crossings in the deep regions of the umbra, it is conceivable that an even more noticeable latitudinal dependance of the distribution of the nightside ionopause positions may actually exist (the low-latitude ionopause is, in fact, expected to grow up to $R \approx 6\,000$ km, when SZ = 145^{0}, see Perez-de-Tejada, 1980)..

Additional experimental evidence in support of these contentions can also be inferred from studies of the position of the Venus bow shock as that recently presented by Slavin *et al.* (1980). Figure 7 of that paper compares the normalized position of various high latitude crossings measured by the Pioneer-Venus magnetometer with those inferred from the (low latitude) Venera measurements. Even though the average bow shock location suitable to both sets of data is approximately the same in the region close to the planet, a gradual discrepancy is apparent far downstream from the terminator where the effects of flow expansion behind the planet are expected. The fact that the Pioneer-Venus crossings occur closer to the cavity axis than the Venera crossings is consistent with the general east-west flattened-out geometry of the magnetic cavity in the direction perpendicular to the solar wind velocity and magnetic vectors as proposed before (more detailed measurements of the bow shock position downstream from the planet are necessary, however, to make an adequate identification of the three dimensional shape of the bow shock surface, Slavin, personal communication, 1980). In situ measurements of the flow direction in the Venus plasma wake carried out with the Pioneer-Venus plasma probe and retarding potential analyzer instruments are currently under examination (Intriligator *et al.*, 1979; Knudsen *et al.*, 1980) and will ultimately provide more direct information to test the flow configuration within the Venus plasma cavity.

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