tivity. Thus, a definitive measure of the H density ratio awaits further statistical analysis. However, we give a preliminary estimate of the night-to-day H density ratio of the order of 10.

The further buildup of H^+ toward the dawnside, where it becomes the dominant topside ion, sets up a situation that has similarities to the polar wind on Earth, where the light ion H^+ is propelled upward away from the planet by the polarization electric field produced in the presence of the heavier ion O^+. If H^+ is to escape in this manner to form a "tail wind" on Venus, it must occur in a region which presents the least resistance or back pressure. This may actually be the case in the postmidnight region where H^+/O^+ reaches a maximum and where the ionopause is observed to exhibit some of its highest elevations on the nightside; that is, the dawnside plasma bulge previously identified by Brace *et al.* (*2*). This is a likely region for H^+ to escape along open magnetic flux tubes because the higher H^+ can extend the more likely it is to merge with the magnetic flux tubes that are directed antisunward (down the tail). Similarly, on the duskside, where O^+ is the dominant constituent in the dusk plasma bulge, a tail wind of O^+ may be present that would be accelerated upward by the polarization electric field it experiences in the presence of O_2^+. Altogether, we may expect O^+ to escape down the tail predominately from the duskside while H^+ escapes predominately from the dawnside.

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Initial Observations of the Nightside Ionosphere of Venus from Pioneer Venus Orbiter Radio Occultations

Abstract. *Pioneer Venus orbiter dual-frequency radio occultation measurements have produced many electron density profiles of the nightside ionosphere of Venus. Thirty-six of these profiles, measured at solar zenith angles (χ) from 90.6° to 163.5°, are discussed here. In the "deep" nightside ionosphere (χ > 110°), the structure and magnitude of the ionization peak are highly variable; the mean peak electron density is 16,700 ± 7,200 (standard deviation) per cubic centimeter. In contrast, the altitude of the peak remains fairly constant with a mean of 142.2 ± 4.1 kilometers, virtually identical to the altitude of the main peak of the dayside terminator ionosphere. The variations in the peak ionization are not directly related to contemporal variations in the solar wind speed. It is shown that electron density distributions similar to those observed in both magnitude and structure can be produced by the precipitation on the nightside of Venus of electron fluxes of about 10^8 per square centimeter per second with energies less than 100 electron volts. This mechanism could very likely be responsible for the maintenance of the persistent nightside ionosphere of Venus, although transport processes may also be important.*

The first results of the Pioneer Venus orbiter radio occultation experiment, which described the nature of the polar ionosphere of Venus near the terminator, have been published (*1*). These earlier measurements were made near the terminator at solar zenith angles (χ) ranging from 86.0° to 93.0°. The results reported here were obtained from measurements taken on the nightside of Ve-

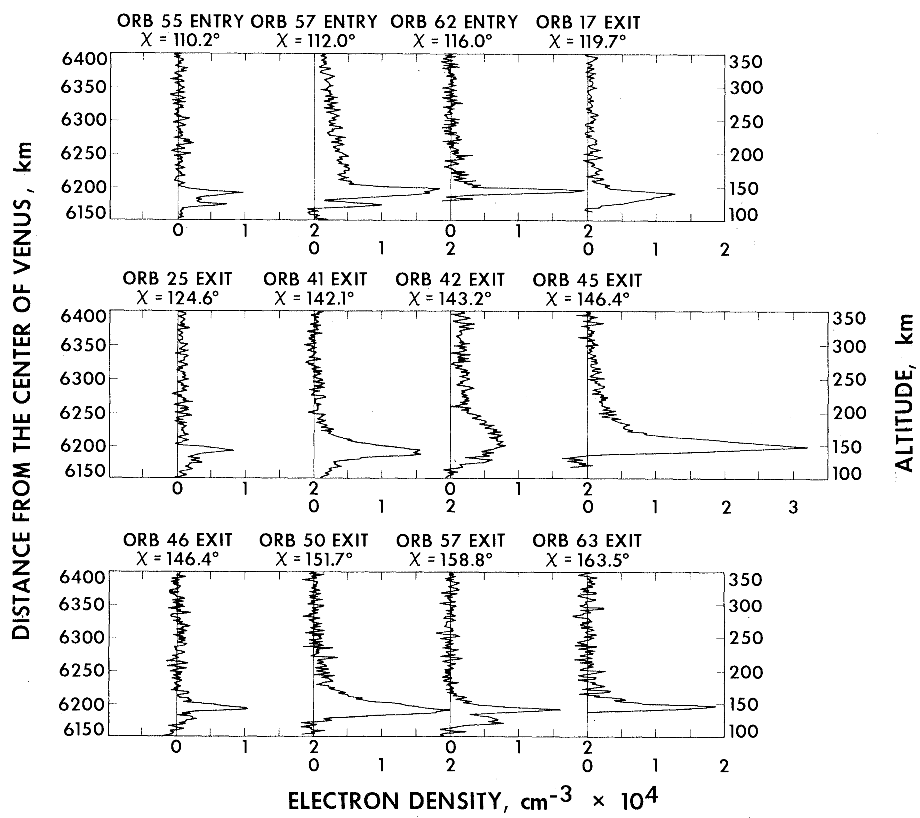

Fig. 1. Electron density profiles in the nightside ionosphere of Venus at solar zenith angles greater than 110°. The electron density scales are linear and extend to 2×10^4 cm^{-3}.

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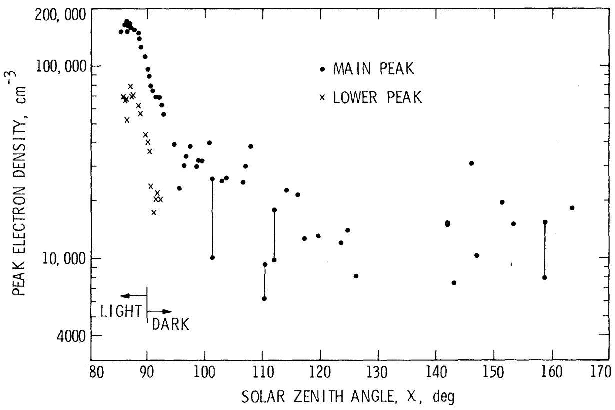

Fig. 2. Peak electron densities for all currently available observations as a function of solar zenith angle.

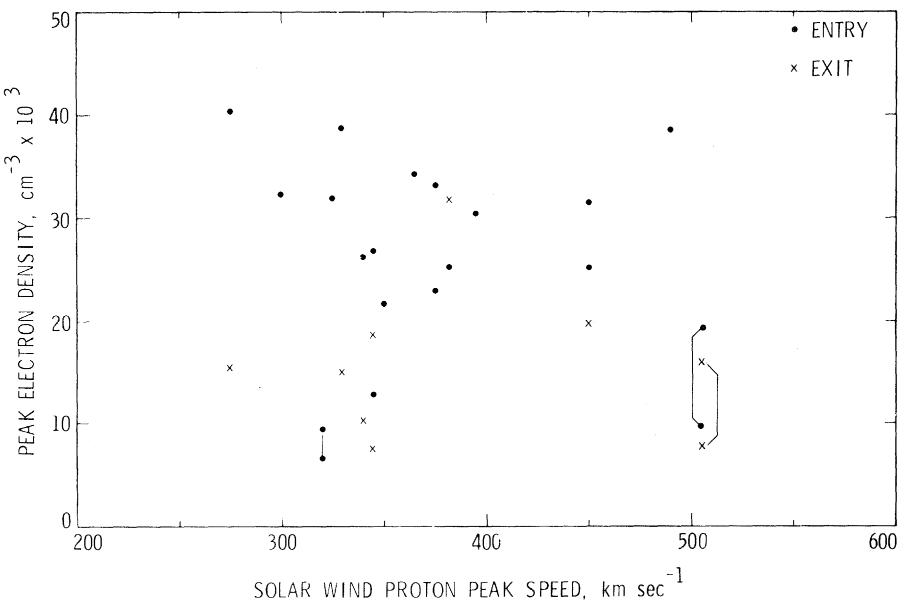

Fig. 3. Peak electron densities observed on the nightside of Venus versus the solar wind proton peak speed reported by the Pioneer Venus plasma analyzer for each day of observation.

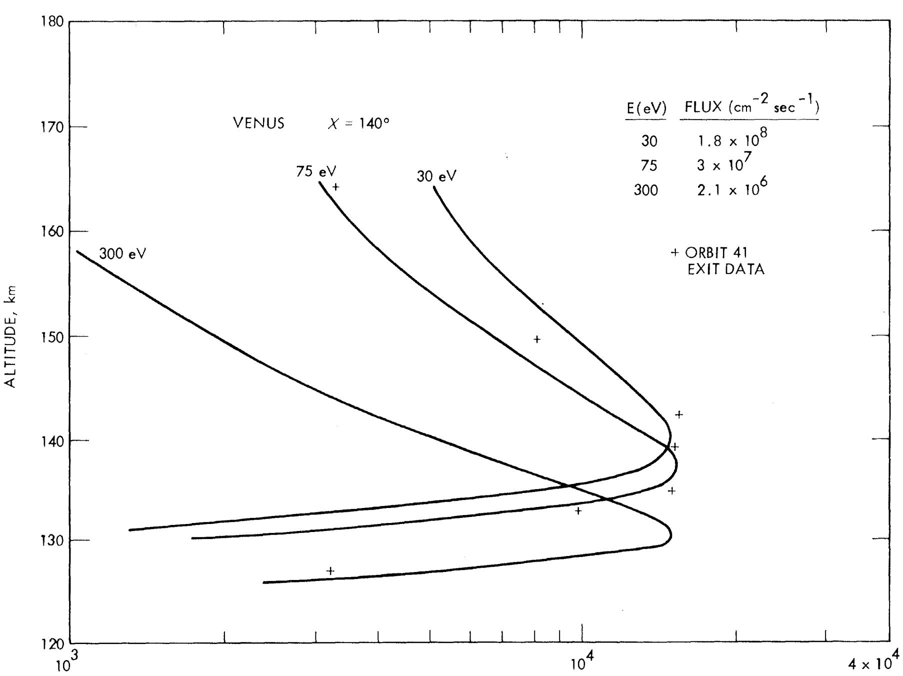

Fig. 4. Computed electron density profiles resulting from the precipitation of 30-, 75-, and 300-eV electrons into the nightside atmosphere modeled after Pioneer Venus in situ measurements. The crosses are points from the electron density profile derived from orbit 41 exit radio occultation.

nus with χ ranging from about 90° to 164°. These measurements were made between Pioneer Venus orbit 29 on 2 January 1979 and orbit 63 on 5 February 1979.

All results reported here were derived from closed-loop S- and X-band data collected by the NASA-Jet Propulsion Laboratory Deep Space Net tracking stations. The differenced Doppler technique described in (*1*) was again used to isolate only the effects of charged particles, and the electron density profiles were obtained through the method of integral inversion (*2*). These results are based on all currently available entry and exit data. The entry data predominate, because in order to obtain the exit data, both the S- and X-band receivers must be quickly locked up before the radio line of sight passes through the Venus ionosphere.

A summary of the available results other than those described in (*1*) appears in Table 1. From Table 1 it is evident that the entry measurements covered latitudes from 89°N to 62°N and solar zenith angles from 87° to about 117°. It is the fortuitous exit measurements that provide coverage of latitudes from 60°S to 13°S and, more importantly, solar zenith angles from about 111° to 164°. It should be pointed out that the gaps in the coverage evident in the results presented here are caused by the lack of suitable closed-loop data, which will be filled in eventually by the use of open-loop data. In addition to the peak electron density and the altitude of the peak, Table 1 lists two other properties of each electron density profile. One is the ionosphere height, which is the altitude at which the effects of any ionization could not be distinguished from the background fluctuations. These fluctuations, caused mostly by random receiver noise in the S- and X-band receiver systems, are typically equivalent to an ionization level of the order of 300 cm^{-3}. This quantity should not be confused with the ionopause height determined by the in situ measurements, which are far more sensitive to low densities of ions and electrons. The other property, baseline stability, is a quantitative indication of the quality of the data from which the electron density profiles were derived. Because the dual-frequency, differenced Doppler measurement is sensitive to all charged particles in the path, not just those in the ionosphere of Venus, fluctuations in the total electron content caused by waves in the solar wind, and possibly fluctuations in Earth's ionosphere, cause the observations outside the Venus ionosphere to show a small wavy structure. This structure is, of course, also present when the ray path is traversing the ionosphere layers and is not separable. The baseline stability number is an attempt to express the effect of such baseline fluctuations on the results and is the ratio of the peak-to-peak phase fluctuations outside the ionosphere to the maximum phase excursion produced by the main ionosphere peak. It varies between 0.014 and about 0.66 and is a good indication of the confidence level of the results when multiplied by the peak electron density.

A visual representation of the nature of the "deep" nightside ionosphere of Venus (orbit 55 entry, $\chi = 110.2°$, to orbit 63 exit, $\chi = 163.5°$) is shown in Fig. 1. The peak electron densities for all profiles, including those discussed in (*1*), are also shown as a function of χ in Fig. 2. It is evident from Fig. 2 that nightside profiles observed in the range of χ from about 95° to about 107° display a rather uniform appearance and have peak electron densities ranging from about 23,000 to about 40,000 cm^{-3} (mean ± standard deviation = 31,600 ± 5,200 cm^{-3}). Beyond $\chi = 110°$ (20° or more beyond the terminator), the electron density profiles become far less uniform both in structure and in peak electron density (see Fig. 1). For all observations between $\chi = 110°$ and 164° the peak density varies from about 7,600 to 31,800 cm^{-3} and is characterized by great variability. For these observations the mean peak electron density is about 16,700 cm^{-3}; however, the standard deviation is 7,200 cm^{-3}. The altitude of the peak, 142.2 ± 4.1 km, remains very nearly at the altitude of the main peak of the dayside terminator ionosphere.

The large degree of variability of the nightside ionosphere on a time scale of 24 hours is well illustrated in Fig. 1. For example, the measurements of orbit 41 exit and orbit 42 exit were obtained 24 hours apart and in close proximity to one another, and whereas orbit 41 displays a fairly typical, if bifurcated, nightside peak, orbit 42 has a shape not usually associated with a planetary ionosphere. Similarly, the measurements from orbit 45 and orbit 46 show a factor of 3 change in peak electron density within 24 hours.

The general nature of the Venus nightside ionosphere obtained from Pioneer Venus radio occultation observations is in good qualitative and quantitative agreement with previous observations from Mariner 10 (*3*) and Veneras 9 and 10 (*4*). However, it is curious that the only nightside profile observed by Mariner 10 ($\chi = 117.7°$) and two of the three profiles shown in (*4*) ($\chi = 144°$ and 146°) display two distinct peaks, while of the 18 measurements beyond $\chi = 110°$ presented here, only three show a distinctly bifurcated structure, although the existence of small layers below the main peak cannot be ruled out in many cases. It is also interesting to note that the double-peak structure appeared only during two closely spaced orbits, 55 and 57, and on orbit 57 the structure appeared in both the entry measurements ($\chi = 112°$) and the exit measurement ($\chi = 158.8°$). Thus, it seems that the appearance of such a double-peak structure is a relatively rare temporal phenomenon, possibly related to the mechanisms that produce the highly variable nightside ionosphere.

In an effort to investigate the relation of the variability of the nightside ionization to other variable phenomena, the peak electron densities were plotted in Fig. 3 against the solar wind proton peak speed as observed by the Pioneer Venus plasma analyzer instrument (*5*). It is evident that no clear correlation exists, and thus the peak electron density observed on any given day is not related to the solar wind speed of that day. It also may be noted from Fig. 3 that the occurrence of double peaks, indicated by points joined by lines, is also apparently unrelated to the magnitude of the solar wind speed.

The presence of a variable, but substantial, nightside ionosphere requires significant transport or direct ionization processes, or both, because of the long Venus night. Several mechanisms for maintaining the nightside ionosphere have been proposed (*6*), such as (i) horizontal transport of metallic ions from the dayside, (ii) horizontal transport of ma-

Table 1. Selected parameters of the Venus nightside ionosphere.

Orbit	Date	χ (deg)	Latitude (deg)*	Longitude (deg)	Peak altitude (km)	Peak electron density ($cm^{-3} \times 10^3$)	Ionosphere height (km)	Baseline stability
3 Exit	7 Dec. 78	111.4	−60.3	97.1	144	33.3	450	0.025
8 Entry	12 Dec. 78	87.0	83.2	278.6	141	164.3	750	0.0125
					135	78.8		
17 Exit	21 Dec. 78	119.7	−54.8	128.2	140	13.1		0.0984
20 Entry	24 Dec. 78	90.6	87.4	307.4	145	79.4	800	0.00532
					130	23.8		
22 Entry	26 Dec. 78	91.4	88.3	311.1	142	69.0	450	0.0114
					133	21.0		
22 Exit	26 Dec. 78	123.7	−51.6	139.8	144	12.3		0.0642
					145	69.2		
23 Exit	27 Dec. 78	124.6	−50.9	142.1	145	14.2		
24 Entry	28 Dec. 78	92.2	89.2	311.3	134	20.1	450	0.00877
					146	63.3		
25 Exit	29 Dec. 78	126.3	−49.5	146.8	139	8.14		0.207
29 Entry	2 Jan. 79	94.4	88.3	156.7	149	39.3	350	0.0973
31 Entry	4 Jan. 79	95.2	87.3	160.3	157	23.4	300	0.0480
33 Entry	6 Jan. 79	96.3	86.2	164.7	153	31.5	550	0.247
34 Entry	7 Jan. 79	96.8	85.6	167.1	150	34.3	450	0.0138
35 Entry	8 Jan. 79	97.3	85.0	169.5	150	38.5	550	0.322
37 Entry	10 Jan. 79	98.4	83.8	174.4	147	30.4	350	0.118
38 Entry	11 Jan. 79	98.8	83.3	176.8	182†	31.9	430	0.659
39 Entry	12 Jan. 79	99.4	82.7	179.3	149	32.5	450	0.0198
41 Entry	14 Jan. 79	100.6	81.3	184.4	144	40.4	550	0.0158
41 Exit	14 Jan. 79	142.1	−36.0	185.7	133	15.6		0.0566
					140	15.5		
42 Entry	15 Jan. 79	101.2	80.6	186.0	142	26.7	300	0.0656
					118	10.1		
42 Exit	15 Jan. 79	143.2	−35.0	188.1	152	7.64		0.141
45 Entry	18 Jan. 79	102.9	78.6	194.6	146	25.2	450	0.0207
45 Exit	18 Jan. 79	146.4	−32.1	195.6	144	31.8	300	0.0386
46 Entry	19 Jan. 79	103.6	77.9	197.1	144	26.3	350	0.100
46 Exit	19 Jan. 79	147.4	−31.1	198.1	140	10.4		0.455
50 Entry	23 Jan. 79	106.6	74.5	207.5	143	25.1	550	0.0306
50 Exit	23 Jan. 79	151.7	−27.1	208.2	139	19.8		0.107
51 Entry	24 Jan. 79	106.9	74.1	210.0	144	30.6	400	0.201
52 Entry	25 Jan. 79	107.7	73.1	212.6	146	38.7	550	0.0325
55 Entry	28 Jan. 79	110.2	70.2	220.4	139	9.49		0.207
					120	6.68		
57 Entry	30 Jan. 79	112.0	68.2	225.6	145	18.3		0.171
					121	9.77		
57 Exit	30 Jan. 79	158.8	−19.6	226.1	138	15.9		0.188
					118	7.75		
60 Entry	2 Feb. 79	114.1	65.7	233.4	145	22.9		0.0603
62 Entry	4 Feb. 79	116.0	63.5	238.6	141	21.5		0.108
63 Entry	5 Feb. 79	117.1	62.3	241.2	142	12.9		0.267
63 Exit	5 Feb. 79	163.5	73.2	241.5	144	18.7		0.223

*Positive latitudes are in the direction of ecliptic north. †This altitude is not significant because of probable trajectory error.

jor ions from the upper regions of the dayside ionosphere followed by downward diffusion, and (iii) direct impact ionization by precipitating electrons or protons or both. The first of these suggestions can now be eliminated as the source responsible for the main density peak observed near 140 km, since the major ions at this altitude and higher have now been identified as O_2^+ and O^+ (*7*). Brace *et al.* (*8*) indicate that the second mechanism is still a possibility, and we show here that the third mechanism is consistent with the radio occultation observations and presents a viable explanation.

Using a nightside neutral density model consistent with Pioneer Venus in situ measurements (*9*), we calculated electron density profiles resulting from the precipitation of 30-, 75-, and 300-eV monoenergetic electrons (Fig. 4). The particle fluxes used were adjusted for each energy to give a peak electron density of 1.5×10^4 cm^{-3}, in agreement with the typical measured value at $\chi = 140°$. It is clear that 300-eV electrons penetrate too deeply, producing a maximum at about 130 rather than 140 km. However, Fig. 4 indicates that fluxes of about 10^8 cm^{-2} sec^{-1} of electrons with energies less than about 100 eV are capable of producing electron density profiles that agree with the observations. (Electrons with a bimodal energy spectrum could be responsible for the appearance of double-peaked ionospheric profiles.)

The ultraviolet airglow experiment and the plasma analyzer on the Pioneer Venus orbiter are expected to provide information on the viability of this proposed impact ionization mechanism. A preliminary sampling of plasma analyzer data (*5*) indicated the presence of electrons with energies of 20 to 250 eV inside the ionosphere with a downward flux of about 5×10^7 cm^{-2} sec^{-1} at an energy of 30 eV. If higher-energy electrons precipitated into the atmosphere at a shallow angle, they would also be able to produce ionization at the required altitude. At present, both impact ionization by precipitating particles and transport and diffusion of major ions are possible sources of the observed nightside ionosphere and may be occurring simultaneously.

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Empirical Models of the Electron Temperature and Density in the Nightside Venus Ionosphere

Abstract. *Empirical models of the electron temperature and electron density of the late afternoon and nightside Venus ionosphere have been derived from Pioneer Venus measurements acquired between 10 December 1978 and 23 March 1979. The models describe the average ionosphere conditions near 18°N latitude between 150 and 700 kilometers altitude for solar zenith angles of 80° to 180°. The average index of solar flux was 200. A major feature of the density model is the factor of 10 decrease beyond 90° followed by a very gradual decrease between 120° and 180°. The density at 150° is about five times greater than observed by Venera 9 and 10 at solar minimum (solar flux ≈ 80), a difference that is probably related to the effects of increased solar activity on the processes that maintain the nightside ionosphere. The nightside electron density profile from the model (above 150 kilometers) can be reproduced theoretically either by transport of O^+ ions from the dayside or by precipitation of low-energy electrons. The ion transport process would require a horizontal flow velocity of about 300 meters per second, a value that is consistent with other Pioneer Venus observations. Although currently available energetic electron data do not yet permit the role of precipitation to be evaluated quantitatively, this process is clearly involved to some extent in the formation of the nightside ionosphere. Perhaps the most surprising feature of the temperature model is that the electron temperature remains high throughout the nightside ionosphere. These high nocturnal temperatures and the existence of a well-defined nightside ionopause suggest that energetic processes occur across the top of the entire nightside ionosphere, maintaining elevated temperatures. A heat flux of 2×10^{10} electron volts per square centimeter per second, introduced at the ionopause, is consistent with the average electron temperature profile on the nightside at a solar zenith angle of 140°.*

Initial Pioneer Venus measurements (*1*) resolved the ion composition and ion and electron thermal structure of the daytime ionosphere at solar zenith angles (SZA) of about 70°. Since the time of these earlier measurements, periapsis has nearly completed its first movement through the nightside ionosphere. Thus direct measurements are now available from 70° SZA in the afternoon sector through 180° and back to about 120° on the dawn side. Brace *et al.* (*2*) used Pioneer Venus data from this period to define the global configuration of the ionopause across the nightside. We have employed orbiter electron temperature probe (OETP) data from these same orbits and a few more recent ones to construct empirical models of the electron density (N_e) and temperature (T_e) within the nightside ionosphere itself. These models describe the average conditions found in the region between 150 and 700 km and near 18°N latitude in the interval between 10 December 1978 and 23 March 1979. Although our goal in constructing these models was to provide a reference against which the spatial and temporal variations of the ionosphere might be resolved and studied, in this report we explore the implications of the models themselves for the maintenance and heating of the nightside ionosphere as a whole.

The operation of the OETP instrument was described elsewhere (*3*). Figure 1