GEOPHYSICAL RESEARCH LETTERS, VOL. 17, NO. 6, PAGES 865-868, MAY 1990

VENUS MANTLE - MARS PLANETOSPHERE: WHAT ARE THE SIMILARITIES AND DIFFERENCES?

Andrew F. Nagy and Tamas I. Gombosi

Space Physics Research Laboratory, Department of Atmospheric, Oceanic and Space Sciences, University of Michigan

Karoly Szego

Central Research Institute for Physics

R. Z. Sagdeev, V. D. Shapiro, and V. I. Shevchenko

Space Research Institute

Abstract. The available data related to the mantle/planetosphere regions of both Mars and Venus are reviewed. It is shown that there are significant similarities in these regions at the two planets. These are: 1) a transition region between the magnetosheath and the ionosphere dominated by heavy, planetary ions; 2) a transition region in which the electron population is different from both the shocked solar wind and the photoelectron ones; 3) a magnetic signature near the transition boundary; and 4) the presence of low frequency electric waves within the transition region.

Introduction

The plasma environment of Venus is the best explored and understood one in our solar system except for that of the earth. On the other hand we know very little about the corresponding regions of our other sister planet Mars. The very recent measurements by a variety of instrument packages, carried aboard the Phobos 2 spacecraft, which were dedicated to the study of the field and particle environment of Mars, added significantly to our body of knowledge, but we are still left with major gaps and uncertainties. One of the more puzzling and/or controversial set of observations obtained by the Phobos 2 instruments, is related to the magnetopause/planetopause and the region inside of this boundary. In this brief note we summarize the information we have available on this region from Phobos 2 and earlier missions to Mars, present our limited data base on the mantle around Venus and discuss the known similarities and differences of these regions.

The Magnetosphere/Planetosphere/Mantle of Mars

Pre-Phobos Information: The Soviet Mars 2, 3 and 5 spacecraft did carry a magnetometer, a narrow angle plasma spectrometer and a wide angle Faraday cup [*Dolginov et al.*, 1976; *Vaisberg et al.*, 1976a]. These instruments did make measurements inside the Martian bow shock, although they never got closer than 1100 km from the surface. These measurements established the presence of a boundary layer, called a magnetopause [*Gringauz*, 1981], which was characterized by a relatively slowly moving, cold plasma of mainly planetary origin. It was estimated that the major constituent of the plasma was O^+, with some heavier ions also present [*Vaisberg et al.*, 1976a]. The thickness of this boundary layer was estimated to be about 350 km on the dayside, 500 km at the terminator and 3 R_M downstream. This boundary layer was said to be analogous to the terrestrial mantle. The magnetometer measurements [*Dolginov*, 1976] indicated that the magnetic field is turbulent in the magnetosheath, but becomes more regular closer to the planet.

Phobos 2 Results: The Phobos 2 instruments, which made observations of the plasma environment of Mars, during the elliptic orbit phase of the mission, were ASPERA [*Lundin et al.*, 1989], HARP [*Shutte et al.*, 1989], TAUS [*Rosenbauer et al.*, 1989], FGMM and MAGMA [*Riedler et al.*, 1989] and PWS [*Grard et al.*, 1989]. The first three made measurements of the plasma characteristics of the region, the next two measured the magnetic field and the last one studied the wave activity. We will limit this brief discussion to data from the first orbit, but the basic characteristics observed during the four relevant elliptic orbits were the same. Figure 1a shows the total magnetic field data from MAGMA [*Riedler et al.* 1989]. The proton and O^+ ion measurements obtained by ASPERA [*Lundin et al.* 1989] are presented in Figure 1b, and the electron energy spectra measured by the HARP [*Shutte et al.*, 1989], are shown in Figure 1c. The wave spectra from the PWS [*Grard et al.*, 1989] is shown in Figure 1 of the accompanying paper by Sagdeev et al. [1990].

The crossing of the bow shock by the spacecraft can be seen clearly in all the data at approximately 18:25 U.T. This corresponds to a radial distance of approximately 5000 km from the center of the planet, very close (less than 10 degrees) to the Sun-Mars line. Though the Rankin-Hugoniot relations have not been checked yet, there is a consensus that this boundary was the bow shock.

After the spacecraft crossed this bow shock it entered a region dominated by solar wind plasma; the flux of cold heavy ions increased as the spacecraft continued its approach toward the planet. About ten to twenty minutes later, sometimes between 18:35 and 18:45 U.T., at a radial distance of about 4300 km from the center of the planet, the spacecraft crossed the next plasma boundary. There is no agreement yet at this time on the nature and the exact location of this boundary among the different instrument groups, who have used various criteria and terminology in defining and referring to this boundary. The magnetometer identified a boundary at 18:37 U.T., which they called the planetopause, at which time a sudden drop in the turbulent nature of the magnetic field took place. At 18:49 a rotational discontinuity was observed by the magnetometer [D. Mohlmann, private communication]; this boundary was called the magnetopause by the experimenters. Both the ASPERA and TAUS instruments noted a transition to a region dominated by heavy, presumably planetary ions during this time interval and they called this boundary the magnetopause. The crossing of the magnetopause occurred at about 18:37 U.T. according to both the

Paper number 90GL00673
0094-8276/90/90GL-00673$03.00

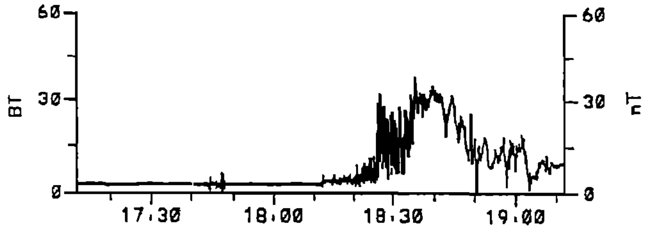

Fig. 1a. Total magnetic field data from the Phobos 2 MAGMA instrument, obtained during the first elliptic orbit on February 1, 1989 [*Grard et al.*, 1989 and *Riedler et al.*, 1989]

ASPERA and TAUS measurements. The ASPERA results indicate that the main ion population inside this planetosphere is O^+ and heavier ions, probably O_2^+, CO^+ etc. The HARP electron measurements also indicated a noticeable change at about 18:37 U.T., going from a highly double peaked to an only slightly double peaked distribution. Finally the wave activity also showed a change in character; Grard et al. [1989] indicated that this transition took place at about 18:42 U.T. and referred to it both as a planetopause and magnetopause. However, a change in the wave activity pattern at 18:37 was also noted by Sagdeev et al. [1990]. In the magnetosheath broad band electric noise was observed, while inside this region (after 18:37 U.T.) discrete plasma bursts appeared, that were interpreted as whistlers by Sagdeev et al., [this issue].

At this time there is clearly no agreement on the exact location and characteristics of this planetopause/magnetopause boundary. Furthermore the question whether there is a single or double boundary and/or if they are permanent features is not resolved. The Phobos 2 spacecraft did not penetrate any deeper into the plasma envelope of Mars than about 860 km, which was the periapsis of these elliptic orbits. No indication of a transition into the ionosphere of Mars was noted during these orbits; therefore during this time period and location the true ionosphere of Mars was constrained to altitudes below 860 km. On one occasion, during the third elliptic orbit, the Langmuir probe detected two isolated patches of thermal plasma [*Grard et al.*, 1989], with densities greater than 500 cm^{-3}, near periapsis. These thermal ion patches/blobs may be similar to the ones observed at Venus [*Brace et al.*, 1983] and probably even at Titan [*Hartle et al.*, 1982].

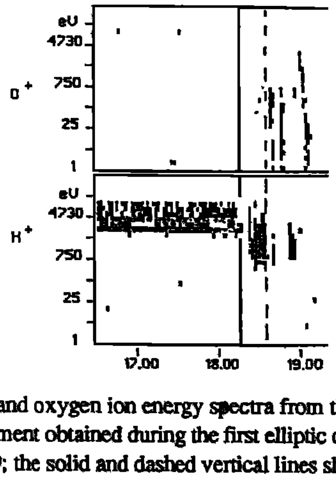

Fig. 1b. Proton and oxygen ion energy spectra from the Phobos 2 ASPERA instrument obtained during the first elliptic orbit on February 1 1989; the solid and dashed vertical lines show the positions of the bowshock and the planeto-pause, as estimated by the experimenters [*Lundin et al.*, 1989]

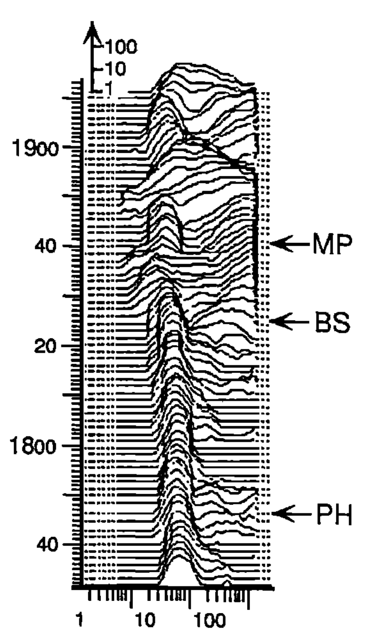

Fig. 1c. Electron energy spectra from the Phobos 2 HARP instrument obtained during the first elliptic orbit on February 1, 1989; the position of the Phobos orbit encounter and the crossing of the bowshock and magnetopause, as estimated by the experimenters, is shown on the figure [*Shutte et al.*, 1989]

Venus Ionosheath-Boundary/Mantle Observations

The Pioneer Venus Orbiter (PVO) has provided a great deal of information about the plasma environment of Venus. The electron observations of the Retarding Potential Analyzer (RPA) instrument on PVO [*Spenner et al., 1980*] established the presence of a transition region between the ionosheath/magnetosheath (in early publications the term ionosheath was commonly used, but more recently it has been called the magnetosheath) and the ionosphere. Spenner et al. [1980] called this transition region the mantle. The observed electron energy spectra in the mantle changes gradually from one which is characteristic of the shocked solar wind to an ionospheric photoelectron one. Spenner et al. [1980] also examined the corresponding magnetic field variations and noted that the magnetic field does undergo a noticeable change as the spacecraft moves across the ionosheath-mantle boundary, which they referred to as the ionosheath boundary (ISB). Figure 2 shows the observed variations of the magnetic field, the low energy (12-40 eV) and "thermal" electron densities along a specific PVO orbit.

Observations by the Orbiter Ion Mass Spectrometer (OIMS) have indicated that superthermal, planetary ions are present in the region "above" the ionopause [*Taylor et al.*, 1981]. The exact ion composition and energy range could not be established by this instrument, which was designed for thermal ion measurements, but it could clearly establish the presence of these energized planetary ions; it was estimated that these ions have energies in the range of 10 to 90 eV. Taylor et al. [1981] interpreted this energetic ion layer as resulting from a "combination of accelerated ionospheric ions and photoions born in the exosphere". Neither the RPA nor the Orbiter Plasma Analyzer (OPA), which was capable of measuring ions with E/Q up to 8000 [*Intriligator et al.*, 1980], made quantitative measurements of this ion population. Taylor et al. [1981] found that coincident with these superthermal ions the low frequency ac electric fields (100 Hz) were also enhanced, as measured

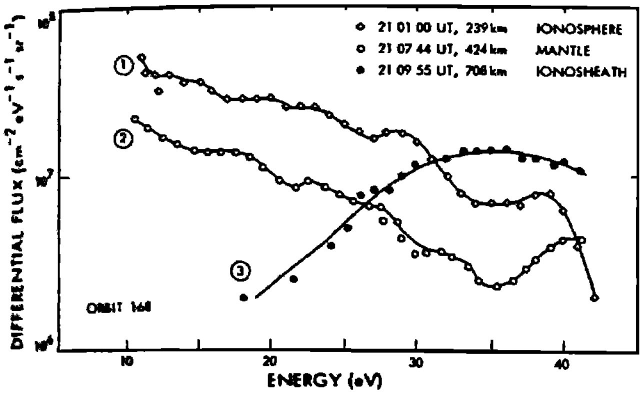

Fig. 2. The magnetic field, the number density of ions in the energy range of 12 to 40 eV, and the total "pseudodensity" measured along an orbit of the Pioneer Venus spacecraft [*Spenner et al.*, 1989]

by the Orbiter Electric Field Detector (OEFD) [*Scarf et al.*, 1980]. An example of such observations is shown in Figure 3. Scarf et al. [1980] indicated that in general they see an abrupt decrease in the amplitude of the 100 Hz waves at the ionopause and they suggest that this is the result of wave-particle interactions between whistler mode waves and ionospheric electrons.

Prior to the Pioneer Venus Orbiter measurements, we did obtain some information on the plasma environment of Venus from the Venera 9 and 10 observations. Narrow and wide angle plasma analyzers provided information on the electron and ion variations across and inside the bow shock [*Vaisberg et al.*, 1976b; *Gringauz et al.*, 1976]. The presence of a region inside the magnetosheath, characterized by a reduced ion flow velocity and ions of probably planetary origin was seen by these instruments. Gringauz et al. [1976] and Verigin et al. [1978] called this region the corpuscular penumbra and compared it to the terrestrial mantle. In a later paper Vaisberg and Zeleny [1984] called this region the mantle and gave a semiquantitative explanation for its formation. They suggested that photoions are created inside the magnetic barrier and are convected toward the wake as a result of both magnetic pressure gradients and magnetic tension. The Venera observations were made near and beyond the terminator and they most likely correspond to the same region as the one called the mantle by the Pioneer Venus experimenters.

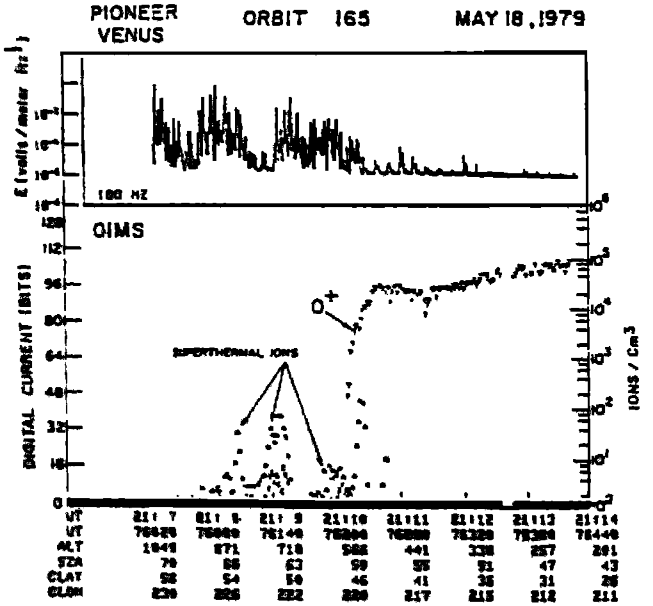

Fig. 3. Electric field and suprathermal ion density data measured along an orbit of the Pioneer Venus spacecraft [*Taylor et al.*, 1981]

Discussion

The observational data base available about the plasma environment of Mars and Venus shows significant similarities. The presence of a well established bow shock and a magnetosheath region, dominated by shocked solar wind plasma populations are clearly seen in all the available and relevant data at both planets. The various spacecraft observations at these two planets have clearly shown that there is a transition region between the magnetosheath and the ionosphere. The nature, structure and extent of this region appears in a somewhat different manner at the two planets during the various spacecraft missions. However, these apparent differences, we believe, are due to a certain degree to the limited data base obtained by the widely varying collection of instruments carried by the different spacecraft. The similarities at the two planets are:

i) a transition region between the magnetosheath and the ionosphere dominated by heavy, planetary ions;
ii) a transition region in which the electron population is different from both the shocked solar wind and the photoelectron ones;
iii) magnetic signature(s) near the transition boundary; and
iv) the presence of low frequency electric waves within the transition region.

It was suggested by Sagdeev et al. [this issue] that the physics of the magnetopause/planetopause region around Mars is governed by those low frequency electric fields which are excited by the interaction of cold planetary ions with the shocked solar wind plasma. This process results in momentum transfer from the solar wind to the planetary ions and has a characteristic length of about 100 km; this in turn creates a transition region between the solar wind and planetary ion dominated regions. Sagdeev et al. [this issue] suggest that the escape of planetary ions into the magnetosheath region is caused by turbulent diffusion. The diffusion length associated with this process was estimated to be a few hundred kilometers, comparable to the width of the boundary region. The frequency of these waves is limited by the fact that their wavelength needs to be longer than the electron Larmor radius. Furthermore it is believed that these waves are excited by Cerenkov resonance, $\omega=ku$, which combined with the previous condition implies that $f<100$Hz. The corresponding characteristic length for this instability is of the order of 200 km.

It is quite feasible that that these same physical processes are in operation in the transition region of both Mars and Venus. The energy source of these waves is the solar wind, therefore the wave amplitudes should be similar at both Mars and Venus despite the differences in ion densities. At Mars the wave amplitudes were about 20 mV/m, (see *Sagdeev et al.*, this issue), which is consistent with the values reported by Scarf et al. [1980] for Venus. A possible consequence of the above mentioned processes is the appearance of a high energy tail in the electron and ion energy spectra; such high energy tail was seen by the HARP [*Shutte et al.*, 1989] in the turbulent region around Mars and consistent with the ORPA observations in the Venus mantle [*Spenner et al.*, 1980].

The suggestion by Vaisberg and Zeleny [1984] that photoionization in the magnetic barrier, followed by convection towards the tail is responsible for the mantle at Venus is not likely to be applicable to Mars. The hot oxygen corona around Mars is smaller than that around Venus [*Nagy and Cravens*, 1988] and therefore the production rate of plasma, be that by photoionization, charge exchange etc., is also reduced significantly in the mantle region.

We are not insisting here that conditions or the dominant physical processes at the two planets are identical. For one thing Mars may have a small intrinsic magnetic field, while we know that Venus does not have one and therefore the boundary between the ionosphere and the transition region may have a different character at the two planets. We know that a clear ionopause is present at Venus, but no clear and consistent indication of such a boundary has been seen at Mars. It is still possible that Mars has an ionopause, because the region between about 350 km and 850 km has still not been explored. However even if there is no ionopause at Mars it is very important to recognize the similarities in the transition region and to use consistent terminology for the two planets. We believe that appropriate and consistent use of descriptive terms is more than an exercise in semantics; it helps to establish and focus on the potential similarities in the processes controlling the behavior of the respective regions in these planetary environments. The term mantle has been used extensively in the past, although planetosphere has also had wide usage recently. We do not try to recommend a choice between the various terms which have been used, but we feel that it is important to select one and stick to it.

The only physical mechanisms which have been proposed so far to explain the observations in the planetosphere/mantle regions of either Mars or Venus are those of Vaisberg and Zeleny [1984] for Venus and Sagdeev et al. [this issue] for Mars. The fact that there are significant phenomenological similarities between the Venus mantle and the planetosphere of Mars, as summarized in this paper, makes the task of coming up with an appropriate model and related physical processes difficult. Any theoretical framework which is put forward to explain the presently available and future data bases must address the observed similarities at the two planets. If a theory is not capable to achieve that, it must explain the reason(s) why and how the two plasma environments are different.

Acknowledgements. The work carried out at The University of Michigan was sponsored by NASA under grants NAG2-491, NAGW-631 and NAGW-1619.

References

Brace, L. H., et al., The ionosphere of Venus: observations and their interpretation, in *Venus*, edited by D. M. Hunten, L. Colin, T. M. Donahue and V.I. Moroz, 779, The University of Arizona Press, Tucson, Arizona, 1983.

Dolginov, S.S., The magnetosphere of Mars, in: *Proc. of Physics of Solar Planetary Environments*, edited by D.J. Williams, *Vol. II*, 872, AGU, Washington, D.C., 1976.

Dolginov, S. S., et al., Magnetic field and plasma inside and outside of the Martian magnetosphere., in: *Proc. of Solar Wind Interaction with Planets Mercury, Venus and Mars.*, edited by N.F. Ness, NASA SP-397, Moscow, 1976.

Gringauz, K. I., et al., Plasma observations near Venus onboard the Venera-9 and 10 satellites by means of wide angle plasma detectors, in: *Proc. of Physics of Solar Planetary Environments*, edited by D.J. Williams, *Vol. II*, 918, AGU, Washington, D. C., 1976.

Gringauz, K. I., A comparison of the magnetospheres of Mars, Venus and the Earth., *Adv. Space Res.*, *1*, 5, 1981.

Hartle, R. E., et al., Titan's ion exosphere from Voyager 1, *J. Geophys. Res.*, *87*, 1383, 1982.

Intriligator, D. S., Wolfe, J. H., and Mihalov, J. D., The Pioneer Venus Orbiter plasma analyzer experiment, *IEEE Trans. Geosci. Rem. Sens.*, *GE-18*, 39, 1980.

Lundin, R., et al., First measurements of the ionospheric plasma escape from Mars, *Nature*, *341*, 609, 1989.

Nagy, A. F., and T. E. Cravens, Hot oxygen atoms in the upper atmospheres of Venus and Mars, *Geophys. Res. Lett.*, *15*, 433, 1988.

Riedler, W., et al., Magnetic fields near Mars: First results, *Nature*, *341*, 604, 1989.

Rosenbauer, H., et al., Ions of martian origin and plasma sheet in the martian magnetosphere: Initial results of the TAUS experiment, *Nature*, *341*, 612, 1989.

Sagdeev, R. Z., et al., Wave activity in the neighborhood of the bow shock of Mars, *Geophys. Res. Lett.*, *17*, this issue, 1990.

Scarf, F. L., et al., Pioneer Venus plasma wave observations: The solar wind Venus interaction, *J. Geophys. Res.*, *85*, 7599, 1980.

Shutte, N. M., et al., Observation of electron and ion fluxes in the vicinity of Mars with the HARP spectrometer, *Nature*, *341*, 614, 1989.

Spenner, K., et al., Observation of the Venus mantle, the boundary region between solar wind and ionosphere, *J. Geophys. Res.*, *85*, 7655, 1980.

Taylor, H. A., et al., Dynamic variations observed in thermal and superthermal ion distributions in the dayside ionosphere of Venus, *Adv. Space Res.*, *1*, 247, 1981.

Vaisberg, O. L., et al., On the nature of the solar wind Mars interaction., in: *Proc. of Solar Wind Interaction with Planets Mercury, Venus and Mars*, edited by N.F. Ness, *21*, NASA SP-397, Moscow, 1976a.

Vaisberg, O. L., et al., Ion flux parameters in the solar wind Venus interaction region according to Venera-9 and Venerea-10 data, in: *Proc. of Physics of Solar Planetary Environments*, edited by D.J. Williams, *Vol. II*, 904, AGU, Washington, D. C., 1976b.

Vaisberg, O. L., and Zeleny, L.M., Formation of the plasma mantle in the venusian magnetosphere, *Icarus*, *58*, 412, 1984.

Verigin, M. I., et al., Plasma near Venus from the Venera 9 and 10 wide angle analyzer data, *J. Geophys. Res.*, *83*, 3721, 1978.

A. F. Nagy and T. I. Gombosi, Space Physics Research Laboratory, Department of Atmospheric, Oceanic and Space Sciences, The University of Michigan, 2455 Hayward, Ann Arbor, Michigan 48109-2143.

K. Szego, Central Research Institute for Physics, P.O. Box 49, H-1525, Budapest 114, Hungary.

R. Z. Sagdeev, V. D. Shapiro and V. I. Shevchenko, Space Research Institute, U.S.S.R. Academy of Sciences, ul. Profsoyunzaya 88/34, Moscow, U.S.S.R. 117810.

(Received December 22, 1989;
revised March 6, 1990;
accepted March 6, 1990)