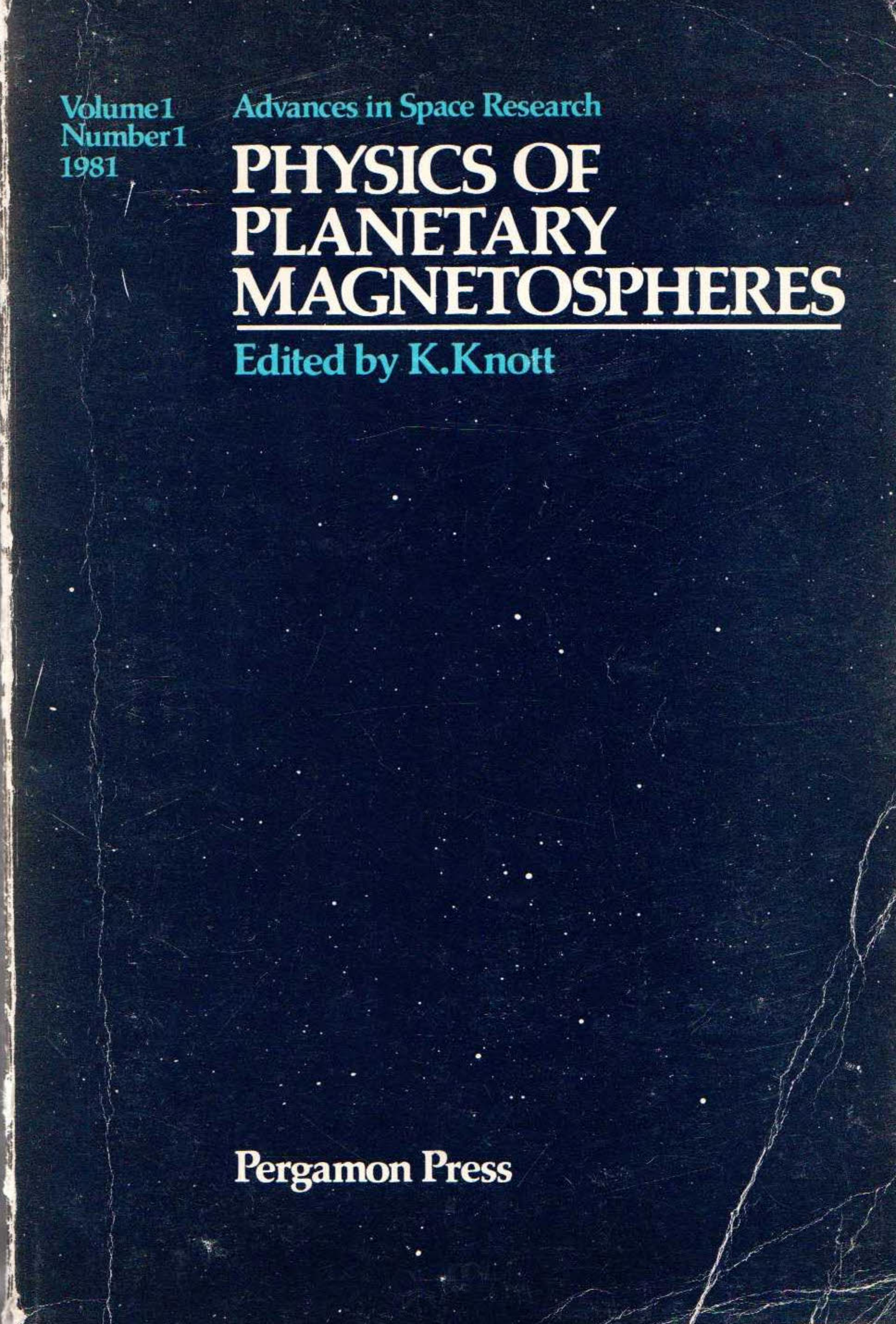

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A COMPARISON OF THE MAGNETOSPHERES OF MARS, VENUS AND THE EARTH

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ABSTRACT

Plasma and magnetic field data from Venera 9,10 and Pioneer Venus Orbiter are used to outline the main features of the induced Venusian magnetosphere. Based on results from the Mars orbiters M-2, M-3 and M-5, evidence is given in favour of an intrinsic magnetic field as origin of the Martian magnetosphere. Comparisons with the geomagnetosphere are made.

INTRODUCTION

Since 1959 when Gold [1] had invented the word "magnetosphere" many definitions of this concept can be found in literature. In most cases, the word "magnetosphere" is used for that region of space where the intrinsic magnetic field of the planet can be detected. Sometimes the space near a planet without intrinsic magnetic field, where the magnetic field topology is similar to a magnetosphere, is called "pseudomagnetosphere". Confusion can be avoided if the following definition is accepted: "Magnetosphere is the limited region of space where the planet's presence causes deviations in value, direction and regularity both from the interplanetary magnetic field configuration and from the field pattern in the magnetosheath downstream the planetary bow-shock if it exists". Such a definition can be applied to all known planets including Venus.

Several reviews were published during the last 5 years where existing magnetic field and plasma measurements near Venus and Mars and the history of their interpretation were described [2-7]. It can be seen from these reviews that amongst the experimental data available for the near-Venus space, the Venera-9,10 (V-9 and V-10) and Pioneer-Venus Orbiter (PVO) data have the highest weight and significance. But not all the V-9 and V-10 data have been published yet in detail and the PVO data are still being acquired and processed. Therefore one of the tasks of this review is the attempt to summarize the basic results of the Venus magnetosphere measurements available now from these satellites.

As far as Mars is concerned most of the available data on its magnetosphere were obtained by the Soviet satellites Mars-2, -3 and -5 in 1971-1974. These satellites did not approach the planet closer than 1100 km. Unfortunately there were gaps of 2 minutes and in some cases of up to 10 minutes between the plasma observations and magnetic measurements on board of Mars-1 and -3, that impaired the spatial resolution of these parameters near the planet. In addition, the number of orbits during which plasma and magnetic instruments were switched on, was insufficient. Therefore some questions connected with the Marian magnetosphere remained unanswered by these missions. The American spacecraft Mariner-6, 7 and 9 (Mar-6,7,9) and Viking-1 and Viking-2 had no instruments for measuring the magnetic field and the solar wind plasma.

In 1975 the data from the M-2, M-3 and M-5 satellites were discussed at the Soviet-American seminar [8]. New experimental data on the Martian magnetosphere have not been obtained yet except from the ionospheric data of Viking-1 and Viking-2 [9]. Nevertheless the plasma and magnetic field data from the Soviet satellites which visited Mars are still under discussion. Using the same set of experimental data some authors conclude that Mars has an intrinsic magnetic field and disagree only in some details, e.g. Dolginov [12], Gringauz et al. [13], [69], Smirnov et al. [14], Intriligator and Smith [11]. On the other hand Russell [10] concludes that Mars has no intrinsic magnetic field. Hence it seems to be reasonable to look once more at these data in order to improve our understanding of the near-Martian environment by comparing them with new results obtained near Venus.

It is quite natural that all phenomena revealed near any other planet are first of all compared with similar phenomena near the Earth. If the peculiarities of the phenomena are similar, it is often concluded that the phenomena are of the same nature. Sometimes such conclusions are not correct. In this review we intend to outline some properties of the geomagnetosphere, and compare them with the magnetospheres of Venus and Mars.

THE VENUS MAGNETOSPHERE

Dayside ionopause. When Dolginov et al. [15] made the magnetic measurements on board the Venera-4 satellite in 1967 at altitudes $\geq$ 200 km it became clear that the intrinsic magnetic field of Venus is too weak to create the obstacle causing the near-planetary bow-shock, and it became more and more obvious that the ionosphere is undoubtedly the obstacle which causes the bow-shock. This was studied from the V-9 and V-10 satellites using the radio-occultation technique [16], [17], from the PVO again using the radio-occultation technique [18], [19], and by some direct techniques (a retarding potential analyzer [20], [21], an electron temperature probe [22], [23], and ion mass-spectrometer [24], [25]). Only those results will be considered here that are of prime importance from the standpoint of magnetospheric physics. Fig. 1 gives the first day-time profile of electron density obtained from Mariner-5 [26]. It shows the essential peculiarity of the day-time profile recurrent on all electron or ion-profiles obtained later - a sharp upper boundary, the ionopause is clearly identified. Fig. 2 illustrates the day-time height distribution of O^+ ions which dominate in the day ionosphere obtained by the PVO ion mass-spectrometer [24]. The distinct ionopause is clearly seen on these profiles. Fig. 3 [23] shows data on heights of the ionopause versus the solar zenith angle: the solid curve is obtained from the V-9 and V-10 satellites and the points from the Mariner-5, -10 and PVO satellites. The V-9/10 curve shows the increase of height of the ionopause as the terminator is approached.

It is evident that the height variations of the ionopause and its average height increased significantly during 1977-1978 years as compared with 1975-1976 (V-9, V-10). The authors of [23] mention that this might be associated with differences in the phase of the solar activity cycle. The tendency for the ionopause height to increase with the solar zenith angle detected by V-9 and V-10 is confirmed by the PVO data. In analyzing the pressure balance at the ionopause the authors of [23] assumed that the ionospheric plasma pressure was 1.5 n_eKT_e (T_e was measured by the electron temperature probe; T_i was assumed to be 0.5 T_e).

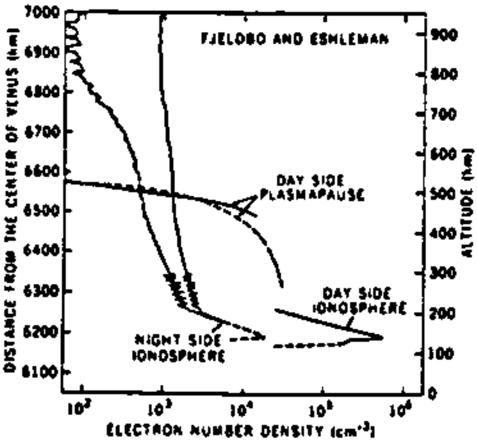


Fig. 1: Venus daytime electron density profile obtained from Mariner-5.

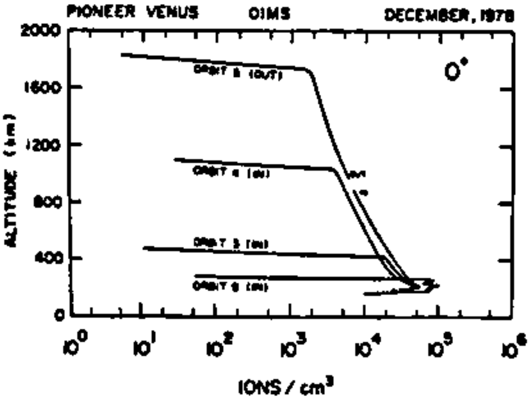


Fig. 2: Venus daytime ion density profile obtained from Pioneer-Venus Orbiter.

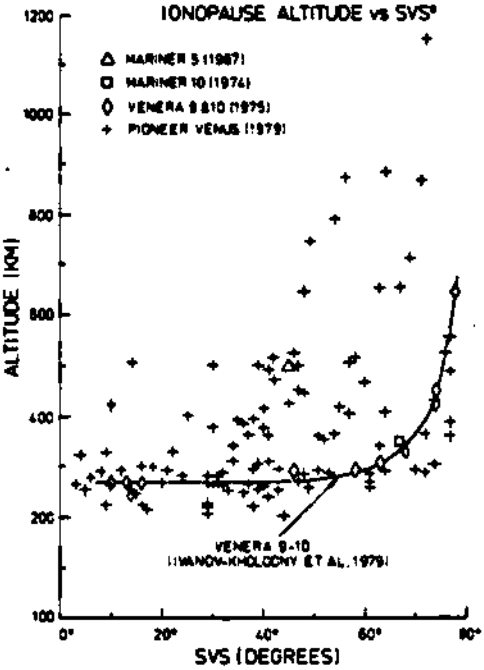


Fig. 3: Position of Venus' ionopause plotted as function of solar zenith angle.

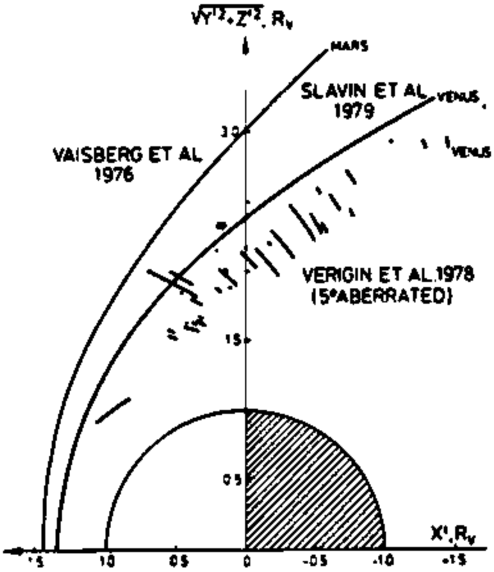


Fig. 4: Regions where Venera-9 and -10 spacecraft crossed the Venusian bow-shock. Figure also gives bow-shock position measured by PVO.

Bow-shock position. Fig. 4 gives several positions of the points at which the V-9 and -10 satellites crossed the bow-shock near Venus determined from the data of the wide-angle plasma detectors (Verigin et al.[27]) corrected for aberration of the solar wind. This figure also gives the average position of the bow-shock based on the data of the PVO magnetic measurements [30], which show the shock to be rather more distant from the planet than observed by V-9 and -10 data. Fig. 5 shows the points at which the PVO satellite crossed the bow-shock [28]. Besides higher average distance from the planet, the Venusian bow-shock also varied significantly in position during PVO measurements. In [29] it is estimated that the variability of the front position was twice as much as that seen by V-9 and V-10. The authors of [28] believe that this can also partially be explained by the higher solar activity. There is one further reason for a greater distance of the shock seen by PVO: its orbit is more inclined to the ecliptic plane than that of V-9 and V-10, which means that V-9 and V-10 crossed the bow-shock at lower latitudes where the interplanetary magnetic field is more parallel to the shock front normal. For PVO the geometry was such that the shock wave was more quasi-perpendicular. This may also explain the larger bow-shock distance seen by PVO. Note that the shock asymmetry associated with the different orientation of the IMF relative to the normal to the front was seen by Romanov et al. [30] based on V-9 and V-10 magnetic measurements. This effect may be revealed only when the bow-shock as a whole is very stable and paper [30] provides additional evidence for this stability during the V-9 and V-10 measurements.

Fig. 5: Magnetic field profile measured by PVO and location of Venusian bow-shock.

Magnetic barrier. Venus' intrinsic magnetic field. The concept of a magnetic barrier being the obstacle in the solar wind interaction with Venus was proposed - mainly on intuitive grounds - and analyzed by a number of authors: Dessler [31], Johnson and Midgley [32], Clutier et al. [34-36], Michel [33]. In references [34-36] it was assumed that diffusion of solar wind magnetic flux and induced currents existed throughout the day-side ionosphere. As boundary condition it was assumed that B=0 at the lower boundary of the ionosphere and that the current maximum coincided with that of the Hall and Pedersen conductivities. The PVO measurements show a very different situation [37]. In our opinion, this non-conformity of the real world with a theoretical forecast is one of the most important results obtained from the PVO mission.

Fig. 5 [23] shows the projections of magnetic field vectors into the plane crossing the PVO and Sun-Venus line in the cylindrical system of coordinates $(x, \sqrt{y^2 + z^2})$. The orbit part near periapsis in which the magnetic field is close to zero lies inside the ionosphere; the part of the orbit with the largest magnetic field is inside the magnetic barrier region. Fig. 6 [23] presents the pressures of the magnetic field $B^2/8\pi$ (thin curve) and of the ionospheric plasma $\sim 1.5\ n_e KT_e$ (thick curve) for the orbit portion near periapsis during the same pass of PVO. The boundaries of the region where the plasma pressure is significant correspond to satellite crossing the ionopause at zenith angles near 45° and 22°. The periapsis occurred at $20^h\ 54^m\ 44^s$. The magnetic pressure peaks over narrow regions with linear dimensions $\sim$10 km where the magnetic field increases sharply in the day ionosphere; such regions were detected by Russell et al. [38] who called them "ropes". These local small-scale increases of the magnetic field are undoubtedly of considerable interest but in this review we cannot discuss them in more detail. Fig. 6 clearly shows that the transition from the condition $\beta = (1.5 n_e KT_e . 8\pi/B^2) \ll 1$ to $\beta \gg 1$ occurs within the height range of $\sim$90 km (a location assumed to correspond to the ionopause) with $B^2/8\pi$ in the magnetic barrier approximately equal to $1.5\ n_e KT_e$, (i.e. there is approximate balance between the magnetic pressure in the magnetic barrier and the ionospheric plasma pressure). Elphic et al. [23] noted that although the situation shown in Fig. 6 is typical there might be cases when a significant magnetic field is observed inside the ionosphere (below the ionopause), but these are rather rare. Such a situation is present in Fig. 7.

One possible interpretation is that the ionopause, being a dynamical phenomenon, moved downward by 100 km for 2 min (from $20^h\ 08^m$ to $20^h\ 10^m$) and then up again. It is also possible that this case corresponds to the formation of the current system deep inside the day ionosphere. However, since the near-planet bow-shock is always observed and significant magnetic fields at altitudes lower than the recorded ionopause are observed only occasionally, the magnetic barrier deflecting the solar wind is evidently formed irrespective of magnetic fields existing at lower heights and is produced by the current in the thin ionopause (thickness of $\sim$90 km). This current is probably closed in some layer of the transition region (magnetosheath), the outer boundary of the magnetic barrier region. The reason why the current in the ionosphere is limited within the thin layer of the ionopause is not yet clear and needs physical explanation.

There is general agreement that the Venusean magnetic field cannot be the obstacle to the solar wind; there is nevertheless discussion as to the upper limit of the magnetic moment of Venus. Dolginov et al. [15] estimated a magnetic moment of 2×10^{22} gauss x cm^3 whereas Russell [39], based on the same data, claims a value of 6×10^{22} gauss x cm^3. The results of the V-9 and V-10 magnetic field and plasma measurements also indicated the existence of a Venus magnetic-plasma tail [27], [40], although there was some difference of opinions regarding the magnetic field measurements [40]. Eroshenko held the opinion that the measured magnetic field would be created by induced ionospheric currents, whereas Dolginov et al. only considered it as evidence for an intrinsic magnetic field of the planet. In 1978 Dolginov et al. [41] derived a value for this magnetic moment as $M_v = (1.2\text{-}2.5) \times 10^{22}$ gauss x cm^3. In 1979 Eroshenko presented his ideas in a separate paper where he showed that the orientation of the neutral layer in the magnetospheric tail of Venus at relatively small distances from the planet changes with the direction of the IMF component perpendicular to the Sun-Venus line [42].

Laboratory experiments [43], [44] have demonstrated that an induced magnetosphere including a magnetotail can be formed when a magnetised plasma flows past a non-conducting body (wax sphere) which is surrounded by an ionosphere. Breus [2] has given additional arguments supporting Eroshenko's [42] point of view. Like Clutier et al. [34-36], Eroshenko suggested that current would flow throughout the entire day-side ionosphere.

The most recent measurements in the Venusian night-time ionosphere [45] led Russell to withdraw his original conclusion [39] that Venus possessed an intrinsic magnetic

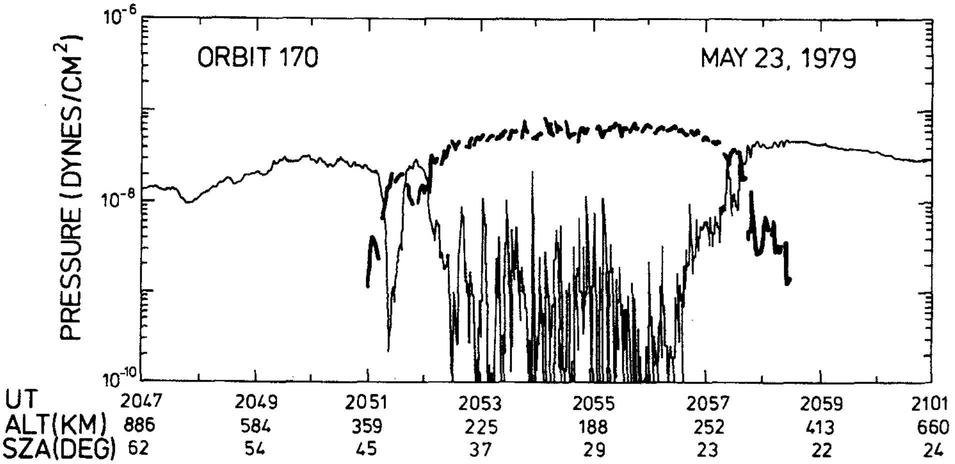


Fig. 6: Magnetic field pressure (thin curve) and ionospheric plasma pressure (thick curve) as function of altitude measured by PVO.

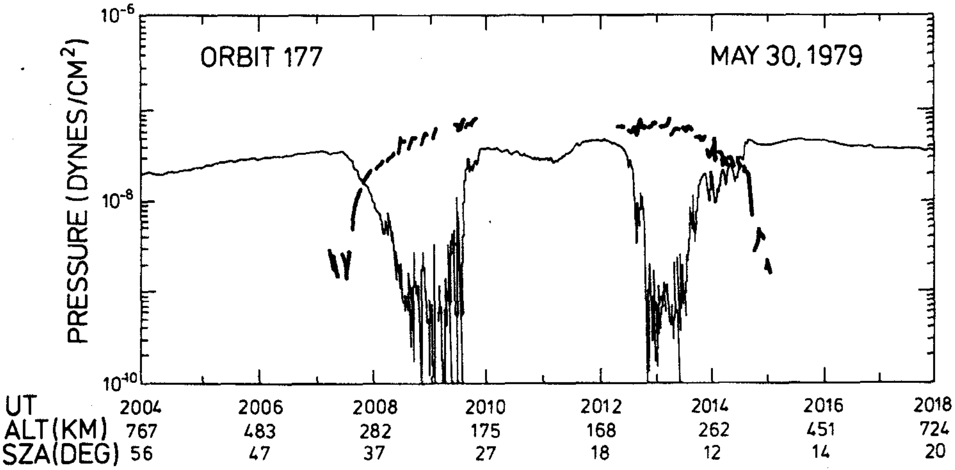


Fig. 7: Same as Fig. 6 but for the case when significant magnetic field is observed inside ionopause.

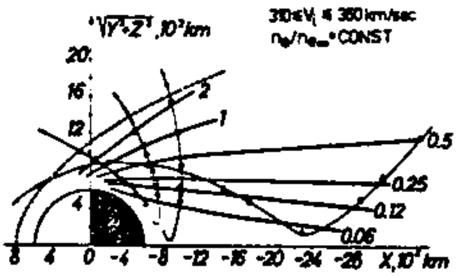


Fig. 8: Distribution of plasma density in the antisolar part of the Venus magnetosphere.

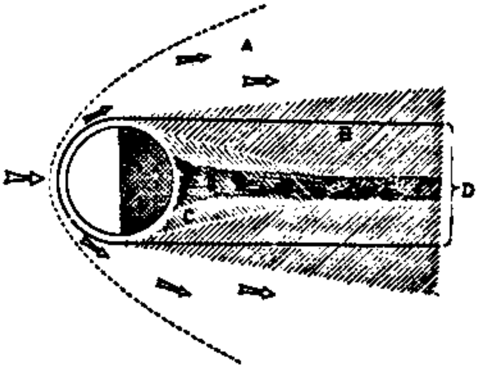


Fig. 9: Schematical presentation of the structure of the Venus magnetosphere. A = transition zone, B = boundary layer, C = corpuscular umbra, D = magnetotail.

moment. Taking into account possible experimental errors he estimated that the upper limit of the planet's magnetic moment be M_V = 4.3 x 10^{21} ± 5x10^{21} gauss x cm^3, i.e. approximately 3 times less than the minimum moment assumed by Dolginov [41]. Thus, one could conclude that the discrepancies existing in the estimates of the Venus' intrinsic magnetic field based on the V-9 and V-10 data and the PVO results are of some interest to the theories on planetary dynamo mechanisms, but not for the physics of Venus' magnetosphere.

Antisolar part of the Venus magnetosphere. We divide the Venusian magnetosphere into two regions separated by the terminator plane and call the "night region" the "antisolar part of the magnetosphere". The presently available PVO data were obtained at relatively low heights ($h \leq R_V$), so in this part of our review we use mainly V-9 and V-10 data.

Fig. 8 [27] shows the distribution of the plasma density in the antisolar part of the Venus magnetosphere obtained from the data of the V-9 and V-10 electron retarding potential analyzers. Contours of equal density are elongated towards the Sun-Venus axis.

Fig. 9 presents schematically the structure of the antisolar magnetosphere in the X,Y-plane which originates from [27]. Of particular interest is the transition zone (magnetosheath). Plasma properties and magnetic field in this region are well described by Spriter's magnetohydrodynamical model for an obstacle impenetrable for the solar wind plasma [46]. The B-region is the boundary layer [46], "corpuscular penumbra" [47], [27] or "rarefaction wave" [48] that is characterized by decreased fluxes of the plasma and its lower velocities as compared with Spriter's proposed nondissipative model [46]. This region expands to the optical umbra of the planet. The authors of [27] note that the quasi-viscous interaction of the solar wind plasma in the transition zone with the obstacle (i.e. with the ionospheric plasma) is the cause of the plasma deceleration in the B-region. Spriter [46] had indicated the possible formation of the wide boundary layer to be due to the reason given above. It was shown in [27] that the experimental data obtained by means of the V-9 and V-10 wide-angle plasma detectors agree qualitatively with Perez de Tejada's and Dryer's calculations for the boundary layer [49], [50]. The part of the B-region adjacent to the terminator was explored by the PVO retarding potential analyzer (Spenner et al., 1979) [51], the authors proposed for this region the name "ionospheric mantle" (without making reference to V-9 and V-10 observations).

Neither V-9, V-10 nor PVO were equipped with energy-mass spectrometers. Such instruments will be rather useful in future studies of the physics of Venus' "corpuscular penumbra". Corpuscular umbra is the "C"-region where the V-9 and V-10 wideangle plasma analyzers did not record regular fluxes of ions from the transition zone [47], [27]. It probably has the shape of a cone, the base of which has a radius $R_V + H_{ipt}$ where R_V is the planet radius and H_{ipt} is the altitude of ionopause at the terminator. The height of the cone is ~4 to 5 R_V. A similar estimate of the corpuscular umbra dimensions (the authors call it "cavity") was made by Intriligator et al. [52] based on PVO plasma analyzer data.

Fluxes of electrons in the energy range of tens and few hundreds eV are very variable but always observed while ions with energies below 4.5 keV are observed only sporadically. Ions with energies E>1-2 keV are not observed in the transition layer (magnetosheath) and probably are created by accelerating processes in the corpuscular umbra or at great distances from the planet in the tail of the magnetosphere, "D". The samples of ion spectra obtained on passing from the corpuscular umbra to the transition layer one can find in [47]. The results obtained in the "C"-region by the PVO measurements of electric fields (not published yet) should be of interest for better understanding the nature of sporadic ions with energies 1 keV<E<4.5 keV observed in the corpuscular umbra.

The region marked D in Fig. 9 corresponds to the Venus magnetotail [40], plasma-magnetic tail [27], magnetoplasma tail [53]. At the boundary of the D-region the magnetic field is stretching along the Sun-Venus line. The B_z and B_y components decrease significantly while the B-scalar increases.

Fig. 10 gives an example of ion spectra measured by the V-10 wide-angle Faraday cup when the satellite crossed the tail boundary at a distance of 5 R_V. The entry into the tail is associated, as it is in the geomagnetosphere, with the abrupt decrease of the plasma flow and the simultaneous increase of magnetic field.

Fig. 11 gives some ion spectra measured by the same Faraday cup deep in the magnetic tail near a point at which B_x changes its sign. It can be seen that $B_x \gg B_{xy}$, thus the field lines are really elongated along the X-axis. It can also be seen that near the point, where B_x passes through zero, the ion spectra change: ions with energies >2 keV appear that were absent in the spectrum before and after this pass. This can be interpreted as the observation of the plasmasheet near the magnetic neutral sheet of Venus' magnetic tail.

The V-9 and V-10 measurements in the distant magnetospheric tail at greater distances from the planet were carried out without knowledge of the attitude of the satellites. This did not allow the orientation of the neutral layer to be determined at great distances from the planet. However, considering the fact that a rotation of the neutral sheet during changes of the IMF-orientation was detected near the planet (Eroshenko [42]) it should be assumed that the orientation of the neutral layer in the tail changes also far from the planet when B_y and B_z in the solar wind change.

The formation of the main maximum in the night time ionosphere of Venus as a result of impact ionization by electrons with energies ≤300 eV, observed in the umbra region by RPA's on board V-9 and V-10 was proposed in [53 - 55]. This consideration required substantial changes in the 1976-1977 models of the night-time neutral atmosphere of Venus, which are now completely confirmed by neutral atmosphere observations on PVO [55], [56].

Current system of the Venus magnetosphere. All observations and considerations mentioned above permit a current system to be constructed that can in a zero order approximation describe the basic features of the configuration in the Venus

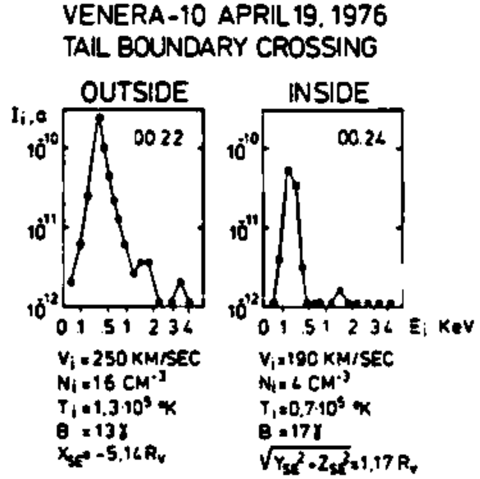


Fig. 10: Ion spectra measured by the wide-angle Faraday cup on Venera-9 illustrating a transition into Venus' magnetic tail.

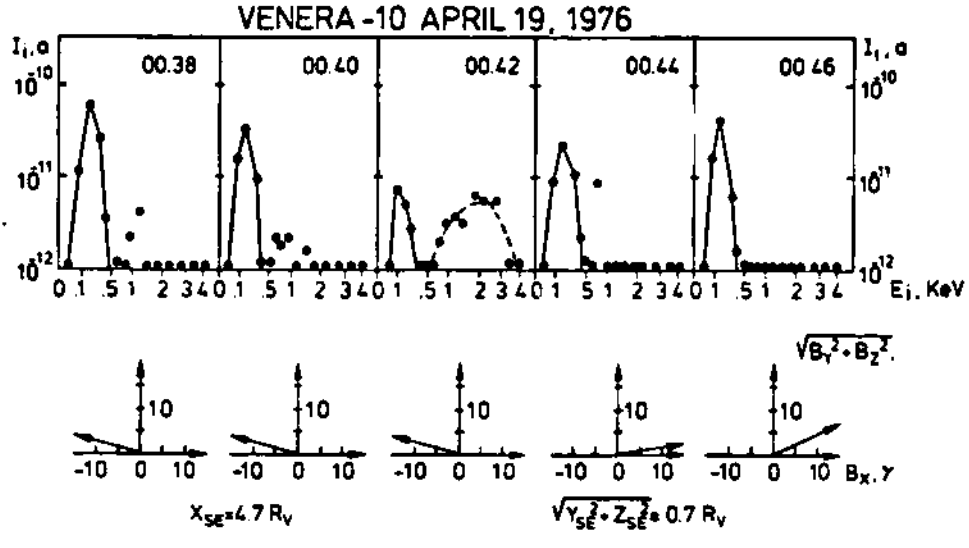


Fig. 11: Ion spectra measured inside the magnetic tail of Venus near a point where the magnetic B_X component changes its sign.

magnetosphere (Fig. 12). This system was designed using topology conjugation of current contours forming the magnetic barrier ahead of the day-side ionopause and a Θ-type current structure encompassing the magnetic tail with two antiparallel bundles of field lines.

The annotation "zero approximation" should be understood not in the sense of Alfvèn who calls approximation adequate for a one-particle problem as a current system of the magnetosphere in "zero approximation" [57], but in the sense that Fig. 12 is oversimplified and in fact the actual current system of the Venus

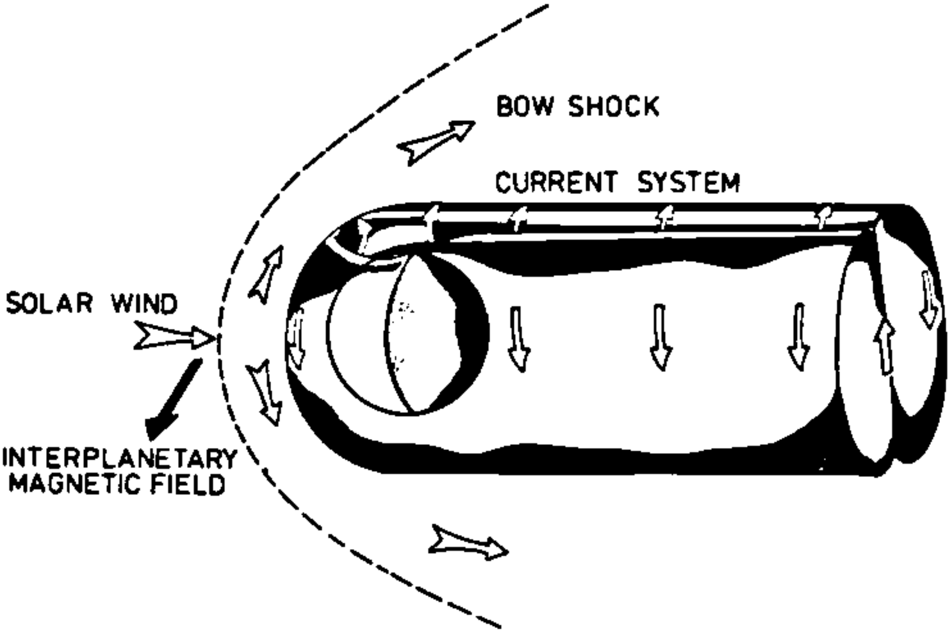


Fig. 12: The current system in the Venus magnetosphere derived from existing observations.

magnetosphere is surely more complicated. The orientation of the current system shown in Fig. 12 must change following variations of the Venus magnetic field B-component in Y, Z-plane orientation.

MARTIAN MAGNETOSPHERE

Some remarks. As mentioned before the Soviet satellites to Mars were not capable of performing measurements at low altitudes. For conclusions about the magnetosphere and the existence of a Martian intrinsic magnetic field the peculiarities of magnetic and plasma experimental data were used in analogy to features of plasma and magnetic data obtained near the Earth, namely:

A. Increase of the magnetic field value after crossing of the magnetopause (from magnetosheath into the magnetosphere).

B. Decrease of the plasma flows after crossing of the magnetopause (as a rule, simultaneously with B-growth).

C. Independence of the magnetic field direction inside the magnetosphere of the varying direction of IMF.

D. Decrease of B-fluctuations in crossing the magnetopause (as compared with the magnetosheath).

Some authors thought it possible to obtain information from:

E. Variability of R-distance of the bow-shock from the obstacle (by the ratio of ΔR-range of variations R to the obstacle dimension) as compared with the case of the Earth (Gringauz [13]).

F. Average position of the near-planet bow-shock (Vaisberg et al. [58], Russell [10], Intriligator and Smith [11]).

Now that we have experimental data on several planetary ionospheres the following feature can also be used to reflect on the nature of a planetary magnetosphere:

G. Presence of the day-side ionopause for the case of an ionospheric nature of the obstacle.

It must be noted, based on Venus observations, that features A and B exist both for the case of intrinsic and induced magnetospheres. The detailed PVO data, on the magnetic field inside the magnetic barrier are not available to the author now and so he cannot judge the comparative B-fluctuation levels; but these data certainly exist and, in general, they could be significant if they differ from the many corresponding data in the Earth magnetosphere. The data given by Slavin et al. [22] indicate that if criterion E is applied to the data on the near-Venus bow-shock, the features are rather similar to those of the Earth; therefore criterion E is of little use for the judgement on the nature of the obstacle near Mars.

The use of the concept "average position of the shock front" has been criticized time and again [60], [2], [12]. It was indicated that it is necessary to analyze each individual position of the bow-shock including the most distant one from the planet. Let us here only mention that although the "average" bow-shock at Mars occurs farther from the planet than in the case of Venus, this difference is not so great. This can be seen from Fig. 4, where the mean Venusian and Martian bow-shock positions are given. Hence the greater distance of the average bow-shock position in the case of Mars compared to Venus is better not to be used in our consideration. Thus, in conclusion, only "C" and "G" features may be regarded as useful for our further considerations.

On the independence of the magnetic field direction inside the Martian magnetosphere on IMF direction. Some passes of the M-2 and M-3 satellites near Mars were performed without a three-axis stabilisation of the satellite. As a result only B-scalars were measured. Only on January 21, 1972 three components of the magnetic field near Mars were measured. Fig. 13 presents the distribution of projections of B-vectors along M-3-orbit, on this day, in the system consisting of coordinates x, $\sqrt{y^2 + z^2}$. Note that Russell is the co-author of the plot in Fig. 5 [23]; he also drew the plot in Fig. 13 using the M-3 data [10]. The plot in Fig. 5 corresponds to the typical case of the "magnetic barrier" near Venus; upon entering in the magnetic barrier the B_x-component does not change its sign as it should according to the theory. The increase of the magnetic field only begins at a point much closer to the planet than to the bow-shock. In plot in Fig. 13, on the contrary, the increase in B starts at a point much closer to the bow-shock than to the planet; the sign of the B_x-component in the zone of the maximum magnetic field is not the same as its sign near the bow-shock. We thus think that the plot in Fig. 13 indicates that the nature of the magnetic field increase detected during the M-3 pass into the Martian day-time magnetosphere differs from that of the magnetic field increase recorded during the PVO passages over the Venus day-side.

Three component magnetograms are agiven in [60] which were obtained during nine passes of M-5 in the Martian magnetosphere tail. Fig. 14 shows the M-5 orbit and one of the magnetograms. The portion 2-3 corresponds approximately to the satellite pass inside the magnetosphere. In five passes, an example of which is shown in Fig. 14, B_x has a constant sign (directed away from the Sun), opposite to that in

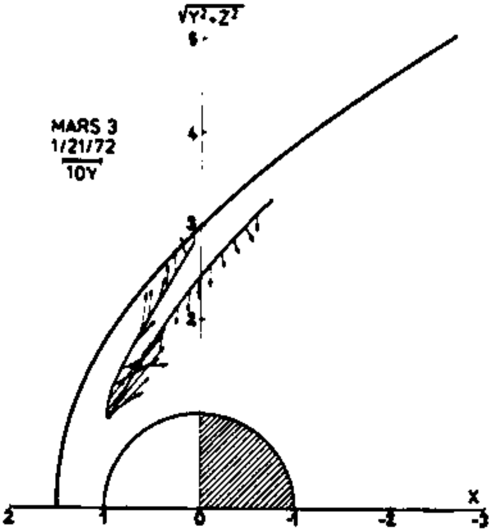
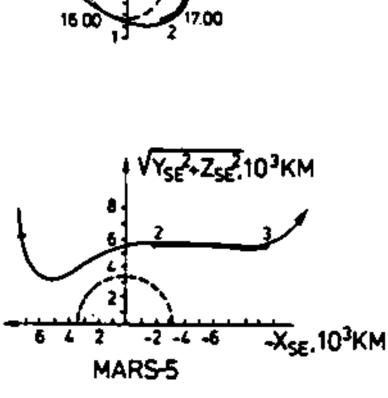
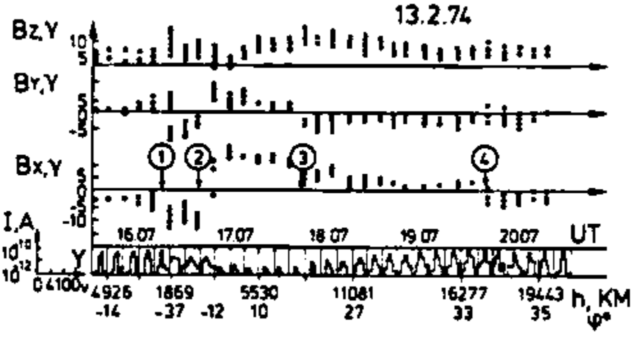


Fig. 13: Magnetic field measurements near Mars by the Mars-3 spacecraft. Vectors are given in an x, $y^2 + z^2$ coordinate system.

Fig. 14: Magnetogram obtained during a pass of the Mars-5 spacecraft through the Mars magnetosphere. Also indicated in the figure is the trajectory of the spacecraft indicating points of measurement.





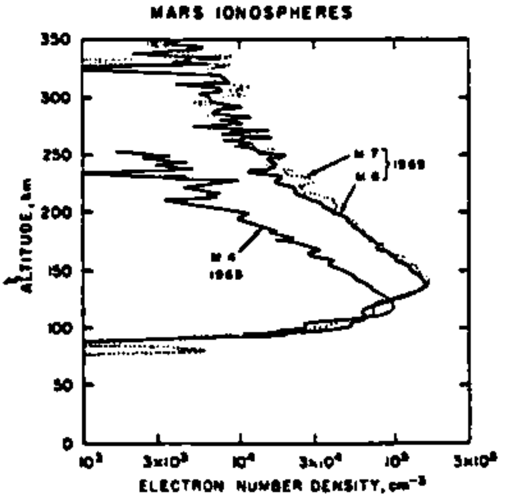


Fig. 15a: Electron density profile of the Mars ionosphere from Mariner-4, -6 and -7.

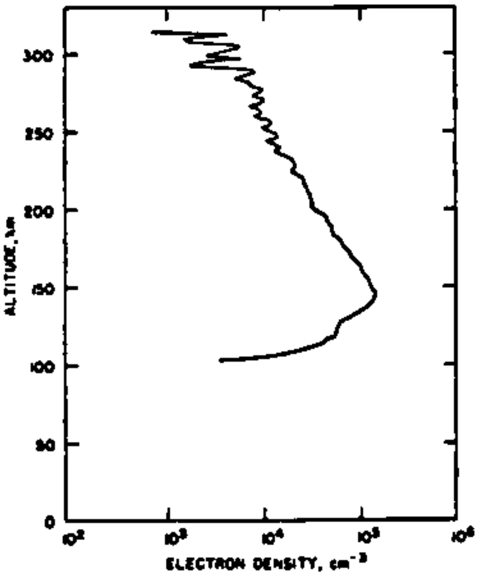


Fig. 15b: Electron density profile of the Mars ionosphere from Mariner-9.

the solar wind and in the transition region. In four other cases B_x in the 2-3 region is either very small or changes its sign inside this region; in one case B_x is small and B_x is directed towards the Sun

It is noted in [60] that since the Martian magnetosphere is small as compared to the Earth's one, the relative value of the magnetic flux generated in it by external sources is much more intense than in the case of the geomagnetosphere; therefore, the areomagnetic variations must be relatively much more significant than the geomagnetic ones may be, up to a degree which changes the sign of the B_x-component in the magnetospheric tail in some cases. The existence in many cases of a stable B_x-component in the magnetosphere tail that does not change its sign with changes of the IMF-directions. Therefore the data of Fig. 14 obtained in the day magnetosphere of Mars, can be interpreted in favour of the presence of the intrinsic areomagnetic field.

Martian ionosphere. The sharp boundary of the day ionosphere (ionopause), the height of which increases with increasing zenith angle is the main peculiarity for this type of solar-wind planet interaction that takes place in the case of Venus. We call it "inductive". So let us analyze the available data on density profiles of the Martian day ionosphere.

Fig. 15 gives profiles obtained by radio-occultation technique of the Martian ionosphere (Fig. 15a from Mariner-4, 1965 [61], [62]). The Mar-4 measurements were made in the period close to solar activity minimum, Mar-6 and Mar-7 measurements were made during moderate solar activity conditions. Significant space-or-time fluctuations were recorded in the upper parts of the profiles but the day-side ionopause is not seen. Fig. 15b presents a profile obtained from Mar-9 [63]. There is no ionopause visible. Kliore et al. in [66] published the

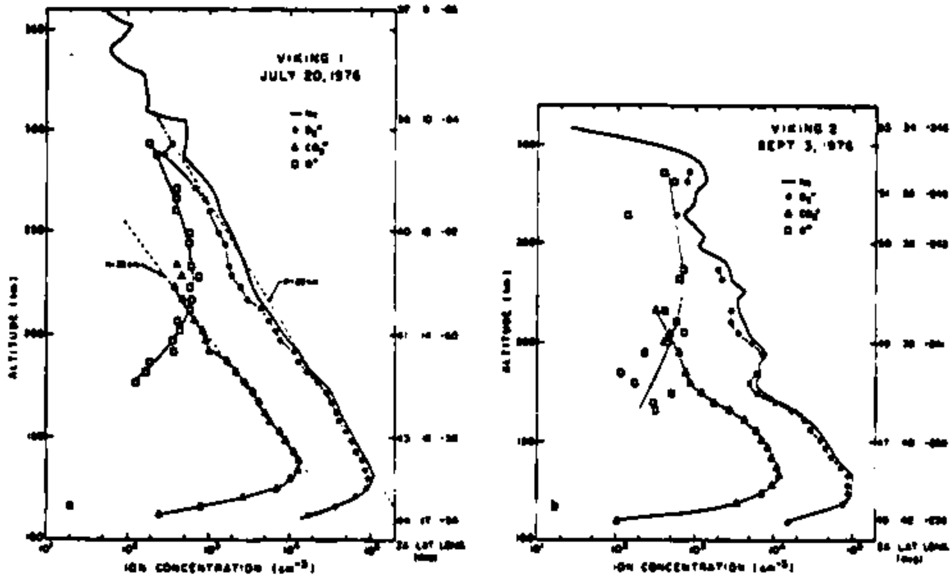


Fig. 16: Ion density profiles in Martian ionosphere from Viking-1 (left) and Viking-2 (right).

ionospheric data obtained from Mariner-9; the ionopause was not mentioend there as a typical feature of the Martian day ionosphere.

Finally, Fig. 16 gives the data obtained by retarding potential analyzers in the Martian day ionosphere during the Viking-1 and -2 descend (Hanson et al. [9]). There is no sign of an ionopause on the Viking-1 data; some resemblance to the ionopause can be seen on the graph of the Viking-2 data.

The estimates show that under reasonable assumptions on solar-wind pressure values, the pressure of the ionospheric plasma in the "ionopause" corresponding to Fig. 16 is entirely insufficient for pressure balance which takes place in the magnetic barrier case and hence the density decrease in the upper part of the density profile of Fig. 16 is not the result of the direct interaction between the solar wind and the Martian ionosphere.

The existing experimental data about the Martian day-side ionosphere obtained by the same technique as the data about the Venus day-side ionosphere provide us with evidence in favour of the absence of an ionopause in the Martian day ionosphere and indicates, therefore, a solar wind interaction with Mars, which differs significantly from that with Venus.

Some arguments in favour of the absence of the intrinsic magnetic field near Mars. Russell [10], in order to reinforce his conclusion on the absence of a Martian intrinsic magnetic field, noted that during the M-3 pass on February 21, 1972 the maximum B occurred not near the periapsis, a fact incompatible, in his opinion, with the presence of an intrinsic field. Dolginov et al. [66] indicated that the Martian magnetic field is dipolar with its axis inclined to the planet rotation axis at an angle 15-20°. Smirnov et al. [14] concluded that the dipole axis is located close to the equatorial plane. So, the position of the day-side cusps of Mars is the subject of discussion.

It is quite evident that if the satellite periapsis is located in the region of the magnetic field depression typical of the day-side cusp, the maximum of the magnetic field along the satellite orbit may not be in the periapsis, and hence, Russell's above-mentioned objection against the Mars-3 data interpretation, according to which Mars has its intrinsic magnetic field, is not convincing.

The data of Vaisberg et al. [67] on the detection of heavy ions in the zone of the solar wind flowing around Mars is used by Russell as the evidence of the direct interaction between the solar wind with the Martian ionosphere and, consequently, of the absence of an intrinsic Martian magnetic field. Bezrukikh et al. [68] analyzed once more Vaisberg's et al. data [67] and showed that the peculiarities of the data, used in [67] for the conlcusion about the detection of heavy ions, can be explained without assuming heavy ions present in the plasma and even if heavy ions really could be detected, this should not be used as evidence for the absence of an intrinsic magnetic field.

On the value of the Martian magnetic moment. Dolginov et al. [66] on the basis of magnetic field data from M-2, M-3 and M-5 orbiters evaluated the magnetic moment of Mars (corresponding to an intrinsic magnetic field) as $M_M=2.5\times10^{22}$ gauss x cm^3. Gringauz et al. [69], considering possible pressure balance and measured stand-off distances, estimated 2×10^{22} gauss x cm^3. Authors of [69] used scaling of the aeromagnetosphere and the geomagnetosphere to obtain the value of M , assuming that both magnetospheres have similar shapes. This assumption was supported by data from Martian magnetosphere crossings by the M-5-orbiter given in [69].

In 1978 Russell, as was mentioned above, reconsidered magnetic data from M-3 and claimed that the upper limit M_M is equal to 2×10^{21} gauss x cm^3. Further, in 1979 Intriligator and Smith [11], again without new experimental data, reconsidered previously published estimates of the Martian magnetic moment and claimed a value of $M_M=8\times10^{21}$ gauss x cm^3. They criticized both Dolginov and Gringauz. The authors of 11 indicated that Dolginov's estimate [66] based on Gaussian coefficient calculation is not correct because the compression of the magnetic field by the solar wind was not taken into account. They claimed that probably there are times when the external solar wind pressure increases in which case the interaction is dominated by the ionosphere rather than by the planet's magnetic field.

One may agree that the criticism of Dolginov's calculations is not entirely groundless. It also is not excluded that in extreme cases of very large solar wind pressure, direct contact between the solar wind and the ionosphere may occur with the consequent creation of a day-side ionopause. Nevertheless the arguments by the authors of [11] are in our opinion not at all convincing. Intriligator and Smith tried to improve considerations on pressure balance by considering this balance at a peculiar solar zenith angle corresponding to Viking ionospheric RPA-measurements, but the absence of simultaneous near-Mars solar wind data makes this improvement purely illusive. Authors of [11] criticize Gringauz for using an altitude of the Martian subsolar magnetopause h_M equal to 1700 km. But the only paper by Gringauz et al. quoted in [11] is paper [70], while in [69], as a matter of fact, a value of $h_M=(1200 \pm 800)$ km was used and its variability was discussed. On the other hand, Intriligator and Smith use the concept of "mean bow-shock position" and scaling of the areomagnetosphere and the geomagnetosphere to obtain the magnetic moment of Mars. The "mean bow-shock position" without analysing the distribution of bow-shock positions is, in our opinion, not more useful than the "mean temperature" of patients in a hospital (some may have fever, some may be dead, the mean temperature may be normal). To use the scaling one must be sure that in cases under consideration the shapes of the magnetospheres are similar; it is obviously impossible to use scaling for the Jovian magnetosphere based on the geomagnetosphere. The only information on the shape of the Martian magnetosphere is given by data from crossing of the magnetopause by Soviet orbiters M-2, M-3 and M-5, which Intriligator and Smith do not consider. That is why their arguments are not convincing.

Taking into account the peculiarities of magnetic and Plasma data from M-2, M-3 and M-5 mentioned in the "Introduction", one can conclude that at present these data are not sufficient for unambiguous definition of M_M. Bearing in mind the influence of a compression of the Martian magnetic field by the solar wind, one may regard the magnetic moment estimated by Dolginov (M_M=2.5x10^{22} gauss x cm^3) as an upper limit of the undoubtedly existing intrinsic magnetic moment of the Mars. We believe that our estimate (M_M=2x10^{22} gauss x cm^3) based on pressure balance and scaling consideration [69] is close to reality. But as it was mentioned in [70] the shape of the areomagnetosphere may vary in time with the solar wind ram pressure or (and) with the sign of the interplanetary magnetic field due to reconnection. If such variations are large enough the scaling may lead to significant errors.

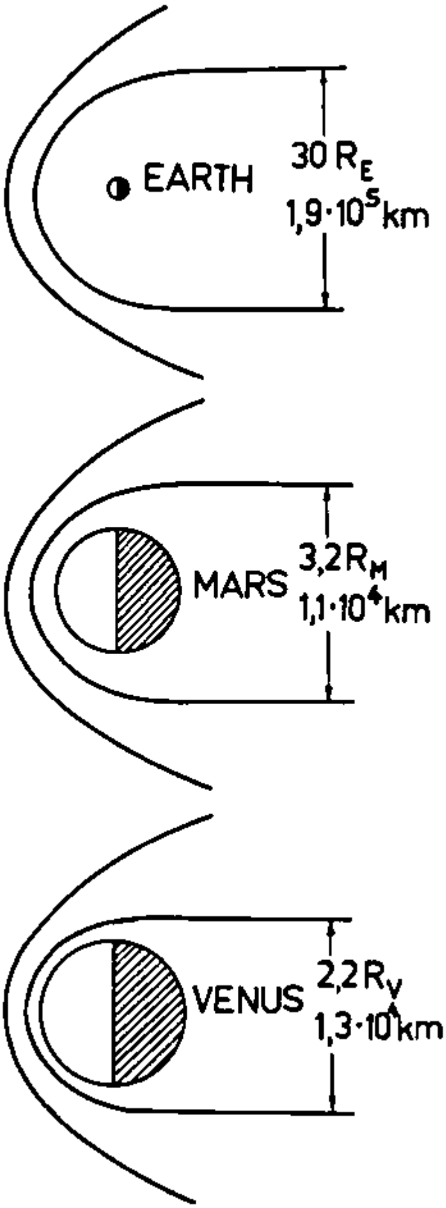


Fig. 17: Scale composium of equatorial cross sections of the magnetospheres of Earth, Mars and Venus.

<u>Magnetospheres of Venus and Mars and the geomagnetosphere</u>. The geomagnetosphere has been studied for more than twenty years. The greatest part of this twenty-year period dealt with the study of the magnetosphere morphology; many significant features of the geomagnetospheric structure were experimentally revealed only a long period of time after the study begun (e.g. day-time polar cusps only in 1971, the diffusive boundary (mantle) in 1971-1972). Regardless of the fact that the experimental study of the geomagnetosphere was carried out by means of tens of Earth satellites, at present, after twenty years of numerous plasma and magnetic measurements in the near-Earth space, the number of unsettled problems in geomagnetospheric physics is still great.

Open problems are related to the solar wind entry into the magnetosphere and to the various mechanisms causing the plasma motion inside the magnetosphere; a number of questions related to the distant part of the geomagnetic tail still remains unanswered. New missions concentrating on answering these questions are under study.

Indeed, the investigation of the Venus magnetosphere is still at its early stage (comparable to the state of the geomagnetospheric research in 1965-66) and the study of the Martian magnetosphere is even farther behind. So it is quite natural that the number of unsolved problems related to the magnetospheres of Mars and Venus is very large and that further studies are needed.

Fig. 17 shows a scale composition of the equational cross sections of the three magnetospheres. The bow-shocks are taken identicaly and the magnetospheres and planets are scaled accordingly. The characteristic cross sections of the magnetic tails of Mars and Venus are given based on the data from M-5 and V-9, V-10.

It is reasonable to list some features of the Earth magnetosphere which are inherent also to the Venusian magnetosphere:

a) a well-developed near-planet bow-shock;

b) the plasma flow behind the bow-shock is sufficiently described by hydromagnetic theory;

c) relative time variability of the distance of the subsolar point of the bow-shock from the obstacle is approximately the same both for Earth and for Venus. The spread of the front positions near Venus was given in Fig. 5; the similar graph for the Earth is presented in [29];

d) existence of the magnetic tail elongated along the Sun-planet line;

e) presence of the plasmasheet separating two bundles of magnetic field lines in the tail (directed towards the Sun and away from the Sun).

Inspite of these common signs, the nature of the obstacles to the solar wind near Earth and Venus is, as we know, quite different. The similarities given above prove only that magnetospheric structures with long magnetic tails can occur in a supersonic magnetized plasma with obstacles present, the nature of which might be essentially different.

There are no doubts that the magnetospheres of our neighbour planets, of Venus, which practically has no intrinsic magnetic field, and of Mars, with a relatively weak intrinsic magnetic field but in contrast to Mercury, with a well developed ionosphere, are peculiar among the magnetospheres of the planets in the Solar System.

CONCLUSION

In spite of the fact that Venus probably has no intrinsic magnetic field, the Venusian magnetosphere has a complicated structure. In particular there exists a magnetic tail directed along the Sun-Venus line. The magnetic field direction in the tail depends on the direction of the azimutal IMF-component. On the basis of V-9, V-10 and PVO observations a simple magnetospheric current system can be proposed. There are substantial arguments supporting the existence of a Martian intrinsic magnetic field, which is weak but sufficient to deflect the solar wind: the topology of the magnetic field in the day-side Martian magnetosphere is different compared to the Venus magnetosphere, and the ionopause is not a characteristic feature of the Martian day-side ionosphere. Mars also has a magnetic tail. Many other similar features exist in the magnetosphere of Venus, Mars and the Earth in spite of the different nature of magnetic field origin at Venus and at Earth and of the Martian magnetosphere peculiarities.

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