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PLASMA OBSERVATIONS NEAR VENUS ONBOARD THE VENERA 9 AND 10 SATELLITES BY MEANS OF WIDE-ANGLE PLASMA DETECTORS

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ABSTRACT

Preliminary results of the measurements on the electron and ion components of plasma obtained by means of wide-angle detectors onboard the Venera-9 and Venera-10 satellites are presented. Stable electron and fluctuating ion fluxes were detected in the optical and corpuscular umbra. As a result of the plasma characteristics observed at a few hundred kilometers above the optical umbra, we refer to this region as corpuscular penumbra. By means of a number of bow shock crossings, we analysed its structure which turned out to be variable with time. The relatively small fluctuation of the bow shock crossing positions and grouping of corresponding shocks near the planet suggest the non-magnetic nature of the Venus obstacle.

1. Introduction

The low-energy plasma measurements were conducted by means of wide-angle detectors installed on Venera-9, 10 space vehicles launched into the Venus satellite orbits on October, 1975. Period of revolution of both satellites was ~ 2 days, the orbit altitude in pericenter ~ 1500 km, in apocenter ~ 110000 km, inclination ~ 30°. The ionic component of plasma was measured in 16 energy intervals from Venera-9 (in energy range 0 to 4400 ev) using a modulated Faraday cup oriented to the Sun with angular diagram ±45°; measurements of the electron component of plasma were carried out using an integral trap oriented in the anti-solar direction (ith angular diagram ±40°) to the analysing grids of which 16 values of retarding voltage were supplied in the range 0 to 300 V. Only the electron plasma component was measured from Venera-10 as the ionic Faraday cup current amplifier put out of operation during the flight to Venus. The equipment used slightly differed from the instruments operated earlier in plasma experiments in the Mars region (detectors are identical) on satellites "Mars-2", "Mars-3" and "Mars-5" and described in detail by Gringauz et al. (1974).

Before the flight of Venera-9, 10 the experimental results relating to the region of solar wind interaction with Venus were not systematic. For the first time the simultaneous disturbances of ionic component of the interplanetary plasma and magnetic field connected with the near-planetary shock wave, were discovered on October 18, 1967 when the Venera-4 station approached to Venus (Gringauz et al., 1968, Dolginov et al., 1968). Later near-planetary shock wave front crossings were registered on October 19, 1967 from "Mariner-5" (Bridge et al., 1967); on May 17, 1969 from Venera-6 (Gringauz et al., 1970) and on February 5, 1975 from Mariner-10 (Bridge et al., 1974, Ness et al., 1974). Measurements of the low-energy plasma ion component were taken from Venera-4 and Venera-6 by means of the wide-angle traps with two values of retarding potential 0 V and +50 V (Gringauz et al., 1970); from Mariner-5 the ion component of plasma was measured too, using a modulated trap in the energy range 40 to 9400 ev (Bridge et al., 1967), and from Mariner-10 the measurements of only electron component of plasma were carried out in the energy range 13 to 715 eV using electrostatic analyzer oriented mainly in the anti-solar direction (Bridge et al., 1974). Thus, before the flight of Venera-9, simultaneous measurements of the plasma electron and ion components in the region of the solar wind interaction with Venus were not conducted. It worth to mention the full absence of the experimental data on the plasma characteristics in the optical umbra of the planet.

The shock wave front position was defined in the previous experiments from Venera-4, Mariner-5, Venera-6 (Gringauz et al., 1968, 1970; Dolginov et al., 1968; Bridge et al., 1967) only with the large angles φ Sun-Venus-vehicle (112^{o}, 138^{o}, 129^{o}, respectively) when the relative uncertainty of the front position was sufficiently small: $\Delta r/r \ll 1$ where r - is the distance from the Venus center to the front, and Δr - is the front position uncertainty associated with the motion character and the front thickness as well as with frequency of plasma or magnetic measurements in each specific experiment. As it was mentioned by Bridge et al., (1975) according to the Mariner-5 and Mariner-10 data recorded from these vehicles front crossings travelling from the magnetosheath with lower r and φ, Δr was ~3000 km and was compared with the dimensions of the obstacle creating the front ($\Delta r/r \approx 0.2$ to 0.3).

Earlier a paper was published (Gringauz et al., 1976a) with the first preliminary data obtained on October 26, 1975 while Venera-9 was flying from the optical umbra of Venus into the solar wind. At present the results of measurements conducted in near-planetary parts of the orbits are partially processed (the first month of operation, 12 flights of Venera-9 and 4 flights of Venera-10). Some results of measurements conducted during these flights are considered and discussed below.

2. Corpuscular and optical umbra, corpuscular penumbra

Plasma measurements in a mode with increased sampling were begun, as a rule, in the optical umbra of the planet at altitude 1500 to 2000 km at the distance 3000 to 4000 km from the Sun-Venus line. In this mode one value of the electron and ion trap current was measured once per second. Since the measurements of the plasma ion component were made in 16 energetic intervals; electron component measurement conducted with 16 values of retarding voltage, and in each energy interval and with each value of retarding voltage the current was measured 10 times, the full differential energy spectrum of ions and integral energy spectrum of electrons were obtained for 160 sec. During this time the satellites with the velocity ~7 km/sec travelled ~1100 km; it should be taken into account in regions with large gradients of the surrounding plasma peculiarities.

Fig. 1 in X , $\sqrt{Y^2+Z^2}$ coordinates (X axis passes through the planet centre and is directed to the Sun) gives the Venera-9 trajectory part during the fly from the optical umbra into the solar wind on November 1, 1975. The energy spectra of ions obtained during this flight are given in the upper part of the Figure. In the optical umbra of the planet the energy spectra of electrons conforming with the density $n_e \sim 1$ cm^{-3} and temperature Te = $(2 \div 5) \cdot 10^5$ °K were regularly measured. In the same region on an average in ~70% of the telemetry samplings the measured ion fluxes turned out to be lower than the instrument sensitivity threshold, and in ~30% of the fluctuating ion fluxes irregularly distributed in all energy intervals up to 4.4 keV. The plasma peculiarities characteristic for the optical umbra of the planet, was recorded at several hundreds kilometers higher than the optical umbra boundary. The region, that is wider than the optical planetary umbra and which is characterized by the absence of distinct directed ion fluxes we refer as corpuscular umbra region.

Fig. 1 shows the spectra (a) of electrons and ions in the corpuscular (and optical) umbra region. The basic mass of readings in the ion spectrum lies lower than the instrument sensitivity; the points show the separate ejections of the ion currents recorded.

Between the corpuscular umbra and the magnetosheath, existing behind the near-planetary shock wave front, a zone called by us as corpuscular penumbra was observed (spectra b in Fig. 1) within which the plasma ion component is characterized by less transport velocities as compared to that in the magnetosheath (spectra (c) in Fig. 1); the directional character of ion motion in the corpuscular penumbra is expressed quite distinctly.

Let us consider the fly out of the corpuscular penumbra in more detail. Fig. 2 gives five successive ion spectra recorded on October 30, 1975 from satellite Venera-9 during its fly from the corpuscular umbra (spectra a,b,c) into the magnetosheath (spectrum e). As mentioned above in each energy interval the current was recorded 10 times (with absence of "failures"), however, because of the transition process while delivering the high and modulating voltage onto the ion trap grid even in the quiet surrounding plasma, the first reading of current, as a rule, differed from the rest. Therefore Fig. 2 gives 9 readings of ion current in each energy interval (in the first energy interval, 0 to 40 eV the last 5 readings of current are given). As it is seen from Fig. 2, the directional character of ion fluxes became noticeable in spectrum d (Fig. 2) when the satellite went out into the penumbra (according to our terminology).

To get an estimation of the plasma parameters in the penumbra, magnetosheath and solar wind the averaged values of currents in each energy intervals were used (by 9 readings). The computated current values in our energy intervals are shown in Fig. 2d, e by solid lines with the parameters of the surrounding plasma (chosen in such a way that the weighted root-mean-square deviation of computated current from the averaged measured currents should be minimum): in penumbra - the ion density is $n_i \sim 1.5$ cm^{-3}; bulk velocity $V_d \sim 180$ km/sec, temperature $T_i \sim 5 \cdot 10^{5}\,^{\circ}K$; in magnetosheath $n_i \sim 2.7$ cm^{-3}, $V \sim 240$ km/sec, $T_i \sim 5.3 \cdot 10^{5}\,^{\circ}K$, i.e. during the flight into the magnetosheath from penumbra on October 30, 1975 the increase of bulk velocity and ion density occurred, their temperature practically did not change.

Non-monotonous change of the computable currents (Fig. 1) can be explained by the chosen values of the relative widths of energy steps. The ion bulk velocity vector deviation from the normal to the trap aperture was not taken into account in the calculation. The analogous estimates of the plasma parameters on November 1, 1975 in the penumbra (spectrum b in Fig. 1) yield $n_i \sim$ 2.9 cm^{-3}, $V \sim 110$ km/sec, $T_i \sim 3\cdot10^{5}\,^{\circ}$K; in the magnetosheath (spectrum c in Fig. 1) $n_i \sim 13$ cm^{-3}, $V \sim 230$ km/sec, $T_i \sim 0.9\cdot10^{5}\,^{\circ}$K.

The bulk velocity and ion density in the magnetosheath also increase during this fly, but the ion temperature is decreased. The lower values of ion temperature estimated from spectrum c (Fig. 1) as compared to b in penumbra can be caused by time variations of currents recorded by trap while taking this spectrum. Indeed, for the subsequent spectra in the magnetosheath on November 1, 1975 the estimated T_i values lay within $(2.6 \div 3.4)\cdot10^{5}\,^{\circ}$K, i.e. during this flight from the penumbra into the magnetosheath the ion temperature probably did not sufficiently change.

Note that the corpuscular penumbra was not recorded during all satellite flights. This can be associated with the fact, that the characteristic size of the penumbra is of the order of the distance at which the whole energy spectrum of ions is taken in the given experiment, and during the satellite fly via the corpuscular penumbra, measurement can be made in those energy intervals where the ion fluxes are absent in penumbra.

3. Magnetosheath and near-planetary shock wave

Let us return to Fig. 1. After flying out from the corpuscular penumbra the satellite at ~5000 km travelled in the magnetosheath. This transition is accompanied by the monotonous growth of electron fluxes with all the retarding potentials (compare spectra c and d in Fig. 1); the bulk velocity of ions increases from 230 km/sec to 270 km/sec; the plasma density (defined from the ion trap recordings) increases from 13 cm^{-3} to 105 cm^{-3}. During the spectrum e taking (Fig. 1) the satellite crossed the shock wave front S and went out into the solar wind (spectrum f in Fig. 1). It is clearly seen from Fig. 1 that in the given session of measurements the S front intersection is distinctly observed as a sharp decrease of the electron fluxes recorded (the ion component measurements at this time were made in energy intervals where the ion fluxes both in the magnetosheath and in the solar wind were absent). In the solar wind in this session of measurements the density was $n_i \sim 35$ cm^{-3}, $T_i \sim 6.5 \cdot 10^4$ °K, $T_e \sim 150 \times 10^3$ °K, $V_i \sim 310$ km/sec. Note that as the retarding voltage increases the electron fluxes fall sharper in the magnetosheath as compared to the solar wind (compare electron spectra c and d in Fig. 1). This can probably be explained not by "cooling" of electrons behind the shock wave front but the sufficient rise of the plasma density because of the satellite motion during taking the whole energy spectrum of electrons (from the large decelerating potentials to the small ones), that leads to the underestimation of electron temperature in the magnetosheath, region formally defined from "energy" spectrum, and overestimation of their "density" as compared to the ion density.

Fig. 3 gives the ion spectra obtained during the session on November 9, 1975 from Venera-9 in the magnetosheath (Fig. 3a) and in the solar wind (Fig. 3b); the calculated current values (see above) are shown in this picture by solid lines. As it is seen from Figure, the plasma ion component in the magnetosheath behind the shock wave front not only decelerates and heats up as compared to that of the solar wind, but it is characterized by sufficiently large fluctuations of ion fluxes in energy intervals with the most fluxes recorded. Under conditions of strongly fluctuating fluxes of charged particles the fluctuation level should be taken into account for adequate description of the plasma state. The used method of determining the plasma parameters described above does not probably allow the reliable numerical results to be obtained.

The behaviour of the obtained parameters of ion and electron components of plasma in the near-planetary shock wave front intersection by Venera-9 on November 11, 1975 is given in Fig. 4. As one can see the n density decreases and V bulk velocity increases as well as the ion temperature decreases in crossing the shock wave front S and going out into the solar wind. Note that the estimates of electron temperature and density given in Fig. 9 are made without consideration of plasma density change in the magnetosheath during a single energy spectrum measurement (see above). This probably causes the exceeding of the electron density in the magnetosheath over ion density, and the absence of sufficient variation of electron temperature at the shock wave front (see Fig. 9). Consideration of the plasma density gradient in the magnetosheath will result a better agreement of the estimates of the electron and ion densities in the magnetosheath, as well as in conclusion on the slight decrease of electron temperature while intersecting the shock wave front and going into the solar wind on November 11, 1975.

Sufficiently high time resolution of the instruments installed on Venera-9, 10 allows the behaviour of the plasma electron and ion components in crossing the near-planetary shock wave front to be studied in detail. Essentially differed front structures were observed at the different revolutions of satellites with crossings of the shock wave front. Results of measurements of electron and ion plasma components in the shock wave front intersection by Venera-9 on October 26, 1975 were given earlier (Gringauz et al., 1976). In this session of measurements the front crossing was recorded by electron and ion detectors simultaneously as a current decrease for 1 to 2 sec that with the satellite velocity and in assumption that the front did not move, allows its thickness to be estimated as 10-15 km (Gringauz et al., 1976). Of course it should not be excluded that in this session of measurement (similar to the considered below) the front transport could occur with the velocity essentially exceeding that of the satellite's (~7 km/sec); in this case the front thickness estimate must be increased.

Fig. 5 gives three successive electron integral energy spectra recorded from Venera-10 on November 2, 1975 flying from the magnetosheath (spectrum a) into the solar wind (spectrum c). In spectrum b the time interval ~20 sec is marked by s appropriating to the shock wave front intersection by the satellite. As it is seen from Figure, electron flux in the time interval s decreased rather monotonously and the shock wave front thickness in this case can be estimated as ~ 150 km assuming again that the shock wave front did not move.

It should be noted that in some sessions of measurements the shock wave front motions were possibly observed. For example, on the Fig. 6 the electron and ion spectra are shown obtained while Venera-9 on November 11, 1975 flies (spectra b) from the magnetosheath (spectra a) into the solar wind (spectra c). In the time interval marked by the dot line the considerable and fast oscillations of ion and electron fluxes were observed in spectra b that can be interpreted as the oscillatory motions of the shock wave front towards the satellite motion with the velocity that 10 to 20 times exceeds the satellite velocity or as pulsating front of width 200 to 300 km. The front motion at a more considerable distance was observed on November 9, 1975 when Venera-9 intersected the near-planetary shock wave front in the points spread in space at 1000 km. It should be also noted that during one flight (Venera-9 on November 7, 1975) a very wide front was observed on which the transition from the charged particles spectra typical for the solar wind to the typical spectra of the magnetosheath occurs in the orbit part of ~3000 km length.

Fig. 7 shows the analyzed cases of the intersections the near Venus shock wave front by Venera-9 (circles) and Venera-10 (points). The solid line with a circle marks shock wave front intersections on November 7, 1975 and on November 9, 1975 when the uncertainty of the front position was ~3000 km and 1000 km respectively. The dot line shows in this picture the shock wave front position computated by Spreiter et al. (1970) for the obstacle, characterized by parameter $H/r_0 = 0.01$ and by the subsolar point altitude above the Venus surface, 500 km (solid line). The short solid lines show the Venera-9 orbit parts where such ion spectra were observed which characteristic for the corpuscular penumbra. As it is seen from Figure, with the chosen obstacle size and shape the observed positions of the corpuscular penumbra and the near-Venus shock wave front are in good agreement with the computated ones.

4. Discussion

A. The corpuscular umbra and penumbra regions

The discovery of ion fluxes in the energy range 1 to 4.4keV in the deep optical and corpuscular umbra of the planet is one of the unexpected, incomprehensible and therefore the most intersecting results of measurements described. As it is noted above and as it is seen from Fig. 2 such fluxes are recorded approximately in ~30% of cases during some flights (in ~70% of the total number of measurements these fluxes are lower than the instrument sensitivity level). However, the ion fluxes in the mentioned energy interval were not recorded in the trajectory parts in the corpuscular umbra located closer to the magnetosheath, in the corpuscular penumbra and in the deepest part of the magnetosheath (compare a and c, d, e spectra in Fig. 2).

The characteristic size of the corpuscular penumbra is ~ 1000 km (see Fig. 1, 7) in a qualitative agreement with the assumption, that it can be formed as a result of erosion of an initially rather sharp boundary of the obstacle (the scale height of the ionized or neutral part of the Venus atmosphere is the natural thickness of the obstacle boundary near the terminator) because of the thermal motion of the plasma particles, or instability of the Kelvin-Helmholtz type on the obstacle boundary. However these mechanisms can explain the plasma penetration deeply into the optical umbra behind Venus, but do not explain the existence of ion fluxes with such energies which were not observed in the corpuscular penumbra region, and it is necessary to assume the presence of the ion accelerating processes deeply inside the corpuscular umbra of the planet. The presence of large fluctuations of ion fluxes deep in the corpuscular umbra of the planet can be an indirect evidence in favour of the fact that, at least some accelerating mechanisms are stochastic.

If ion fluxes in the optical and corpuscular umbra of Venus were on the limit of the instrument sensitivity, then electron fluxes in these regions were always reliably measured with all retarding potentials (0 to 300 V), and for characteristic parameters of the plasma electron component in the energy range 10 to 80 eV we obtained $n_e \sim 1$ cm^{-3}, $T_e \sim (2$ to $5) \cdot 10^{5}$ °K. The preliminary estimates show that an influence of these electron fluxes on the neutral atmosphere can provide the existence of the Venus nightside ionosphere. The authors will analyse this problem in a separate paper.

It should be noted that in the previous plasma experiments in the Venus region there have already been observed the phenomenon which we can interpret now as entry into the corpuscular penumbra. While Venera-4 was approaching the planet surface, the ion flux recorded by the integral trap at altitude ~ 3000 km dropped to the values less than those in the solar wind (Gringauz et al., 1968). While Mariner-5 was approaching the optical umbra the ion fluxes recorded by this vehicle also decreased (Bridge et al., 1967), and due to the reconsidered data analysis in the region of the nearest approaching the vehicle to the optical umbra, at ~ 2500 km from it the flux dropped to the values lower than the instrument sensitivity limit (Bridge et al., 1975). The position of Venera-4 (rhomb) and Mariner-5 (triangle) at the appropriate time moments is shown in Fig. 7. The dash lines in Fig. 7 show the Mach "cone" with opening angle ϑ =arcsin $1/M$, M=8. It is seen from Figure, that both the Venera-9 orbit parts where the ion spectra, characteristic for the penumbra were observed and the region with the minimum ion fluxes (Mariner-5 data) lies inside the Mach cone with $M \lesssim 8$. The phenomena observed from Mariner-5 by their character and location can be interpreted as an entry of this vehicle into corpuscular penumbra (and marked in Bridge et al., 1975, dissappearing of fluxes is possibly associated with Mariner-5 being at this moment in the corpuscular umbra of the planet). Venera-4 was beyond the Mach "cone" (Fig. 7) when the recorded ion fluxes dropped to the values lower than in the solar wind. However, with its further approach to the planet the ion fluxes recorded continued to decrease (dropped to the instrument sensitivity level at altitude ~2500 km) that also conforms with behaviour of the plasma ion component observed while Venera-9 entered the corpuscular penumbra.

We can make some conclusions on the obstacle height over the sunlit part of the planet when interpreting the corpuscular penumbra as the smearing boundary of the obstacle that stops the solar wind near Venus and therefore, believing that the obstacle height corresponds to the middle of the penumbra. As it is seen from Fig. 7 the typical distance from the Venus's optical umbra up to the middle of orbital sections where ion spectra were observed (we associated them with the corpuscular penumbra) amounts to about 800 km. The obstacle height over the planetary surface (and after terminator the obstacle height is over the geometrical umbra) is naturally assumed to be a monotonically increasing function of φ -angle. Hence, over the sunlit Venus the height of the obstacle that stops the solar wind is less than about 800 km. It is the experimental evidence in favour of the fact that the steep fall observed in the electron density profiles at about 500 km in the Venus ionosphere (Fijeldbo and Eshleman, 1969) is a consequence of the interaction between the Venus ionosphere and the solar wind.

B. Magnetosheath and near-planetary shock wave

As it has been mentioned above and seen from Fig. 4 the plasma density n , increases while the satellites move in the magnetosheath from the corpuscular penumbra to the shock wave front S, and then jumpingly decreases at the shock wave front. This density increase is sometimes rather significant (by 20 to 50 times); the plasma density decreases more than four times was also observed at the shock wave front. Such large jumps of the plasma density at the shock wave front and the growth of n between the corpuscular umbra zone and the front is possibly associated with the presence of the additional degrees of freedom in the plasma at the magnetosheath region (oscillatory) and with the appropriate decrease of the adiabatic exponent as compared to the frequently used value 5/3. It is not excluded that the increased gradients of the plasma density in the direction from the shock wave front to the corpuscular umbra boundary as compared to the analogous case in the Earth are associated with different nature of the obstacle: magnetopause near the Earth and the diffusive atmospheric boundary near Venus. However both of these conclusions need further theoretical and experimental confirmations. It should be taken into account that the plasma parameter estimates under the conditions of strongly fluctuating particle fluxes are not sufficiently reliable (see above). The comparison of the plasma parameter jumps at the shock wave front with the jumps calculated by the Rankine-Hugoniot relation assumes the absence of strong fluctuations of the plasma parameters behind the front at distances much less than the radius of the shock wave front curvature. Such a plasma state can be absent behind the near-Venus shock wave. Indeed, the linear dimension of the strong fluctuation region behind the collisionless shock wave near Venus and the Earth is defined by the solar wind plasma parameters and must be approximately the same. However, the characteristic size of the obstacle for the solar wind near Venus is ~10 times smaller than that near the Earth ($\sim 6\text{x}10^3$km and $\sim 6\text{x}10^4$km respectively). According to the measurements taken from the Vela-4 satellite strong fluctuations were observed by Montgomery et al. (1970) behind the near-terrestrial shock wave front in the region of ~1500 to 3000 km distance (sometimes its distance amounted ~ $3x10^4$ km), and the plasma parameters in both sides of this region were compared with the Rankine-Hugoniot relations (Montgomery et al., 1970). For Venus ~1500 to 3000 km are compared to the magnetosheath dimension and in this case the plasma current characteristics in the magnetosheath beyond the zone of strongly fluctuating fluxes will be not determined by local Rankine-Hugoniot relations but the total picture of the flow arround the planet.

Despite of the possible absence of the plasma state with small fluctuations in the Venus's magnetosheath, the obstacle and the shock wave front positions detected near Venus agreed with gasodynamic calculations Spreiter et al., 1970) carried out under the assumption that the obstacle boundary is a tangential discontinuity and the Rankine-Hugoniot relations are performed locally at the shock wave front (very small duration of the strong fluctuation region behind the shock wave front). Though for the flow around the Venus both these assumptions become less valid (as compared to the flow of solar wind around the Earth); nevertheless, the measurements and, in particular, the agreement of the mutual positions of the near-planetary shock wave front and the obstacle with the gasodynamic calculations allow the application (at least qualitative) of gasodynamic approximations in the case of the solar wind interaction with Venus.

It can be noted that the intersection points of the shock wave front by satellites (Fig. 7) with the different revolutions around the planet are grouped near the front position indicated by the dashed line. Only in five cases from 16 flights were the deviations from the front (reckoned in the normal to the front) ~ 2000 km. This fact, probably indicates the nonmagnetic nature of the obstacle creating the near-Venus shock wave. Really, if the atmosphere or ionosphere of the Venus is an obstacle, then due to the low scale heights in the atmosphere and ionosphere as compared to the planetary radius the obstacle dimension must be rather stable, even with great changes of the solar wind dynamic pressure, and according to Spreiter et al., (1970) for $M \gtrsim 5$ and given obstacle dimension the front position only slightly depends on M. Near the Earth (Bezrukikh et al., 1976; Fairfield, 1971) and Mars (Gringauz, 1975; Gringauz et al., 1976b) the near-planetary shock wave positions are more changeable.

Let us discuss now the near-Venus shock wave front peculiarities marked during separate flights. All front intersections given here are recorded by Venera-9 and Venera-10 over the dawn side of Venus[*)] in rather narrow interval of planetocentric distances r and angles φ (see Fig. 7). The near-planetary front intersections over the dawn side of Venus approximately at the same interval r and φ were earlier observed from Mariner-5 and Mariner-10 (Bridge et al., 1967, 1974; Ness et al., 1974). According to the data obtained from these vehicles the uncertainty of the front position was, as noted above, ~ 3000 km and was interpreted in terms of "parallel" shock wave (Bridge et al., 1975).

[*)] Here the side looking in the direction of the Venus orbital motion despite its own reverse rotation is regarded as the morning side (by analogy with the Earth).

Really, over the dawn side of Venus the expected directions of the interplanetary spiral magnetic field and the normal to the shock wave front are rather collinear than orthogonal. However, a very wide shock wave front with the characteristic dimension ~3000 km was observed only once in 16 flights on November 7, 1975 and is not considered to be typical.

The great difference of time intervals for which satellites crossed the shock wave front (from $1\div2$ sec to 5 min or from $10\div15$ to ~3000 km with unmoved front) can be associated with the different classes of shock wave structures depending on Mach number, heat energy density relation to the magnetic field energy density, the angle between the direction of interplanetary magnetic field force lines and the shock wave front ϑ, ion and electron temperature relation etc. The character of structure and the shock wave front width changed depending on these parameters and the front width can make up, e.g.

$\sim c/\omega_0 \approx 2\,km$, $\omega_0 = \sqrt{\frac{4\pi ne^2}{m}}$ - Langmuir frequency

$\sim c/\Omega_0 \approx 70\,km$, $\Omega_0 = \sqrt{\frac{4\pi ne^2}{M}}$ - ionic Langmuir frequency

$\sim c\vartheta/\Omega_0 \approx 2\div70\,km$, $\sqrt{\frac{m}{M}} < \vartheta < 1$; ρ_i - ionic thermal Larmor radius

etc. (Sagdeev, 1964). The estimates of the front width are made with $n \approx 10\ cm^{-3}$, $T \approx 2.10^{5}\,^{\circ}K$, $H \approx 10\,\gamma$. One can see that the estimates of width of the collisionless shock wave obtained from experiments on Venera-9, 10 are not inconsistent with the modern theoretical conceptions. Further detailed studying of the separate intersections of the shock wave near Venus will require the simultaneous data on the plasma electron and ion components and three components of magnetic field.

5. Conclusion

1. Multiple measurements of electron and ion plasma component were carried out by means of wide-angle plasma detectors in the optical and corpuscular umbra of Venus, in corpuscular penumbra, in the magnetosheath during the front intersection by the near-planetary shock wave and in the solar wind.

2. Electron fluxes appropriating to the density $\sim 1\ cm^{-3}$ and temperature $T \simeq (2 \div 5) \times 10^{5}$ °K were detected in the optical and corpuscular umbra of the planet; in these regions the ion fluxes fluctuate and are distributed randomly over all energetic intervals up to 4.4 keV. Electron fluxes discovered can ionize the Venus neutral atmosphere and explain the existence of the Venus nightside ionosphere.

3. Corpuscular penumbra is detected at hundreds of kilometers higher than the optical umbra; the plasma density and bulk velocity there are less than these in the magnetosheath.

4. Charged particle fluxes in the magnetosheath strongly fluctuate; plasma density estimates show its considerable increase during satellite flights from the corpuscular penumbra to the shock wave front.

5. The measurements carried out during a number of intersections of near-planetary shock wave front showed that the front structure considerably varies in time (from sharp front with the thickness on the order of 10 km to diffusive stretched over ~3000 km).

6. The observed points of intersection by satellites at different flights have rather small spread and the appropriate front positions are grouped near the planet, this fact apparently indicates the non-magnetic nature of the obstacle near Venus.

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FIGURE CAPTIONS

Fig.1. A part of Venera-9 trajectory near Venus and the energy spectra of electrons and ions obtained during this flight. "S" was the satellite position when it crossed the bow shock (dashed line). Solid line is the obstacle position according to this shock.

Fig.2. The ion spectra recorded during the flight of Venera-9 from corpuscular umbra (a, b, c) across the corpuscular penumbra (d) into the magnetosheath (e). t_0 is the beginning of the given spectrum. Solid lines are the calculated currents.

Fig.3. Ion spectra in the magnetosheath (a) and in the solar wind (b). Solid lines are the calculated currents while t_0 is the beginning of the given spectrum.

Fig.4. The behaviour of the calculated ion and electron parameters near the intersection of the "S" bow shock. In the calculations we neglected the density variation during the recording of the spectra.

Fig.5. The energy spectra of electrons registered by Venera-10 from the magnetosheath (a) into the solar wind (c) intersecting the "S" bow shock. U_R is the retarding potential of the analysing grid of the detector.

Fig.6. Eenergy spectra of ions and electrons recorded by Venera-9 flying from magnetosheath (a) to the solar wind (c). In the time interval marked by the dashed line on spectrum (b) the considerable and fast oscil-

lations of ion and electron fluxes were observed. U_R is the retarding potential of the analysing grid of the detector while E_i is the mean energy of the given energetic interval of the Faraday cup.

Fig.7. Bow shock crossing of Venera-9 and Venera-10. The solid line with cross represents the position of the optical umbra.

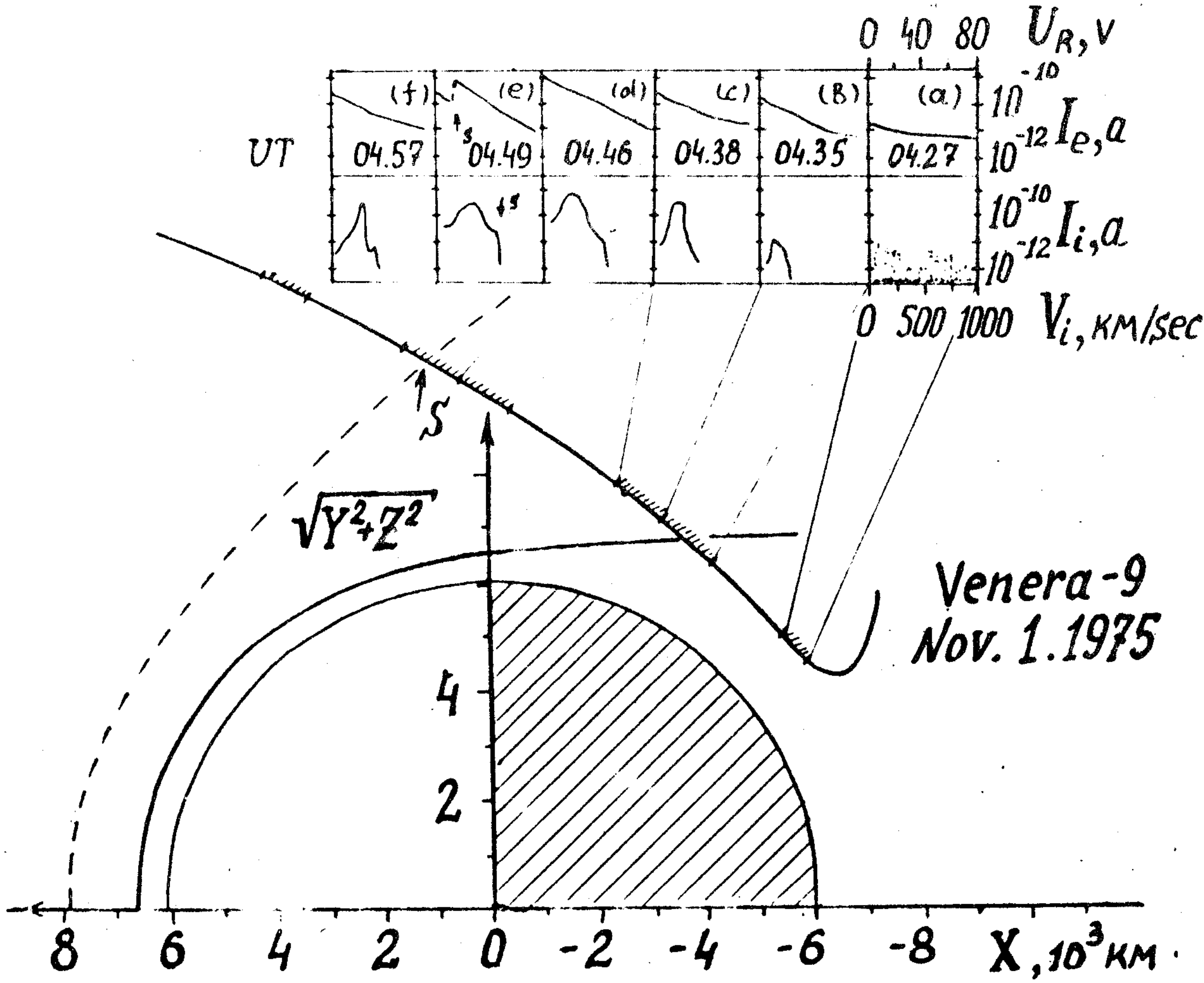
 0 40 80 U_R, v
(f)
(e)
(d)
(c)
(B)
(a)
10^{-10}
10^{-12} I_e, a
UT
04.57
04.49
04.46
04.38
04.35
04.27
10^{-10} I_i, a
10^{-12}
0 500 1000 V_i, км/sec
S
$\sqrt{Y^2+Z^2}$
4
2
Venera-9
Nov. 1.1975
8
6
4
2
0
-2
-4
-6
-8
X, 10^3 км

Fig. 1

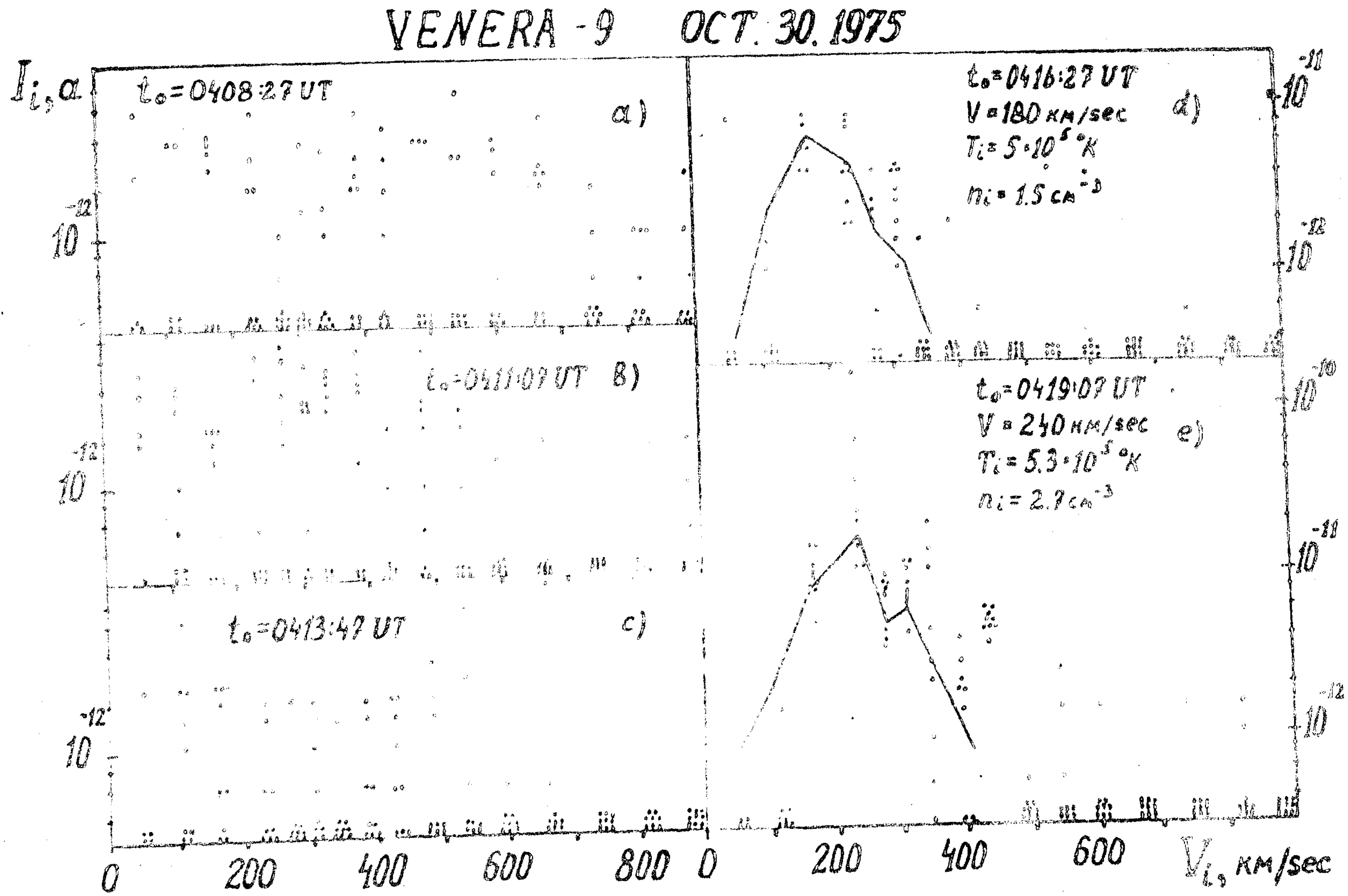

VENERA -9 OCT. 30. 1975
I_i, a
t_o=0408:27 UT
a)
t_o=0411:07 UT
B)
t_o=0413:47 UT
c)
t_o=0416:27 UT
V=180 км/sec
T_i= 5·10^5 °K
n_i= 1.5 см$^{-3}$
d)
t_o=0419:07 UT
V = 240 км/sec
T_i = 5.3·10^5 °K
n_i = 2.7 см$^{-3}$
e)
10^{-12}
10^{-12}
10^{-12}
10^{-11}
10^{-12}
10^{-10}
10^{-11}
10^{-12}
0
200
400
600
800
0
200
400
600
V_i, км/sec

Fig.2

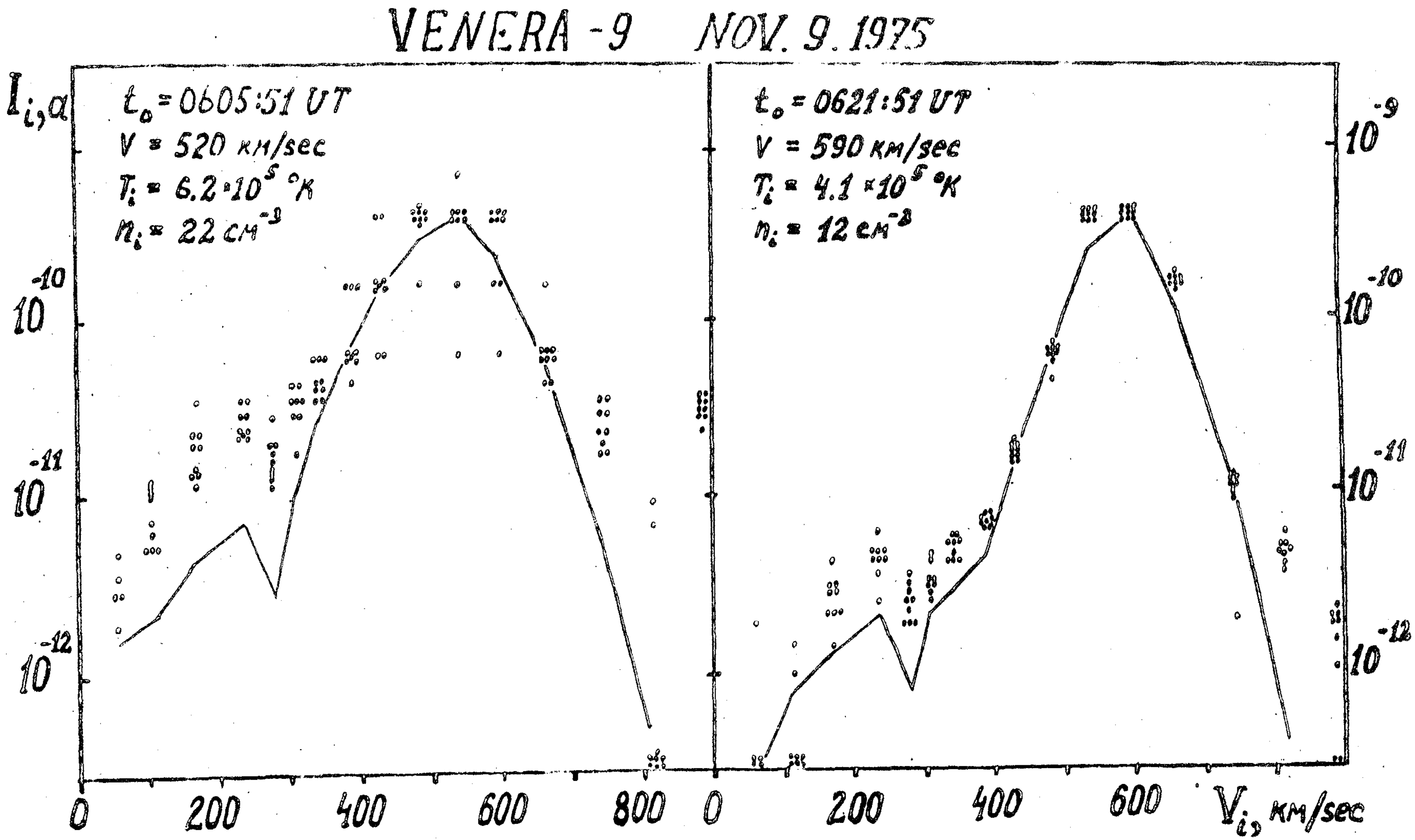

VENERA -9 NOV. 9.1975
I_i, a
t_0 = 0605:51 UT
V = 520 км/sec
T_i = 6.2·10^5 °K
n_i = 22 см$^{-3}$
t_0 = 0621:51 UT
V = 590 км/sec
T_i = 4.1×10^5 °K
n_i = 12 см$^{-3}$
10^{-9}
10^{-10}
10^{-11}
10^{-12}
0
200
400
600
800
V_i, км/sec

Fig.3

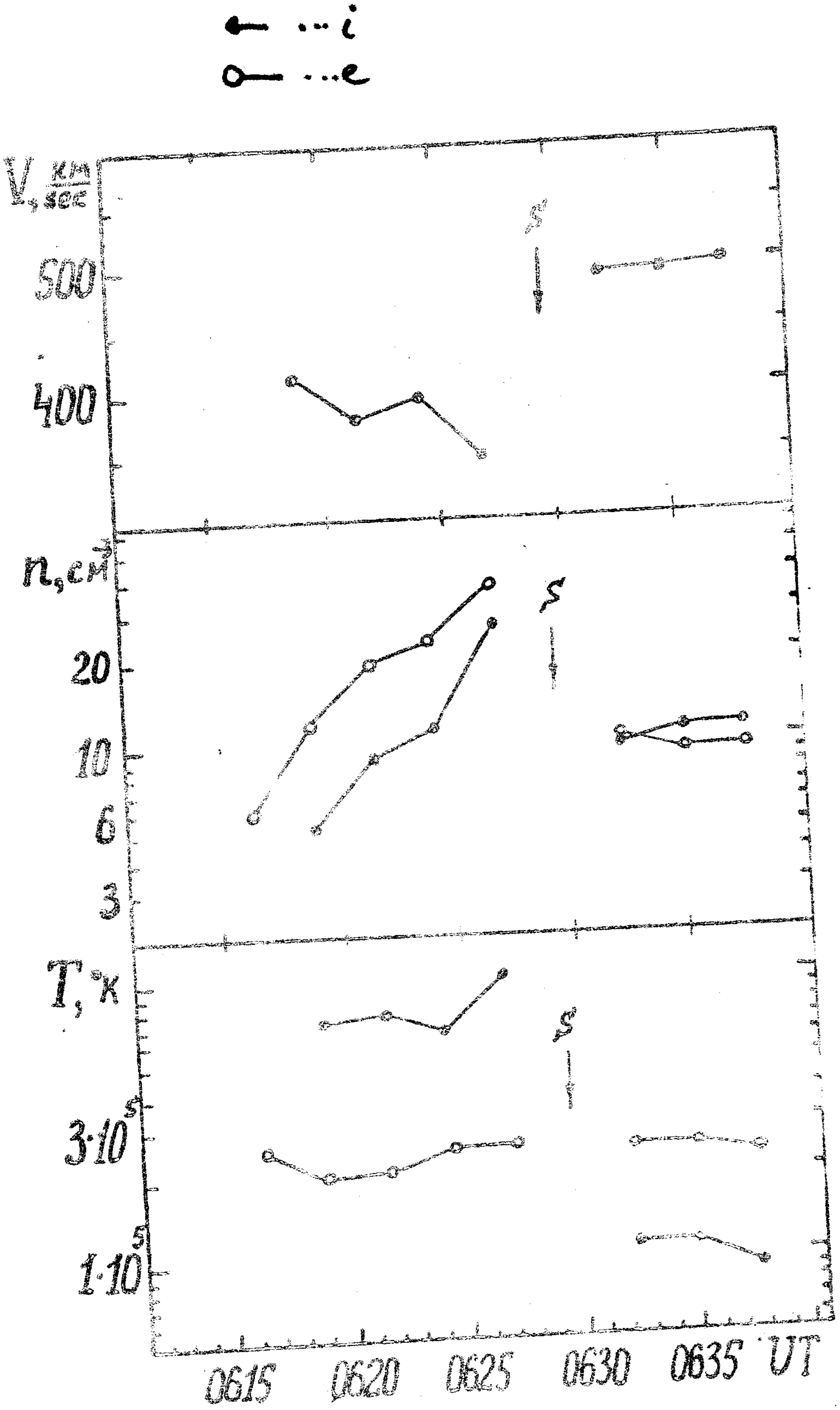

...i
...e
V, km/sec
500
400
S
n, cm⁻³
20
10
6
3
S
T, °K
3·10⁵
1·10⁵
S
0615
0620
0625
0630
0635
UT

Fig.4

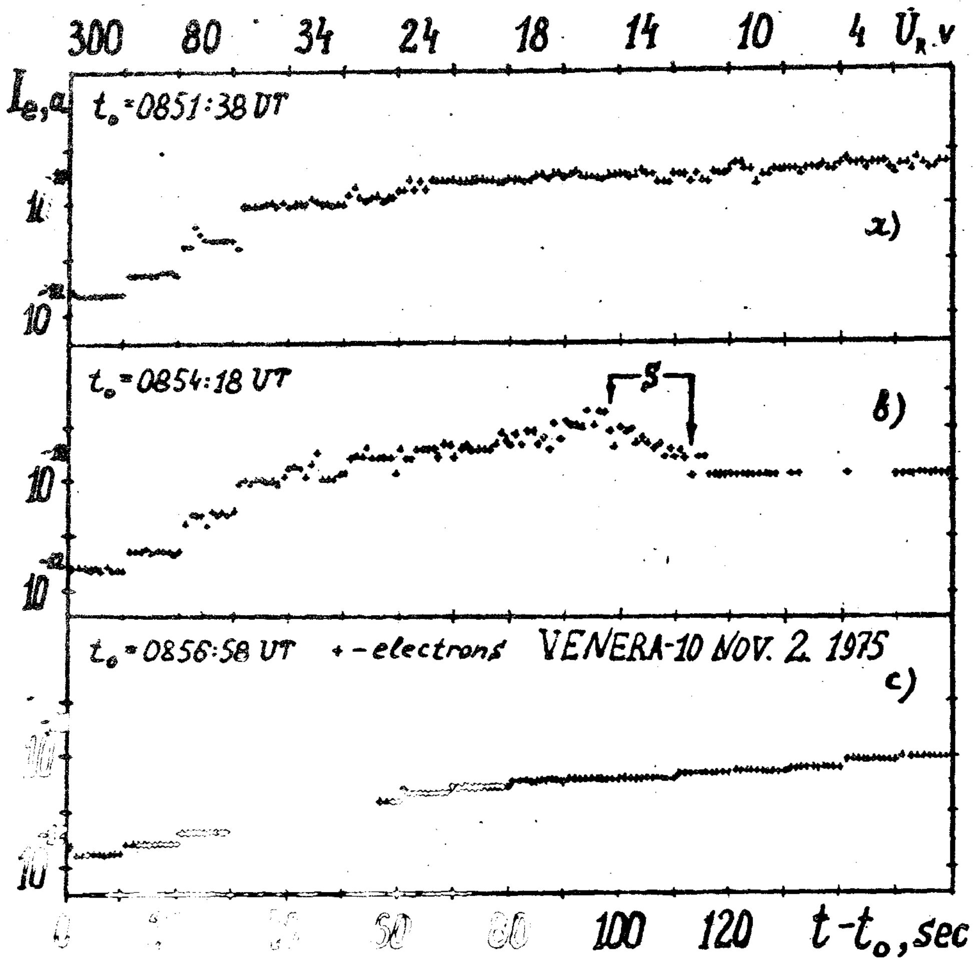
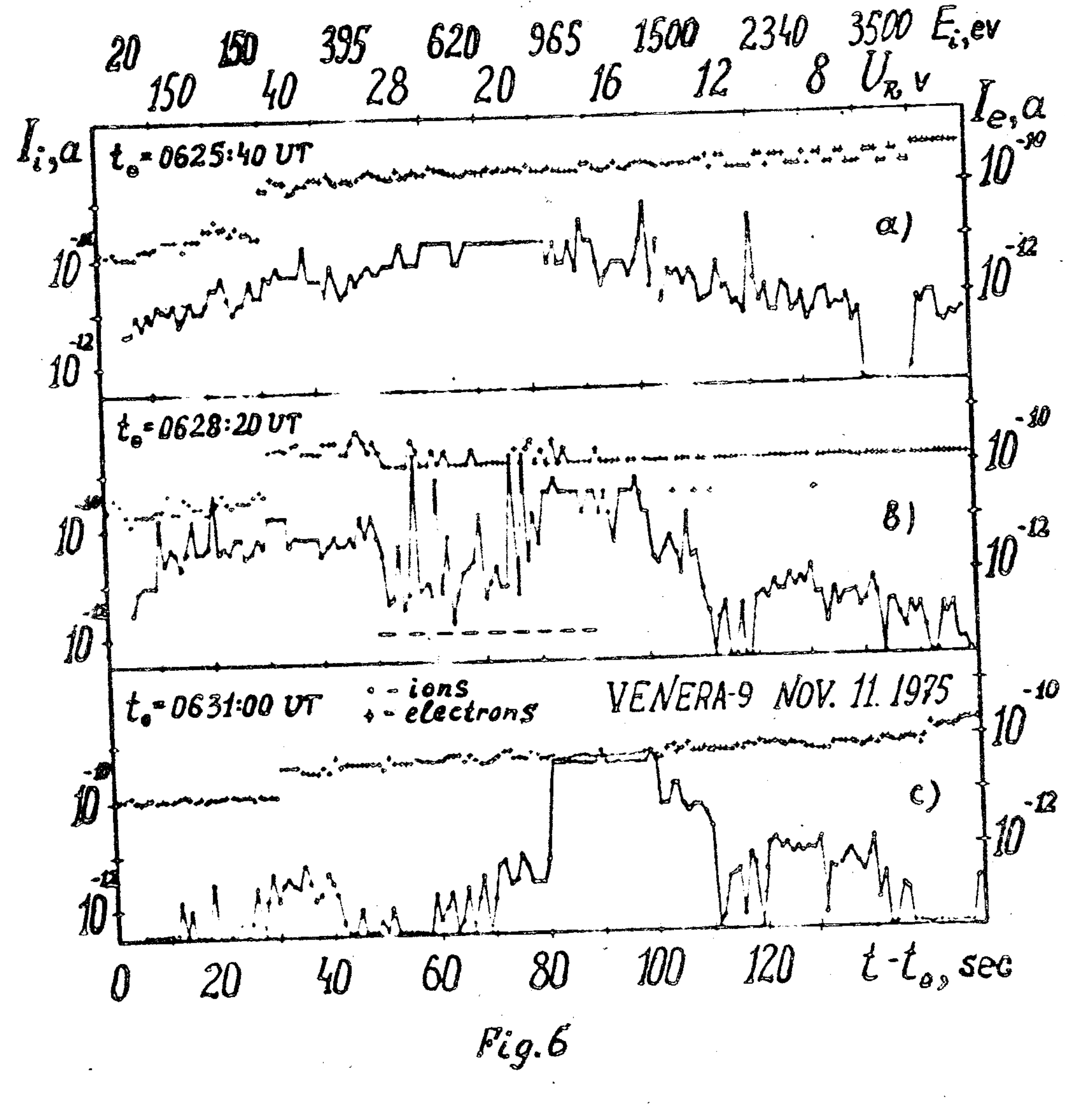

300
80
34
24
18
14
10
4
U_R, v
I_e, a
t_o = 0851:38 UT
a)
10^{-11}
10^{-12}
t_o = 0854:18 UT
S
b)
10^{-11}
10^{-12}
t_o = 0856:58 UT
+ - electrons
VENERA-10 NOV. 2. 1975
c)
10
10
0
20
40
60
80
100
120
$t-t_o$, sec

Fig. 5



20 150 395 620 965 1500 2340 3500 E_i, ev
150 40 28 20 16 12 8 U_R, v
I_i, a
I_e, a
t_0 = 0625:40 UT
a)
t_0 = 0628:20 UT
в)
t_0 = 0631:00 UT
∘ - ions
+ - electrons
VENERA-9 NOV. 11. 1975
c)
10^{-10}
10^{-12}
0 20 40 60 80 100 120 $t - t_0$, sec

Fig.6

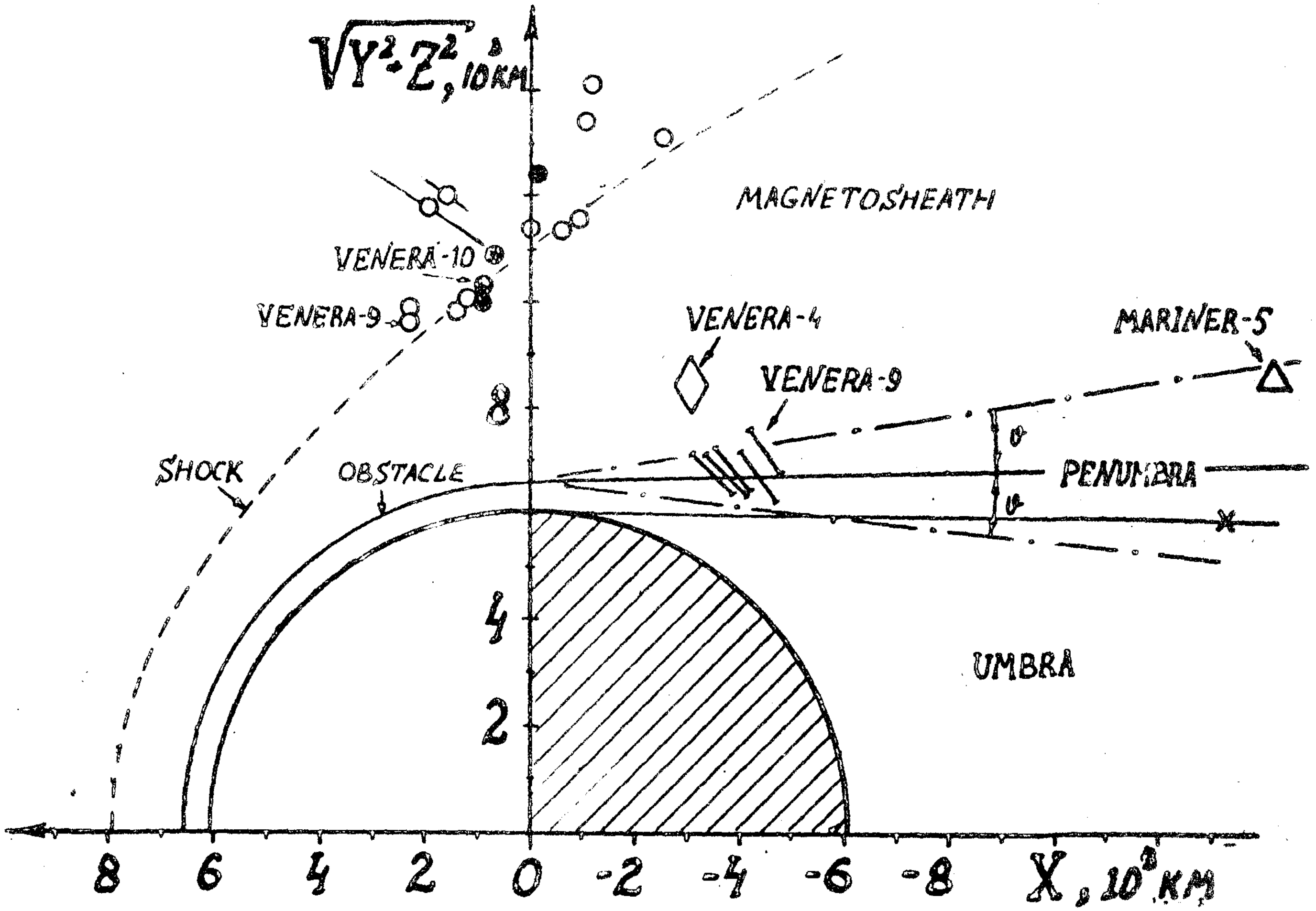

√Y²+Z², 10³KM
MAGNETOSHEATH
VENERA-10
VENERA-9
VENERA-4
MARINER-5
VENERA-9
8
θ
PENUMBRA
θ
SHOCK
OBSTACLE
4
2
UMBRA
8
6
4
2
0
-2
-4
-6
-8
X, 10³ KM

Fig.7

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