ICARUS 18, 54–58 (1973)

Preliminary Results on Plasma Electrons from Mars-2 and Mars-3

K. I. GRINGAUZ, V. V. BEZRUKIKH, G. I. VOLKOV,
T. K. BREUS, I. S. MUSATOV, L. P. HAVKIN, AND
G. P. SLOUTCHONKOV

Institute for Space Research, Academy of Sciences of the USSR, Moscow, USSR

Received June 7, 1972

A preliminary analysis is presented of the first results on plasma electrons near Mars obtained by retarding potential analyzers onboard the Mars-2 and Mars-3 orbiters. Two zones of significantly increased electron density or temperature were uncovered; one near Mars, which is interpreted as the solar wind shock front in interaction with Mars, and the other $>10^5$ km from Mars.

Measurements of solar wind plasma electrons were among the scientific experiments aboard the spacecrafts Mars-2 and Mars-3 launched into orbits around the planet Mars. On both satellites measurements were made by the retarding potential method with the use of two identical traps with a plane orifice. A similar method was used by Serbu (1968) for measurements of solar wind electrons onboard Explorer-35. The distinctive feature of the experiments under discussion is the fact that during the whole period of measurement, the traps were located in the shadow of the spacecraft and the traps' axes were oriented in the antisolar direction. The characteristics of the plasma electrons detected near the illuminated and the shadowed parts of the spacecraft surface must be quite close because the random velocities of the solar plasma electrons greatly exceed the spacecraft velocity and the velocities of the solar wind fluxes. (In particular, this follows from the experiments with electrostatic analyzers made by Montgomery *et al.* (1968) aboard the spinning Vela satellites.) The location of the trap on the shadowed part of the spacecraft enables us to remove the influence of photoelectrons which could penetrate into it from the closely spaced parts of the spacecraft surface and from the trap elements. However, the possibility cannot be ruled out that some photoelectrons omitted from the illuminated surface of the spacecraft can have "finite" trajectories and orbit the spacecraft as its satellites, creating a cloud of photoelectrons even above the shadowed part of the surface. The possibility of the presence of marked photoelectron densities over the shadowed part of the spacecraft is mentioned in particular by Grard and Tunaley (1971). The penetrations of such electrons with finite orbits into the trap was substantially reduced by the design of the trap which allowed the detection of only the electrons with velocities lying at comparatively small angles from the trap axis.

The volt-ampere characteristic (the retarding curve) was recorded during 30–50 sec for 14 values of retarding potential; the maximum retarding potentials had values of 20, 50, 100 or 400 V and were automatically changed according to the measured plasma parameters. A more detailed description of the instrument will be published elsewhere.

During the entire orbit (with the exception of ~1 hr close to pericentre) 1 volt-ampere characteristic was recorded every 10 min; near the pericentre the instrument was switched off or was switched into a regime in which the volt-ampere characteristics were recorded every 2 min. The planes of the orbits of both Mars satellites are inclined to the ecliptic at an angle of 40°. The orbit of

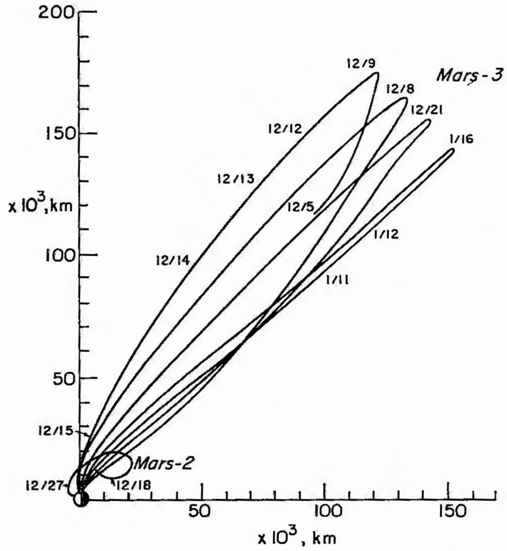

FIG. 1. Polar coordinate representation of the orbits of the Mars-2 and Mars-3 satellites during parts of December 1971 and January 1972 when retarding potential analyzer results reported in the present paper were performed.

Mars-2 has pericentre ~4800 km (1400 km from the planet's surface), apocentre ~28 000 km, and period of revolution ~$17^h 55^m$. The orbit of Mars-3 has pericentre ~4650 km (1250 km from the planet's surface), apocentre ~21 200 km, and period of revolution $12^d 16^h 30^m$. At present, preliminary reduction has been performed of data from the first four revolutions of Mars-3 (December 5, 1971 through January 21, 1972) and some revolutions of Mars-2 (for December 17–18, 22–23, 1971).

Figure 1 shows the evolution of the Mars-3 orbit during the first four revolutions, and one of the Mars-2 orbits, in a polar reference frame, in which the axis is coincident with the Sun–Mars line and the polar angle is equal to the Sun–Mars–satellite angle. During all Mars-3 revolutions mentioned the regular and repetitive variations of electron characteristics along the orbit were recorded. The data given below represent one Mars-3 orbit for the period of December 12–25, 1971, and three Mars-2 orbits for December 17, 18, and 22, 1971.

In Fig. 2 the retarding curves are given which were recorded along the Mars-2 orbit shown in Fig. 3. This orbit was subdivided into four zones; in each of the zones the retarding curves are of a definite nature. Zone V of Fig. 3 is characteristic of the data obtained from the Mars-2 orbits.

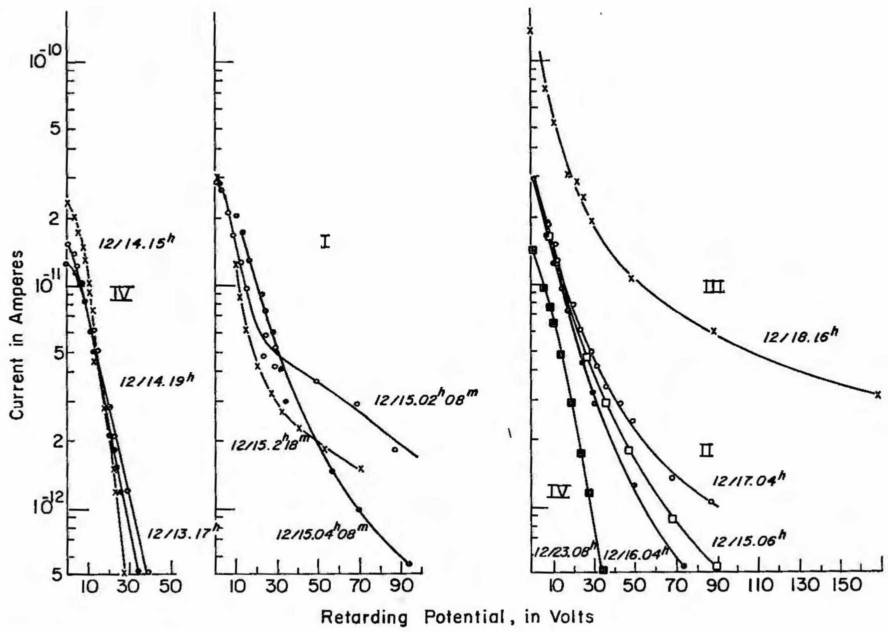

FIG. 2. Volt-ampere characteristics of four zones of the Mars-2 orbit shown in Fig. 3.

One can see from Figs. 2 and 3 that in Zone IV, i.e., in the descending part of the Mars-3 orbit (December 12 through December 15, 1971) at and after apocentre (December 21–25), the electrons are completely retarded at potentials of 30–40 V, and the measured currents at the zero retarding potential are relatively small. In Zone I (close to the planet) on December 15–16, the retarding potential greatly increases and sections with small slope appear in the retarding curves (see Fig. 2) which seem to correspond to "superthermal" tails of the velocity distribution function. The currents at the zone's retarding potential also increase. In Zone II the potentials of complete retardation decrease compared with Zone I although they remain substantially greater than in Zone IV; in general the superthermal tails also diminish. In the end of Zone II (December 17) there is some increase in the tails and zero-potential currents, and finally in Zone III there is a drastic increase both in currents and in the potentials of complete retardation of electrons (the latter reach 270–400 V). When the satellite moves away from the planet and from the Sun–Mars line, the recorded currents and the complete retarding potentials again decline and the retarding curves take the form characteristic of Zone IV.

Temperatures and densities of electrons were estimated from the retardation curves which approximately correspond to the four above zones (see table in Fig. 3). In an electronic computer the experimental retardation curve was approximated by the curve corresponding to the isotropic Maxwellian electron energy distribution function, and so the values of the temperature T_e and density N_e of the electrons were determined. In cases where the retarding curve had a superthermal tail, a certain "effective temperature" T_e' representing the energy of the tail particles was also determined. T_e and N_e values typical for each zone are also given in the table in Fig. 3. Figure 3 also shows the locations of the shock-wave fronts evaluated for Mach numbers $M = 1.4$ and 5 by the gas-dynamic equation of Obayashi (1965). A detailed description of the reduction of the raw experimental data will be given in the future.

Zone	Satellite	Te, °K	Te', °K	n_e, cm^{-3}
I	Mars - 3	2.5×10^5	$5 \times 10^5 - 10^6$	1
II	Mars - 3	1.5×10^5	5×10^5	1 - 1.5
III	Mars - 3	$2.8 - 4 \times 10^5$	$5 - 7 \times 10^5$	2 - 4
IV	Mars - 3	$(4-6) \times 10^4$	——	0.2-0.5
V	Mars - 2	$(3-4) \times 10^5$	$6 \times 10^5 - 2 \times 10^6$	20

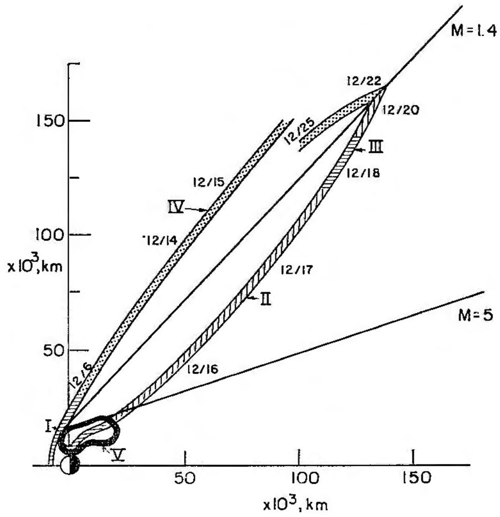

FIG. 3. Electron temperature, T_e; effective electron temperature, T_e', in the superthermal tail of the energy distribution function; and electron density, N_e, in five zones of the Mars-2 and Mars-3 orbits. Also shown are the location of the solar wind shock fronts for Mach numbers 1.4 and 5.

The retardation curves corresponding to Zone IV in Fig. 3 (for December 13–15 and after December 21) are very similar to curves recorded during the approach to the planet, before injection of the spacecraft into orbit around Mars, and also to retardation curves obtained by Serbu (1968) in the quiet solar wind with the Explorer-35 satellite (with allowance for the fact that the current sensitivity of our instrument was more than an order of magnitude higher than Serbu's). This gives grounds for the assumption that Zone IV (the "coldest" zone) corresponds to the undisturbed interplanetary medium.

The electron temperature increase on December 15, when the Mars-3 satellite was approaching the planet and had traversed from Zone IV into Zone I, seems to be accounted for by the disturbance (shock wave) in the interplanetary medium formed by the streamlines around the planet by the solar wind. Such disturbances were observed near Venus from the ion and magnetic field measurements on October 18, 1967 aboard the spacecraft Venera-4 (Gringauz *et al.*, 1968; Dolginov *et al.*, 1968); on October 19, 1967 aboard Mariner-5 (Bridge *et al.*, 1967); and on May 17, 1969 aboard the spacecraft Venera-6 (Gringauz *et al.*, 1970).

All experimental data available to date on the interaction between planets having no (or very small) inherent magnetic fields H_i, and the solar wind are limited to the above three experiments, in which the disturbances of the solar wind by such planets were observed at distances no more than 10 radii from the planet's centre. Data on disturbances at distances of several tens of planetary radii were absent. The disturbance of the solar wind by the planet Mars has been repeatedly discussed theoretically, and the possibility of shock-wave type disturbance formation near Mars was predicted with some assurance (Dessler, 1968; Dryer and Heckman, 1967; Spreiter *et al.*, 1970). Hence the disturbance in Zone I, near the planet, can apparently be classified as an intersection of the shock-front region by the satellite Mars-3.

As for two other zones (Zones II and III in Fig. 3) the authors of the present paper, having reduced the data from the first revolution of Mars-3, have the impression that variations of electron characteristics outside of Zone I reflect changes of the temperature and density of the solar wind electrons in the interplanetary medium undisturbed by the planet. However the analysis of the results from the next three revolutions of Mars-3 (the results from one of them are shown in Figs. 3 and 4) made it possible to subdivide each of the orbits shown in Fig. 1 into four zones similar to those of Fig. 3. The temperature and density values in the zones are somewhat variable from orbit to orbit, apparently because of the temporal variations of the solar wind, but nevertheless the nature of these parameters' variations along the orbit is conserved: the high temperature zone was always observed near the pericentre of the orbits; additionally, one more "hot zone" (similar to Zone III in Fig. 3) with increased electron density was always observed in the ascending part of the orbits.

The results of the electron temperature and density measurements aboard Mars-3 during the period of December 17–22, 1971 were compared with the results of similar measurements aboard Mars-2 obtained from its three revolutions during the same time interval. The comparison showed that temperatures T_e and T_e' and density N_e measured by Mars-2 always had high values and exceeded those values measured by Mars-3 (see table in Fig. 3). Figure 4 shows three pairs of retardation curves obtained simultaneously (within minutes) on both satellites on December 17, when

Satellite	Date	Te, °K	Te', °K	n_e cm^{-3}
Mars-2	12/17 04^h03^m	5×10^5	8×10^5	20
Mars-3	04^h17^m	1.6×10^5	4×10^5	1.5
Mars-2	12/18 08^h03^m	2.8×10^5	6×10^5	4
Mars-3	06^h47^m	2.9×10^5	4.5×10^5	2.5
Mars-2	12/22 3^h-4^h	9.5×10^4	1.9×10^4	2.7
Mars-3	3^h-4^h	7×10^4	—	0.5

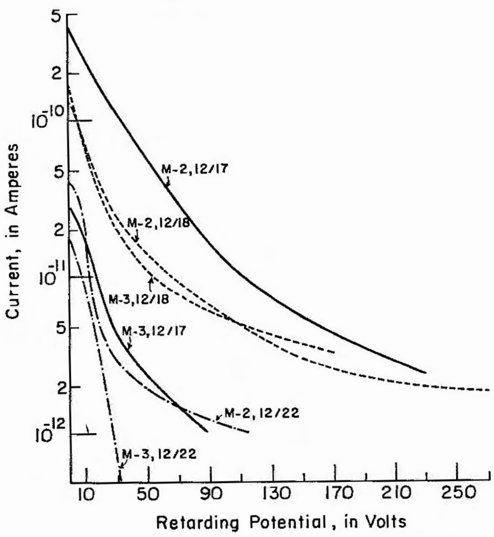

FIG. 4. Near-simultaneous recordings of volt-ampere characteristics by the Mars-2 and Mars-3 orbiters. The inset table shows derived values of T_e, T_e', and N_e.

Mars-3 was in Zone II, on December 18 when Mars-3 was in the "hot zone" III, and on December 22 when Mars-3 was in the "cold zone" IV.

One can see from Fig. 4 (see retardation curves and the table) that the highest T_e and N_e values obtained along the orbit of Mars-2 (on December 17) correspond to relatively low T_e and N_e values measured along the Mars-3 orbit. On December 18 when the temperatures and densities measured along the Mars-2 orbit fell, the T_e and N_e values measured by Mars-3 drastically increased.

From our point of view, this convincingly suggests that the variations of T_e and N_e observed along the orbits of the Mars satellites are not due to temporal variations of solar wind but reflect the spatial distribution (stable to sufficient degree) of temperature and density of electrons near the planet.

The present paper gives the first preliminary results of electron temperature and density measurements along the orbits of the Mars-2 and Mars-3 satellites. The measurements show the existence of regular and repetitive changes of N_e and T_e along the satellites' orbits at distances from the planet up to several tens of planetary radii. In particular two zones with substantially increased values were found; one of them (which lies close to the planet) seems to correspond to the shock-front region formed when the solar wind flows past the planet. The second zone of "hot electrons" is located at distances $> 10^5$ km from the planet.

Acknowledgment

The editor thanks Mr. Thomas McDonough for editorial assistance with this paper.

References

Bridge, H. S., Lazarus, A. J., Snyder, C. W., Smith, E. P., Davis, L. Jr., Coleman, P. J. Jr., and Jones, D. E. (1967). Mariner V: Plasma and magnetic field observed near Venus. *Science* **158**, 1669.

Dessler, A. J. (1968). *In* "The Atmospheres of Venus and Mars" (J. C. Brandt and M. B. McElroy, eds.), p. 241. Gordon and Breach, New York, London, Paris.

Dolginov, Sh. Sh., Zhuzgov, L. N., and Yeroshenko, E. C. (1968). *Kosm. Issled.* **6**, 564 (translated as "Magnetic field investigation with planetary station Venera-4" *Cosmic Res.* **6**, 469).

Dryer, M., and Heckman, G. R. (1967). Application of the hypersonic analog to the standing shock of Mars. *Solar Phys.* **2**, 112.

Grard, R. J. L., and Tunaley, J. K. E. (1971). Photoelectron sheath near a planar probe in interplanetary space. *J. Geophys. Res.* **76**, 2498.

Gringauz, K. I., Bezrukikh, V. V., Musatov, L. S., and Breus, T. K. (1968). *Kosm. Issled.* **6**, 411 (translated as "Plasma measurements in the vicinity of Venus by the space vehicle Venus-4" *Cosmic Res.* **6**, 350).

Gringauz, K. I., Bezrukikh, V. V., Volkov, G. I., Musatov, L. S., and Breus, T. K. (1970). *Kosm. Issled.* **8**, 431 (translated as "Interplanetary disturbances near Venus determined from Venera-4 and Venera-6" *Cosmic Res.* **8**, 393).

Montgomery, M. D., Bame, S. J., and Hundhausen, A. J. (1968). Solar wind electrons: Vela-4 measurements. *J. Geophys. Res.* **73**, 4999.

Obayashi, T. (1965). "Space Research IV," North-Holland Publ. Co., Amsterdam.

Serbu, G. P. (1968). Explorer-35 measurements of low energy plasma in lunar orbit. Preprint X615-68-232, Goddard Space Flight Center.

Spreiter, J. R., Summers, A. L., and Rizzi, A. W. (1970). Solar wind flow past nonmagnetic planets—Venus and Mars. *Planet. Space Sci.* **18**, 281.