THE NIGHTTIME IONOSPHERE OF MARS FROM MARS-4 AND MARS-5 RADIO OCCULTATION DUAL-FREQUENCY MEASUREMENTS

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ABSTRACT

Dual-frequency radio sounding of the Martian nighttime ionosphere was carried out during the exits from behind the planet of the Mars-4 spacecraft on February 2, 1974 and the Mars-5 spacecraft on February 18, 1974. In these experiments, the spacecraft transmitter emitted two coherent monochromatic signals in decimeter ($\lambda_1 \approx 32$ cm) and centimeter ($\lambda_2 \approx 8$ cm) wavelength ranges. At the Earth-receiving station, the reduced phase difference (or frequencies) of these signals was measured.

The nighttime ionosphere of Mars measured in both cases had a peak electron density of $\sim 5 \times 10^3/\text{cm}^3$ at an altitude of 110 to 130 km. At the times of spacecraft exit, the solar zenith angles at the point of occultation were 127° and 106°, respectively. The height profiles of electron concentration were obtained assuming spherical symmetry of the Martian ionosphere.

Moreover, the results obtained allowed the conclusion that above the main maximum there is an additional one and also that plasma possibly exists at low altitudes above the planetary surface. However, these conclusions require experimental confirmations.

INTRODUCTION

Dual-frequency radio sounding of the Martian nighttime atmosphere above the dark surface of the planet was carried out during exits from behind the planet of the Mars-4 and Mars-5 spacecraft on February 10 and on February 18, 1974, respectively. The main aim of these experiments was the detection of the Martian nighttime ionosphere and the determination of the height profile of electron concentration.

At exit, the solar zenith angle at the point of contact of the radio beam with the planetary surface was $\chi \approx 127°$; the areographic coordinates of this point were latitude $\Theta \approx 9°$S, longitude $\Lambda \approx 236°$W, and local time $\sim 3^h 30^m$. The season in this Martian region was autumn. The second exit was in spring at a solar zenith angle of 106° with coordinates $\Theta \approx 38°$N, $\Lambda \approx 214°$W, and local time $4^h 30^m$.

METHODOLOGY

During these experiments, the spacecraft transmitters emitted two coherent monochromatic signals in decimeter ($\lambda_1 \approx 32$ cm) and centimeter ($\lambda_2 \approx 8$ cm) wavelength ranges where the frequency ratio is $f_2/f_1 = 4$. Each signal was separately received at the Earth-based point and was processed by two independent systems of a dispersion interferometer [1, 2] which were essentially modified for increase of reliability and accuracy of measurements. In the system [1], the reduced phase difference of received signals was recorded and measured by the analog technique:

$$\Delta\Psi = \frac{4}{15}(4\phi_1 - \phi_2),$$

where ϕ_1 and ϕ_2 are the total phases of decimeter and centimeter signals, respectively. In the system, the two received signals are initially recorded on magnetic tape and then processed by a digital computer. In this case, after digital filtering in the band $\Delta f_F \approx 0.8$ Hz, the frequency of each signal was measured and a reduced frequency difference was calculated as

$$\Delta f = \frac{1}{2\pi}\frac{4}{15}(4\dot{\phi}_1 - \dot{\phi}_2),$$

where $\dot{\phi}_1$ and $\dot{\phi}_2$ are the time derivatives of the total phases of the received signals.

For decreasing the fluctuation errors of measurements, values of $\Delta\Psi(t)$ and $\Delta f(t)$ were smoothed by a running average method over 11 points. Five minutes later, after exit of the station from behind the planet, in the control part of the mission free from the influence of the Martian ionosphere, the mean values $\overline{\Delta\Psi}$ and $\overline{\Delta f}$ caused by electron concentration changes along the radio wave propagation path were measured. For separation of the effects caused only by the Martian ionosphere, the mean values were extrapolated backward to the surface and subtracted from the results of the measurements. The measured values of $\Delta\Psi(t)$ and $\Delta f(t)$ as a function of the height, h, of the radio beam above the Martian surface were obtained from the trajectory data and from the diffraction pattern of the change of signal amplitude which was found at exit of the spacecraft from behind the planet.

RESULTS

The variation of the values $\Delta\Psi$ and Δf with time, measured from the moment of exit of Mars-4 on February 10, 1974 and with height h [3], are given in figure 1. The curve of Δf is of the characteristic S-shape, and the absolute value Δf does not exceed 0.016 Hz. The initial value, $\Delta\Psi(0)$, at the moment of exit was assumed to be equal to zero. Since $\Delta\Psi$ is in proportion to the integral electron concentration, the height shape $\Delta\Psi(h)$ shows a change of $\Delta N(h)$ in the ionosphere sampled. The maximum increase, $\Delta N_{n\ max} \sim 6 \times 10^{11}/\text{cm}^2$, corresponds to a maximum change of $\Delta\Psi_{max} \sim 320°$. On a control part of the mission, the mean-square fluctuation errors of measurement of the values $\Delta\Psi$ and Δf caused by receiver noise and by electron concentration variations along the path of communication were estimated to be $\sigma_{\Delta\Psi} \approx 14°$, and $\sigma_{\Delta f} \approx 0.003$ Hz.

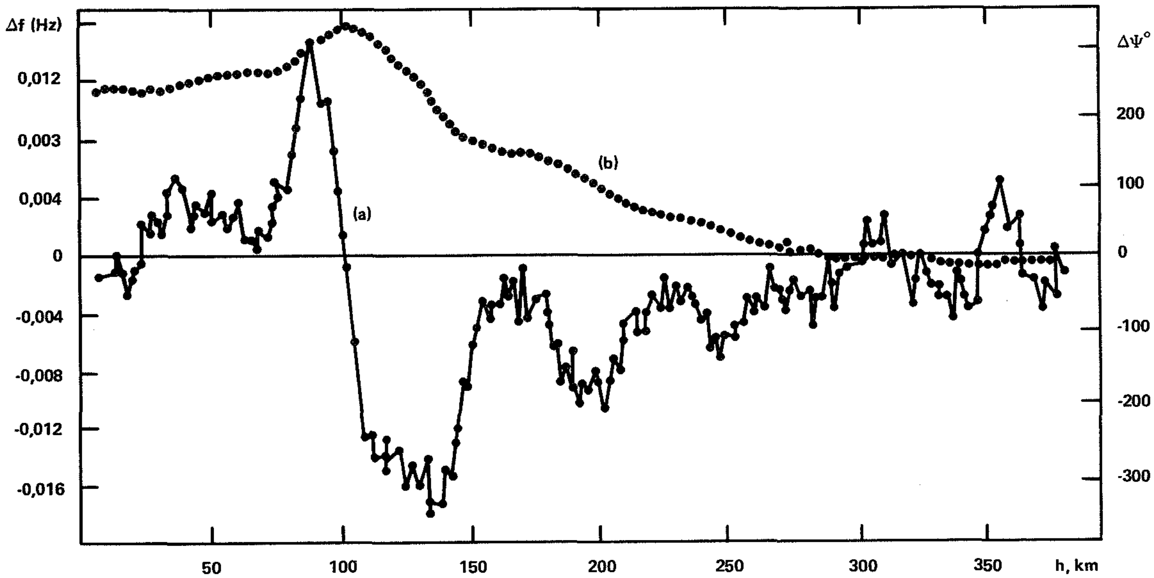

Figure 1. Dependence of reduced frequency (a) and phase (b) differences on the distance between the radio beam and the Martian surface.

The height profile of the electron concentration, N(h), in the nighttime Martian ionosphere is given in figure 2. It was calculated from the data obtained using the assumption of spherical symmetry of the ionosphere sampled. The mean-square error, σ_N, is slightly dependent upon the height and is about $250/cm^3$. A possible displacement of the curve N(h), due to errors of approximation of the mean shape of the integral electron concentration changes along the path of communication at the time of radio sounding, was estimated to be $\Delta N \approx \pm 500/cm^3$.

The profile N(h) at the exit, February 10, 1974, has the main peak at a height of ~110 km above the surface with the electron concentration $N_m \approx 4.6 \times 10^3/cm^3$. A regular profile shape is followed up to the height of ~250 km, where the measured values become comparable with errors of measurements. An additional ionization peak on this profile, at the height of ~180 km with concentration $\sim 2.2 \times 10^3/cm^3$ and a formally-obtained value of plasma concentration $\sim 10^3/cm^3$ in the 0- to 80-km height range, are seen in figure 2.

The second exit was under unfavorable meteorological conditions. The reception of signals in the centimeter wave range was followed by deep amplitude fluctuations, almost up to the noise level. Recording of signals was accomplished only by a system with magnetic tape. The technique of processing the recorded information is similar to that described above. The results of this measurement are less reliable than those of the previous one but considering them together, one can draw some conclusions.

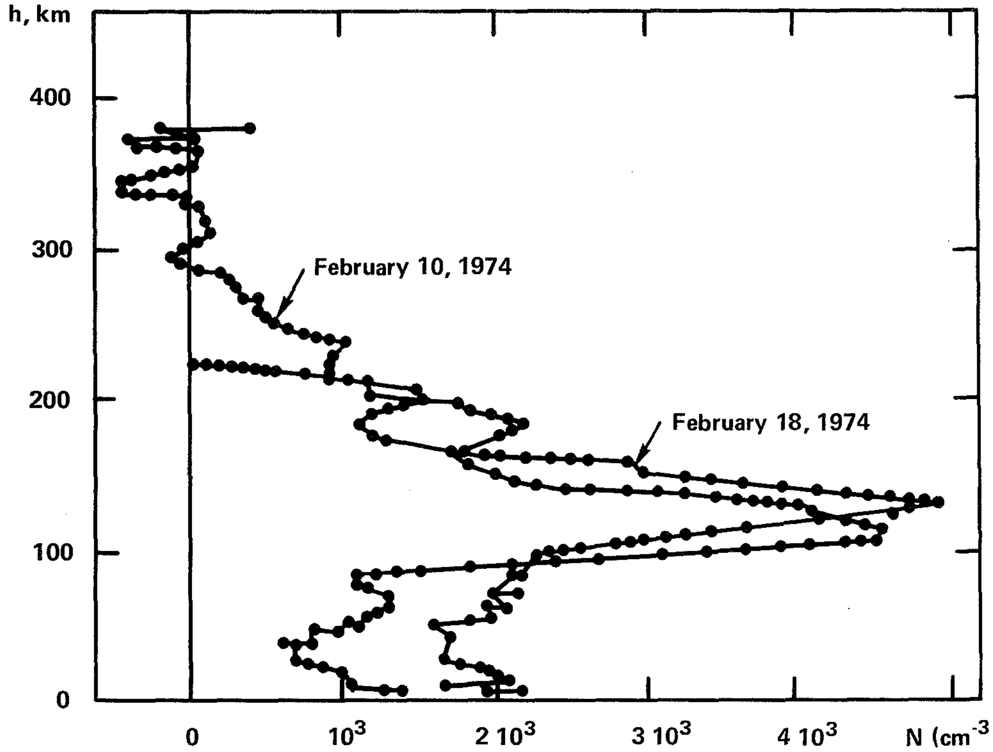

Figure 2. Distribution of electron concentration, N(h), in the nighttime ionosphere of Mars.

The profile N(h) obtained for this exit is also given in figure 2. The electron concentration for the main peak is located at a height of ~130 km and is ~5 $\times$ $10^3/cm^3$. At the level of ~210 km, a secondary peak is noticed with an electron concentration ~1.5 $\times$ $10^3/cm^3$. At heights higher than 210 km, the concentration sharply decreases and higher than 220 km, the regular profile shape was not practically followed. In the 0- to 80-km height interval, the data obtained also show the possible existence of a plasma with a concentration of ~1.9 $\times$ $10^3/cm^3$.

DISCUSSION

Martian Ionosphere in the Nighttime

Given the above experimental data for the two sets of measurements, the existence of a Martian ionosphere in the nighttime is indicated. The maximum values of the electron concentration in both cases are almost equal (~4.6 $\times$ $10^3/cm^3$ and ~5 $\times$ $10^3/cm^3$), but the heights of these maxima are different (110 and 130 km). Repeated checking of calculations of height determination has confirmed this height separation.

It can be proven that the nighttime ionosphere of Mars cannot be considered as a part of the daytime ionosphere. Really, the process of decrease of electron concentration in the ionosphere after sunset is characterized by the time constant $\tau = 1/\alpha N_0$, where N_0 is the value of the electron concentration at the moment of "switching-off" the source of ionization and $\alpha = 2.55 \times 10^{-7}/cm^3 s$ is the effective coefficient of recombination. If we take the minimum value of $N_0 \sim 10^4/cm^3$ for an estimate, τ is 400 s. It is obvious that with this value, the charged particles of any ionospheric plasma must practically be recombined completely within several hours after sunset. Apparently it is necessary to suppose the presence of an additional source of ionization, not connected directly with solar radiation, to explain the fact of the existence on Mars of a nighttime ionosphere.

Additional Maxima of Ionization

The additional maxima of ionization, located at the heights of ~190 and ~210 km, are seen on both profiles. Besides the high-altitude separation between them and the lower altitude main maxima, the difference of 20 km coincides with the height distance between the main maxima. In our opinion, these circumstances increase the probability of the supposition about the reality of the existence of the additional maxima. This conclusion, however, needs further confirmation.

Presence of Near-Surface Plasma

The conclusion of the possible presence of plasma in the 0- to 80-km height interval was made on the basis of the formal inversion using a spherically-symmetric approximation. This effect, however, may occur due to other reasons. One of them is the fact that a random increase of integral electron concentration along the path of communication has the effect of the apparent presence of plasma, for the solution of the inverse problem could take place with radio sounding of the region of small heights. However, the possibility of the occurrence of that variation at the necessary time during two exits is unlikely. The similarity of both these profiles in the 0- to 80-km interval shows apparently the generality of this effect. Such a cause can be the asymmetry of the ionosphere sampled which is special during the exit on February 18, 1974. However, quantitative consideration of this problem becomes complicated due to the absence of a model, not only of the nighttime, but also the daytime Martian ionosphere, without which such an analysis is rather difficult to perform.

CONCLUSIONS

Experiments on dual-frequency radio sounding of the atmosphere above the dark Martian surface gave us the possibility to detect reliably the nighttime ionosphere with an electron concentration $\sim 4.6 \times 10^3/cm^3$ for the main peak located at a height of 110 km above the planet's surface.

Perhaps an additional source of ionization is responsible for the formation of the Mars nighttime ionosphere. The profiles obtained permit us to suggest conclusions about the presence of the additional peak of ionization above the main one and the possible existence of plasma at heights below 80 km. These, however, require new experiments in order to confirm the tentative conclusions.

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QUESTIONS

Savich/Ness: How many measurements of the nightside ionosphere were made? Since the spacecraft operated for more than two revolutions, as indicated by the data from the magnetometer and plasma devices, I would have thought you'd have more data.

Savich: We have two measurements of the nightside ionosphere on February 10 and 18. Our instrument was not operating during the other orbits.

Savich/Bauer: Did you obtain any dayside profiles of the Martian ionosphere? Is the lowermost part of the Martian ionosphere uncontaminated by effects from the neutral atmosphere?

Savich: Yes. We have two profiles of the evening Martian ionosphere with zenith angles of about 82° and 72°, respectively. The dual-frequency method, to first approximation, excludes the effects of the neutral atmosphere on the parameters being measured.