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SOME RESULTS OF CISLUNAR PLASMA RESEARCH

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ABSTRACT

The main results of plasma cislunar investigations, carried out during Luna-19 and Luna-22 spacecraft flights by means of dual-frequency dispersion interferometry, are briefly outlined. It is shown that a thin layer of plasma, with a height of several tens of kilometers and a maximum concentration of the order 10^3 electrons/cm^3 exists above the solar illuminated lunar surface.

A physical model of the formation and existence of such a plasma in cislunar space is proposed, taking into account the influence of local magnetic areas on the Moon.

INTRODUCTION

The problem of the formation of plasma in cislunar space is closely connected with a series of other problems of space physics and requires for its solution reliable experimental data on the plasma parameters and regularities of its space-time variations. This important problem may be solved by means of repeated occultation experiments with a two-frequency dispersion interferometer using lunar satellites.

A series of these two-frequency occultation studies has been carried out during Luna-19 and Luna-22 spacecraft flights. The transmitter of the dispersion interferometer was mounted onboard these spacecraft. It emitted two coherent monochromatic signals in the wavelength range of λ_1 = 32 cm, λ_2 = 8 cm, $p = \lambda_1/\lambda_2 = 4$. These signals were simultaneously received at the Earth-based station and the phase delays of the lower frequency signal were measured relative to the higher frequency:

$$\Psi(t) = [p\,\phi_1(t) - \phi_2(t)] \cong 2\pi e^2 (p^2 - 1)(mc\omega_2)^{-1} \int N(t, \ell)d\ell$$

where

ϕ_1, ϕ_2 = total phase of received signals,

$\int N(t, \ell)d\ell$ = integrated electron concentration along the path of the signal.

METHODOLOGY

For further processing, there were selected from all occultation measurements those for which the influence of Earth's ionosphere was minimum. The average change of the measured value caused by Earth's ionosphere was determined by processing of calibration measurements made during the last 15 to 20 min before the moment of occultation. The average change determined by such a method was used for the calculation of the difference between Earth's ionosphere change and real measured values during cislunar plasma radio sounding. The data obtained represent the variation of integrated electron concentration in the cislunar space as a function of time or height above the lunar surface.

The data so obtained allowed the solution of the inverse problem assuming spherical symmetry of plasma in the region studied and a calculation of the height profile of electron concentration distribution near the Moon.

RESULTS

Figure 1 shows the average profile of electron concentration due to three occultation measurements obtained during the flight of Luna-19 (June 11, 1972). The solar zenith angle $\underline{\chi}$ at this moment was 89° [1, 2]. The same figure also gives some other profiles obtained during Luna-22 experiments in 1974 for various solar zenith angles $49° \leqslant \chi \leqslant 86°$ [3].

The analysis of experimental data and the profiles obtained results in the following conclusions:

- Plasma is not observed over the nightside of the Moon's surface ($\sigma \pm 200/cm^3$).
- Plasma does exist over the sunlit surface of the Moon.
- The vertical extent of the region occupied by the plasma is some tens of kilometers.
- The electron concentration reaches $\sim 10^3/cm^3$ in the height interval below 10 km.

DISCUSSION

The known hypotheses [4, 5] do not agree with the experimental data obtained. Therefore, a new physical model of the formation and the existence of the plasma in cislunar space is suggested. This model takes into account the effects of the interaction of the solar wind with the local magnetic fields. In recent years, local magnetic fields with intensity 30 to 300 $\underline{\gamma}$ have been discovered on the Moon [6]. The horizontal sizes of these fields may reach many tens or hundreds of kilometers. Although the height extent of their fields is not measured at present, it is rather fair to suggest that the height extent is comparable with the horizontal one.

Therefore a magnetic screen, protecting the lower region from the direct influence of the solar wind, is formed above the regions which at the height of some tens of kilometers create magnetic fields of $\sim 50\ \underline{\gamma}$ intensity. Thus, the formation and the existence of the

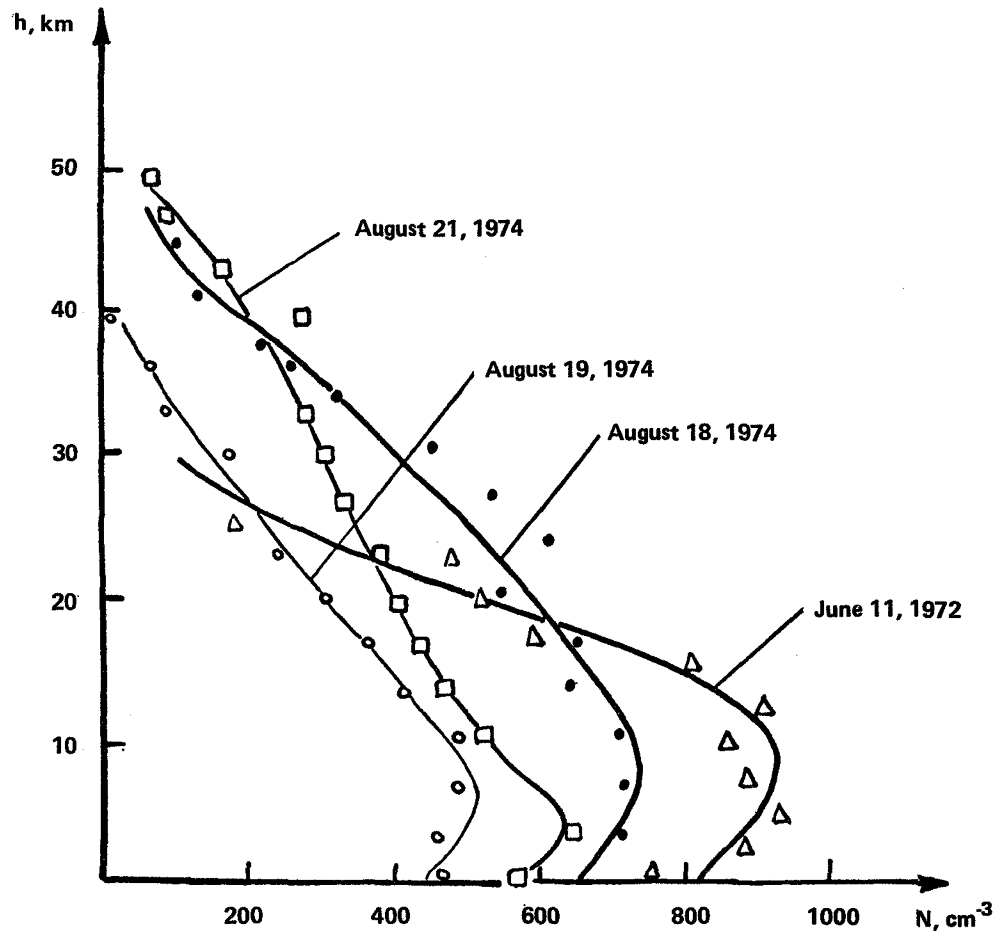

Figure 1. The experimental dependence of the electron concentration on height above the lunar surface.

magnetized plasma as a result of ionization of neutral atoms of heavy gases (for example, argon evaporated from the lunar soil) may be possible below this level. The above-mentioned screen protects the plasma from being swept away by the solar wind. The lifetime of the charged particles formed is determined by the structure of local magnetic fields. Under favorable conditions, the formation of magnetic traps substantially increasing the lifetime of these particles is possible.

Consider a local magnetic region with a horizontal size ~100 km and assume, for simplicity, that its field has a dipole character. Let the effective dipole of this region be placed at a depth of 100 km and with a field intensity ~100 γ at the surface of the Moon. Then it is easy to show that at the height of 50 km above the surface, the unperturbed field of such a region has the magnitude 30 γ. Under the action of the solar wind, this is compressed and its intensity is increased by a factor of 2. Therefore, at the height of 50 km above the surface, the value B is about 60 γ which, as is known [7], is enough for slowing and stopping the solar wind.

The process of ionization of neutral particles by solar radiation below this level leads to the formation of a plasma. The ionization time of heavy gases in the lunar atmosphere, for example, argon ([A] $\sim 10^{-6}$ cm^{-3}) is about 10^6 s [8]. Hence, the complete rate of ion formation near the surface of the Moon is q = 1/cm^3 s.

The charged particles of the magnetized cislunar plasma will have a complex movement which, in the guiding center approximation, may be expanded into three components: a cyclotron rotation around the field line, a movement along the field line, and a slow displacement (drift) in the direction perpendicular to the field. The result of this movement is the precipitation of charged particles on the surface. In the simplest case, the charged particle moves from the point of its creation along a spiral path about the field line and some time later reaches the surface of the Moon and is neutralized. In a more complex case, if the inhomogeneity of the local magnetic field satisfies certain definite conditions, the particles make oscillatory movements between the points of reflection, similar to those which occur in the radiation belts of the Earth.

Hence, the lifetime of the charged particles in cislunar space will be defined by their drift time and it may be rather longer than in the first case. An evaluation has been carried out based on the known correlations [7] and shows that in the first case, the lifetime may be of the order $\tau_1 \cong 10^4$ s. The concentration of charged particles may reach

$$N_i = q \cdot \tau_1 = 4 \times 10^2/\text{cm}^3$$

and

$$N_2 = q \cdot \tau_2 \cdot \eta \leqslant 2 \times 10^3/\text{cm}^3$$

accordingly where $\eta \sim 0.2$ is the capture coefficient, about which there are no data in the case considered. The evaluations of the concentration of cislunar plasma carried out based on the model described give values which are in agreement with experimental data.

It is of great importance to mention that the gyroradius of argon ions in a magnetic field of $\sim 50\ \gamma$ is several kilometers. This may be the reason for the decrease of the plasma concentration at a height smaller than the gyroradius and the reason for the formation of the maximum in the distribution of the electron concentration over the surface of the Moon.

Of course the interpretation suggested is only a qualitative model and the conclusions require a more detailed examination.

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QUESTIONS

Savich/Podgorny: If the plasma shell at the Moon's surface has a temperature of about 10 eV, its pressure can stop the solar-wind flux. But in the case of a collisionless plasma, a problem arises about the thickness of the shell which can supply the momentum transfer. In our laboratory experiments it was shown that the length over which momentum transfer occurs may be of the order of several electron cyclotron radii. The Moon's plasma shell thickness is of the order of the electron gyroradius and complete momentum transfer may hardly exist and some disturbances therefore may arise. It is impossible to exclude that such disturbances were observed by Ness on the nightside along the lunar Mach cone.

Savich/Galeev: I want to comment on the remark of Dr. Podgorny about the role of a two-stream ion instability of a plasma in the magnetic field with respect to the physics of solar-wind ionospheric interactions. It should be mentioned that in the weak interplanetary magnetic field, the growth rate of the ion-ion two-stream instability, γ, is much less than $\omega \approx \omega_{LH}$, where ω_{LH} is a lower hybrid frequency, and this instability provides the effective mean free path on the order of 10 γ times the velocity of the solar-wind speed, that is, larger than the height of the Moon's ionosphere. But the solar-wind ions move with velocities greater than the ionospheric electron thermal velocity and they can excite the Langmuir waves in the ionosphere and thus they could be stopped in a distance of order 10 km.

Savich/Dessler: Was there any difference in the plasma number density between sunrise and sunset?

Savich: At sunset on the Moon the measurements were not carried out.

Savich/Ness: At what phase of the Moon are the measurements made? Do they apply only to limbs or beyond?

Savich: All the measurements were made near the limb and near sunrise within solar zenith angles from 89° to 49° on the lunar dayside.