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Dusty plasma processes and interaction of lunar dust with the matter

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Abstract

The dusty plasma system in the surface layer of the illuminated part of the Moon is considered. The size distribution for dust particles over the Moon is obtained. The distribution of dust particle electric charges over sizes and heights is found on the basis of the size distribution. Dust distributions are discussed in connection with cohesion and adhesion of lunar dust.

1. Introduction

The future lunar missions Luna-Glob and Luna-Resource are planned to be equipped with instruments both for direct detection of dust particles over the surface of the Moon and for optical measurements. Figure 1 shows the scheme of the location of instruments (at heights of 20 and 90 cm over the surface of the Moon) detecting dust particles at the Luna-Glob and Luna-Resource stations. Measurements are planned in the daytime to ensure the power supply of instruments at lunar stations owing to solar energy. The purpose of the present investigation is to describe properties of dusty plasma system in the surface layer of the illuminated part of the Moon which are important for dust interaction with the matter.

2. Dusty plasma

The surface of the Moon is charged under the action of the electromagnetic radiation of the Sun, solar-wind plasma, and plasma of the Earth's magnetotail. The surface of the Moon interacting with solar radiation emits electrons owing to the photoelectric effect, which leads to the formation of the photoelectron layer over the surface. Dust particles located on or near the surface of the Moon absorb photoelectrons, photons of solar radiation, electrons which are separated from the dust particle surfaces due to the photoelectric effect, electrons and ions of the solar wind, and, if the Moon is in the Earth's magnetotail, electrons and ions of the magnetospheric plasma. All these processes lead to the charging of dust particles, their interaction with the charged surface of the Moon, rise and motion of dust, as well as the interaction of the dust particles with surfaces of the space stations, etc.

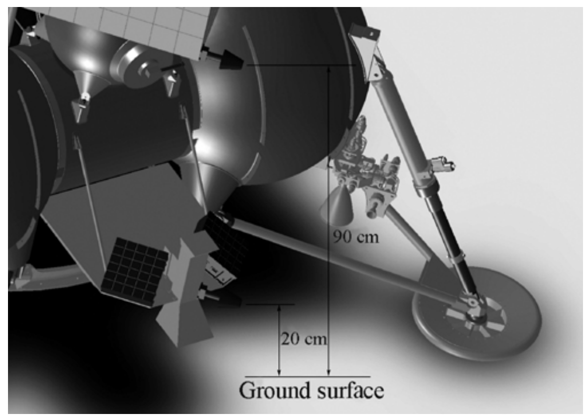

Figure 1: Scheme of the location of instruments (at heights of 20 and 90 cm over the surface of the Moon) detecting dust particles at the Luna-Glob and Luna-Resource stations.

3. Dust particle distribution

A significant characteristic of lunar dust in its interaction with the matter is the dust particle distribution. The behavior of dust particles in the surface layer is described by the equations expressing their dynamics and charging [1]. Calculations with the set of these equations make it possible to determine the size distribution of dust particles over the Moon. The probability of the presence of a particle at a certain height h (which is inversely proportional to the time of presence of a particle at this height) is calculated. This probability is multiplied by a normalization factor, which is calculated to ensure an adequate description of the size distribution of surface lunar dust. To determine the normalization factor, we used the data from [2] that made it possible to plot the distribution of dust particles of the surface of the Moon in the size range from 20 to 500 μm. This distribution is in good agreement with the Kolmogorov distribution [3], which is the size distribution of particles in the case of multiple crushing. This fact is in agreement with the conclusions [2] that the surface of the Moon is regolith evolving because of multiple crushing under meteorite impacts. The authors of [3] showed that the Kolmogorov distribution for the case of multiple crushing is valid at least for particles with sizes $\lesssim 100$ nm. Therefore, the distribution of dust particles of the surface of the Moon that was obtained using the data from [2] can be extended down to a size of 100 nm.

The size distribution thus obtained for dust particles over the Moon has the form

$$dN_d \approx \frac{Ada}{\sqrt{2\pi}\sigma a^4 \tau_{\max} v(h,\theta)} \exp\left\{-\frac{[\ln(a)-\Lambda]^2}{2\sigma^2}\right\}.$$

Here, $\tau_{\max} = \int_0^{H_{\max}} dh/v(h,\theta)$, $v(h,\theta) =$

$$= \sqrt{4Z_d(h,\theta)\left(\frac{T_{e,\mathrm{ph}}}{m_d}\right)\ln\left[1+\sqrt{\frac{\theta}{2}}\left(\frac{h}{\lambda_D}\right)\right] - 2g_M h},$$

where $H_{\max}$ is the maximum rise height of the dust particle with the size a (measured in microns); $A \approx 8.48 \times 10^{-4}$ cm has the meaning of the effective depth of the dust layer that can be separated from the surface; $\sigma = 1.29$ is the parameter of the Kolmogorov distribution; and $\Lambda \approx 4.12$ is the median of the Kolmogorov distribution, Z_d is the charge number of a dust particle, $T_{e,\mathrm{ph}}$ is the temperature of photoelectrons, m_d is the mass of a dust particle, θ is the subsolar angle, λ_D is the photoelectron Debye length, g_M is the acceleration of gravity near the surface of the Moon.

4. Cohesion and adhesion of lunar dust

Cohesion of lunar dust is an important process of interaction for the dust on the surface of the Moon and for the formation of the dusty plasma system over the Moon. Indeed, the process of dust particle charging on the lunar surface due to the action of the solar radiation can result in the violation of the inequality $Z_d^2 e^2/8\pi a^4 < \sigma_{\mathrm{coh}}$, where e is the electron charge, σ_{coh} is the cohesion. This occurs for $a \lesssim 100$ nm. Thus due to dust particle charging and destructing electrostatic forces the particles with $a \lesssim 100$ nm on the lunar surface cease to be combined in the conglomerates due to cohesion, are subjected to mechanical motions, rise over lunar surface, and participate in the formation of the dusty plasma system. The sizes $a \sim 100$ nm are typical those for the particles levitating over the lunar surface.

As it has been mentioned, lunar dust is a potential problem for planned manned lunar missions. If fine regolith particles are deposited on a surface of, say, space apparatus, then surface energy related to (e.g., van der Waals) adhesion forces and static-electric forces are likely to be the strongest contributors to adhesion. The typical electric charge on dust particles scales nearly linearly in proportion to the particles' size. In this case adhesion of the finest particles is dominated by charge effects in most cases.

Using the above size distribution obtained for dust particles over the Moon, we have found the distribution of dust particle charge depending on the size and the height. The typical dust particle charges are of the order of $+100e$, where $-e$ is the electron charge, for the particles with sizes of order several hundred nm. The distribution of dust particle charges has a significant effect on the electrostatic adhesion of particles to surfaces. An awareness of the distribution is impotant, e.g., for creation of cleaning methods for removing dust particles from surfaces.

Acknowledgements

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