Lunar dusty ionosphere

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The lunar ionosphere contains electrons, ions, neutrals, and fine dust particles. Despite the existence of neutrals in the lunar atmosphere on the lunar dayside ($\sim 10^5$ cm^{-3}), the long photo-ionization time-scales ($\sim 10-100$ days) combined with rapid ion pick-up by the solar wind (~ 1 s) should limit the associated electron number densities to only ~ 1 cm^{-3} [1]. However, there are some indications on larger electron number densities in the lunar ionosphere. In particular, the Soviet Luna 19 and 22 spacecraft conducted a series of radio occultation measurements to determine the line-of-sight electron column number density, or total electron content, above the limb of the Moon as a function of tangent height [2]. From these measurements they inferred the presence of a "lunar ionosphere" above the sunlit lunar surface with peak electron number densities of 500 to 1000 cm^{-3}. This points out to the existence of other mechanisms of electron appearance (not associated with simple ionization of neutrals in the lunar atmosphere). Electrons in the lunar ionosphere can appear due to the photoemission from the lunar surface as well as from the surfaces of dust particles levitating over the Moon. Here, we discuss whether there are the sources of lunar dust particles which can result in sufficiently intensive photoemission on (and over) the lunar dayside.

The discovery of the lunar dust was made in postsunset Surveyor lunar lander TV camera images of the lunar horizon. These Surveyor images revealed the presence of a near-surface (e.g., scale height of $\sim$10-30 cm) glow that was observed to persist for several hours after sunset, and to have a brightness near $10^{-6}B_{\text{Sun}}$ (Sun brightness) [3]. This effect was related to sunlight scattering at the terminators giving rise to "horizon glow" and "streamers" above the lunar surface [4]. Subsequent investigations have shown that the sunlight was most likely scattered by electrostatically charged dust grains originating from the surface [5]. During the Apollo missions 0.1 μm–scale dust was observed up to about 100 km altitude.

The upcoming lunar missions assume often the investigation of the lunar dust. The NASA's LADEE (Lunar Atmosphere and Dust Environment Explorer) mission is supposed to be launched in 2013. LADEE is a robotic mission that will orbit the Moon to gather detailed information about the lunar atmosphere, conditions near the surface and environmental influences on lunar dust. The Russian (Roscosmos) missions Luna-Glob and Luna-Resource (the latter jointly with India) have been designed for studying the lunar polar regions. These missions will, in particular, include investigations of dust near the surface of the Moon [6]. It is planned to equip the Luna-Glob and Luna-Resource stations with instruments both for direct detection of dust particles over the surface of the Moon (piezoelectric impact sensor (IS) and electrostatic sensor (ES)) and for optical measurements (overview camera (Cam O) and stereocamera (Cam S)). Fig. 1 shows the scheme of the location of the above instruments 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, that tallies well with the study of the lunar ionosphere over the lunar dayside.

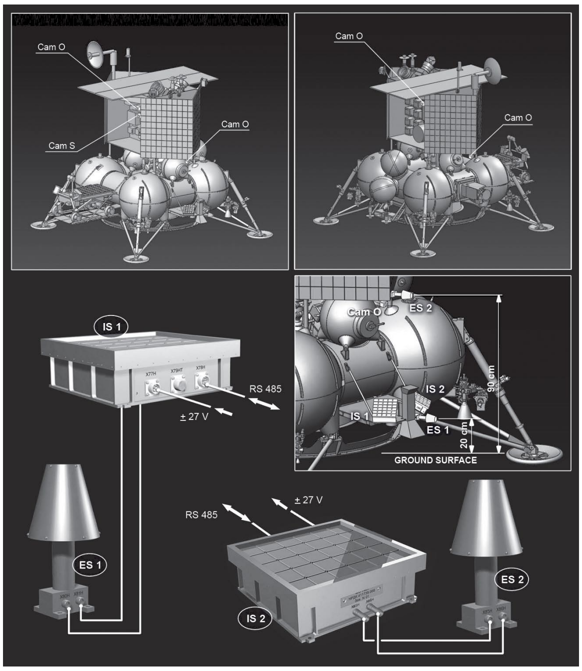

Figure 1: *The scheme of the location of the instruments both for direct detection of dust particles over the surface of the Moon and for optical measurements at the Luna-Glob and Luna-Resource stations*

At the daytime 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 and dusts levitating over the lunar surface interact with solar radiation. They emit electrons owing to the photoelectric effect, which leads to the formation of the photoelectron layer over the surface. Dusts located on or near the surface of the Moon absorb photoelectrons, photons of solar radiation, electrons and ions. All these processes lead to the charging of dust particles, their interaction with the charged surface of the Moon, rise and levitation of dust.

Based on the results obtained within Suprathermal Ion Detector Experiment (SIDE) and Charged Particle Lunar Environment Experiment (CPLEE), it was learned [1] that the lunar ionosphere is directly coupled to the interplanetary electric field. As a result, ion fluxes are non-thermal, highly directional, and quite variable. Very near the surface a dayside photoelectron sheath with height of a few hundred meters and a number density of the order of 10^4 cm^{-3} exists [7].

To describe the behaviour of dust component over the sunlit part of the Moon we have developed a model [8] in which the charging of dust particles over the surface of the Moon is calculated taking into account the effect of photoelectrons, electrons and ions of the solar wind, and solar radiation. In the model we take into account the photoelectrons from both the lunar surface and the surfaces of dust particles. The consideration of the photoelectrons from the dust particle surfaces requires a self-consistent investigation because the photoelectrons influence dust particle distributions while the dust particle distributions determine the number of the photoelectrons. In our calculations, we have used the data which agree with those obtained in the SIDE [1] and the CPLEE [7]. In particular, we have used the value of $3.7 \cdot 10^4$ cm^{-3} for the photoelectron number density near the lunar surface.

In Fig. 2 the histograms characterizing the number densities of dust particles over the surface of the Moon are presented for three magnitudes of the subsolar angle $\theta = 77^o$, 82^o, and 87^o. Furthermore, the bottom right panel of Fig. 2 shows the maximum possible rise heights of dust particles depending on their sizes. The length of a single-color horizontal segment in each of the histograms shown in Fig. 2 characterizes the density of particles (in cm^{-3}) with sizes in the corresponding interval (indicated on the right scale) at the corresponding heights. The total length of the horizontal segment in the histogram corresponds to the total density of the particles with the sizes presented in this plot. The dust particle charges do not exceed, as a rule, the values of the order of $q_d = Z_d e \sim 10e$, where $-e$ is the electron charge. Thus the electron number densities $n_e \sim Z_d n_d$ do not exceed the values of the order of 10^4 cm^{-3} and decrease with the height, the photoelectron sheath being formed with height of a few hundred meters which is in a good agreement with the data [7].

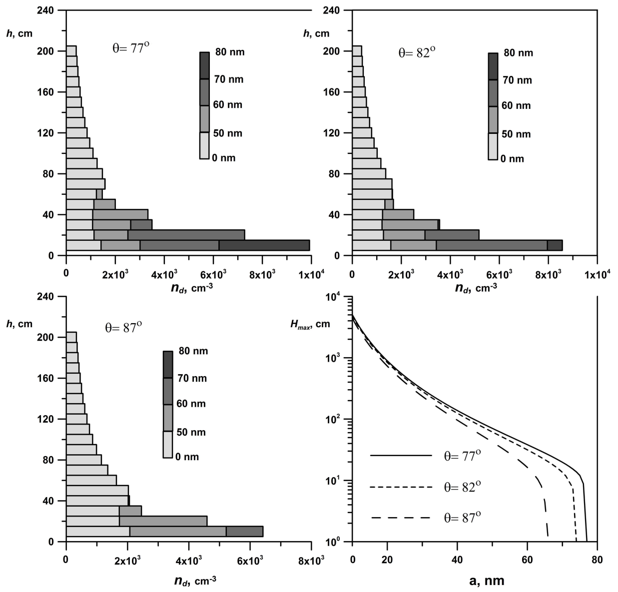

Figure 2: *The number densities of dust particles over the lunar regolith surface for three magnitudes of the subsolar angle $\theta = 77^o$ (top left panel), 82^o (top right panel), and 87^o (bottom left panel) as well as the maximum possible rise heights of dust particles vs dust particle sizes (bottom right panel)*

Fig. 2 shows that the dust levitation effects do not result in the rise of 100 nm dust particles up to the altitudes of about 100 km over the lunar surface. A phenomenon which can be responsible for an appearance of dust particles (and electrons with the number densities $n_e \sim Z_d n_d$) at the altitudes of about 100 km is related to impacts of meteoroids or man-made projectiles with the surface of the Moon [9]. The evolution of the impact plume can lead to the formation of charged particles. One type of the particles (small droplets) is created as a result of the process of condensation which takes place during the expansion of the vapor plume. The period of the formation of the centers of condensation is very short and all droplets have approximately the same size. The degree of condensation is usually between 0.1 and 0.5. The droplets move together with the substance of the plume. Their speed exceeds often the first astronautical velocity for the Moon, 1.68 km/s, and the droplets will not fall down the surface of the Moon. Moreover, the droplets with the speeds between the first and second astronautical velocities, *i.e.*, between 1.68 and 2.375 km/s, perform finite movement around the Moon. This shows that the effect of condensation of micrometeoriod substance after impact can be important from the viewpoint of explanation of dust particle rise to high altitudes in addition to the dusty plasma effects.

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