

Localized structures of nanosize charged dust grains in the lunar exosphere

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The upcoming lunar missions assume often the investigation of the lunar dust. The NASA's LADEE (Lunar Atmosphere and Dust Environment Explorer) mission was launched in 2013. LADEE is a robotic mission that will orbit the Moon to gather detailed information about the lunar exosphere, conditions near the surface and environmental influences on lunar dust. The Russian (Roscosmos) missions Luna-25 and Luna-27 have been designed for studying the lunar polar regions. These missions will, in particular, include investigations of dust near the surface of the Moon [1, 2]. Measurements are planned in the daytime to ensure the power supply of instruments at lunar stations owing to solar energy.

Dusty plasmas over the lunar surface admits [3] the existence of the well-known dust acoustic (DA) waves [4]. The present paper deals with localized DA structures - solitons under the conditions of the dusty plasmas over the Moon, paying special attention to the height-distribution of dust over the Moon. DA structures over the Moon are associated with the DA waves and are of special interest since it is on the rather long DA time scale, where the dust dynamics plays a special role. They can thus be detected by ground based or orbital measurements. For example, lower-hybrid envelope solitons were observed in space plasmas by the FREJA satellite [5].

Here, we consider the case when the Moon is not located in the terrestrial magnetosphere tail, therefore, the influence of the magnetosphere tail plasma on the illuminated side of the Moon is insignificant. We determine the parameters of DA solitons in the dependence on the height over the lunar surface.

Plasmas over the lunar dayside contain electrons, ions, neutrals, and fine dust particles [6]. Dusts located on or near the surface of the Moon absorb 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 [1, 2, 7].

Despite the existence of neutrals in the lunar atmosphere on the lunar dayside ($\sim 10^5 \text{ cm}^{-3}$), 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 and ion number densities to only $\sim 1 \text{ cm}^{-3}$. However, there are some indications on larger electron number densities in the lunar

ionosphere. In particular, the Soviet Luna-19 and Luna-22 spacecrafsts 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 [8]. From these measurements they inferred the presence of a “lunar ionosphere” above the sunlit lunar surface with electron number densities reaching 1000 cm^{-3} .

Electrons over the lunar dayside appear due to the photoemission from the lunar surface as well as from the surfaces of dust particles levitating over the Moon, while the photoelectron emission is due to the solar vacuum ultraviolet (VUV) radiation. For lunar regolith the number densities of the photoelectrons near the surface of the Moon may exceed the values of the order of 10^5 cm^{-3} while their temperature is about $0.1 - 0.2 \text{ eV}$ [2]. These parameters differ the photoelectrons from the electrons of the solar wind. The typical solar wind parameters are: the electron and ion (proton) number densities $n_{eS} \approx n_{iS} = 8.7 \text{ cm}^{-3}$, the electron temperature $T_{eS} = 12 \text{ eV}$, the ion temperature $T_{iS} = 6 \text{ eV}$, the solar wind velocity $u_S = 400 \cdot 10^5 \text{ cm/s}$.

The plasma-dust system in the near-surface layer of the illuminated part of the Moon is described using the model developed in Refs. [1, 2], in which the charging of dust particles above the lunar surface is calculated with account for the influence of photoelectrons, electrons, and ions of the solar wind and the solar radiation. Typical distributions of charged dust particles over the sunlit lunar surface are given in Fig. 1.

The quasi-hydrodynamic one-dimensional propagation of DA waves is governed by the conservation equations, Boltzmann distributions,

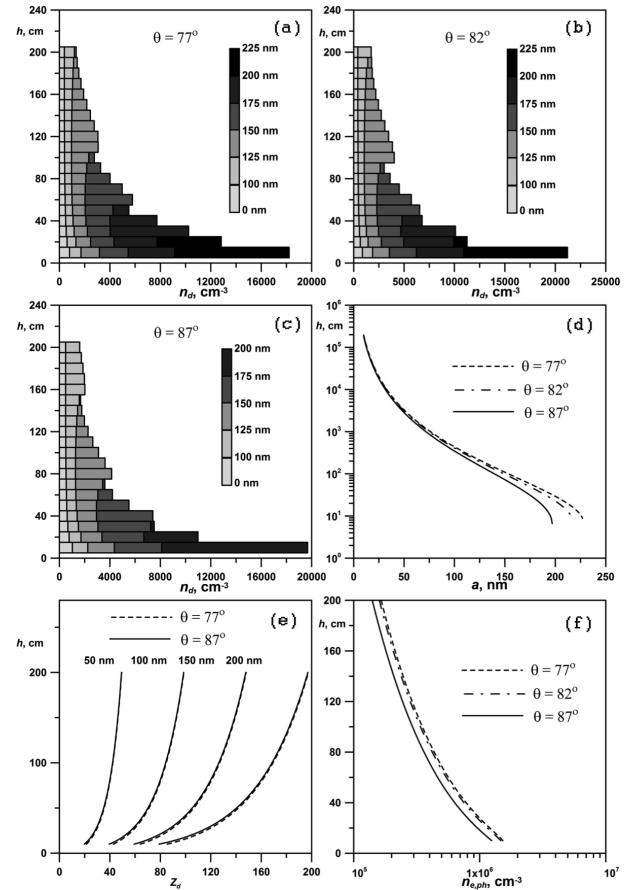


Figure 1: Distributions of dust particles over the lunar surface calculated for the subsolar angles $\theta = (a) 77^\circ$, (b) 82° , and (c) 87° , the maximum heights (d) that may be attained by dust particles of the size a , height distributions of charge numbers Z_d of dust particles (e) over the lunar regolith areas calculated for different subsolar angles and the dust particle sizes of 50, 100, 150, and 200 nm, and photoelectron distributions over the lunar surface (f); h is the height over the lunar surface

and the Poisson equations

$$\begin{aligned} \partial_t n_d + \partial_x (n_d v_d) &= 0, \quad \partial_t v_d + v_d \partial_x v_d = \frac{Z_d e}{m_d} \partial_x \varphi, \\ n_e = n_{e0} \exp\left(\frac{e\varphi}{T_e}\right), \quad n_i = n_{i0} \exp\left(-\frac{e\varphi}{T_i}\right), \quad \partial_x^2 \varphi &= 4\pi e (n_e + Z_d n_d - n_i), \end{aligned} \quad (1)$$

where φ is the electrostatic potential; x and t are the space and time variables; n_α and $n_{\alpha0}$ ($\alpha = e, i, d$) are the density and the unperturbed density of the electrons, ions and dust particles; m_d , v_d , and Z_d are the mass, velocity, and charge number ($q_d = -Z_d e$) of a dust particle; q_d is the dust particle charge and $-e$ is the electron charge; and $T_{e(i)}$ is the electron (ion) temperature. The equations are valid if the characteristic velocity of the process is larger than the dust thermal speed and much less than the ion thermal speed.

The main contributions to the terms of the above equations containing the electron parameters are made by photoelectrons, while to those containing the ion parameters are made by solar wind ions. The role of ions in the formation of DA structures in dusty plasmas over the illuminated part of the Moon is negligibly small. Thus below the ion contribution is omitted. Furthermore, we neglect dust charge variations within the soliton.

We now look for solutions of (1) in the form of localized wave structures propagating with constant velocities M in the x -direction. Thus, all the parameters involved depend on x and t only through the variable $\xi = x - Mt$. We shall assume that all perturbations vanish for $\xi \rightarrow \pm\infty$.

We use the standard Sagdeev potential approach and reduce the problem to the analysis of the effective energy integral

$$\frac{1}{2} (\varphi_\xi)^2 + V(\varphi) = 0, \quad (2)$$

where the normalizations $e\varphi/T_e \rightarrow \varphi$ and $M/c_d \rightarrow M$ have been used, and

$$V(\varphi) = 1 - \exp(\varphi) + |M|d \left(|M| - \sqrt{M^2 - 2Z_d \varphi} \right). \quad (3)$$

Here, $c_d = \sqrt{T_i/m_d}$ and $d = n_{d0}/n_{e0}$; $Z_d < 0$.

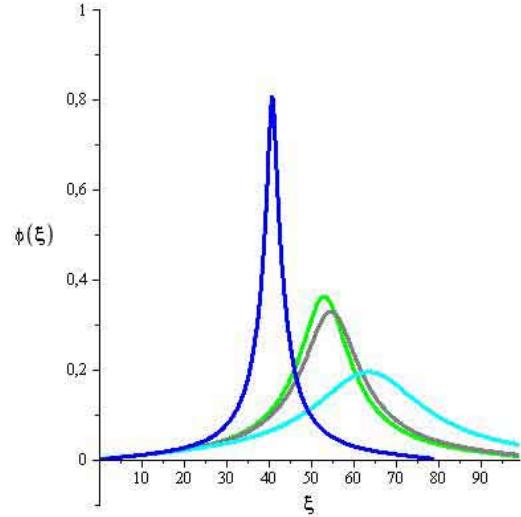


Figure 2: The $\varphi(\xi)$ profiles for DA solitons at different altitudes h . The parameters are $M = 2.1$; $h = 10$ cm (violet curve), $h = 50$ cm (green curve), $h = 100$ cm (grey curve), and $h = 150$ cm (aquamarine curve). The subsolar angle is 82°

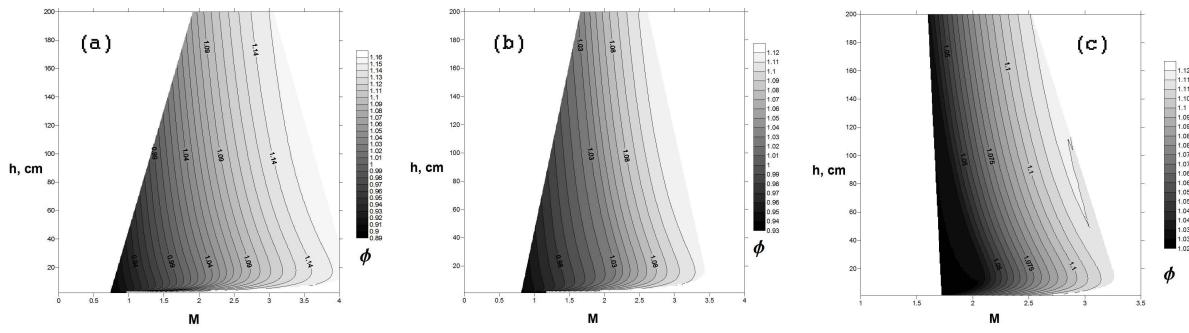


Figure 3: The height-dependencies of the Mach numbers and the soliton amplitudes for the subsolar angles $\theta = (a) 77^\circ$, (b) 82° , and (c) 87°

For the existence of localized DA structures, the Sagdeev potential $V(\varphi)$ must have a local maximum at $\varphi = 0$, and the equation $V(\varphi) = 0$ must have at least one more real solution $\varphi_0 \neq 0$. A local maximum of the Sagdeev potential $V(\varphi) = 0$ at the point $\varphi_0 \neq 0$ exists if

$$M^2 > Z_d^2 d / (1 - Z_d d). \quad (4)$$

The $\varphi(\xi)$ profiles for DA solitons at different altitudes are given in Fig. 2. Fig. 3 represents the height-dependencies of the Mach numbers and the soliton amplitudes. The data presented in Figs. 2 and 3 are calculated for the dusty plasma parameters presented in Fig. 1. The photo-electron temperature is assumed to be 0.15 eV.

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