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Lunar dust lofting due to surface electric field and charging within Micro-cavities between dust grains above the terminator region

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Abstract

It has been suggested that lunar dust grains can be transported by the electrostatic forces above the lunar terminator and produce the lunar horizon glow (LHG) by forward-scattering of sunlight. In addition, the recent experiments have shown that dust grains can be lofted in the vacuum chamber due to charging within micro-cavities by absorbing the emitted secondary electrons under the electron beam current (Wang et al., 2016; Schwan et al., 2017). In this study, the required charge within micro-cavities in order to separate dust particles from the lunar surface are estimated by using the surface electric field and the forces of gravity and contact. In addition, the maximum heights for dust grains are calculated by initial vertical launching velocity from the surface and the acceleration within the electron sheath against the gravity. The following calculations are performed for the particles with 0.1, 1 and 5 μm radius, and the variation of ambient plasma conditions are studied throughout solar wind data of CME passages on 8–13 February 1997, 1–3 May 1998 and 8–12 March 2012. Current balance method is used to estimate the surface potential, electric field and Debye length to investigate how the lunar dust particles are mobilized under the various conditions. First, strong negative surface potentials can be observed during the post-shock plasma passages, and it produces stronger electrostatic forces acting on the lofted dust particles. Second, submicron-sized dust particles are launched from the surface less frequently than the larger size grains due to the charging time. The height predictions of the dust grains with 5 μm radius are similar to the LHG observations of Surveyor mission, and the results suggest that the heights of micron-sized dust grains are controlled by the initial vertical launching velocity more than the surface electric field, unlike the smaller sized particles. Finally, strong electrostatic forces are not sufficient solely to loft the dust particles to higher altitudes since a charged dust requires accelerating for a proper time and distance in the electron sheath.

Keywords: Lunar dust lofting; Lunar surface charging; Dust charging; Solar wind; Coronal mass ejection

1. Introduction

The Moon directly interacts with dynamic plasma conditions in the absence of a global magnetic field and a dense atmosphere. It spends most of its time under the solar wind influence, and it also travels through the magnetotail, magnetosheath and bow shock while it orbits the Earth. Even though the solar wind plasma has lower temperature and higher density than the magnetospheric plasma, enhanced fluxes of charged particles can be observed in some cases such as solar energetic particle events (SEPs) (Halekas et al., 2009) and CMEs (Farrell et al., 2013). In addition, the fluxes of energetic particles can be seen during geomagnetic storms and substorms (Colwell et al., 2007; Asano et al., 2010; Vaverka et al., 2016). In all of these cases, the lunar surface potential is controlled by the surrounding plasma conditions and the photoemission of electrons from the dayside of the Moon due to solar UV and X-ray radiation. The main current sources can be expressed as the collection of ambient plasma electrons and ions, the

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photoemission of electrons and the secondary electron emission from the lunar surface.

The measurements and the simulation results point out that the lunar surface potential is highly variable, and the range of the potential values differs according to the location on the Moon such as subsolar point, night side or the terminator region as well as the ambient plasma conditions. It was observed that the lunar surface potential was approximately +10 V on the dayside and −100 V near the terminator and night side regions under the solar wind during Apollo missions (Freeman and Ibrahim, 1975; Whipple, 1981), and Manka (1973) reported approximately +10 V on the dayside and −38 V on the lunar terminator under the average solar wind conditions by the current balance calculation. Furthermore, +2.85 V on the subsolar point and −47.4 V on the terminator region have been determined for the slow stream solar wind conditions, whereas +4.22 V on the subsolar point and −44.9 V on the terminator region were calculated for the fast stream solar wind (Stubbs et al., 2014). In addition, the lunar surface potential ranging from +10 V to −4 kV by various ambient plasma conditions were reported previously (Walbridge, 1969), and the theoretical model predictions are roughly in agreement with the previous observations (Freeman and Ibrahim, 1975; Manka, 1973; Harada et al., 2013; Stubbs et al., 2014).

There is a soil-like layer above the bedrock of the Moon, which is also called as lunar regolith, and it is produced by small meteoroid impacts on the lunar surface (Stubbs et al., 2014; Popel et al., 2016). The size of particles ranges from several centimeters to submicron size, and the small-scale particles are also referred as the lunar dust, which can be transported by the electrostatic forces above the lunar surface (Rennilson and Criswell, 1974; Stubbs et al., 2014). In addition, it has been suspected to be the reason of lunar horizon glow (LHG) over the years (Criswell, 1973; Rennilson and Criswell, 1974; McCoy, 1976; Glenar et al., 2011). All observations of the LHG were related to the lunar terminator, and lofted and/or levitated dust grains by the electrostatic forces were proposed to be the reason of forward-scattering of the sunlight. It was first spotted by the TV cameras of Surveyor missions in 1966 and 1968, and the excessive brightness to coronal and zodiacal light (CZL) indicated that the dust population was considerably higher than the levels that can be produced by micrometeorite ejecta from the lunar surface (Criswell, 1973; Rennilson and Criswell, 1974). Therefore, electrostatic dust transportation was proposed to be the responsible physical mechanism for the LHG near the lunar surface. Following the Surveyor observations, high-altitude LHG was also reported during Apollo missions, and it was understood that LHG is a variable phenomenon at higher altitudes since it was present during the image sequences of Apollo 15 on orbit, whereas there was no trace of excessive brightness to CZL during Apollo 16 (McCoy, 1976; Glenar et al., 2011; Stubbs et al., 2006). The physical mechanism behind the existence of the dust grains is still unexplained at high altitudes. In addition, the dust population during Surveyor observations is estimated as micron-sized, whereas it is suspected to be submicron-sized during Apollo missions. The dust lofting and lunar surface charging are represented in Fig. 1.

Previously, Clementine star tracker navigation cameras searched for the forward-scattering of the sunlight; however, the high-altitude LHG was not detected during these measurements, and it suggested that dust abundances are not influenced by the electrostatic transportation at the altitudes that are detectable during an orbital mission (Glenar et al., 2014). The Lunar Atmosphere and Dust Environment Explorer (LADEE) mission measured the dust particles between 3 and 250 km altitudes around the Moon, and the results concluded that the dust densities suggested by the LHG observations during the Apollo 15 orbit sequences were not present (Horanyi et al., 2015; Szalay and Horányi, 2015). In addition, LRO (Lunar Reconnaissance Orbiter) The Lyman-Alpha Mapping Project (LAMP) UV spectrograph measurements could not measure any distinguishable dust densities suggesting any excessive brightness above the lunar horizon (Feldman et al., 2014). During the measurements the solar wind conditions were unremarkable; however, the annual meteor showers were present. The difference between the measured dust populations requires further investigation.

In this study our purpose is to investigate the maximum height variation of dust grains due to micro-cavity charging and the surface electric field under various ambient plasma conditions. First, lunar surface charging, the initial separation of the dust particles and the maximum height calculations are explained in Section 2. Data acquisition and calculation method is described in Section 3. The selected CME events are investigated in Section 4, and the results are discussed and concluded in Sections 5 and 6.

2. Simulation method

2.1. Lunar surface charging

The current balance approach is used to calculate the terminator region surface potential by the flowing plasma equations (Manka, 1973; Stubbs et al., 2014). Since the plasma conditions are highly variable during the passage of CMEs, the influence of different parameters on the surface potential, the electric field and the electron sheath above the lunar terminator surface can be investigated. Several assumptions are applied for simplification such as:

- The Moon is a perfect sphere, and the lunar radius is 1737 km.
- The surface potential and the electric field above the terminator region are in the equilibrium state for each step of the simulation, and the lunar surface electric field is estimated by one-dimensional Debye shielding (Stubbs et al., 2006).

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