Simulations of the Lunar Photoelectron Sheath and Associated Dust Grain Levitation Equilibria

Andrew R. Poppe and Mihály Horányi, Laboratory for Atmospheric and Space Physics, Boulder, CO; Department of Physics, University of Colorado, Boulder, CO; NASA Lunar Science Institute: Colorado Center for Lunar Dust and Atmospheric Science (poppe@lasp.colorado.edu, horanyi@colorado.edu)

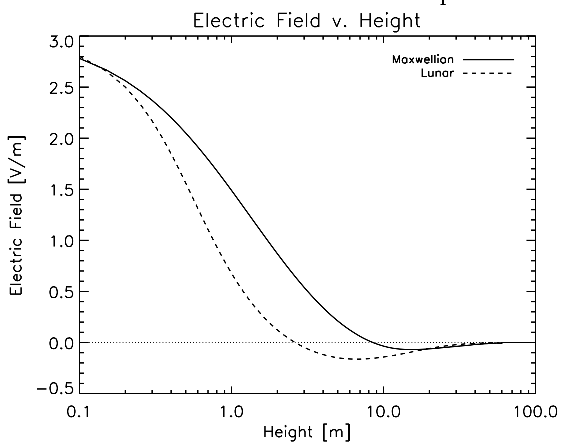

Figure 1: The electric field as a function of height on the lunar surface in the Maxwellian and lunar cases.

Introduction: Several measurements from the Apollo-era have suggested that the lunar surface is an active environment for micron and sub-micron sized dust particles. These measurements include Surveyor images of lunar horizon glow [1], results from the Lunar Ejecta and Meteorites (LEAM) experiment deployed during the Apollo 17 mission [2], and Apollo astronaut sketches of the near-surface environment [3]. Dust grains on the lunar surface will charge due to exposure to solar UV radiation and the ambient solar wind plasma and are thought to be electrostatically levitated and transported across the lunar surface. Several models have been developed in an effort to explain this phenomenon [4, 5], and recent laboratory experiments have confirmed the ability to charge and levitate dust grains in a plasma [6, 7, 8], however, the picture is still incomplete.

Photoelectron Sheath Simulation: A comprehensive understanding of the lunar surface plasma environment is required in order to assess the possibility and explain the subsequent behavior of electrostatically levitated lunar dust grains. The lunar surface is exposed to solar UV light, which induces photoemission, and the ambient solar wind plasma, which, due to the higher electron mobility, charges the surface negatively. The photoemission current is approximately an order of magnitude greater than the solar wind electron collection current, and therefore, the lunar surface is expected to charge positively. A photoelectron sheath will develop immediately above the lunar surface on the order of meters in thickness. While photoelectron sheaths have been studied before [9], these studies have not been done specifically for the lunar surface. We simulate the lunar photoelectron sheath via a 1-dimensional particle-in-cell (PIC) code, tailored to the lunar surface. On one side of the simulation, the lunar surface emits photoelectrons with a specified energy distribution, while $T_{sw} = 10$ eV solar wind electrons and ions enter the simulation from the opposite end. We simulate two photoelectron energy distributions: a $T_{pe} = 2.2$ eV Maxwellian and the energy distribution measured from lunar fines returned by the Apollo missions [10]. The charge on the lunar surface is continuously calculated in order to maintain charge conservation.

The electric field as a function of height for both the Maxwellian and lunar cases is shown in Figure 1. The lunar electric field is consistently weaker than the Maxwellian electric field and both cases have regions of negative (downward-pointing) fields, corresponding to a non-monotonic potential profile. The presence of non-monotonic sheath potentials has been analytically studied before [11] and has implications for the ability of the sheath to levitate dust grains. Regions of negative (downward-pointing) electric fields, present in a non-monotonic sheath potential, cannot support any dust levitation and correspondingly place a limit on the maximum height for dust grain levitation.

Dust Levitation: The ability of a photoelectron sheath to levitate dust grains depends on the charge on the dust grain and the strength of the sheath electric field. We employ a test-particle method to analyze the necessary conditions for dust grain levitation, using the sheath profiles from the PIC simulations for both the Maxwellian and lunar cases. The dust grain charge as a function of grain radius is determined by finding the grain potential at which the charging currents sum to zero and using the capacitance of a spherical grain to determine the charge. A grain will levitate if the electric force on the particle balances the gravitation force. Figure 2 shows the equilibrium levitation height as a function of particle size for both the Maxwellian and lunar cases. The Maxwellian sheath cannot levitate particles with radii, $r > 0.15$ μm, while the lunar sheath cannot levitate particles with radii, $r > 0.085$ μm. Additionally, for any particle size, the maximum levitation heights for the Maxwellian and lunar cases are 8.5 m and 2.5 m, re-

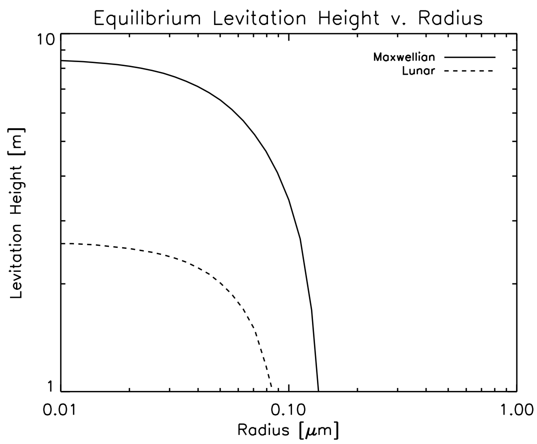

Figure 2: The equilibrium levitation height as a function of grain radius for dust grains on the lunar surface in the Maxwellian and lunar cases.

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While the 1-dimensional nature of the model necessarily limits the effects of spatially-varying boundary conditions, the results nevertheless place important constraints on the ability of the lunar photoelectron sheath to levitate micron and sub-micron dust grains. The strength of the sheath electric field dominates this capability and relative to a Maxwellian with an equivalent photoelectron temperature, the lunar photoelectron sheath is much less able to levitate dust particles. Future work will expand the model to two dimensions in order to include phenomena such as sunlit-shadowed boundaries, which are thought to build up massive horizontal electric fields, and local lunar topography, which could influence the equilibria and trajectories of levitated dust grains. We also plan to address the variability of the local plasma environment, such as the change in solar UV irradiation through the solar cycle and change in the solar wind temperature and flux. This variability could drastically change the ability of the lunar photoelectron sheath to levitate and transport dust grains.

References

[1] J. J. Rennilson and D. R. Criswell. Surveyor observations of lunar horizon-glow. *The Moon*, 10: 121–142, 1974. [2] O. E. Berg, *et al.* Preliminary results of a cosmic dust experiment on the moon. *Geo. Res. Lett.*, 1(7):289–290, Nov. 1974. [3] H. A. Zook and J. E. McCoy. Large scale lunar horizon glow and a high altitude lunar dust exosphere. *Geo. Res. Lett.*, 18(11): 2117–2120, Nov. 1991. [4] T. Nitter, O. Havnes, and F. Melandsø. Levitation and dynamics of charged dust in the photoelectron sheath above surfaces in space. *J. Geo. Res.*, 103(A4):6605–6620, 1998. [5] T. J. Stubbs, R. R. Vondrak, and W. M. Farrell. A dynamic fountain model for lunar dust. *Adv. Space Res.*, 37:59–66, 2006.
[6] A. A. Sickafoose, *et al.* Photoelectric charging of dust particles in vacuum. *Phys. Rev. Lett.*, 84(26), June 2000. [7] A. A. Sickafoose, *et al.* Experimental investigations of photoelectric and triboelectric charging of dust. *J. Geo. Res.*, 106(A5):8343–8356, May 2001.
[8] X. Wang, M. Horányi, and S. Robertson. Experiments on dust transport in plasma to investigate the origin of the lunar horizon glow. *J. Geo. Res.*, 114, 2009. [9] R. J. L. Grard and J. K. E. Tunaley. Photoelectron sheath near a planar probe in interplanetary space. *J. Geo. Res.*, 76(10):2498–2505, 1971. [10] B. Feuerbacher, *et al.* Photoemission from lunar surface fines and the lunar photoelectron sheath. *Proc. 3rd Lunar Sci. Conf.*, 3:2655–2663, 1972.
[11] R. L. Guernsey and J. H. M. Fu. Potential distribution surrounding a photo-emitting plate in a dilute plasma. *J. Geo. Res.*, 75(16):3193–3199, June 1970.