Artemis Science White Paper
The Complex Electromagnetic Environment at the Lunar South Pole

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The glow observed at the western lunar horizon by Surveyor 5, 6, and 7 was first speculated to be the result of scattered sunlight through levitated charged dust grains in a strong electrostatic field [1]. Sunrise streamers observed from lunar orbit by the Apollo missions were also attributed to scattered sunlight from higher altitude particulates [2,3]. However, while electric fields could accelerate charged particles to reach tens of kilometers in altitude [4], ejecta from micrometeorite impacts can also provide a relatively continuous mechanism for populating the dusty lunar exosphere. This results in the 'gardening' of the lunar surface [5]. More obvious ejecta can also be seen radiating from large craters and perhaps in lunar swirls that have interacted with crustal magnetic fields [6].

As the moon lacks a protective magnetic field like Earth, it is both exposed to the complete effects of the Sun and serves as neutral barrier. On the sunlit side, X-ray and UV photons generate photoelectrons in the lunar regolith. The result is a small positive surface potential of about +10 V [7]. The dark side of the moon, however, faces a plasma void because it blocks the solar wind. As electrons in the solar wind plasma have a higher thermal velocity, these electrons fill the plasma void first and create a significant negative surface potential of about -400 V [8]. These day-night electric potential differences are consistent with surface measurements by the Apollo Lunar Surface Experiment Package (ALSEP) and the Suprathermal Ion Detector Experiment (SIDE) deployed during Apollo 14 and 15 [9].

In addition to surface electric potential swings from day to night, further observations support an increase in exospheric dust density in this terminator region. For example, the Apollo 17 Lunar Ejecta and Meteorites (LEAM) experiment recorded a significant increase in surface impact events across the terminator [10], and the Lunar Dust Experiment (LDEX) on board the Lunar Atmosphere and Dust Environment Explorer (LADEE) recorded a significant increase in dust density tens of kilometers above the terminator [11]. However, each observation can be explained by an increase in charged dust mobility from a strong electric potential gradient, or a higher micrometeorite impact rate due to the ram direction of the Earth-moon orbit; the sunrise terminator is always the "leading edge" of the lunar surface [3]. Consequently, the relative contribution of each exospheric dust population model, electromagnetic or impact ejecta, remains unclear. By improving, or resolving, our understanding of the electromagnetic environment on the moon, significant inroads can be made on understanding the planetary processes on all airless bodies, volatile cycles, and surface interactions with the Sun.

Scientific exploration of the lunar south pole by a crew presents a unique opportunity to carry out a detailed survey of the lunar electromagnetic and dust environment. In situ data will enable tight constraints on exospheric dust population processes, the electromagnetic transportation of volatiles across airless bodies, and the charging of surfaces directly exposed to the solar flux and the solar wind.

At the lunar poles, the altitude of the Sun is permanently low. This produces two significant environments relevant to the charging of the lunar surface.

First, the lunar south pole has a high density of permanently shadowed regions (PSRs), a high density of near-permanently lit regions, and a high density of sunlight to shadow sharp transitions. Consequently, the south pole region is potentially dominated by strong and complex electric potential gradients; the surface regularly transitions from small positive potentials to large negative potentials [12]. ***If the exospheric dust density is higher at the lunar south pole, with a corresponding increase in the electric potential gradient, then electromagnetic dust levitation could be considered the dominant exospheric dust population method.***

Second, the poles are perpetually near the terminator. As demonstrated by LEAM and LDEX, an increased exospheric dust density is expected in these regions from either large electric potentials or micrometeorite ejecta. However, the south pole is not directly on the “leading edge” of the lunar orbit, and so the effects of micrometeorite impacts is expected to be lower. In other words, at the lunar poles one of the proposed mechanisms of populating the dusty exosphere will be minimized. ***Therefore, if no significant drop in the exospheric dust density is detected, electromagnetic dust levitation could be considered the dominant exospheric dust population method.***

In addition to advancing our understanding of planetary science and space physics, the electromagnetic environment at the lunar south pole has implications to crewed surface operations. Surface activity will produce sudden, forceful interactions with the lunar surface due to plume impingements from Human Landing Systems [13], and gentler, more prolonged interactions due to crew movements across the surface. In both cases, a significant increase in lofted dust will occur. As with the Apollo missions [14], the effects of lunar dust on surface activities will significantly increase risk to the crew and the Artemis systems because crew health and system performance may degenerate. These effects will compound as mission lengths increase. The electromagnetic effects at the lunar south pole could play a role in the trajectories of plume-ejecta and charge build up on surface systems. Electrostatic forces may result in failures of EVA suits and other seals due to abrasive regolith intrusion, may reduce the efficiency of photovoltaics power generators, and may impact thermal controls as radiators also become coated.

With a high-fidelity electromagnetic survey of the lunar south pole during the Artemis III mission, we can advance our knowledge of planetary processes, volatiles, and the impacts of the solar flux and solar wind. Such data will also enable retirement and mitigation of known risks to Artemis and potential future platforms that may be constructed to study the universe. To that end, the following scientific objective are recommended for the Artemis III human crew:

Science Objective 1: What are the surface electric potentials, how do they vary between sunlit and shadowed regions, and do they evolve over a lunation?

Science Objective 2: What is the physical density of lofted dust, how does this vary between sunlit and shadowed regions, how does this evolve over a lunation, how does this vary with micrometeorite flux (meteor showers), plume-surface interactions, and crew movement?

Science Objective 3: What is the charge density of lofted dust and how will that impact surface systems, i.e., rate of dust deposition and charge build-up on surfaces?

Science Objective 4: Can the evolution of lofted dust be predicted in order to inform crew activities, i.e., minimize risk to crew and surface systems during extended missions?

To date, the SCEM and ASM reports, the LEAG Science Objective Sci-D-7 (to study the behavior of granular media in the lunar environment), the Lunar Polar Volatiles Explorer, and the Lunar Geophysical Network highlighted in the most recent Planetary Decadal, have focused on volatile extraction in the context of ISRU. It is therefore timely to begin addressing the near surface electromagnetic environment and the physical processes that affect exospheric dust dynamics that pose potential risks.

References: [1] Rennilson, J. J. & Criswell, D. R., *Moon,* **1974***, 10*, 121-142. [2] McCoy, J. E. & Criswell, D. R. *Lunar and Planetary Science Conf. Proceedings,* **1974***, 3*, 2991-3005. [3] Glenar, D. A.; Stubbs, T. J.; McCoy, J. E. & Vondrak, R. R. *PLANSS,* **2011***, 59*, 1695-1707. [4] Stubbs, T. J.; Vondrak, R. R. & Farrell, W. M. *Advances in Space Research,* **2006***, 37*, 59-66. [5] Grün, E.; Horanyi, M. & Sternovsky, Z. *PLANSS,* **2011***, 59*, 1672-1680. [6] Garrick-Bethell, I.; Head, J. W. & Pieters, C. M. *Icarus,* **2011***, 212*, 480-492. [7] Stubbs, T. J. et al. *Dust in Planetary Systems,* **2007***, 643*, 181-184. [8] Halekas, J. S.; Lin, R. P. & Mitchell, D. L. *GRL,* **2005***, 32*, L09102. [9] Fenner, M. A.; Freeman J. W., J. & Hills, H. K. *Lunar and Planetary Science Conference,* **1973***, 4*, 234. [10] Berg, O. E.; Richardson, F. F.; Rhee, J. W. & Auer, S. *GRL,* **1974***, 1*, 289-290. [11] Horányi, M. et al. *Nature,* **2015***, 522*, 324-326. [12] Halekas, J. S.; Lin, R. P. & Mitchell, D. L. *GRL,* **2005***, 32*, L09102. [13] Lane, J. E. & Metzger, P. T. *Acta Geophysica,* **2015***, 63*, 568-599. [14] Gaier, J. R. & Creel, R. A. The Effects of Lunar Dust on Advanced EVAs, *Presentation,* **2005**.