LUNAR ELECTRIC FIELDS AND DUST: IMPLICATIONS FOR IN SITU RESOURCE UTILIZATION.

J.S. Halekas[1], G.T. Delory[1], T.J. Stubbs[2,3], W.M. Farrell[3], R.R. Vondrak[3], M.R. Collier[3],
[1]Space Sciences Laboratory, University of California, Berkeley, CA 94720, jazzman@ssl.berkeley.edu, [2]University of Maryland, Baltimore County, Baltimore, MD 21250, [3]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771.

Introduction: Although the lunar environment is often considered to be essentially static, it is in fact very electrically active. Measurements from the Lunar Prospector spacecraft imply lunar surface electrostatic potentials as large as 5 kilovolts during extreme space weather events. Surface electrification likely also affects dust, with observations from the Apollo era indicating transport of lunar dust to altitudes of ~100 km, and acceleration of charged dust grains to speeds of up to ~1 km/sec near the lunar terminator. Electrified dust grains can adhere to machinery, and large electric fields could also directly affect machinery.

All astronauts who walked on the Moon reported difficulties with lunar dust. These problems were likely worsened by the fact that the dust was electrically charged, enhancing its adhesive properties. Electrified dust is likely to have similarly significant effects on any machinery operating for prolonged periods in the lunar environment. Characterization of lunar surface charging and dust electrification and transport is therefore an important step in preparing for serious in situ resource utilization efforts.

Lunar Electric Fields: The surface of the Moon charges in response to currents incident on its surface, and is exposed to a variety of different charging environments during its orbit around the Earth, with charging currents spanning several orders of magnitude. On the sunlit hemisphere, photoelectron emission usually dominates, ensuring a small positive surface potential. On the night side, however, plasma currents dominate, and the lunar surface charges to a negative potential on the order of the electron temperature (typically ~50-100 V in the solar wind wake and magnetospheric tail lobes). See Fig. 1.

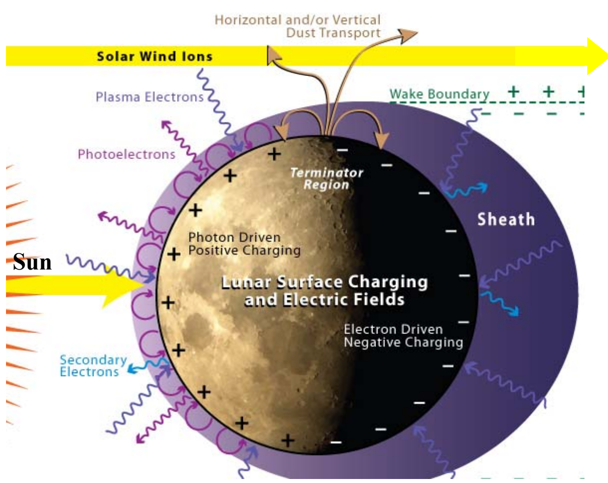

Figure 1: Schematic of lunar electric field environment (not to scale).

Apollo data placed some constraints on lunar surface potentials [1,2,3,4], and recent measurements by the Lunar Prospector (LP) spacecraft [5,6,7,8] have also added to our knowledge of lunar electric fields. Typical lunar nightside potentials are on the order of ~50-100 V negative. However, during some time periods surface potentials can reach much higher values. When the Moon is immersed in the energetic and turbulent plasma of the terrestrial plasmasheet, negative surface potentials of several kV have been observed [6]. Meanwhile, surface potentials as large as -5 kV have been observed during extreme space weather events. Our knowledge of the lunar electrostatic environment is still limited, though, especially in terms of how electric fields and dust are coupled.

Lunar Dust Transport: Dust is a significant component of the lunar environment that may affect both human health and system reliability [9, 10]. This was made apparent by the discovery of “lunar horizon glow” and “streamers” at altitudes of 10-100 km from orbit during the Apollo missions [11,12] and, more recently, Clementine [13]; as well as photographic evidence of levitated dust at much lower altitudes (<1 m) from the Surveyor 1, 5, 6, and 7 spacecraft [14]. Simple electrostatic levitation may explain some low altitude observations. Dynamic dust motion (“lofting”), on the other hand, may be required to explain observations of high altitude dust concentrations [15].

The Apollo 17 Lunar Ejecta and Meteorite (LEAM) experiment, meanwhile, though designed to measure hypervelocity micrometeorite impacts, instead mostly detected lower velocity (<1 km/s) dust impact, especially near the terminator regions [16]. These data provide compelling evidence for significant horizontal and vertical charged dust transport, raising the spectre of a “dusty sleet” which may persist for days at the surface each month near local sunset and sunrise. The effects of such accelerated dust on ISRU machinery should be carefully considered.

Lunar Dust Properties: Dust is defined as the finest component of the regolith (<100μm). The average lunar regolith grain size is ~70μm (too fine to see with the human eye), with roughly 10-20 weight percent smaller than 20μm [17]. The dust component from Apollo samples contains some grains as small as 0.01μm [18]. Grain shapes are highly variable and can range from spherical to extremely angular; with grains commonly somewhat elongated [19]. The sharp "barbed" shapes of many dust grains enable efficient mechanical adhesion to surfaces.

The low electrical conductivity of the regolith allows individual dust grains to retain electrostatic charge [19], thereby ensuring that the large lunar surface electric fields described above should result in significant dust transport.

Dust Adhesion and Abrasion: During the Apollo missions, dust adhering to spacesuits was a significant problem. Mechanical adhesion was likely due to the barbed shapes of the dust grains, which allowed them to work into the fabric. Alan Bean noted that "…*dust tends to rub deeper into the garment than to brush off*" [20]. Electrostatic effects due to charging of dust by photoionization, plasma current, and/or triboelectric effects likely only exacerbated this situation. It was found that the abrasive effect of adhered dust can wear through the fabric of a spacesuit, drastically reducing its useful lifetime [20, 21].

Problems were also experienced during Lunar Roving Vehicle (LRV) excursions, with dust being kicked up and covering exposed areas, leading to increased friction at mechanical surfaces [19, 21]. The resulting abrasive effect of dust increases wear and tear, significantly limiting the lifetime of surface equipment.

From the recovery and examination of parts from Surveyor 3 during Apollo 12, it was found that dust accumulation and adhesion were greater than anticiapted on both aluminum and painted surfaces [19].

When considering ISRU opportunities, which may require operation of machinery for long periods of time on the lunar surface - machinery which may itself be kicking up large amounts of dust during normal operation – it is therefore important to consider the abrasive effects of dust over time.

Necessary Measurements: So far, most observations of lunar electric fields and dust electrification and charging have been obtained from experiments not specifically designed to address this problem. To fully understand the coupled dust-plasma system around the Moon, it will be necessary to perform specific targeted measurement. Necessary measurements include:

1. Directly measuring electric fields, plasma parameters, and the mass, velocity and charge state of dust grains above the lunar surface.
2. Measuring lunar electric fields as a function of altitude, selenographic location, solar illumination conditions, and plasma conditions, and correlating these observations with dust measurements.
3. Determining the size and concentration of dust as a function of altitude, etc. in the lunar exosphere.

Conclusions: The lunar electrodynamic environment is complex, with plasma, electric fields, and dust tightly coupled. To date, few targeted measurements of this coupled system have been perfomed and our understanding is limited, especially regarding dynamical effects. However, dust is likely to have significant effects on ISRU efforts, particularly since it can become electrified and get accelerated. Therefore, an important step in preparing for ISRU is to close this gap in our knowledge and fully characterize lunar surface charging and dust electrification and transport.

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