LUNAR SURFACE CHARGING: MAGNITUDE AND IMPLICATIONS AS A FUNCTION OF SPACE AND TIME. J. S. Halekas[1], G.T. Delory[1], T.J. Stubbs[2,3], W.M. Farrell[2], and R.P. Lin[1,4], [1]Space Sciences Laboratory, U.C. Berkeley, [2]NASA Goddard Space Flight Center, [3]University of Maryland, Baltimore County, [4]Physics Department, U.C. Berkeley. Corresponding author's e-mail: jazzman@ssl.berkeley.edu.

Introduction: Although some might consider the lunar surface essentially dormant, it is in fact very electrically active, with the Moon's lack of a significant exosphere or global magnetic field leaving its surface exposed to the ambient space plasma environment. The highly variable plasmas encountered by the Moon in the solar wind and terrestrial magnetosphere drive surface charging which varies over orders of magnitude, with surface electrostatic potentials reaching values as large as -5 kV during particularly disturbed conditions. Surface charging depends fundamentally on the properties of both the surface and the ambient plasma, and therefore studying this phenomenon allows us to better understand the lunar regolith, as well as advancing fundamental plasma physics. In addition, surface charging and its likely role in dust electrification and transport may have significant implications for surface exploration and in situ resource utilization (ISRU).

Background: Theoretically, the Moon should charge to small positive values of ~+5-10V on the sunlit hemisphere (where photoemission dominates), and to larger negative values of ~-100V on the shadowed hemisphere (where photoemission is absent, and plasma currents dominate) [1,2]. These expectations have been largely borne out by observations on the surface by the ALSEP package [3] and by electron reflectometry from orbit by Lunar Prospector (LP) [4]. However, LP observations have also revealed that the surface can charge to kV-scale potentials when the Moon encounters energetic plasmas in the terrestrial plasmasheet [5] or during solar energetic particle (SEP) events [6]. Previously, however, the orbital observations from LP have remained relatively uncertain, since the charging properties of the spacecraft were not well understood and analyses utilized relatively simple techniques to remotely infer surface potentials.

New Analysis Techniques and Results: We now present new lunar surface charging results, as a function of both space and time, utilizing improved analysis techniques. A combination of data analysis and modeling have allowed us to self-consistently determine the spacecraft potential in both sunlight and shadow, thereby enabling unambiguous determination of the lunar surface potential, with no offsets. Meanwhile, we have improved our technique for remotely sensing the lunar surface potential, by self-consistently treating ambient electrons reflected by the surface potential and secondary electrons accelerated through the plasma sheath from the charged surface.

Figs. 1 and 2 show examples of our new results. Fig. 1 shows lunar surface charging in the terrestrial magnetosphere, on April 29, 1999. For the first part of this time interval, the Moon is in the very quiet and relatively cool tail lobe region. In the lobe, the lunar surface potential lies close to zero on the sunlit hemisphere, and at -100-200 V on the shadowed hemisphere. However, when the Moon enters the much hotter plasmasheet (at ~19:55, as indicated by the dramatic change in the electron spectrum), the surface potential increases significantly, to ~-500 V. This large negative surface potential persists even in sunlight, but only while the plasmasheet fluxes remain at their highest. When the incident electron fluxes drop slightly, the surface potential returns to a normal sunlit level near zero, before increasing again as electron fluxes increase.

Fig. 2, meanwhile, shows lunar surface charging during a large SEP event, on May 6, 1998. Even during these very disturbed plasma conditions, the lunar potential in the solar wind (corresponding roughly to times in sunlight) remains near zero. However, in the wake (shadow), lunar surface potentials reach the highest values ever measured by LP, of nearly -4 kV, with the largest surface potentials observed in the central wake.

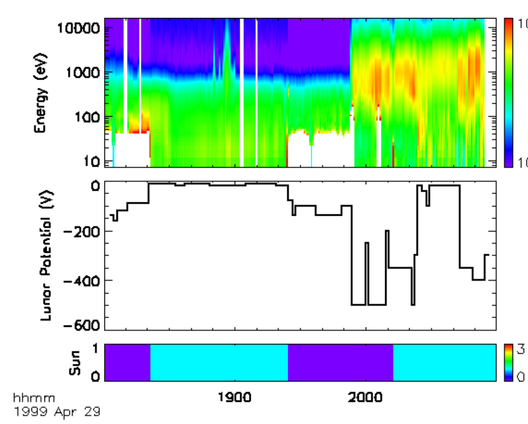

Figure 1: Electron energy spectra and lunar surface potential for two orbits in the terrestrial magnetosphere. Blank regions in the electron spectrogram represent regions of phase space not measured. Color bar shows sun/shadow for spacecraft.

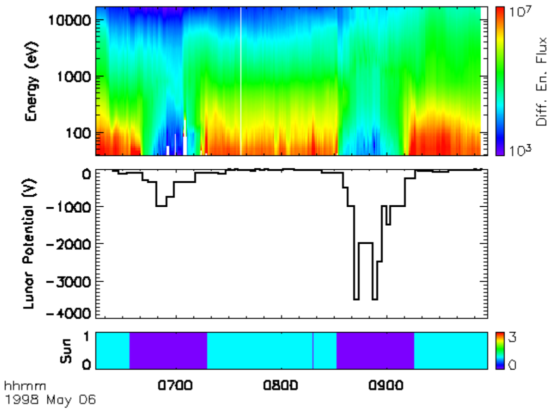

Figure 2: Electron energy spectra and lunar surface potential for two orbits in the solar wind during a large solar energetic particle event.

Scientific Implications: Lunar surface charging depends critically on both the properties of the ambient plasma environment and of the surface regolith. By studying surface charging process, we can better understand a basic space plasma physics phenomenon, with universal applicability for airless bodies in the solar system. However, there is also the promise of better understanding the properties of the lunar surface regolith. For instance, the negative surface charging observed in sunlight in the plasmasheet is unexpected, and may indicate that lunar photoemission is not always as large as predicted by laboratory experiments [5]. Furthermore, by measuring negative charging in shadow, and correlating with incident electron temperature, we can constrain the secondary electron emission properties of the surface. These properties have been measured in the laboratory [7], but we do not know how the lunar regolith actually behaves in situ. Early results of our analyses suggest that the secondary electron emission yield of the lunar regolith may be smaller than predicted. Studies of this kind will allow us to determine how the properties of regolith materials on the lunar surface compare to measurements of lunar samples in the laboratory – in essence, finding ground truth.

Implications for Exploration: In addition to the clear scientific relevance of lunar surface charging, surface electrification also has potentially significant implications for human and robotic exploration and in situ resource utilization. The electric fields themselves may affect machinery on the surface – this process has been demonstrated to be a leading cause of spacecraft failures in space [8]. Surface electric fields had few demonstrably significant effects on the Apollo missions, but these missions were conducted with limited exposure to the terrestrial plasmasheet or SEP events, and astronauts only experienced the lunar surface in the relatively benign surface charging environment in the morning sector, with electric fields therefore expected to remain at relatively low levels. In a more energetic plasma environment, surface electric fields might have more significant effects, especially considering the abrupt changes in surface potential often encountered (e.g. Fig. 1).

In addition, surface electric fields also likely contribute to dust charging and transport. There is substantial observational support for dust levitation a few meters above the surface [9], and some evidence for dust transport to much greater altitudes [10] and highly accelerated dust [11]. Dust was a significant hindrance and hazard for astronauts during the Apollo programs [12], and must be reckoned with in any future exploration plans.

Conclusions: Using new analysis techniques, we characterize lunar surface charging as a function of both space and time. Lunar surface charging is a fundamental space physics process, and its study allows us to both advance plasma physics and better understand the lunar regolith. In addition, lunar surface electrification may be a concern for exploration, both directly and via its effect on lunar dust.

References: [1] Manka R. H. (1973), in *Photon and Particle Interactions with Surfaces in Space*, 347-361. [2] Stubbs T.J. et al. (2007), in *Dust in Planetary Systems*, ESA SP-643, 181-184. [3] Freeman J.W. and Ibrahim M. (1975), *Moon*, 14, 103-114. [4] Halekas J.S. et al. (2002), *Geophys. Res. Lett.*, 29, 10.1029/ 2001GL014428. [5] Halekas J.S. et al. (2005), *Geophys. Res. Lett.*, 32, 10.1029/2005GL022627. [6] Halekas J.S. et al. (2007), *Geophys. Res. Lett.*, 34, 10.1029/ 2006GL028517. [7] Horanyi M. et al. (1996), *J. Geophys. Res.*, 103, 8575-8580. [8] Leach R.D. (1995), *AIAA 1995 Space Programs and Technologies Conference*. [9] Rennilson J.J. and Criswell D.R. (1974), *Moon*, 10, 121-142. [10] McCoy J.E. (1976), *Proc. Lunar Sci. Conf.*, 7, 1087-1112. [11] Berg O.E. et al. (1976), in *Interplanetary Dust and Zodiacal Light*, 233-237. [12] Goodwin R. (2002), *Apollo 17 – The NASA Mission Reports: Vol 1*.