A HELIOPHYSICAL MONITORING NETWORK FOR THE NEAR-SURFACE LUNAR PLASMA AND RADIATION ENVIRONMENTS.

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Introduction: The Moon is perpetually immersed in various plasma environments, irradiated by solar ultraviolet (UV) and X-rays [1,2], and bombarded by highly energetic particles, such as galactic cosmic rays (GCRs) and solar energetic particles (SEPs) [3]. The importance of "space radiation" from GCRs and SEPs is well appreciated, and will be the focus of the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument aboard NASA's Lunar Reconnaissance Orbiter (LRO) [3]. However, recently there has been a growing concern over the effects of the ambient plasma environment and solar UV/X-rays on the near-surface lunar space environment [4,5].

The Lunar Plasma Environment: Observations from Apollo show that the surface of the Moon is electrically charged [6]. The lunar dayside charges to ~ +10 V due to the photoemission of electrons by incident solar UV/X-rays (i.e., loss of negative charge), while the near-terminator region charges to ~ −100 V due to the higher fluxes of fast moving plasma electrons compared with the slower moving plasma ions (i.e., accumulation of negative charge) [1, 2, 6]. More recently, observations from the Lunar Prospector Electron Reflectometer (LP/ER) reveal that the Moon can charge up to ~ −4 kV during SEP events [7].

The near-surface plasma environment is further complicated by the lunar wake and magnetic anomalies. The lunar wake is a "void" that forms downstream of the Moon in the solar wind and is filled with tenuous hot electrons and ion beams [8]. The fundamental plasma processes that form and re-fill the wake are still not well understood [5]. Exactly how solar wind plasma interacts with magnetic anomalies on the lunar surface is very much an open question [5]. It is possible that some anomalies can "stand-off" the solar wind plasma and limit the space weathering of the underlying regolith [9].

Impact on Exploration: Under certain conditions, the resulting lunar surface electric fields could pose electrostatic discharge (ESD) hazards to robotic and human explorers [5]. The greatest ESD risk is anticipated to occur near the terminator and on the nightside, since this is where the extreme lunar charging has been observed, and it is likely much more difficult for objects to reach a common electrical "ground" at these locations.

It is important to appreciate that the Apollo astronauts only experienced the relatively benign lunar plasma environment in the morning sector – well away from the terminator. We also note that the polar sites under consideration by NASA for a future lunar outpost, such as the rim of Shackleton crater, are always in the vicinity of the terminator.

In addition, there is evidence that lunar dust, particularly with radii <10 μm, can become charged and electrostatically transported by the surface electric fields [10, 11, 12]. Apollo astronauts reported having significant problems with lunar dust adhering to suits and equipment and penetrating seals – these problems were likely exacerbated by the electrostatic properties of the dust [13, 14].

Future Measurement Requirements: Our knowledge of how the near-surface plasma environment varies both spatially and temporally is very limited; in fact, the observations currently available are from instruments not specifically designed for that purpose (e.g., Apollo SIDE: characterize lunar atmosphere [6]; LP/ER: map magnetic anomalies [7]). If we are to adequately understand the near-surface lunar space environment and be able predict its behavior, then we require a more comprehensive set of targeted measurements from both orbit and the surface.

Measurement:	**Instrumentation:**
Surface electric fields	Electric fields boom
Plasma characteristics	Electron and ion Spectrometers
Energetic particles	Solid State Telescope
Ion species	Ion Mass Spectrometer
Magnetic field	Magnetometer
Dust mass, velocity and electric charge	Radio Frequency (RF) Detector
Exospheric dust concentrations	Photometer or CCD imager with filters (passive); LIDAR (active)

Table 1: Required measurements and instrumentation for characterizing the lunar plasma and radiation environments.

The benefit of observations from orbit is that they give a global/macro-scale perspective on the lunar plasma environment; whereas, measurements from the surface give insight into the micro-scale processes and provide a "ground-truth". Ideally, observations from orbit and the surface would occur simultaneously, such that the surface measurements could be used to calibrate the orbital observations, which would in turn give context to the surface measurements [14].

Fortunately, the instrumentation required to characterize the lunar plasma and radiation environments, as listed in Table 1, comes with considerable spaceflight heritage, e.g. the Lunar Emissions, Electrons and Dust (LEED) suite concept. The comprehensive set of measurements from these instruments would cover the major "causes" and "effects" in the dynamically coupled lunar plasma-surface-dust system.

At our current state of knowledge, these measurements taken at any point on the lunar surface would significantly advance our knowledge of this environment. Here we discuss the advantages of various locations for making surface measurements:

Equatorial site. This would allow conditions under a full range of solar zenith angles to be investigated from the subsolar point near local noon to the deep wake near local midnight.

Polar site. Currently this location would be most relevant to the objectives of the Vision for Space Exploration (VSE) and astronaut safety. A polar site would permit the active terminator region to be continuously monitored. In addition, we could look for the influence of any nearby permanently shadowed regions (PSRs).

Mare site. Assuming that the surrounding mare region is fairly flat and free of magnetic anomalies, the measurements from this location would be relatively easy to interpret and would provide a valuable test of our basic surface charging models [e.g., 1, 2].

Highland site. This type of site could be used to test for the effects of surrounding topography. Shadowing from nearby topographic features can cause areas of the dayside to charge negative. In addition, it is possible that "mini-wakes" could form downstream of mountains and ridges ("orographic-style" effects) [15].

Geologically active site. There are many sites on the Moon that appear to be geologically active [16], such as those associated with outgassing from the interior, where it would be very interesting to assess the effects on the local plasma environment. For example, it would be fascinating to see if there are any signatures attributable to Transient Lunar Phenomena (TLP) near the Aristarchus plateau [16].

Magnetic anomaly site. This would allow the study of how the plasma and radiation environments are modified by a strong local magnetic field. This has implication for the space weathering of the regolith and the "shielding" of astronauts on the surface [5].

Ideally, we would have various combinations of the above types of locations in order to thoroughly test our understanding of this environment. However, a good start would be to have two stations to compare against each other, one at an equatorial mare location, and the other at a polar highland location. The former will allow us to understand the underlying global scale processes from a surface perspective, while the latter will permit us to investigate topographic effects and the near-terminator region.

Since we would like to observe this environment over the widest range of plasma and solar UV conditions, the longer the stations are operating the better. Heliophysics missions typically fly for at least 2 years, but are often extended to cover a greater fraction of a solar cycle (~11 years).

As mentioned previously, any observations from the surface would be greatly enhanced by complementary observations from lunar orbit, preferably at low altitudes (~20 – 100 km). The Lunar-Solar Interactions Explorer (LuSIE) mission concept would be ideally suited for this purpose.

An upstream monitor in the solar wind, such as the ACE or Wind spacecraft, would be needed to provide data on the inputs the lunar plasma environment.

The lunar topographic data gathered by LRO Lunar Orbiter Laser Altimeter (LOLA) [3] will be vital for providing context and helping with site selection for the network stations. The space radiation data returned by LRO CRaTER will serve as a benchmark for the energetic particles observed at the surface, and will help identify any local sources of radiation.

Conclusions: A heliophysics monitoring network would provide an excellent opportunity to significantly enhance our understanding of the near-surface plasma and radiation environments, and would be extremely valuable to both lunar science and exploration.

References: [1] Manka R. H. (1973) *Photon & Particle Interactions with Surfaces in Space*, 347–361. [2] Stubbs T. J. et al. (2007) *ESA SP-643*, 181–184. [3] Chin G. et al. (2007) *Space Sci. Rev.* [4] *The Scientific Context for Exploration of the Moon: Final Report,* (2007) *NRC* 11954. [5] *NAC Heliophysics Science & the Moon* (2007), NP-2007-07-80-MSFC Pub8-40716. [6] Freeman J. W. and Ibrahim M. (1975) *The Moon*, 8, 103–114. [7] Halekas J.S. et al. (2007) *Geophys. Res. Lett.*, 34, L02111. [8] Farrell W. M. et al. (1998) *J. Geophys. Res.*, 103, 23,653–23,660. [9] Lin R. P. et al. (1998) *Science*, 281, 1480–1484. [10] Rennilson J. J. and Criswell D.R. (1974) *The Moon*, 10, 121. [11] McCoy J. E. (1976) *Proc. Lunar Sci. Conf. 7th*, 1087. [12] Zook H. A. and McCoy J. E. (1991) *Geophys. Res. Lett.*, 18, 2117. [13] Goodwin R. (2002) *Apollo 17: The NASA Mission Reports: Vol. 1.* [14] Stubbs T. J. et al. (2007) *ESA SP-643*, 239–243. [15] Farrell W. M. et al. (2007) *Geophys. Res. Lett.*, 34, L14201. [16] Heiken G. H. et al. (1991) *Lunar Sourcebook: A User's Guide to the Moon*.