White Paper for *Frontiers of Plasma Science Panel*

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Indicate the primary area this white paper addresses by placing "P" in right column.
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	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	S
• Turbulence and transport	
• Interactions of plasmas and waves	P
• Plasma self-organization	
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	"X"
Oral	
Poster	
Either Oral or Poster	
Will not attend	X

Title:	**Plasma-surface interactions of obstacles in flowing plasmas**
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- ***Describe the research frontier*** **and importance of the scientific challenge.**

Airless bodies are ubiquitous in our solar system, including the Moon, most of the planetary moons, asteroids and dormant comets. The surfaces of these airless bodies and their dusty regolith are directly exposed to the solar wind plasma or co-rotation plasmas of their parent planets and solar UV radiation, creating rich and complex surface processes, such as photoemission, backscattering, secondary electron emission, sputtering and the charging of the dusty surface, to name a few. These plasma-surface interactions play an important role in space weathering, exosphere and dust mobilization that ultimately shape the surfaces to how they appear today. However, the exact physics of the surface processes and near-surface plasma environments is not well understood because high-altitude in-situ observations are not capable to address the detailed physical processes at the surface. Research work in this area would mainly rely on laboratory experiments complemented with computer simulations.

In the upstream plasma region, the majority of the plasma is absorbed on the surface. When the bodies are in the solar wind with which the solar UV illumination is aligned, photoelectrons often play a role in the surface charging because of their larger density than solar wind particles. When the planetary moons are in the co-rotation plasmas, the UV illumination has an angle to the plasma flow. The upstream surface charge can be quite different, depending on the angle. In contrast to upstream surfaces, the downstream region holds a vastly different plasma environment. Here, a tenuous plasma void (wake) is created. The wake physics has been addressed by many ways, including theories, laboratory and in-situ experiments. A basic picture is as follows. When the surrounding plasma refills the wake, the much more mobile

electrons move inwards ahead of the ions, producing an ambipolar electric field (because of charge separation) that accelerates ions and decelerates electrons into the wake. The counter-streaming ions across the wake can create instabilities, slowing ions to remain in the wake. However, the charge/potential distribution on the surface and the sheath structures above the surface in the wake region remains unknown. In general, the surface is expected to be charged highly negative by thermalized electrons but the secondary electron emission may play a role in the current balance. At the boundary between the upstream and downstream regions, a so-called terminator region is expected to have a large charge difference and thus to be a favorable place for the dust to be lifted off due to electrostatic forces. Also atoms/molecules released from the surfaces by ion sputtering will replenish their exospheres.

In addition to the plasma interactions with the surfaces of the global bodies described above, there are also many localized interactions on the surface. For instance, several simulation studies [1, 2] have shown that so-called mini-wakes can form inside the craters in which the wake is half-bounded by the crater floor. Recently, plasma interactions with lunar crustal magnetic fields have attracted significant interest because their consequences are found to be correlated with high-albedo swirl-shaped markers on the lunar surface [3]. The solar wind plasma can be stood off by the strong magnetic anomalies from space weathering the surface in these regions [4]. The surfaces in intermediately strong anomalies may also be charged by unmagnetized ions while the electrons are magnetically shielded away to a much larger positive potential than the typical photoemission-dominated levels of several volts [5].

Electrostatic dust lofting and transport are long-standing problems that have been suggested to be responsible for several observed phenomena on the surfaces of airless bodies, including the lunar horizon glow [6], the dust ponds on asteroid Eros [7], and the spokes in the Saturn's rings [8]. It may also be partially responsible for recent Rosetta observations of the high-density of fluffy dust particles in the vicinity of Comet 67P/Churyumov–Gerasimenko [9]. It remains unresolved how dust particles collect sufficient charge and become electrostatically lofted and moved on these surfaces. In the past years, laboratory experiments have demonstrated that dust particles do become mobilized and even lofted when exposed to plasmas [10, 11]. Although a charge fluctuation model [12] was developed, no existing theoretical models can fully explain either the laboratory or the in-situ observations, leaving the exact mechanisms for electrostatic dust mobilization a mystery.

In summary, plasma-surface interactions of airless bodies and their dusty regolith are very dynamic and are both important in basic plasma physics and planetary and geological sciences.

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

In order to characterize the detailed plasma dynamics around an obstacle in a flowing plasma, high measurement spatial resolution is needed, which thus requires a large-scale plasma chamber (Fig. 1 as an example). The chamber should consist of three sections in general: an ion gun, a small pressure differential chamber and a main experimental chamber. The small differential chamber is used for maintaining a good vacuum (less than 10^{-5} Torr) in the main experimental chamber in order to reduce charge-exchange ions. Obstacles with various geometries will be inserted in the simulated plasma flow and illuminated with the UV lamps for creating photoemission from the surfaces. The surface charge/potential can be measured with segmented conducting sheets attached to the surfaces of the obstacles. Diagnostic probes can be installed on a two-axis translation stage. A good camera system that is capable to image micron-sized dust particles is needed for recording dust trajectories. Computer simulations with the capability to handle the charge on surfaces need to be developed.

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit.***

This research work has the impact on space plasmas, planetary and geological sciences (e.g., space weathering, exosphere and dust mobilization) and basic plasma physics (e.g., the plasma wake). It will largely improve our understanding of the fundamental physics of the charging of dust on surfaces and will thus help to resolve the long-standing mysteries of electrostatic dust lofting and transport on airless bodies.

References (Maximum 1 page)

[1]. Farrell, W. M., T. J. Stubbs, J. S. Halekas, R. M. Killen, G. T. Delory, M. R. Collier, and R. R. Vondrak (2010), Anticipated electrical environment within permanently shadowed lunar craters, J. Geophys. Res., 115, E03004, doi:10.1029/2009JE003464.

[2] Zimmerman, M. I., W. M. Farrell, T. J. Stubbs, J. S. Halekas, and T. L. Jackson (2011), Solar wind access to lunar polar craters: Feedback between surface charging and plasma expansion, Geophys. Res. Lett., 38, L19202, doi:10.1029/2011GL048880.

[3] Hood, L. L., and G. Schubert (1980), Lunar magnetic anomalies and surface optical properties, Science, 208, 49–51, doi:10.1126/science.208.4439.49.

[4] Deca, J., A. Divin, G. Lapenta, B. Lembège, S. Markidis, and M. Horányi (2014), Electromagnetic Particle-in-Cell Simulations of the Solar Wind Interaction with Lunar Magnetic Anomalies, *Phys. Rev. Lett*., 112, 151102, doi: 10.1103/PhysRevLett.112.151102.

[5] Howes, C. T., X. Wang, J. Deca, and M. Horányi (2015), Laboratory investigation of lunar surface electric potentials in magnetic anomaly regions, Geophys. Res. Lett., 42, doi:10.1002/2015GL063943.

[6] Zook, H.A. and J.E. McCoy (1991), Large-scale lunar horizon glow and a high altitude lunar dust exosphere, Geophys. Res. Lett., 18, 2117-2120.

[7] Robinson, M.S., P.C. Thomas, J. Veverka, S. Murchie, B. Carcich (2001), The nature of ponded deposits on Eros, Nature 413, 396–400.

[8] Mitchell, C.J., M. Horanyi, O. Havnes, and C.C. Porco (2006), Saturn's Spokes: Lost and Found, Science, 311, 1587.

[9] Schulz, R. et al. (2015), Nature, 518, 216-218, doi:10.1038/nature14159.

[10] Wang, X., M. Horányi, and S. Robertson (2010), Investigation of dust transport on the lunar surface in a laboratory plasma with an electron beam, J. Geophys. Res., 115, A11102, doi:10.1029/2010JA015465.

[11] Flanagan, T. M. and J. Goree (2006), Dust release from surfaces exposed to plasma, Phys. Plasmas 13, 123504.

[12] Sheridan, T., and A. Hayes (2011), Charge fluctuations for particles on a surface exposed to plasma, Appl. Phys. Lett., 98, 091501, doi:10.1063/1.3560302.

Figures (maximum 1 page)

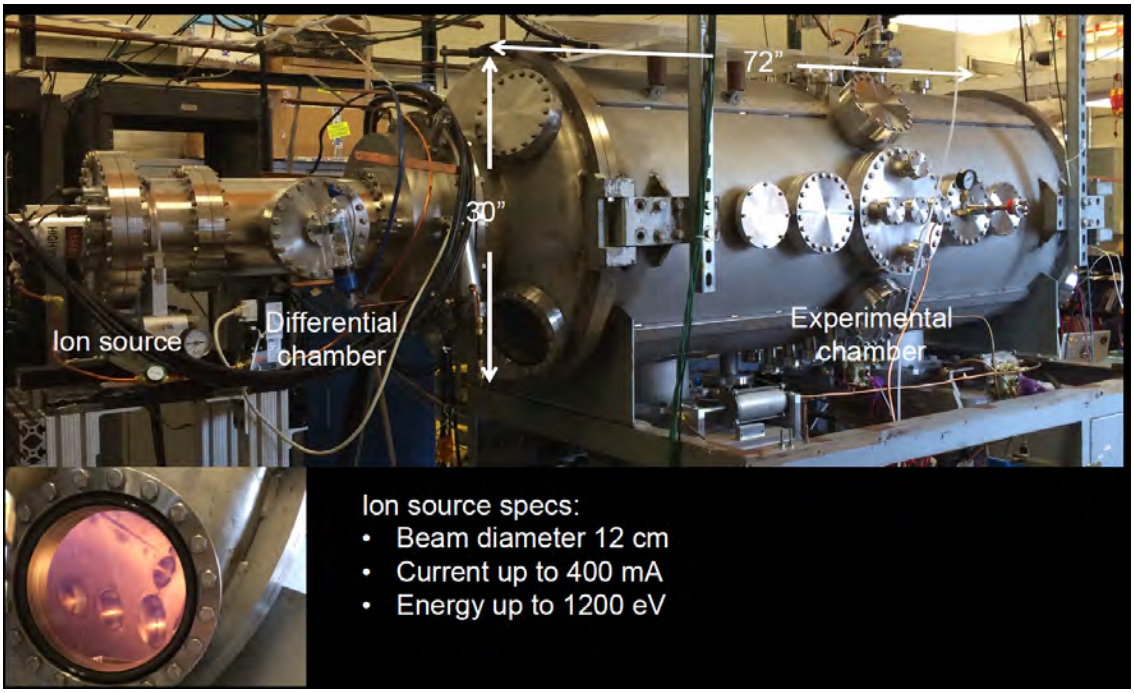

Fig. 1 The solar wind plasma simulation chamber at the University of Colorado - Boulder.