LUNAR POLAR CRATER EXPLORATION: ELECTRICAL GROUNDING IN AN ELECTRON CLOUD

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Introduction: Exploration of the lunar polar regions is of interest due to the possible stores of water ice. A new model validates the possibility of a pure electron plasma populating shadowed craters on the Moon. Formed in the wake of the solar wind as it flows over a topographic obstacle, this electron cloud region of negative space charge is unlike any familiar terrestrial environment. In the context of exploration, electrical grounding in a region devoid of positive charges can be potentially problematic for EVA equipment such as astronaut suits and rovers. We present new results pertaining to the lunar polar environment, and a preliminary study of its impact on future exploration missions.

Electron cloud presents novel physics environment: Typical plasma consists of roughly equal parts electrons and protons. Non-neutral plasma confinement over large length and time scales is uncommon. A steady-state electron cloud, spanning hundreds to thousands of meters, presents a unique and novel environment for exploration.

A laboratory example of an electrostatically confined electron plasma, called an electron sheath, is formed at the plasma interface of a positively charged surface. Two key features differentiate the presently studied electron cloud from an electron sheath: (i) The electron cloud can be much larger than the typical Debye length scale for plasma charge shielding, and (ii) the electron cloud produces a *negative* floating potential at the surface.

The physics of the lunar crater electron cloud can be explained by the following mechanism: Under typical conditions at 1 AU, the electron thermal speed (~1400 km/s) is much faster than the solar wind flow speed (~400 km/s), which is in turn much faster than the proton thermal speed (~32 km/s). The separation of timescales associated with these different speeds produces a situation where, as the solar wind flows over a shadowed crater, a fast electron wake fills the crater while a slower proton wake expands farther downstream. The result – depicted in Figure 1 – is a substantial electron cloud region, which is maintained in steady-state as long as there is a constant flux of solar wind. Thus the separation of time scales translates in steady-state to a distinct spatial separation.

This unique plasma wake structure may influence a variety of lunar surface processes, including dust transport, surface sputtering, and distribution of volatile materials.

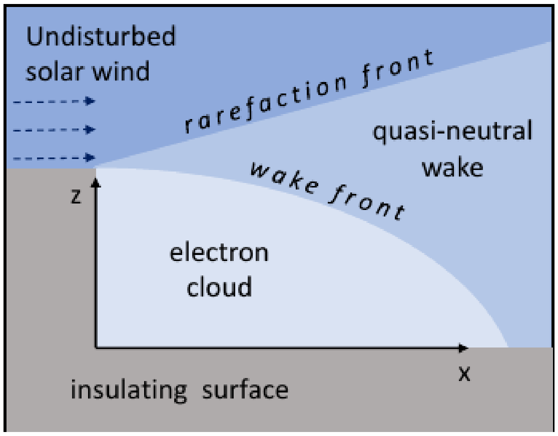

Fig. 1: The solar wind plasma wake in a lunar polar crater.

New formulation extends plasma wake model to include the electron cloud: Existing models of this process focus primarily on the ion wake, which can be approximated by a self-similar plasma expansion process [1]. The cavity formed interior to the ion wake, however, is yet to be properly addressed. Our model helps explain the results of existing plasma simulations [2], which predict a substantial region of negative space charge beyond the ion wake front.

In the new formulation, the structure of the electron density and electrostatic potential is determined analytically by the steady-state boundary conditions. At the upper boundary, where the electron cloud interfaces with the quasi-neutral plasma, flux conservation requires continuous electron density. The lower boundary consists of an insulating surface which develops a negative floating potential to repel the incoming electrons. The simple 1D model for the vertical plasma distribution is combined with a uniform horizontal speed to form the 2D wake structure.

In addition to its explanatory power, a major advantage of the new analytic model is its fast computation rate in comparison with the aforementioned simulations. Preliminary calculations below show good qualitative agreement with the simulations from Reference [2].

Preliminary results show good qualitative agreement with previous studies: As an illustrative case, we present the resulting plasma wake structure for a flat 500m-deep crater. The nominal electron density and temperature of the undisturbed plasma are taken to be 5×10^6 m^{-3} and 11eV, respectively.

Figure 2 below shows the electron density throughout the wake region. The distribution is continuous across the quasi-neutral wake front (solid line), as well as across the wake rarefaction front (dashed line). Owing to the ambipolar potential, the density is observed to decrease by two orders of magnitude, from ~10^6 to ~10^4 particles per cubic meter.

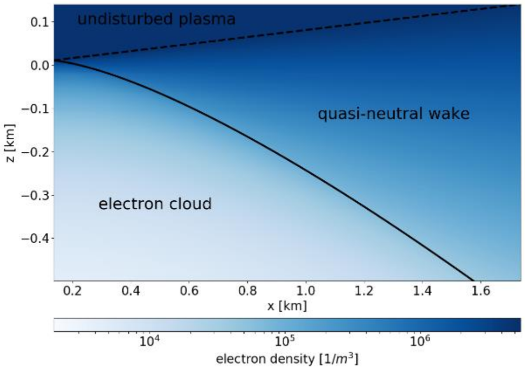

Fig. 2: Electron density distribution.

The corresponding electrostatic potential (Figure 3) shows a floating potential of -77V at the crater floor near the base of the crater wall, and diminishes toward the ion front.

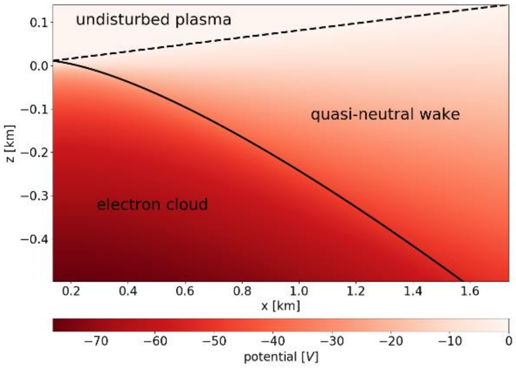

Fig. 3: Electrostatic potential distribution.

Figure 4 emphasizes the unique feature of the electron cloud, namely its extended space charge region, which is uncommon in typical plasma.

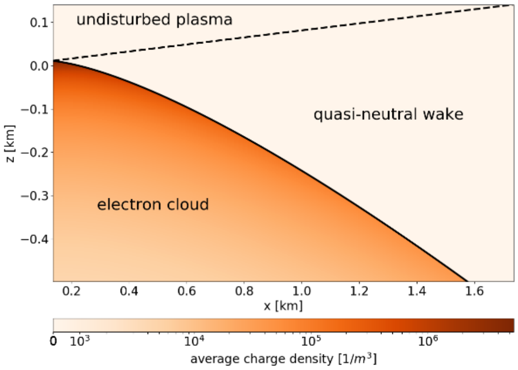

Fig. 4: Average charge density distribution.

Qualitatively similar figures were produces by the simulations in Ref. [2], but with a somewhat more negative surface potential and corresponding density profile. This discrepancy can be explained by the fluid nature of the present model, which neglects the suprathermal electrons which overcome the potential barrier and strike the surface, building up additional surface charge. Incorporation of this effect is a work in progress.

Simulations examine the dynamic charge accumulation/dissipation on roving astronauts: Electrical grounding is challenging for EVA equipment in airless environments. Local charge can build up to high levels in the absence of ambient air (charge exchange), in particular where there is no direct sunlight (photoemission). This charge buildup could lead to an electric discharge hazard for equipment.

These conditions exist to a limited extent on the ISS and other spacecrafts. On the Moon, however, much larger charge accumulation can occur over the course of an EVA mission, as static electricity is generated by walking/driving along the surface (tribocharging) [3]. Since the surface of the Moon is a very good electrical insulator, the only source of charge dissipation at a shadowed crater surface is the tenuous plasma.

Previous lunar missions avoided the challenge of electrical grounding by remaining in direct sunlight and solar wind flow. Future missions to the lunar polar regions may face steady-state electron cloud conditions. Furthermore, missions of longer duration may face temporary electron cloud regions anywhere along the lunar terminator, lasting as long as the solar wind flows approximately horizontally above the surface, with residual surface charge remaining until the return to daylight.

The extent, distribution and effect of charge accumulation is a complex problem, depending upon the materials and structure of the EVA equipment – e.g. space suit or rover – as well as the surface material, and of course the plasma environment. Advanced simulations of the process are underway.

References:

[1] Farrell, W. M., T. J. Stubbs, J. S. Halekas, R. M. Killen, G. T. Delory, M. R. Collier, and R. R. Vondrak (2010), JGR, 115 (E3). [2] Zimmerman, M. I., W. M. Farrell, T. J. Stubbs, J. S. Halekas, and T. L. Jackson (2011), GRL, 38 (19). [3] Jackson, T. L., W. M. Farrell, R. M. Killen, G. T. Delory, J. S. Halekas, and T. J. Stubbs (2011), JSR, 48 (4).