MAPPING THE SURFACE POTENTIAL AND ION FLOW IN THE LUNAR SOUTH POLAR REGION.

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Introduction: The solar wind is a collisionless plasma that is directly incident onto the lunar surface. The plasma, at nominally 5 particles/cm^3 and a speed of 400 km/sec, can be thought of as an electrical 'fluid': any separation between the electrons and ions of the plasma gives rise to a resorting electric field that will attempt to maintain the charge-neutral state of the ionized gas. Thus, pressure gradients from collisions do not maintain the fluid nature – electric forces instead that play that role.

At the lunar terminator and polar regions, the solar wind bulk ion flow is primarily horizontal over the lunar surface. Local topography then acts to block or obstruct the plasma as it flows – creating voids in the solar wind fluid immediately downstream of the obstacle (south polar mountain or crater).

Since the plasma is collisionless, there is not a gas pressure to 'push' the plasma into the voids. Instead, due to their intrinsically higher thermal velocity, the low-mass electrons move into the void ahead of the ions. The electron-ion charge separation at the flanks of the void creates an electric field that then acts to divert the solar wind ions into the void. Thus, via electrical forces, the void in the plasma fills in. The lack of plasma in these voids increases electrical dissipation times for roving/drilling human systems and affects local plasma sputtering in the void regions.

The plasma expansion process is known to operate at the large (global) scale in the plasma void created downstream of the Moon itself [1]. Since the process is 'self-similar' and can act at small scales as well, it is expected to act on regional and local scales over local south polar topography [2-5] (Figure 1).

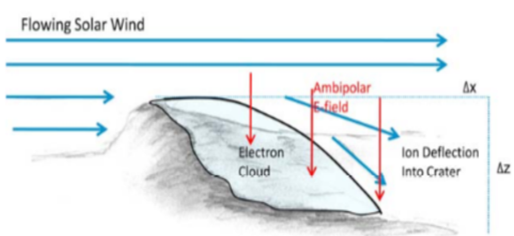

Figure 1. An illustration of the plasma expansion process over local topography at the south pole [2].

It was analytically demonstrated [4] that the many local obstructions and wakes that form across the terminator topography (maintains, craters) at 10-100 km scales merge seamlessly into the larger global Moon-scale expansion at scales of 1000-10000 km.

Instantaneous Local Mini-Wake Formation: Over the course of a lunation, the solar wind will flow overtop a polar crater or about a polar mountain in a direction that is defined by the local sun angle. There is thus an instantaneous solar wind flow-obstacle configuration. For example, in Figure 1, the solar wind is flowing from left to right, but ½ of a lunation later, the solar wind flows in the figure from right to left.

Consider a case where the solar wind flows horizontally overtop a polar crater located at the south pole. As described, the plasma will expand into the crater due to the migration of electrons into the void. There are two electrostatic potentials that define this expanding plasma [2, 5]: (1) The 'ambipolar' or expansion potential associated with the E-field that is acting to divert/deflect the ions into the void and (2) the near-surface plasma sheath potential defined by those electrons and ions involved in current balance right at the crater floor. The density, n, of the expanding plasma in the crater is less than that in the solar wind, n_o, with the density reduced by $n/n_o \sim \exp(e\Phi_A/kT_e)$, with Φ_A being the ambipolar potential and T_e being the electron temperature.

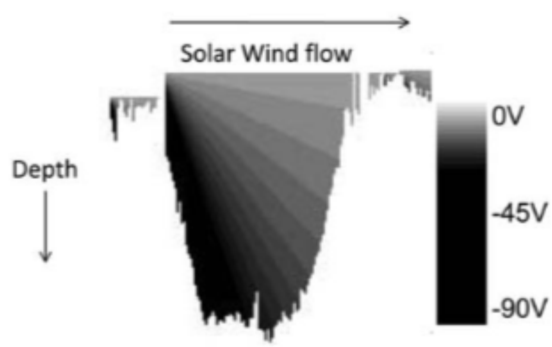

Figure 2. The modeled plasma expansion potential in Shoemaker Crater [2].

Figure 2 shows the ambipolar or expansion potential, Φ_A, in Shoemaker crater for a solar wind of 5 particles/cm^3, flow speed of 400 km/sec, and 10 eV electron temperature using analytical expressions in [2]. Along the leeward edge of the flow, the ambipolar potential is close to -90 volts. Thus, the plasma density in this part of the expansion is reduced by ~ 10^4 compared to solar wind values.

Given the analytical expressions for the plasma expansion and surface potential [2,5], maps of the instantaneous surface potential can be generated assuming a specific solar wind ion flow direction (i.e., for a given sun angle) – like that shown in Figure 3.

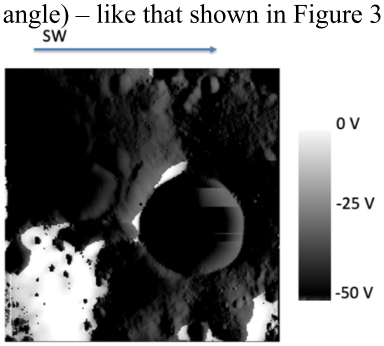

Figure 3. The modeled surface potential around Shackleton crater for a west-flowing solar wind. White regions/positive surface potentials are located in sunlit regions (created via surface photoelectron emission). Dark regions/negative surface potentials are located in shadowed regions behind obstacles where the plasma expansion process is operating.

Besides analytical calculations, particle-in-cell plasma simulation codes (Figure 4) were developed to model this plasma expansion into polar craters – providing substantiation for the development of mini-wakes in local topography.

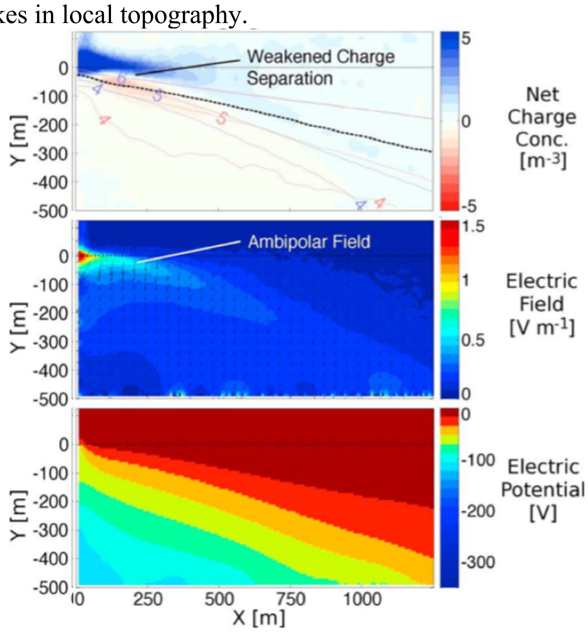

Figure 4. The particle-in-cell code model result for the plasma expansion into a modeled crater of 500-m depth (steep wall located at the left edge, plasma flowing from left to right). Note the development of large negative surface potentials exceeding -100V [3].

Integrated Solar Wind Ion Inflow. The integrated ion flux to the south polar crater floor has also been recently calculated over a lunation [6]. At any instant, the leeward crater wall obtains the least influx, while the windward or far crater wall obtains a near full solar wind ion influx. The crater floor has an overall lower flux. Over a lunation, the leeward and windward walls reverse positions in the flow, but the floor in the central region of the crater still obtains relatively low solar wind ion influx in the expansion process. Figure 5 shows the lunation-averaged solar wind ion influx (via the expansion process [5]).

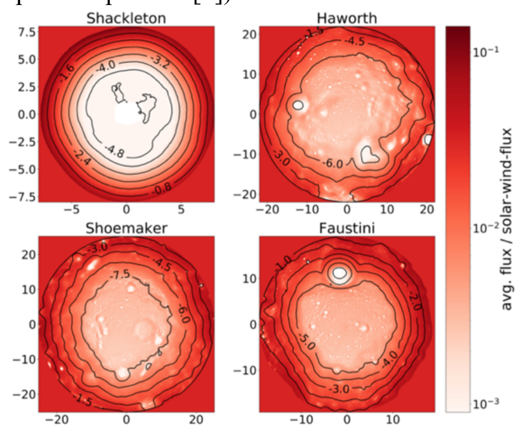

Figure 5. Solar wind ion influx into south polar craters [6].

As indicated in these crater maps, Shackleton crater gets very little solar wind ion influx to its floor (almost 1000 times less compared to the unobstructed flux). We thus expect the sputtering loss rate of surface volatiles to be greatly reduced in this crater compared to the others. We also note that local 'craters-in-craters' located within Haworth and Faustini have greatly reduced time-integrated ion inflow resulting in a decreased plasma sputtering loss rates in these features.

Applications. Maps of the surface potentials are indicative of the local plasma available for removing any charge buildup on human systems. Dissipation times are expected to be longer within plasma-starved polar craters [2]. Maps of ion influx into craters are used to estimate the plasma sputtering loss rates for use in understanding the lifetimes of the icy-regolith found on south polar crater floors.

References. [1] Ogilvie, K. W., et al. (1996), Geophys. Res. Lett., 23, 1255-1258. [2] Farrell W. M. et al. (2010), J. Geophys. Res., 114, E03004. [3] Zimmerman, M. I. et al. (2011), Geophys. Res. Lett., 38, L19202. [4] Zimmerman, M. I. et al. (2013), Icarus, 992-998. [5] Rhodes, D. J. and W. M. Farrell (2019), J. Geophys. Res., 124, 4983-4993. [6] Rhodes, D. J. and W. M. Farrell (2020), Solar wind hydrogen flux in lunar south-pole craters, in prep.