ELECTROSTATIC TRANSPORT OF LUNAR DUST: PRELIMINARY EXPERIMENTAL OBSERVATIONS. J. Marshall[1], S. Davis[2], and J. Laub[1], [1]SETI Institute, 515 N. Whisman Rd., Mountain View, CA 94043; jmarshall@seti.org, [2]NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035; sdavis@mail.arc.nasa.gov.

A lunar dust laboratory has been established in the Space Science Division at NASA Ames to evaluate fundamental electrostatic processes at the Moon's surface. Photoelectric charging, triboelectric charging, and interactions of these processes are being investigated for dust-size materials.

The first experiments were conducted in a large belljar system, capable of moderate vacuum conditions. The experiments involved tribocharging of dust in a simulation of anthropogenic interaction with the lunar surface (construction of habitats, vehicular activity, mining, etc). An electric field simulating the solar-plasma induced E-field of the lunar surface was created with parallel charged capacitor plates of 25 cm diameter; the field is linear, but field-shaping to create lunar-like exponentially decaying E-fields will be conducted in the near future. Small amounts of test materials were placed on a vibrating cup that rested on the lower capacitor plate –essentially mechanically decoupled from the plate, but providing E-field continuity across the cup. Agitation of the dust samples was induced by a vibrator suspended below the plate.

Preliminary tests have produced electrostatic levitation of 1-2 μm ballotini with a density of 2.5 g/cc and a lunar simulant JSC-1AF, comprised essentially of crushed basalt with a density of about 3.0 g/cc. The applied vibrational tribocharging in vacuum achieved approximately 0.1 to 0.15 of the Gaussian Limit (GL defined as 1.0 for air/1 bar); the threshold for levitation occurred at a field strength of 2250 V/m, corresponding to only a few hundred (negative) charges per particle. This field strength drops to 375 V/m when gravitationally scaled for the Moon, while dust tribocharging to GL >1.0 (possible in harder vacuum) lowers the levitation threshold to only a few tens of V/m or less. It seems possible that anthropogenic disturbance of lunar dust could potentially pollute the lunar environment with levitated particles and severely impair scientific experiments requiring a pristine lunar exosphere (such as telescopic investigations). Tests are currently underway to define the lowest field strength that will induce dust levitation from tribocharging.

Levitated dust samples were caught on the upper plate by a carbon adhesive pad that was attached to an SEM (scanning electron microscope) stub. After a test, the stub could be removed and taken directly to the SEM. From these microscope observations, it was ascertained that the ballotini levitated generally as small aggregates, although there was also levitation of single particles (Figure 1). Clusters as large as 16 ballotini were observed. Lunar simulant with a large size range (submicron to ~100 micron) also showed a tendency to levitate as small clusters, although less pronounced (Figure 2). Particles as large as 60 μm were levitated in the field strengths noted above. Therefore, it is not just dust that can be levitated in moderate fields. Sixty microns is sand-size material.

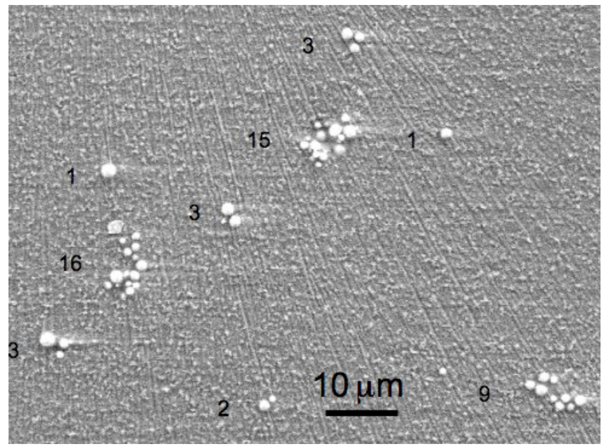

Figure 1: *Levitated ballotini aggregates caught on a carbon-coated SEM stub. Numbers indicate cluster sizes.*

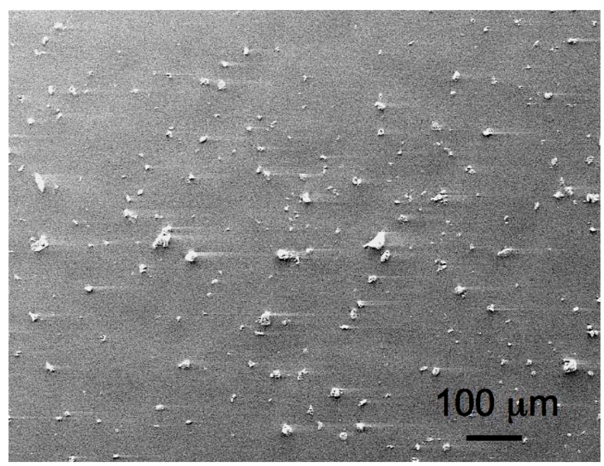

Figure 2: *Levitated lunar simulant JSC-1AF. Note scale bar compared to Figure 1.*

In addition to levitation of particles, a process of "fountaining" was also observed for the ballotini. Large clusters of particles, visible to the naked eye, and comprised of hundreds/thousands of individual 1-2 μm ballotini, were projected upwards several centimeters from the vibrating bed of material. Their trajectories were ballistic, leading to the clusters falling back to the bed. It is suspected that these were van der Waals clusters, but fountaining was not observed for the lunar simulant.

A particle will levitate when the upward force F_2 exceeds the downward force F_1, i.e., when

$$q.E > m.g$$

where q is charge on the particle (C), E is the electric field (V/m), m is particle mass (kg), and g is gravitational acceleration (m/s^{-2}). The threshold of motion is defined as $q.E \cong m.g$. Note that this relationship does not take interparticle cohesion into consideration. So, a better relationship to define the levitation condition is:

$$F_2 > F_1 + F_3$$

where F_3 is the interparticle force due to electrostatic and/or van der Waals (vdW) forces. F_3 is currently undefined, and we do not know the extent to which F_2 exceeds F_1+F_3. Some assumptions can be made. We observe that the levitated particles continue to adhere to the upper plate even after the plate potential is switched off (on a non-adhesive surface). And the adhesion continues for longer than the expectancy for charge retention. It can therefore be assumed that the vdW force is responsible, as confirmed by the fact that the particles were not displaced in the presence of an AC corona generated by a Tesla coil. So the force that has to be overcome to cause levitation has to be greater than the weight plus adhesion forces, or > 2 F_l. Hence:

$$F_2 \geq 2 F_1$$

The net upward force on a particle ***once it has lifted*** is therefore approximated by:

$$F_2 - F_1 = 2F_1 - F_1 = F_1$$

In other words, we can expect a net lofting acceleration for a particle to be approximately equal to -10 $m.s^{-2}$ (under 1 g conditions).

The balance of forces for a particle to have a ballistic (fountaining) trajectory, as opposed to a lofting trajectory (where the particle continues to accelerate unless the field strength diminishes with height) becomes :

$$F_e + F_i \geq F_r \quad \text{(by definition, } F_e < F_r\text{)}$$

where subscripts e = electric field, i = impulse, and r = resistive. The impulse force on the left side of the equation causes lift-off of the large aggregates. The impulse force is electrostatic in nature, but one in which the causative charge is not carried with the grain once it lifts (otherwise it would have a lofting trajectory).

Future work will include an upgrade of the chamber since the vacuum of belljar systems is limited by the jar seal. The new chamber will also incorporate flat windows to enable undistorted imaging. A high-speed, high-magnification camera system is currently being acquired so that levitated particles can be imaged in flight. Science investigations will extend to photo-charged dust using UV irradiation of the test bed, and combinations of photocharging and tribocharging effects. Electrostatic transport of dust at the Terminator is of particular interest. In order to better simulate the surface E-fields of the Moon, we will install parallel curved capacitor plates. These produce an inhomogeneous, exponentially decaying field away from the lower plate, the rate of decay being a function of plate curvature. It is hoped that this will enable particles to be trapped in a levitated layer as gravity comes into balance with lift forces somewhere midway between the plates. Such experiments are intended to determine if the dust forms a discrete hovering layer or a continuous cloud varying in particle size with height, if there is hunting of the particles attempting dynamic equilibrium, and if there are triboelectric consequences of colliding particles.

It is also planned that the facility will serve for calibration of scattering measurements conducted remotely for the lunar exosphere, as well as serving as a test facility for lunar instrument/sensor development related to both orbital and landed missions.