Determining Diagnostic Capabilities of Dust by Exploring Lunar Swirls

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Introduction: First observed by the Surveyor missions and later the Apollo astronauts, a glow above the lunar horizon created by the refraction of light through a cloud of dust particles can be seen just before the sun rises into view over the silhouette of the moon. The understanding of the mechanics behind this "Lunar Horizon Glow" is fascinating from a scientific perspective. More so, it may also provide a critical clue to determining the role that dust will play in the daily environment of future lunar missions as it is lofted by human activity. In prior modeling and experimental work, it is argued that the glow originates from lunar regolith levitating off the surface of the moon due to photoelectric charging effects. In addition, the presence of lunar swirls like the Reiner Gamma formation shown in Figure 1 not only suggests that these levitating charged dust particles exist but may stay charged long enough to interact with residual magnetic fields as they fall back to the lunar surface. Although there is little modeling experimental data to explain the physical processes at play, what does exist suggests that the field of dusty plasma is well suited for the task of exploring the underlying physics. This project examines lunar simulant lofting under varying experimental conditions and a second series of charging mechanisms. Inspired by the above, experiments will investigate plasma at higher pressures to determine the viability of using dust to diagnose other environments such as those observed in Ion engines or the upper level of planetary atmospheres.

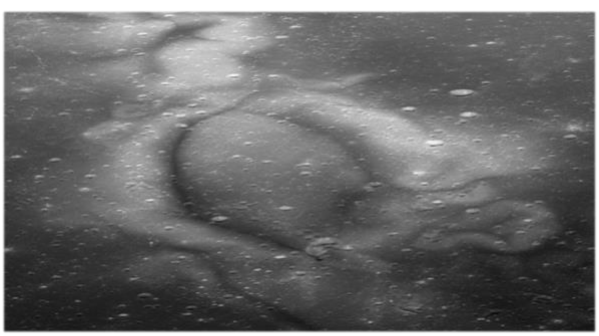

Figure 1: Lunar swirls. Reiner Gamma Formation [1]

Experimental Facility: All experiments took place at CASPER's Dusty Plasma facility using a GEC RF reference cell. This device provided a wide variety of charging environments and pressures.

Experiment: The setup consisted of a plate with a 5mm circular indentation in the middle. JSC-1 lunar simulant is placed into this indentation and exposed to vacuum conditions. This plate was placed directly on top of the lower electrode. The experiment's pressures ranged between 20 mTorr and 200 mTorr, while powers were limited to between 0 Watts & 20 Watts. The dust was lofted using a signal generator and an amplifier connected to the bottom electrode, thereby establishing a controlled bias on the plate. The signal generator supplied a 10 Hz square wave signal and the bias applied to the plate oscillated as a square wave signal between 0V and -2V. A lamp and diffusive barrier provided backlighting for the JSC-1 particles.

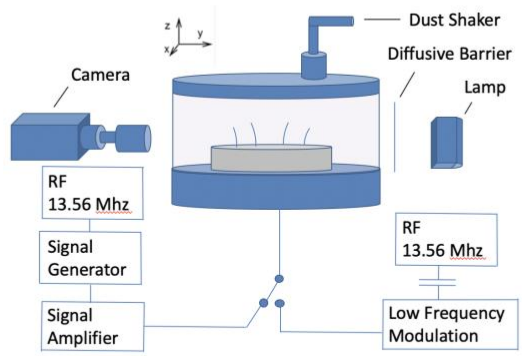

Figure 2: Experimental Setup

When the signal generator was switched on, a 2.5 second video was recorded. The background was then subtracted and the particles tracked individually using a program called "Tracker" [4]. Also, a coffee grind distribution app was used to approximate particle size [3]. Two regimes were examined:

Triboelectric charging. Collecting charge on particles by mixing them into the indentation on the plate was attempted. Efforts were made to shorten the time between runs so that the particle charge did not change appreciably during the experiment.

Plasma. For experiments with plasma present, the dust was allowed to sit overnight in the cell at a high vacuum to de-charge. A generated plasma then became the primary charging source. Both power and pressure were then varied between runs. Additionally, a magnet formation was placed underneath a dust pile, lofting attempts made, and a pattern on the glass plate observed.

Results Summary:

Triboelectric charging. Plasma was not ignited for this set of experiments. Dust was placed into the cell immediately after being deposited onto the disk and the chamber evacuated. When the lower electrode's bias turned on, a high degree of lofting was observed as shown in Figure 3 below. As time passed, less and less lofting was observed until hardly any occurred. However, several runs were performed before having to open the cell and stir the particles.

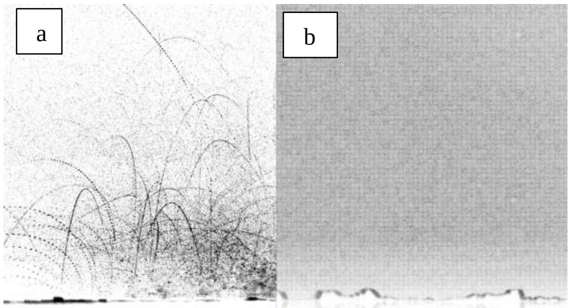

Figure 3: No Plasma. Pressure: 100 mTorr
a.) Fresh pile in crater b.) Pile left overnight

Due to the absence of plasma, it is assumed that charging was primarily triboelectric.

Plasma. The pressure was varied while the power remained fixed at 20 Watts. A sample of the particle velocity data is shown in Figure 4.

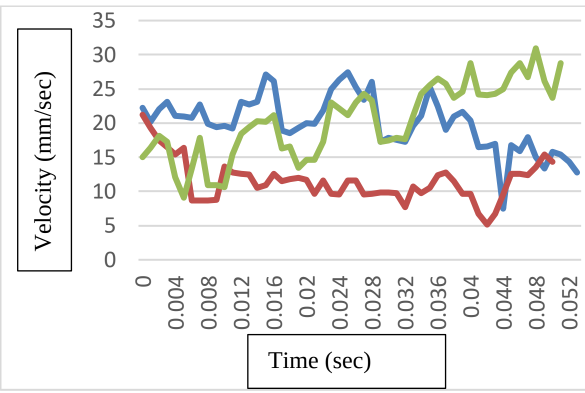

Figure 4: Comparison between lofted particles at 80 mTorr (Blue), 60 mTorr (Green), and 20 mTorr (Red)

As shown, particles behaved differently as they moved through the plasma sheath.

Finally, the Reiner Gamma inspired magnet formation created by 27 N40 magnets [5] was placed in the cell. The chamber's pressure was set to 100 mTorr and the power set to 20 Watts. After several experiments, the plate was removed and the glass cover examined. Clear distribution patterns were visible, indicating that the lofted dust did indeed interact with the magnetic field. A before and after example is shown in Figure 5, which can be compared with Figure 1.

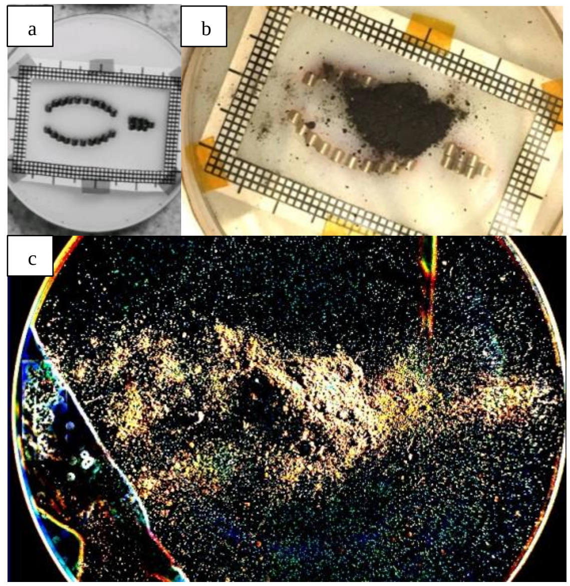

Figure 5: a.) Reiner Gamma formation plate [2] b.) Dust pile on glass plate before lofting runs c.) Dust pile on glass plate after lofting runs.

Conclusion: As shown, tracking the regolith lofted from the lunar surface could provide important information about both the lunar surface and the dust mitigation process.

However, several steps need to be taken to continue this project. First, the existing data should be compared with previous experimental and numerical results and verified against existing models. Second, a way to control triboelectric charging and (or perhaps create it without breaking vacuum) needs to be developed. Third, additional experimental data is necessary, including magnet formation runs at varying parameters. Lastly, the development of scaling techniques is essential to forecast what may be seen on the moon. Each of these will be examined in the future.

Acknowledgments:
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References:[1] Brett Denevi, Mark Robinson, et al. "The Distribution and Extent of Lunar Swirls," Icarus No. 273, Page 53-67 [2] Dropmann, Michael; Laufer, Rene; et al. "Analysis of magnetic field plasma interactions using microparticles as probes" Baylor University, 26 Aug. 2015 [3] Gagne, Jonathan, "**An App to Measure your Coffee Grind Size Distribution**" https://coffeeadastra.com/2019/04/07/an-app-to-measure-your-coffee-grind-size-distribution-2, Accessed 10/2020 (Special thanks to Luke at Pinewood Coffee Shop in Waco Texas who recommended this app.) [4] "Tracker (Video Analysis and Modeling Tool)," https://physlets.org/tracker/, accessed 11/2020 [5] Michael Dropmann, M. Chen, et al. "Mapping of force fields in a capacitively driven rf plasma discharge." J. Plasma Phys. (2016), vol. 82, Cambridge University Press 2016