

Laser-Assisted Dust Lunar Experiment: Investigating Electrostatic Dust Transport on the Moon

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Introduction: Dust levitation on the lunar surface, first observed by Surveyor 6 as “horizon glow” at the terminator [1], remains a critical challenge in understanding electrostatic dust transport mechanisms. Lunar dust poses significant hazards to surface operations - including optical degradation of instruments, interference with lunar astronomy, accelerated wear of mechanical systems, and serious risks to astronaut health. Understanding these dynamics is essential for the success of future missions such as Artemis and the establishment of sustainable lunar bases [2].

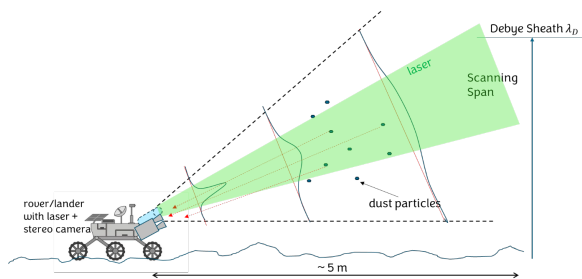


Figure 1: Schematic of the experimental. Laser light scatters off dust particles, captured by a stereo camera to determine 3D position.

This research presents **LADLE** ((Laser-Assisted Dust Lunar Experiment) - a compact (~810 g, 10 W nominal, 17 W peak), 1–2U-compatible instrument using a 532 nm pulsed laser (100 μ J, 1 ns, >50 Hz) and a four-mirror stereo camera to detect 1–100 μ m lunar dust particles at velocities up to 10 m/s within 5 m range (FOV >5.6°, f/# ~5.6) [4]. Coupled with electrostatic charging and dust fountain models [3], simulations show particles escape the Debye sheath under fast solar wind, reaching $Z_{\text{max}} \approx 50$ m and $V_{\text{exit}} > 5$ m/s [7]. SNR modeling (Mie, $n = 1.56 - 0.01j$) confirms reliable detection (SNR > 10) for >1 μ m particles at 5 m (Fig. 2).

Experimental Setup: A laboratory breadboard system was constructed to validate the concept. A diode-pumped solid-state (DPSS) laser (532 nm, 0.1 mJ, 1 ns, 34 mrad divergence) is synchronized via a signal generator with a Thorlabs CMOS camera (3.45 μ m pixel pitch, global shutter, 35–800 fps) and a variable F/# objective lens. The stereo vision system, enabled by a four-mirror optical path, allows 3D particle reconstruction from a single detector. Dust analogs - 10 μ m Ag-coated SiO₂ spheres, 30 μ m Copper spheres - were generated for test purposes [6]. Initial experiments successfully captured scattered laser light from particles, confirming detection capability and validating the instrument’s optical and triggering architecture.

Summary and Conclusions: The LADLE has demonstrated proof of concept and technical implementation for in situ lunar dust levitation measurements. Initial results confirm the detection of micron-scale particles under controlled conditions, with data now being used to refine particle tracking algorithms and improve size/velocity estimation accuracy. Future work will focus on optimizing detection algorithms for backscattered intensity, integrating high-frame-rate (≥ 100 fps) imaging for velocity resolution up to 10 m/s, and adapting the system into a compact 1–2 U payload (total mass: ~810 g, including 20% margin; power: 10 W nominal, 17 W peak) for lunar lander integration.

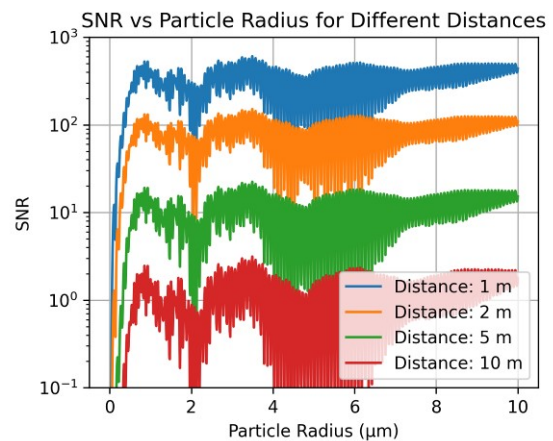


Figure 2: Calculated SNR for different distances. SNR > 10 for >1 μ m particles at 5 m (532 nm laser, $n = 1.56 - 0.01j$) [5].

The instrument **LADLE** operates at TRL 3–4 and is poised to deliver the first direct, quantitative measurements of electrostatic dust dynamics on the Moon. This advancement will enable improved risk mitigation for surface systems, inform lunar base design, and provide critical validation for plasma-dust interaction models essential for planetary exploration.

References: [1] Colwell et al. (2009) ASCE 0893-1321. [2] Horányi M. et al. (2024) Phil.Trans. R. Soc. A 382: 20230075. [3] Stubbs et al. (2005) j.asr.2005.04.048. [4] H. Luo et al. (2021) Measurement 186, 110083. [5] Davis, S. et al. (2013) PSS 90 (2014) 28–36. [6] Li, Yanwei et al. (2023) Appl. Sci. 2023, 13, 4441. [7] T.J. Stubbs et al. (2014) PSS 10-27