LUNAR WEATHER ARRAY: AN ENVIRONMENTAL MONITORING STATION FOR ENABLING SUSTAINABLE LUNAR SURFACE OPERATIONS. N. Traeden[1], E. Eshelman[1], M. Long[1], K. Bywaters[1], K. Hubbard[1], and K. Zacny[1]. [1]Honeybee Robotics, 2408 Lincoln Ave, Altadena, CA 91001 (nwtraeden@honeybeerobotics.com).

Introduction: As the international community pursues a sustained human and robotic presence on the Moon, the promise of utilizing local resources—In-Situ Resource Utilization (ISRU)—becomes paramount to logistical and economic viability. However, all surface activities, from mining and manufacturing to transportation and habitat maintenance, will contend with a persistent and damaging environmental challenge: lunar dust. Understanding the behavior of this dust, both natural (Fig. 1) and anthropogenically generated, is critical for mission planning, hardware design, and operational safety.

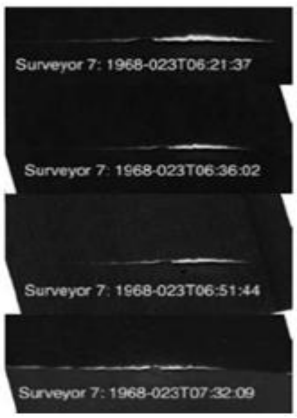

Figure 1. Horizon glow observed by the lunar Surveyor 7 mission [5]. This glow is believed to be from electrostatic lofting of lunar dust.

The Lunar Weather Array (LWA) is a surface-deployable environmental monitoring station designed to provide real-time situational awareness of the lunar dust environment. By characterizing dust transport at local and regional scales, LWA provides data essential for mitigating risks to ISRU equipment and ensuring the long-term sustainability of lunar enterprise. Developed by Honeybee Robotics, LWA is currently being matured from TRL 4 to TRL 6 under a NASA DALI award to prepare it for near-term flight opportunities. This abstract provides an overview of the LWA instrument, its direct applications to space resources activities, and a summary of its development progress.

Instrument Design and Measurement Principle: LWA is a compact instrument that integrates three measurement functions inta a single package (Fig. 2).

Time-of-Flight Lidar: The primary instrument is a backscatter lidar. LWA emits short, energetic pulses from a 532 nm laser and measures the return signal scattered by airborne dust particles. By timing the return pulse, it determines the distance to the dust cloud, and by measuring the signal intensity, it determines the dust concentration. A gimbaled pointing mirror allows the laser to be scanned across the sky or targeted at specific areas, generating a full 3D volumetric map of dust distribution over time. This allows for the direct measurement of dust plume velocity and direction.

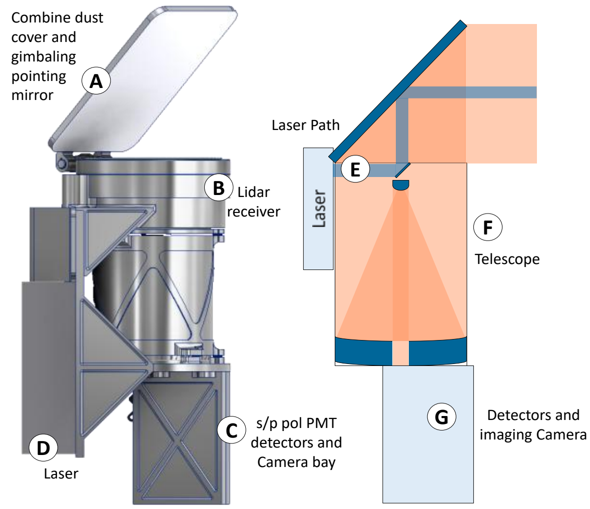

Figure 2. CAD model of Lunar Weather Array. A) Combined dust cover and pointing mirror, B) Lidar receiver, C) Detectors and Camera, D) Laser transmitter, E) Laser transmitter optical path, F) Telescope receiver optical path, G) Detector and camera optical paths.

Polarimeter: The lidar receiver includes polarization-sensitive detectors. By measuring the depolarization of the backscattered laser light, LWA can infer information about the shape and composition of dust grains, distinguishing between irregular, freshly-disturbed regolith and potentially more processed or spherical particles.

Passive Photometer: By pointing the receiver telescope toward the horizon without firing the laser, LWA can function as a photometer. This allows it to measure faint phenomena like horizon glow, believed to be caused by the natural electrostatic lofting of dust at the terminator.

This integrated approach allows LWA to characterize the complete dust cycle, from the natural background environment to large-scale plumes generated by surface activities (Fig. 3).

Relevance to Space Resources Operations: The data provided by LWA is not purely academic; it is operational data that directly enables the safety and efficiency of ISRU. The ability to monitor the dust environment in real-time addresses several key challenges identified for lunar surface systems [1,2].

- Monitoring ISRU Plumes: Excavation, regolith hauling, and beneficiation processes will inevitably generate significant dust plumes. LWA can be used to monitor the extent, density, and drift direction of these plumes in real-time. This data is critical for establishing safe standoff distances for personnel and equipment, validating contamination models, and scheduling operations during favorable conditions (e.g., periods of low natural electrostatic activity).

- Protecting High-Value Assets: Dust accumulation degrades the performance of critical systems like solar arrays and thermal radiators, while abrasive particles can damage mechanisms and seals. LWA can provide alerts when dust concentrations exceed acceptable thresholds, informing decisions to pause activity or deploy protective measures.

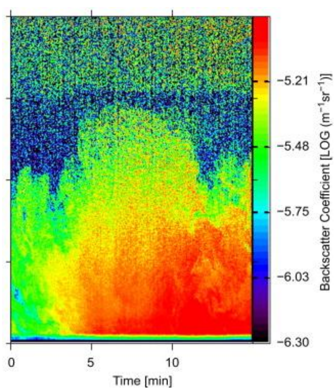

Figure 3. Dust observed by the Phoenix lidar in the Martian atmosphere [4] (below). Color corresponds to the strength of the dust backscatter signal. LWA produces similar data products for lunar environment. Figure reprinted from Dickinson, C., et al. (2011).

- Characterizing Landing/Launch Effects: LWA can be used to characterize the large-scale dust curtains generated by rocket plumes during landing and launch. For a burgeoning lunar economy with multiple providers, understanding these effects is essential for deconflicting surface logistics and protecting assets at adjacent landing pads or worksites.

- Establishing an Environmental Baseline: Before large-scale ISRU operations begin, LWA can characterize the natural background dust environment, including transport from micrometeorite impacts and electrostatic lofting. This baseline is crucial for assessing the environmental impact of industrial activities and understanding how anthropogenic dust interacts with the natural surface-to-exosphere transport cycle.

Technology Maturation and Performance Validation: The LWA project has established a clear path to a flight-ready (TRL 6) system. Instrument requirements were derived from high-level science and exploration goals defined by NASA [3], ensuring the system is designed to provide actionable data. The primary tool for performance validation is the instrument link budget, which models the expected Signal-to-Noise Ratio (SNR) for a given dust concentration and range. This analysis confirms that the LWA design can detect and characterize dust plumes at ranges from meters to kilometers, sufficient for monitoring local ISRU activities and regional transport.

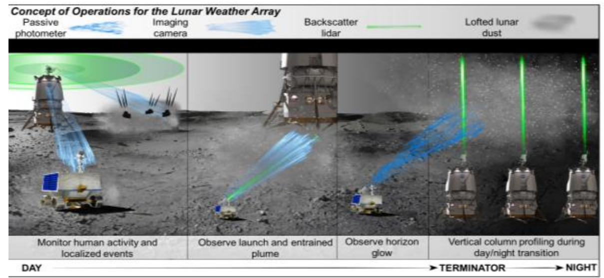

Figure 4. LWA Concept of Operations, monitoring the environment; observing launch and characterizing the launch plume; observing horizon glow; and monitoring dust levitation and lofting during day/night transitions.

To reduce technical risk, a brassboard version of the most critical long-lead component, the laser, has been procured and characterized. This laser meets or exceeds key performance requirements, demonstrating a pulse energy of 42 mJ at a 30 Hz repetition rate, validating the link budget model and confirming the viability of the instrument design.

Conclusion and Path Forward: The Lunar Weather Array is a capable, multi-faceted instrument that provides critical environmental data to enable safe and sustainable space resource operations. By providing real-time awareness of both natural and human-caused dust hazards, LWA reduces operational risk, protects high-value assets, and supports the development of a robust lunar economy. Having successfully defined the system requirements and de-risked key components, the LWA project is now proceeding toward a Preliminary Design Review (PDR). The next phase will involve the assembly and environmental testing of a TRL 6 prototype, positioning LWA as a ready-to-fly monitoring solution for upcoming CLPS and Artemis missions.

References: [1] Pohlen, M. et al. (2022) *npj Microgravity*, 8, 55. [2] Winterhalter, D. et al. (2020) *NASA Engineering and Safety Center (NESC) Workshop*, NESC-RP-19-01469. [3] Artemis III Science Definition Team Report (2020) NASA/SP-202050009602. [4] Dickinson, C., et al. (2011). Lidar atmospheric measurements on Mars and Earth. Planetary and Space Science, 59(10), 942–951. [5] Grün, E. & Horanyi, Mihaly & Sternovsky, Zoltan. (2011). The lunar dust environment. Planetary and Space Science - PLANET SPACE SCI. 59. 1672-1680.