Lunar Weather Array: An Environmental Monitoring Station for Enabling Sustainable Lunar Surface Operations

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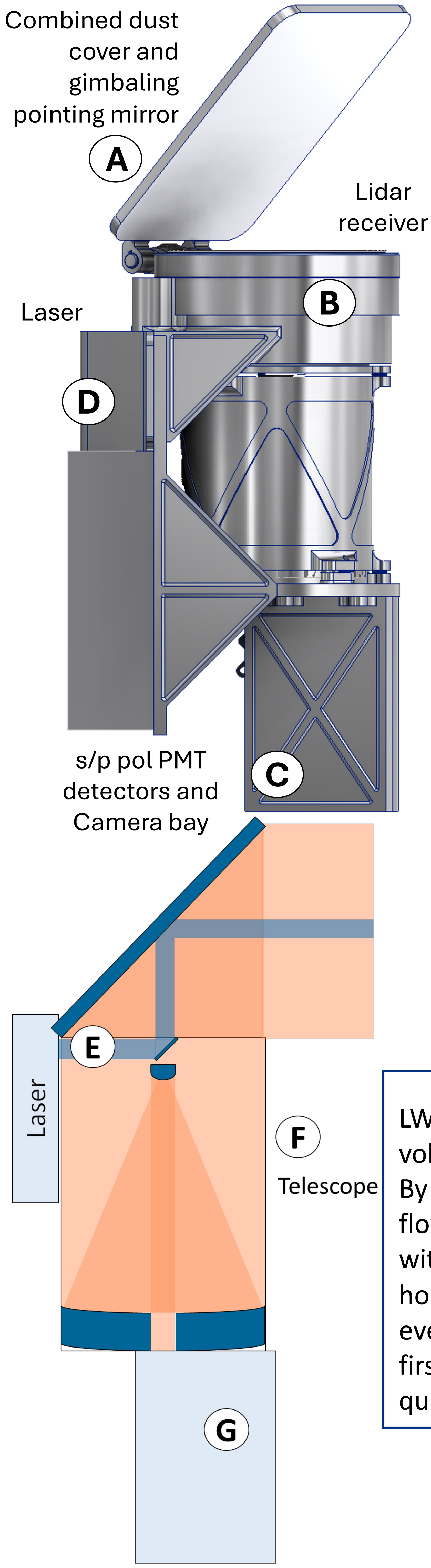
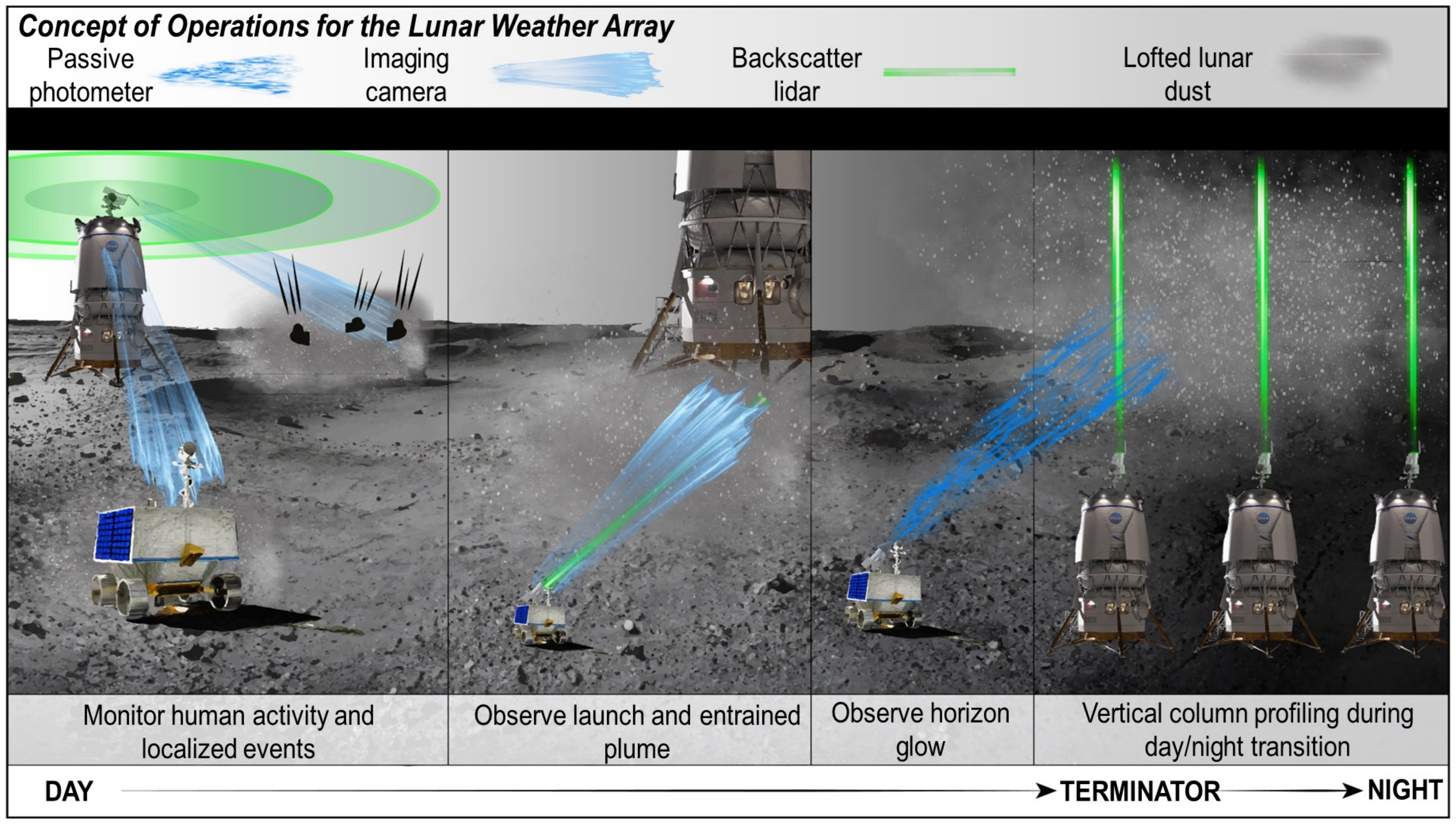


CAD model and optical diagram of Lunar Weather Array instrument.
A) Combined dust cover and pointing mirror, B) Lidar receiver, C) Detectors and Camera, D) Laser transmitter, E) Laser transmitter optical path, F) Telescope receiver optical path, G)Detector and camera optical paths.

Ten Second Summary

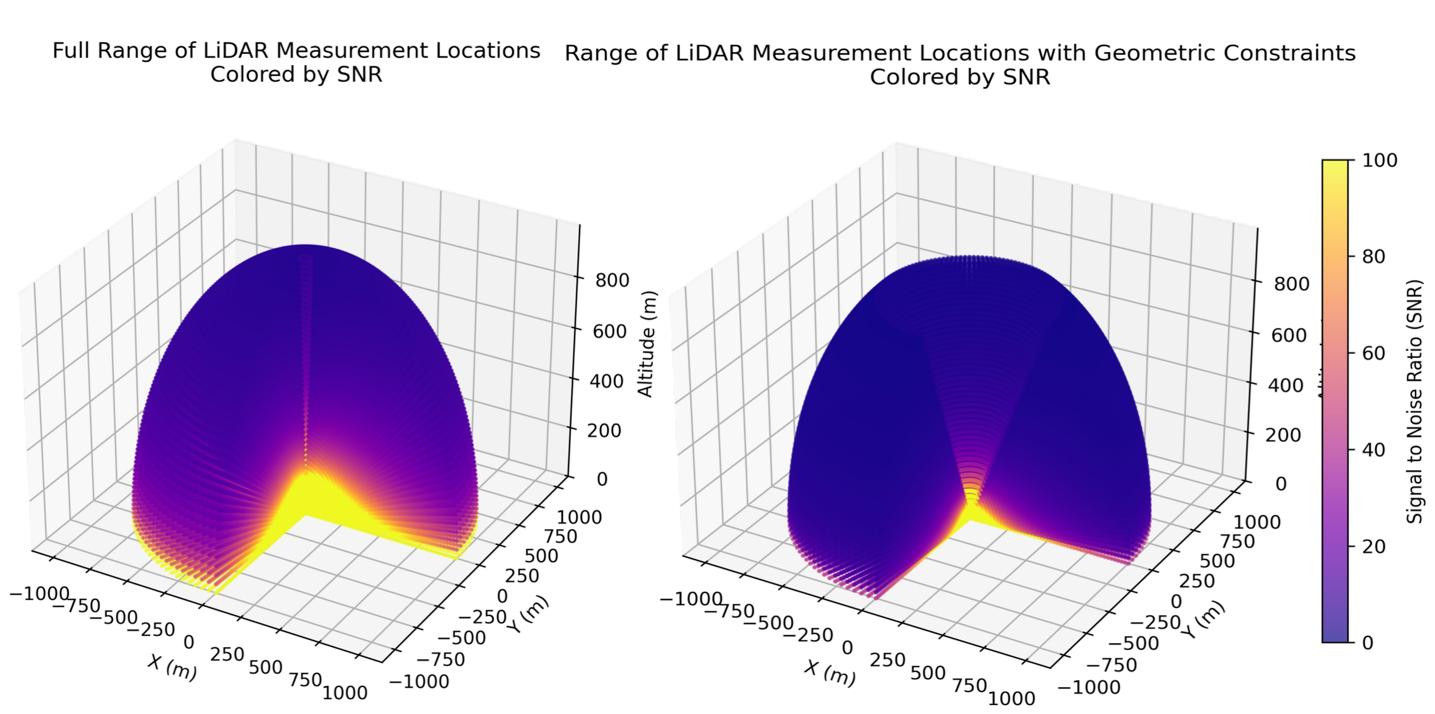
Lunar Weather Array (LWA) is a compact, surface-deployable, backscatter lidar instrument for studying and monitoring the lunar dust environment. LWA will 1) improve understanding of surface-to-exospheric lunar dust dynamics, and 2) establish a surface environmental monitoring station to inform safe human and robotic operations. The increased cadence of lunar missions and anticipated sustained level of human presence motivate the near-term development of LWA under DALI.



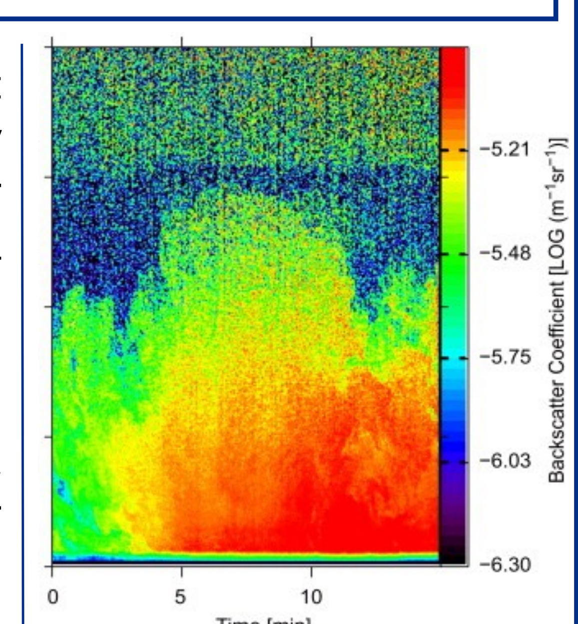
LWA Concept of Operations, monitoring the environment; observing launch and characterizing the launch plume; observing horizon glow; and monitoring dust levitation and lofting during day/night transitions.

System Overview

LWA integrates a backscatter lidar, a gimbaled pointing mirror, and an imaging camera. LWA generates a volumetric point cloud of dust distribution by measuring dust-scattered light from an outgoing laser pulse. By performing repeated measurements over short timescales, LWA can monitor dust transport's vector flow and direction from meter to kilometer scales. By pointing LWA's optical receiver towards the horizon with the two-axis gimbal and operating without the laser, LWA acts as a passive photometer to observe horizon glow [3]. An onboard camera in combination with the lidar visualizes the horizon and monitors events such as EVAs, launches, and meteorite/micrometeorite impacts. With these capabilities, for the first time, LWA connects measurements of surface dust transport to exospheric dust flow, answering open questions regarding the role of electrostatic lofting in generating and sustaining the dust exosphere.



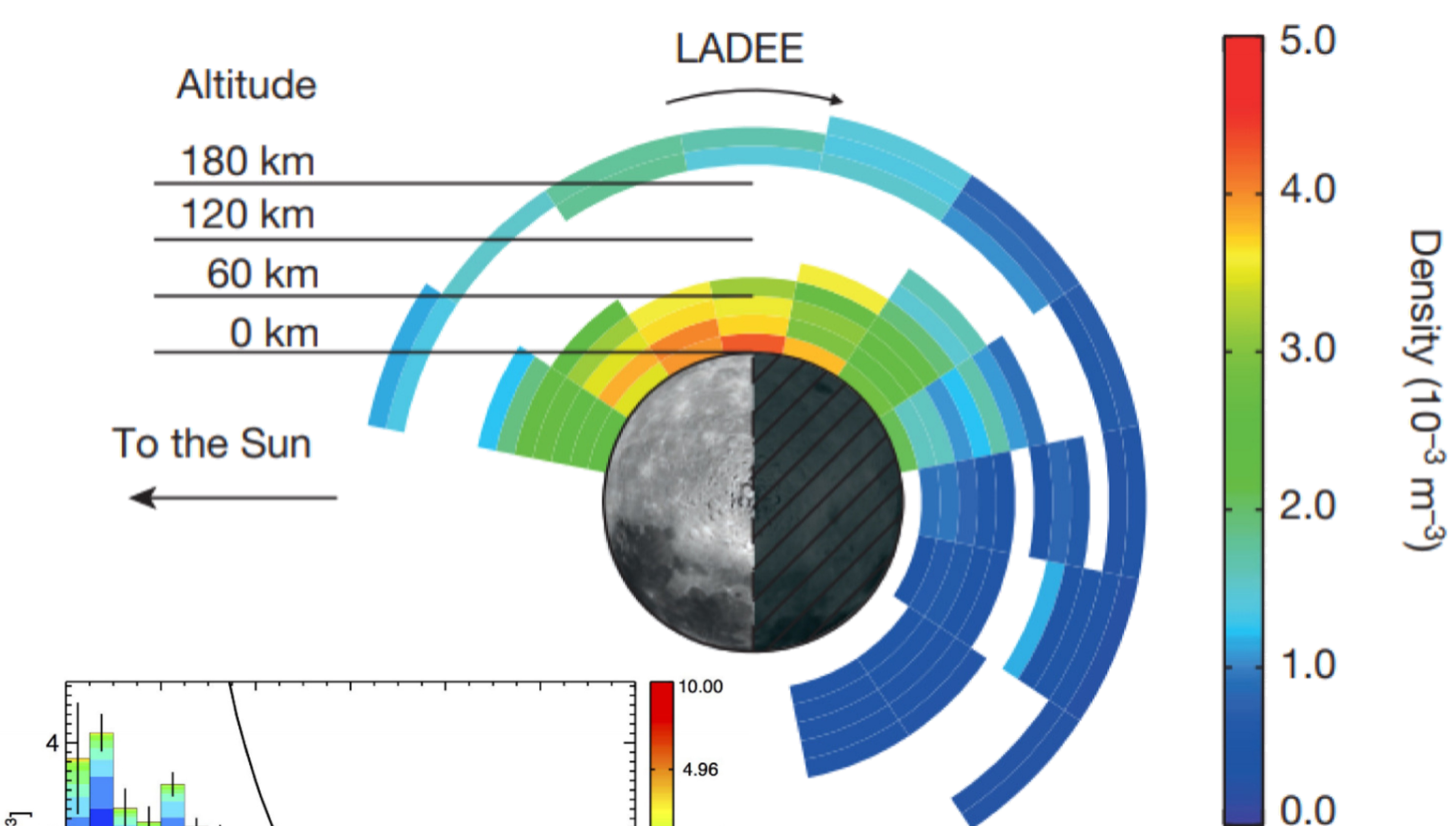
LWA model of dust cloud particle density and performance for expected operational field of view. Analysis results show near-surface (1-50 m altitude) high SNR resulting in shorter measurement duration necessity.

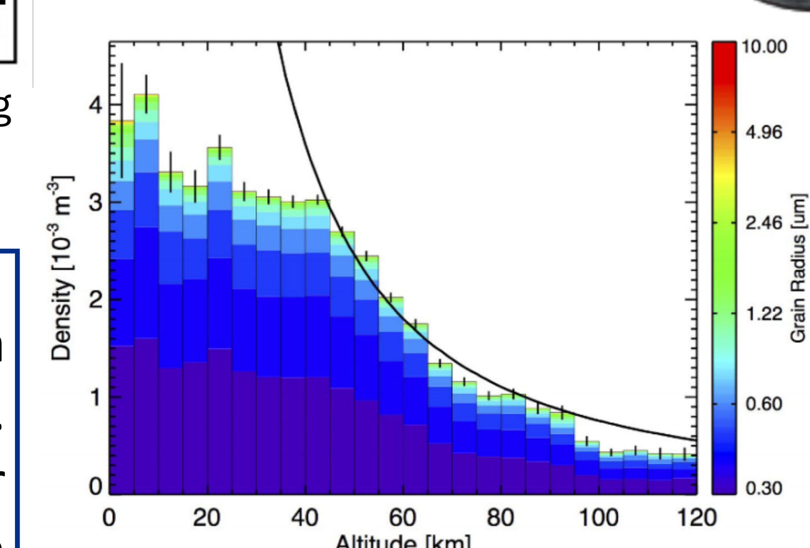


Dust observed by the Phoenix lidar in the Martian atmosphere [4] (below). Color corresponds to the strength of the dust backscatter signal. LWA produces similar data products for lunar environment. Figure reprinted from Dickinson, C., et al. (2011).

Problem Statement

Lunar dust poses a potential safety hazard for spaceflight hardware and human health due to the small size, abrasive nature, and electrical charging of dust particles [1]. Studying the behavior of dust from the local to global scale is necessary to understand where and when dust poses a risk for future landed missions. The current under-standing of global dust behavior is informed by NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE), which characterized the global dust exosphere from orbit [2]. Surface observations by Surveyor missions and Apollo 17's Lunar Ejecta and Meteorites Experiment (LEAM) measured surface dust charging and near-surface lofting. However, a knowledge gap exists in understanding the mechanisms for surface-to-exospheric dust transport processes.





Exospheric lunar dust density detected by LADEE [2]. LADEE results show that the density of dust increases at the terminator and decreases as a function of altitude. Figures reprinted from Sharma, H. et al. (2021).

Project Progress

The team has developed a baseline version of the Lunar Weather Array link budget to fit the needs of this project, and which will be matured throughout hardware design and development. The link budget includes performance capabilities of individual optical elements for both the transmitted and receiving optics paths. We use a calculated dust backscatter coefficient based on altitude and approximated particle optical properties (modeled as volcanic dust). This allows us to derive a predicted SNR for a set of measurement conditions. The team has defined a baseline laser architecture and are working towards finalization of the TRL 6 laser specification. The brassboard laser has been procured and set up in our lab and has gone through initial tests and second harmonic conversion efficiency characterization. The laser has a max pulse energy of 42 mJ and a 30 Hz repetition rate with a pulse width of 9 ns. These parameters feed into our link budget to further mature our predicted performance model.

[1] Pohlen, M. et al. Overview of lunar dust toxicity risk. npj Microgravity 8, 55 (2022). https://doi.org/10.1038/s41526-022-00244-1 Author A. B. and Author C. D. (1997) JGR, 90, 1151–1154
[2] Sharma, H. et al. (2021). Constraining low-altitude lunar dust using the LADEE-UVS data. Journal of Geophysical Research: Planets, 126, e2021JE006935.
[3] Criswell, D. R. (1973), Horizon-glow and the motion of lunar dust, in Photon and Particle Inter-actions with Surfaces in Space, vol. 37, pp. 545–556, D. Reidel Publishing Company, Dordrecht.
[4] Dickinson, C., et al. (2011). Lidar atmospheric measurements on Mars and Earth. Planetary and Space Science, 59(10), 942–951. https://doi.org/10.1016/j.pss.2010.03.004