Probing the Surface Composition of the Moon with a Dust Analyzer

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Micrometeoroid impacts bombard the moon from all throughout interplanetary space, excavating craters sized by the meteorite's speed, radius and composition [1]. Hypervelocity impacts dislodge ejecta from the surface with speeds sometimes exceeding the lunar escape velocity. This talk describes a possible dust instrument, to be placed on a lunar polar orbit, that could quantitatively characterize the temporal and spatial influx of Interplanetary Dust Particles (IDPs). The instrument provides a critical measurement in understanding the evolution of volatiles in the permanently shadowed regions (PSRs) in the polar regions of the Moon. Earth-based IR observations can distinguish silicate minerals, but measurements of water and carbon-bearing minerals are limited by the Earth's atmosphere. The proposed instrument would permit in-situ detections of dust particles based on impact ionization time-of-flight (TOF) mass spectrometry, determining mass, speed and composition.

Modern dust instruments can measure the composition of ejected particles from PSRs and gauge the availability of water and other volatiles for ISRU. Only ~100 such dust detections are needed. These measurements can be performed from orbit, with a spatial resolution comparable to the altitude of the orbiting spacecraft. Such instruments have been calibrated using the dust accelerator facility at IMPACT/LASP, CU Boulder. Figure 1 depicts an impact ionization TOF mass spectrum for Opal, a candidate hydrated mineral on the lunar surface. This impact was recorded at a velocity of ~ 1.6 km/s, typical for a detection from an orbiting spacecraft at 100 km above the lunar surface. The box delineates the water (W=H2O) line clearly appearing at 18u.

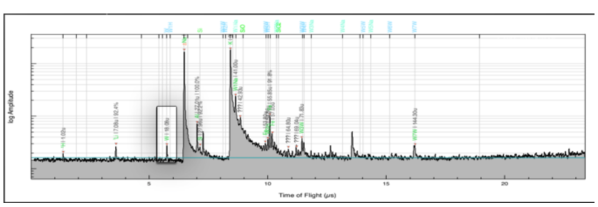

Figure 1: Recent experiments at the SSERVI/IMPACT dust accelerator demonstrated that water clusters can be recognized in impact-induced time-of-flight (TOF) mass spectra.

Water is thought to be continually delivered to the Moon through geological timescales by water-bearing comets and asteroids and produced continuously in-situ by the impacts of solar wind protons on oxygen-rich minerals exposed on the surface. Escaped dust particles may contain volatiles such as water ice [2]. This is in line with the subject of question Q4.3e: "What Exogenic Volatile and Non-Volatile Materials Are Delivered to Planetary Bodies?" from the Planetary Science Decadal Survey Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 [3]. Detection of water in hydrated minerals may serve as a tracer for other volatiles. Potassium (K) has been studied on the lunar surface, but outstanding questions remain about the abundance of sodium (Na). Both signatures appear in the spectrum shown in figure 1, demonstrating the instrument's ability to measure the relative abundances of these elements.

The Lunar Dust Experiment (LDEX) onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission successfully made more than 140,000 similar measurements, establishing the flux and size distribution of impacting particles from orbit [4]. The strategic research guideline posed by the decadal to "Determine the origin of polar volatiles by obtaining and analyzing the properties of ices found within the permanently shadowed craters located near the lunar and Mercurian poles" would be explored by this instrument through many detections over its orbit as demonstrated by LDEX. Since only ~100 detections are needed to establish the provenance of a given dust population [5], more than enough measurements would be made by the proposed instrument over its orbit for an in-depth characterization of the density of volatiles on the lunar surface.

References:

[1] M. Horányi, J. R. Szalay, and X. Wang, "The lunar dust environment: concerns for Moon-based astronomy," Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 382, no. 2271, May 2024.

[2] J.P. Pabari, S. Nambiar, V. Shah, Anil Bhardwaj, Lunar regolith and water ice escape due to micrometeorite bombardment, Icarus, Volume 338, 2020, 113510, ISSN 0019-1035, https://doi.org/10.1016/j.icarus.2019.113510.

[3] National Academies of Sciences, Engineering, and Medicine. (2023). Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032. Washington, DC: National Academies Press.

[4] M. Horanyi et al., The Lunar Dust Experiment (LDEX) Onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) Mission. Space Sci Rev 185, 93-113 (2014).

[5] Cohen BA, Szalay JR, Rivkin AS, Richardson JA, Klima RL, Ernst CM, Chabot NL, Sternovsky Z, Horányi M. Using dust shed from asteroids as microsamples to link remote measurements with meteorite classes. Meteorit Planet Sci. 2019 Sep 1;54(9):2046-2066.