Lunar Mist: Exploring Pyroclastic Deposits at J. Herschel Crater and Performing Active Water Experiments on the Moon to Resolve Lunar Hydration Debates.

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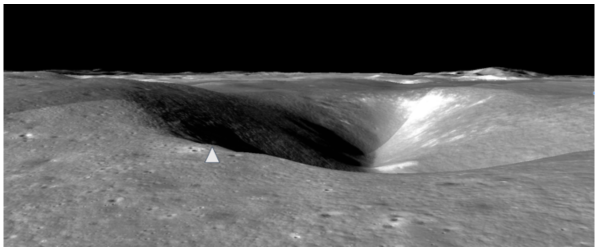
Introduction: Lunar Mist is a mission concept proposed in response to NASA's 2022 Payloads and Research Investigations on the Surface of the Moon (PRISM). Lunar Mist proposes to explore the Moon's J. Herschel crater, primarily to address two key questions: (1) What is the nature of volcanic materials emplaced on the surface from the lunar interior? (2) What is the physical state, composition, abundance, and retention capacity of lunar hydration as a function of temperature, local time, and regolith properties?



Fig, 1: LROC image of J. Herschel crater at the proposed landing site just outside of the putative vent.

The landed surface mission would be the first to characterize a pyroclastic deposit [*e.g.,* 1-3] and to perform an active water release experiment on the Moon to constrain diurnal variations and trapped hydration abundance. Its suite of instruments would methodically probe the adsorption and subsequent evolution of lunar surface hydration. Pyroclastic deposits could sequester ancient, magmatic hydration in addition to transient water formed on the surface through solar wind or micrometeoroid impacts. J. Herschel is at a high latitude (62°N, 42°W) and has been shown to have enhanced surface hydration [*e.g.,* 4]. The site also hosts a putative vent on the eastern floor, providing acess to deposits that may represent a window into the primitive materials in the the lunar interior [1,5].

Payload: The Lunar Mist mission places instruments on both a lander and a rover. The lander payload includes a multispectral color and stereoscopic imager (Mistcam – developed at Arizona State University and Malin Space Science Systems, Inc.) and a mass spectrometer (Mist-Mass Spectrometer Observing Lunar Operations – M-MSolo – developed at Kennedy Space Center). The rover payload includes a multi-component infrared spectrometer/thermal radiometer/visible imager (Lunar Environments Sensing Instruments – LESI – developed at NASA Ames Research Center) and a UV spectrograph (MistUVS – developed at the Southwest Research Institute). Both the rover and the lander would also each be fitted with a "Doser" – a repurposed CubeSat resist-to-jet thruster, to infuse H_2O vapor onto the lunar regolith. The Doser on the lander would contain H_2O^{18} to make it distinguishable from lingering lander exhaust.

Loc.	Instrument / Item	Capability	Lead Institution
Lander	Mistcam	Multispectral /stereoscopic imager	ASU/MSSS
	M-MSolo	Mass Spectrometer	KSC
	Doser	Emplaces H_2O^{18}	SwRI
Rover	LESI	IR spectrometer/thermal radiometer/visible imager	ARC
	MistUVS	Ultraviolet Spectrograph	SwRI
	Doser	Emlpaces H_2O	SwRI

Science Objectives: The Lunar Mist mission has four primary science objectives, each of which is traceable to key specific higher-level Planetary Decadal Survey, LEAG, and/or Artemis science questions:

(1) To constrain the origin and evolution of the geology/geomorphology and the eruption style of the pyroclastic material at J. Herschel, Mistcam would perform geologic, geomorphologic and limited mineralogic science measurements, acquiring 360° panoramas of the site at mm/pixel to cm/pixel resolution and generating a digital terrain model of the site at vertical scales $\leq$ 10 cm.

(2) To characterize the composition and volatile abundance in the lunar interior, Mistcam, LESI and MistUVS would acquire compositional and mineralogic information at different distances from the vent as well as in specific regions where regolith diversity could be expected, for example within ejecta blocks or along crater rays.

(3) To differentiate the contribution of H_2O vs. OH on the total surface hydration at J. Herschel, MistUVS and LESI would measure the 165 nm, 3 μm and 6 μm spectral features associated with hydration on the natural surface and after dosing the surface with unambiguous H_2O. The 6 μm feature is known to be associated only with molecular water and was recently detected on the Moon with SOFIA observations [6]. The 3 μm feature has been detected across the lunar surface [7]; however, the feature's shape and band center vary depending on the speciation of the hydration (OH and H_2O). The 165 nm feature, which has also been detected to migrate across the lunar surface [8] is thought to be affiliated with water only, but may also be influenced by OH. By performing the active water experiment on the lunar surface, Lunar Mist would disentangle the cause of observed hydration on the Moon, which has implications for the water's sources and longevity on the surface. Laboratory experiments cannot yet simulate the regolith structure and lunar environment in a way that explains the observations of hydration on the Moon.

(4) To characterize the effects of local time, temperature, and regolith properties on the abundance of trapped magmatic hydration vs naturally-occurring surface hydration, LESI and MistUVS observe the spectral hydration features pre- and post-water dose as a function of time of day and at diverse regolith/composition locations within a 1 km radius of the landing site, including the lander's "blast zone". The M-MSolo's measurements of water vapor during the H_2O^{18} dosing experiments characterize the sticking coefficient, retention, and evolution of emplaced water.

Implications: Lunar Mist's comprehensive and innovative payload suite would directly address many outstanding, contradictory interpretations of abundance and speciation of hydration on the Moon. Through simultaneous, high-spatial resolution observations of the three spectral hydration features pre- and post-water dosing, Lunar Mist would distinguish how OH and H_2O are manifested spectrally, how the features' strengths relate to one another, and how they evolve post exposure to H_2O. Through the rover's mobility, Lunar Mist would explore the variation of natural and exposed hydration abundances at lunar soils with differing compositional and structural properties. By performing small loops to extend the phase angle measurements and creating artificial shadows, Lunar Mist would determine the sensitivity of hydration measurements and models to phase angle and surface temperatures. The sticking coefficiency of water onto the surface would be constrained through mass spectrometery measurements during and just after exposing the surface to H_2O. Through the first detailed exploration of a pyroclastic deposit, and in particular one that hosts a putative vent, Lunar Mist would assess the structure, particle distribution, compositional heterogeneities, and volatile abundance of the region to constrain the eruptive style of the pyroclastic deposit at J. Herschel, with implications for other, similar deposits on the Moon.

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