

THE PEREGRINE ION TRAP MASS SPECTROMETER (PITMS): A CLPS-DELIVERED ION TRAP MASS SPECTROMETER FOR *IN SITU* STUDIES OF LUNAR VOLATILES.

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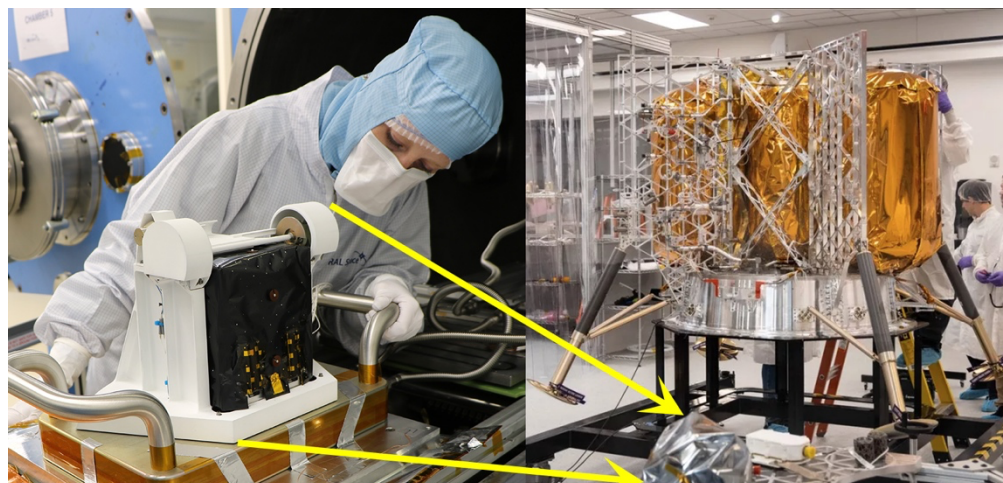


Figure 1. (left) The PITMS instrument going into thermal vacuum testing, and (right) integrated onto the deck of the Peregrine-1 lander assembled in the background.

Introduction: Landed mass spectrometers are uniquely positioned to assess the volatile components of the lunar regolith and exosphere and observe their behavior from dawn to dusk. Characterizing lunar volatile reservoirs and evaluating their interrelations is a high priority for both lunar science and for exploration purposes, as water could represent a key resource for human utilization.

The Peregrine Ion Trap Mass Spectrometer (PITMS) is a mass spectrometer experiment manifested aboard the first flight of Astrobotic's Peregrine lunar lander. PITMS will measure the abundance and temporal variability of volatiles, linking surface properties and composition to LADEE measurements from orbit, and providing a mid-latitude point of comparison for polar measurements planned by VIPER, PROSPECT, and other missions.

Lunar near-surface water: The Moon has a tenuous atmosphere (exosphere) primarily made of neon, helium, and argon [1], molecular hydrogen [2], with smaller abundances of methane [3], sodium, and potassium [4]. The LADEE Neutral Mass Spectrometer (NMS) and Ultraviolet Spectrometer (UVS) identified the primary atmospheric constituents at this altitude, their density, and variability [1, 4]. To date, water and OH have only been detected in the exosphere during meteor stream events by the LADEE NMS and UVS [5].

The only comparable surface measurement was made by the Lunar Atmospheric Composition Experi-

ment (LACE) on Apollo 17. LACE was a miniature magnetic deflection mass spectrometer deployed on the surface and operated for 9 months. LACE was routinely swamped by artifacts emanating from the nearby lunar module descent stage and other abandoned equipment during the lunar daytime, but obtained firm detections of two species, argon and helium, and upper limits for other volatile species of interest, including N₂, CO, CO₂, and CH₄ [6]. OH/H₂O was not determined due to the high backgrounds inside and outside the instrument.

Modern *in situ* analyses carried out by mass spectrometry are important to determine the origin, flux and fate of volatile compounds that may make their way toward the lunar poles, particularly from multiple landing sites and during different seasons. PITMS will measure the OH/H₂O abundance from the lunar surface and improve quantification of other exospheric species of interest. The PITMS ground-level measurements can be combined in space and time with LADEE measurements at altitude to inform models of the volatile flux across the Moon, from equator to pole.

PITMS instrument: PITMS is a partnership between NASA Goddard Space Flight Center (GSFC), The Open University (OU), and ESA, consisting of an ESA-provided mass spectrometer (sensor, electronics, controller, power supply boards) and a GSFC wrapper that provides sensor aperture protection, thermal control, and structural elements. PITMS leverages ESA PROSPECT development and develops a standalone mass spectrometer suitable for small lunar landers.

The PITMS sensor has direct heritage from the Ptolemy mass spectrometer that made the first in situ measurements of volatiles and organics on comet 67P with the Rosetta lander, Philae [6]. It has a unit mass resolution up to an upper mass-to-charge (m/z) limit of 150 Da. Operating in a passive sampling mode, ambient gases enter PITMS through an aperture and diffuse around the mass analyzer cavity. They will be ionized using an electron impact ion source and trapped in a radiofrequency field. Manipulation of the field facilitates the ejection of the ions into the electron multiplier detector in order of increasing m/z with amplitudes related to abundance. This passive technique was used during Rosetta's flyby of asteroid Lutetia and at 67P during Philae's "bounce" after landing [7, 8].

GSFC integrated the sensor and electronics with a thermal base plate, radiator, and deployable dust cover. The integrated PITMS payload and science investigation will be operated by GSFC with an international team of scientists. PITMS is manifested on the first flight of Astrobotic's Peregrine lander, which will fly as a co-manifested payload aboard the maiden flight of ULA's Vulcan Centaur vehicle in late 2022 or early 2023. The lander is targeted for the Lacus Mortis basaltic lava plain in the northeastern part of the Moon ($\sim 45^\circ$ N), near an apparent skylight [9]. PITMS operations will commence soon after touchdown with the release of the dust cover. PITMS will continually scan at up to 10 Hz and integrate the mass spectra onboard if needed to build signal to noise ratio. We expect to monitor the decay in the lunar exosphere from its post-landing peak, punctuated by any stimuli that create transient increases (i.e., lander exhaust desorption, lunar surface's compound desorption/release with temperature during the lunar day, migration from lower latitudes).

Expected scientific output: The PITMS investigation will provide time-resolved variability of OH, H₂O, noble gases, nitrogen, and sodium compounds released from the soil and present in the exosphere over the course of a lunar day. Water and other volatile molecules formed by the solar wind and contributed by exogenous sources have been hypothesized to migrate to high latitudes, eventually becoming trapped at the poles (e.g., [10]). However, [1] hypothesized that one reason why the water exosphere was undetected by LADEE is that surface-correlated water may not undergo multiple ballistic hops – molecules may only hop once and get destroyed, rather than contributing to the polar reservoir. At 45° N and with a zenith-looking aperture, PITMS is situated to sense any polar-propagating volatiles as they migrate poleward. For example, if the sensed water abundance drops over the mission lifetime, but does not level off, then very likely there is not a

global exosphere of water and thus no poleward movement. However, if the water levels become uniform near the end of the mission (with the approach of the terminator), then it supports the presence of a global exosphere of water that contributes to the polar reservoir.

Volatile compounds (including water) will be deposited onto the lunar surface by the lander itself. Observing the release of these vapor species over the lunar day will provide information on the properties of the regolith and the nature of the landing plume interaction with it. The exposed regolith is constantly being activated through bombardment by the solar wind and impactors, creating sites that bind volatile species such as water. Laboratory observations of water bound to lunar regolith shows a distribution of activation energies peaking near 0.7 eV, but with a high energy tail beyond 1 eV [11-13]. PITMS will sense the water outgassing throughout a lunar day, to understand the potency of the lunar surface as an adsorption/desorption substrate, affecting our models of plume-originating water retention in the actual space environment [14].

PITMS observations on the Peregrine-1 lander will complement descent plume characterization by SEAL [15] and surface observations by MSolo [16]. PITMS data will also be integrated with data from other instruments on board the Peregrine lander for a more comprehensive approach to understanding the surface and exosphere composition. The PITMS data provide a critical mid-latitude link to future polar mass specs to characterize the latitudinal migration of volatiles from equator to poles. provides a key link to the polar volatile migration story.

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