In-Situ Studies of the Lunar Water Cycle by Ion Trap Mass Spectrometry

Conference or Workshop Item

IN-SITU STUDIES OF THE LUNAR WATER CYCLE BY ION TRAP MASS SPECTROMETRY

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Introduction: Whereas the Moon might have previously been considered 'a completely waterless planet' [1], multiple recent discoveries in sample analysis [2] and remote sensing [3] are changing that paradigm. The numerous missions that are in preparation by agencies and commercial entities present an opportunity to obtain multiple in-situ measurements of volatiles at the lunar surface that could provide ground truth for remote sensing and may reveal the dynamic water and volatiles cycles potentially occurring on the Moon today. It is furthermore important that these studies are performed before the fragile lunar atmosphere is perturbed by further human activity [4]. This paper describes mass spectrometers being developed for these upcoming missions, to study the present-day occurrence and processing of water and volatiles at the Moon. It focusses on plans for new instruments to study the lunar exosphere in-situ.

Mass spectrometers for volatiles analysis: A particularly compact and versatile mass spectrometer was developed for the Ptolemy instrument [5] on the Philae lander of the Rosetta mission to comet 67P. This was an ion trap mass spectrometer (ITMS) with an approximate volume of 1 litre and mass 1 kg including electronics. Analyte molecules are subjected to a flow of electrons emitted by a cold cathode (field effect) or heated wire filament (thermionic emission) source. The resulting analyte ions may become bound or 'trapped' within stable orbits within a cavity defined by a ring electrode and two end cap electrodes all of hyperbolic profile. The quadrupolar trapping field is created by the application of suitable radiofrequency potentials to these electrodes. Subsequent manipulation of that field enables the ejection of the ions into an external secondary electron multiplier detector in order of increasing mass-to-charge (m/z) ratio. The output of that detector thus constitutes a mass spectrum, representing nature of the analyte (m/z ratio of fragment ions) and its concentration (peak area). The process of ionization, mass sorting and detection of ions is rapid such that a full mass spectrum in the range up to m/z ~150 (appropriate for most volatiles) takes around 10-20 milliseconds.

Instrument Implementation: Drawing upon heritage from the Ptolemy instrument, an ITMS is being developed for use in ESA's PROSPECT package as part of the Roscosmos Luna-27 lander (Figure 1) planned to visit the south polar region of the Moon in 2023-4 [6]. The ITMS forms part of the 'ProSPA' analytical laboratory [7]. It accepts regolith from the 'ProSEED' drill, which samples at depths up to ~1.2 m, comparable to those probed by remote sensing from orbiters and sufficient to sample beneath the uppermost layers potentially contaminated by exhaust emissions during landing. The drill can translate laterally enabling multiple boreholes across an arc ~0.5 m.

Although highly capable, the mass of PROSPECT (some 30+ kg) means that other, simpler systems may be beneficial to utilise the ITMS on smaller landed platforms. Examples in development include:

i-Drill [8] is an instrumented ~1.2 m drill which utilizes the heat generated during descent to release and transport volatiles to an integral ITMS for evolved gas analysis all for <15-20 kg.

LUVMI is a lightweight rover affording increased lateral coverage to the ITMS [9] integrated within a '**Lunar Volatiles Scout**' [10] instrument of <2 kg and accessing depths of 15-20 cm. Future developments may incorporate the ITMS within probes to be deployed in areas otherwise inaccessible to the rover.

L-DART [11] - named for 'Direct Analysis of Resource Traps' - is a more extreme example in which probes or 'darts' are released from low lunar orbit and self-deploy at a speed of ~300 metres/sec into targeted regions of the Moon including PSRs such as Cabeus crater. The probes penetrate to a depth of several metres, and on-board instruments measure regolith geotechnical, thermal and volatile properties before, during and/or after impact. A rugged, impact-hardened ITMS provides the first true in-situ measurements of PSR volatiles, which are released during the high-energy landing and subsequent thermal soak.

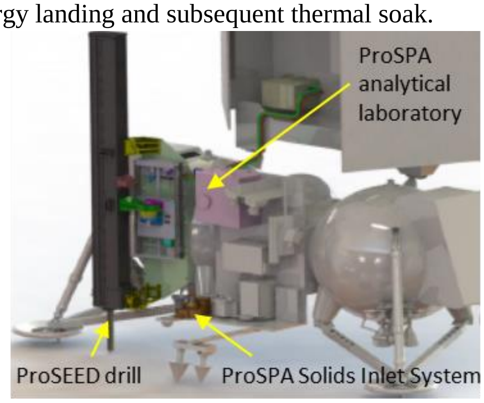

Fig 1: PROSPECT elements ProSPA & ProSEED on Luna-27 lander (IKI/Roscosmos/Leonardo)

ITMS for lunar exosphere studies: The nature and dynamics of the lunar exosphere are still poorly understood. The Moon has a very tenuous atmosphere (exosphere) made up primarily of neon, helium, and argon, [12], molecular hydrogen [13], with smaller abundances of methane [14], sodium, and potassium [15]. To date, water and OH have only been reported in the exosphere during meteor stream events by the LADEE NMS and UVS [16]. Because of the rate at which atoms escape from the lunar atmosphere, there must be a continuous source of particles to maintain even a tenuous atmosphere. Work in the last decade has pointed to a lunar "water" cycle with three principal components: primordial (interior) water, surficial water (linked to solar wind and meteorites), and polar (sequestered) water. Identifying and characterizing the lunar volatile reservoirs and evaluating their interrelations is a high priority for both lunar science and for exploration purposes, as surficial water could represent a key resource for human utilisation.

With the foregoing motivation, proposals have recently been submitted to both ESA and NASA for an ITMS on landed missions to provide the first in-situ quantification of OH/H_2O on the lunar surface. The ITMS would provide this measurement, along with vastly improved quantitation of exospheric species of interest to both science and human exploration as outlined above. In addition to measuring the abundance of these species, the investigation would link the surface to upper exosphere via the LADEE measurements, constraining models for the global evolution of these species. Monitoring the diurnal variability of the species would provide insights into the surface chemistry that creates, maintains, and/or sequesters such molecules. This landed investigation would be useful anywhere on the Moon: equatorial siting would be particularly useful to compare with LADEE, but polar would be particularly useful in monitoring migration of water molecules toward PSRs. At the time of writing the ITMS has been selected by NASA in the frame of its Commercial Lunar Payload Services program and is under review at ESA.

The proposed instrument is based on Ptolemy heritage as updated within the PROSPECT/ProSPA program. In the CLPS implementation, the ITMS will be supplied by The Open University and housed in a mechanical and thermal interface adapter provided by NASA Goddard Spaceflight Center. This adapter consists of four parts: a custom interface plate to attach ITMS to the lander, a deployable door over the MS inlet valve for landing, a baffle to shield the instrument from lander-derived species; and a passive thermal control solution for the specific lander selected by NASA (Figure 2).

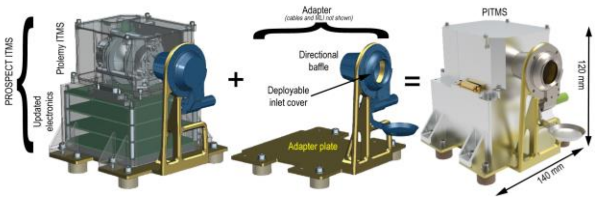

Figure 2: ITMS derived from European heritage packed within NASA GSFC adapter for NASA CLPS

The goal is to monitor the tenuous near-surface lunar exosphere up to m/z 150 throughout the mission, in response to natural (*e.g.,* diurnal temperature cycle) and artificial (*e.g.,* landing event, lander activities) stimuli. The measurement would characterise the lunar exosphere after descent and landing, and throughout the lunar day to understand the release and movement of volatile species. The investigation would provide measurements of the exosphere that would significantly improve our knowledge of the abundance and behavior of volatiles on the Moon, linking the lunar surface to LADEE measurements, and inform robotic and human mission design by characterising the interaction between surface assets and the lunar environment. Deployment of similar packages on multiple landers would assist in building a global picture of the lunar volatiles cycle.

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