A Very Light Weight Low Cost Compact Mass Spectrometer for Measuring Lunar Volatiles. B.M. Jones[1,2], R. Hodyss[3] and T. M. Orlando[1,2,4], [1]School of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, GA [2]Center for Space Technology and Research, Georgia Institute of Technology, Atlanta, GA [3]Jet Propulsion Laboratory, Pasadena, CA [4]School of Physics, Georgia Institute of Technology, Atlanta, GA (thomas.orlando@chemistry.gatech.edu)

Introduction: The existence of physisorbed water (H_2O) [1] or the water equivalent in the form of solar wind implanted hydroxyls (-OH) [2] in lunar surface soils and rocks has been postulated over decades. Sources of lunar water on and within the Moon are: primordial water, water delivered via comets and meteorites, released/formed during an impact event, and implantation from solar wind. These processes have been inferred from observations from the Moon Mineralogy Mapper (M^3) [1], Visual and Infrared Mapping Spectrometer (VIMS) [2], and Deep Impact Extended Investigation (DIXI) [3] and observed in laboratory settings [4-6]. Understanding how water interacts with lunar regolith yields key knowledge on the global evolution and allows us to assess the viability of *in-situ resource utilization* for long term habitation. As such, detecting and quantifying water and other volatiles released during a diurnal excursion and during an impact event is critical. Desorbing neutrals from the regolith from diurnal warm up or an impact event can be detected using a very light weight, low power consumption portable mass spectrometer that utilizes micro-plasma or cold electron ionization sources. All ions produced by these sources are injected into a ion trap mass spectrometer during the desorption/release process. The novel design/configuration allows *detection of water without the complicated background subtraction usually associated with hot-filament electron impact ionizers*. In addition, the design is modular allowing individual components to be retrofitted on other lunar lander missions. Furthermore, the miniature mass spectrometer components can be used in future SmallSat and CubeSat applications or can be a simple hand-held instrument for EVA operations.

Mass Spectrometer: Ion trap mass spectrometers have numerous operational parameters that make them ideally matched for *in situ* mission applications; these include: higher trapping capacities, <1 amu mass resolving powers, low power consumption and are relativey easily fabricated. A commercially available ion trap mass spectrometer known as the Auto Resonant Ion Trap Mass Spectrometer (ARIT-MS)[7] will be adapted for this instument (Figure 1). The ARIT-MS is relatively simple with only three electrostatic lenses that form an anharmonic ion trap. In this configuration, the electrostatic lenses trap the ions and will then force them to oscillate at a particular natural frequency (hence, autoresonance) similar to the behaviour of a marble dropped into a parabolic bowl. The ions are trapped for

an indefinite amount of time. From here, ion ejection and subsequent mass detection is accomplished by sweeping the frequency on the exit plate. As it reaches the resonant frequency of that particular mass, the ion gains slightly more momentum with each oscillation until the amplitude exceeds the length of the trap, i.e. it is ejected. It is then detected via a secondary electron multiplier or relevant analogous ion detector. The inherit simplicity of this ion trap design makes it ideally suited for "on-board" or "on-surface" mass spectrometry. They are 1) compact in design (~15 cm in length), 2) low power (mW operational range), 3) do
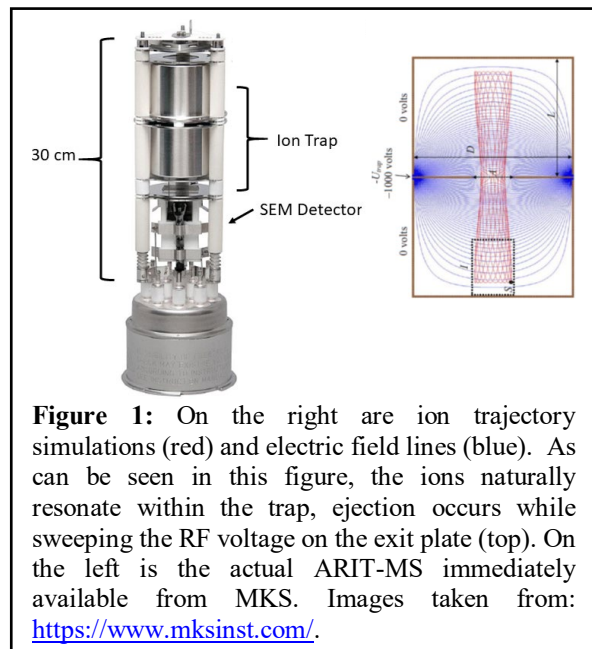

Figure 1: On the right are ion trajectory simulations (red) and electric field lines (blue). As can be seen in this figure, the ions naturally resonate within the trap, ejection occurs while sweeping the RF voltage on the exit plate (top). On the left is the actual ARIT-MS immediately available from MKS. Images taken from: https://www.mksinst.com/.

not require stringent manufacturing tolerances, 4) have high mass sensitivity as the integration (trapping time) is adjustable, 5) can have almost infinite mass range and 6) operates in continuous mode.

Ionization Sources: Micro-plasmas are weakly ionized discharges that represent a new and fascinating realm of plasma science. These micro-plasmas are based on the '*pd* scaling' breakdown of the well-known Paschen law due to the small (< 100 micron diameter pore size) dimensions and routine atmospheric pressure operation. Consequently, the applied voltage necessary to achieve a discharge condition is typically less than a few hundred volts and the overall power dissipation is minimal compared to other discharge sources. Typical configurations are referred to as micro-hollow cathode

discharges (MHCDs) and these can be operated using DC or pulsed potentials. In the latter case, monopolar pulsed (nsec) excitation leads to increased electron energy distributions while minimizing the gas temperature. When supporting the plasma with rare gases mixed with a few percent H_2, efficient production of atomic hydrogen Lyman-α (121.6 nm) and Lyman-β (102.5 nm) lines is possible [8-10]. The GIT group recently measured the 121.6 nm flux at JPL to be on the order of 10^{10} photons $cm^{-2}s^{-1}$. The GIT group also recently demonstrated that MHCD devices are useful, low weight and low power (~10 W) consumption sources for ionizing gas-phase molecules and desorbates released from solid and liquid samples[11, 12]. The MHCD shown in Figure 2a was constructed from two molybdenum foil electrodes, each 100 μm thick, separated by a thin (100 μm) mica insulating sheet
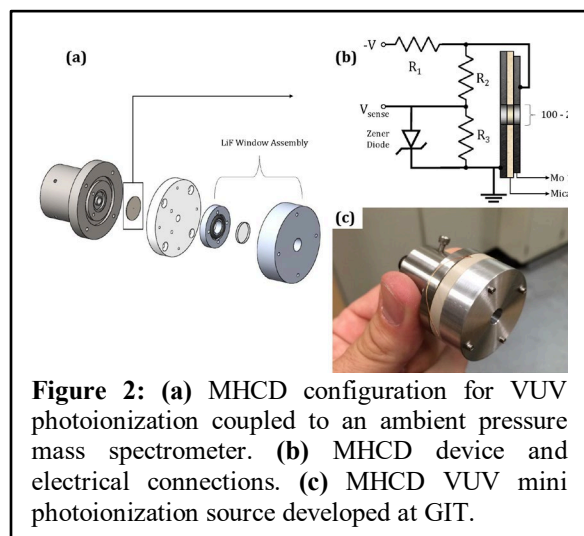

Figure 2: (a) MHCD configuration for VUV photoionization coupled to an ambient pressure mass spectrometer. **(b)** MHCD device and electrical connections. **(c)** MHCD VUV mini photoionization source developed at GIT.

and capped with a VUV transmitting LiF window. Figure 2b shows the electrical circuit and 2c the actual assembled device that can be easily scaled down in size.

Since the MHCDs with windows are limited to photon energies of 10.2 eV, they are unable to ionize several molecules of interest such as water (12.6 eV), nitrogen (15.58 eV), hydrogen (15.43 eV) carbon dioxide (13.7 eV), carbon monoxide (14.0 eV), and methane (12.6 eV). Therefore, we are proposing to also implement a simple cold electron impact ionization source utilizing low power UV emitting photodiodes and photon electron multipliers. Here, a commercially available deep ultraviolet ($\lambda = 255 \pm 10$ nm) range light-emitting diode (UVTOP255) is directly coupled with a chevron stack of two multichannel plates of approximately 12 mm in diameter. Ultraviolet photons then strike the surface of the MCP stack initiating an exponential generation of electrons. The cascade of electrons emitting from the surface of the MCP plate are biased relative to ground to accelerate the electrons to an appropriate kinetic energy for impact ionization.

These sources have been characterized in the literature[13] with typical emission currents in the 10 μA range. These sources are readily assembled and utilize simple off the shelf components, are of low power consumption, have a much longer lifetime than a standard hot filament electron source, *do not outgas* thereby eliminating possible data artifacts, and can be assembled as an array in the event of failure compensated with redundancy. *Note these micro-plasma and cold electron impact ionization sources can be retrofitted to any mass spectrometry system (such as designs with flight heritage).*
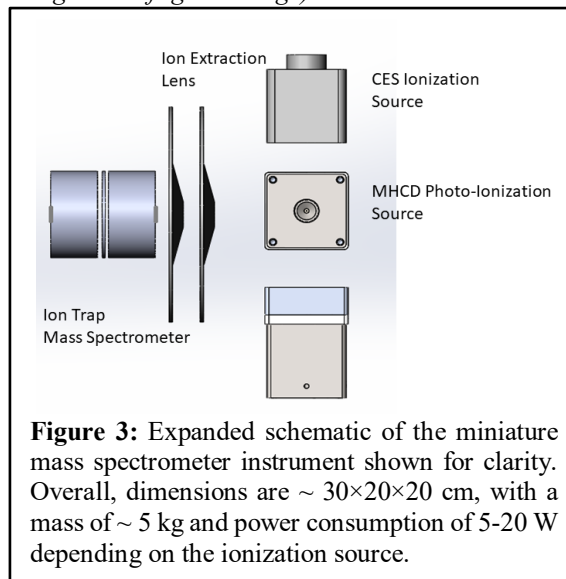

Figure 3: Expanded schematic of the miniature mass spectrometer instrument shown for clarity. Overall, dimensions are ~ 30×20×20 cm, with a mass of ~ 5 kg and power consumption of 5-20 W depending on the ionization source.

Physical Parameters: A schematic of the instrument is shown in Figure 3. Overall the physical dimensions are approximately 30×20×20 cm. The mass of the instrument is approximately 2 kg including the gas storage tanks that are necessary for the operation of the MHCD. Dimensions and mass of the control electronics is estimated at 5 kg. Crew interaction is variable as it may be used as a handheld device or a permanent data recorder at a specified location.

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