4D CHARACTERIZATION OF THE LUNAR VOLATILE CYCLE USING *IN SITU* MASS SPECTROMETRY. B. A. Cohen[1], K. E. Mandt[2], and R. D. Arevalo, Jr.[3]. [1]NASA Goddard Space Flight Center, Greenbelt MD (barbara.a.cohen@nasa.gov), [2]JHU Applied Physics Laboratory, Laurel MD; [3]University of Maryland, College Park MD.

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, addressing NASA science and exploration goals. 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]. 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. Characterizing lunar volatile reservoirs and evaluating their interrelations is a high priority for both lunar science and for human exploration purposes, as water is an essential component of *in situ* resource utilization objectives.

Multiple spacecraft have observed water and hydroxyl in the lunar mid-latitudes, as detected in IR and FUV reflectance spectra [5-10]. These surface reflectance features may exhibit seasonal and possibly even diurnal variabilities. The LADEE Neutral Mass Spectrometer (NMS) and UltraViolet Spectrometer (UVS) identified the primary atmospheric constituents at altitude, their density, and variability [1, 4]. To date, water and OH have only been reported in the exosphere during meteor stream events by the LADEE NMS and UVS [11]. A definitive observation of exospheric water and OH released from the surface during nominal times remains elusive.

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, both important to future human activities. The exposed regolith is constantly being activated through bombardment by the solar wind and impactors, creating sites that bind volatile species such as water; the water molecules will outgas from the surface over time as the surface is progressively warmed, informing our models of plume-originating water retention in the actual space environment.

Instrumentation: The only surface exospheric measurement was made by the Lunar Atmospheric Composition Experiment (LACE) on Apollo 17. LACE was a miniature magnetic sector mass spectrometer deployed on the surface and oriented to intercept and measure the downward flux of gases. This instrument had a mass range of 1-110 amu and a sensitivity of 1 cps (~200 cm^{-3}), 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 endogenous gases, argon and helium. Possible pre-sunrise detections of other species were obtained (see review in [12]), but only upper limits were determined for most of the volatile species of interest, including N_2, CO, CO_2, and CH_4; OH/H_2O was not determined due to the high backgrounds both inside and outside the instrument.

Astrobotic's Peregrine-1 lander (currently scheduled for late 2022) will be the first to emplace landed mass spectrometers since the LACE experiment. The lander is targeted for the Lacus Mortis basaltic lava plain in the northeastern part of the Moon at ~45°N latitude. Three mass spectrometers will make complementary measurements, arrayed in different orientation in azimuth and elevation around the lander. Observations collected by the Peregrine Ion Trap Mass Spectrometer (PITMS) [13] will complement the descent plume characterization provided by the Surface and Exosphere Alteration by Landers (SEAL) instrument [14]. The third mass spectrometer, the Mass Spectrometer Observing Lunar Operations (MSolo) instrument [15], is also carried on several other CLPS deliveries. On the Masten 19C payload, it will passively sniff the exosphere in a manner similar to the Peregrine-1 mission from a south polar site. On PRIME-1 and VIPER, MSolo will primarily be used to assess the volatile abundance of drilled soil samples, but can also be used in a passive mode for exospheric observations.

Creating a 4D Understanding: Though manifested individually, multiple mass spectrometers going to the lunar surface should be thought of as a cohesive network that will provide temporally- and spatially-resolved measurements of OH/H_2O on the lunar surface, along with improved quantification of exospheric species of interest to both science and human exploration. Multiple measurements of the lunar atmosphere and surface-lander interactions can be incredibly valuable, particularly from multiple landing sites and during different seasons.

These investigations will provide measurements of the exosphere to significantly improve our knowledge of the abundance and behavior of volatiles on the Moon, linking the lunar surface to LADEE measurements from orbit, and informing future robotic and human mission design. Another area that could be explored with multiple mass spectrometers on the surface is outgassing from the interior. Observations from Apollo and later by LRO suggest the Aristarchus region as a potential source (e.g., [16]). Measuring outgassed species before the exosphere is swamped by robotic and human activity could elucidate key details of lunar interior structure and composition.

We recommend that NASA continue to invest in mass spectrometry instrumentation and deploy these capabilities as frequently as possible, ideally in more and more capable situations (longer lifetimes, terminator/overnight operations, etc.). A coordinated campaign of exospheric mass spectrometry measurements, linking observations made from global locations, through diurnal and seasonal cycles, and under other effects like meteor showers and robotic and human activities, will help resolve high-priority, Decadal-level science questions.

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