LUNAR VOLATILE SYSTEM DYNAMICS: OBSERVATIONS ENABLED BY THE DEEP SPACE GATEWAY. C. I. Honniball[1] , P. G. Lucey[1], N. Petro[2] D. Hurley[3], W. Farrell[2], [1]University of Hawaii at Manoa, 1680 East-West Rd, Honolulu, HI 96822, cih@higp.hawaii.edu, [2]NASA/Goddard Space Flight Center, Greenbelt, MD 20771, [3]The Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723

Introduction: A decade of observations from many spacecraft has shown that the Moon possesses a dynamic volatile system that includes interaction with the solar wind and coronal mass ejections, micrometeorites and larger objects, and outgassing from the lunar interior with time-varying signals present in the atmosphere and on the surface. While low altitude orbital measurements are invaluable, several of the proposed Deep Space Gateway orbits offer a unique vantage point for long duration remote sensing monitoring of the lunar volatile system. In addition, the potential for higher power and mass instruments are enabling of measurements impractical for smaller spacecraft. We present a notional science and technical case for dedicated long duration remote sensing of the Moon to understand the dynamics of its volatile system.

Science Case: In the present epoch it appears that the principal sources of volatiles to the Moon are the solar wind (including solar storms) and meteorite impact, with lesser contributions from outgassing or sputtering (K, Na, Rd [1]). Redistribution of ancient volatiles by moderate impacts capable of reaching depths of several meters may also be a source of volatiles into the lunar volatile system. Solar wind principally supplies hydrogen in the form of moderate energy protons; reactions with the surface appear to supply H_2 to the atmosphere [2]. The time-variable 3 micron surface absorption [3] may also be due to solar wind input producing time-variable hydroxyl or possibly water. Formation of carbon compounds from solar wind C and H in surface chemical reactions is also proposed to explain methane detected in the atmosphere [4].

Meteorite impact can stimulate mobile volatile production in several ways. Common meteorite types contain water in various forms that can be released on impact. Some laboratory experiments indicate molecular water is not produced from proton irradiation under typical lunar conditions [5]. However, the temperatures achieved in meteorite impact may be high enough to enable production of water from a hydrogen enriched silicate surface.

Both the solar wind source and meteoritic sources are dynamic. Solar wind is variable on the solar cycle timescale, and if coronal mass ejections are included the energy and flux of solar particles vary by orders of magnitude. The solar wind flux to the surface is also modulated by the Moon's passage through the Earth's magnetotail and this passage is known to strongly affect the flux of He in the lunar atmosphere [6].

An important result of the LADEE mission was that meteor streams had a strong effect on atmospheric species including water [7,8].

While these observations have been invaluable, there are numerous unanswered questions. Among these are whether water is produced on the lunar surface and propagates to the poles, charging polar cold traps, or is the time variable surface signal an artifact or due to hydrogen and hydroxyl chemistry occurring within surface grains producing no mobile species other than H_2? The hydrogen budget itself is not fully accounted for and it is unknown whether hydrogen is in accumulation, equilibrium or loss from the Moon. Observations from the Deep Space Gateway may provide a means to answers to these questions.

The Gateway Vantage Point: While the orbit of the Deep Space Gateway is as yet undetermined, studies suggest an extremely eccentric orbit with apolune tens of thousands of kilometers above the lunar surface is likely [9]. From many of these candidate orbits the Moon would subtend only a few degrees for most of the orbit, enabling a synoptic view of the Moon for remote sensing, and enabling simultaneous imaging of the entire lunar atmosphere nearly continuously. For higher resolution observations, the final orbit may not include very low perlunes, but even a few thousand km range offers the potential for relatively high resolution observations with modest telescopes.

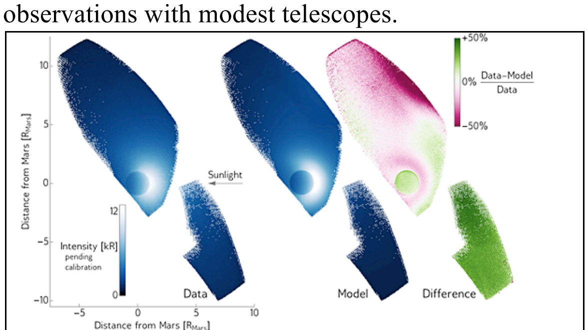

Figure 1. Images of atomic hydrogen corona around Mars obtained by the MAVEN mission.

The Gateway Resource Advantage: A remote sensing package on a crewed spacecraft is offered several advantages not typically present in dedicated science mission satellites: mass, power, thermal control and serviceability. As we will see below, a key water-related infrared observation is probably impractical on a Discovery class mission owing to its mass, power consumption, and heat dissipation.

Proposed Experiment: The MAVEN spacecraft provided dramatic imagery of the entire extended Mars atmosphere during its approach to that planet (Figure 1), synoptic observations that could not be repeated once in orbit [10]. Lunar column densities are far lower [11], so a similar result would require longer integration times, nevertheless, a sensitive UV spectrometer or imager would enjoy long counting times at long ranges for many of the proposed Gateway orbits and provide long duration monitoring of the lunar atmosphere, and detailed correlations of its composition and dynamics with volatile inputs and their variations.

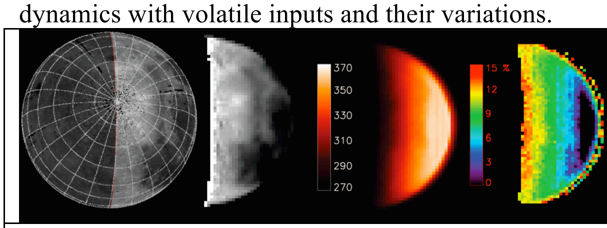

Figure 2. Deep Impact IR view of the lunar North Pole showing the depth of the 3 micron water feature (right). A similar map at 6 microns would definitively show the abundance of molecular water, day and night.

An outstanding question regarding lunar surface volatiles is the nature of the time variable 3 micron absorption feature reported by Sunshine et al. [3]. It has long been hypothesized that solar wind hydrogen can cause production of hydroxyl by reaction with lunar surface oxygen [eg. 12], and that formation may include water and that this water may migrate to the lunar poles and be trapped in regions of permanent shadow[13]. However, the relative abundance of water and hydoxyl is unknown [3] and there have been doubts cast on the time variability of the spectral feature owing to disagreements surrounding correction for thermal emission contamination of the reflectance signal [14].

Table 1. Gateway resource requirements

Instrument Analog	Mass	Power	Volume m^3	Special requirements	Orbit
MAVEN IUVS	30 kg	30W	0.1	Pointing system	Apolune > 50,000 km
GHAPS Cross-dispersed IR spectrograph	100 kg	100W	0.1	Access to Gateway thermal control	Perilune <1000 km

Molecular water exhibits a narrow emission feature near 6 microns due a fundamental vibration, and at these long wavelengths, solar reflected flux is minimal, so detection and mapping of a 6 micron feature provides definitive characterization of molecular water. Emitted fluxes are strongly dependent on temperature, and within the limitations of a modest spacecraft detection and mapping is likely limited to temperatures above 220K (about 70 degrees of latitude). However, the potential for power in the 100W range on the Gateway would enable a fully cryogenic instrument that could map the extent of water on the lunar nightside as well as dayside at a resolution of 1 km. This capability would enable direct detection of lunar surface water variations in the 10s of ppm range.

References:

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