

Measurements to Understand the Origin and Evolution of Hydroxyl and Water on the Illuminated Moon C.

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Introduction.

The presence and distribution of water and hydroxyl in the inner solar system, including the Moon, are of particular interest for their implication to the evolution of solar system and as potential resources for sustaining human exploration. Hydroxyl and possibly molecular water was discovered in the surface of the illuminated Moon in 2009 from measurements by three independent spacecraft (Pieters et al., 2009; Sunshine et al., 2009; Clark, 2009). These initial measurements and subsequent analyses (e.g. McCord et al., 2011) demonstrate the chemical form is hydroxyl with some indication molecular water could also be present. There is also evidence for diurnal variation between noon and evening (e.g. Sunshine et al., 2009) though it is debated whether the mechanism responsible for this variation is due to a change in abundance or can be ascribed to photometric effects because the observations are obtained at different emission and incident angles.

Discussion

Multiple hypotheses exist as to the origin and evolution volatiles on the illuminated Moon, with contributions including solar wind, cometary, internal lunar water, and sputtered polar water possible. Considerable theoretical and laboratory work explored various mechanism related to its origin, evolution, chemistry, and physical state(s) resulting in an increased understanding of the interaction between solar wind particles, molecular water, and regolith materials. Laboratory experiments and modeling generally suggest a solar wind origin for the majority of the observed OH on the illuminated Moon. Lunar agglutinate glasses have been found to have a D/H ratio consistent with a significant component derived from solar wind implantation (Liu et al., 2012). Laboratory measurements have demonstrated that a hydroxyl absorption feature in the IR is produced in lunar samples that are irradiated with protons or deuterons, analogous to solar wind formation of OH in lunar soils (e.g. Ichimura et al. 2012). Temperature programmed desorption measurements and subsequent modeling demonstrate there will be a temperature dependency in the stability of hydroxyl and water (Hibbitts et al., 2011; Poston et al., 2013), and there will likely be a compositional dependency in this thermal stability (e.g. Poston et al., 2015), as well as a potential compositional dependency on the shape, position, and strength of the IR absorption feature associated with adsorbed or internal hydroxyl (Dyar et al., 2012). Solar wind particles may also migrate from

the illuminated Moon to the poles (e.g. Crider and Vondrak, 2000) to significantly contribute to the observed elevated volatile abundance at the poles (e.g. Feldman et al., 1998; Lawrence et al., 2006). However, models also suggest the very small amounts of volatiles observed on the illuminated Moon would be very stable, chemically bound to the lunar grains and difficult to remove (e.g. Starukina & Shkuratov, 2000).

To more fully understand water on the Moon, a more complete understanding is needed of the sources, sinks, evolutionary paths, and abundances of the hydroxyl and possible water already detected on the illuminated portion of the Moon. Inference from existing measurements is hampered by limitations including one or more of insufficient spectral range, observations obtained from different times of day and with different photometry, varying surface temperatures, and insufficient sampling of any one terrain over a large portion of a lunation. To understand the origin and evolution of hydroxyl and potentially water on the illuminated Moon, spectral imaging measurements over a large fraction of a lunation or longer would be able to observe the potential increase and loss of volatile from the illuminated lunar surface. The spectral range will need to include the infrared where hydroxyl, molecular water, and ice absorb; all at slightly different wavelengths between 2.6 and 3.6 μm . Spectral sampling would ideally be continuous such as with a hyperspectral pushbroom spectrometer. Spectral resolution needs to be no better than ~ 20 nm to resolve the exact position of the possibly compositionally dependent absorption feature of hydroxyl in the lunar surface while significantly coarser resolution would still enable the discrimination of hydroxyl from molecular water or ice (Figure 1). Because the maximum absorption of OH is between 2.7 and 2.9 μm while the absorption feature of molecular water is centered near 2.95 μm and water ice near 3.1 μm , a multispectral approach would be able to discern locations that contain mixtures of these states of water. Global imaging, at a resolution applicable to geologic features would be able to investigate the potential temperature, compositional, geologic, and photometric relationships in the volatile abundance. Repeated measurements of terrain can be used to isolate possible effects of temperature, composition, and illumination on volatile abundance, especially if the Moon is observed over multiple lunations at different viewing geometries.

Two Potential Mission Approaches to this Measurement. These observations are not possible with ground-based or current aircraft borne instrumentation, as neither is capable of obtaining both the spectral coverage and repeated coverage through-out a lunation, or are not able to track the Moon. However, either a lunar orbiter, or a multi-week stratospheric balloon borne observatory could obtain these measurements using instrumentation very similar what has already flown, such as the Chandrayaan-1 M3 imaging spectrometer and the BRRISON Infrared Camera with a 9-position cryogenic filter wheel. For instance,

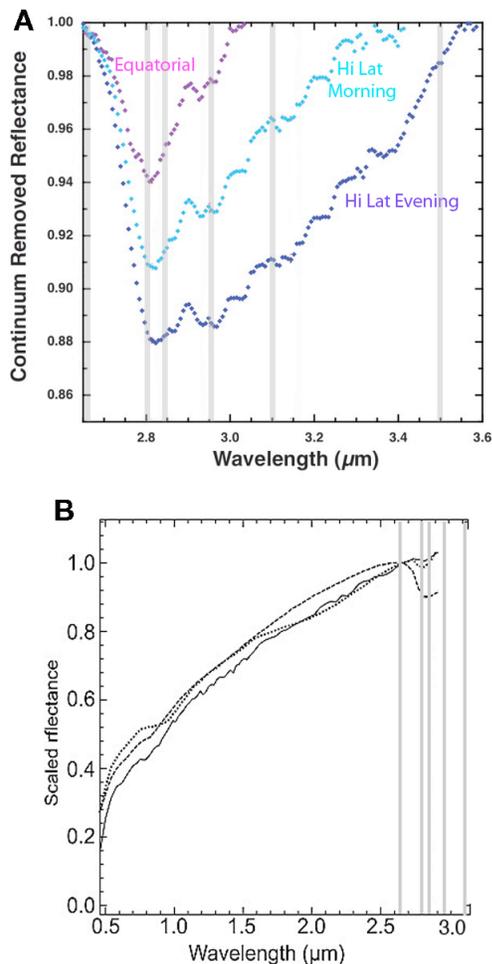


Figure 1. (a) Modified Sunshine, 2009, Figure 1, showing how only 6 bands can characterize this absorption feature including the possible change in bandshape in EPOXI data that is resolved by sampling at 2.8 and 2.85 microns. (b) Modified McCord et al., 2011, Figure 6, showing how just 5 bands could characterize changes in bandshape. Note, the BRRISON Infrared Camera can sample 9 wavelengths.

a precessing elliptical lunar orbit would enable global coverage of the near and far side during apoapsis and potentially excellent coverage of high latitudes. An earth-based long-duration balloon flight has already been demonstrated to be able to make the required multispectral imaging measurements with a current imaging capability of 2 km/pixels at the equator (Cheng et al., 2014; Hibbitts et al., 2015).

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