Cubesat-based Infrared Lunar Astronomy: Water-ice Signatures

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Analyses of infrared absorption spectra have identified water and hydroxyl (–OH) absorption bands at ~3 µm within the lunar surface. Spatial distribution of the –OH signal suggests that water is formed by the interaction of the regolith-embedded solar wind with silicates and other oxides in the lunar regolith. Solar wind H and He are released from grains of the molten lunar-produced glass, after partly reducing the contained FeO to produce water.

Purpose

To explore different water-ice signatures on the moon and the infrared technologies employed in their investigation by prospective cubesat-intended Artemis payloads in the near future ---

1. Lunar Flashlight
2. Lunar IceCube
3. Lunar-H Mapper.

Method

A literature review of infrared findings of lunar characteristics was summarized to include challenges of their respective data collection. Inferences from the findings were elaborated, suggesting additional objectives for further investigation into lunar water-ice signatures. Infrared technologies being developed were described as payloads for prospective cubesat or rover deployment on the moon were described.

OASIS embraces an overarching science theme of "following water from galaxies, through protostellar systems, to oceans." This theme requires space-borne observations of galaxies, molecular clouds, protoplanetary disks, and solar system objects. From its Sun-Earth L1 halo orbit.

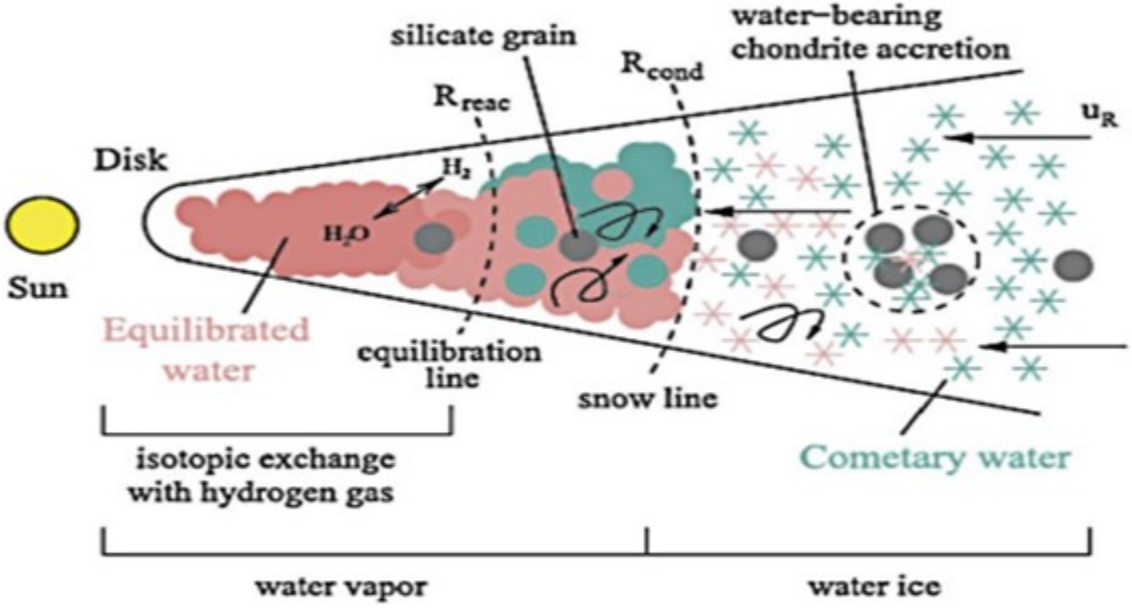
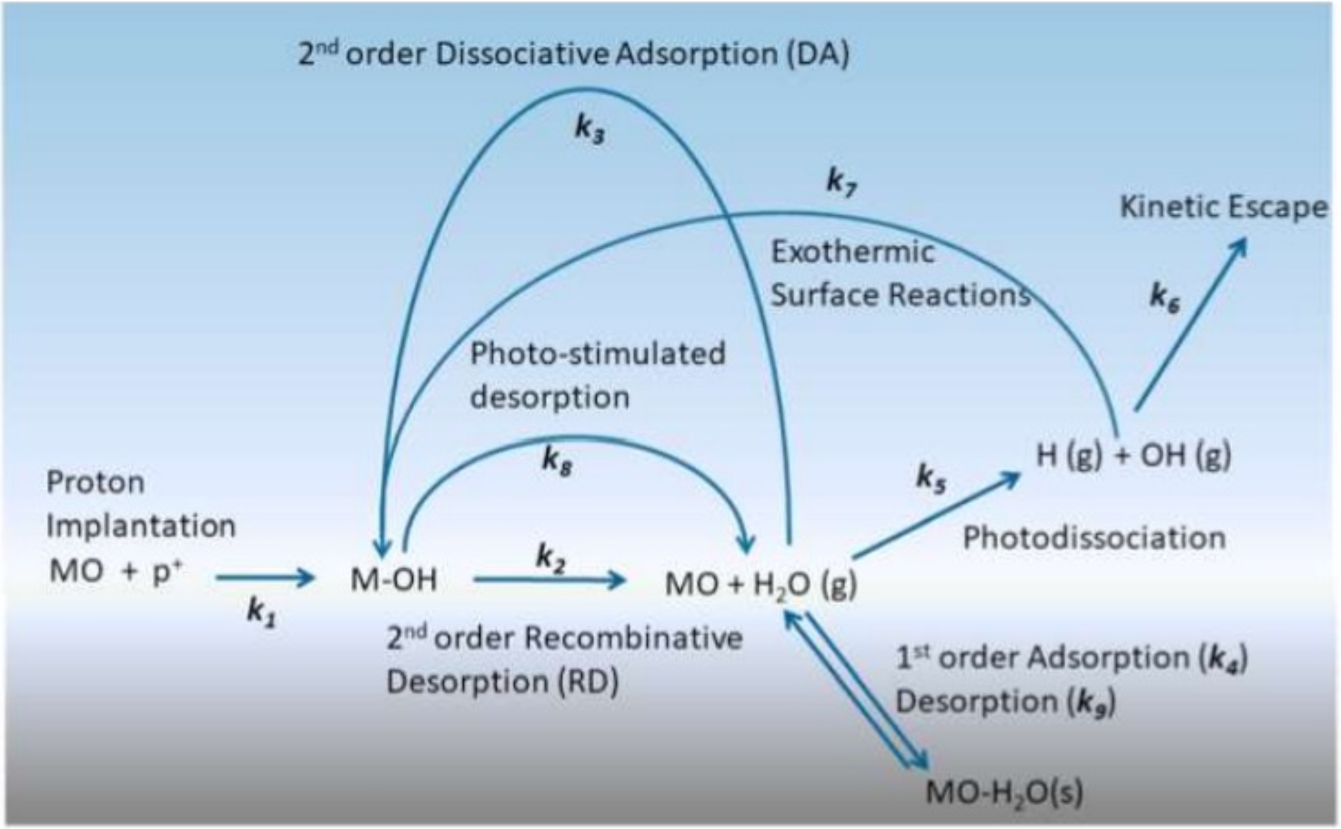


Figure 2. Illustration of the formation of a D/H gradient with heliocentric distanceOASIS will permit probing conditions across this gradient. Vertical mixing of ice grains to the photosphere of the disk where photodesorption and photochemistry produces atomic oxygen. This atomic oxygen is then transported downwards again where chemistry reforms it into H2O and HDO on ice grain surfaces but with much reduced deuterium fractionation (see for example becomes very important. The key process is mixing of ice grains to the surface of the disk.

Chemical Kinetics Model: Solar Wind-induced Water Cycle

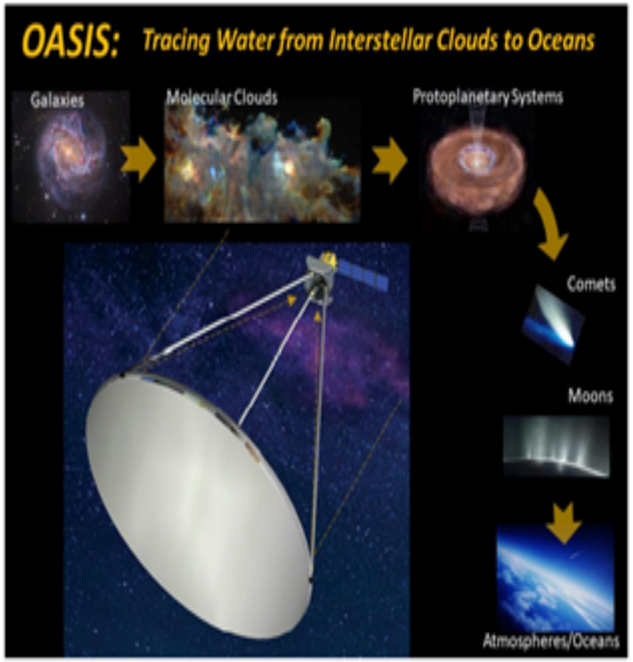
Utilizing available data sets on temperature-driven water formation and desorption from metal oxides (e.g., SiO_2, TiO_2, and Al_2O_3 with surface hydroxyl defects(-OH) and experimental data from a lunar mare regolith Apollo sample (10084), the 2.8 µm Optical signal on the Moon is modeled. Specifically, the presence and persistence of this band result from the balance of formation and loss mechanisms associated with solar wind production and thermal transformation of hydroxyls on and within the regolith. Though this mechanism forms gas-phase H_2O on the sunlit side, photodissociation and photo dissociative adsorption lead to rehydroxylation and very limited exospheric water over a lunation.



Case	Lat	Time of Day hrs	Temp K	Total Signal/Reflectivity @ 3um photons/sec		SNR	Band depth/PPM water		
							0.1 @ 1000	0.05 @ 500	0.01 @ 100
1	0	+/-6.2	163	3254	2760	52	276	138	27
2	60	0 noon	335	39045	26400	162	2640	1320	264
3	20	+/-4.3	304	24279	20963	145	2096	1480	210
4	0	0 noon	395	150777	52800	230	5280	2640	528

Water-ice lunar signature 1.

The first evidence for water ice on the Moon came from observations of neutrons from the Lunar Prospector orbiter, where neutron flux spectra were interpreted as providing evidence for hydrogen in the form of water ice at the lunar poles. Direct evidence for hydration on the lunar surface was detected by the Moon Mineralogy Mapper (M3) on the Chandrayaan-1 orbiter, by the EPOXI mission during a lunar flyby, and by Cassini/VIMS during its lunar flyby en route to Saturn. These 3-mm observations showed a mixture of adsorbed water and OH in the lunar regolith.



With its large collecting area and suite of terahertz heterodyne receivers, OASIS will have the sensitivity to follow the water trail from galaxies to oceans, as well as directly measure gas mass in a wide variety of astrophysical objects from observations of the ground-state HD line.

Figure 1. OASIS Concept. The science objectives of OASIS are met by utilizing a 17-meter inflatable aperture and cryogenic, terahertz receivers operating in a Sun-Earth L1 Halo Orbit. From this vantage point, the unparalleled sensitivity of OASIS will, for the first time, describe the water trail from galaxies to oceans.[1]

Measuring H_2 Abundance on Lunar Surface to Infer H_2O Presence

Inversing water ice from neutron data (Neutron Spectrometer)

- The cosmic rays of the Milky Way interact with the surface of the moon to generate a stream of neutrons.

- After a series of elastic or inelastic collisions with the nucleus of lunar surface agglutinates, neutrons form a balanced energy spectrum on the lunar surface distribution.

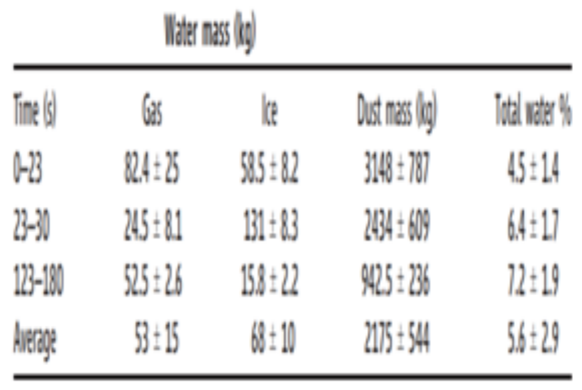
- Hydrogen atoms and neutrons have the same mass, so the superthermal neutrons are the most sensitive to the existence of hydrogen. If the hydrogen abundance in a certain area is high, the hyperthermal / fast neutrons ($0.5eV< Energy <0.5$ MeV) loses energy and becomes thermal neutrons ($< 0.5eV$). So,

- Neutron spectrometer determines H_2 Abundance by measuring the decrease in the flux of superthermal neutrons and the increase in the flux of thermal neutrons.

- The superheated neutron flux is inversely proportional to the hydrogen content in the region. Scientists rely on this to determine the hydrogen abundance on the moon's surface, and then use the hydrogen abundance to vaguely judge the water ice content in the region.

Water-ice lunar signature 2.

On 9 October 2009, a spent Centaur rocket struck the persistently shadowed region within the lunar south pole crater Cabeus, ejecting debris, dust, and vapor. This material was observed by a second “shepherding” spacecraft, which carried nine instruments, including cameras, spectrometers, and a radiometer. Near-infrared absorbance attributed to water vapor and ice and ultraviolet emissions attributable to hydroxyl radicals support the presence of water in the debris. The maximum total water vapor and water ice within the instrument field of view was 155 T 12 kilograms. Given the estimated total excavated mass of regolith that reached sunlight, and hence was observable, the concentration of water ice in the regolith at the LCROSS impact site is estimated to be 5.6 T 2.9% by mass.



	Water mass (kg)			
Time (s)	Gas	Ice	Dust mass (kg)	Total water %
0–23	82.4 ± 25	58.5 ± 8.2	3148 ± 787	4.5 ± 1.4
23–30	24.5 ± 8.1	131 ± 8.3	2434 ± 609	6.4 ± 1.7
123–180	52.5 ± 2.6	15.8 ± 2.2	942.5 ± 236	7.2 ± 1.9
Average	53 ± 15	68 ± 10	2175 ± 544	5.6 ± 2.9

It is difficult to differentiate water vapor that sublimated from water ice grains in sunlight from water vapor sublimated from heated surfaces in and near the crater; thus, these estimates for the total mixing ratio of water in the ejecta cloud, based on the mass of ejecta observed in sunlight, are likely to be overestimates during this early period when the ejecta cloud was smaller than the instrument FOV.

Table 1. Summary of the total water vapor and ice and ejecta dust in the Near InfraRed instrument field of view. Values shown are the average value across the averaging period, and errors are 1 SD.

Lunar Polar Hydrogen Mapper (LunaH-Map)	To produce a high-resolution map of the Moon's bulk water deposits, unveiling new details about the spatial and depth distribution of potential ice previously identified during a variety of missions.	The Miniature Neutron Spectrometer (Mini-NS) uses a set of CLYC scintillators to detect neutrons and has a gadolinium shield to provide sensitivity primarily to neutrons above 0.5 eV.
Lunar InfraRed Imaging (LunIR)	To collect data about the lunar surface: --material composition --thermal signatures -- presence of water. LunIR's infrared sensor will map the Moon during both day and night and can collect data at much higher temperatures than similar sensors per innovative micro-cryocooler technology (t0 -234 degrees F)..	Minerals such as pyroxene, plagioclase, olivine, and ilmenite, in different sizes and shapes, constitute most of the lunar surface rocks. They have distinctive spectral characteristics in the Visible and Near-infrared (VIS/NIR) wavebands.
Lunar IceCube	To prospect, locate, and estimate amount and composition of water ice deposits on the Moon	BIRCHES, Broadband InfraRed Compact, High-resolution Exploration Spectrometer to characterize and distinguish important volatiles (water, H2S, NH3, CO2, CH4, OH, organics) and mineral bands, BIRCHES has the high spectral resolution (5nm) and wavelength range (1 to 4μm) needed to distinguish phase states of water.
Lunar Flashlight	To explore, locate, and estimate size and composition of water ice deposits on the Moon	To carry an active multi-band reflectometer to measure the reflectance of the lunar surface from orbit near water ice absorption peaks.
OMOTENASHI (Outstanding MOon exploration TEchnologies demonstrated by NAno Semi-Hard Impactor)	Small spacecraft and semi-hard lander of the 6U cubesat format that will demonstrate low-cost technology to land and explore the lunar surface.	
Lunar Compact Infrared Imaging System (L-CIRiS)	Includes a radiometer determining the thermal stability of volatiles based on temperature measurements.	To determine the presence and abundance of water ice and other volatiles on lunar surface and subsurface.

CLPS Payloads for 2022

Company

- Peregrine and Griffin Landers (Astrobotic Technologies)
- Nova - C lander (Lockheed Martin Space)
- XL-1 lander (Masten Space Systems)
- Genesis/ Blue Ghost lander (Firefly Aerospace)

Payload Instruments

- Linear Energy Transfer Spectrometer, to monitor the lunar surface radiation.
- Magnetometer, to measure the surface magnetic field.
- Low-frequency Radio Observations from the Near Side Lunar Surface, a radio experiment to measure photoelectron sheath density near the surface.
- A set of three instruments to collect data during entry, descent and landing on the lunar surface to help develop future crewed landers.
- Stereo Cameras for Lunar Plume-Surface Studies is a set of cameras for monitoring the interaction between the lander engine plume and the lunar surface.
- Surface and Exosphere Alterations by Landers, another landing monitor to study the effects of spacecraft on the lunar exosphere.
- Navigation Doppler Lidar for Precise Velocity and Range Sensing is a velocity and ranging lidar instrument designed to make lunar landings more precise.
- Near-Infrared Volatile Spectrometer System, is an imaging spectrometer to analyze the composition of the lunar surface.
- Neutron Spectrometer System and Advanced Neutron Measurements at the Lunar Surface, are a pair of neutron detectors to quantify the hydrogen -and therefore water near the surface.
- Ion-Trap Mass Spectrometer for Lunar Surface Volatiles, is a mass spectrometer for measuring volatiles on the surface and in the exosphere.
- Solar Cell Demonstration Platform for Enabling Long-Term Lunar Surface Power, a next-generation solar array for long-term missions.
- Lunar Node 1 Navigation Demonstrator, a navigation beacon for providing geolocation for orbiters and landing craft.

Thank you,
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