EPSC Abstracts
Vol. 10, EPSC2015-829, 2015
European Planetary Science Congress 2015

Quantifying the Lunar Hydrogen Cycle: A Fast, Effective, and Economical CubeSat Approach

Michael R. Collier (1), M.L. Adams (1), S. Barabash (2), P.C. Calhoun (1), P.E. Clark (3), W.M. Farrell (1), D.C. Folta (1), J. Halekas (4), S.E. Haque (5), D.M. Hurley (6), M. Keidar (5), J.W. Keller (1), R.M. Killen (1), C. Kletzing (4), R.J. MacDowall (1), B.K. Malphrus (7), R.R. McNeil (7), R.R. Vondrak (1), and M. Wieser (2)

(1) NASA/GSFC, (2) Swedish Institute of Space Physics, Kiruna, (3) Catholic University of America, (4) University of Iowa, (5) George Washington University, (6) JHU/APL, (7) Morehead State University

Abstract: The Lunar H Albedo

The Moon breathes hydrogen: solar wind protons and micro-meteoroids deliver hydrogen to the lunar surface at local rates that depend on surface composition, local topography, and the presence of structures such as magnetic anomalies. Because the lunar surface is generally saturated with hydrogen, the implanted hydrogen escapes the surface and forms the hydrogen exosphere through a variety of processes including sputtering, recoil, and diffusion - giving the surface an effective hydrogen “albedo.” These processes can lead to hydrogen deposition into cold traps and the formation of OH, and possibly water, through chemical alteration of oxygen-bearing minerals. Exospheric hydrogen is reclaimed by the solar wind as picked-up photoions and charge-exchange products. *The exact pathway for each of these processes remains unknown, especially at regional scales, and quantifying each of these processes in this “lunar hydrogen cycle” as a function of solar zenith angle and plasma and space environment will lead to a unified understanding of the plasma, exospheric, and geologic Moon.* CubeSats provide a fast, effective, and economical approach to quantifying the currently unknown parameters in the lunar hydrogen cycle.

1. Recent Results: A Paradigm Shift

The last 6 years have been paradigm-changing in lunar science, with the discovery of an active water and hydroxyl environment (i.e., water cycle) at the Moon. Besides the LCROSS confirmation of water existing within the lunar polar cold traps [2, 10], a set of IR sensors discovered an OH veneer that extends all the way down to the lunar equator, and which may even possess a modern, dynamic diurnal component [1, 8, 11]. The solar wind is on the “short list” of sources for this OH veneer (see review by McCord et al. [7]), yet the solar wind has its own cycle of H implantation and release that has yet to be fully investigated/quantified. If solar wind H is a component of the larger lunar water cycle, quantifying the amount that is lost back into space is vital in order to gain insights and understanding on the amount of H retained.

There are tantalizing recent observations of the complexity of the solar wind H/regolith interaction that suggest a large reflected hydrogen albedo. Using the ion analyzer onboard Kaguya, Saito et al. [9] detected a near mono-energetic population of backscattered protons off the lunar surface, in non-magnetic regions being a few percent of the incident solar wind. However, in magnetic anomaly regions, this reflected ion density increased to over 50% of the inflowing solar wind protons.

While surface-facing ion spectrometers observe an anomalous H^+ emission, the low energy neutral atom spectrometers onboard IBEX [6] and Chandrayaan-1 [5, 12] revealed the presence of non-thermal neutral H atom emission, with surface emission flux levels at ~10-35% of solar wind influx at energies >30 eV. The H atom emission also exhibits strong spatial variations with a significant reduction in neutral reflection within magnetic anomalies.

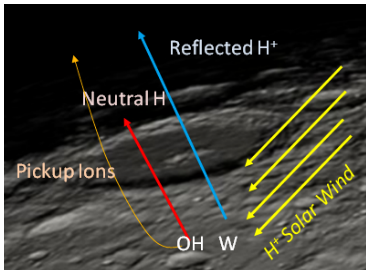

Figure 1: Surface-reflected hydrogen components.

A picture is developing (see **Figure 1**) in which incoming solar wind hydrogen seeds the lunar surface with OH (as a source of water) but also is backscattered from the surface to form an H-exosphere. A hydrogen budget has yet to be quantified, and is necessary to determine the amount of OH (and water) created by the solar wind. For example, Crider and Vondrak [3, 4] found that the solar wind was an adequate singular source of polar water if 100% of the solar wind is converted to water (to subsequently migrate to the poles). However, observations suggest that a substantial portion of solar wind may not be retained to form OH and water.

2. A CubeSat Approach

A 6U CubeSat with an ion spectrometer that observes simultaneously the impinging solar wind and the reflected ion component and a nadir-facing low-energy neutral atom imager that observes the upward moving neutral hydrogen will provide quantitative answers to important outstanding questions regarding the lunar hydrogen cycle by: (1) Obtaining a time-averaged back-scattered proton and hydrogen value from the lunar surface integrated over the mission lifetime with the spacecraft in close proximity to the surface, (2) Determining the regional mineralogy influence on proton and hydrogen albedo, (3) Quantifying the signatures of the putative diurnal migration of hydrogen products and determining their origin and (4) Deriving the space environment (i.e., impactors and solar storms) effects on anomalous escape of hydrogen.

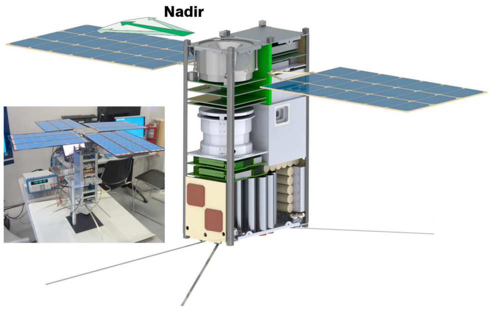

Figure 2: A CubeSat to quantify the lunar H cycle.

To this end, we have developed a CubeSat concept shown in **Figure 2**.

References

[1] Clark, R.N.: Detection of adsorbed water and hydroxyl on the Moon, Science, 326, 5952, 562-564, doi:10.1126/science.1178105, 2009.

[2] Colaprete, A., et al.: Detection of water in the LCROSS ejecta plume, 330, 6003, 463-468, doi:10.1126/science.1186986, 2010.

[3] Crider, D. and R. Vondrak: The solar wind as a possible source of lunar polar hydrogen deposits, J. Geophys. Res., 105, 26,773-26,782, 2000.

[4] Crider, D. and R. Vondrak: Space weathering effects on lunar cold trap deposits, J. Geophys. Res., 108, E7, doi:10.1029/2002JE002030, 2003.

[5] Futaana, Y., S. Barabash, M. Wieser, M. Homlstrom, C. Lue, P. Wurz, A. Schaufelberger, A. Bhardwaj, M.B. Dhanya, and K. Asamura: Empirical energy spectra of neutralized solar wind protons from the lunar regolith, J. Geophys. Res., 177, E05005, doi:10.1029/2011JE004019, 2012.

[6] McComas, D.J. et al.: Lunar backscatter and neutralization of the solar wind: First observations of neutral atoms from the Moon, Geophys. Res. Lett., 36, L12104, doi:10.1029/2009GL038794, 2009.

[7] McCord, T.B., L.A. Taylor, J.-P. Combe, G. Kramer, C.M. Pieters, J.M. Sunshine, and R.N. Clark: Sources and physicsl processes responsibe for OH/H_2O in the lunar soil as revealed by the Moon Mineralogy Mapper (M^3), J. Geophys. Res., 116, E00G05, doi:10.1029/2010JE003711, 2011.

[8] Pieters, C.M. et al.: Character and spatial distribution of PH/H2O on the surface of the moon seen by M-3 on Chandrayaan-1, Science, 325, 5952, 568-572, doi:10.1126/science.1178658, 2009.

[9] Saito, Y., et al.: Solar wind proton reflection at the lunar surface: Low energy ion measurement by MAP‑PACE onboard SELENE (KAGUYA), Geophys. Res. Lett., 35, L24205, doi:10.1029/2008GL036077, 2008.

[10] Schultz, P.H., B. Hermalyn, A. Colaprete, K. Ennico, M. Shirley, and W.S. Marshall: The LCROSS cratering experiment, Science, 330, 6003, 468-472, doi:10.1126/science.1187454, 2010.

[11] Sunshine, J.M., T.L. Farnham, L.M. Feaga, O. Groussin, F. Merlin, R.E. Milliken, and M.F. A'Hearn: Temporal and spatial variability of lunar hydration as observed by the Deep Impact spacecraft, Sciencexpress, 8 pp., doi:10.1126/science.1179788, 2009.

[12] Wieser, M., S. Barabash, Y. Futaana, M. Holmström, A. Bhardwaj, R. Sridharan, M.B. Dhanya, P. Wurz, A. Schaufelberger, and K. Asamura: Extremely high reflection of solar wind protons as neutral hydrogen atoms from regolith in space, Planet. Space Sci., 57, 2132-2134, 2009.