

SPATIAL VARIATION OF LUNAR SURFACE HYDRATION AND THE IMPLICATIONS FOR ITS SOURCES: SOLAR/EARTH WINDS OR OTHERS? H. Z. Wang¹, J. Zhang^{1*}, Q. Q. Shi^{1*}, K. K. Khurana², I. J. Rae³, J. Liu⁴, R. L. Guo⁵, J. Chen¹, A. M. Tian¹, S. T. Yao¹, S. C. Bai¹, H. Zhang⁵, Z. C. Ling¹, X. H. Fu¹, Y. Wei⁵, W. L. Liu⁶, S. Y. Fu⁷, Q. G. Zong⁷, Z. Y. Pu⁷; ¹Shandong Prov Key Lab Opt Astron & Solar Terr Env, Sch Space Sci & Phys, Shandong Univ, Weihai, China (sqq@sdu.edu.cn; zhang_jiang@sdu.edu.cn); ²Inst Geophys & Planetary Phys, Los Angeles, CA; ³Mullard Space Sci Lab, Dept Space & Climate Phys, Univ Coll London, Dorking, England; ⁴State Key Lab Space Weather, NSSC, CAS, Beijing, China; ⁵Inst Geol & Geophys, CAS, Beijing, China; ⁶Space Sci Inst, Sch Astronaut, Beihang Univ, Beijing, China; ⁷Sch Earth & Space Sci, Peking Univ, Beijing, China.

Introduction: Recent studies suggest a wet Moon with unambiguous evidences of various forms of lunar water (e.g., polar ice and global OH/H₂O) based on orbital observations [1-5] and laboratory analysis [6-8].

Solar wind, which could explain the lunar dynamic dehydration-rehydration diurnal cycle, is considered to be an important source of lunar surface water [4], other than comets, asteroids, and lunar interior [6, 9-11]. This is also supported by lunar soil analysis and ion irradiation experiments in laboratory [7-8].

During about three quarters of the lunar orbit, the Moon is in the solar wind. However, during the rest of the lunar orbit (for 4-5 days every month), the Moon is in the magnetosphere, in which most of the solar wind particles are shielded outside. Lunar surface water abundance in the Earth's magnetosphere remains unclear [12-13]. Whether particles in the magnetosphere, which is much different from those in the solar wind, contribute to the lunar surface hydration production appears to be an interesting topic.

Methods: We selected the Chandrayaan-1 Moon Mineralogy Mapper (M³) data obtained from January 26, 2009 to February 23, 2009 in cold thermal condition. In order to suppress thermal residuals in the M³ data, only those covering polar regions (latitude above 70°) are selected due to their lower temperatures. Bad pixels with lower and flat reflectance spectra are removed based on their wavelength-reflectance 2D histogram. The absorption depth at 2.8 μm is calculated as an indicator of lunar surface OH/H₂O abundance as described in [2] (Fig. 1).

To study the spatial and temporal variations of lunar surface hydration, especially those inside/outside the Earth's magnetosphere, the full-moon time, around which the Moon is in the magnetosphere, are taken as zero epoch. The interval when the Moon is in the magnetosphere is determined by Kaguya observations in February 2009. The data points are binned into 5° latitude and 24 hour intervals. We then computed the probability of 2.8 μm absorption depth between 0.05 and 0.2 to represent OH/H₂O abundance level for each bin.

To investigate the correlation between lunar surface hydration and the incident ion energy flux, we

also computed the average ion energy spectrum and ~1 KeV median/inter-quartile values of ion energy flux incident on the Moon using the data from the ARTEMIS Electrostatic Analyzer (ESA) from September 28, 2011 to October 14, 2012 and determined the prominent plasma environment boundaries between the solar wind and the Earth's magnetosphere.

Results and Discussion: As shown by Fig. 2 (a-b), the lunar surface OH/H₂O abundance increases with latitude toward the polar regions, which is consistent with previous studies [2-5], and the anomaly indicated with rectangle in Fig. 2a is caused by highland materials within Goldschmidt crater [2]. It is also found that the OH/H₂O abundance inside the Earth's magnetotail (red shading in Fig. 2 a-b) remains nearly the same level as those when the Moon is exposed to solar wind, a phenomenon also noticed by [13] using LRO LAMP data. It is well known that when the Moon passes through the Earth's magnetotail, solar wind incident on the Moon vanishes. We can find that the incoming ion flux is mainly from the Earth's magnetosphere whose energy flux at ~1 KeV is much lower than that from the solar wind (Fig.2 c-d).

When the Moon is in the Earth's magnetotail, if there were no source providing additional OH/H₂O at the same time, its abundance should decrease with time due to the losses caused by thermal heating and photo-destruction. However, there are several other possible sources. First, if there are very large water reservoirs in the polar regions, surface OH/H₂O would be hardly affected by the lack of solar wind over time scales of a few days, then, any small changes would be attributable to migration/diffusion of the hydrated molecules [13]; otherwise, the charged particles inside the magnetosphere could also provide another possible source [14], although the overall ion flux in the magnetosphere appears to be much lower than that in the solar wind. If protons are the sole source of lunar surface water both in the solar wind and in the magnetosphere, the constancy of OH/H₂O abundance in the magnetosphere and the solar wind, may imply that the fluxes of protons which can most effectively interact with lunar surface materials are similar in the solar wind and in the magnetosphere. In Fig. 3 we plot the main ion energy fluxes in the solar wind and in the magnetosphere

and obtain two groups of intersection points, one is around 250-400 eV, another around 2-7 KeV, where the proton fluxes are similar. If the lunar hydration was caused primarily by protons in these “optimal” energy bands, the constancy of OH/H₂O abundance over one lunar orbit would be understandable. The existence of these optimal interaction energies needs to be studied by further theoretical simulations and laboratory experiments.

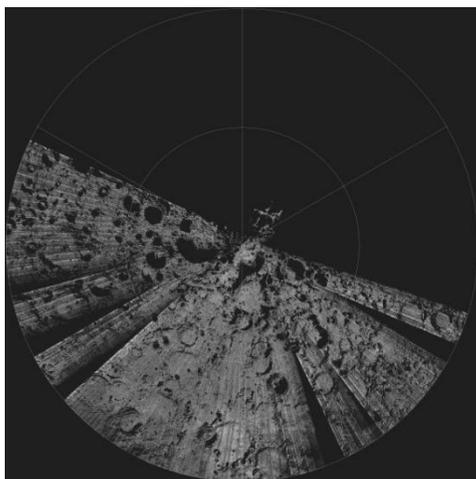


Fig 1. 2.8 μm OH/H₂O absorption depth in the lunar northern polar region derived from the M³ observations from 2009-Jan-26 to 2009-Feb-23.

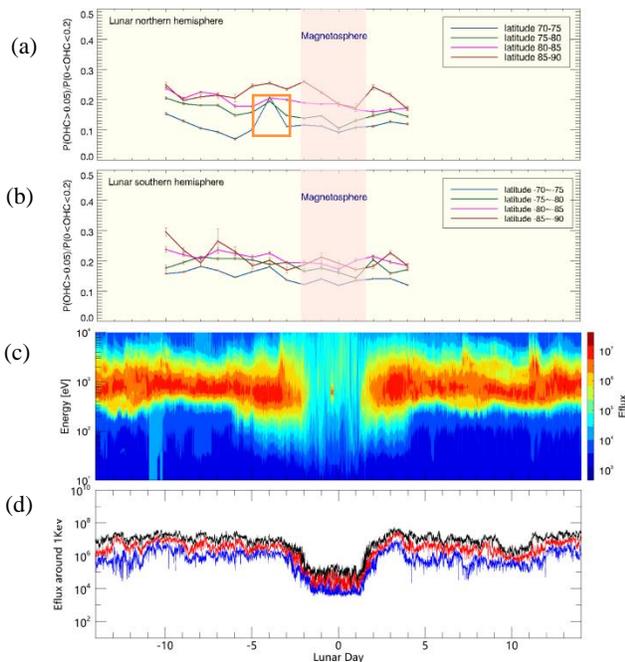


Fig 2. (a-b) The probability of 2.8 μm absorption depth between 0.05 and 0.2 to represent OH/H₂O abundance level for each day, the red shading denote times in the Earth’s magnetosphere. (c-d) Average ion energy spec-

trum and ion energy flux distribution around ~1 KeV from 2011-Sep-28 to 2012-Oct-14.

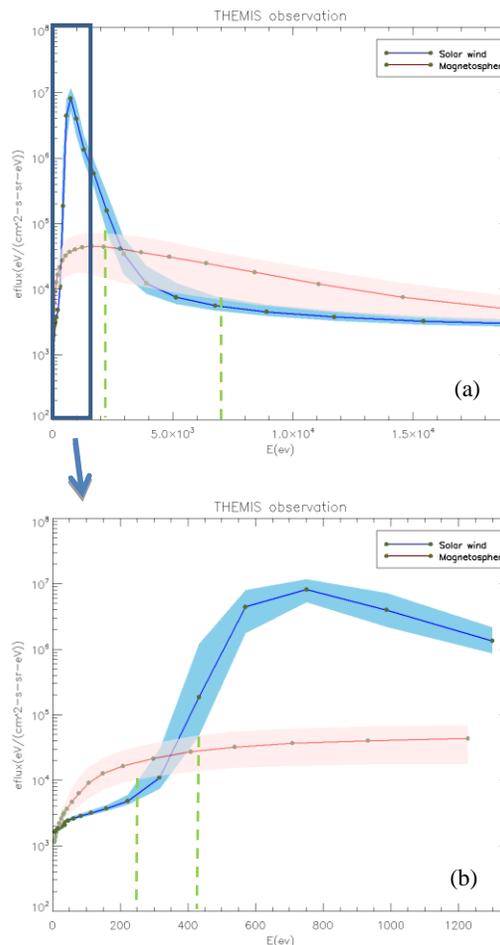


Fig 3. Ion energy fluxes for high (a) and low (b) energy ranges in the solar wind and in the magnetosphere. The overlappings, 250-400 eV and 2-7 KeV, represent optimal energies for OH/H₂O production.

References:[1] Colaprete A. et al. (2010) *Science*, 330, 463–468. [2] Pieters C. M. et al. (2009) *Science*, 326, 568–572. [3] Clark R. N. et al. (2009) *Science*, 326, 526–564. [4] Sunshine J. M. et al. (2009) *Science*, 326, 565–568. [5] Hendrix A. R. et al. (2012) *JGR*, 117, E12001. [6] Saal A. E. et al. (2008) *Nature*, 454, 192. [7] Liu Y. et al. (2012) *Nat. Geosci.*, 1601, 779–782. [8] Djouadi Z. et al. (2011) *A&A*, 531, A96. [9] Schaible M. J., and Baragiola R. A. (2014) *JGR*, 119, 2017–2028. [10] Greenwood J. P. et al. (2011) *Nat. Geosci.*, 4, 79–82. [11] Lucey P. (2009) *Elements*, 5, 41–46. [12] Wang H. Z. et al. (2017) *LPSC, XLVIII, #1831*. [13] Hendrix A. R. et al. (2017) *LPSC, XLVIII, #2149*. [14] Starukhina L. and Shkuratov Y. (2000) *Icarus*, 147, 585.