EPSC Abstracts
Vol. 10, EPSC2015-738-1, 2015
European Planetary Science Congress 2015

Hydrogen at the Lunar Terminator

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Abstract

Suppression of the Moon's naturally occurring epithermal neutron leakage flux near the equatorial dawn terminator is consistent with the presence of diurnally varying quantities of hydrogen in the regolith with maximum concentration on the day side of the dawn terminator. This flux suppression has been observed using the Lunar Exploration Neutron Detector (LEND) on the polar-orbiting Lunar Reconnaissance Orbiter (LRO). The chemical form of hydrogen is not determined, but other remote sensing methods and elemental availability suggest water. The observed variability is interpreted as frost collecting in or on the cold nightside surface, thermally desorbing in sunlight during the lunar morning, and migrating away from the warm subsolar region across the nearby terminator to return to the lunar surface. The maximum concentration, averaged over the upper ~1 m of regolith to which neutron detection is sensitive, is estimated to be 0.0125±0.0022 weight-percent water-equivalent hydrogen (wt% WEH), yielding an accumulation of 190±30 ml recoverable water per square meter of regolith at each dawn. The source of hydrogen (water) must be in equilibrium with losses due to solar photolysis and escape. A chemical recycling process or self-shielding from solar UV must be assumed in order to bring the loss rate down to compatibility with possible sources, including solar wind or micrometeoroid delivery of hydrogen, which require near-complete retention of hydrogen, or outgassing of primordial volatiles, for which a plausible supply rate requires significantly less retention efficiency.

1. Introduction

Mineral hydration on the lunar surface has been detected in reflected near-IR and UV light, but the quantity is not well constrained [1,2,4,5]; it could be anything from a few microns thick layer of lightly hydrated material, to extending deep into the surface. The magnitude of hydration varies diurnally, with maximum near the terminators and minimum near noon. The Lunar Exploration Neutron Detector (LEND) on LRO can uses a different remote-sensing technique, measuring the flux of cosmic-ray induced neutrons from the lunar surface [3]. Neutron remote-sensing is insensitive to solar illumination and probes approximately a meter deep into the surface, enabling LEND to explore the concentration of hydrogen in the lunar surface at all times of the lunar day and night.

2. Results

The presence of hydrogen in the regolith results in suppressing the flux of epithermal neutrons (neutrons of energy near but greater than thermal), as scattering from protons efficiently degrades the energy of epithermal neutrons into the thermal regime. A cadmium foil intercepts such low-energy neutrons before reaching the detector. Maximum flux suppression for epithermal neutrons is found at about 06:35 local time and least flux suppression at 14:35. The maximum of low-energy epithermal neutron flux covers a period of about six hours of local time, starting at 14:35. The high-energy epithermal flux has a unique maximum that coincides with the beginning of the plateau in SETN signal. Contrast between the most flux-suppressed interval and the maximum flux is 5.6 times uncertainty. The observed distribution implies that the least-hydrogenated regolith appears in the mid- to late-afternoon while the most-hydrogenated regolith appears on the dayside of the dawn terminator. This distribution is partially consistent with observed mineral hydration [2,5], which shows peak hydration symmetrically near both dawn and dusk terminators and minimum at noon. Minimal neutron suppression at dusk suggests that the total column of hydrogenated regolith is very small, even though hydration in a thin surface layer may be comparable to the corresponding region near the dawn terminator.

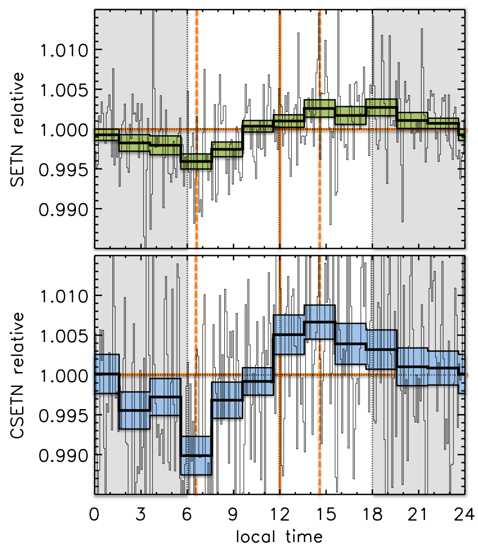

Figure 2: Neutron flux *vs.* local time for low energy (*upper*) and high energy (*lower*) epithermal neutrons. Gray indicates lunar night. Flux suppression near the dawn terminator, biased toward the day side.

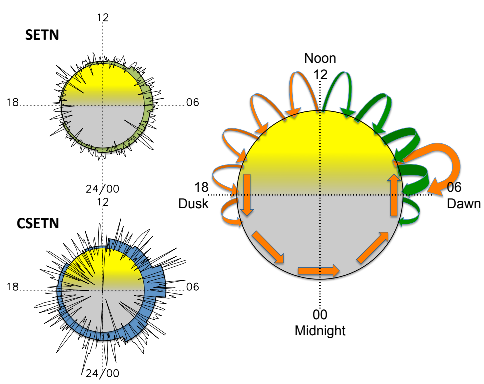

Figure 3: Hydrogen (water) distribution with local time and lateral transport. (*upper left*) Hydrogen concentration from low-energy epithermal neutron flux. (*lower left*) Hydrogen concentration from high-energy epithermal neutron flux. (*right*) Schematic of volatile migration (curved arrows) and transport in regolith by lunar rotation (tangential arrows). Volatiles migrate east (orange), condense onto night regolith, remobilize after dawn and migrate back to cold terminator. Volatiles that migrate west (green) are reinforced by thermally desorbed volatiles in the morning sector.

6. Summary and Conclusions

The distribution in local time of epithermal neutron flux is consistent with a maximum of hydrogen-bearing volatiles just after lunar dawn but widely distributed at lesser concentration up to the afternoon and extending across much of the lunar night. A distribution that is fixed near dawn despite lunar rotation requires a diurnal cycle in which volatiles desorb and migrate across the terminator to be readsorbed on the cold nightside surface. Only about 1% of the inventory at dawn will be in gas phase above the surface. The relative magnitude of response in the two LEND detector systems is consistent with hydrogen in a shallow layer of 3–15 cm depth, nominally ~6 cm.

Acknowledgements

Data are archived at http://wwwpds.wustl.edu. TAL was supported by NASA's Lunar Reconnaissance Orbiter project under NASA award number NNG06EO90A. The Russian co-authors were supported by grant No. 14-22-00249 of the Russian Scientific Foundation. The Russian Federal Space Agency supplied the LEND instrument to NASA and the LRO project.

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