New Insights Into Hydrogen at the Lunar Poles from the Detection of Fast and Epithermal Neutron Signatures.

Richard S. Miller[1], Gaurish Nerurkar[1], and David J. Lawrence[2], [1]University of Alabama in Huntsville (Richard.S.Miller@uah.edu), [2]Johns Hopkins Applied Physics Laboratory

We report the first definitive detection of a fast-neutron signature consistent with enhanced lunar hydrogen abundances. Specifically, we observe a highly localized distribution, consistent with Shackleton Crater, corresponding to a footprint averaged 0.13 ± 0.01% (144 ± 11 ppm) water equivalent hydrogen (WEH) by weight. In addition, we also report new results using epithermal neutrons from the *Lunar Prospector* (LP) and *Lunar Reconnaissance Orbiter* (LRO) orbital neutron spectroscopy datasets. We present new spatial distributions for epithermal-derived hydrogen abundances at the lunar poles including a footprint averaged abundance of 0.05 ± 0.01% (56 ± 11 ppm) WEH by weight poleward of 80^o (each pole), with maxima of 0.073% (81 ppm) and 0.065% (72 ppm) at the North and South poles, respectively. The analysis uses a rigorous statistical approach that enables significance determination, spatial distribution analyses, and new details regarding the relationships between the individual detector datasets. Comparisons to previous results and preliminary insolation and topographical correlations will also be presented.

Introduction

Two missions have provided global neutron measurements of the lunar surface. NASA's *Lunar Prospector* (LP) and *Lunar Reconnaissance Orbiter* (LRO) have contributed important information about elemental abundances on the Moon using spectrometers capable of detecting neutrons across a broad range of energies. Of particular interest have been investigations focusing on the lunar poles, where the combination of topographic features and limited solar illumination may conspire to form cold-traps for volatile compounds such as water.

The leakage flux of secondary neutrons has proven to be an important remote sensing tool not only at the Moon, but for other airless solar system bodies as well [1]. Orbital neutron spectroscopy is commonly divided into three distinct energy regimes - thermal (low energy), epithermal (intermediate energy), and fast (high energy). Each provides complimentary elemental information. Observed neutron deficits in the epithermal and fast neutron ranges are indicative of energy loss and in turn suggestive of an enhanced hydrogen abundances [2].

Data

Lunar Prospector orbited the Moon for approximately 1.5 years beginning in January 1998. Initially placed into a 100 km circular, polar orbit, it was lowered to 30 km for the final 6 months of the mission. The LP-NS included two identical ^{3}He proportional counters, one covered with Sn and the other with Cd[3]. Although both detectors were sensitive to epithermal neutrons (0.4-100 eV), only the Sn-covered detector was also sensitive to thermal neutrons (<0.4 eV) due to the large capture cross section of Cd. Fast neutrons (0.6-9 MeV) were detected using the scintillator-based LP-GRS [3]. This instrument incorporated a borated plastic scintillator as a charged-particle veto surrounding a BGO crystal for γ-ray detection. The 220 days of low-altitude (30 km) operations are used for the analysis presented here, and was obtained

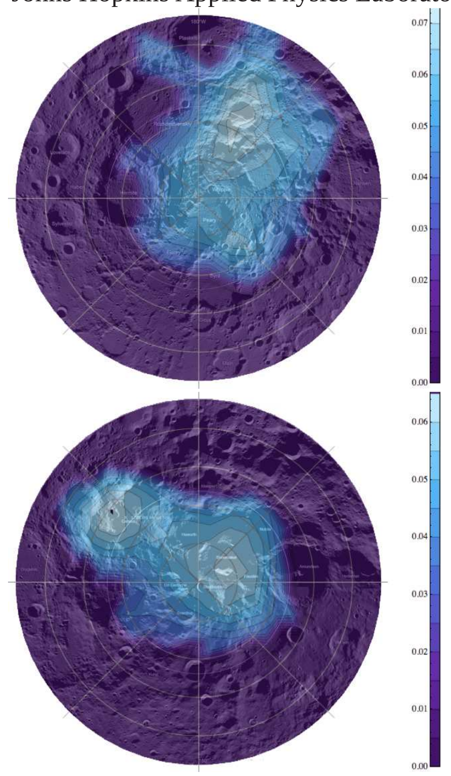

Figure 1: Epthermal-derived polar water distributions for the North (top) and South (bottom) polar regions, using BOTH LP and LRO datasets. The weight percentage of water is shown overlaid on topographical maps of the Moon made by the *Lunar Reconnaissance Orbiter* Camera (LROC) at a resolution of 400m/pixel. An orthographic projection is shown.

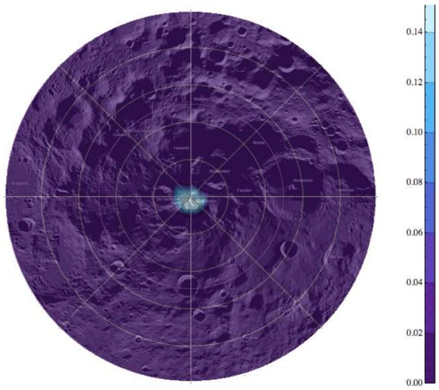

Figure 2: Fast neutron-derived polar water distributions for the South polar region. Overlay similar to Figure 1.

from the *Planetary Data System* (PDS) public archive.

The Lunar Exploration Neutron Detector (LEND) is unique since it incorporates a combination of uncollimated and collimated ^{3}He sensors [4,5]. One of the four uncollimated sensors (SETN) is configured for epithermal neutron detection (>0.4 eV), as are the four collimated sensors (CSETN). The latter are installed within a collimating module intended to provide improved spatial resolution relative to uncollimated sensors. This collimator has external layers of polyethylene and internal layers of ^{10}B designed to moderate and absorb neutrons incident from beyond the collimator's 5.6^o field-of-view (half-opening angle). The present analysis uses the LEND averaged science data (ALD), consisting of spatially averaged data acquired from September 2009 through September 2010, and includes both uncollimated and collimated data available through the PDS.

Analysis

Proper determination of statistical significance and confidence intervals are often overlooked experimental challenges. In fact, approximate methods are commonly used for simplicity or to reduce computation requirements. However, the importance of using an accurate analysis methodology must take precedence over ease of use, particularly in low signal-to-noise experiments. Advanced statistical techniques can incorporate the fundamental discrete statistical distributions governing particle detection experiments, including underlying uncertainties. This is critical for an accurate determination of significance.

Two analysis methodologies have been employed. First, a correlation analysis has been used to quantify the strength of the correlations between datasets. This has enabled an important LP-LRO epithermal neutron cross-validation, as well as to provide benchmarks for relationships between epithermal and fast neutrons. A second technique, based on the likelihood-ratio method (LRM), has been used to evaluate the significances of observed neutron deficits and their spatial distributions. The statistical descriptions relevant to this work are based on particle *counts*, not *rates*, and therefore require the use of exposure distributions. Details of the statistical analysis framework employed here will be presented [6].

Figure 1 shows the resulting WEH abundance maps for the North and South polar regions, produced using a dataset incorporating both LP and LRO uncollimated epithermal datasets - the first multi-mission neutron analysis of the Moon. A similar map derived using the LP fast neutron dataset is shown in Figure 2, showing a highly localized signature consistent with Shackleton Crater. This represents the first definitive detection of a fast neutron signature at the lunar poles. Deficiencies in previous count rate-based analysis methodologies [2,7] were unable to detect, let alone localize, this signature. Ongoing analyses will investigate the influence of average atomic mass effects on this result. If the hydrogen interpretation remains viable there are implications to burial depth and a connection to other lunar parameters measured by LRO.

Summary

Using multi-mission orbital neutron spectroscopy observations of the Moon we have evaluated the relationships between the LP and LRO neutron datasets, determined significances of observed neutron signatures, and derived hydrogen (water ice) abundance maps at the lunar poles. Treating these data as a comprehensive resource a number of useful results have been obtained, including the first detection of a fast neutron signature.

References

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