Hydrogen at the lunar poles: search strategies and tradeoffs for a surface-based neutron spectrometer

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One of the major science and exploration objectives of future lunar studies is to determine the distribution and compositional state of hydrogen on meter-sized spatial scales. This is particularly true for the lunar-polar regions where substantial deposits are anticipated within permanently shadowed craters. The morphology of these hydrogen deposits will enable a deeper understanding of the sources of lunar polar volatiles, and provide critical information and additional insights into transport processes operating at the poles.

Results from multiple missions show strong evidence for hydrogen deposits at the lunar poles. Unfortunately, the lateral distribution information provided by these missions is limited to very large areas (e.g. 1-10 km^2), with limited knowledge of composition or depth.

A straightforward and robust way to make detailed hydrogen composition and distribution measurements may be via surface-based neutron spectroscopy. Here we present progress of our development of a model to address the tradeoffs, capabilities, and survey strategies for a rover-mounted, or stationary, neutron telescope capable of addressing the lunar-polar hydrogen exploration challenge.

Background

Mounting evidence for enhanced hydrogen concentrations at the lunar poles comes from a number of missions and instruments. These include: the Lunar Prospector neutron spectrometers (LP-NS) [1], Clementine radar reflection analyses [2], observations from the Lunar Reconnaissance Orbiter (LRO and Lunar Crater Observation and Sensing Satellite (LCROSS) missions [3,4,5], and radar measurements from the Chandrayaan-1 mission [6].

One of the most important results alluded to by these observations is the suggestion that enhanced hydrogen deposits may be associated with permanently shadowed regions (PSRs) on the Moon. These cold traps, among the coldest locations in our solar system, can serve as reservoirs for any hydrogen that migrates to or is directly deposited within them.

Definitive evaluation of the hydrogen-PSR association may ultimately require in-situ observations from within a PSR, rather than from orbit. Such an approach will provide enhanced localization and characterization

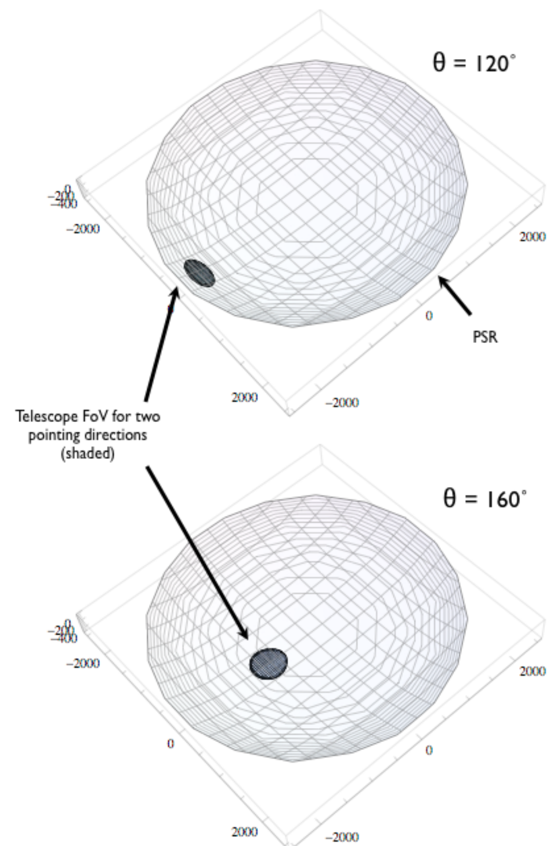

Figure 1: Crater Geometry Example. Two examples of the ellipsoidal crater model showing the projected neutron telescope field-of-view. The telescope is located at crater center with viewing angles as shown (relative to zenith).

performance, which in turn will benefit origin studies, resource utilization, and perhaps even human exploration.

Neutron Spectroscopy

Neutron spectroscopy is a highly effective means to probe for the presence of hydrogen (e.g. water). In planetary applications, including the one outlined here, neutrons are produced by galactic cosmic ray bombardment of an airless planetary body [7], and thus represent a naturally available probe. These secondary neutrons propagate through the regolith, and ultimately leave the lunar surface. The resulting lunar neutron emission spectrum is effectively imprinted with composition information due to absorption by elements with high neutron cross-sections, and/or moderated in energy by the presence of hydrogen.

Project Goals

Our goals are to derive requirement specifications for, and evaluate the capabilities of, a neutron spectroscopy instrument (or suite of instruments) capable of characterizing hydrogen (e.g. water) deposits within lunar permanently shadowed regions (PSRs).

Specifically, our efforts are focused on performance measures and tradeoffs useful for evaluating instrument design candidates. The ongoing analyses include, but are not limited to, the following:

- Composition (% weight H_2O) discrimination capabilities
- Morphology characterization capabilities, including localization and depth
- Survey strategies, including dwell time requirements
- Search geometries, including single & multiple telescope implementations
- Neutron count rates

Simulation

To meet the top-level project goals we have developed a set of simulation tools incorporating a PSR crater geometry, cosmic-ray induced neutron emission, and a generic neutron telescope. Specifically, the crater is modeled as an ellipsoidal surface with user defined geometrical parameters, such as crater diameter and depth, as well as a baseline Ferroan Anorthrosite (FAN) composition. Hydrogen (water) can be incorporated into the PSR in any number of morphologies, from small localized regions to a uniform crater distribution.

The existing simulation is quasi-analytic rather than a full-scale Monte Carlo. Instead of simulating the generation, propagation, and emission of secondary neutrons due to cosmic-ray interactions in the regolith, tabulated neutron spectra derived from previous simulations of FAN regolith [8] are used. Neutron moderation due to the presence of hydrogen is reflected in intensity and spectral changes that have also been tabulated.

The user can define observing parameters of a hypothetical neutron telescope including field-of-view, pointing direction, sensitive energy range, detection efficiency, and background rejection capability. Once the telescope is 'placed' within the crater, the resulting neutron count rates are determined by computing the area within the projected field-of-view, evaluating efficiencies due neutron angular distribution, and incorporating relevant detector parameters. The resulting neutron count rates, and the associated statistical uncertainties, subsequently enable the tradeoff analyses of various scenarios.

Likelihood Analysis

The presence of hydrogen leads to (energy dependent) enhancements or deficits in neutron count rates relative to dry regolith. Therefore, to facilitate model testing a likelihood ratio approach has been implemented in which 'observed' count rates are compared to those expected from a null hypothesis of dry regolith (0% weight H_2O). Using this methodology we have evaluated the exposure (area$\times$time) required to identify hydrogen deposits at a pre-determined statistical confidence level, for given a particular observational scenario. This exposure is then used to perform telescope implementation and search strategy tradeoff analyses. Likelihood analyses can also be used to perform imaging, or more appropriately, localization analyses. We are currently extending this work to evaluate improved spatial localization capabilities.

Summary

A surface-based neutron telescope may hold significant promise as a tool for probing lunar PSRs in general, and for characterizing the morphology of hydrogen within these cold traps. We have developed a framework with which to evaluate the performance of in-situ PSR neutron observations, are deriving telescope requirement specifications, and ultimately PSR search strategies.

References

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