EPSC Abstracts
Vol. 10, EPSC2015-170, 2015
European Planetary Science Congress 2015

EPSC
European Planetary Science Congress

The Impact of Craters on Neutron Fluxes and Lunar Polar Hydrogen Abundances

V.R. Eke (1), K.E. Bower (1), S. Diserens (1), M. Ryder (1), P.E.L. Yeomans (1), L.F.A. Teodoro (2), R.C. Elphic (3), W.C. Feldman (4), B. Hermalyn (5), C.M. Lavelle (6), D.J. Lawrence (6), S. Maurice (7)
(1) Institute for Computational Cosmology, Department of Physics, Durham University, South Road, Durham. DH1 3LE, UK, (2) BAER, Planetary Systems Branch, Space Science and Astrobiology Division, MS 245-3, NASA Ames Research Center, Moffett Field, CA 94035, USA, (3) Planetary Systems Branch, Space Science and Astrobiology Division, MS 245-3, NASA Ames Research Center, Moffett Field, CA 94035, USA, (4), Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719, USA, (5) University of Hawaii, Honolulu, HI, USA, (6) The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA, (7) IRAP, Toulouse, France. (v.r.eke@durham.ac.uk)

Abstract

Hydrogen abundances in lunar polar cold traps are investigated using remotely-sensed neutron count rates. The effect of neutron beaming from craters is measured using data from the Lunar Prospector Neutron Spectrometer (LPNS) and understood in the context of a simple model. This enables a reanalysis of data near the lunar poles, accounting for the topographical impact on the neutron count rates, leading to improved estimates of the hydrogen abundance in the various cold traps. For the case of Cabeus, taking into account the topographical effect increases the inferred water-equivalent hydrogen weight percentage from $\sim 1\%$ to $\sim 4\%$, consistent with that measured using the LCROSS impactor.

1. Introduction

The composition of the near-surface lunar regolith can be inferred using the spectrum of neutrons leaking from the Moon following cosmic ray spallation events [3, 2]. Neutron spectroscopy has been used to create maps of the hydrogen abundance within 70 cm of the surface, allowing conclusions to be drawn about the spatial distribution of volumetrically significant water ice deposits [3, 8]. This search has focused on polar cold traps where water ice is stable against sublimation. However, these efforts have yet to account for the geometrical impact of craters on the detected neutron fluxes. The weak beaming of neutrons normal to the emitting surface might combine with a concave crater surface to focus neutrons over the crater. This would increase the remotely-sensed neutron count rate, opposing the decrease in epithermal neutron count rate produced by a hydrogen-rich regolith. In order to make an unbiased estimate of the hydrogen content in polar cold traps, this factor should be understood and accounted for. We will: 1) quantify how neutron count rates change as the detector moves relative to craters, 2) describe a model that can account for these observations and 3) discuss the consequences of our findings for estimates of hydrogen concentrations in polar cold traps, with reference to previous results such as that from the LCROSS impactor [1].

2. Data and model

The LPNS epithermal neutron data are used [6] in order to quantify the variation in neutron count rate with cratercentric distance, because this dataset has the best spatial resolution of the available lunar neutron datasets [9]. In order to model the effect of topography, the Lunar Orbiter Laser Altimeter (LOLA) global $1^\circ/64$ digital elevation model is used [7]. The set of craters being considered is chosen to be a "highland" subset of those found by [4], where this is defined as craters with centres having latitude$> -30^\circ$, |longitude|$> 90^\circ$ and radii, $r_{\rm c} > 10$km.

The model is essentially the result of a numerical integration over the entire surface visible from the detector. It takes into account the varying cosmic ray flux impacting into the azimuthally-symmetric crater embedded into an otherwise spherical surface. The crater topography includes a central flat infill region, a constant radius of curvature wall leading up to the uplifted rim, with a constant gradient outer uplifted slope back to the unperturbed lunar surface. The neutron flux from the surface is beamed like $\sqrt{\cos\theta}$, where θ is the angle to the surface normal, as advocated by Monte Carlo neutron transport simulations [5]. In addition, 75% of neutrons aimed at the lunar surface are allowed to be reemitted, rather than being absorbed into the regolith.

3. Results

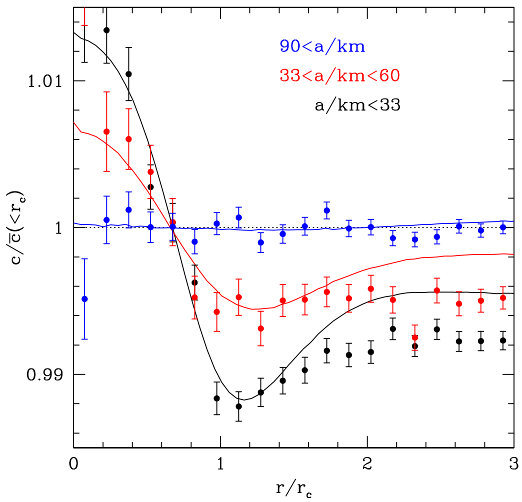

Figure 1: The stacked, normalised epithermal neutron count rate profile for the LPNS (points) and model (lines), for craters with radii in the range $40 - 50$ km. The results have been split by detector altitude, a.

The comparison of LPNS and model epithermal neutron count rate profiles around craters with $r_c = 40 - 50$ km is shown in Fig. 1 with the observations split by detector altitude. In order to decrease the size of the uncertainties in the LPNS profiles, all 115 craters within this radius range have been stacked together. The count rates, c, have been normalised by the average count rate within the crater before stacking together craters. A central bump is seen in the count rate, when the detector is sufficiently low for its footprint to be small enough to resolve this feature. From low altitude, the mean count rate over the crater is $\sim 0.8\%$ greater than that measured outside the crater. The model, as described in the previous section, shows very similar features, but overpredicts the normalised count rate at $r/r_c > 2$ by $\sim 0.25\%$. To make the model fit the LPNS profiles as well as is shown in Fig. 1, the flux emitted from within $2r_c$ has been increased by 0.35%. While the underlying physical justification for this is unclear, it may be the result of localised surface, or near-surface, roughness that might enhance the emitted neutron flux.

For some of the larger polar craters containing permanently shaded regions, there are sufficient observations that useful individual profiles can be constructed. Of particular interest is Cabeus crater. In order to fit the epithermal neutron count rate profile around Cabeus, the model needs the equivalent of ~ 4.5 wt% WEH placed into a circular disc covering the central 275 km^2 in a $r_c = 42$ km crater with the best-fitting topographical model parameters for Cabeus. This is over 4 times as large as the value inferred by [8], who did not account for the effect of topography.

4. Summary and Conclusions

The impact of topography on the remotely sensed neutron count rate has been quantified and largely understood using LPNS data and a simple geometrical model. Focussing of neutrons over craters increases the count rate, which looks like a reduction in hydrogen concentration. Taking into account this topographical effect can significantly change the inferred volatile content in polar cold traps.

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