THE IMPACT OF CRATERS ON NEUTRON FLUXES. 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] and S. Maurice[7], [1]Institute for Computational Cosmology, Department of Physics, Durham University, South Road, Durham. DH1 3LE, UK (v.r.eke@durham.ac.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, 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.

Introduction: The composition of the near-surface lunar regolith has previously been inferred using the spectrum of neutrons leaking from the Moon following cosmic ray spallation events [1,2]. 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 [1,3]. This search has focused on polar cold traps where water ice is stable against sublimation. However, no systematic study has yet been made of the geometrical impact of craters on the detected neutron fluxes. Also, any systematic difference between the crater interior and exterior, for instance in composition or surface properties, could affect the neutron flux. If the presence of a crater does have an impact upon the detected count rate, then the inferred hydrogen concentrations in polar cold traps should be corrected accordingly. 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 what such measurements tell us about the lunar surface.

Data: This analysis requires a set of craters to be studied, topographical data to motivate the shapes of the model craters, and orbital neutron count rate time series data for different neutron energy ranges.

Crater data set: The craters of Head et al. [4], with radii greater than 10 km, |longitude| > 90^o and all latitudes > -30^o, are used for this analysis. These cuts on crater locations restrict the sample to highland regions, leaving a total of ~2000 craters.

Neutron data set: The Lunar Prospector Neutron Spectrometer (LPNS) data provide count rates in three different energy ranges: fast, epithermal and thermal [1]. Using all three of these in this analysis provides the opportunity to disentangle effects due to composition from those due to other factors, because the different energy neutrons respond differently to changes in composition.

Topographical data set: The LOLA global 1^o/64 DEM [5] is used to determine the average crater profiles for different-sized crater subsamples. Two of which are shown in Figure 1.

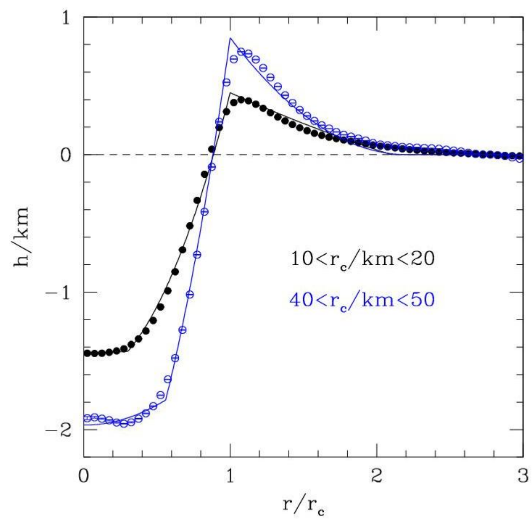

Fig. 1: The azimuthally-averaged stacked height profiles, h, as a function of distance from the crater centre, r, in crater radii, r_c, for two sets of different sized craters (circles). Curves show the fitted analytical profiles used to construct model craters.

Results: The largest variations in LPNS count rate result from changing surface composition and amount to a ~10-20% effect. To detect any crater signal, which will be at a level significantly lower than this, requires averaging of the results from different craters. In order to stack together many craters, the count rates and radii are normalized by the mean count rate within each crater and the crater radius respectively. Average neutron count rate profiles for the different energy ranges and sets of craters of different size are shown in Figure 2, colour-coded by crater size. There is a significant ~1% increase in neutron count rate when the LPNS is located over craters. This count rate bump is largest over the biggest craters and for the thermal and epithermal neutrons. A similar deviation is seen in the fast neutron results, albeit at a lower amplitude. The omnidirectional LPNS spatial resolution of 45 km full-width, half-max [6] precludes the possibility of seeing a large count rate bump over the smaller craters, because it blurs over any crater-related features.

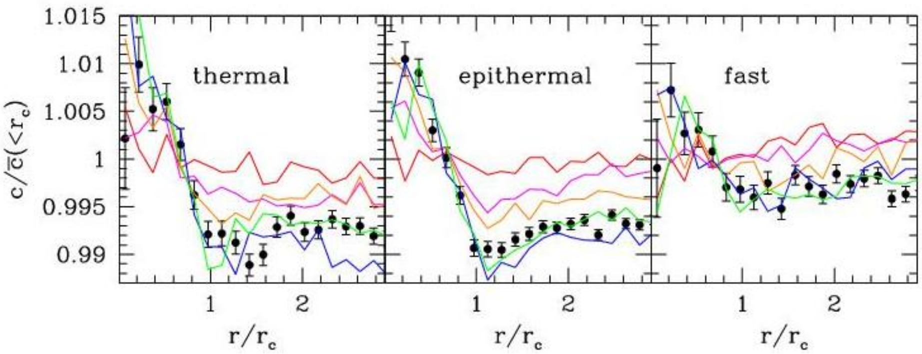

Fig. 2: Stacked neutron count rate profiles around craters with radii 10-20 km (red), 20-30 km (magenta), 30-40 km (orange), 40-50 km (black points), 50-60 km (blue), and 60-80 km (green), for different energy neutrons.

Model: To predict the neutron count rate profile, a model has been constructed that takes into account the crater topography, how this shields the crater interior from incoming cosmic rays, and the weak beaming of neutrons out of the regolith. By numerically integrating the neutron leakage flux over the lunar surface visible from the orbiting detector, accounting for the crater topography measured from the LOLA DEM, a model count rate profile has been calculated. The results are shown by the black curve in Figure 3, compared with the epithermal neutron data for 40-50 km radius craters. Like the data, the model shows a maximum count rate over the crater centre and a minimum located near the crater rim. This occurs because the emitted neutrons are preferentially aimed normal to the lunar surface, and this slight focusing amplifies the counts over the crater at the expense of those over the surrounding regions.

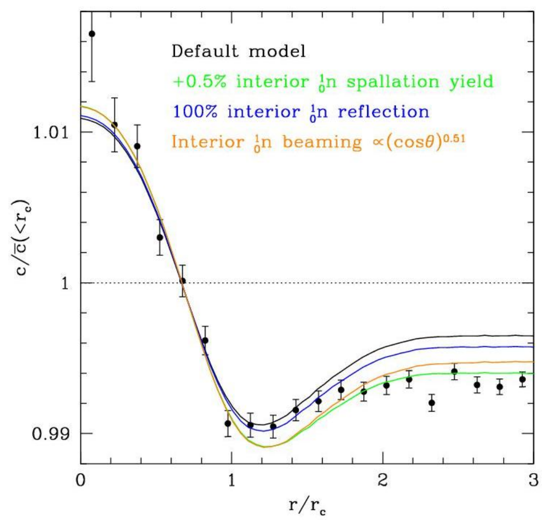

Fig. 3: LPNS epithermal count rate profile for craters with 40 < r_c/km < 50 (points), and the model profiles for the default model (black line), and three slightly different models (green, blue and orange lines).

Also shown in the figure are results when the model is changed in an attempt to fit better the LPNS results: increasing the neutron spallation yield by 0.5% within the crater, allowing all (rather than the default of zero) neutrons aimed at crater walls to be reflected, and increasing the beaming of neutrons from the crater interior surface. Given the approximation involved in fitting the analytical model crater topographical profile, either increasing the neutron spallation yield or beaming within the crater can fit the count rate profile.

Discussion: Why do the fast neutron results differ so much from the thermal and epithermal ones? Fast neutrons were detected using the anti-coincidence shield around the LP Gamma-Ray Spectrometer, not a helium-3 tube, but the spatial response function should be similar [6].

What might give rise to an enhanced neutron spallation yield or increased beaming of emitted neutrons within craters of the sort that slightly better reproduces the thermal and epithermal results? One possible explanation, which can be tested using neutron transport simulations, is that the crater interior is rough on scales of the neutron mean-free path (~10 cm). If so, then this might provide a new use for planetary neutron data that would complement studies of surface roughness based upon thermal infrared [7,8] and radar [9] measurements.

There are small but significant systematic variations in the neutron count rate profiles in the vicinities of lunar craters. These features can be largely explained by the effect of topography and neutron beaming from the surface, and imply that previously inferred hydrogen concentrations in polar cold traps should be corrected upwards. For example, that in Shoemaker crater should be increased by a factor of ~1.2 due to this.

References: [1] Feldman W. C. et al. (1998) *Science, 281*, 1496. [2] Elphic R. C. et al. (1998) *Science, 281*, 1493. [3] Teodoro L. F. A. et al. (2010) *GRL, 118*, 689. [4] Head J. W. et al. (2010) *Science, 329*, 1504. [5] Smith D. E. et al. (2010) *GRL, 37*, 18204. [6] Maurice S. et al. (2004) *JGR*, 109, E07S04. [7] Bandfield J. L. et al. (2011) *JGR, 116*, E00H02. [8] Bandfield J. L. et al. (2015) *Icarus, 248*, 357. [9] Ghent R. et al. (2005) *JGR, 110,* 2005.