A Recent, Large Multi-Impact event on the Moon

J.-P. Williams[1], J. L. Bandfield[2], D. A. Paige[1], B. T. Greenhagen[3], E. J. Speyerer[4], R. R. Ghent[5], [1]Earth, Planetary, and Space Sciences, University of California, Los Angeles, CA, 90095, USA (jpierre@mars.ucla.edu), [2]Space Sciences Institute, Boulder CO, USA, [3]Johns Hopkins University, Applied Physics Lab, Laurel MD, USA, [4]School of Earth and Space Sciences, Arizona State Univ., Tempe AZ, USA, [5]University of Toronto, Earth Sciences, Toronto ON, Canada.

Introduction: A new class of small, fresh impact craters has been recently identified on the Moon through the systematic mapping of lunar surface temperatures [1] by the Diviner instrument aboard the Lunar Reconnaissance Orbiter (LRO) [2]. It has been recognized that patches of anomalously cold nighttime regolith temperatures, cold spots, are associated with recent lunar impacts [3]. This provides a way of identifying recently formed impact craters on the moon (Fig. 1).

Crater diameters: We have conducted a survey of craters associated with cold spots using LROC images [4] to measure the crater diameters. A total to 2046 craters have been identified with cold spots between latitude $\pm 50°$ and measured with diameters ranging from 43 to 2315 m. The resulting crater size-frequency distribution (CSFD) provides a good fit the Neukum Production Function [5] for diameters $\gtrsim 300$ m and indicates a survival time for cold spots of $\sim 100-200$ ka (Fig. 2).

Results: The distribution of the craters is not homogeneous and indicates that impacts do not accumulate uniformly on the Moon. A clustering of craters $800-2315$ m in diameter is observed on the far side between longitudes $110°$ and $180°$ E (Fig. 3) indicating a recent, large multi-impact event occurred; possibly the result of a swarm of 100 m-scale fragments from a disrupted asteroid or comet impacting the Moon. Statistical analysis using the Rayleigh z test [6] indicates unimodal directionality in the distribution of longitudes indicating high confidence ($> 95\%$) against a random distribution. It is expected to take a couple Myrs for this many craters in this diameter range to form within this range of longitudes. Cold spots do not likely persist for such a long duration. Ray material from South Ray crater ($D = 680$ m) sampled by Apollo 16 yielded a cosmic-ray exposure age of ~ 2 Ma [7]; however South Ray crater is not associated with a cold spot.

Additionally, a longitudinal asymmetry is observed due to a difference in encounter velocities resulting from the Moon's synchronous rotation where the apex of orbital motion has accumulated a greater density of craters (Fig. 4). These observations demonstrate how the delivery of exogenic material to the Moon can be heterogeneous in both space and time.

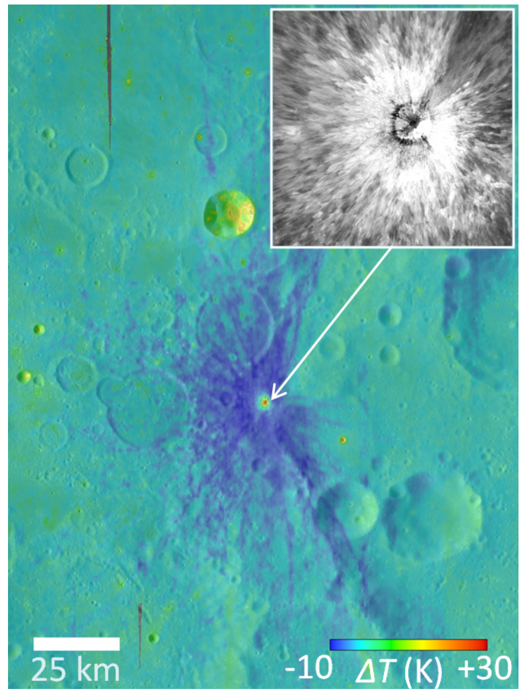

Figure 1: Nighttime rock-free regolith temperature deviations [1] with LROC WAC global mosaic used for shading showing a cold spot associated with a 1 km diameter crater at $5.39°$ S, $90.76°$ E.

References

[1] J. L. Bandfield, *et al.* Lunar surface rock abundance and regolith fines temperatures derived from LRO Diviner Radiometer data. *J. Geophys. Res.*, 116, 2011. doi:10.1029/2011JE003866.

[2] D. A. Paige, *et al.* The Lunar Reconnaissance Orbiter Diviner Lunar Radiometer Experiment. *Space Sci. Rev.*, 150:125–160, 2010.

[3] J. L. Bandfield, *et al.* Lunar cold spots: Granular flow features and extensive insulating materials surrounding young craters. *Icarus*, 231:221–231, 2014.

[4] M.S. Robinson, *et al.* Lunar Reconnaissance Orbiter Camera (LROC) instrument overview. *Space Sci. Rev.*, 150:81–124, 2010.

[5] G. Neukum, *et al.* Cratering Records in the Inner Solar System in Relation to the Lunar Reference System. *Space Sci. Rev.*, 96:55–86, 2001.

[6] N. I. Fisher. In *Statistical Analysis of Circular Data*. Cambridge University Press, 1993.

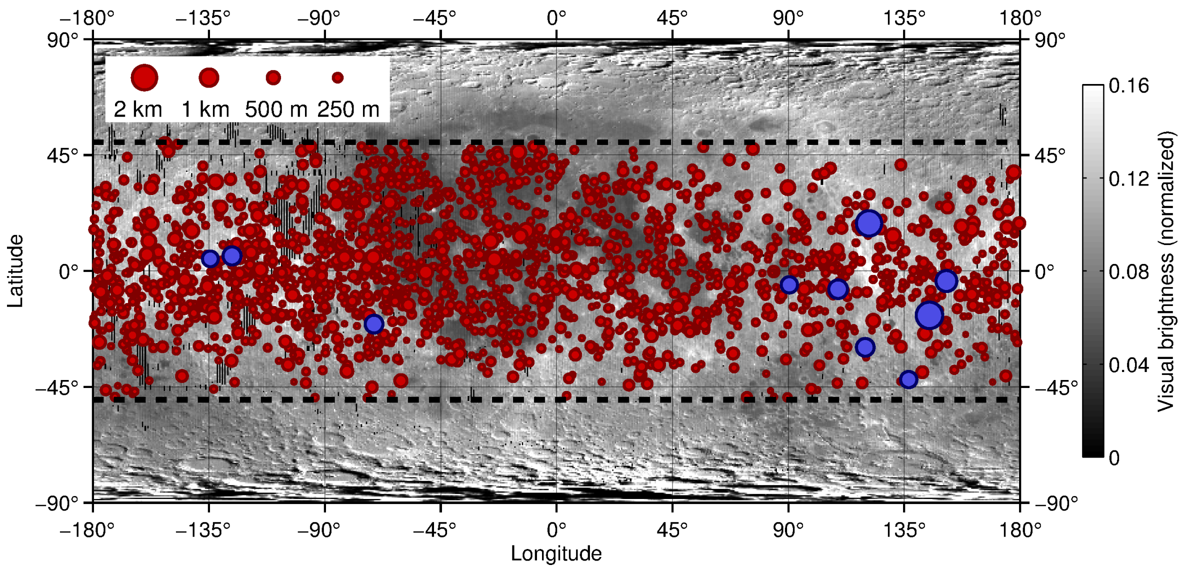

Figure 3: Locations of lunar cold spot craters $\pm 50°$ latitude, with larger craters $D \gtrsim 800$ m indicated in blue. Symbol sizes are scaled by crater diameter. The concentration of larger craters at $135°$ longitude suggests they were formed during a single event.

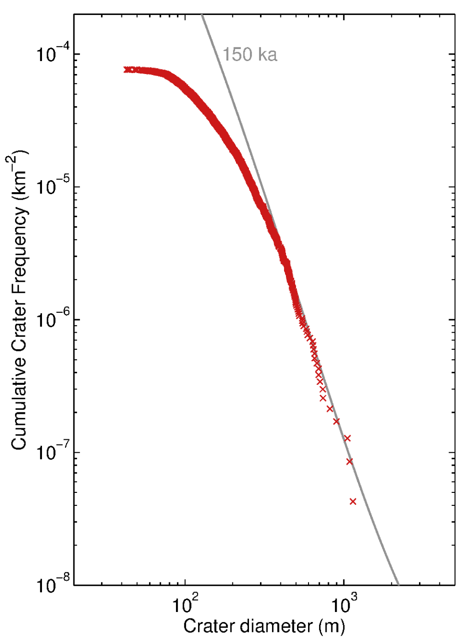

Figure 2: Cumulative size-frequency distribution of cold spot craters and the 150 ka Neukum production function [5] excluding longitudes $110°$ to $180°$ E.

[7] D. Stöffler and G. Ryder. Stratigraphy and isotope ages of lunar geologic units: chronology standard for the inner solar system. *Planet. Space. Sci.*, 96:9–54, 2001.

[8] M. Le Feuvre and M. A. Wieczorek. Nonuniform cratering of the Moon and a revised crater chronology of the inner, Solar System. *Icarus*, 214:1–20, 2011.

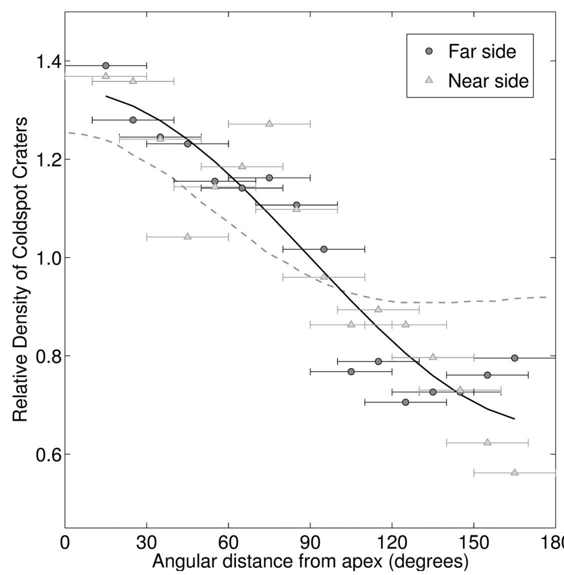

Figure 4: Distribution of relative cold spot crater density as a function of angular distance from the apex of lunar orbital motion for the far side (circles) and the near side (triangles). The density of craters over a $30°$ longitude range is plotted every $10°$. Solid curve is a least squares fit sinusoid $1 + 0.34 \cos(\beta)$ and dashed grey curve is the predicted relative cratering rate for crater diameters larger than 1 km of [8] for the entire Moon.