Large Lunar Cold Spots: Ages and Distribution

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Introduction: Nighttime observations by the Diviner instrument aboard the Lunar Reconnaissance Orbiter [1] have revealed patches of anomalously cold regolith temperatures associated with young impact craters [2]. Using a survey of cold spots identified in nighttime regolith temperature maps [3], Williams et al. [4] measured the diameters of the cold spot source craters. The distribution of craters is not homogeneous with a greater density of cold spots in the western hemisphere reflecting the Moons synchronous rotation. The relative density of the craters varies by a factor ~ 2 between the apex (90° W) and antapex (90° E) of motion. However, the distribution of the largest cold spots with source craters $D > 800$ m, does not follow this trend. These craters were found to be concentrated in the eastern (trailing) hemisphere (Fig. 1). This distribution is difficult to reconcile with synchronous rotation and statistically unlikely to be random, leading Williams et al. [4] to suggest that the clustering of craters may have resulted from a swarm of fragments impacting the Moon in a single event.

Methods: We have surveyed recently published global maps of regolith thermophysical properties that reveal cold spots in greater detail [5]. The cold spots are charaterized by having more insulating material near the surface characterized by a parameter H (see [6] for details). Using LROC NAC images, crater counts were conducted on the ejecta of all large cold spot source craters with the exception of two (numbered 8 and 10 in Figures), as these occurred on the walls of large craters where steep slopes rendered crater counts unreliable.

Results: The survey of global H-parameter values revealed several additional large cold spots that were not apparent in the nighttime regolith temperatures (Fig. 1). Absolute model ages based on that of [7] range from ~ 200 ka to ~ 1.3 Ma with the cold spots apparent only in the H-parameter map all older than 0.5 Ma (Fig. 2). The other cold spots are generally younger than 0.5 Ma with the exception of three.

Discussion: The additional population of cold spots identifed in the H-parameter map indicate that cold spots are not reliably detected by regolith temperature alone after ~ 0.5 Ma but persist to ages older than ~ 1 Ma. The distribution of the older cold spots is more consitent with a random distribution and a variation in ages for the younger craters show they are not related to a single event as proposed by Williams et al. [4]. However, as with smaller craters, large cold spots should form preferentially on the leading side, which is not observed. Several of the young craters do have overlapping ages and a multi-impact event on the trailing far side involving 2 to 4 craters in the last ~ 0.5 Ma cannot be ruled out as a possible explanation for the distribution of the young cold spots.

Alternatively, the destruction rate of the large cold spots is enhanced on the leading hemisphere. The formation and destruction of cold spots is not well understood making this scenario difficult to assess and would require a size-dependent process that allows smaller cold spots to persist as the hemispheric asymmetry is present for smaller cold spots. Smaller impacts, down to the limit of Diviner resolution, appear to create cold spots and it is not clear how their destruction results from the superposition of additional impacts.

References

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

[2] 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.

[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] J.-P. Williams, *et al.* A Recent, Large Multi-Impact Event on the Moon. *Lunar Planet. Sci. Conf.*, 48th, 2017.

[5] T. M. Powell, *et al.* Lunar cold spot properties and degradation. *Lunar Planet. Sci. Conf.*, 49th, 2018.

[6] P. O. Hayne, *et al.* Global regolith thermophysical properties of the Moon from the Diviner Lunar Radiometer Experiment. *J. Geophys. Res.*, 2018. doi: 10.1002/2017JE005387.

[7] J.-P. Williams, *et al.* The production of small primary craters on Mars and the Moon. *Icarus*, 235:23–36, 2014.

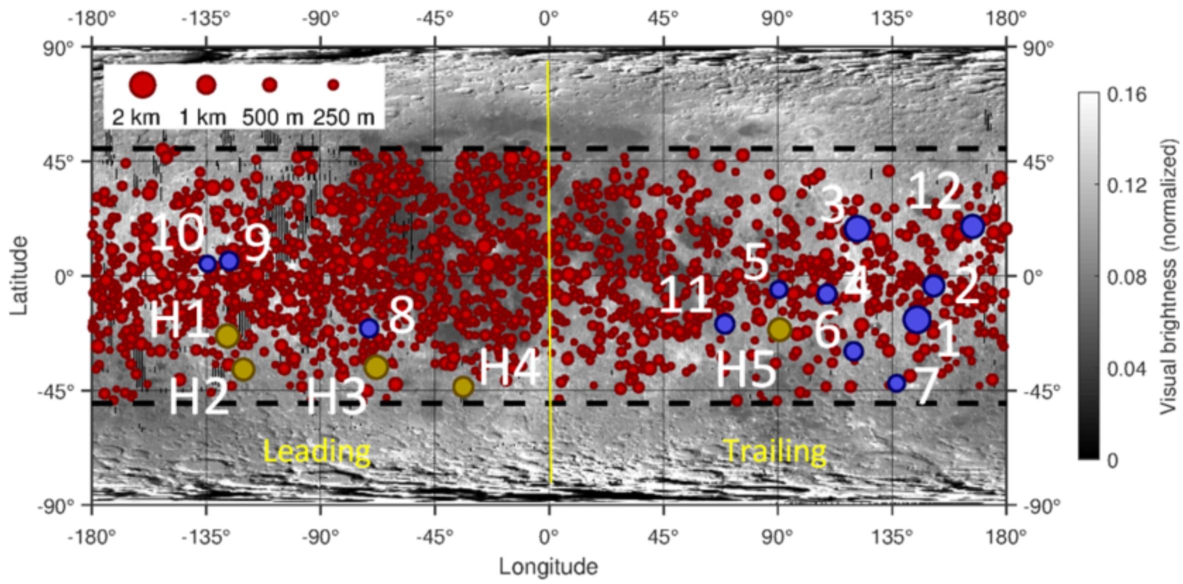

Figure 1: Locations of lunar cold spot craters $\pm 50°$ latitude, with larger craters $D > 800$ m indicated in blue and yellow where yellow indicates they are only observed in H-parameter maps. Symbol sizes are scaled by crater diameter and the leading and trailing hemispheres are noted.

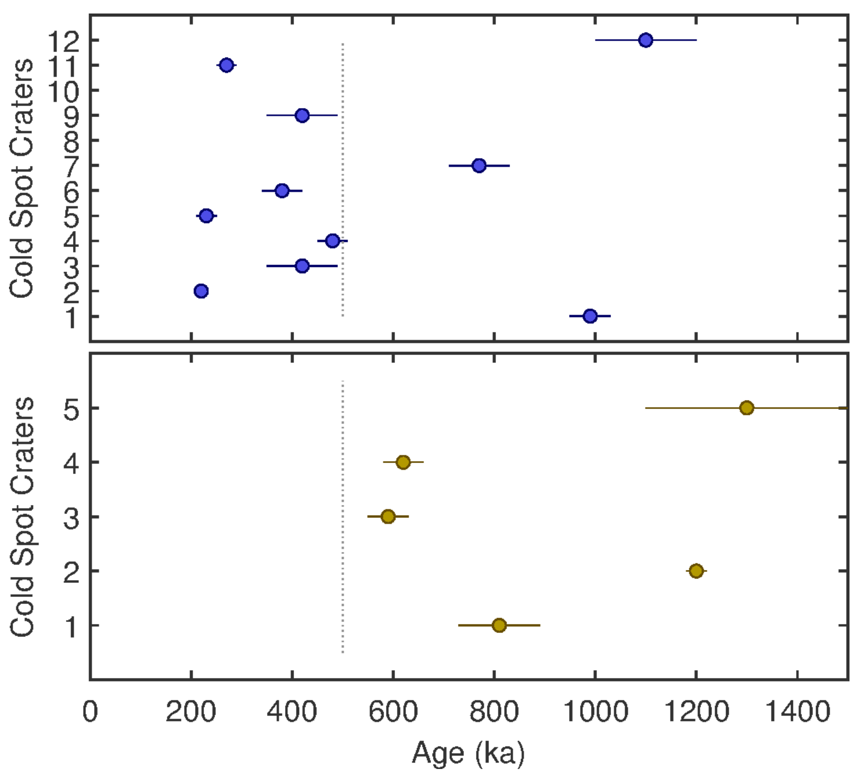

Figure 2: The absolute model ages derived from crater counts on the ejecta of the large ($D > 800$ m) cold spot craters. (top) Cold spots observed in regolith temperatures and (bottom) cold spots only observed in H-parameter maps. Crater numbers correspond to numbering in Fig. 1. Error bars are statistical uncertainties in crater counts. Vertical dashed line denote 0.5 Ma age.