IMPROVED HYDROGEN MAPS OF THE LUNAR SOUTH POLE BY THE LUNAR POLAR HYDROGEN MAPPER (LUNAH-MAP) CUBESAT MISSION.
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Introduction: The Lunar Polar Hydrogen Mapper (LunaH-Map) spacecraft will orbit the Moon and produce high spatial resolution maps of bulk hydrogen abundances within the top meter of lunar south polar regolith [1]. These maps will provide important constraints on the abundance and nature of lunar polar volatiles. Improved understanding of the spatial distribution of hydrogen enrichments throughout the lunar South Pole will inform models of the emplacement and preservation history of lunar polar volatiles. Thick ice deposits (delivered by water rich asteroids or comets) may be pervasive at high southern latitudes [2]. Impact gardening could vertically redistribute the ice, bringing it closer to the surface [2,3]. The higher spatial resolution measurements provided by LunaH-Map could test this hypothesis by determining whether the observed distributions of hydrogen consistent with those predicted by ice stability modeling. These landing-site scale (10-20 km^2) maps of bulk hydrogen enrichments will also be used to identify key sites for future landed exploration of the lunar south pole.

LunaH-Map is a NASA Science Mission Directorate (SMD) mission selected by the Small Innovative Missions for PLanetary Exploration (SIMPLEx) program in late 2015 and is currently co-manifested on the Space Launch System (SLS) Artemis-1 mission. LunaH-Map is a 6U (14 kg) spacecraft that will deploy from Artemis-1 and use a small low-thrust propulsion system to maneuver into a highly eccentric orbit around the Moon where a miniature neutron spectrometer (Mini-NS) will measure the epithermal neutron flux from the lunar South Pole (**Fig. 1**). To produce high spatial-resolution maps, a low-altitude perilune (<25 km) is required by the uncollimated neutron spectrometer. After the spacecraft enters the science orbit (~15 km perilune, 3150 km apolune eccentric orbit with a ~4.7 hour period), the Mini-NS will collect data from 70S poleward each orbit. The epithermal neutron count rates will be used to produce maps of hydrogen (e.g. water-ice) enrichments throughout the lunar south pole, including within permanently shadowed regions (PSRs). PSR target areas, as well as an example ground track over Shoemaker (with altitude and PSR contribution to the observed signal) are shown in **Fig. 2**. In this work, we provide a preliminary assessment of the mapping capabilities of the LunaH-Map Mini-NS for variable hydrogen enrichments within permanently shadowed regions of the south pole.

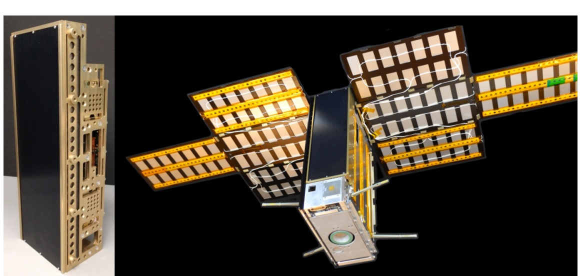

Figure 1: *Left* LunaH-Map neutron spectrometer (2U). *Right* The LunaH-Map spacecraft, with solar arrays and antennas (10 cm each) deployed. Mini-NS occupies ~200 square-cm area on the front face of the spacecraft.

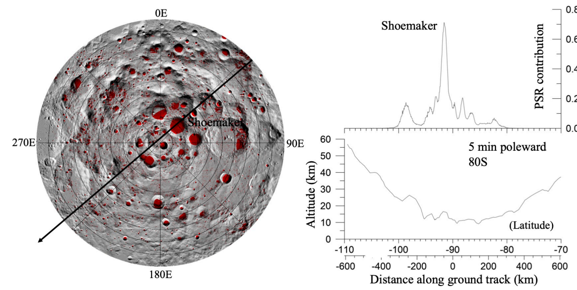

Figure 2: *Left* PSR map with LunaH-Map ground-track (light blue) through Shoemaker PSR. *Top Right* Contribution of PSRs to neutron signal along the ground-track. *Bottom Right* Altitude along the ground track binned every 1-second. The shape model used in the simulation was derived from the LOLA topographic data set.

Mission Status: The LunaH-Map Mini-NS was designed and built in partnership between Arizona State University (ASU) and Radiation Monitoring Devices [4]. The Mini-NS was calibrated at the Los Alamos National Laboratory Neutron Free In-Air Facility. Spacecraft integration, testing and development are led by ASU in partnership with a small and agile team of experienced engineering professionals at AZ Space Technologies, LLC and Qwaltec, Inc. Subsystems and components have been developed in close partnership with commercial vendors. LunaH-Map has met all major mission milestones and passed all design reviews [1]. As the first SIMPLEx mission, LunaH-Map is a pathfinder for the development of small, science-driven, high-risk, high-reward planetary science missions. LunaH-Map demonstrates how very small spacecraft missions may provide complementary data for NASA SMD missions while addressing unique and compelling science goals.

Predictive Neutron Mapping: We present preliminary results of end-to-end simulations of LunaH-Map data and map products given prospective orbits and subsurface ice configurations representing different hypotheses for emplacement, redistribution, and removal of H-bearing species. The modeling approach is similar to that used for Dawn [e.g., 5, 6]. We use a polygonal shape model of the Moon, the current LunaH-Map SPK file describing the science orbit, and time variable sampling of 1 second poleward of 70S to produce maps of neutron counts following the methods described in [3]. Potential ice (water-equivalent-hydrogen) abundances within PSRs used in modeling of LunaH-Map predictive mapping were derived from Lunar Prospector (LP) data, while PSRs are drawn using LOLA shape models [7-10]. PSRs and test ice abundances are shown in **Fig. 3**.

Results: Our preliminary results (**Fig. 4 right**) show that LunaH-Map can detect and resolve ice cold-trapped within PSRs. Future work will explore the sensitivity of LunaH-Map to subsurface ice in permafrost regions outside the PSRs. If higher abundances of H than those modeled are present, LunaH-Map will be able to identify those regions. Low altitude measurements from LunaH-Map will enable high spatial resolution mapping of PSRs and the surrounding permafrost. LunaH-Map data will also provide verification of results of previous missions (LP/LEND). For future modeling and testing, we will determine if LunaH-Map is sensitive to the distribution of H that is consistent with expected permafrost depths, and evaluate if LunaH-Map will be able to identify possible anomalies resulting from impact processes.

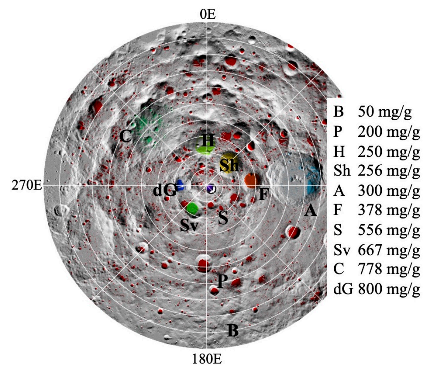

Figure 3: PSR map showing test ice enrichments used in the preliminary analysis of the LunaH-Map science mapping capabilities shown in Figure 4. PSR regions are drawn using the LOLA shape model and NAC data [9, 10]. Ice enrichments are approximate based on a combination of Lunar Prospector and Lunar Reconnaissance Orbiter water-equivalent-hydrogen maps [7, 8]. C: Cabeus; H: Haworth; Sh: Shoemaker; F: Faustini; dG: de Gerlache; Sv: Sverdrup; A: Amundsen; S: Shackleton; P: all other PSRs; B: lunar highlands (background).

References: [1] Hardgrove et al., (*in press*) IEEE A&ESM. [2] Rubanenko L. et al. (2019), Nature Geoscience, doi: 10.1038/s41561-019-0405-8. [3] Prettyman et al. (2019) AGU Fall Meeting, Abstract P54A-05. [4] Hardgrove et al., (2018) International Workshop on Instrumentation for Planetary Missions. [5] Prettyman et al. (2016) Science 355. [6] Prettyman et al. (2019) LPSC, 1356. [7] Elphic, R. C. et al. (2007) GRL 34. [8] Sanin et al. (2017) Icarus 283. [9] Mazarico, E. et al (2011) Icarus 211. [10] Cisceros, E. et al. (2017), LPSC 48. [11] Feldman W.C. et al. (2001), JGR 106.

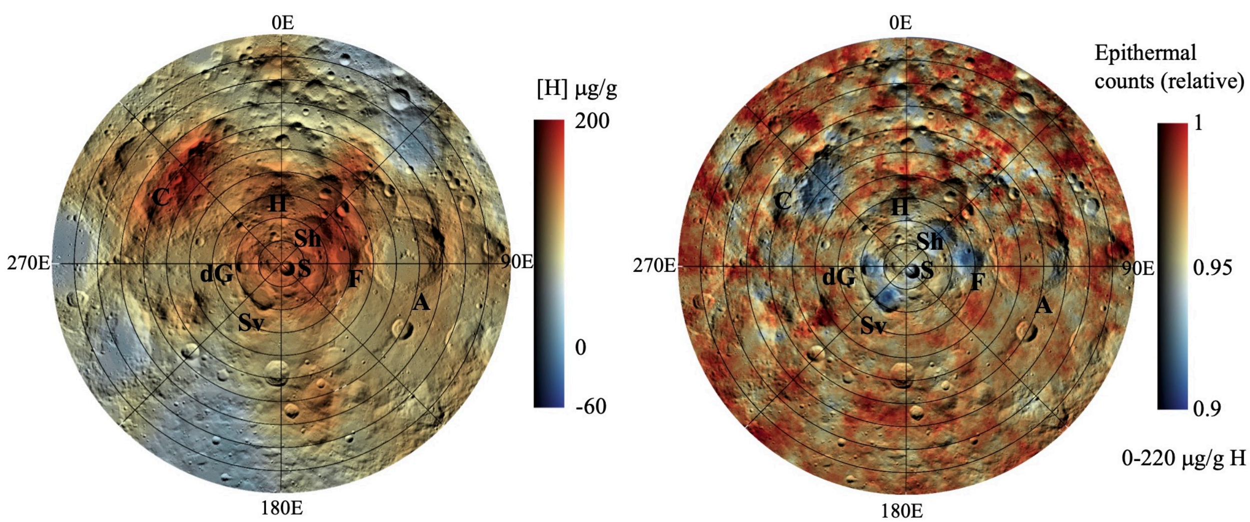

Figure 4: (left) Map produced by Lunar Prospector of H abundance at the lunar South Pole [11] and (right) predicted LunaH-Map epithermal neutron count rate map using the PSR ice enrichments shown in Figure 3. LunaH-Map predicted map assumes Poisson noise and the full 56-day science mission (280 orbits). Hydrogen in large PSRs can be quantified in 30 days (150 orbits).