PASSIVE PROSPECTING FOR SUBSURFACE LUNAR ICE USING THE ASKARYAN EFFECT WITH THE COSMIC RAY LUNAR SOUNDER (CoRaLS).

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Introduction: Permanently shadowed regions (PSRs) at the lunar poles maintain the thermal conditions necessary to harbor tens-of-meters thick deposits of nearly pure water ice for geologic time [1]. Such ice deposits have been unambiguously discovered by radar investigations within the PSRs of Mercury, however observations of the Moon’s PSRs have not resulted in the same level of certainty [2]. Models of ice delivery by ancient large hydrated impacts show that thick ice deposits could be buried and preserved below thick ejecta and subsequently heterogeneously mixes with underlying regolith [3,4]. If Mercury-like ice deposits exist on the moon, they will have been emplaced and disrupted by stochastic impact events. Because of their largely stochastic evolution, in order to find large subsurface ice deposits, we must be able to probe deeply and across a large area.

The Cosmic Ray Lunar Sounder (CoRaLS), a new orbital mission concept funded for development through the Development and Advancement of Lunar Instrumentation program (DALI), will have the ability to detect and characterize subsurface ice deposits (Figure 1) using the Askaryan effect of ultra-high energy cosmic ray impacts. CoRaLS represents a unique and viable method to probe for ice deeply and widely enough to conclusively discover or deny the existence of buried coherent ice deposits on the Moon.

Askaryan Effect: The lunar regolith is continuously bombarded by cosmic rays, from GeV (109 eV) up to ZeV energies (1021 eV). Due to the lack of a lunar atmosphere, ultrahigh energy cosmic rays (UHECR) (energies >1018 eV) enter the regolith unimpeded with their full energy. These cosmic rays produce strong secondary particle cascades within the regolith, extending for up to 10 meters at the highest energies. These particle cascades produce strong, coherent, wide-bandwidth, linearly-polarized radio pulses, demonstrated in numerous laboratory measurements over the last two decades; this emission process is known as the Askaryan effect [5]. Such UHECR-induced pulses are routinely observed in terrestrial atmospheric cascades by ground arrays, and have been observed by suborbital payloads from distances up to 700 km or more.

Passive Prospecting for Lunar Ice: The cosmic ray-induced radio emission, created in the first few meters of the regolith via the Askaryan effect, will reflect off any subsurface ice layers (with lateral extent greater than ~5 m), including thin layers that are ~1 cm thick, as well as the regolith-bedrock interface. From its orbital altitude of ~25 km, CoRaLS’ dual-polarization interferometric radio receiver array can observe both the direct and reflected radio emission from these UHECR impacts. Analysis of the direct and reflected radio signals, including the spectrum, amplitude, and polarization, allows for reconstructing the presence and properties of subsurface ice and bedrock layers.

These laboratory and Earth-based measurements, in conjunction with detailed full-wave electromagnetic simulations, confirm that such pulses will be observable by CoRaLS using existing radio receiver technology. The advantage of this technique over orbital active radar sounders is that the cosmic ray source acts as a high-quality dipole antenna embedded directly in the regolith very close to the targets of interest, avoiding both the decoherence, and surface clutter and losses, of a traditional active radar sounding design. Over a two-year mission, CoRaLS would make ~600 independent detections of subsurface ice layers using roughly ~10,000 UHECR impacts and will be able to find and statistically characterize the subsurface ice distribution with ~1 km location resolution, characterize the depth and thickness distribution of a subset of well-measured ice layers, and measure the global lunar regolith depth distribution.

References: [1] Paige D. A et al. (2010), Science, 330, 6003 [2] Fa W. et al. (2013), JGR: Planets, 118 [3] Costello E. S et al. (2021), JGR: Planets, 125, 3 [4] Cannon K. M. et al. (2020), GRL, 47, 21 [5] Saltzberg D. and Gorham P. W et al. (2001), PRL, 86.

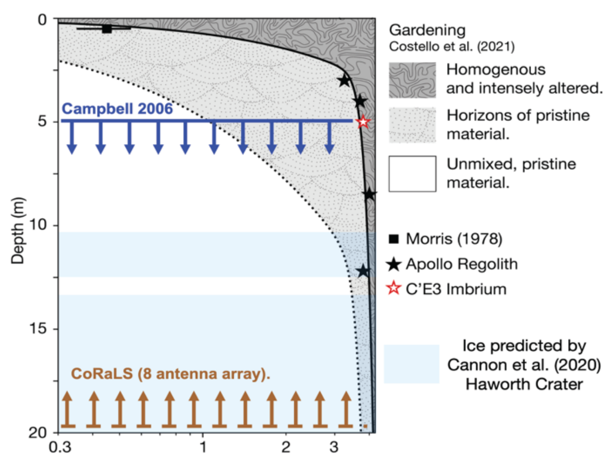

Figure 1: CoRaLS sensing depth and coverage would enable the discovery of model-predicted ice at depth.