Passive Detection of Subsurface Lunar Ice using the Askaryan Effect with the Cosmic Ray Lunar Sounder (CoRaLS).
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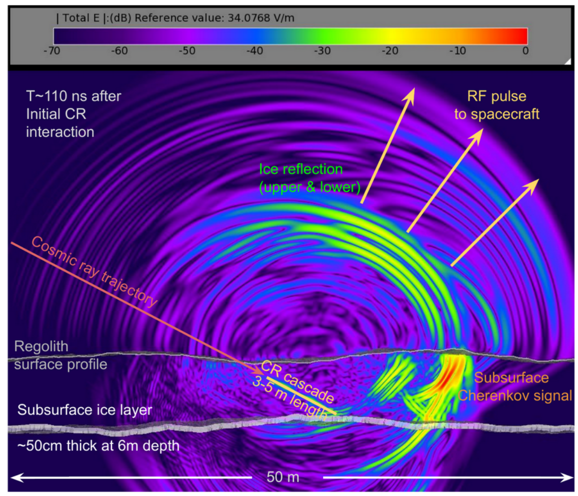
Introduction: Permanently shadowed regions (PSRs) at the lunar poles maintain the thermal conditions necessary to harbor tens-of-meters thick deposits of nearly pure water ice for geologic time [1]. Such ice deposits have been unambiguously discovered by radar investigations within the PSRs of Mercury, 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 [3]. Therefore, if there are extensive ice deposits on the Moon, they may be buried below a > 1 m thick layer of regolith [4].

The *Cosmic Ray Lunar Sounder (CoRaLS)*, a new orbital mission concept, will have the ability to detect and characterize subsurface ice deposits within the top 10-20 meters of lunar regolith, using the *Askaryan effect* of ultrahigh energy cosmic ray impacts, and may definitively discover or disprove the presence of extensive subsurface ice deposits in lunar PSRs.

Askaryan Effect: The lunar regolith is continually bombarded by cosmic rays, from GeV (10^9 eV) up to ZeV energies (10^{21} eV). Due to the lack of a lunar atmosphere, ultrahigh energy cosmic rays (UHECR) (energies $>10^{18}$ 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.

Cosmic Ray Lunar Sounder (CoRaLS): 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 (see figure), 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 may be able to 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:

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