CRYPTEX: A MISSION CONCEPT TO TEST THE PRESENCE, PROPERTIES, AND GEOPHYSICAL CONTEXT OF LUNAR CRYPTOMARIA.

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Introduction and Motivation: One of the earliest and most fundamental observations of the Moon is that the surface is split into light and dark terrains. The dark terrain, which was termed “maria” (“mare” in the singular) by early astronomers, is now well established to be basaltic lava flows, while the light terrain is referred to as the “highlands” and is the ancient anorthositic lunar crust that has been heavily bombarded and gardened by meteorite impacts.

“Cryptomaria” refers to lava flows that were subsequently buried, and therefore obscured from view, by higher albedo basin/crater ejecta. These buried lava flows are also thought to be some of the earliest emplaced basalts in lunar history. The presence of cryptomaria has been inferred in a variety of ways, but the first and most common is through the presence of dark-halo craters (DHCs) in visible images [1–2]. DHCs tend to be small (<10 km) craters and have a characteristic ring of dark ejecta that is thought to result from the excavation of subsurface basalts, which incorporates dark basaltic material into the ejecta. These basalts are therefore thought to underlie the higher-albedo surface materials at depths of meters to hundreds of meters [1,3]. Additional criteria, such as spectral mixing and geochemical analyses of the composition of surface materials to look for basaltic signatures in the regolith via remote sensing, as well as proximity to maria, are also used in the identification of cryptomaria [2]. Radar, which is capable of probing to greater depth than spectroscopy, has also been used to look for areas of low backscatter due to the attenuating effects of ilmenite in lunar basalts and to constrain cryptomare extent and burial depths [4–5]. [6] argued that mass concentrations observed in gravity data may identify candidate cryptomaria regions as well, and [7] used data from the Gravity Recovery and Interior Laboratory (GRAIL) mission to find positive Bouguer gravity anomalies coincident with proposed cryptomaria along an arc in the southern lunar near side extending across Schiller-Schickard, Maurolycus, Mare Austale, and Lomonosov-Fleming regions.

Quantifying the distribution and total amount of volcanism on the Moon is essential for understanding lunar thermal history [8], but is hampered by the highly uncertain locations and volumes of cryptomaria. Mapping cryptomaria so far has been indirect and challenging, relying on the fortuitous confluence of events (e.g., the right impact conditions at the right locations at the right time to create DHCs) or on the geological interpretation of remote sensing datasets, which often have non-unique solutions and require enough basaltic material to be incorporated into the upper microns of surface materials to be detectable in spectral datasets. A direct, in situ test of a cryptomare deposit at even one location would be game-changing. Measurements by CryptEx, the Cryptomaria Explorer, would characterize the physical properties of cryptomaria at our landing site. These measurements will serve as “ground truth” that will also anchor global gravity inversions, greatly enabling our ability to constrain the global cryptomaria inventory.

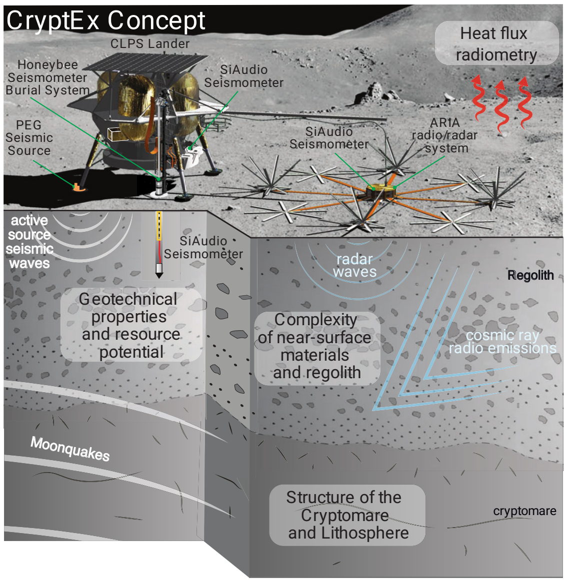

Figure 1: The CryptEx mission concept and instrument suite overview.

Landing Site: The optimal region for testing hypotheses on cryptomaria is the region near Schiller and Schickard craters. This Schiller-Schickard region is one of the most established sites for cryptomaria, providing an optimal landing location for finally ground-truthing the decades-old hypothesis (and community assumptions) of the presence of cryptomaria. The Schiller-

Schickard region features abundant DHCs, geochemical evidence of basalt material, gravity signatures of subsurface mass concentrations, and areas of depressed radar backscatter similar to that of surface maria. The materials that bury the Schiller-Schickard lava flows are thought to be mostly from the Orientale basin-forming-impact event to the northwest [2,9]. Schiller-Schickard thus provides a unique site for a geophysical investigation of the lunar subsurface, serving as a portal into the early volcanic history of the Moon as well as the near-surface and deep interior (Fig. 1).

Science Objectives: CryptEx's instrument suite would deploy both traditional and new geophysical methods to detect and explore buried cryptomare basalt and its setting. Our mission concept has the following overarching science objectives: (1) Characterize the earliest volcanic history of the Moon by quantifying the volume and burial processes of cryptomaria, (2) Characterize the crustal structure at the landing site, from the surface to the crust-mantle boundary, and (3) Quantify present-day seismic activity on the Moon compared to the Apollo era. The science investigations directly address SMD objectives outlined in the NASA 2022 Strategic Plan, as well as multiple key questions from the 2023–2032 Planetary Science and Astrobiology Decadal Survey and the 2007 National Academies report, "The Scientific Context for Exploration of the Moon.".

Instrument Suite: The mission would contain an instrument suite of (1) active and passive source seismology, and (2) ground-penetrating radar (GPR) and passive radiowave radiometry. The Active Seismic Experiment (ASE) would generate seismic waves using a 10 J propelled energy generator (PEG) and constrain internal regolith and cryptomare structures probed by surface waves and reflected waves to at least 100 Hz using a PEG active seismic source to provide 10 J impulsive energy. The Passive Seismic Experiment (PSE) would detect moonquakes and their three-component waveforms (allowing for particle motion analysis to aid in S-P time calculations), and characterize the megaregolith subsurface structure down to the crust-mantle boundary using autocorrelations and receiver functions calculated from signals in the 1–10 Hz range. The Askaryan Regolith Imaging Array (ARIA) radar system would measure the cryptomare interface and regolith properties through dielectric contrasts, roughness, and scattering via antenna waveforms with full Stokes parameters at 250–750 MHz in active radar and in radiometric and cosmic ray passive bistatic radar data.

We have fully simulated ARIA's active radar using advanced EM modeling tools based on the Finite Difference Time Domain (FDTD) method. The simulations apply reasonable dielectric parameters for the regolith, including a gradient in permittivity with depth, and accurate antenna models with realistic couplings. We use a radar pulse with bandwidth and shape matching our expected pulse generator. Fig. 2 shows overlain raw radar returns as antenna voltage vs. time, along with a section view for the 3D FDTD model results, for a simulation with a 40 m-deep cryptomare layer with realistic geophysical roughness [10], and embedded scattering centers of random spheres of basalt with a volume distribution derived from the Chang'E-3 observed surficial rock distributions [11]. For this simulation we have assumed highlands regolith of $\tan\delta = 0.001$ and basalt with a mean permittivity of $\varepsilon = 7.7$ and porosity of 7%. The returns from the cryptomare layer at 40 m depth are clear even in the raw data (Fig. 2).

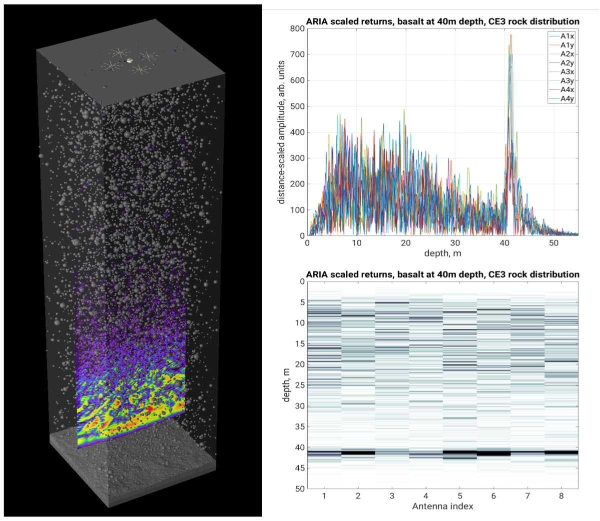

Figure 2: ARIA radar FDTD simulation results for cryptomare buried at 40 m depth.

Team: The CryptEx mission team structure is:
PI: Peter Gorham (UHawaiʻi at Mānoa).
Deputy PI: Ali Bramson (Purdue University).
Instrument Leads: ARIA: Christian Miki (UHawaiʻi Mānoa) and Seismometers: Dani DellaGiustina (UArizona). *Project Manager*: S.H. (Hop) Bailey (UArizona).
The team features *Co-Is* from the following institutions: UChicago, OSU, Purdue, UArizona, UMD, PSI, UAF, UHawaiʻi, SLAC, and NASA MSFC, with *collaborators* from Stanford and NPS (see author list).

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