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Radar Sounding of Europa's Subsurface Properties and Processes: The View from Earth

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Abstract

A primary objective of future Europa studies will be to characterize the distribution of shallow subsurface water as well as to identify any ice-ocean interface [1]. Other objectives will be to understand the formation of surface and subsurface features associated with interchange processes between any ocean and the surface as well as regional and global heat flow variations. Orbital radar sounding, a now maturing technology, will be an essential tool for this work. We review the hypothesized processes that control the thermal, compositional and structural properties, and therefore the dielectric character, of the subsurface of Europa's icy shell. We introduce fundamental concepts in radar sounding and then assess analog processes represented by, and sounded in, Earth's ice sheet. We use these Earth analog studies to define the radar imaging approach for Europa's subsurface that will be most useful for testing the hypotheses for the formation of major features.

Europa is a hypothesized site of incipient habitably because of its potentially vast subsurface ocean. The presence of this water reservoir has been inferred indirectly from Europa's induced magnetic field [2, 3] and tectonic mapping of its young surface [4, 5]. Future space-based geodetic measurements of Europa's time varying gravity field would definitively demonstrate the existence of an ocean. However, understanding this ocean's coupling to its overlying crust — key for understanding Europa's astrobiologic potential — will require sounding Europa's third dimension.

Airborne ice penetrating radar is now a mature tool in terrestrial studies of Earth's ice sheets [6], and orbital examples have been successfully deployed at Earth's Moon and Mars. Recent terrestrial examples include the University of Texas's High Capability Airborne Radar Sounder (HiCARS) [7], the British Antarctic Survey's PASIN system [8], and the University of Kansas's IPR and CARDS systems [9]. Spaceborne demonstrations include NASA's Apollo 17's ALSE [10], JAXA's LRS system on the Kaguya lunar orbiter [11], MARSIS onboard ESA's Mars Express [12], and SHARAD onboard NASA's Mars Reconnaissance Orbiter [13]. We review the target of observations, Europa's ice crust and the ocean that likely lies beneath; summarize the state of the art of radar sounding systems; survey previous observations made by ice penetrating radar at Earth; and examine the challenge of operating such a system at Europa.

Liquid water containing impurities (brine), is an effective conductor of electricity, and hence strongly dissipates electromagnetic energy. In addition, strong contrast in real permittivity at radio frequencies between pure water ice ($\varepsilon \sim 3.15$) and liquid water ($\varepsilon \sim 80$; [7, 14]) lead to a large dielectric impedance contrast that typically results in a highly reflective interface, with a reflection of half or more the incident power, compared to a thousandth of the incident power reflected by silicate rock. It is this strong contrast that enables exploration for water within of Europa's crust.

We can use Earth analog studies to describe the radar imaging approach for Europa's subsurface that will be most useful for supporting/refuting the hypotheses for the formation of major surface/subsurface features as well as for "pure" exploration of Europa's icy shell and its interface with the underlying ocean.

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