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# Radar-Sounding of Icy Mantles and Comets Using Natural Radio Noise

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## 1. Introduction

Radar-sounding of ice sheets on Earth yields crucial information on ice history and dynamics, including discoveries of subglacial lakes beneath 3-4 km of ice [1]. Mars Express and the Mars Reconnaissance Orbiter (MRO) have now demonstrated the corresponding power of orbital radar sounding for planetary exploration, in particular by imaging structures within and beneath kilometers of Martian water ice [2-4]. Based on this experience, a sophisticated orbital radar sounder is planned for a flagship mission to Europa, with the aim of imaging stratigraphy, faults, diapirs and other geological structure in the upper few kilometers of the water-ice mantle there, and possibly even detecting the upper surface of the (likely) underlying ocean [5]. Recent modeling of the formation and evolution of volatile-rich bodies suggests that oceans or lakes of liquid water occur beneath water-ice mantles in a surprising variety of places, including Ceres in the outer asteroid belt [6], 3 of the 4 Galilean moons of Jupiter as well as Enceladus and Titan in the Saturnian system [7], and possibly even Pluto [8]. Thus there is now a wide scope for low-cost missions to bodies of exceptional interest, and for radar sounding of icy mantles to image near-surface structural geology related to underlying water (whether past or present).

## 2. Natural Radio Noise Sources

However, conventional radar sounding from orbit is challenging in low-cost missions, in large part because of the power (and corresponding mass) budget of radar transmitters [5]. Terrestrial experience suggests an alternative approach based (1) on using environmental radio noise (or noise-like sources) as radar illumination; and (2) detecting echoes of noise-like illumination by means of correlation processing. This approach is presently used, for example, to study nonlinear dynamics in Earth's ionosphere using noise-like illumination from commercial FM radio stations [9]. At Europa, Jovian hecto- and decameter radio emission [10] would provide a very strong, natural radar 'source' at the wavelengths which are commonly used for ice-sounding – we estimate a source level at the Europan surface on the order of $10^4$ times that provided by the MRO Shallow Radar (SHARAD) transmitter at the surface of Mars. At Ceres (mean orbital radius 2.75 AU) and sunward, solar radio noise is a viable illumination source – we estimate the power flux in solar-storm noise near 30 MHz [11] at Ceres to be within a factor of 20 of that provided by SHARAD (which relies on a dipole antenna for reception).

## 3. Prospective Target and Path

The possible roles of asteroids and comets in delivering organic compounds to the early Earth [12], and the possibility of a liquid layer within Ceres even at present [6], motivate particular interest in those bodies as targets for low-cost missions. Moreover, arrivals of the Rosetta spacecraft at Comet 67P/Churyumov-Gerasimenko in August 2014 (with the CONSERT radio-sounding experiment) and Dawn at Ceres in February 2015 may well (judging from experience elsewhere in the solar system) result in surprising discoveries that motivate further study. We therefore focus here on the technical prospects for sounding comets and icy mantles of asteroids, using correlation radar with solar radio-noise-illumination, at 3 AU and sunward. We derive from statistics of solar radio noise and correlation processing the required observation time-scales as functions of observational figures of merit (e.g., resolutions). We consider associated downlink requirements in comparison to those for conventional radar sounding. Finally, because the concept of sounding using natural radio noise is presently at low TRL for planetary missions (we estimate TRL 2-3 for that application), we outline a prospective effort to raise the TRL by sounding a terrestrial ice sheet using solar radio emission at roughly 30 MHz.

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