RIME-REASON Synergistic Opportunities for Surface and Near-surface Investigations of Icy Moons

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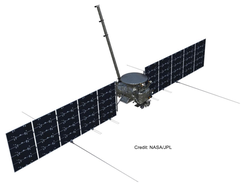
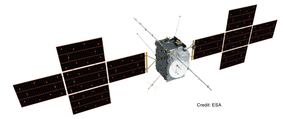




EGU23-10554

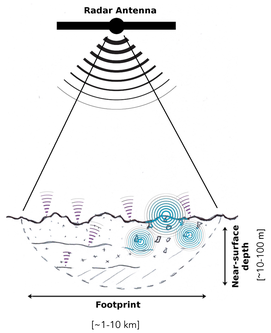
A. Purpose

We assess the use of multi-frequency/bandwidth radar reflectometry for characterizing the near-surface* properties of icy moons in the context of rough surfaces.

This approach can be used to investigate processes that influence the near-surface composition and structure (layer thickness and porosity), such as regolith generation, mass movements, brine infiltration and refreezing, and plume fall-out deposits.

The coherent surface return from the Radar for Icy Moons Exploration (RIME) on ESA's Jupiter Icy Moons Explorer (JUICE) mission and the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) on NASA's Europa Clipper mission is sensitive to bulk near-surface properties and surface roughness.

Radar system	Mission	Center frequency	Bandwidth	Vertical resolution in ice (ε = 3.15)
REASON	Europa Clipper	9 MHz 60 MHz	1 MHz 10 MHz	85 m 8.5 m
RIME	JUICE	9 MHz	1 MHz 2.8 MHz	85 m 30 m



*The near-surface depth is defined as the vertical resolution (i.e., skin depth) of each radar system.

The footprint is governed by the signal **bandwidth** and spacecraft **altitude**.

The near-surface depth is governed by the signal **bandwidth** and **permittivity (ε)**, the latter which depends on near-surface structure and composition.

References

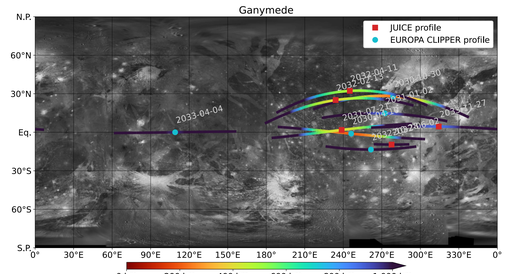
Chan et al., 2023; Gerekos et al., 2018; Grima et al., 2014; Grima et al., 2016; Heggy et al., 2012; Jia et al., 2021; Kofman et al., 2015; Li et al., 2022; Moore et al., 1999; Mouginot et al., 2009; Seignovert et al. 2023; Shepard et al., 2001

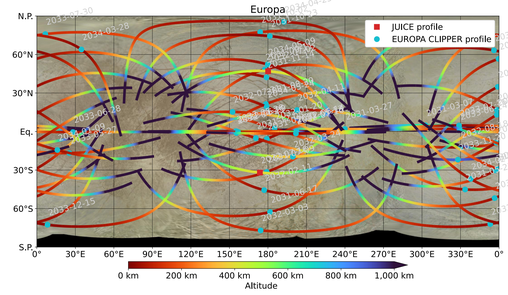
Acknowledgements

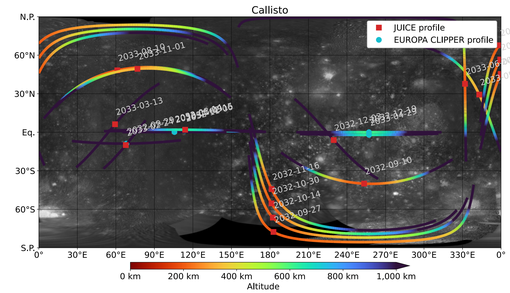
This work was supported by RIME/JUICE (ESA), REASON/Europa Clipper (NASA), and the G. Unger Vetlesen Foundation.

B. Opportunities for Joint Science

Does not include ground tracks during orbital phase of JUICE around Ganymede







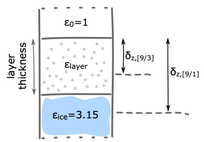
C. Analytical Approach

The ratio of the coherent power derived from two radars with the same center frequency at 9 MHz but different bandwidths (1 vs. 2.8 MHz) is primarily sensitive to reflectivity compared to surface roughness. Coherent ratio variability can then be used to constrain near-surface layer thickness and porosity.

$$P_c = r^2 e^{-\left(\frac{4\pi\sigma_h}{\lambda}\right)^2}$$

- P_c is the coherent power
- r is the reflection coefficient
- σ_h is the RMS height (i.e., surface roughness)
- H is the Hurst exponent

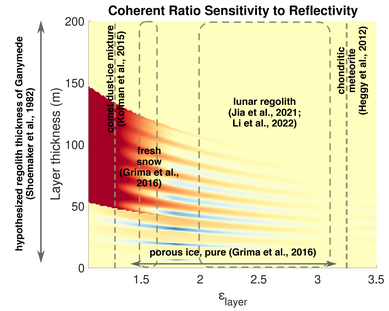
Thin layer model

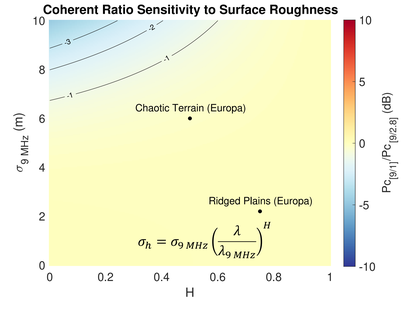


δ_z = near-surface depth

$$r = \frac{r_{0-layer} + r_{layer-ice} e^{2i\beta}}{1 + r_{0-layer} r_{layer-ice} e^{2i\beta}}$$

$$\beta = \frac{2\pi}{\lambda} \sqrt{\varepsilon_{layer}} \times (layer\ thickness)$$





D. Concept Validation and Future Work

Radar scattering simulations of both proxy and observed surface roughness will be performed across altitudes and bandwidths to validate uncertainties in the analytical approach for discriminating near-surface layering described above.

The model is based on the multilayer Stratton-Chu coherent simulator (Gerekos et al., 2018) modified to incorporate scattering contributions from all frequencies contained within the radar chirp.

The Radar Statistical Reconnaissance method (Grima et al., 2014) will be used to derive P_c from simulation results.

	Surface 1	Surface 2	
	[9/1 MHz]	[9/1 MHz]	[9/2.8 MHz]
Sim. # 1	✓	✓	✓
:	:	:	:
Sim. #1000	✓	✓	✓

Case 1: RIME and REASON crossovers, which might not share the same footprint

- relevant for producing a homogenous radiometric dataset for complementary [9/1 MHz] radar measurements across the icy Galilean moons
- investigate the use of bandwidth filtering of RIME [9/2.8 MHz] for calibration with REASON [9/1 MHz]

Case 2: RIME [9/2.8 MHz] ground tracks, where footprints share the same scattering characteristics as REASON [9/1 MHz] intersections

- assess the coherent ratio sensitivity to surface roughness and reflectivity
- investigate the use of bandwidth filtering to produce multiple sets of observations along RIME [9/2.8 MHz] ground tracks