



Probing Callisto's Interior: A Radio Science Investigation from a Landed Platform

Sebastien Le Maistre^{1,2}, Valerio Filice^{2,3}, Alfonso Caldiero^{1,2}, Marta Goli^{1,2}, Julien Laurent-Varin⁴, Rose-Marie Baland¹, Marie Yseboodt¹, Antony Trinh¹, Alexis Coyette⁵, Jean-Charles Marty⁴, Tim Van Hoolst^{1,6}, and Veronique Dehant^{1,2}

¹Royal Observatory of Belgium, Brussels, Belgium (sebastien.lemastre@oma.be)

²UCLouvain, Louvain-la-Neuve, Belgium

³Delft University of Technology, Delft, The Netherlands

⁴Centre National d'Études Spatiales, Toulouse, France

⁵Namur Institute for Complex System (naXys), Namur, Belgium

⁶Institute of Astronomy, KU Leuven, Leuven, Belgium

Callisto, the outermost Galilean moon of Jupiter, remains one of the most enigmatic large bodies in the Solar System. Although spacecraft flybys have revealed a geologically ancient and relatively inert surface, its internal structure is still poorly constrained (e.g., [1]). Determining whether Callisto harbors a subsurface ocean or has experienced differentiation is crucial to understanding its formation and thermal and geological evolution. We present a radio science experiment concept for a lander mission to Callisto, designed to measure its rotation, tidal response, and ephemeris with high precision in order to infer its internal structure and dynamical state.

The proposed experiment uses two-way Doppler tracking between the lander and Earth-based antennas, employing a Ka- or X-band coherent transponder (e.g., LaRa [2]). By collecting coherent Doppler data over multiple orbital periods of Callisto, we aim to detect tidal deformations (characterized by the Love number h_2), forced longitudinal librations, and the orientation of Callisto's spin axis. We perform an end-to-end simulation to quantify the experiment's sensitivity to these key geodetic observables, which are directly linked to the presence and thickness of a subsurface liquid layer and to the degree of differentiation of the interior. The estimated precision in rotation and tidal parameters is then propagated to interior structure parameters (such as the thickness and density of internal layers) and compared against theoretical models, including undifferentiated, partially differentiated, and ocean-bearing structures.

In addition, we evaluate the potential of lander-based radiometric data to refine Callisto's ephemeris, providing improved constraints on tidal dissipation processes within the Jovian system and enabling long-term tests of gravitational theories. Accurate knowledge of the migration rate of Callisto could also shed light on the origin of Jupiter's obliquity of 3.12 degree [3].

This study demonstrates that a single lander, equipped with a well-designed radio science experiment, can deliver essential constraints on Callisto's deep interior, offering a valuable geophysical complement to orbital and flyby investigations.

[1] T. Van Hoolst et al., Geophysical characterization of the interiors of Ganymede, Callisto and Europa by ESA's JUPITER ICy moons Explorer. *Space Science Reviews*, 220(5):54S, 2024.

[2] Le Maistre et al., LaRa, an X-band coherent transponder ready to fly. In *European Planetary Science Congress*, pages EPSC2022–1169, 2022.

[3] Dbouk and Wisdom. The origin of jupiter's obliquity. The Planetary Science Journal, 4(10):188, 2023.