Integrated Europa Interior Science with Europa Clipper

Poster 1746

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1. Introduction

The *Galileo* mission to Jupiter revealed that Europa was an ocean world. The *Galileo* magnetometer experiment in particular provided strong evidence for a briny subsurface ocean beneath the ice shell, likely in contact with the rocky core [1]. Within the ice shell and ocean, a number of tectonic and geodynamic process may operate either today or at some point in the past, including solid ice convection, diapirism, subsumption, and interstitial lake formation.

The goals of the *Europa Clipper* mission include characterization of the interior; confirmation of the presence of a subsurface ocean; identification of constraints on the depth to this ocean, and on its salinity and thickness, determination of processes of surface-ice-ocean exchange.

Three broad categories of investigation (augmented by several auxiliary measurements) are planned to interrogate different aspects of the subsurface structure and properties of the ice shell and ocean:

- Magnetic induction
- Subsurface radar sounding
- Tidal deformation

Alone, each of these investigations will reveal unique information. Together, the synergy between these investigations will expose the secrets of the europan interior in unprecedented detail, an essential step in evaluating the habitability of this ocean world [3].

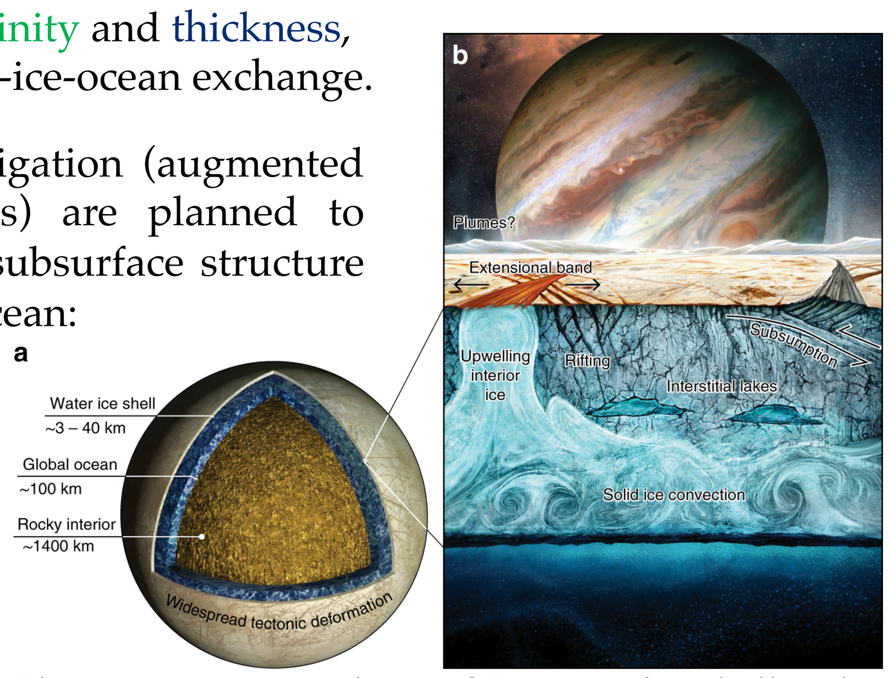

Figure 1: Cutaway views of Europa's ice shell and ocean, showing the scale of (a) the individual layers in relation to each other, and (b) an artistic schematic* of different tectonic and geodynamic processes that might operate within the ice shell [2].

2. Magnetic Induction

- A time-varying magnetic field imposed on a **conducting** body induces electric currents which generate a magnetic field in a sense to oppose the driving field.
- At Europa, the external magnetic field varies at Jupiter's ~11-hr synodic period and Europa's ~ 85-hr orbital period. Figure 2 shows a simulation of Jupiter's magnetic field at Clipper's location over the tour.

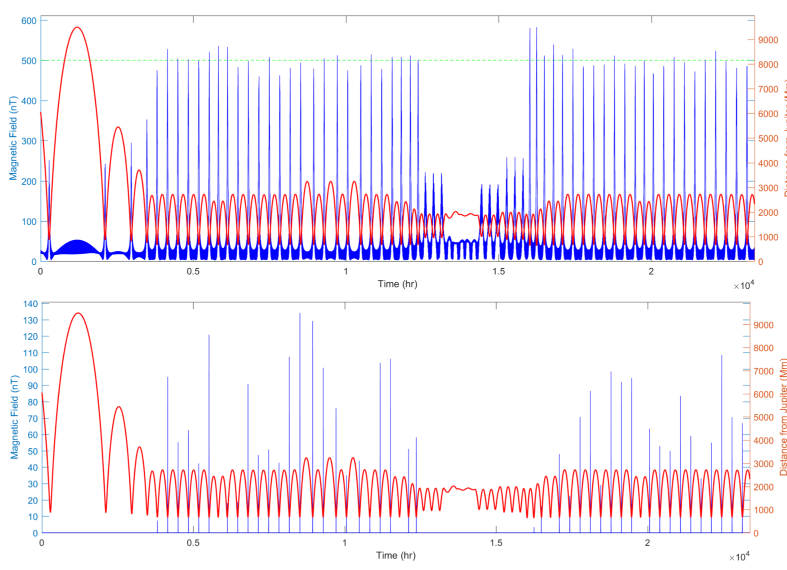

Figure 2: Simulation of Jupiter's magnetic field at *Clipper*'s location for the 17F12v2 trajectory (top). Simulation of Europa's induced magnetic field (11 hr and 85 hr components) at *Clipper*'s location (bottom).

- Europa Clipper Magnetometer (ECM) measures field components at two frequencies to yield estimates of the ocean thickness and conductivity (Figure 3).
- Distinguished from fields of currents flowing in the local plasma near Europa (Plasma Instrument for Magnetic Sounding (PIMS) and modeling).

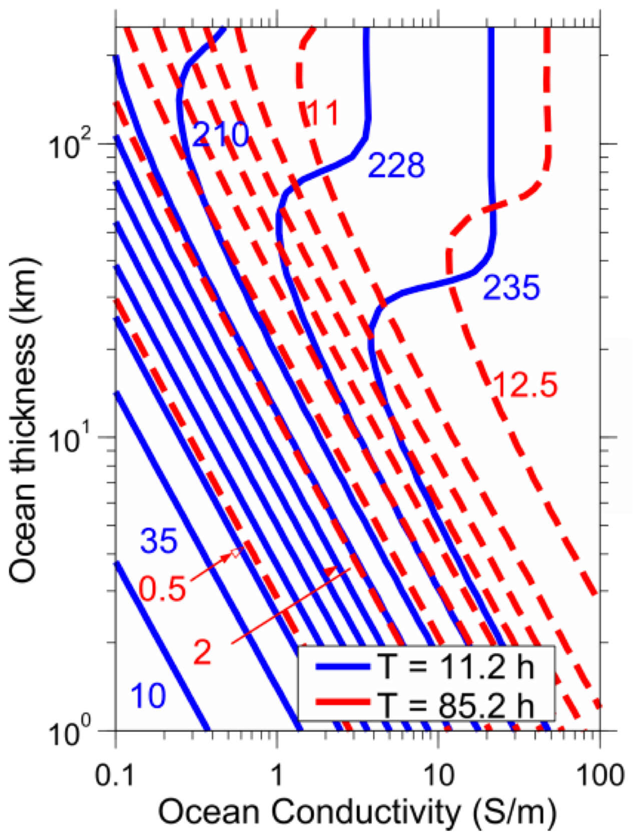

Figure 3: Surface magnitude of the dipole induced at the synodic (blue) and orbital (red) periods. Contours indicate the magnetic field strength at that frequency in nT.

3. Subsurface Sounding

- Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) to locally image the subsurface of the ice shell (Fig. 4).
- Dual-frequency ice-penetrating radar provides robustness against the unknown europan environment.
- Detection of an ice-water interface would be unambiguous constraint on the ice shell thickness. Unlikely unless ice shell is thin (≲) 10 km and/or thermally conductive, but can place constraints on the ice shell's thermophysical structure [4].
- Shallow subsurface sounding will detect any shallow pockets of melt or dipping structures within the ice shell
- Multiple datasets can be used to assess the europan interior against Europa Point Models (Figure 5).
- Supported by imaging data from the Europa Imaging System (EIS) and VHF cross track interferometry to discriminate off-nadir surface clutter.

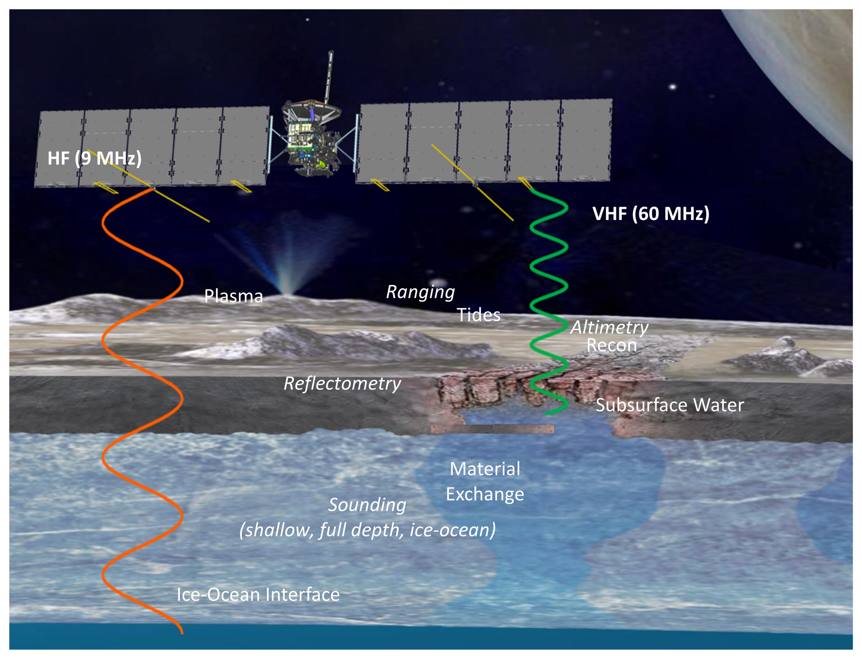

Figure 4: Cutaway view of Europa's water ice shell with the *Europa Clipper* spacecraft above the surface. REASON's planned science investigations and measurement techniques (italics) are labeled.

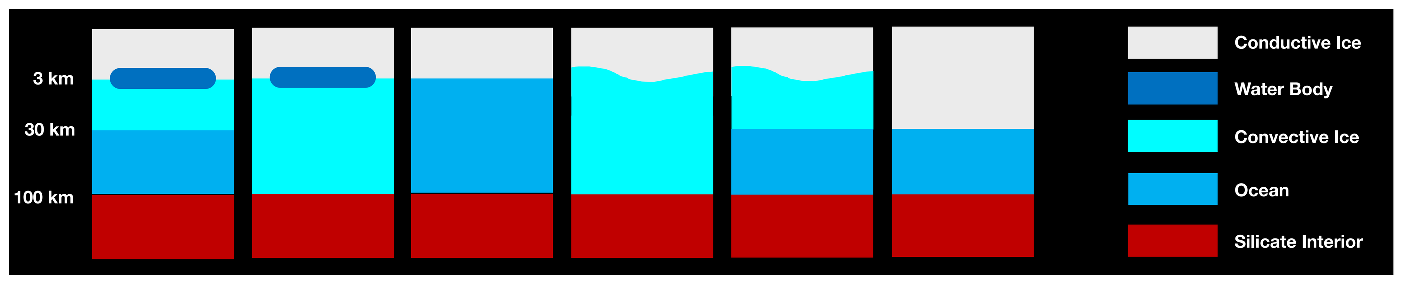

Figure 5: Variety of Europa Point Models that sample the range of published scientific hypotheses, as well as Europa's known properties. REASON measurement requirements evaluated using ensembles of these point models

4. Tidal Deformation

- Telecom subsystem will track two-way, Doppler shift of the radio link between the spacecraft and Earth to yield line-of-sight velocity of the spacecraft, which is controlled by the gravity field [5].
- Time-varying component of gravity (characterized by degree-2 tidal potential Love number k_2) is controlled by the effective rigidity of the ice, a function of the ice shell thickness and rheological properties.
- Ranges from REASON at crossover locations (Figure 6) improve orbit determination of spacecraft; yield displacement tidal Love number h_2.
- Combination of Love numbers can reduce dependence on rigidity (Figure 7).

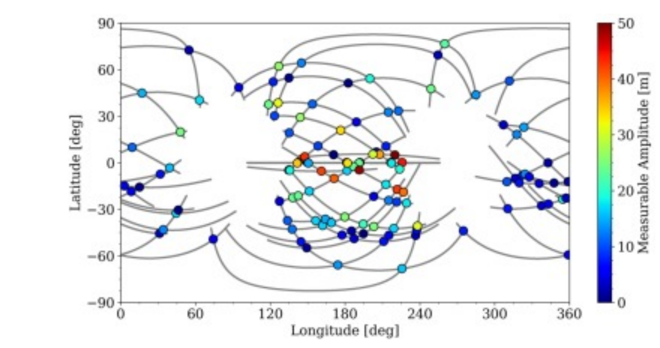

Figure 6: Map of cross-over locations on the 17F12v2 trajectory up to an altitude of 1000 km. Color indicates measurable tidal amplitude at the respective cross over point for $h_2 = 1.2$. Adapted from [6]

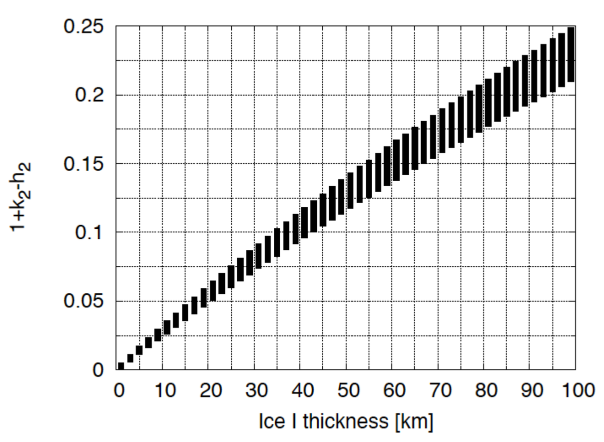

Figure 7: The quantity $\Delta = 1 + k_2 - h_2$ constrains the thickness of the ice shell more precisely than either Love number alone [7].

5. Auxiliary Measurements

- Static gravity J_2 & C_{22} (Radio Science): test if ice shell is in hydrostatic equilibrium [8]
- Surface heat flux (Europa Thermal Emission Spectrometer: E-THEMIS) used to estimate thickness of conducting ice.
  - Thermal anomalies indicate recent intrusion
- Along-track topography profiles (REASON VHF) constrain elastic thickness
  - Conductive: tidal heating regionally thins ice shell, lower elevation over hotspots
  - Convective: tidal heating promotes more vigorous convection, elevated topography over hotspots
- Limb profiles and Astrometry (EIS / EUROPA-UVS) constrain Europa's shape; stellar occultations can constrain topography
- Libration amplitude from geodetic / photogrammetric control of images (EIS), informs on thickness of ice shell.

6. Synthesis

- Three primary quantities to measure for L1 science: ice shell thickness, ocean thickness, ocean saliniity
- Three main investigations give linear combinations of the above:
  - Magnetic induction:
    - Depth to ocean (ice shell thickness)
    - Combination of ocean thickness and conductivity (salinity)
  - Subsurface sounding
    - Thickness of conductive layer (portion of ice shell thickness)
    - Lower bound on ice shell thickness
  - Tidal deformation / static gravity
    - Combination of ice shell thickness and rheology
    - Silicate core radius (constrains ocean thickness)
- Multiple auxiliary measurements to further constrain structure
- Combining multiple datasets is a powerful way of characterizing the interior of Europa and habitability of its subsurface ocean [3].

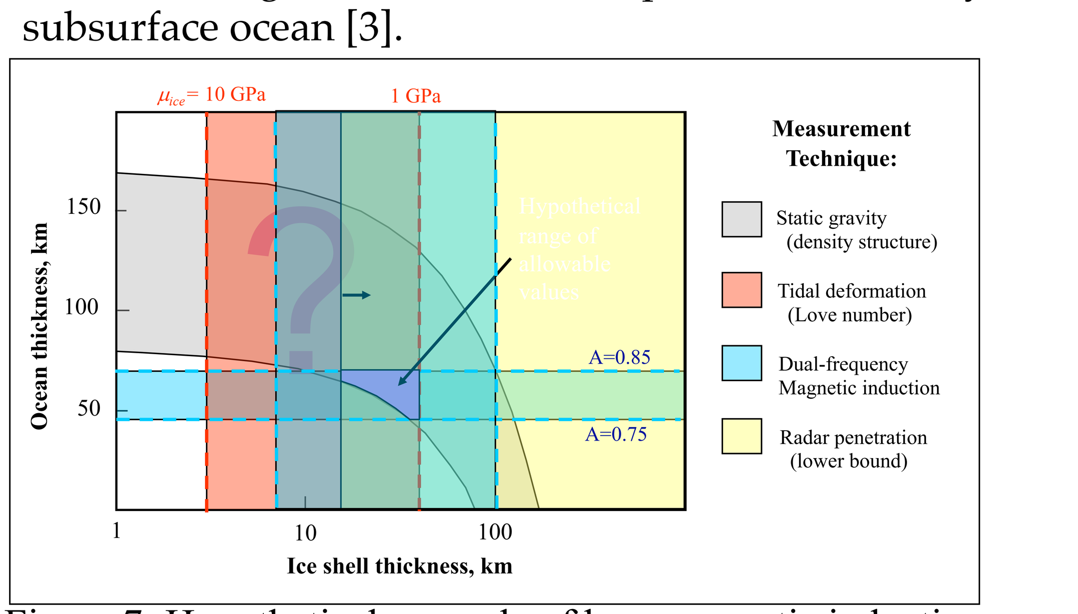

Figure 7: Hypothetical example of how magnetic induction, subsurface sounding and tidal deformation could be used in conjunction to constrain the ice shell and ocean properties of Europa. Here *A* is the dimensionless induction response and μ_{ice} is the rigidity of the ice shell. Static gravity provides a constraint on the total thickness of the ice+ocean.

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References [1] Kivelson M.G. et al. (2000) *Science 289*, 1340–1343. [2] Howell, S. M. and Pappalardo R. T. (2020) *Nature Comm. 11*, 1311. [3] Vance S.D. et al. (2018) *JGR 123*, 180–205. [4] Blankenship D.D. et al. (2009) in *Europa* (Univ. of Ariz. Press), 631–653. [5] Verma A. and Margot J.-L. (2018) *Icarus 314*, 35–49. [6] Steinbrügge, G. et al. (2019), *EPSL 482*, 334–341. [7] Wahr J.W. et al. (2006) *JGR 111*, E12005. [8] Anderson J.D. et al. (1998) *Science 281*, 2019–2022.