INTEGRATED EUROPA INTERIOR SCIENCE WITH EUROPA CLIPPER.

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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]. One of the goals of the *Europa Clipper* mission is to confirm and constrain the depth to this subsurface ocean, provide information on ocean salinity, and determine processes of surface-ice-ocean exchange. In pursuit of this goal, three broad categories of investigation are planned to interrogate different aspects of the subsurface structure and properties of the ice shell and ocean: magnetic induction, subsurface radar sounding, and 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 [2].

Magnetic Induction: Europa's induced magnetic field implies the presence of an electrically conducting fluid layer. To follow up on *Galileo*'s discovery [1], *Europa Clipper* includes a facility magnetometer (ECM), which will provide constraints on three parameters: the ocean thickness, conductivity and depth below the surface (i.e., ice shell thickness). The *Europa Clipper* spacecraft will conduct more than 40 close flybys of Europa, enabling electromagnetic induction observations at multiple frequencies. The response at the 11-hr synodic rotation period is primarily sensitive to the thickness of the ice, and the response at the 85-hr period is controlled by the ocean thickness and conductivity, the latter of which is a measure of the salinity of the ocean. *Galileo* only measured the shorter period component, thus our knowledge of the europan interior based on the data gained from *Europa Clipper* will immensely improve upon what was learned from *Galileo.*

The tradeoff between the ocean thickness and salinity can be further decoupled by measuring response at the 5.6-hr period, and obtaining better knowledge of Jupiter's magnetospheric field, which ECM will characterize far from Europa. The magnetospheric field includes contributions from plasma currents. These sources of uncertainty will be constrained by plasma measurements obtained by the Plasma Instrument for Magnetic Sounding (PIMS).

Subsurface Sounding: A complementary approach to investigating the interior is to locally image the shallow and deep subsurface of the ice shell. This will be performed by the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON), a dual-frequency ice-penetrating radar. REASON will generate shallow Very-High Frequency (VHF), full-depth VHF, and High Frequency (HF) radargrams of the subsurface. Because VHF is more resistant to Jovian radiofrequency (RF) noise and HF is less sensitive to scattering off rough surfaces and porous regolith, using the two bands together provides robustness against the unknown europan environment.

Although detection of an ice-water interface would be the most unambiguous constraint on the ice shell thickness, such detection is likely only if the ice shell is thin ($\lesssim$) 10 km and/or thermally conductive. However, because radar attenuation in ice is a strong function of the temperature, the radar's penetration depth for internal structures corresponds to the majority of the thickness of the conductive portion of the ice shell (which may be underlain by a warm, convecting layer) [3]. Thus, even though the radar may not detect the ice/ocean interface itself, the pattern of penetration and attenuation can also place constraints on the ice shell's thermophysical structure that would reveal mechanisms of surface-ice-ocean exchange.

In addition, shallow subsurface sounding will detect any shallow pockets of melt or dipping structures within the ice shell, and will be supported by imaging data from the Europa Imaging System (EIS) and VHF cross track interferometry to discriminate off-nadir surface clutter.

Tidal Deformation: Tidal forces cause the ice shell to deform periodically. The RF system on *Europa Clipper* will be used to conduct a radio science investigation to measure the tidal deformation. The two-way, Doppler shift of the radio link between the spacecraft and the Earth-based Deep Space Network (DSN) will be tracked near closest approach on each flyby. These measurements will yield the line-of-sight velocity of the spacecraft and can be used to solve for the gravity field [4].

By taking measurements at multiple true anomalies in Europa's orbit, the time-varying component of the gravity is obtained, characterized by the degree-2 tidal potential Love number k_2, which describes the distribution of mass as the ice shell is distorted by the tidal forces. The magnitude of the deformation is determined by the effective rigidity of the ice, which is a function of the ice shell thickness and rheological properties.

Radio science can be supported by ranging data acquired by REASON at crossover locations, to improve orbit determination of the spacecraft. The range measurements will be combined with imaging data to map the radar returns to a known geometry. The REASON ranging data could also be used to obtain the displacement tidal Love number h_2. Although the investigation carries no requirement to obtain h_2, this would be highly beneficial. The quantity $\Delta = 1 + k_2 - h_2$ is far less sensitive to the rigidity of the ice, and constrains the thickness more precisely than either Love number alone [5].

Auxiliary Measurements: In addition to the three investigations discussed above, several other datasets could further constrain the possible structure. The same radio science data used to determine the gravitational tides can also provide estimates of the static degree-2 gravity coefficients (J_2 and C_{22}). Measurement of these coefficients can be used to test the *Galileo* assumption that Europa is in hydrostatic equilibrium [4, 6].

The surface heat flux as measured with the Europa Thermal Emission Spectrometer (E-THEMIS) can reveal information about the thickness of the conducting layer, which will be compared to that from sounding. In general, the heat flux and thickness should inversely correlate, and deviations would indicate a thermal anomaly (e.g., a recent intrusion). The heat flux can also be compared with the thickness obtained from induction in order to estimate the fraction of heating generated with the ice shell (from tidal dissipation) as opposed to that generated below the ice shell (e.g., radioactive heating in the silicates, oceanic dissipation).

Another method to constrain the elastic thickness and heat flux of Europa is to use along-track profiles of the surface topography, collected by the REASON VHF altimetry investigation. If the ice shell were conductive, then variations in tidal heating and surface temperature would regionally thin or thicken the ice shell. If the ice shell is isostatically compensated, the surface elevation would be lower over warmer regions. Conversely, if the lower ice shell is convecting, then locally higher tidal heating could result in more vigorous convection rather than thinning. Assuming a constant shell thickness, topography should be elevated over hot spots, an expression of plume buoyancy, albeit modulated (damped) by lithospheric resistance.

Additionally, images acquired by EIS will be used to constrain Europa's shape (using limb profiles), and libration amplitude (through geodetic and photogrammetric control of images at different true anomalies), both of which directly inform on the structure and thickness of the ice shell.

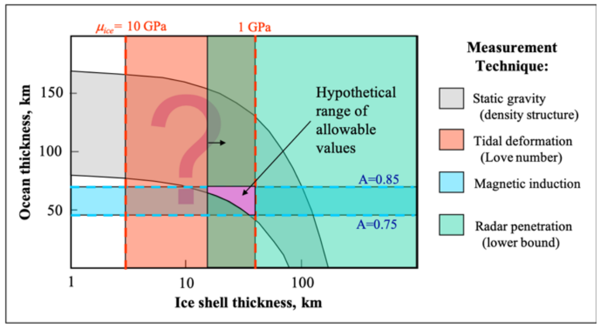

Figure 1: Hypothetical example of how magnetic induction, subsurface sounding and tidal deformation could be used in conjunction to constrain the ice shell and ocean properties of Europa. Here A is the dimensionless induction response and μ_{ice} is the rigidity of the ice shell. Static gravity provides a constraint on the total thickness of the ice+ocean.

Synthesis: We have described several key investigations (and a number of auxiliary datasets) that will be carried out on the *Europa Clipper* mission, providing at least three independent measurements characterizing Europa's interior. Each measurement technique has different sensitivities, dependencies and limitations, and measures different quantities.

The magnetic induction investigation will result in a measure of the depth to the ocean (ice shell thickness) and estimates of the ocean thickness and salinity. In contrast, subsurface sounding measures ice shell properties. Although the radar may not penetrate all the way through the ice shell, it will provide a measure of the elastic portion and establish a lower bound for the full shell thickness. Tidal deformation and static gravity measurements can place constraints on the thickness of the ice shell, and on the silicate radius (and hence indirectly on the ocean thickness), respectively.

In Figure 1, we show a hypothetical example of how the diversity of interior investigations could combine in order to provide the necessary constraints on the ice shell and ocean properties. Combining multiple datasets is a powerful way of characterizing the interior of Europa and habitability of its subsurface ocean [2].

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