EXPLORING THE INTERIOR OF EUROPA WITH EUROPA CLIPPER. J.H. Roberts[1], M.L. Cable[2], C.A. Raymond[2], D.M. Schroeder[3], A.M. Rymer[1], W.S. Kiefer[4] and the Europa Clipper Interior Thematic Working Group, [1]Johns Hopkins Applied Physics Laboratory, Laurel, MD, USA; [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [3]Stanford Univ., Stanford, CA, USA, [4]Lunar & Planetary Inst., Houston, TX, USA

Introduction: The *Galileo* mission to Jupiter revealed that Europa was an ocean world. The 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 processes may operate today or have operated 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; constraints on the depth to this ocean, and its salinity and thickness; and determination of processes of material exchange between the surface, ice shell, and ocean as illustrated in Figure 1.

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. These investigations are supplemented by several auxiliary measurements. 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: The external magnetic field at Europa varies at multiple frequencies as a result of Jupiter's rotation, Europa's orbital motion, and the interaction of the Jovian magnetosphere with the solar wind. The largest variation (~200 nT) occurs at the 11.2 hr synodic period, principally due to the 9.6° tilt of Jupiter's dipole axis with respect to its spin axis. Variation at the orbital (85.2 hr) and second harmonic of the synodic period (5.6 hr) are expected to produce appreciable induction responses (~20 nT), which can break the single-frequency degeneracy, revealing a unique combination of ice shell thickness, ocean thickness, and ocean conductivity that fits the data.

These measurements will be performed by the Europa Clipper Magnetometer (ECM) with needed corrections for plasma perturbations provided by the Plasma Instrument for Magnetic Sounding (PIMS). ECM measurements of Jupiter's magnetic field far from Europa ($\gtrsim 3R_{\text{Europa}}$) will be combined with data taken

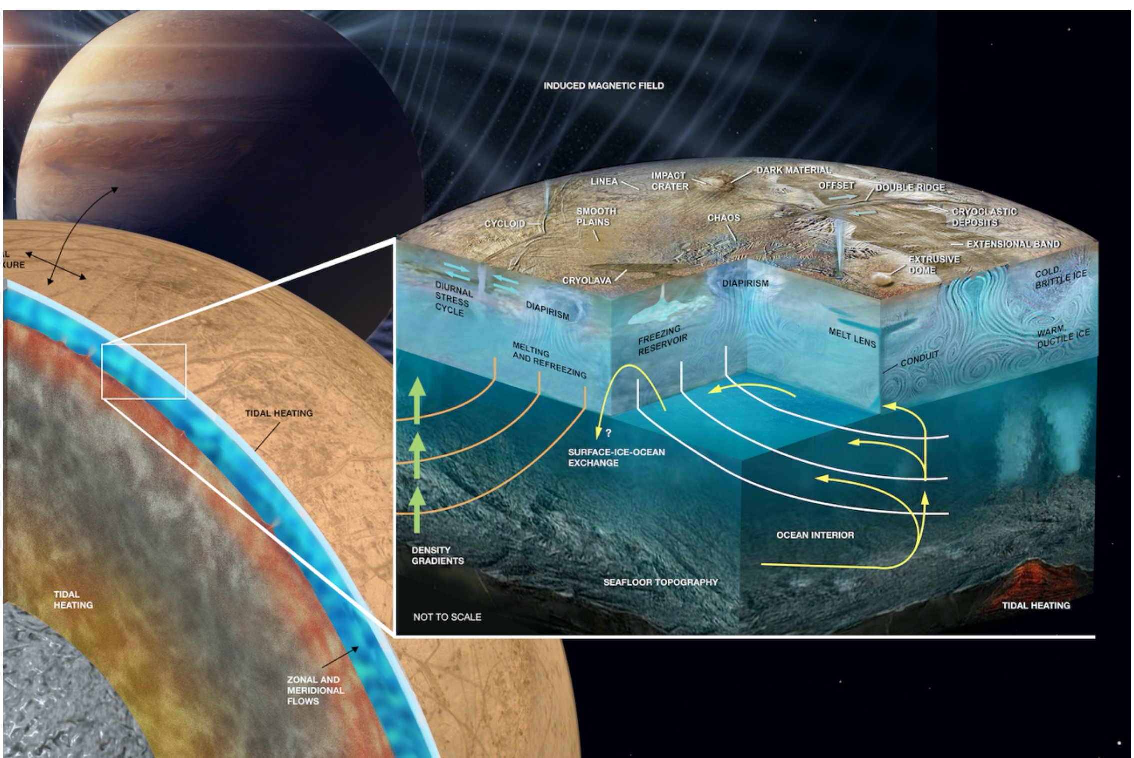

Figure 1: Artist's conception of the interior of Europa, highlighting the processes in the ice shell and ocean. Image Credit: David Hinkle for [3].

during close approaches to determine the driving and induced field amplitudes at least two frequencies with an accuracy of ±1.5 nT. For the expected driving field amplitudes and plausible ocean structures, this is sufficient to characterize Europa's internal structure.

Subsurface Sounding: The REASON radar sounder on *Europa Clipper* will characterize the vertical structure of the ice shell and surface-ice shell-ocean exchange. REASON uses two complementary radar arrays: a low resolution 9 MHz high frequency (HF) array for sounding that is intended to penetrate more reliably into Europa's ice crust, and a 60 MHz very high frequency (VHF) dual-channel interferometric array for both sounding and altimetry with high resolution.

Detection of an ice-water interface would be an unambiguous constraint on the ice shell thickness, but this is likely only if the ice shell is thin ($\lesssim$ 10 km) and/or thermally conductive. However, even if the radar does not detect the 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 [4].

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: The time variations of Europa's gravity field can be determined by accurately tracking *Europa Clipper* as it flies by Europa over a range of orbital phases. Radio signals received and retransmitted by the spacecraft enable precise observations of the Doppler-shifted signal frequency, and thus of the spacecraft line-of-sight velocity with respect to Earth. The Doppler tracking data that will be obtained close to Europa will allow the determination of key static and time-variable gravity field parameters over the course of the entire *Europa Clipper* mission. Simulations conducted with the expected Doppler observation accuracy show that the tidal Love number k_2 can be recovered to an accuracy of < 0.05 [5].

Europa Clipper will use the VHF component of the radar sounder REASON (Blankenship et al., this issue) as an altimeter. During the tour, the spacecraft groundtracks over the surface of Europa intersect, leading to "cross-over" points 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.

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. Measurements of shorter wavelength gravity anomalies will determine lateral variability in ice shell structure and the possible existence of topography on the seafloor. Geodetic observations (shape-determination, libration, obliquity) provide critical constraints to characterize and understand Europa's interior structure, including its radial mass distribution and ice shell properties. Many of these observations will be multi-instrument investigations, as the global shape model will be derived from visible and ultraviolet imaging (EIS, Europa-UVS) and radar altimetry (REASON) data.

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, heat flux and thickness should inversely correlate, and deviations would indicate a thermal anomaly. The heat flux can also be compared with the thickness obtained from induction in order to estimate the fraction of heating generated within vs. below the ice shell.

The elastic thickness and heat flux of Europa can be estimated using along-track profiles of the surface topography, collected by the REASON VHF altimetry. Assuming constant shell thickness, topography should be elevated over hot spots, an expression of plume buoyancy, albeit modulated by lithospheric resistance.

Finally, surface compositional data (from MISE, MASPEX, SUDA) on endogenic salts and H_2/CO_2/H_2O ratios in plumes would constrain the composition of suboceanic rocks and yield indirect constraints on Europa's density profile.

Synthesis: We have described several key investigations (and a number of auxiliary datasets) that will be carried out by *Europa Clipper*, providing independent measurements characterizing Europa's interior. Each measurement technique has different sensitivities, dependencies and limitations, and measures different quantities. Although no single instrument can fully characterize the ice shell, a *combination* of measurements provides a much more complete picture. Combining multiple datasets is a powerful way of characterizing the interior of Europa and habitability of its subsurface ocean [2].

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