EUROPA'S INTERIOR STRUCTURE AND SALINITY BASED ON THE ORIGIN OF ITS VOLATILES. J. C. Castillo-Rogez[1], M. Melwani Daswani[1], A. Genova[2], C. S. Glein[3], C. J. Cochrane[1], S. M. Howell[1], J. I. Lunine[4], E. Mazarico[5], R. S. Park[1], G. Steinbrugge[1], S. D. Vance[1], B. P. Weiss[6], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (Julie.C.Castillo@jpl.nasa.gov), [2]Sapienza University of Rome, Italy, [3]Southwest Research Institute, San Antonio, TX, USA, [4]Department of Astronomy, Cornell University, Ithaca, NY, USA, [5]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [6]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA.

Introduction: The Europa Clipper mission, scheduled to launch in 2024, will carry a comprehensive payload for the exploration of Europa's habitability [1]. A major component of habitability assessment is the composition of the subsurface ocean, a function of the initial complement and subsequent evolution of volatiles. The range of ocean electrical conductivity allows for superchondritic abundances of volatile elements [2]. The accretion of non-water ices supplied from planetesimal reservoirs far in the outer solar system, in particular carbon dioxide and ammonia, can represent a significant source of solutes (e.g., bi/carbonate ions, ammonium), as observed at Saturn's moon Enceladus and dwarf planet Ceres. In this presentation, we assess the range of interior structures and ocean salinity expected for various assumptions on Europa's origin and evolution pathways and assess their expressions in the Europa Clipper gravity/radio science investigation (G/RS moment of inertia, tidal Love number k_2), the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON, tidal Love number h_2) and the Europa Clipper Magnetometer (ECM, ocean conductance).

Europa's Formation and Evolution: We consider several endmembers for Europa's origin based on the literature. Origin influences in particular the metal content, volatile composition, and thus the products of aqueous alteration.

(E1) Formation from anhydrous chondritic rock and water [3]; in this case, the ocean salinity comes primarily from the leaching of soluble elements from the rock. Sulfur may contribute to the ocean salinity in the form of sulfate ion, although it is more likely in FeS form.

(E2) Formation from anhydrous rock and a fraction of cometary volatiles (pebble) [4]; solutes come from both rock leaching and non-water ices.

(E3) Formation from carbonaceous chondrite material [5]. A significant fraction of CO_2 is produced from the breakdown of carbonates and released to the ocean, as well as ammonia from the breakdown of organic matter, and hydrocarbons and small organics in low abundances. Some gas species may incorporate in clathrate hydrates that could accrete in and increase the strength of the crust depending on their composition [5,6].

In terms of thermal evolution, it is expected that Europa's mantle would significantly dehydrate as the temperature increases above ~750 K. The extent of dehydration is unknown but we will present several scenarios during the meeting.

Exogenic sulfur delivered from Io may also contribute to the ocean's salinity.

Observational Constraints: Measurements by the *Galileo* spacecraft are used to bound the properties of Europa's interior. The magnetometer data yielded bounds on the ocean electrical conductivity (EC) from <1 to >> 10 S/m, based on error bars and wide ranges of possible ocean composition and thickness [2]. For the lower bound, salinity is primarily ascribed to leaching of major elements from the rock, chlorides and maybe some sulfate ions. Leaching from rock yields an EC of ~0.2 S/m for a carbonaceous chondrite composition [7]. Hence, higher EC values require an additional source of solutes. Carbonates and ammonium are an alternative or additional possibility, as suggested by [7] but not accounted for in EC estimates for Europa to date. Taking ocean compositions derived by [7] for a NH_4-CO_3 ocean yields an ocean density between ~1005 and >1100 kg/m^3. Ranges specific to each composition considered here will be presented at the meeting.

The other Galileo observation used in this study is the moment of inertia (MoI) inferred from gravity observations. Published values for Europa's mean MoI range from 0.3405±0.0022 [8] to 0.3547±0.0024 [9]. The Europa Clipper G/RS Experiment is expected to improve the MoI precision to ±0.0002 [10], although the accuracy will depend on assessing how close Europa is to the hydrostatic equilibrium. A wide range of interior structures can match the moment of inertia, even if the error bars on MoI are small and additional filters (e.g., reference compositions) are applied.

Methodology: We compute the tidal Love numbers for a broad range of interior structures after [11] and the salinity and EC based on [7,12]. We do

not track the thermal evolution of the icy shell and instead assume a wide range of thicknesses and thermal states informed by the literature [13]. Bounds on rocky mantle thermal evolution are developed based on the approach by [14]. The presence of a metallic core is not required for the upper range of MoI values [9] but core formation is likely, considering Europa's heat budget. Thermal evolution bounds the fraction of the rocky mantle reaching dehydration and metal separation temperatures and thus the range of possible core size. Bounds on thermal evolution can also help quantify the abundances of volatiles derived from the mantle supplied to the ocean but this is fraught with uncertainties.

Key Results: As shown previously [e.g., 16], k_2 and h_2 are primarily determined by the ice shell thickness D, ocean density ρ_{oc}, and ice shell viscosity η_i for D≳ 20 km. For D>20 km, the ocean density introduces the error on the shell thickness estimation of ~5 to 10 km.

The current target (guideline) for the determination of h_2 and k_2 is <0.15 and <0.06, respectively. In absence of additional constraints, these measurement uncertainties lead to large uncertainties on shell thickness. The combination $1+k_2-h_2$ is less influenced by the ocean density, but the relatively poor recovery projected for h_2 may limit the information that can be derived on the shell thickness. Ice shell viscosity and core size and state also influence the tidal Love numbers.

The ocean conductance derived from ECM, as well as compositional constraints provided by other Europa Clipper instruments [1] (e.g., occurrence/absence of carbonates; exogenic vs. endogenic origin of sulfur compounds), could decrease that uncertainty. Conversely, G/RS' constraints on hydrosphere structure can support the ECM data inversion in terms of hydrospheric structure. Decreasing the uncertainty on ocean density can then help bound other internal properties. Additional constraints on the shell properties would be provided by G/RS (higher degree harmonic coefficients [10], REASON and geological observations [e.g., 1].

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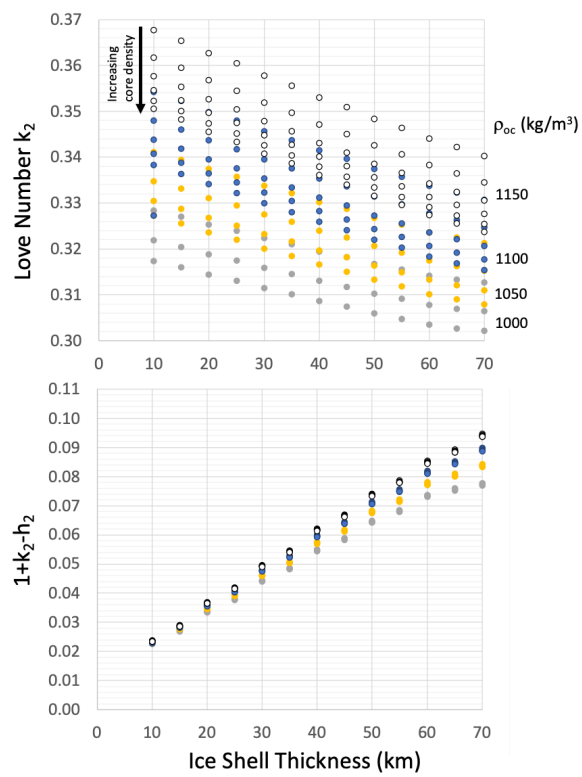

Figure 1. Dependence of Europa's tidal Love numbers h_2 and k_2 on shell thickness and ocean density ρ_{oc}. This example assumes a convective profile with a reference viscosity $\eta_o = 5\times10^{14}$ Pa s when the ice shell thickness is > 20 km. The other dimension captured in these plots is the density of a metallic core (here assumed liquid) between 5500 and 8000 kg/m^3 that encompasses various contents in sulfur and other light elements.