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Exploring Europa and Ganymede's Internal Structure: A Statistical Perspective

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Introduction

Past missions, such as Galileo, Cassini and Juno, have significantly advanced our understanding of icy moons. Through their measurements, these missions unveiled the presence of subsurface water reservoirs. Building on these discoveries, upcoming missions, JUICE and Europa Clipper, hold the potential to further enhance our understanding of the hydrospheres by delivering new and improved data, including tidal deformation measurements (Cappuccio et al., 2020; Cappuccio et al., 2022; Mazarico et al., 2023).

Our study aims to characterize the hydrospheres of Europa and Ganymede. Europa, a smaller satellite, possesses a less extensive hydrosphere, where internal pressures are not expected to reach the levels required for the formation of high-pressure ice phases. In contrast, Ganymede, a larger and differentiated satellite, is known to harbour high-pressure ice phases within its hydrosphere. To evaluate these differences, we employed a combination of known thermodynamic properties (Choukroun and Grasset, 2010; Mcdougall and Barker., 2011; Journaux et al., 2020) alongside satellites' parameters to assess their plausible internal structures. Additionally, we include anticipated Love number measurements from upcoming missions such as JUICE and Europa Clipper into our statistical analysis, aiming to enhance our understanding of the moons' structural characteristics.

Model

We employed the PlanetProfile (Styczinski et al., 2023; Vance et al., 2018) to analyse the internal structure, evaluating 1D models of structure based on fundamental planetary properties such as mass (M), moment of inertia (MOI), and radius (R).

Additionally, we coupled the PlanetProfile with the Markov chain Monte Carlo (MCMC, Foreman-Mackey et al., 2013) method to assess the statistical properties of the interior structure. Furthermore, to obtain Love numbers, necessary for determining tidal deformation, we will use own library, based on Sabadini and Vermeersen (2004).

Results

Europa

We assume that Europa is fully differentiated into the hydrosphere, mantle, and core to assess the structure. We analyzed the internal structure of two different oceanic compositions: Seawater and a solution containing $MgSO_4$ salt. For Seawater, our statistical analysis includes variables such as M, R, and MOI assuming normal distribution and the temperature at the interface Ih-ocean interface, T_b, between 249K and 272.5K, assuming uniform distribution. For $MgSO_4$ solution, salinity was incorporated as an additional variable, constrained within the range of 1-10 wt%, assuming uniform distribution.

The results for Seawater is depicted in Figure 1. For $MgSO_4$ solution, findings are presented in Figure 2. As expected, our observations confirm the composition of Europa's hydrosphere consists of Ih ice and ocean. In the case of Seawater, despite assuming a uniform distribution of Tb, the actual distribution appears to be non-uniform, likely due to the absence of a corresponding model for the given parameters (R, M, MOI, T_b). However, Figure 2 illustrates that the introduction of salinity allows for lower values of T_b.

Ganymede

To model internal structure of Ganymede, we used same procedure as in the case of Europe. We also assumed that Ganymede is fully differentiated. However, the hydrosphere is further divided into layers of Ih ice, liquid ocean and layers of high-pressure ice phases.

In the case of Ganymede, we only worked with the composition of the $MgSO_4$ salt ocean, whose salinity ranged within the same values as in the case of Europa. The results for Ganymede with $MgSO_4$ solution are presented in Figure 3. By comparing with Figure 2, we observe a greater thickness of the ocean, as was expected.

Summary

We modelled the internal structure of the icy moons Europa and Ganymede, for the cases of Seawater composition for Europa, and $MgSO_4$ solution for both Europa and Ganymede. The PlanetProfile was used and modified by implementing Markov chains, using Emcee library. Europa's

hydrosphere is composed of a layer of Ih ice and ocean, and the hydrosphere of Ganymede is composed of layers of Ih ice, ocean, and high-pressure phases of ice, which agrees with theoretical assumptions. Furthermore, we integrate anticipated Love number measurements to reduce the uncertainty in the determination of the internal structure.

Acknowledgement

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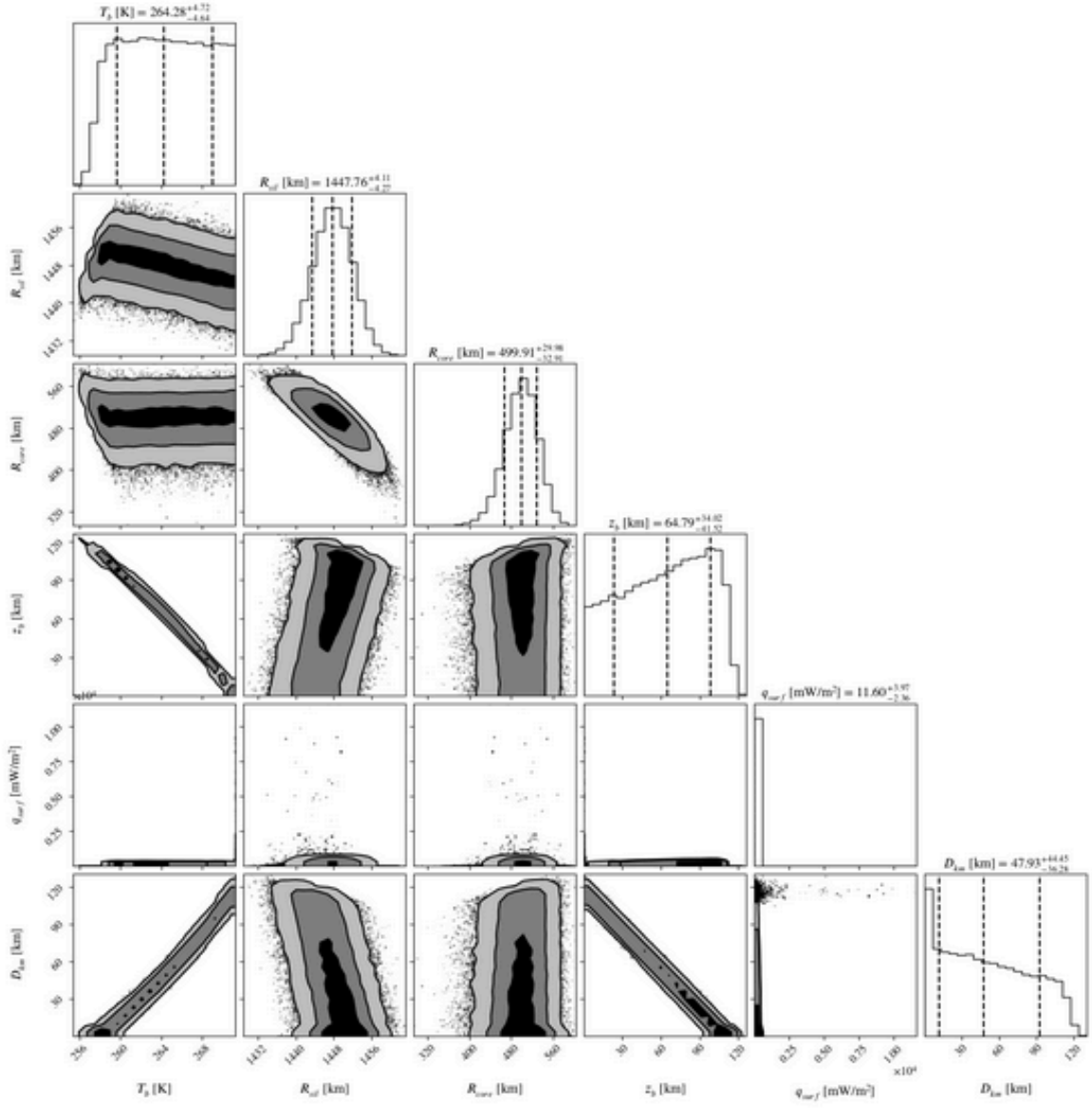

Figure 1: Corner graph (Foreman-Mackey, 2016) depicting statistical distribution for model Seawater for Europa. T_b is the temperature at the ice-ocean interface, R_{sil} and R_{core} denote the radius of a mantle, resp. the radius of a core, z_b is the depth of the ice-ocean interface, q_{surf} represents the heat flux at the surface and D is the thickness of the ocean. We used values R = 1560±0.8 km, M = (4.80± 0.005) x10^{22} kg and MOI=0.3547±0.0024 (Gomez Casajus et al.; 2021). Fe-FeS ratio in the core is set at 20% and surface temperature T_{surf} 110K.

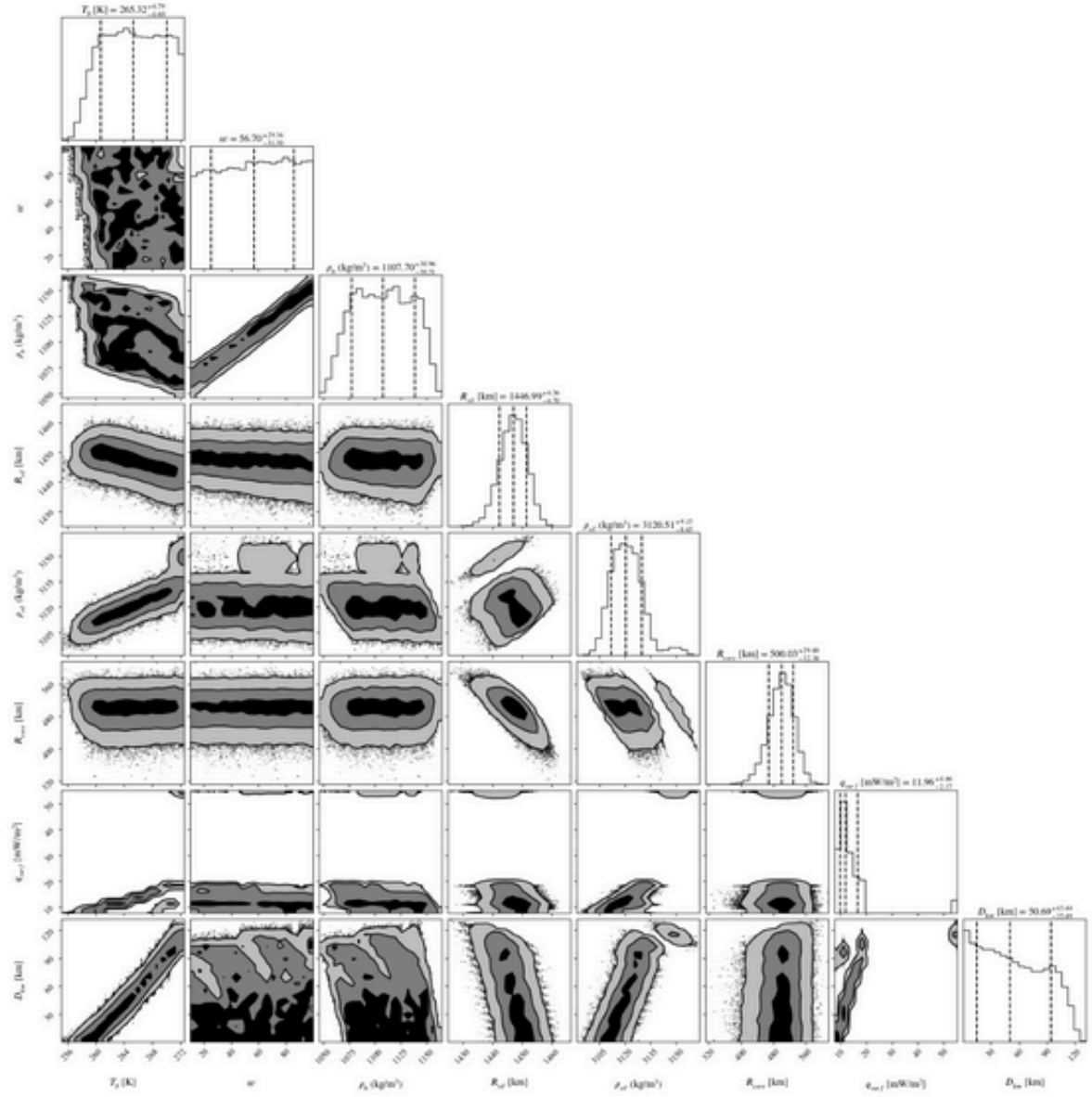

Figure 2: Corner graph depicting statistical distribution for model including $MgSO_4$ solution in the ocean for Europa. ρ_h is the density of the hydrosphere, the rest of notation is same as in Figure 1. Parameters are same as in Figure 1.

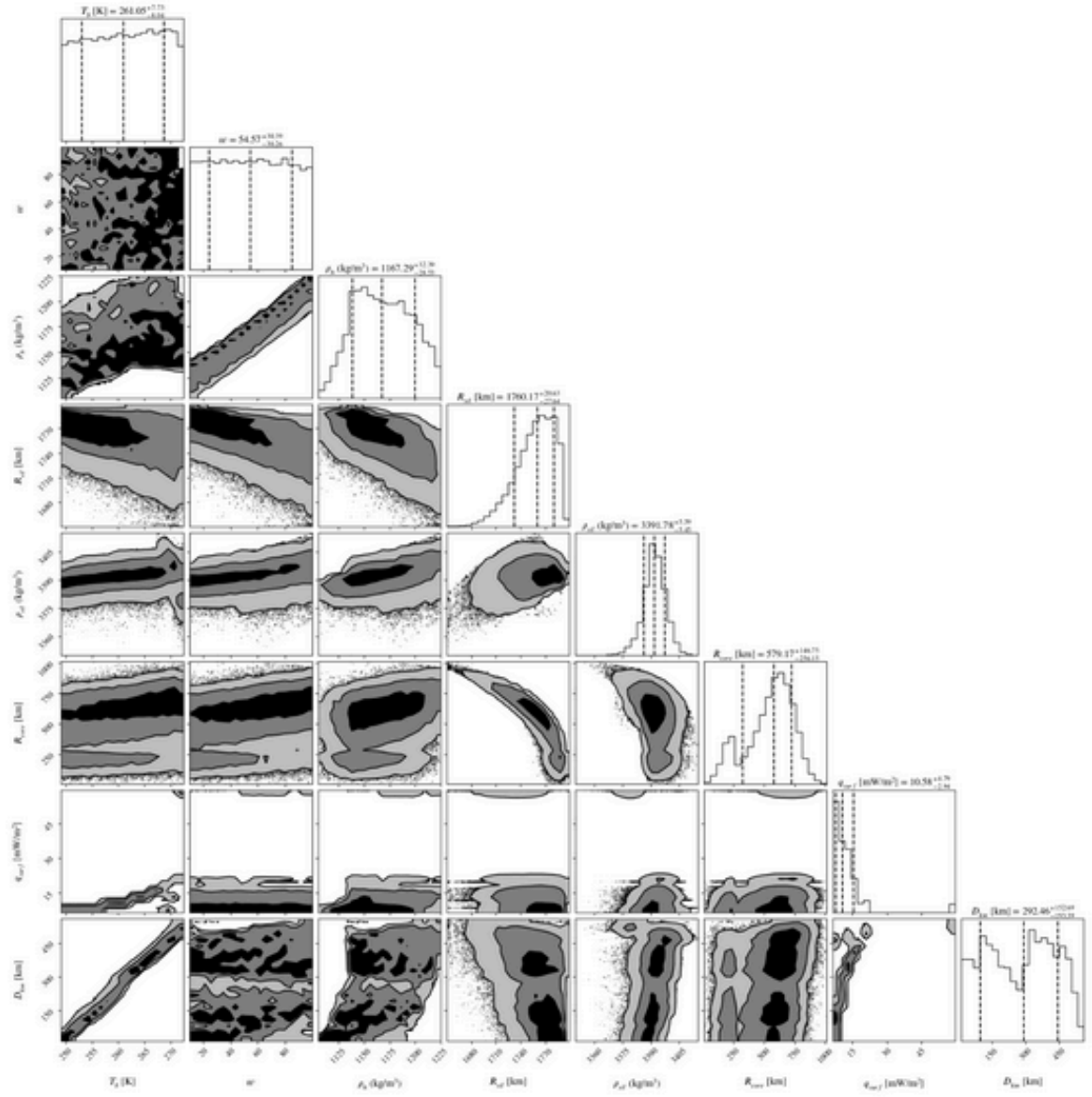

Figure 3: Corner graph depicting statistical distribution for a model including $MgSO_4$ in the ocean for Ganymede. Notation is the same as in Figure 2. We used values R = 2631.2±0.8 km, M = (1.482±0.0002) x10^{23} kg and MOI = 0.3115±0.0028 (Schubert et al., 2004). The values for T_{surf} and T_b, same as Fe-FeS ratio in core, were used same as with Europa.