CONSTRAINING THE THICKNESS OF EUROPA'S ICE SHELL WITH OBSERVATIONS OF FUNDAMENTAL MODE RAYLEIGH WAVE DISPERSION.

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Introduction: Geophysical evidence from the Galileo mission hints that Europa's ice shell is underlain by a global water ocean (e.g., [1- 3]). However, the thickness of the ice shell and the connectivity between the ocean and surface is still unclear. Seismology offers a promising means of probing Europa's ice shell structure since tidally induced ice fracturing events provide a natural source of seismic energy to illuminate the subsurface (e.g., [4 - 6]). A future seismic lander mission to Europa will likely employ a variety of techniques to image the interior, including body wave, surface wave, and normal mode seismology. Here, we use numerical simulations of seismic wave propagation on Europa in order to investigate the potential of using surface wave dispersion measurements to constrain the ice shell thickness.

Numerical simulations of wave propagation: We simulate seismic wave propagation through thermodynamically self-consistent models of Europa's interior [7] at frequencies up to 1 Hz using the spectral-element method (SEM) code AxiSEM [8] (Fig. 1). The modeling suggests that Mw 3 or greater events, which may be fairly common on Europa (e.g., [9]), are likely to produce Rayleigh waves that could be observed globally by commonly employed seismic instruments.

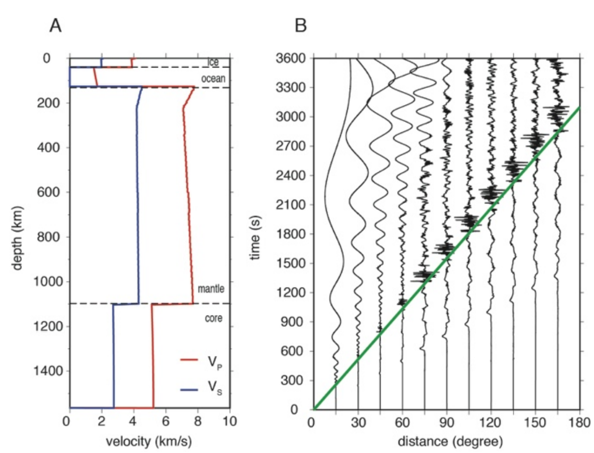

Figure 1. (A) Compressional (red) and shear (blue) velocity structure of Europa's interior [7]. (B) Synthetic displacement record section calculated for a model with a 5 km thick ice shell. The green line shows the Rayleigh wave first arrivals.

The presence of a global ocean below Europa's ice shell leads to a characteristic Rayleigh wave dispersion pattern, which may be diagnostic of the ice shell thickness. High frequency Rayleigh waves arrive first, followed by long period waves, which travel slower because they are more sensitive to the low velocity subsurface ocean. (Fig 1B).

Structural inversion: We measure fundamental mode Rayleigh wave dispersion from SEM synthetics at periods between 10-200 s using the multiple filter technique [10], and invert the resulting group velocity dispersion curve for ice shell structure using a Markov chain Monte Carlo (McMC) approach. This approach allows us to estimate the best fitting ice sheet thickness as well as to estimate model parameter uncertainties. We choose a simple 3 layer model parameterization, comprised of a regolith layer, an ice layer, and a subsurface ocean. The boundary between the ocean and silicate mantle is fixed at 127 km depth.

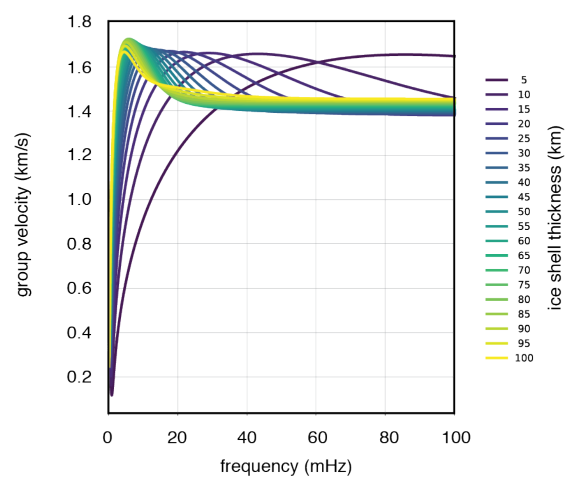

Figure 2. Group velocity dispersion curves predicted for ice shells ranging in thickness from 5 km to 100 km.

At each iteration of the McMC inversion, we propose an ice layer thickness, a regolith thickness and shear velocity, and an epicentral distance. We assume uniform priors for both the regolith thickness (between 0 km and 5 km) and shear velocity (between 0.5 km/s and 2.0 km/s). For simplification, we assume that the ice layer has a shear velocity of Vs = 2.0 km/s, and assume a uniform prior of the ice thickness (between 1 km and 127 km).Vp is assumed to be twice Vs, and the density is fixed at 1000 kg/m^3 in each layer.

For a proposed ice shell structure, we forward calculate fundamental model Rayleigh wave group velocity dispersion curves at periods between 10 - 200 s using the normal mode summation code MINEOS [11] (Fig

2). Since group velocity cannot be precisely determined without knowing the exact source location, we convert group velocity dispersion curves to group travel time curves using the proposed epicentral distance. The mean travel time misfit is removed in order to account for uncertainties in the source origin time, and the difference between observed and predicted group travel time is then used in the misfit function.

Figure 3 shows an example of a structural inversion for a target model with a 5 km thick ice shell. In this case we used a Mw 3 event located 20 degrees away from the station. We added noise from the loudest Europa noise model of Panning et al. (2018) [9] to the SEM synthetics in order to simulate measurement uncertainty. The recovered ice shell thickness and epicentral distance is in good agreement with the true model. On the other hand, the velocity structure of the uppermost portion of the ice shell is not well resolved, likely because surface waves with periods 10 s and greater average over a broad depth range.

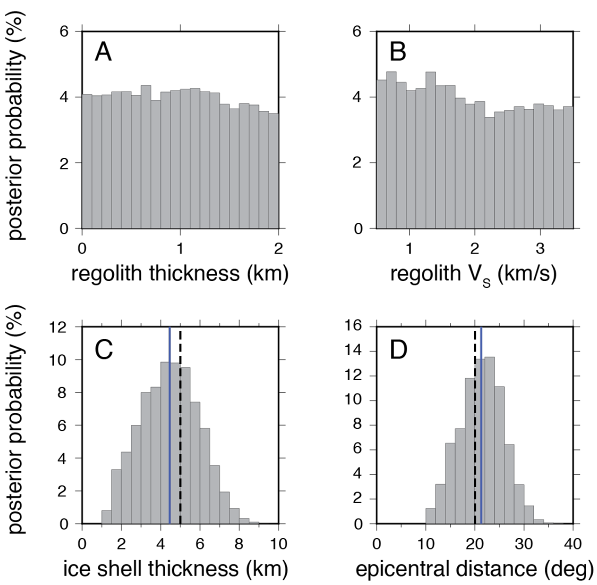

Figure 3. Posterior distributions of (A) regolith thickness, (B) regolith shear velocity, (C) ice shell thickness, and (D) epicentral distance, after 100000 iterations. The dashed vertical lines indicate the true model parameters and the blue lines indicate the mean of the McMC ensemble solution.

Conclusions and outlook: Our preliminary results show that if Mw 3 or greater events are common on Europa, and the seismic noise environment is quiet (e.g., [9]), a broadband seismometer capable of measuring displacement at periods between 10-200 s has potential to constrain Europa's ice shell thickness from observations of surface wave dispersion. However, for thick ice shells, group velocity dispersion curves may be more difficult to measure which hinders model resolution.

Future work will focus on determining how limited instrument bandwidth, varying instrument and environmental noise, and scattering will affect the recovery of interior structure. The results will be useful for determining instrument requirements for a future seismic lander mission to Europa.

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