P53D-3477 : Sensing the Endgame for Callisto’s Ocean

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Abstract

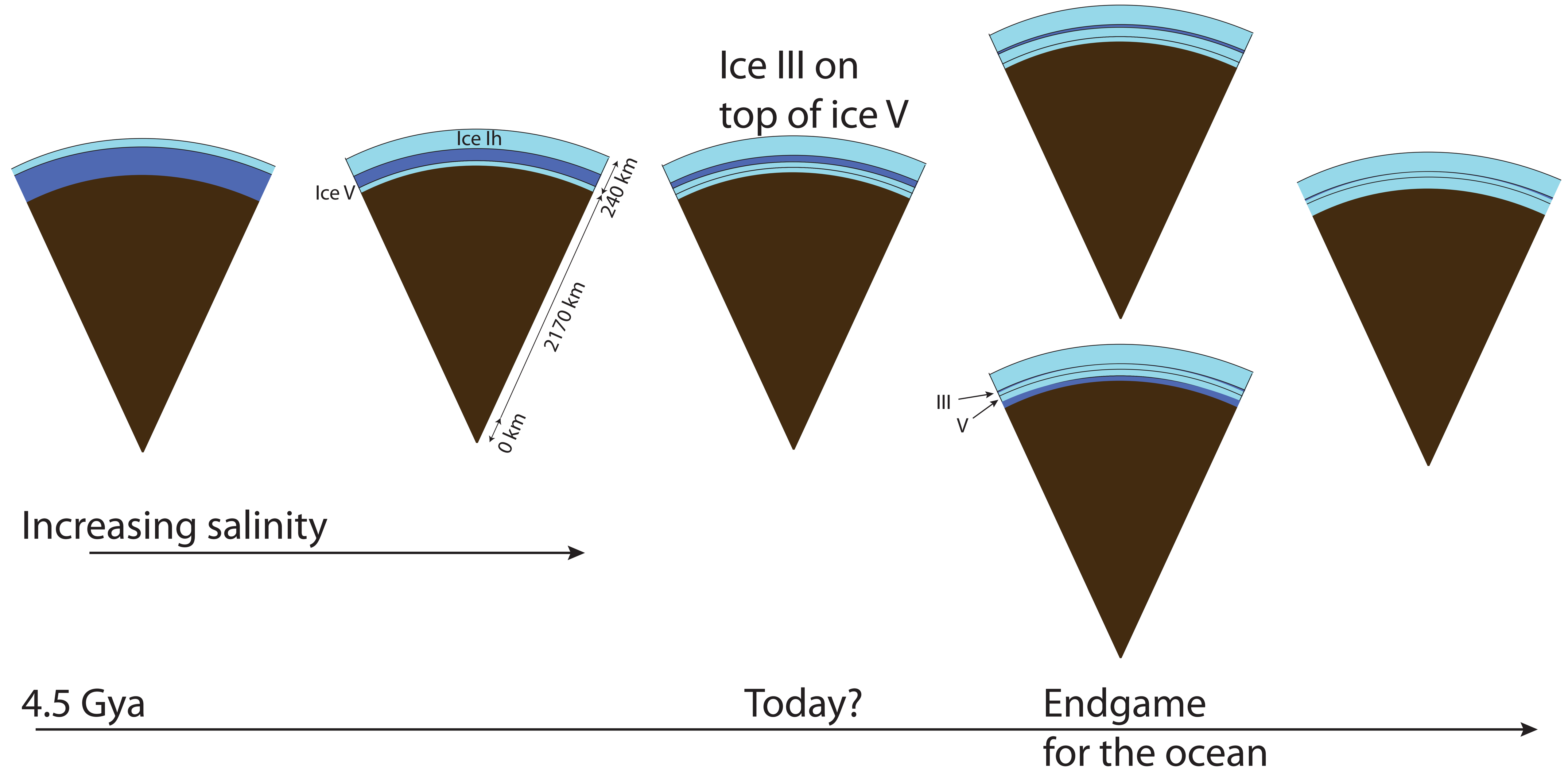
We explore the possibility that Callisto’s ocean sits beneath its high-pressure ice, rather than above it. Oceans perched between ice phases are considered to be stable configurations for Ganymede, Callisto, and Titan. High-pressure ices under the liquid water ocean will transport heat and solutes into the ocean as long as the convective adiabat for the ice remains close to the melting temperature (Choblet et al. 2017, Kalousova and Sotin 2018). However, this configuration may become unstable when the perched ocean is close to freezing and its salinity increases, if the ocean becomes denser than the underlying ice. This scenario could easily occur for Callisto.

Among the oceans in the solar system, Callisto’s must be among the coldest and most saline because the internal heat appears to be low. Surface geology indicates its lithosphere is fully stagnant, in contrast with Europa, Ganymede, and Enceladus (Moore et al. 2004). Solid-state convection may continue beneath less than 100 km or dirty non-convecting ice (McKinnon, 2006). And just below this layer may reside a liquid water ocean that is the lag deposit of Callisto's thicker primordial ocean, the concentrated result of 4 Gyr of freezing.

Using representative interior structures based on the current constraints from the *Galileo* mission (Schubert et al. 2004) coupled with recently obtained thermodynamic data (Vance et al. 2018), we demonstrate the possibility for using magnetic induction to identify where the ocean currently resides in Callisto.

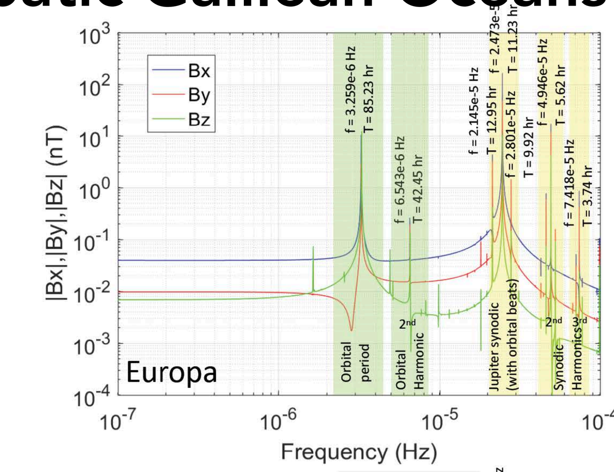
What is the Final Stage of Freezing for an Ocean with High-Pressure Ice?

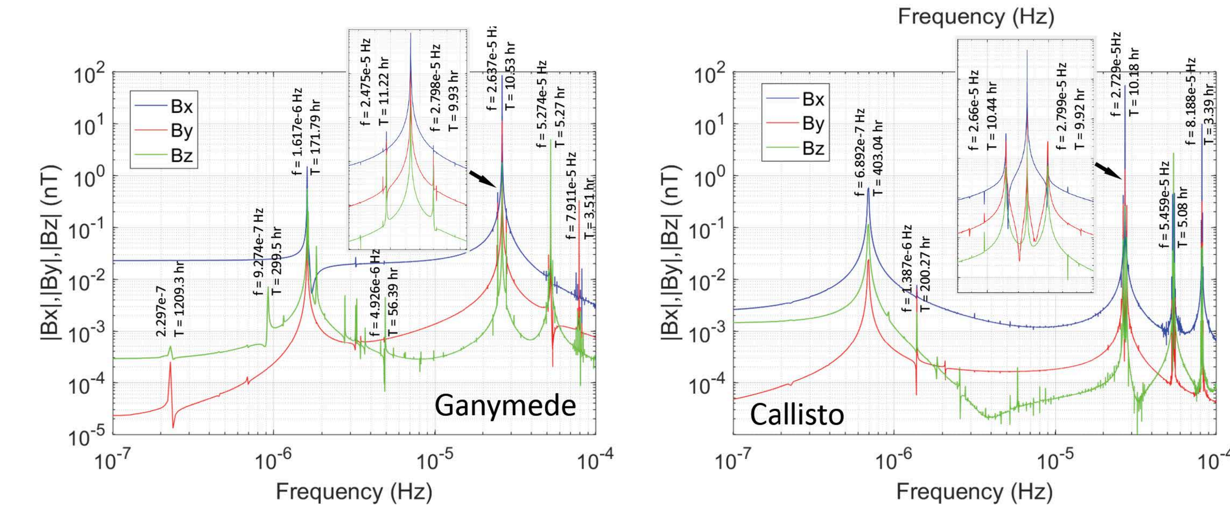
Representative structures of Callisto consistent with its inferred moment of inertia (Schubert et al. 2004)
Note that *Galileo* gravity science for Callisto assumes hydrostatic equilibrium which may not apply (Gao and Stevenson 2013)
0.2 mol/kgH_2O $MgSO_4$ salinity for an initial ocean 100 km ocean freezing to 20 km would increase by about 5x, becoming denser than ices III and V (Vance et al. 2018)
Though gravitationally unstable and potentially able to migrate through the high-pressure ice (Kalousova et al. 2018), a dense overlying ocean might instead dilute into the ice and accelerate its overturning. The efficiency of migration would be reflected in the presence or absence of a trapped layer at the seafloor



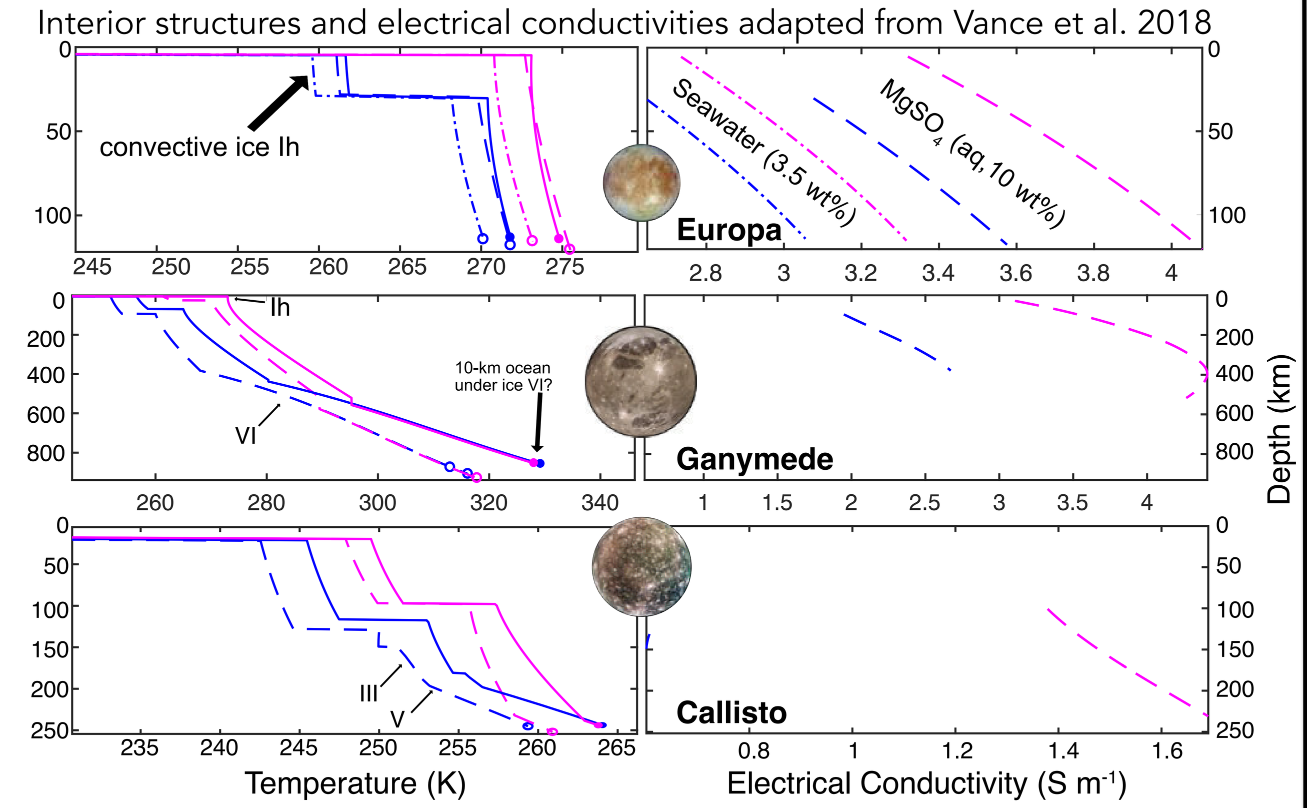
Radial Calculations of Magnetic Induction in Adiabatic Galilean Oceans

- Jupiter’s dipole magnetic field is tilted and rotates rapidly
- The Galilean moons have eccentric orbits
- We examine the induction responses of the Galilean moons at associated driving frequencies

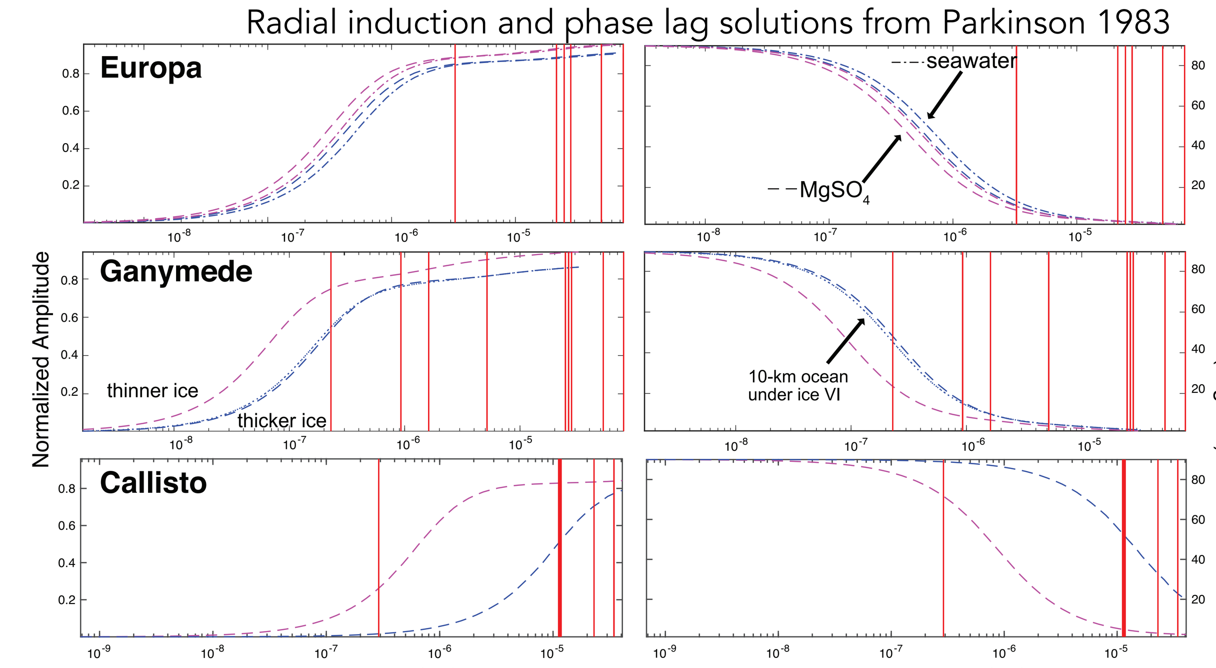




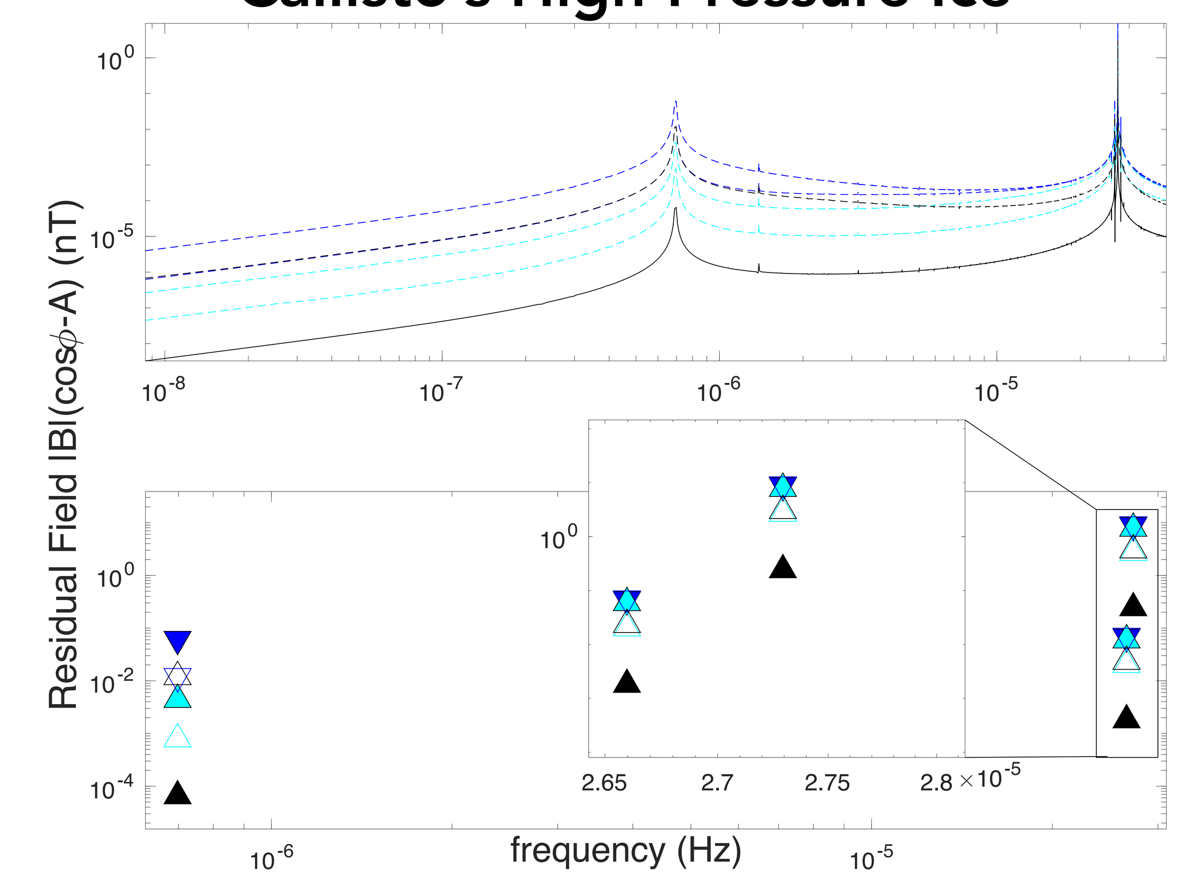
Interior structures and electrical conductivities adapted from Vance et al. 2018



Radial induction and phase lag solutions from Parkinson 1983



Sensing an Ocean Under Callisto’s High-Pressure Ice



		T_b (K)	T_{mean} (K)	D_{Ih} (km)	D_{ocean} (km)	log < k > (S m^{-1})	Residual Field (nT)		
	Callisto					log f (Hz)	**-6.1617**	**-4.5751**	**-4.5639**
▼	$MgSO_4$ 10Wt%	255.7	256.9	99	130	0.18	0.06155	0.06811	8.87256
▲		250.0	251.5	129	18	-0.76	0.00440	0.05916	7.77593
▽	$MgSO_4$ 1Wt%	257.4	259.6	99	132	-0.64	0.01213	0.07047	9.19807
△		250.8	250.9	128	21	-1.05	0.00079	0.02014	2.68688
△	10 km 20 S m^{-1} layer	250.0	251.5	129	18	-0.76	0.01188	0.02321	3.02011
▲	no overlying ocean	250.0	251.5	129	18	-0.76	0.00007	0.00180	0.24097

- Residuals of the mean field (accounting for phase lag) suggest detectable signatures that would distinguish between the scenarios shown here

- Nominal sensitivity of the JUpiter ICy moons Explorer is 0.01nT (JUICE SDT)
- Sensitivity of better than 0.001nT might be needed
- A dedicated Callisto mission with 1e-5nT sensitivity might be able to use additional frequency content
- Using multiple frequencies can address non-uniqueness

References

Choblet, G. et al. (2017). Heat transport in the high-pressure ice mantle of large icy moons. Icarus, 285:252–262.

Gao, P. and Stevenson, D. J. (2013). Nonhydrostatic effects and the determination of icy satellites’ moment of inertia. Icarus, 226(2):1185–1191.

JUICE Science Study Team. (2011). JUICE. Exploring the emergence of habitable worlds around gas giants. Assessment Study Report, ESA/SRE, 18, 2011.

Kalousovà, K. and Sotin, C. (2018). Melting in high-pressure ice layers of large ocean worlds - implications for volatiles transport. Geophysical Research Letters.

McKinnon, W. (2006). On convection in ice I shells of outer solar system bodies, with detailed application to Callisto. Icarus, 183(2):435–450.

Moore, et al. (2004). Callisto. Jupiter. The Planet, Satellites and Magnetosphere, 1:397–426.

Moore, J. and Pappalardo, R. (2011). Titan: An exogenic world? Icarus, 212:790–806.

Schubert, G. et al. (2004). Interior composition, structure and dynamics of the Galilean satellites. Jupiter: The Planet, Satellites and Magnetosphere, pages 281–306.

Vance, S. D. et al. (2018). Geophysical investigations of habitability in ice-covered ocean worlds. Journal of Geophysical Research: Planets, 123, 180–205.