Comparison of Stratified and Effective Rheological Models For Icy Worlds

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Research questions

- Moons and planets modeled after homogeneous laboratory-based rheologies
- Two layered and homogeneous models used to predict core-mantle mechanical decoupling from measured librations
- Mimicking the dissipative behavior of a stratified body with a complex homogeneous laboratory-based rheological model

Contents

- Andrade rheology in the time domain: Enceladus
- Librations of a body with a deformable mantle and a fluid core: Enceladus
- Sundberg-Cooper rheology vs stratified rheology: TRAPPIST-1e planet

General rheology

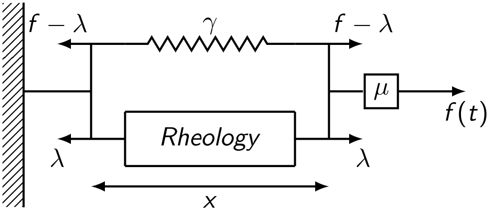


Figure: General oscilator. The rheology can be replaced by the rheologies below, for example.

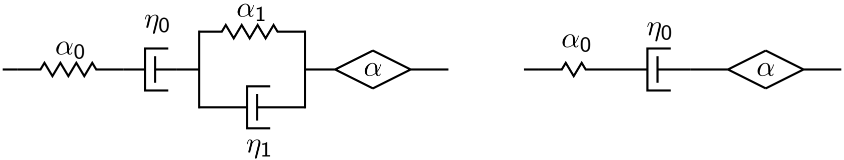
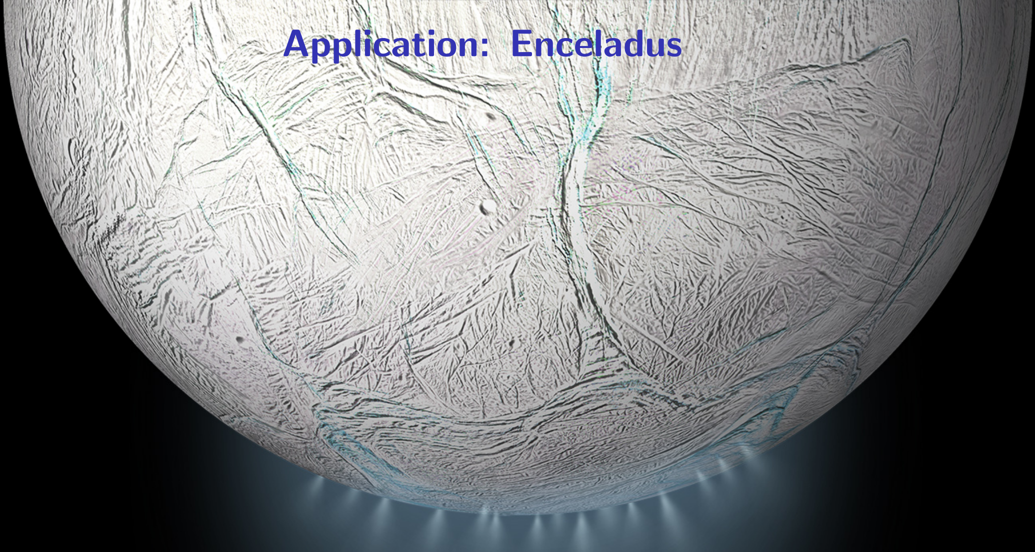


Figure: The Sundberg-Cooper model (left) and the Andrade model (right)

Application: Enceladus



The forced libration amplitude along with the observation of plumes on the South pole of Enceladus suggest a subsurface ocean.

Image Credit: NASA/JPL

Observed vs modeled librations with Andrade rheology

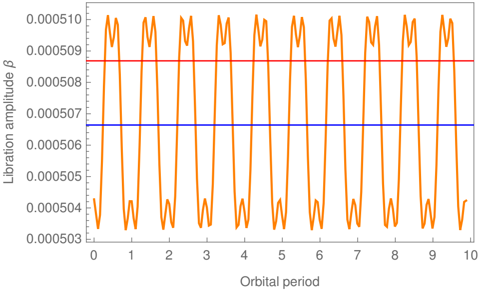


Figure: Andrade rheology: Libration of Enceladus

Modeled libration ~ 0.000508 rad
vs observed 0.0021 rad (Thomas et al. 2016) or 0.0027 rad (Nadezhdina et al. 2016)

- Can be explained by assuming core libration of $\sim 0.6\%$ of that of the shell

Two layered body

- **Can we reproduce observed libations of an ocean world with two layered model?**
- **Observed vs mantle vs Tisserand frame librations**
- **Forced libration amplitude as an argument for core-mantle mechanical decoupling**

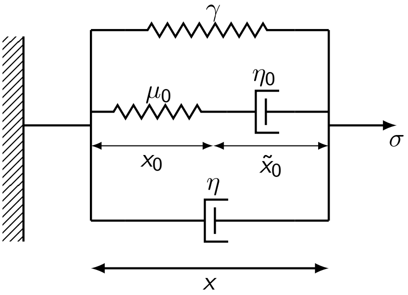


Figure: **Mantle rheology:**The damper η and the Maxwell element (μ_0, η_0) represent the effect of the macroscopic (spatial average) rheology of the mantle; x, x_0 and $\tilde{x}_0$ denote strains and σ the stress

Mantle vs Tisserand frame vs observed librations of Enceladus

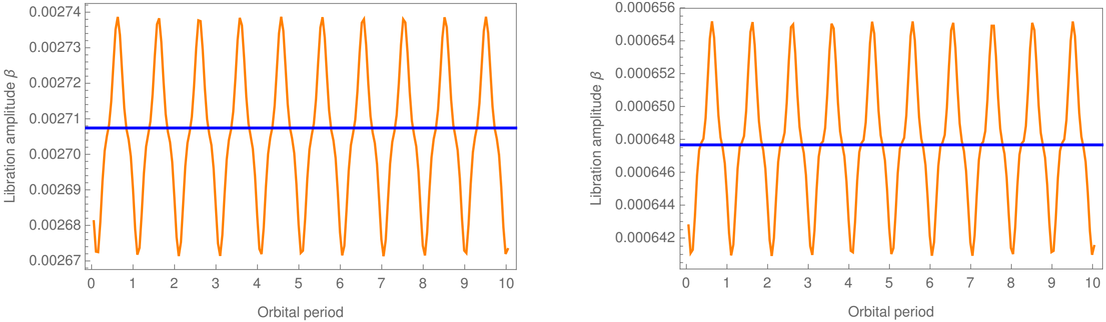


Figure: Libration amplitude comparison

Mantle $\sim$ 0.00271 rad vs Tisserand frame$\sim$ 0.000648 rad
vs observed 0.0021 rad (Thomas et al. 2016) or 0.0027 rad (Nadezhdina et al. 2016)

TRAPPIST-1e planet with an icy layer

- **Suggested internal structure**
  Five layers: liquid core, two mantle layers, two ice layers
- **The effect of the icy crust**
  Second peak in the tidal response at higher frequencies
- **Sundberg–Cooper rheology**
  The homogeneous rheology mimics well multilayered dissipative behavior

TRAPPIST-1e modeled with stratified vs homogeneous rheology

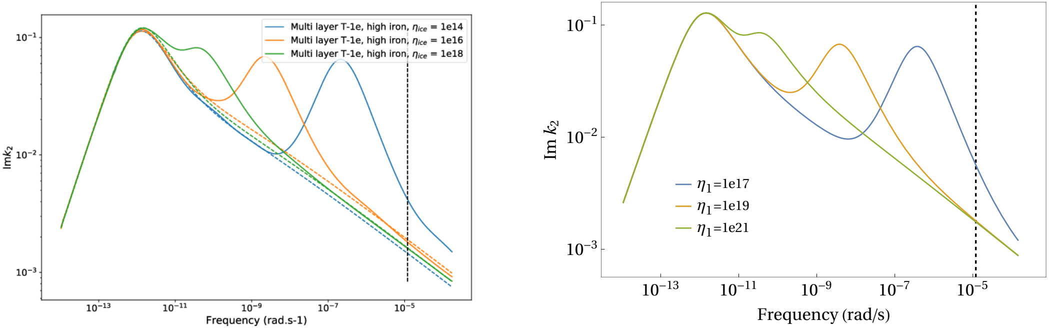


Figure: Frequency dependence of the dissipation.
The left figure is taken from Bolmont et al. (2020, Fig. 11) and was obtained with a stratified rheology. The right figure was obtained with a homogeneous Sundberg-Cooper rheology in Gevorgyan (2021, Fig. 4).

Conclusions

- **Laboratory-based homogeneous rheologies are important to model bodies with little observational data available**
- **Two layered rheology can be used to model librations of a body with a subsurface ocean**
- **Homogeneous rheology can be used to model dissipation of an icy body with no ocean**

References

- Gevorgyan, Y. *A & A* **650**, A141 (2021).
- Gevorgyan, Y. et al. *Icarus* **343**, 113610 (2020).