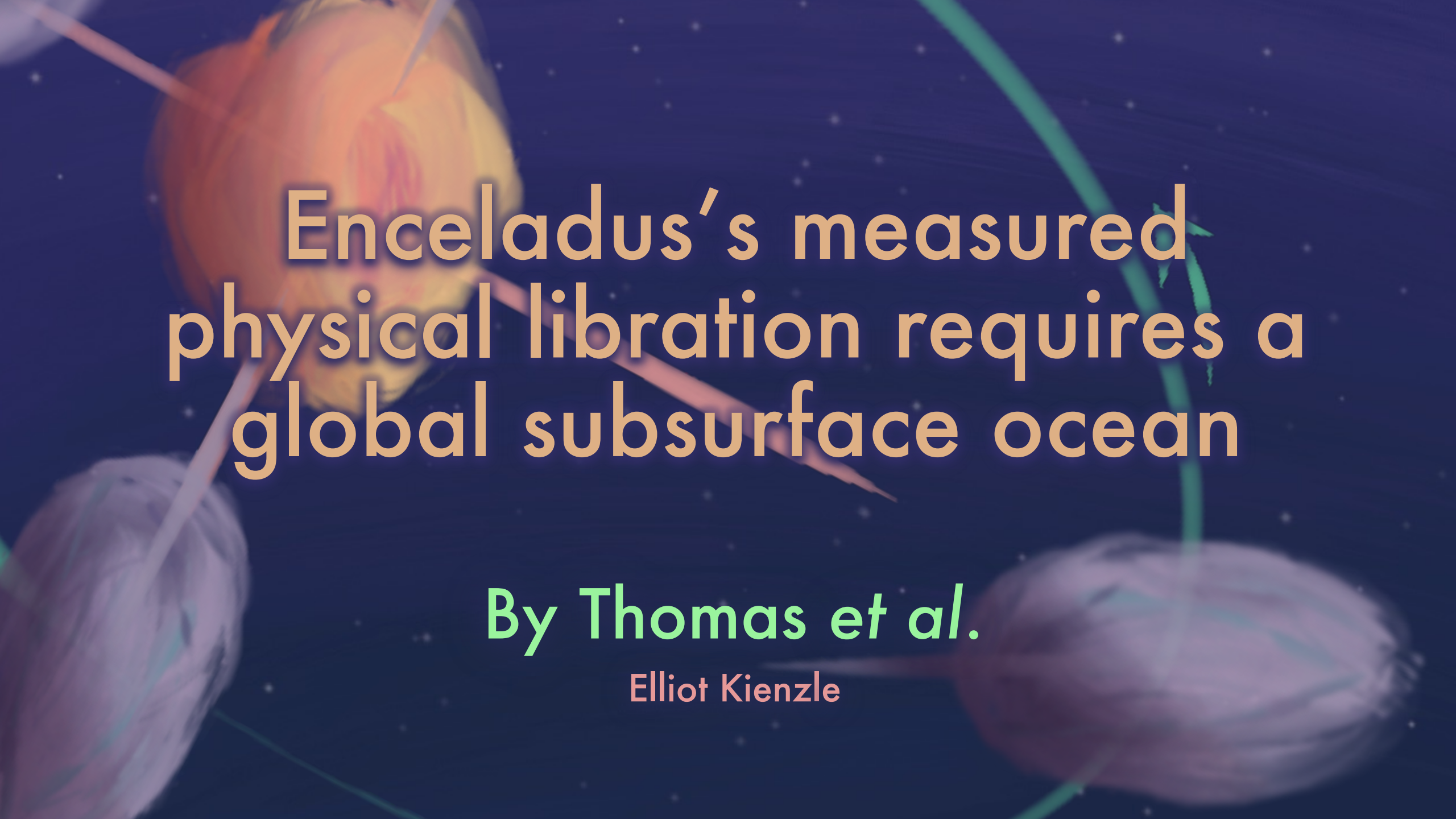


Enceladus's measured physical libration requires a global subsurface ocean

By Thomas *et al.*

Elliot Kienzle

Lay of the land

- Water detected:

Cassini Observes the Active South Pole of Enceladus

C. C. Porco,[1*] P. Helfenstein,[2] P. C. Thomas,[2] A. P. Ingersoll,[3] J. Wisdom,[4] R. West,[5] G. Neukum,[6] T. Denk,[6] R. Wagner,[7] T. Roatsch,[7] S. Kieffer,[8] E. Turtle,[9] A. McEwen,[9] T. V. Johnson,[5] J. Rathbun,[10] J. Veverka,[2] D. Wilson,[1] J. Perry,[9] J. Spitale,[1] A. Brahic,[11] J. A. Burns,[2] A. D. DelGenio,[12] L. Dones,[13] C. D. Murray,[14] S. Squyres[2]

- Salt => Subsurface Sea!

Ongoing hydrothermal activities within Enceladus

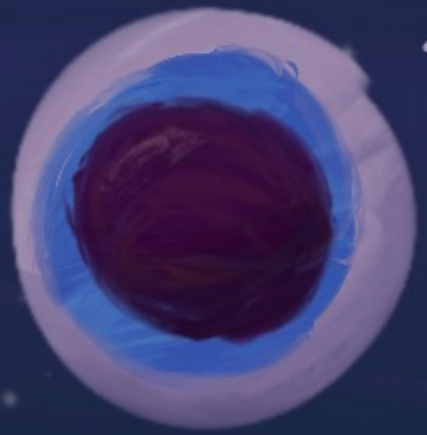
Hsiang-Wen Hsu[1]*, Frank Postberg[2,3]*, Yasuhito Sekine[4]*, Takazo Shibuya[5], Sascha Kempf[1], Mihály Horányi[1], Antal Juhász[1,6], Nicolas Altobelli[7], Katsuhiko Suzuki[8], Yuka Masaki[8], Tatsu Kuwatani[9], Shogo Tachibana[10], Sin-iti Sirono[11], Georg Moragas-Klostermeyer[3] & Ralf Srama[3]

- Is the sea local, or global? Inconclusive…

thought experement:

2 outwardly identical spheres:

rigid



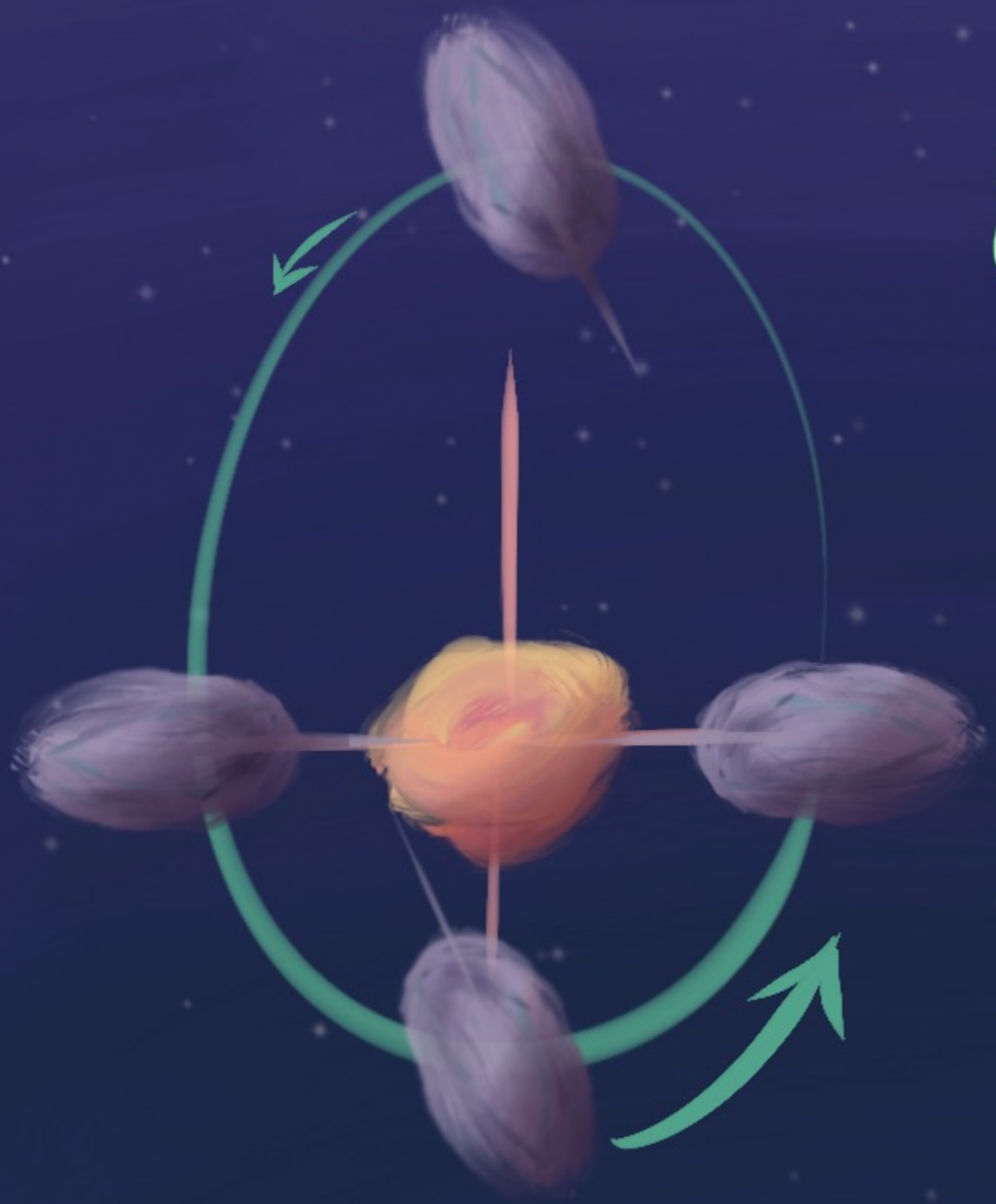
floating inner sphere

Which is which?

Tidal locking:

Circular orbit

Synchronous Rotation



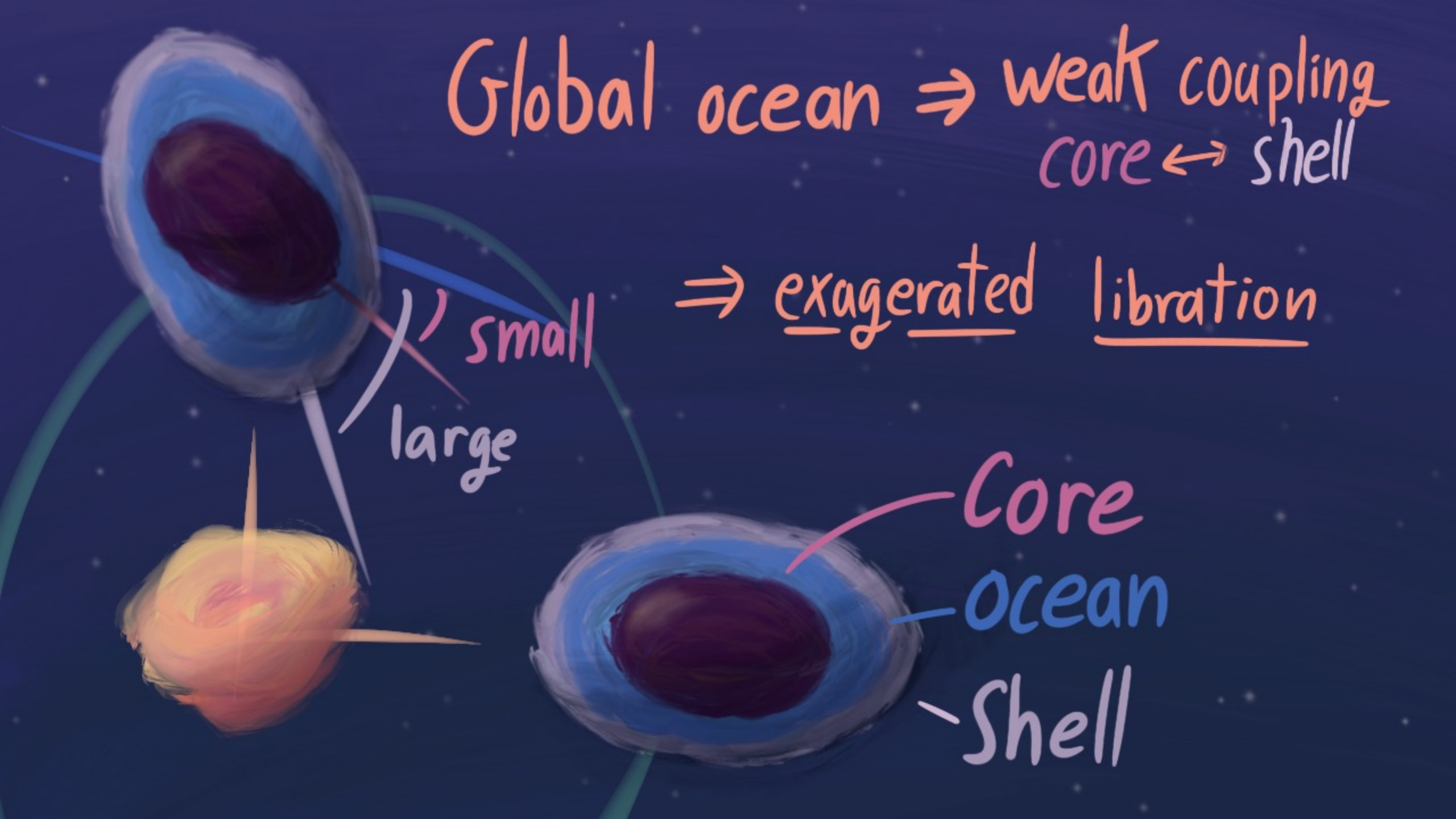
Elliptical Orbit

Kepler's 2nd law

⇓

can't always be aligned

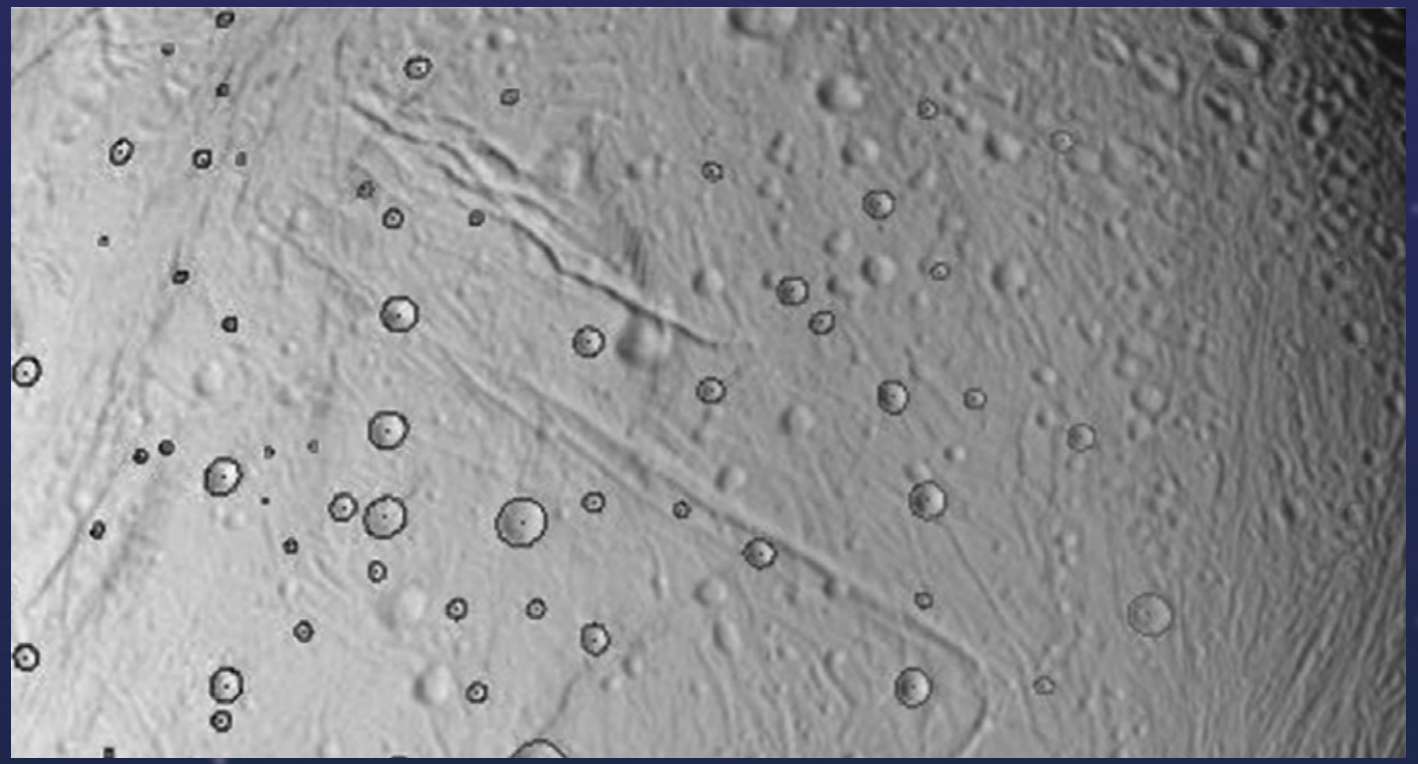

torque
expected angle
– true angle =
Physical libration
measures responce to torque


Global ocean ⇒ weak coupling
core ↔ shell
⇒ exagerated libration
small
large
Core
ocean
Shell

Measurement:

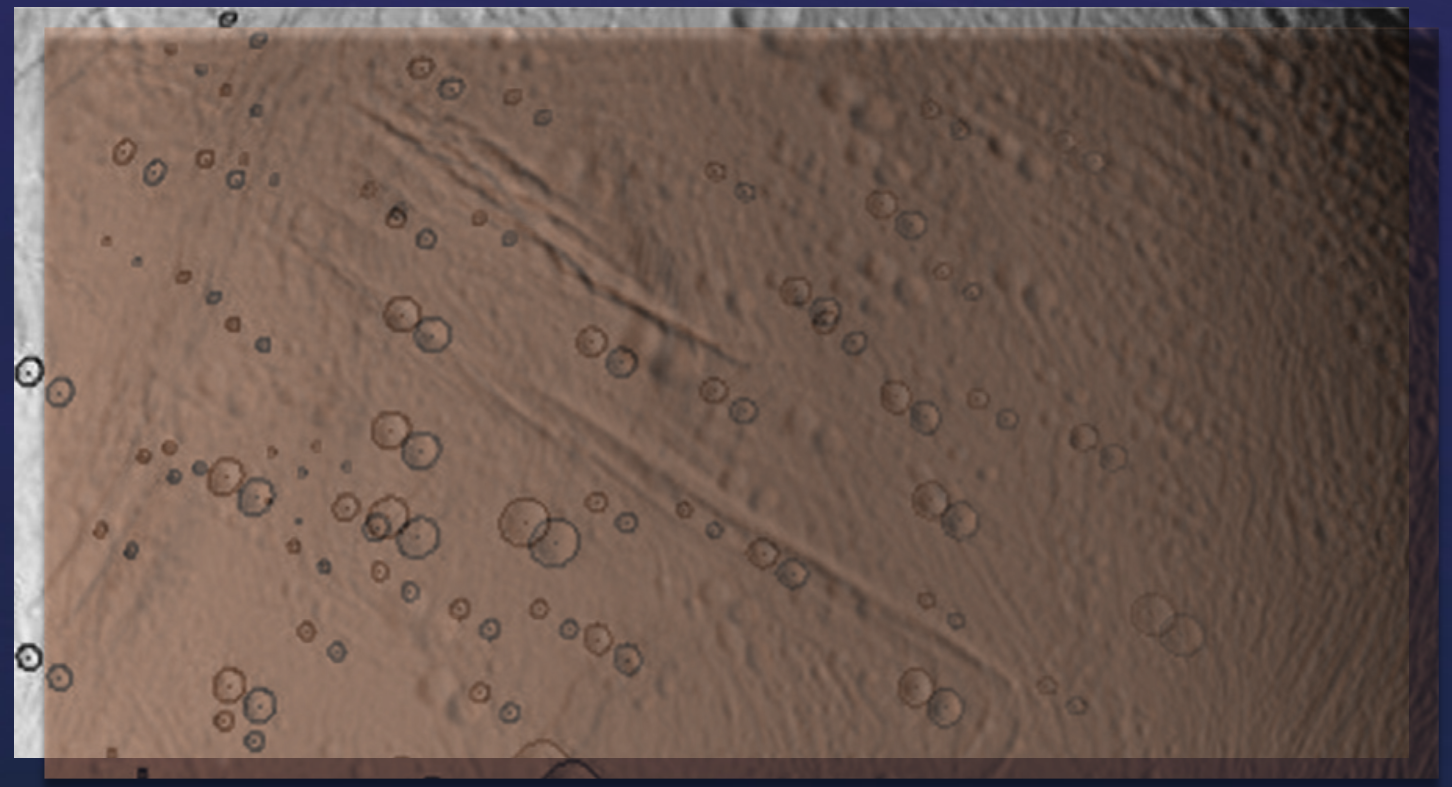
Take Picture

Locate Craters



Measurement:

Take Picture



Locate Craters

Predict crater locations
(for given libration)

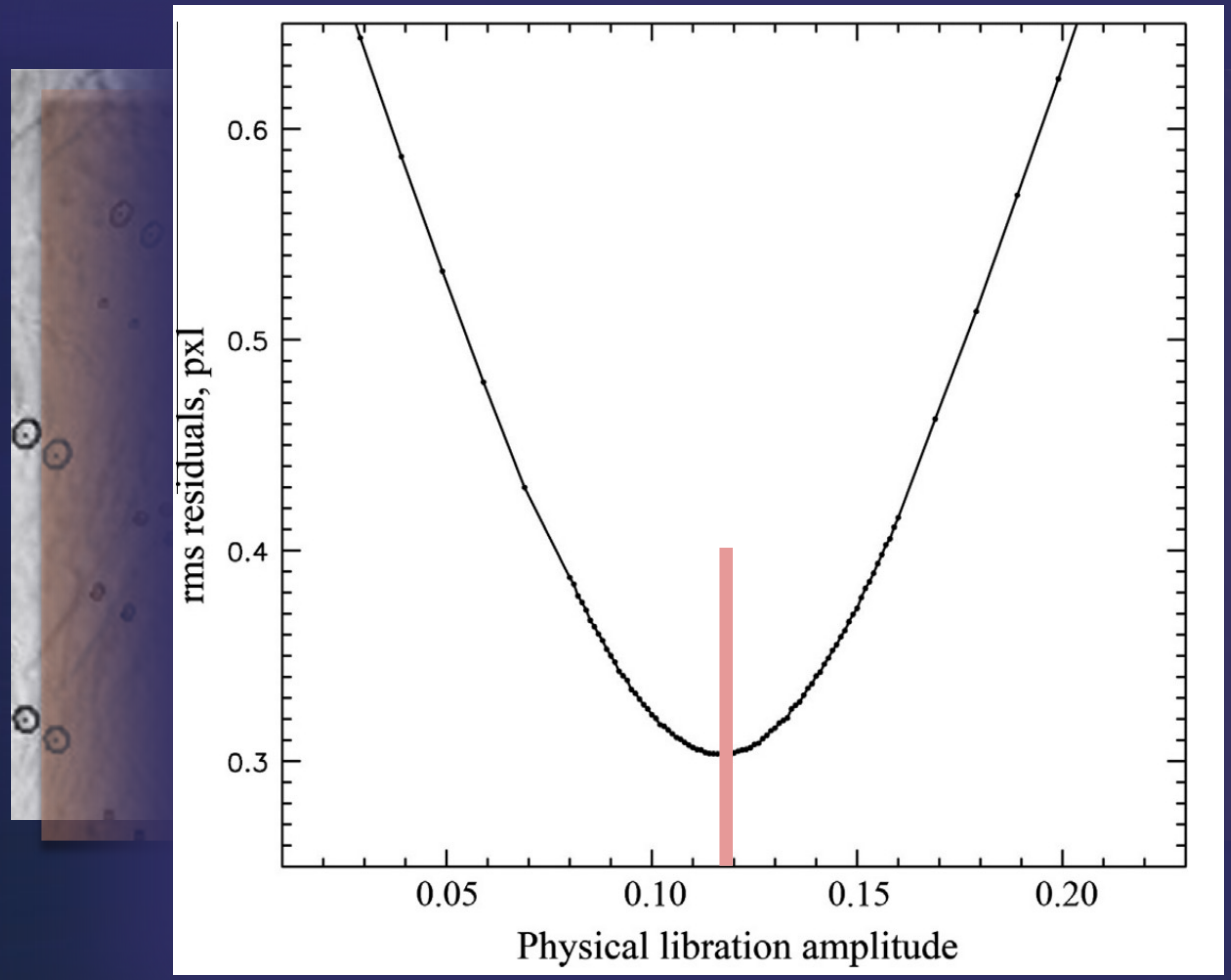
Measurement:

Take Picture

Locate Craters

Predict crater locations
(for given libration)

Choose libration to minimize error

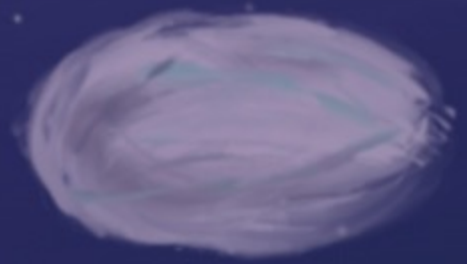


Result

- 340 pictures, 5873 craters
- Subtle effect: ~ 1 pixel!
- Uncertainty from some pretty robust statistics

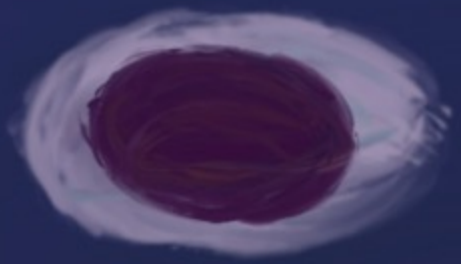
Enceladus Libration: 0.120 ± 0.014°

Rigid Model:



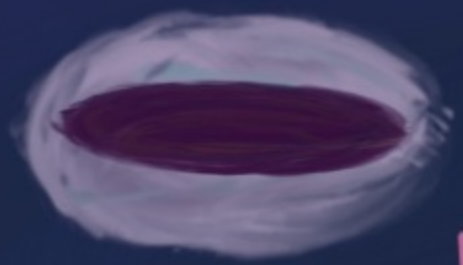
uniform:

libration .032°



hydrostatic core:

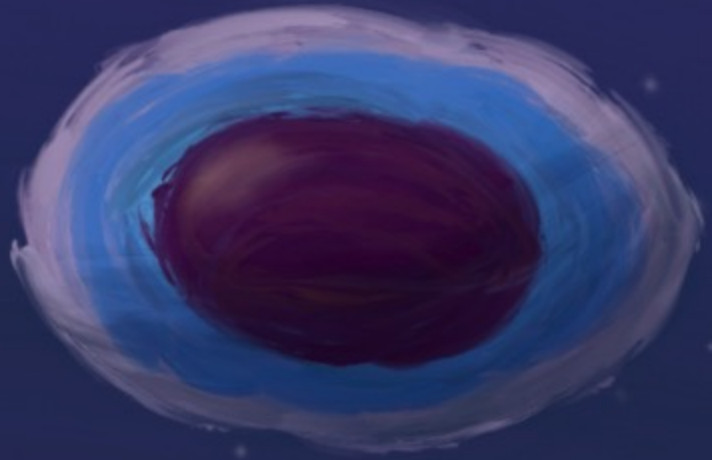
libration .032-.034°



Weird core:

not seen in gravity data

Global ocean:



ice: ~25 km thick

Ocean: ~30 km deep

libration .120° ✓

Impact

- Settled global ocean debate
  - Used well-vetted techniques w/ new data
  - Cited by literally everyone

- I find model mathematically unsatisfying
  - But the community is convinced

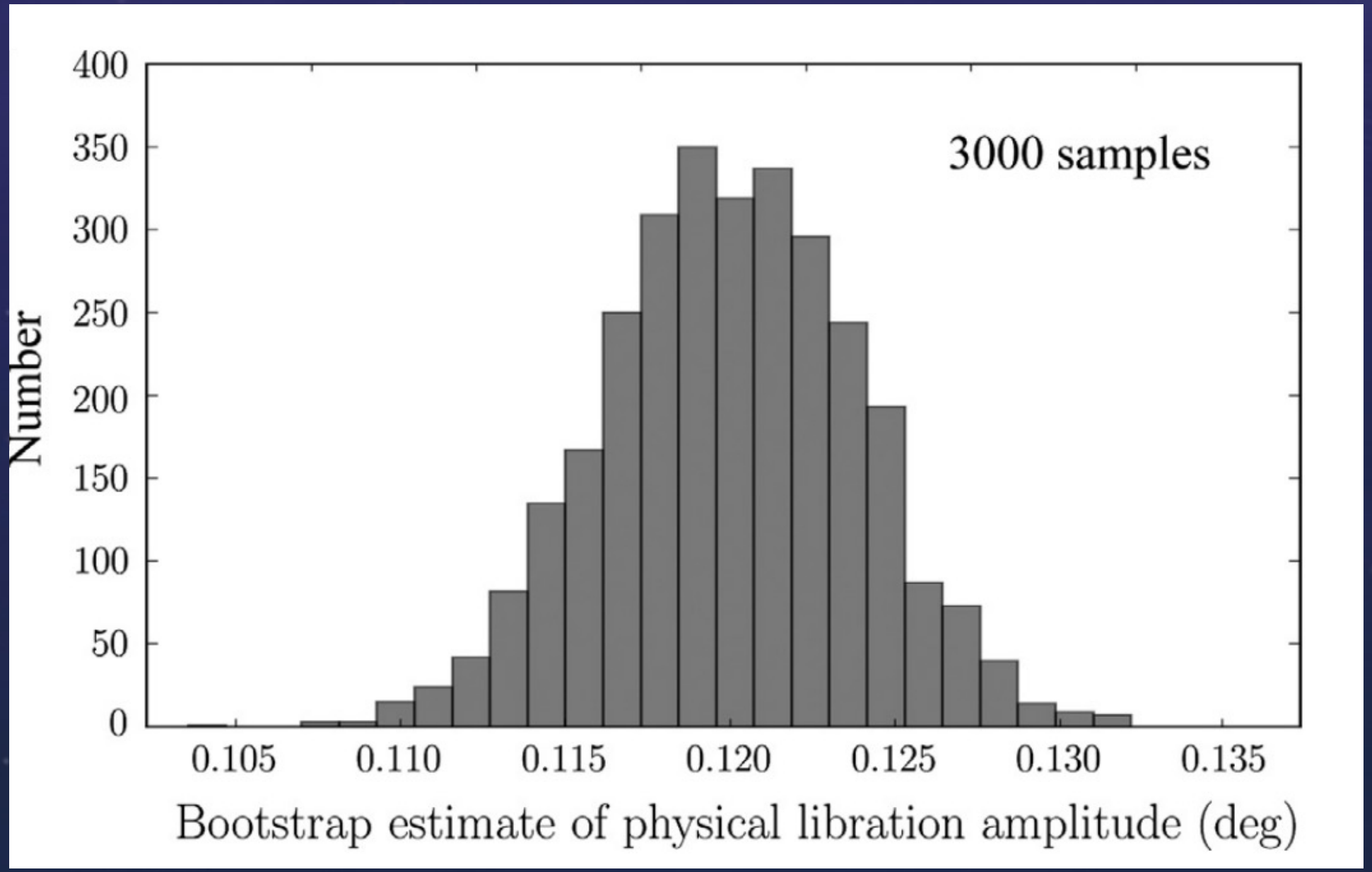
Question:

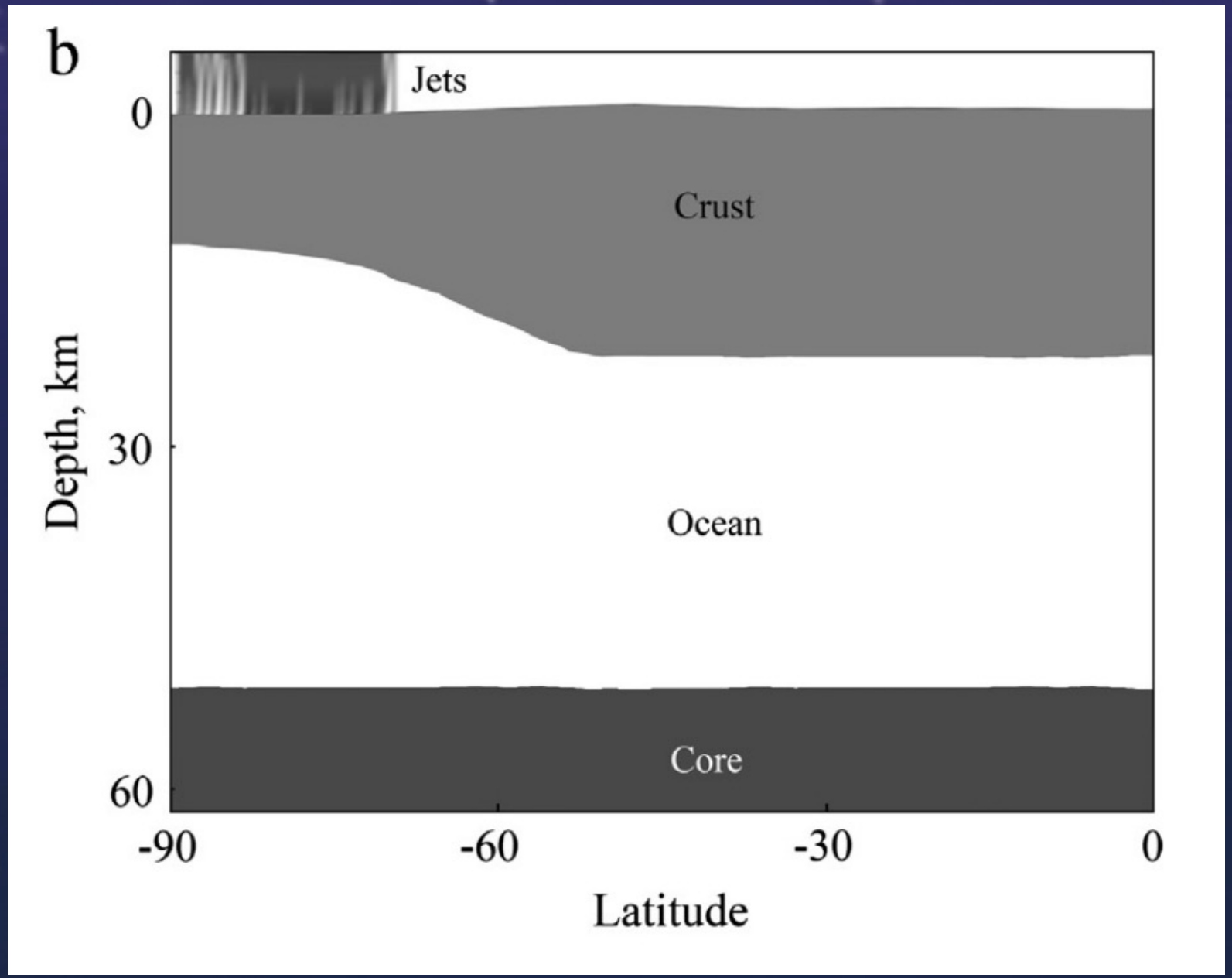
Are you convinced?

- Is their modeling conclusive?
- Can you think of any other wild causes for the high libration?
  - Is it aliens?

Refrences

- Enceladus's measured physical libration requires a global subsurface ocean (Thomas et. al, 2016)
- Ongoing hydrothermal activities within Enceladus (Hsu et. al, 2015)
- Cassini Observes the Active South Pole of Enceladus (Porco et. Al, 2006)


3000 samples
Number
400
350
300
250
200
150
100
50
0
0.105
0.110
0.115
0.120
0.125
0.130
0.135
Bootstrap estimate of physical libration amplitude (deg)


b
Jets
Crust
Ocean
Core
Depth, km
0
30
60
-90
-60
-30
0
Latitude

$$\gamma \approx \frac{2e}{1 - 1/(3\Sigma)},$$

Rigid

$$\Sigma = \frac{a^2 - b^2}{a^2 + b^2},$$

Core

$$\Sigma = \frac{V\rho_s(a_s^2 - b_s^2) + V_c(\rho_c - \rho_s)(a_c^2 - b_c^2)}{V\rho_s(a_s^2 + b_s^2) + V_c(\rho_c - \rho_s)(a_c^2 + b_c^2)},$$

$$a_c \approx r_c\left(1 + \frac{1}{3}\alpha_c + \frac{1}{2}\beta_c\right),$$

$$b_c \approx r_c\left(1 + \frac{1}{3}\alpha_c - \frac{1}{2}\beta_c\right),$$

Ocean

$$\gamma_s = \frac{1}{C_c C_s} \frac{2e[K_s(K_c + 2K_{int} - n^2 C_c) + 2K_{int}K_c]}{(n^2 - \omega_1^2)(n^2 - \omega_2^2)},$$