

# Enceladus's measured physical libration requires a global subsurface ocean

By Thomas et al.

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# Lay of the land

- Water detected:
- Salt => Subsurface Sea!
- Is the sea local, or global? Inconclusive...

## Cassini Observes the Active South Pole of Enceladus

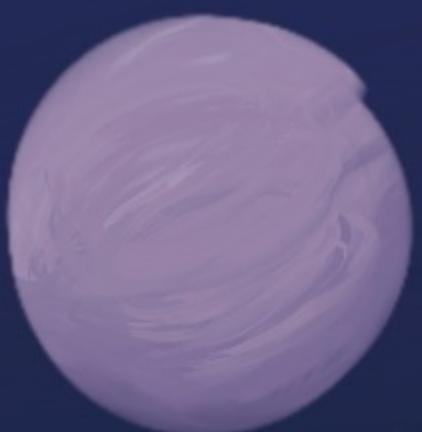
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## Ongoing hydrothermal activities within Enceladus

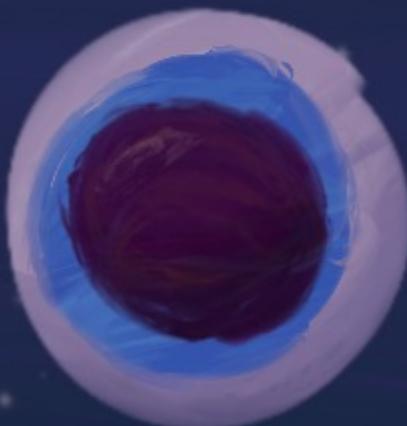
Hsiang-Wen Hsu<sup>1\*</sup>, Frank Postberg<sup>2,3\*</sup>, Yasuhito Sekine<sup>4\*</sup>, Takazo Shibuya<sup>5</sup>, Sascha Kempf<sup>1</sup>, Mihály Horányi<sup>1</sup>, Antal Juhász<sup>1,6</sup>, Nicolas Altobelli<sup>7</sup>, Katsuhiko Suzuki<sup>8</sup>, Yuka Masaki<sup>8</sup>, Tatsu Kuwatani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

thought experiment:

2 outwardly identical spheres:



rigid



floating  
inner sphere

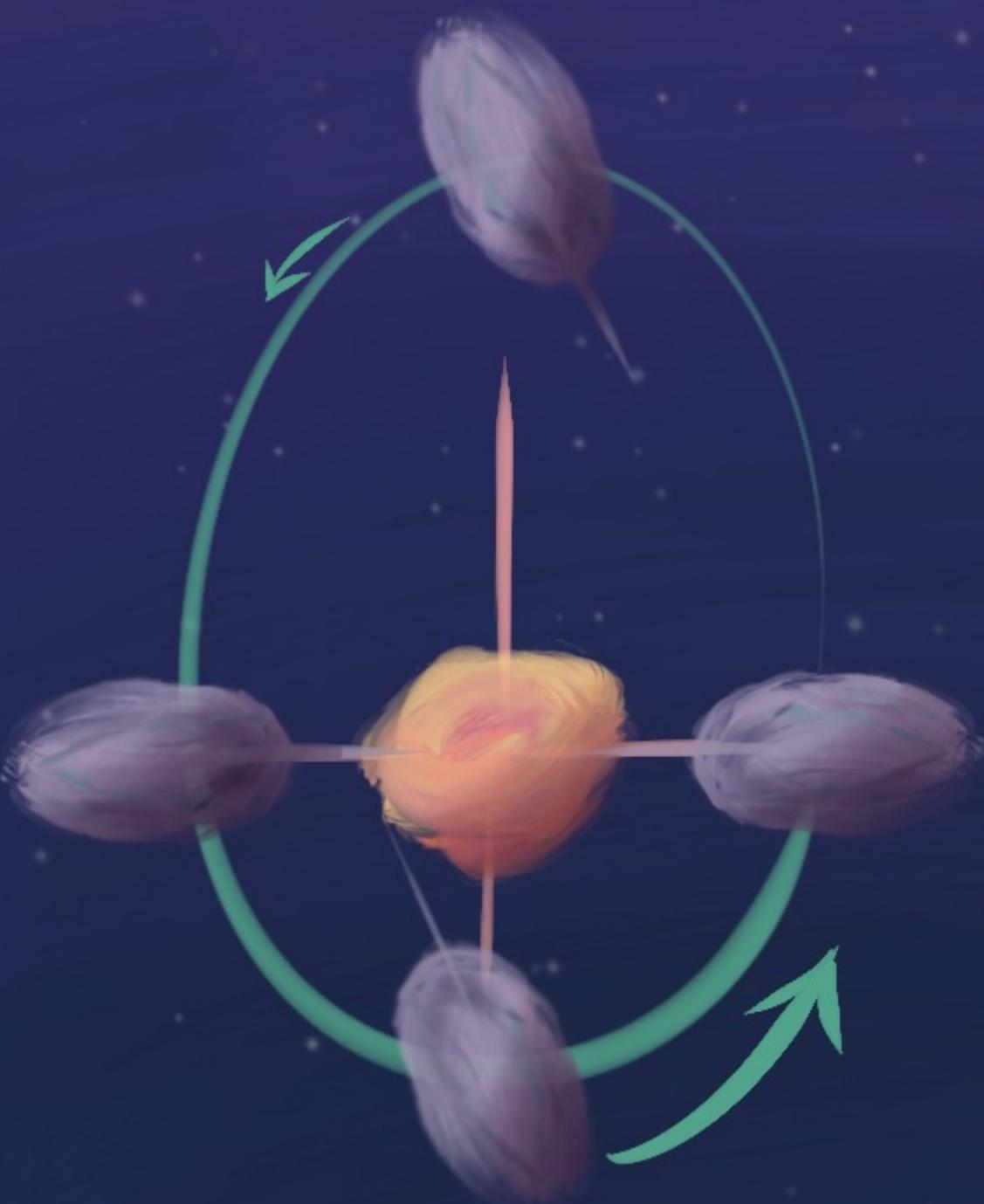
Which is which?

A diagram illustrating tidal locking. In the center is a yellow-orange star with a visible surface texture. It is surrounded by five smaller, reddish-pink planets, each with a distinct elliptical shape. The planets are arranged in a circle around the star, connected by thin pink lines. A thick green circle represents the orbital path of the outermost planet. The background is a dark blue space with small white stars.

Tidal locking:

Circular orbit

Synchronous  
Rotation

A diagram illustrating an elliptical orbit. A central yellow-orange Sun is at the center of the ellipse. Five purple, textured celestial bodies, representing planets or moons, are shown at different points along the green elliptical path. A pink vertical line passes through the Sun and the middle celestial body. Two curved green arrows indicate the direction of motion: one arrow on the upper-left arc points left, and another on the lower-right arc points right.

# Elliptical Orbit

Kepler's 2nd law

↓  
can't always be  
aligned

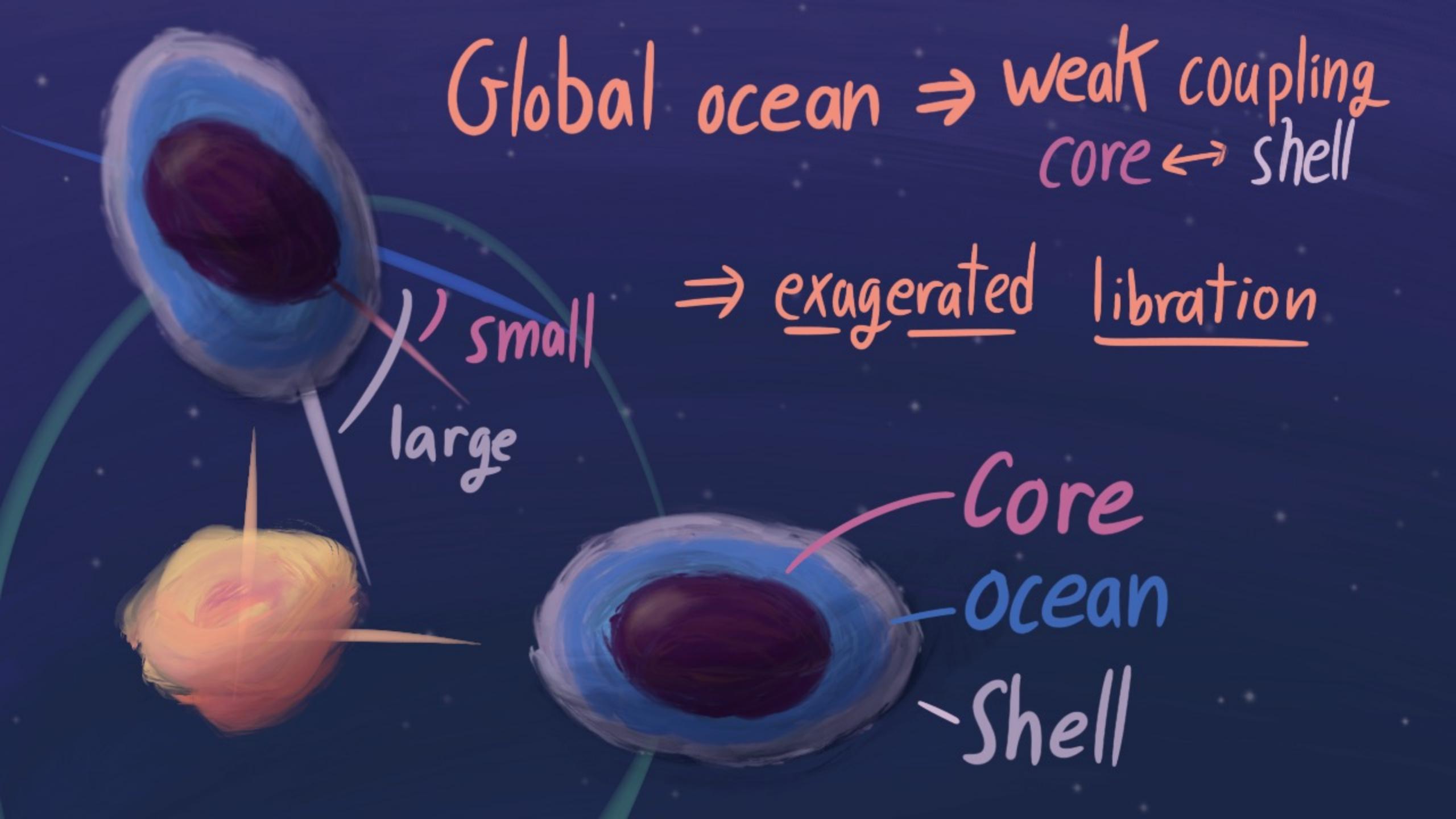


expected angle

- true angle =

Physical libration

measures response to torque



Global ocean  $\Rightarrow$  weak coupling  
core  $\leftrightarrow$  shell

$\Rightarrow$  exaggerated libration

) small

large

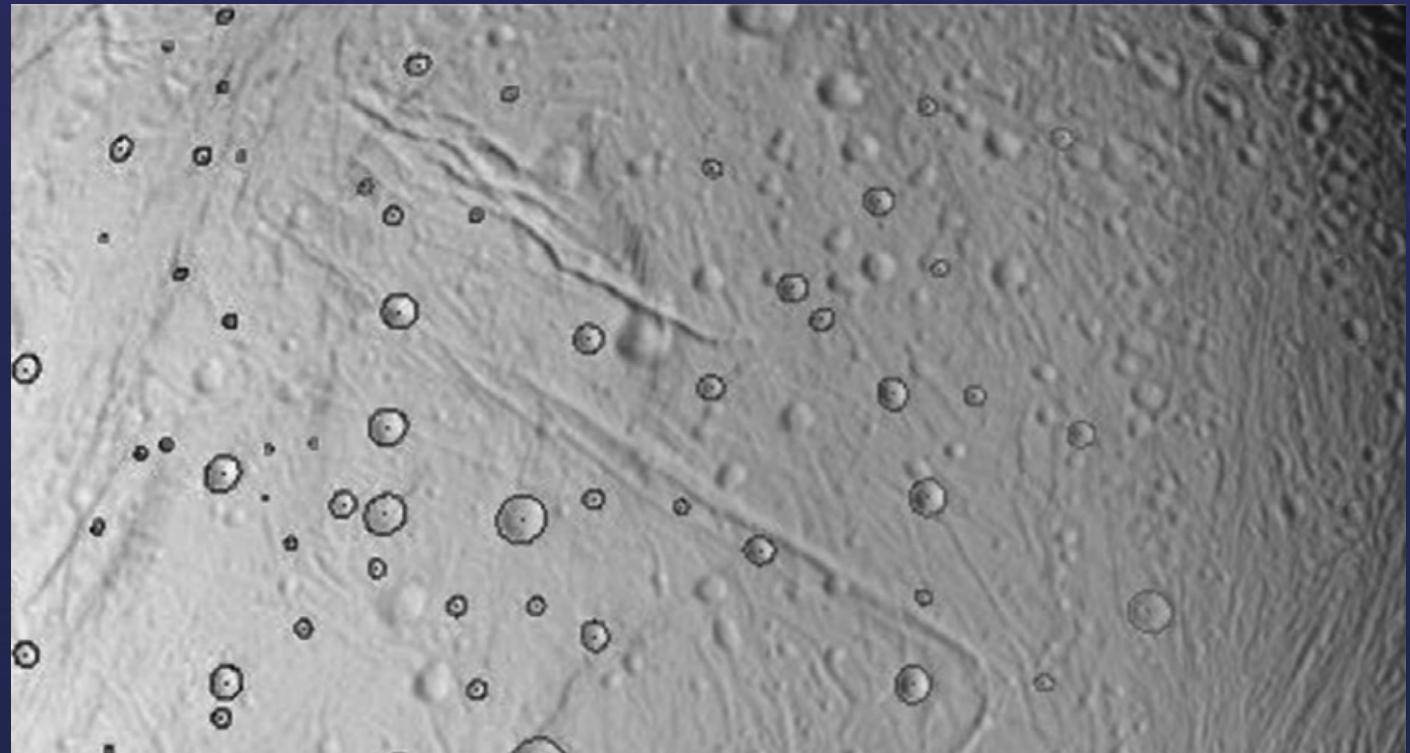
Core  
- ocean  
- Shell

# Measurement:

Take Picture



Locate Craters



# Measurement:

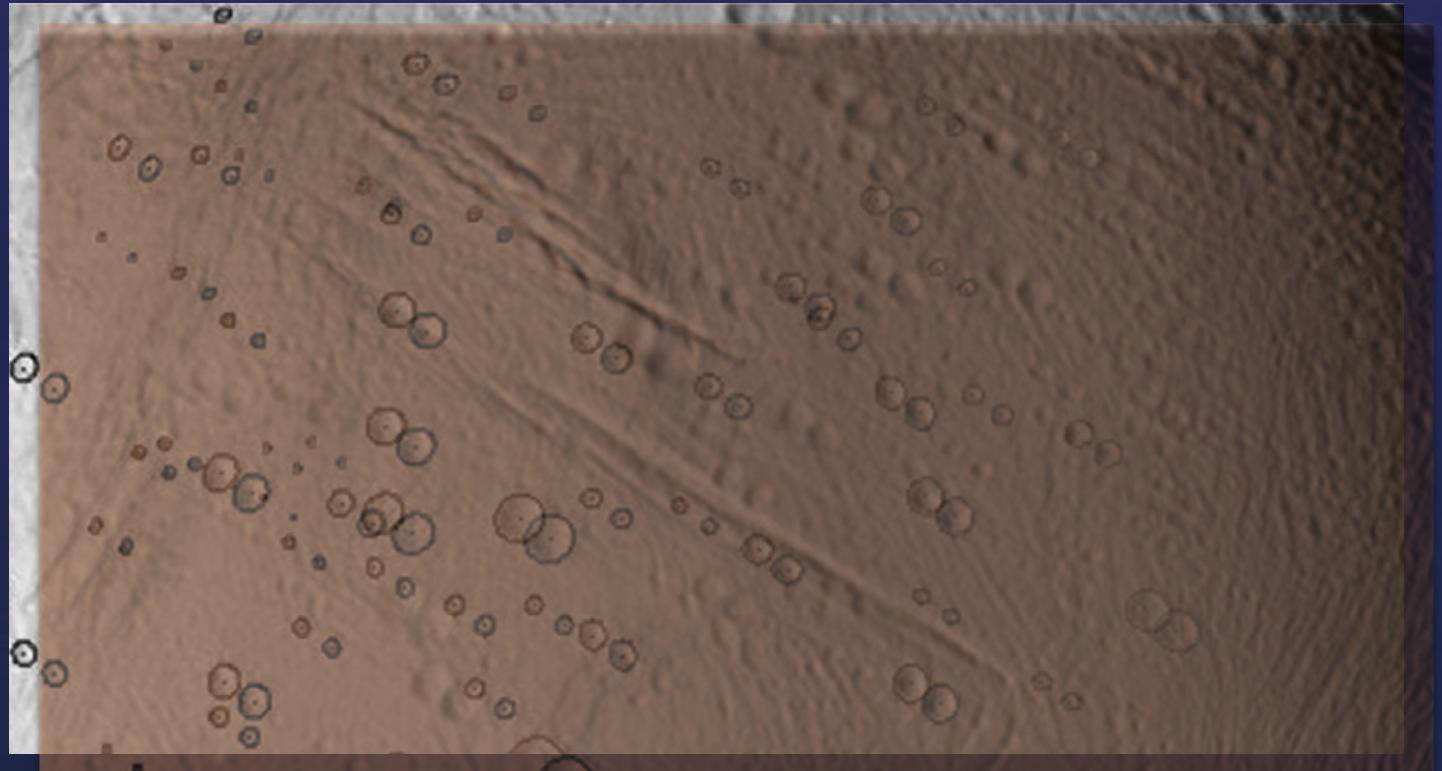
Take Picture



Locate Craters



Predict crater locations  
(for given libration)



# Measurement:

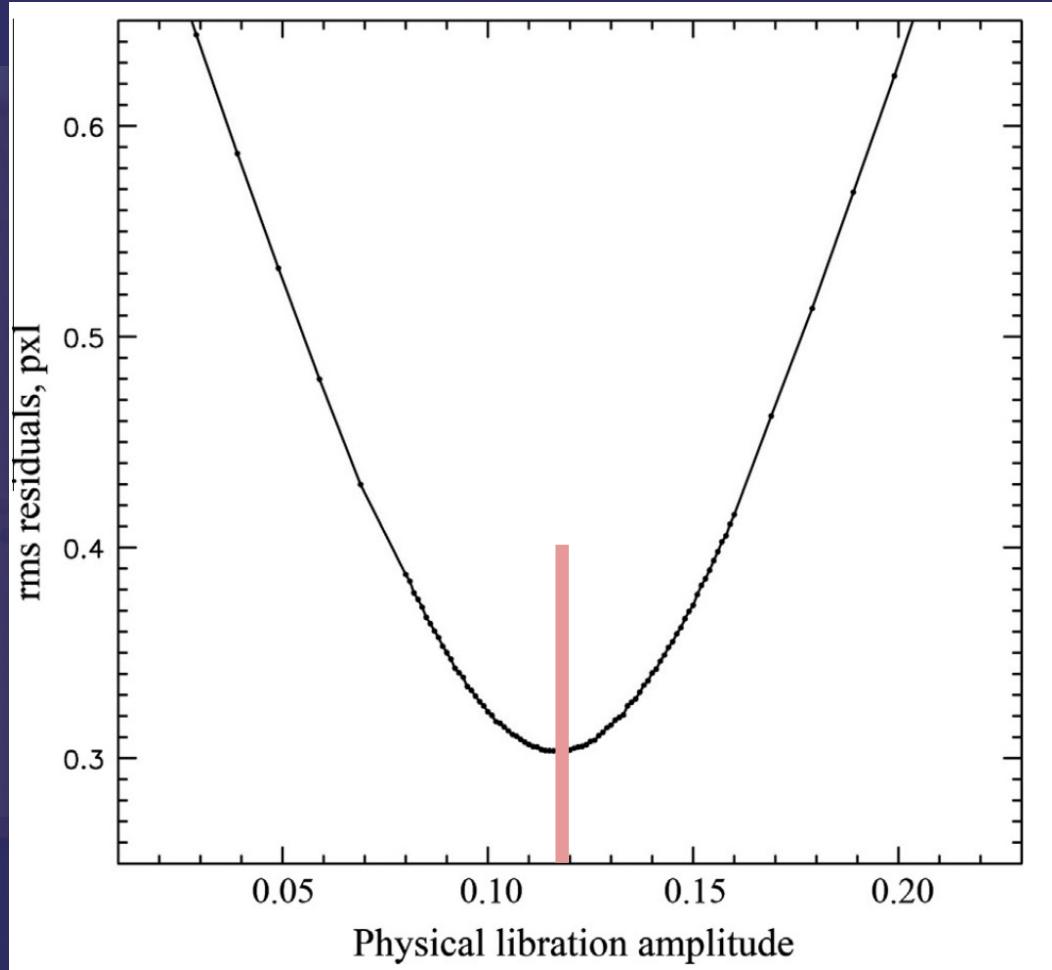
Take Picture



Locate Craters



Predict crater locations  
(for given libration)



Choose libration to minimize error



# Result

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

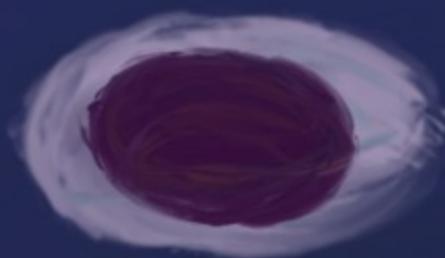
**Enceladus Libration:  $0.120 \pm 0.014^\circ$**

Rigid Model:



uniform:

libration  $.032^\circ$



hydrostatic core:

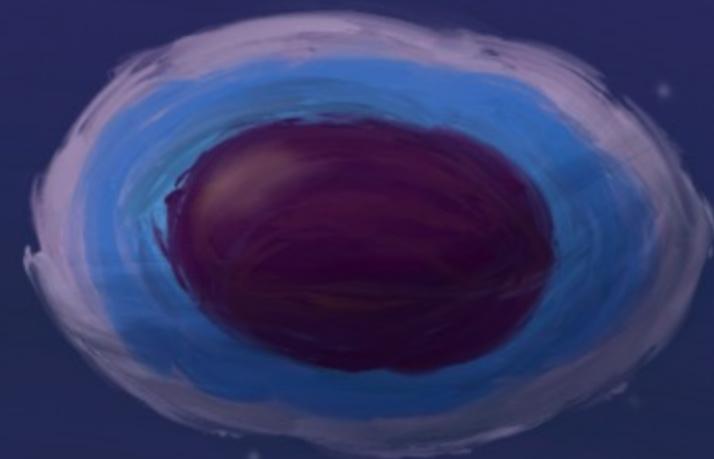
libration  $.032\text{--}.034^\circ$



Weird core:

not seen in gravity data

Global ocean:



ice: ~25 Km thick

Ocean: ~30 Km deep

libration  $.120^\circ$  ✓

# 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

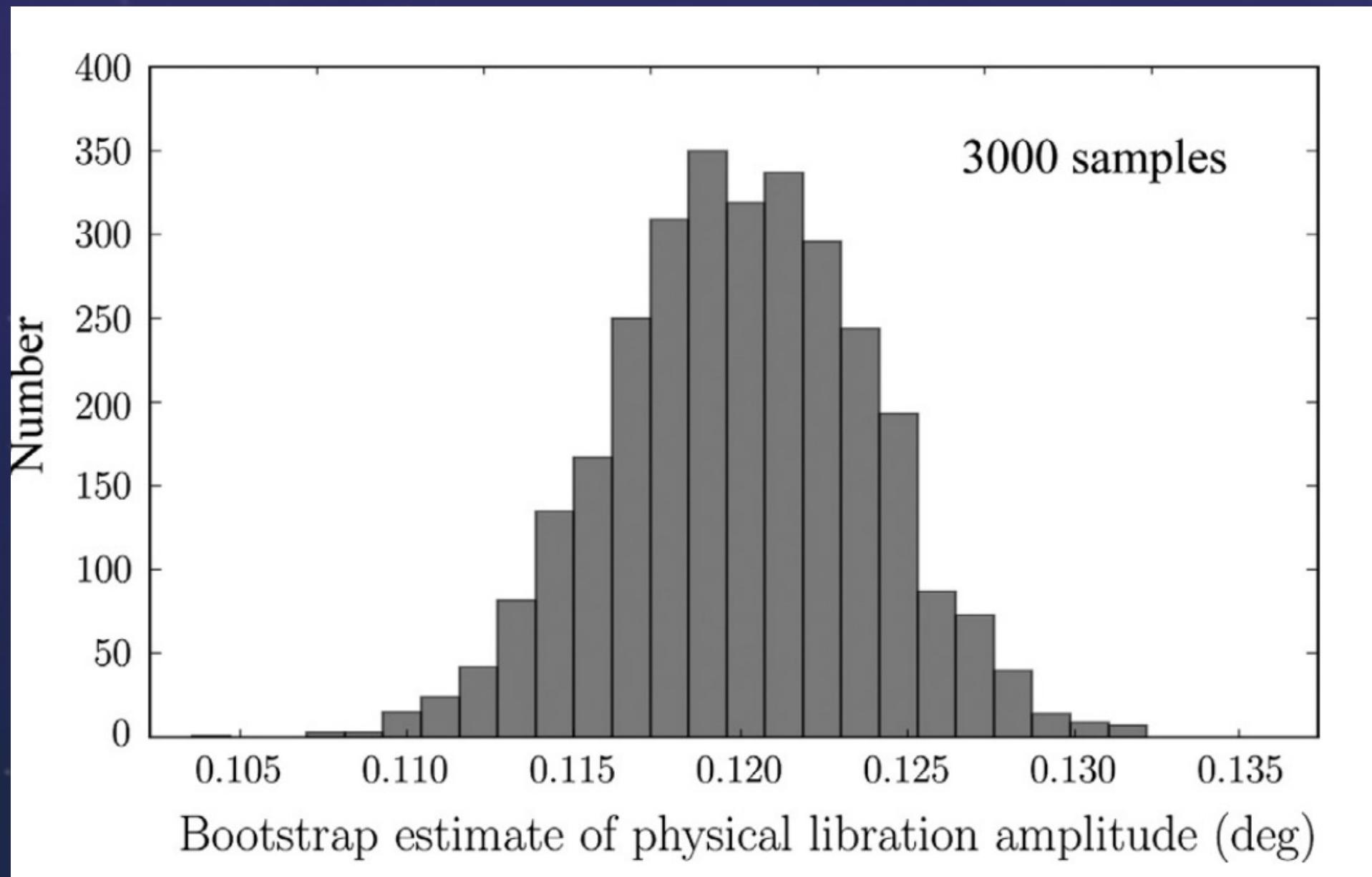
# Question:

Are you convinced?

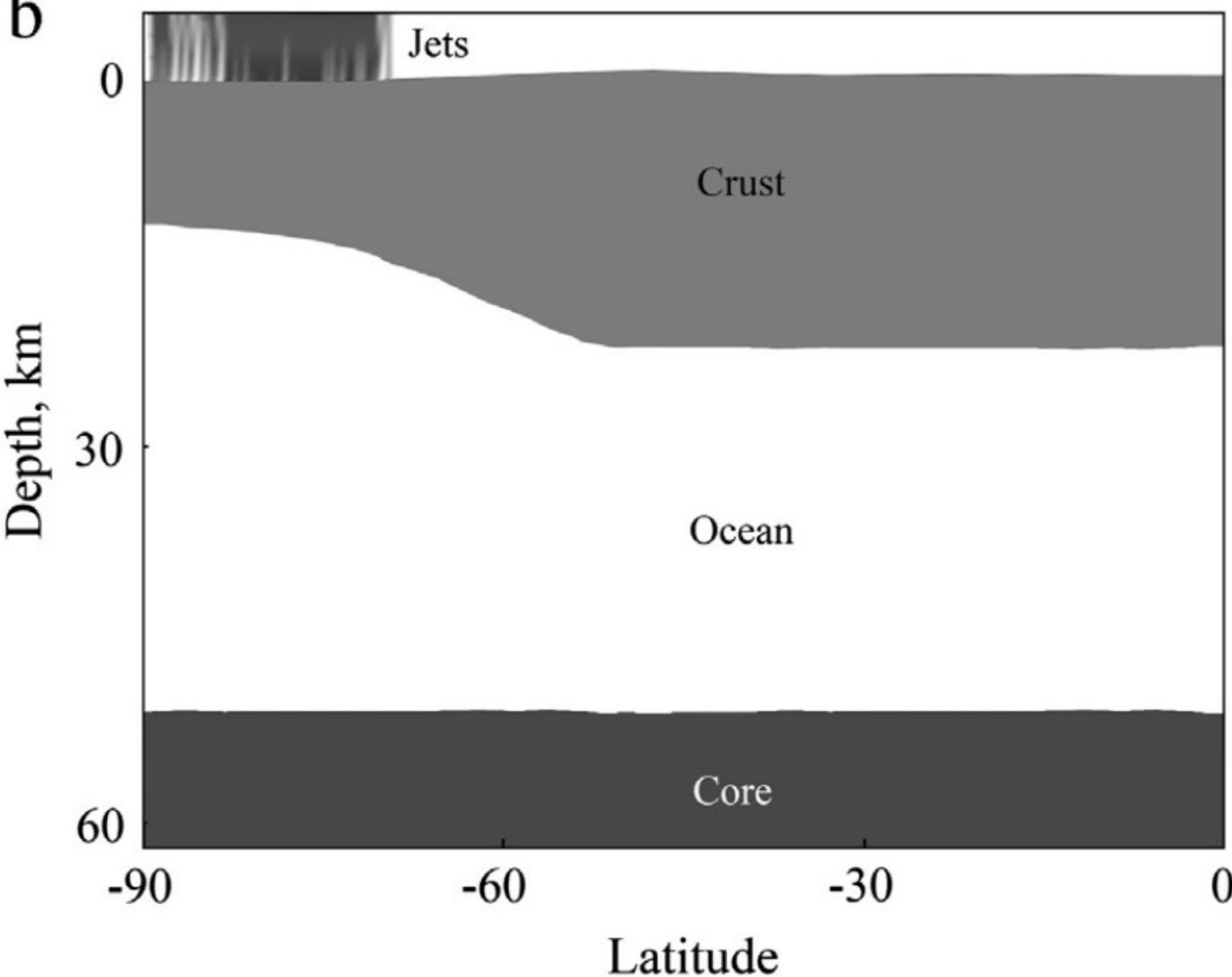
- Is their modeling conclusive?
- Can you think of any other wild causes for the high libration?
  - Is it aliens?

# References

- 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)



**b**



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

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

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

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

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

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