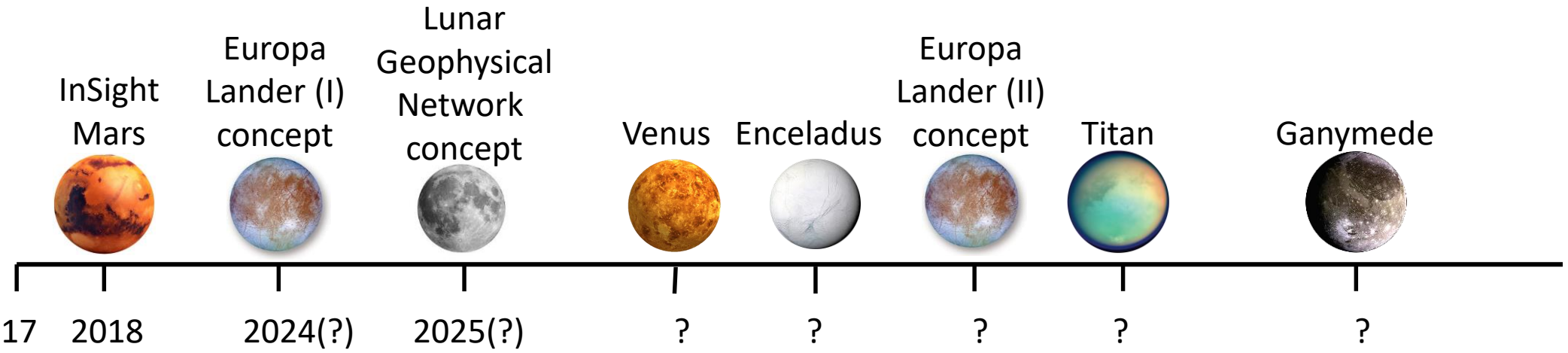
Seismic Exploration of Europa and Other Ocean Worlds

Steve Vance[1] (svance@jpl.nasa.gov)

Sharon Kedar[1], Sridhar Anandakrishnan[2], W. Bruce Banerdt[1], Bruce G Bills[1], Fabio Cammarano[3], Julie C Castillo[1], Hsin-Hua Huang (**黃信樺**)[4,5], Jennifer M Jackson[4], Philippe Henri Lognonne[6], Ralph D Lorenz[7], Mark P Panning[8], William T Pike[9], Simon C. Stähler[10] and Victor C Tsai[4],

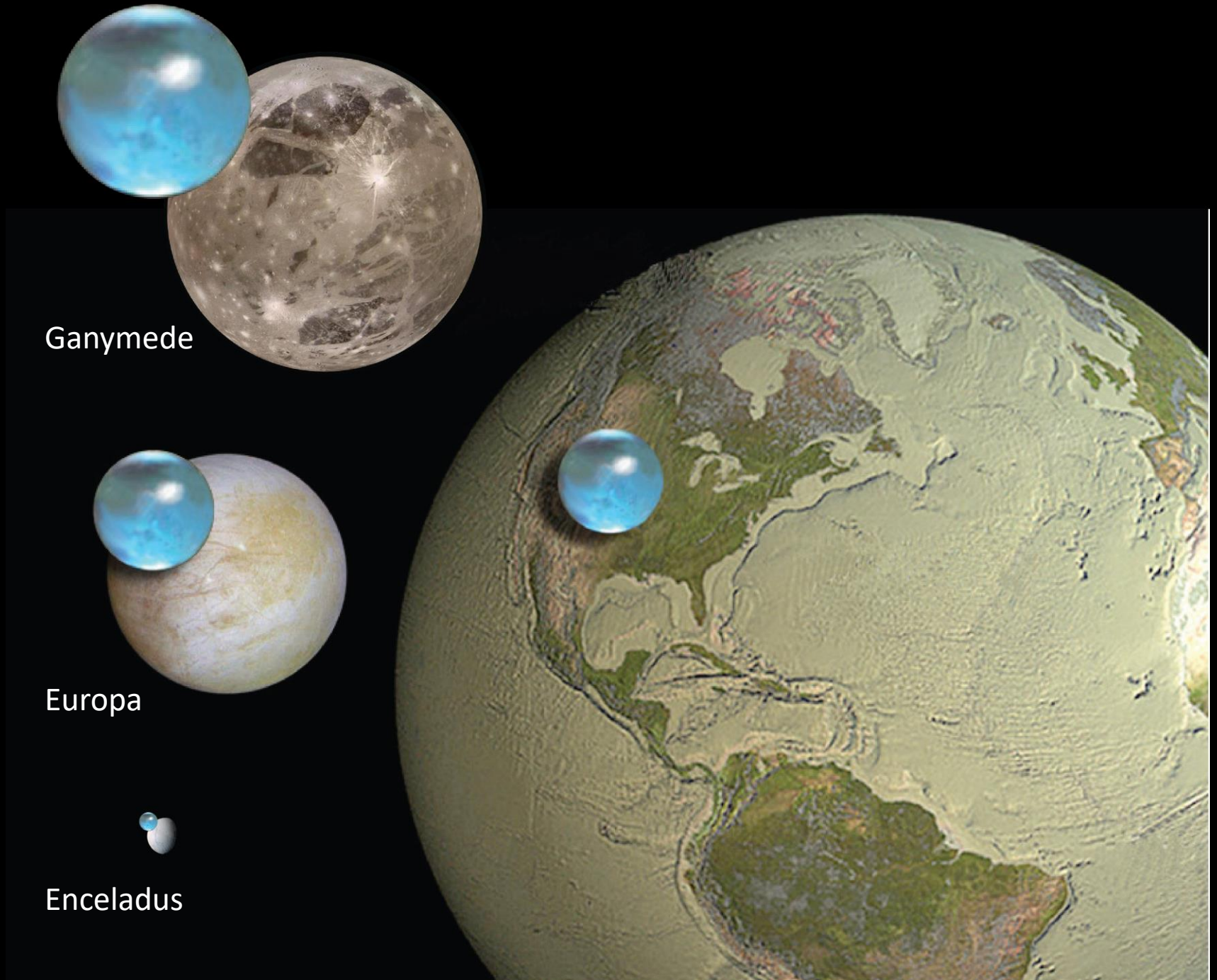
(1)Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States, (2)Pennsylvania State University Main Campus, University Park, PA, United States, (3) U. Roma Tre, Rome, Italy, (4)California Institute of Technology, Pasadena, CA, United States, (5) Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, (6)Institut de Physique du Globe de Paris, Paris, France, (7)Johns Hopkins University Applied Physics Laboratory, Laurel, MD, United States, (8)Univ of FL-Geological Sciences, Gainesville, FL, United States, (9)Imperial College London, London, SW7, United Kingdom, (10) ETH, Zurich, Switzerland



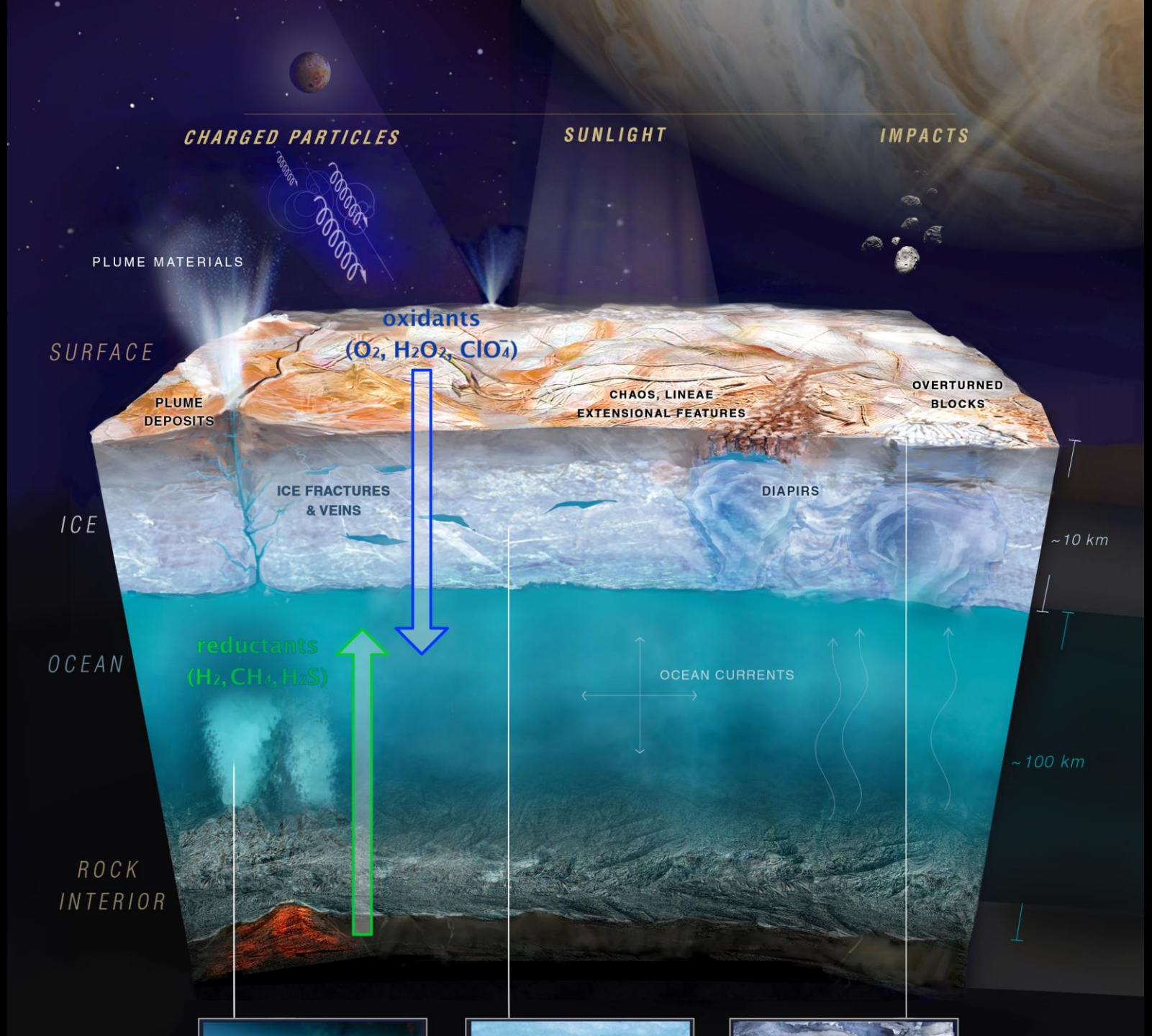
© 2017 California Institute of Technology. All rights reserved. Government sponsorship acknowledged. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

Seismology in Ocean Worlds

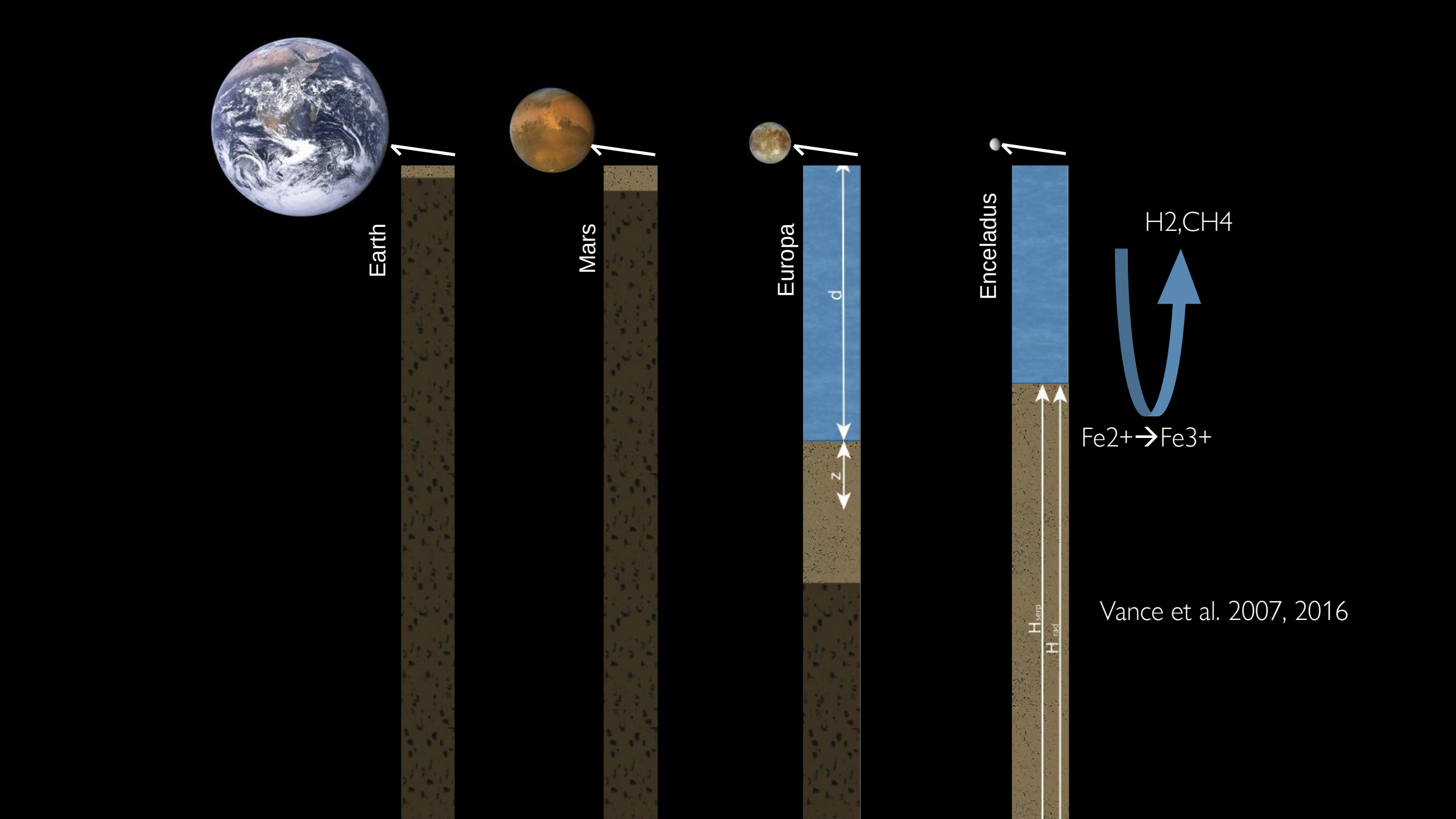
- How might ocean worlds be habitable?
  - Need to understand redox fluxes and reservoirs
- How might we use geophysics to test for habitability?
  - Focus here is on seismology


Ganymede
Europa
Enceladus

Europa

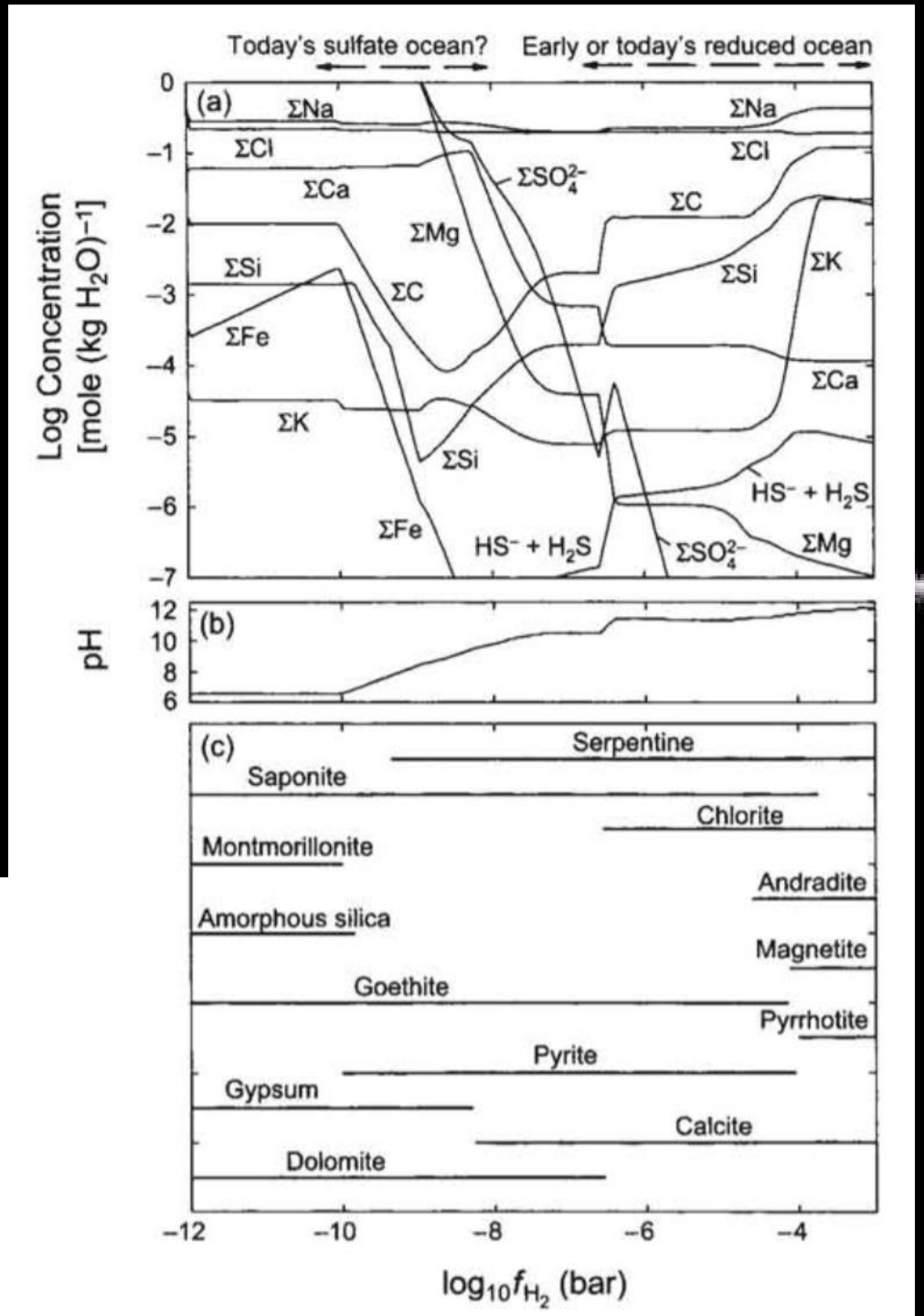


Modified from the 2016 Lander SDT Report


Earth
Mars
Europa
Enceladus
d
z
H2,CH4
Fe2+→Fe3+
Vance et al. 2007, 2016

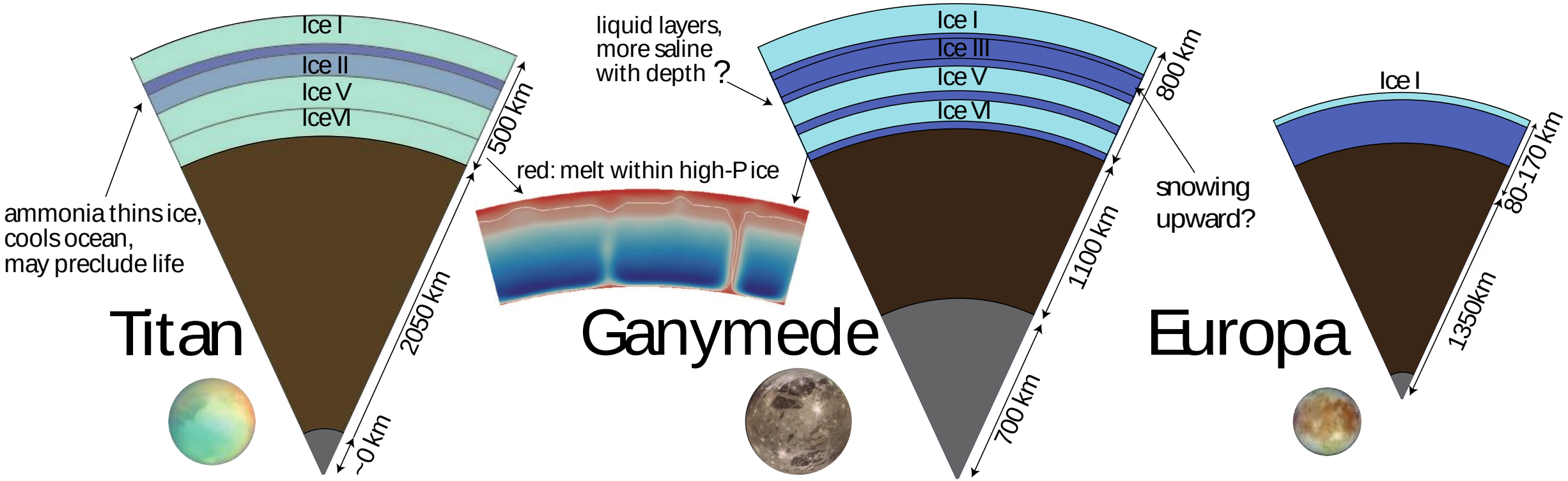
$MgSO_4$

?



NaCl

Zolotov and Kargel 2009



Choblet + 2017

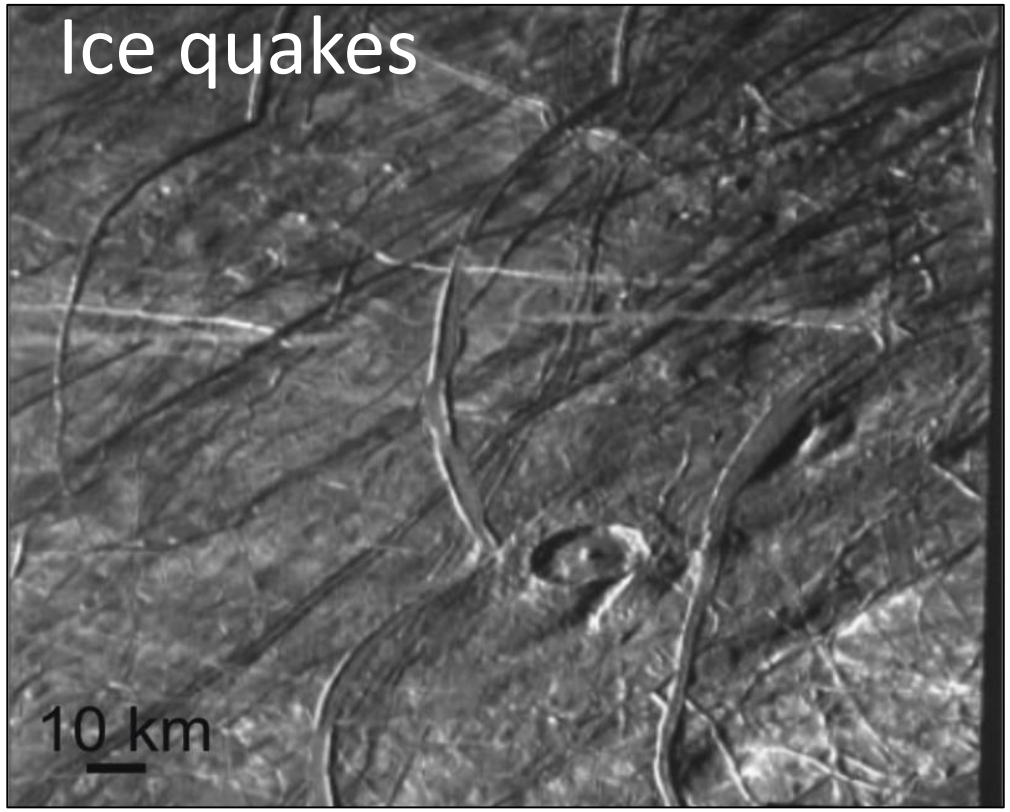
Vance + 2014

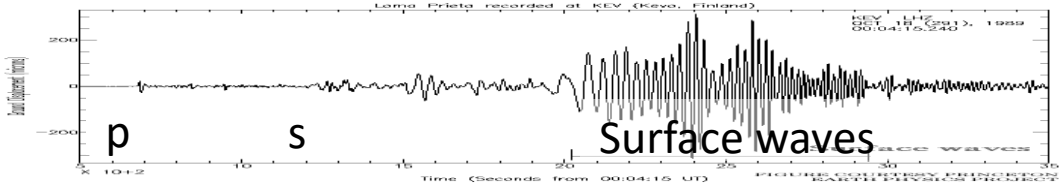
	Mean Radius in km	Bulk Density in kg m^{-3}	Moment of Inertia (C/MR^2)	Inferred H_2O thickness in km	Rotation Period In hrs	Radiogenic Heat in GW	Tidal Dissipation in GW	Seismic Energy Release in GW (%)
Earth[a]	6371	5514	0.3307	3.5	24	31,000	**2636±16**	22 (0.8)
Moon[a,b]	1738	3340	0.3929 ±0.0009	n/a	672	420	**1.36±0.19**	$6x10^{-7}$ ($0.4x10^{-5}$)
Mars[c]	3397	3933	0.3662 ±0.0017	n/a	24.6230	3,300	**--**	?
Europa[d,e,f]	1565.0 ±8.0	2989 ±46	0.346 ±0.005	80-170	84.4	200	**<10,000 >1000 (ocean) 1-10 (rock)**	?
Ganymede[e,f,g]	2631.17 ±1.7	1942.0 ±4.8	0.3115 ±0.0028	750-900	171.7	500	**<50 >1 (ocean)**	?
Callisto[e,f]	2410.3 ±1.5	1834.4 ±3.4	0.3549 ±0.0042	350-450	400.5	400	**<20 >4 (ocean)**	?
Titan[e,h,i]	2574.73 ±0.09	1879.8 ±0.2	0.3438 ±0.0005	500-700	382.7	400	**<400 >11 (ocean)**	?
Enceladus[e,h,j]	252.1 ±0.1	1609 ±5	0.335	60-80	32.9	0.3	**<20 >10 (ocean)**	?

a) Williams et al., 2001 b) Goins et al., 1981; Williams et al., 1996; Siegler and Smekrar, 2014 c) Folkner et al., 1997, Nimmo and Faul, 2013 d) Tobie et al. 2003, Hussmann et al., 2006; Vance et al., 2007 e) Chen et al., 2014; Tyler, 2014 f) Schubert et al. 2004 g) Bland et al., 2015 h)

Vance et al. *under revision*

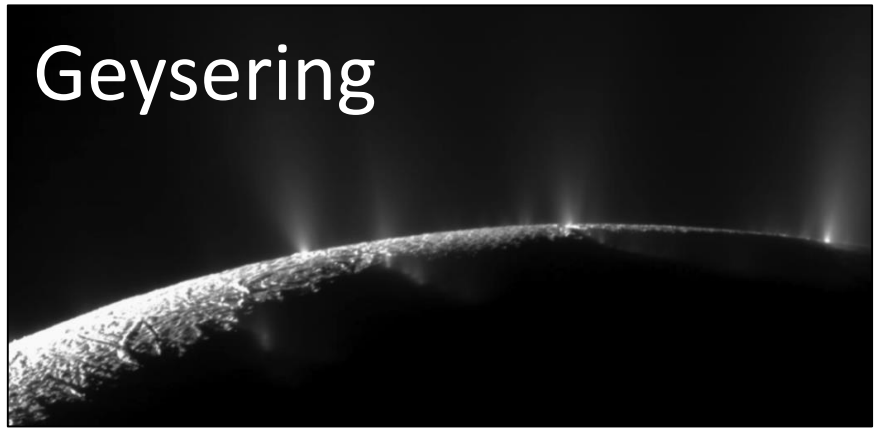
How might an ocean world sound?

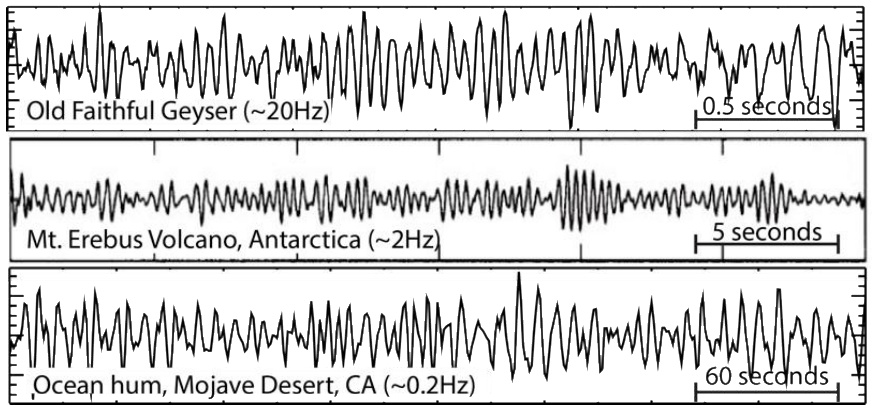


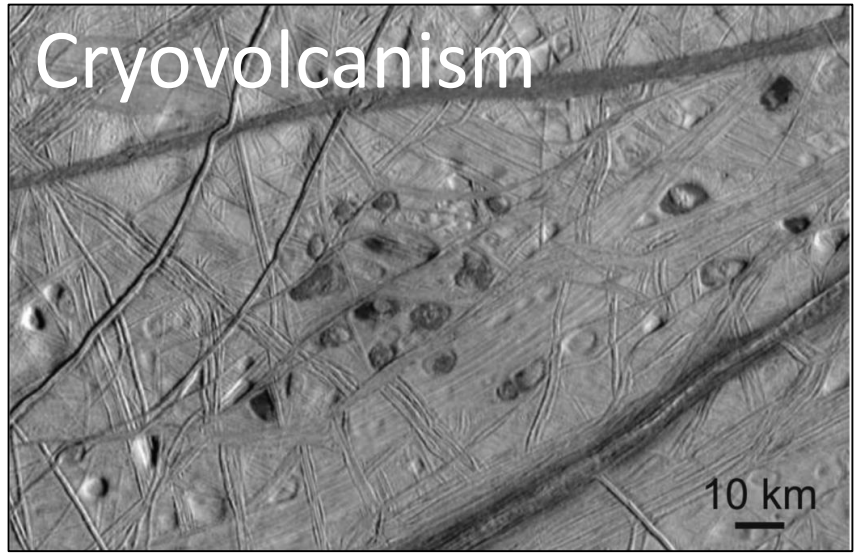


Europa's ice is young and geologically active

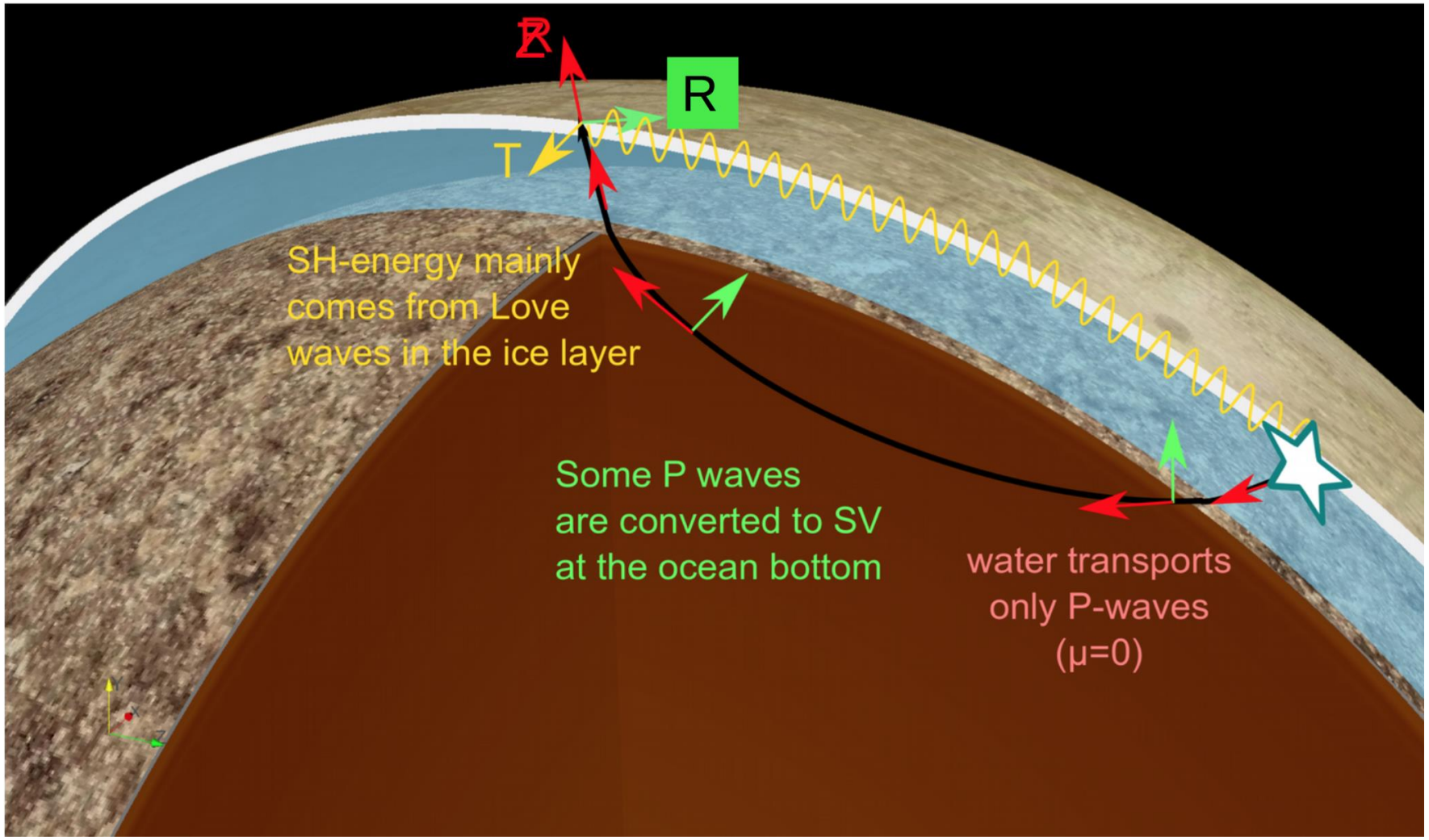
Fluid flow induced seismicity: continuous background "hum"



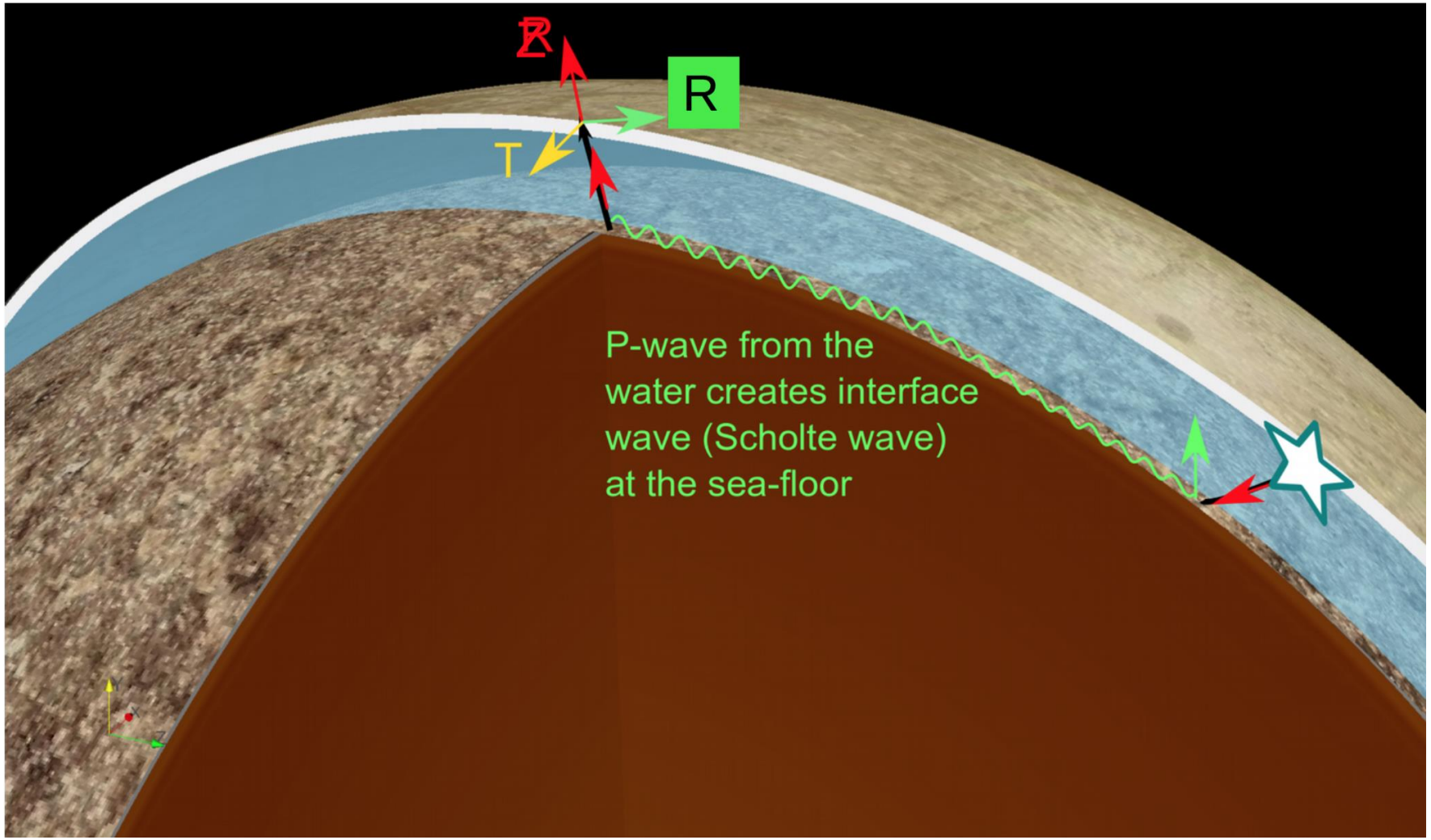




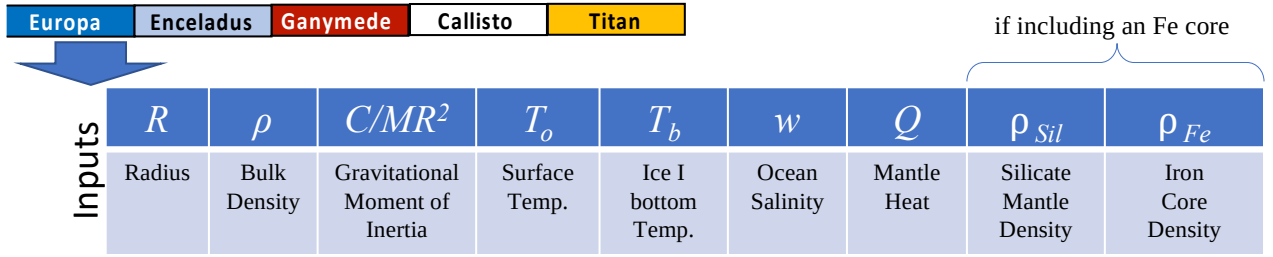
Sensing the mantle and ice



Sensing the mantle and ice



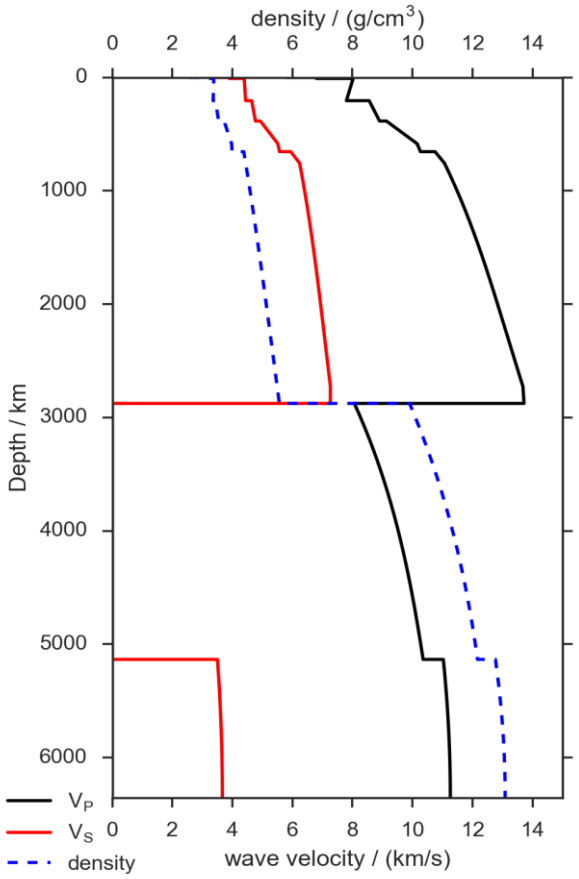
PlanetProfile



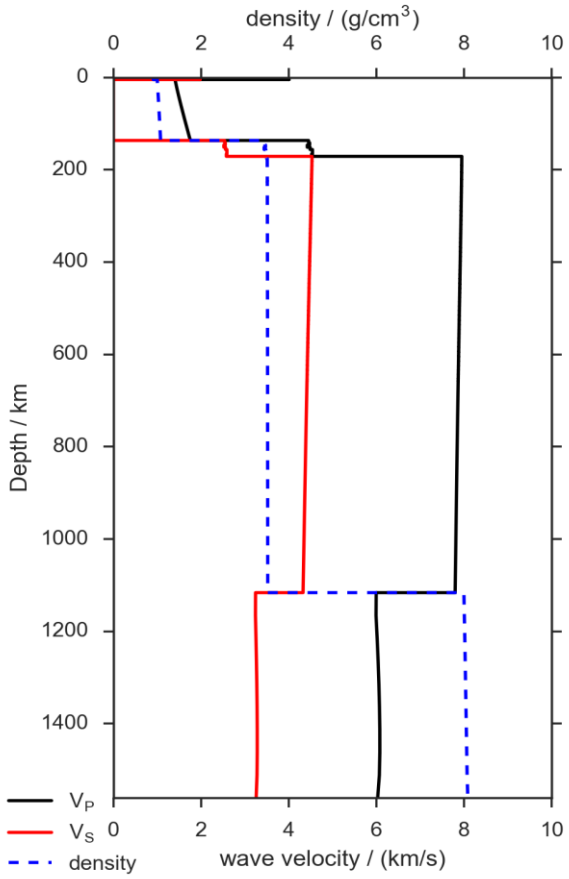
github.com/vancesteven/PlanetProfile
Vance et al. *in prep.*

Seismic Models

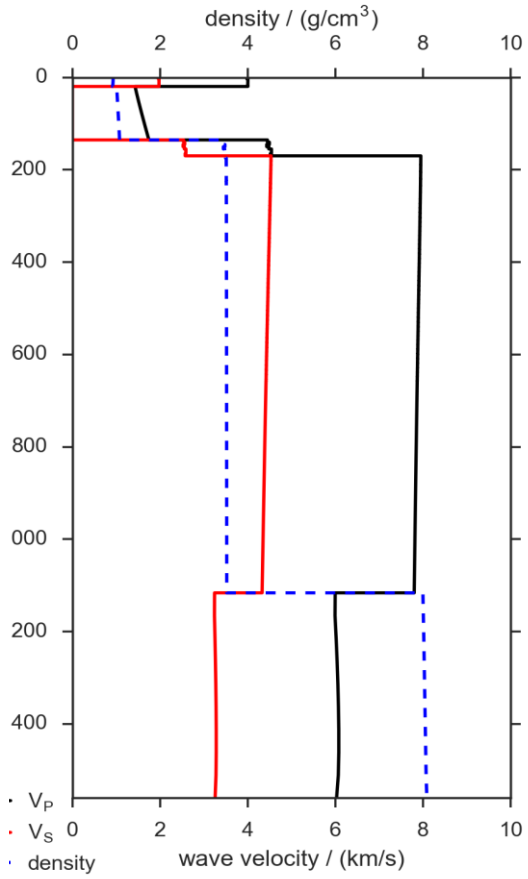
Earth



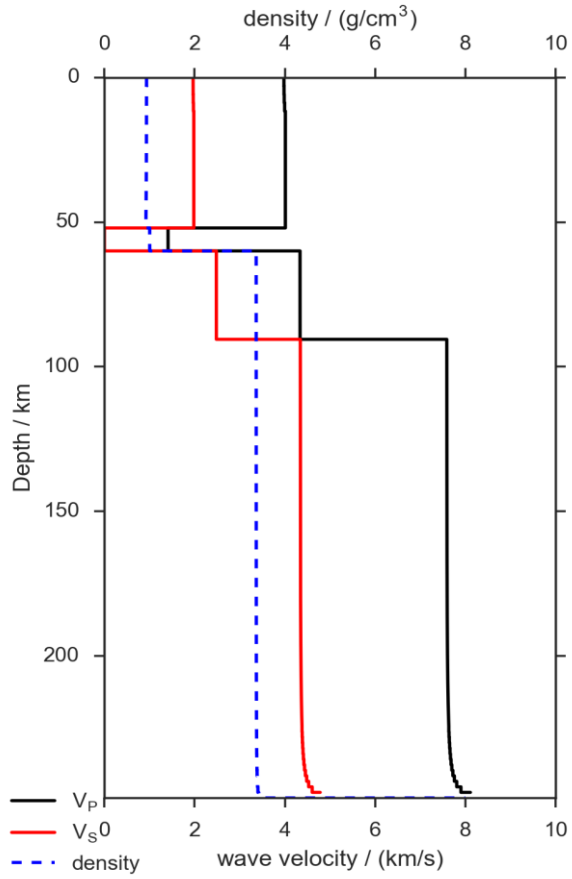
Europa (5km Ice)



Europa (20km Ice)

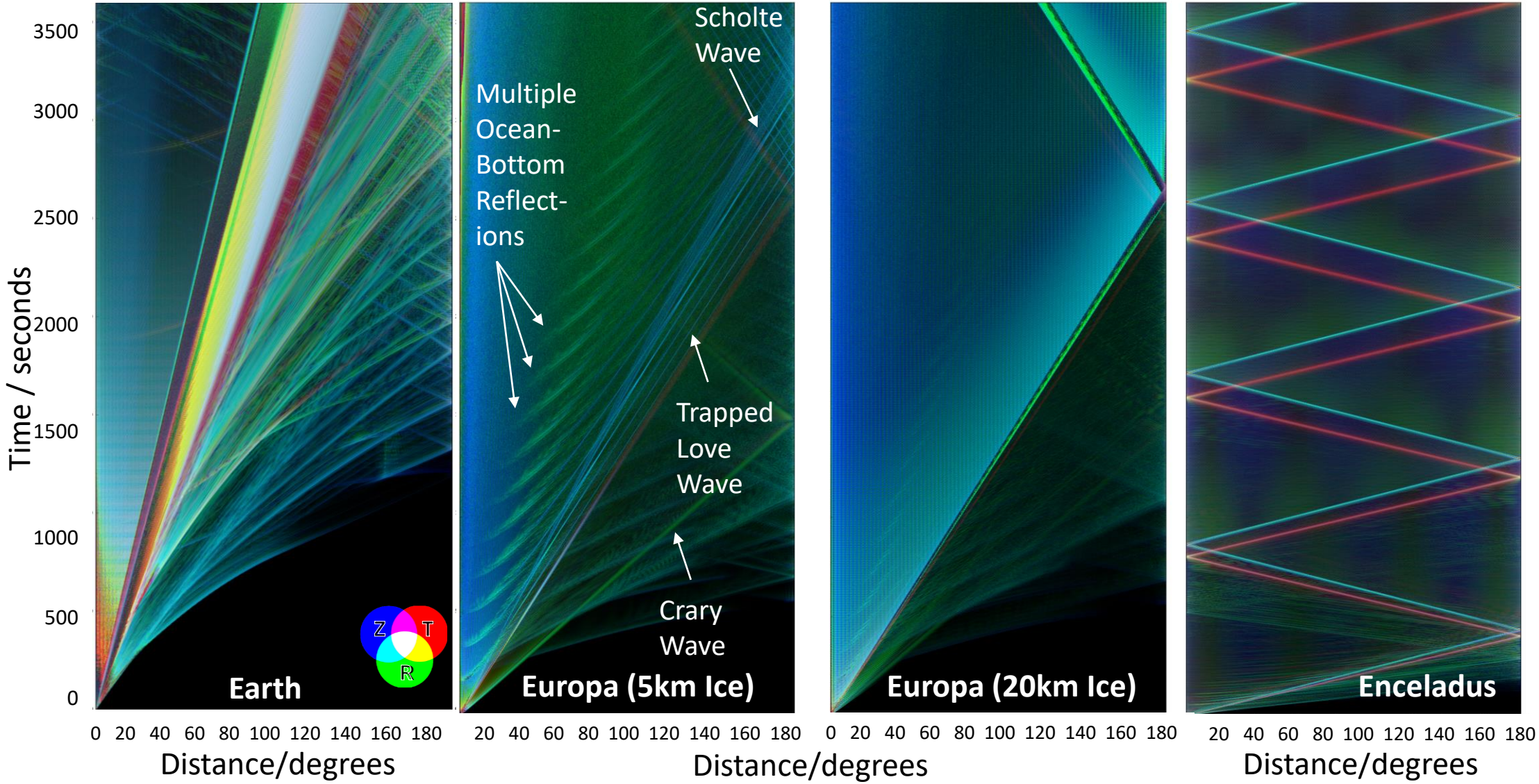


Enceladus



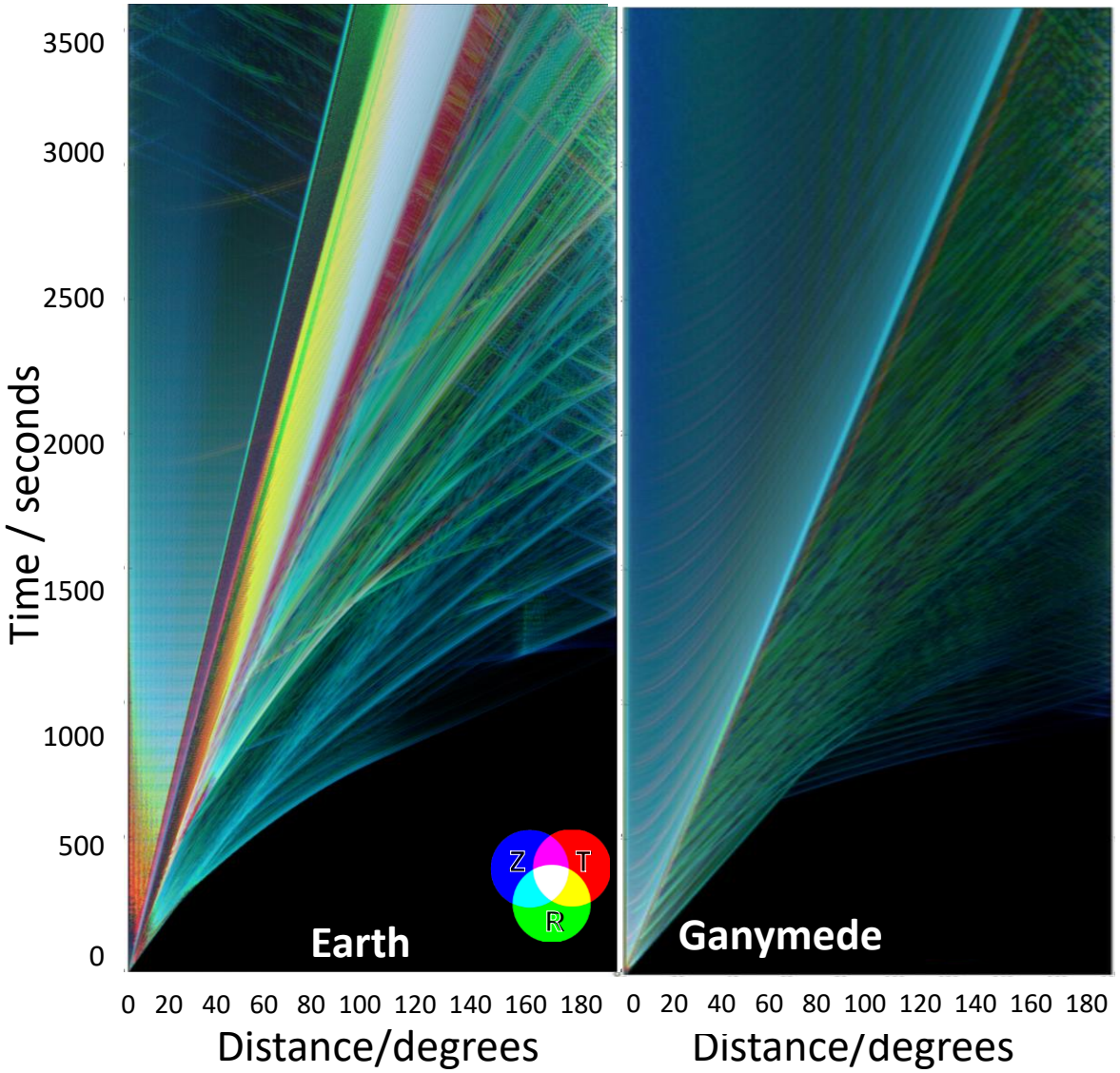
Each Ocean World Has a Unique Seismic Signature

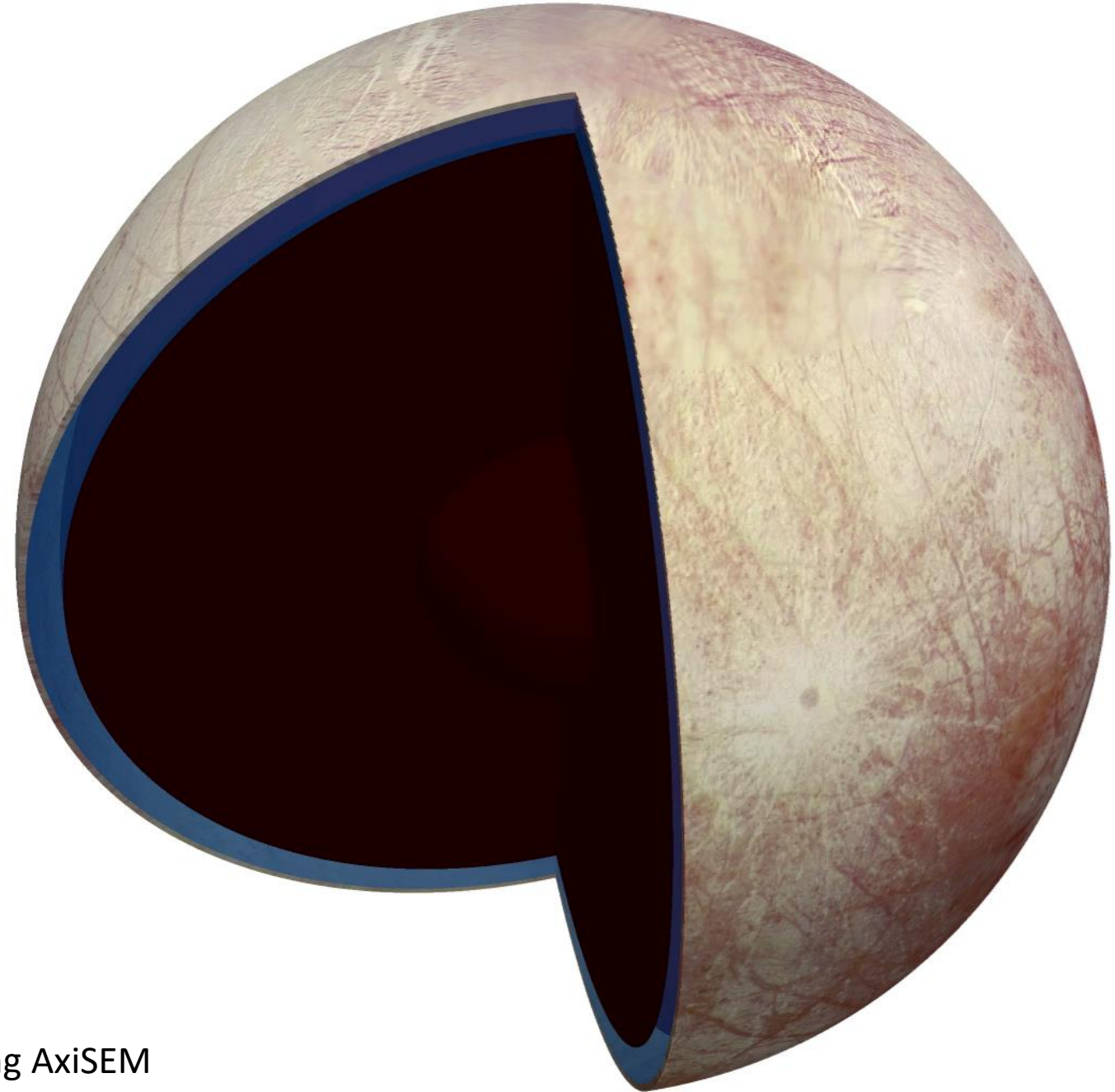
Stähler et al., *submitted.*



Each Ocean World Has a Unique Seismic Signature

Stähler et al., *submitted.*



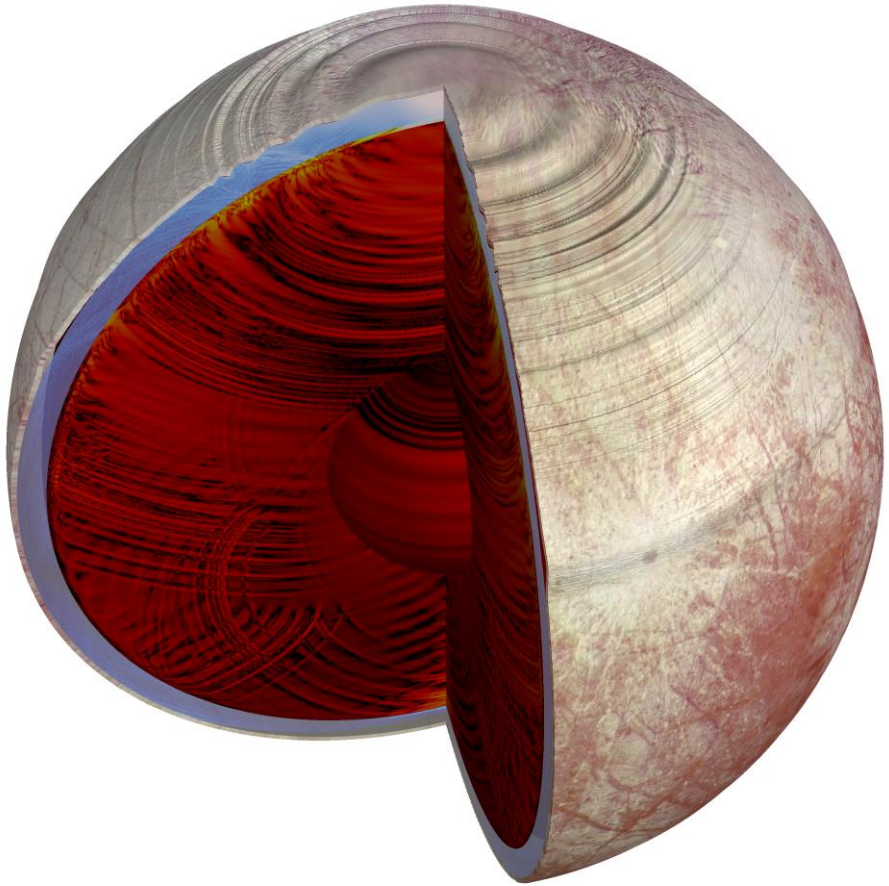


Produced by Simon Stähler using AxiSEM

Estimating the Background Noise

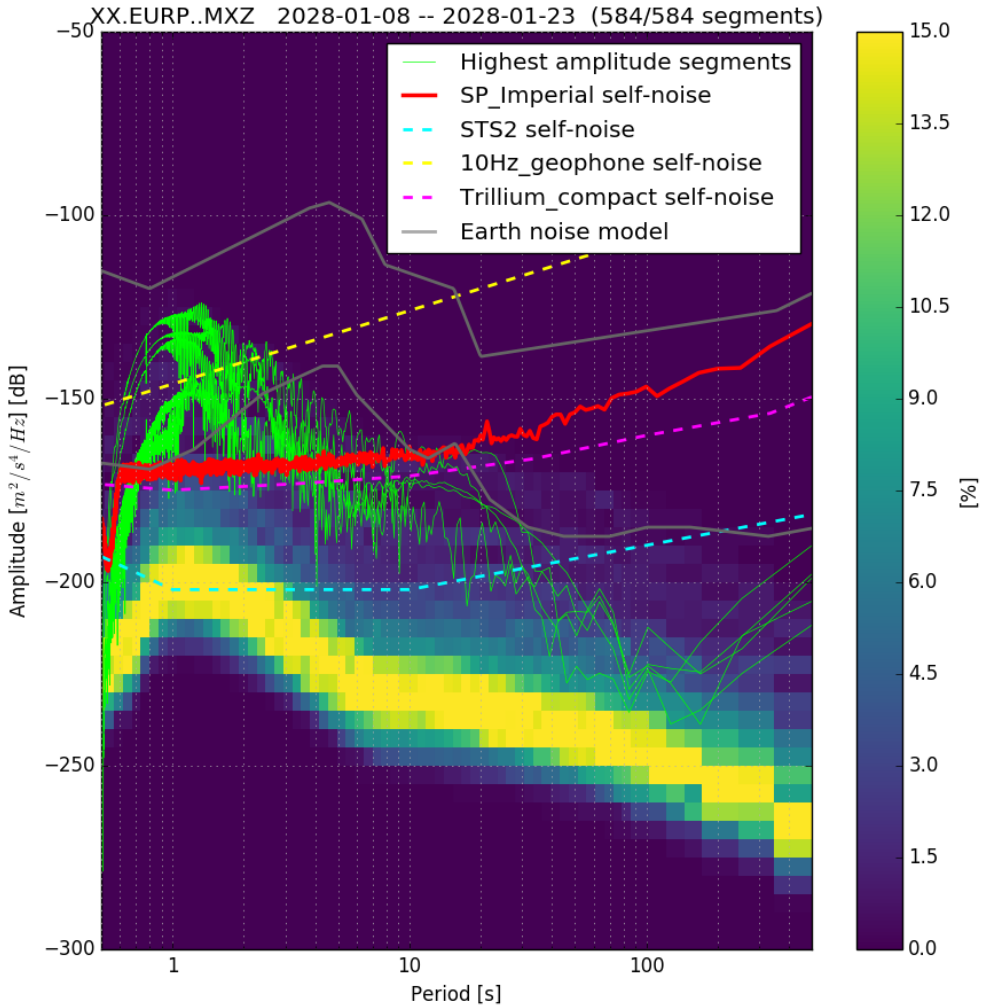
Panning et al., submitted.

AxiSEM/Instaseis is used to compute a series of 1 week long noise records,
which are used to compute probabilistic power spectral density plots for different seismicity models and Europa structure models,



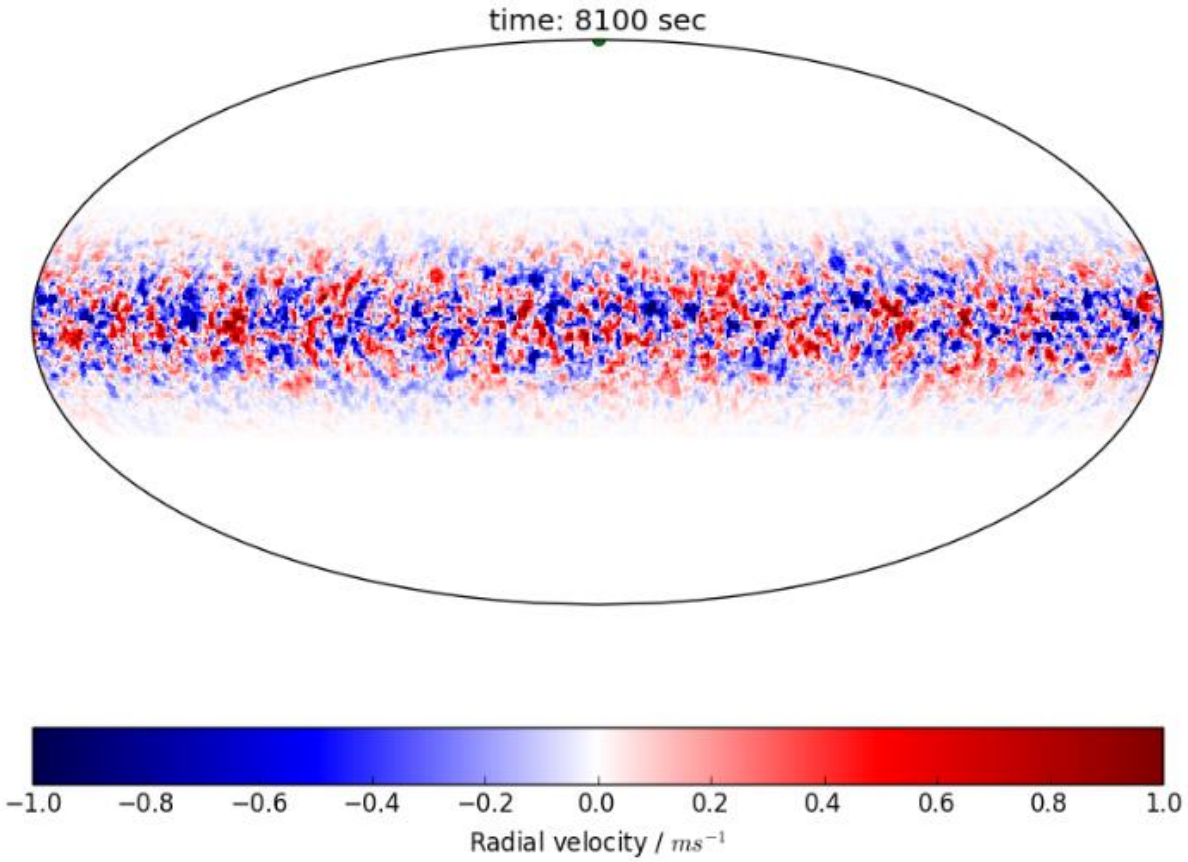
Assumptions:

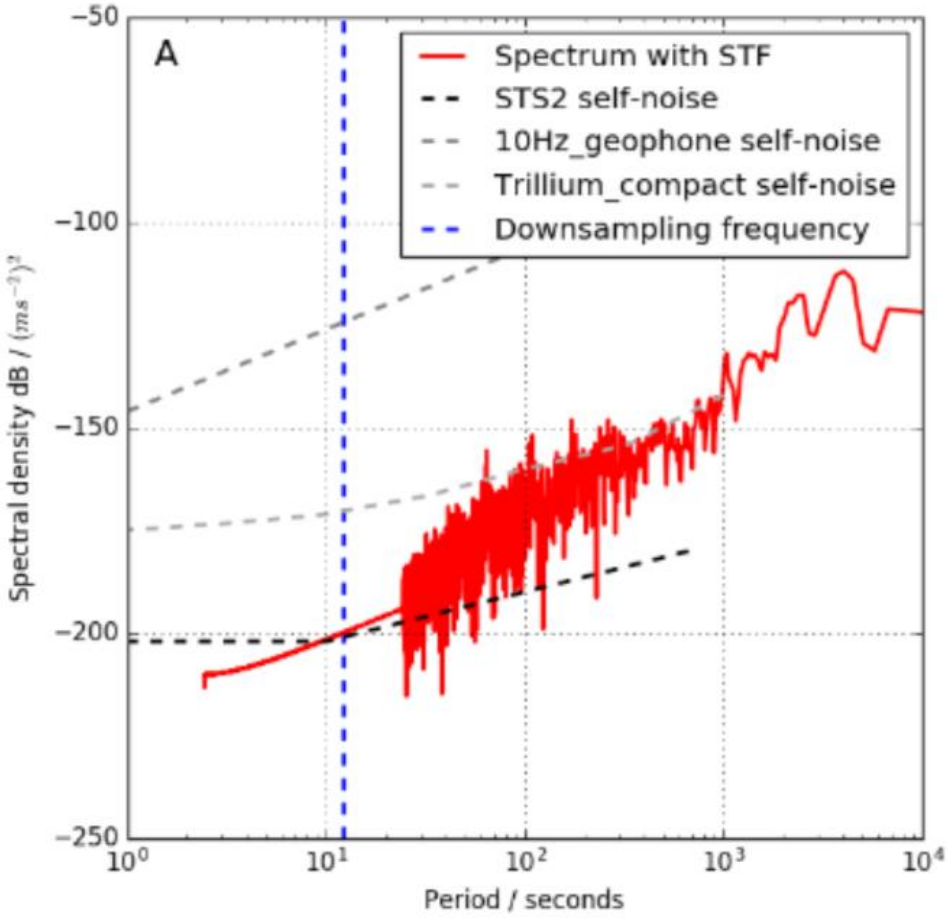
- Tidal dissipation
- Largest moment release



Estimating the Background Noise

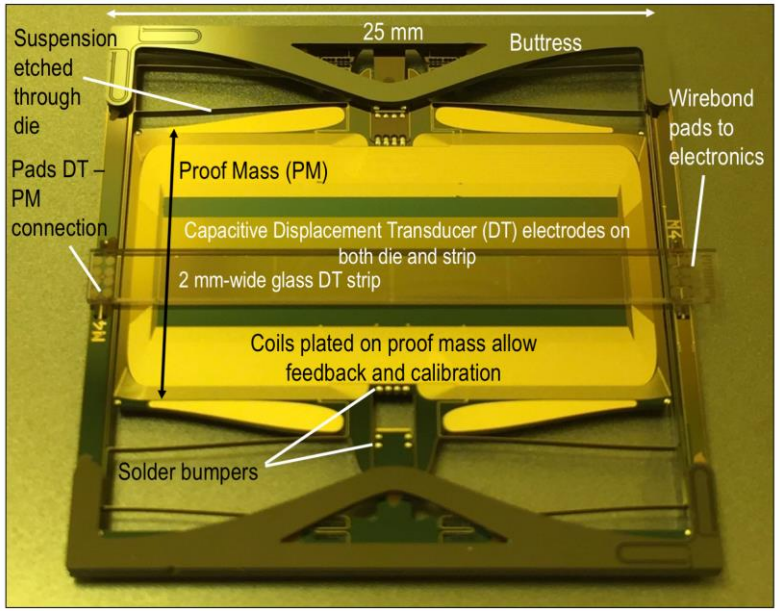
Panning et al., *in prep.*





Seismic Measurement of the Tide

InSight SP



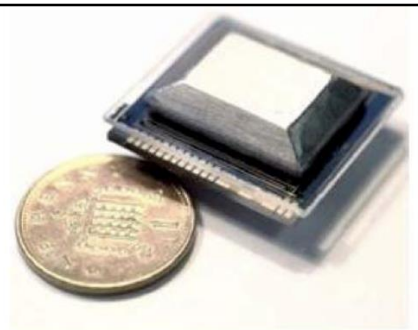
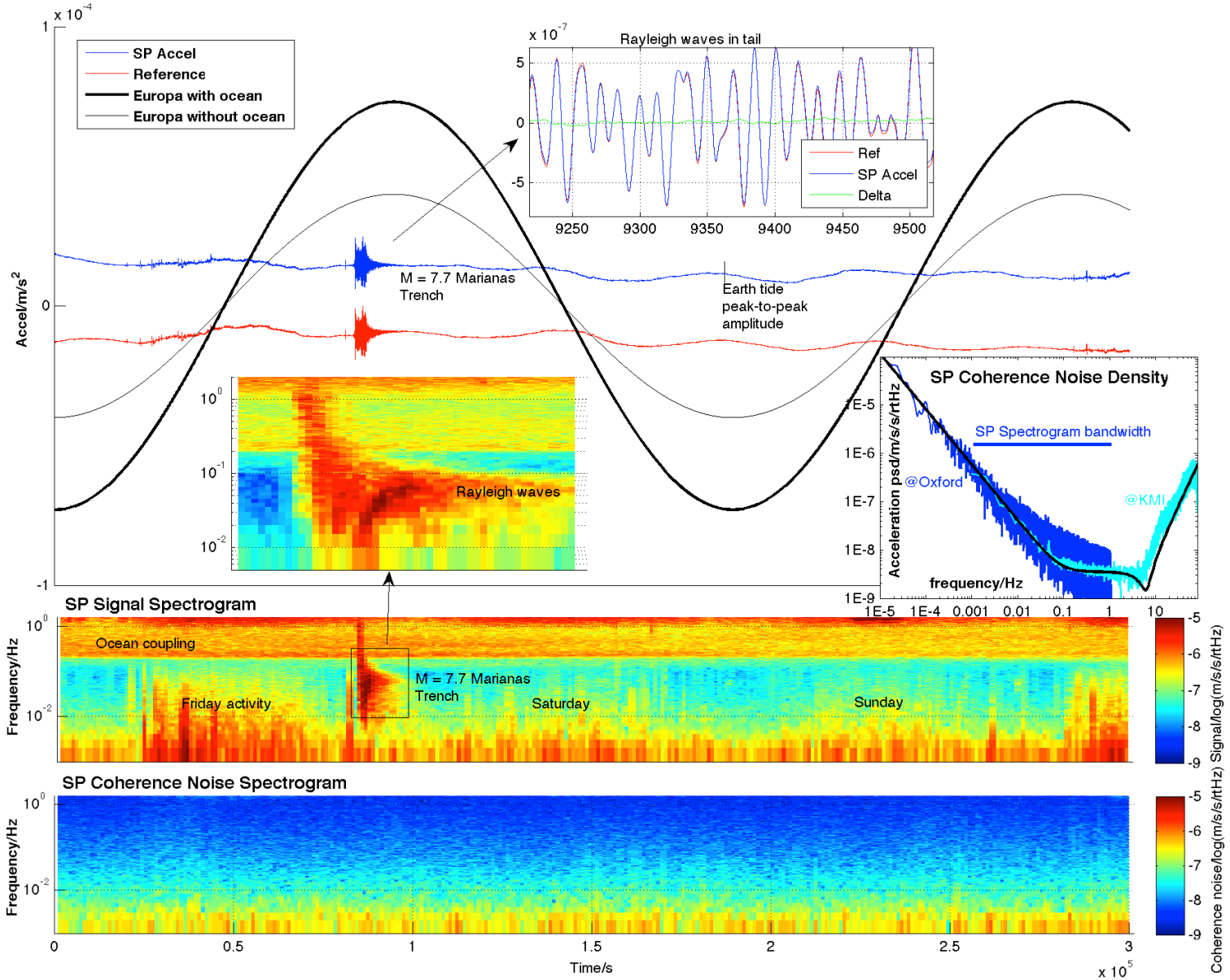
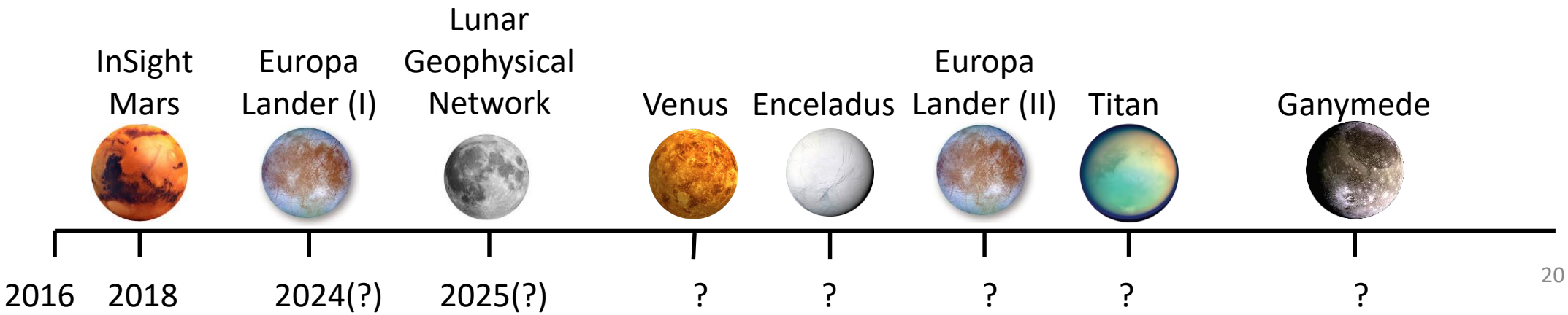


Figure 4.5.7. Example of the GSS Baseline model payload instrument, the short-period (SP) seismometer of SEIS from the Mars InSight 2018 Lander.

2016 Europa Lander SDT Report



Conclusions

- Icy ocean worlds are likely to be seismically active
- Seismic activity is likely to be varied, combining ice-quakes, tidal deformation, fluid induced seismicity (geysering, cryovolcanism, ocean circulation & acoustics)
- Each world has a unique seismic signature that can constrain habitability
- “Vital Signs” – the unique signs of present day fluid motion may carry fundamental information about the depth and nature of volatiles + ocean circulation