

Destination: Europa



Cynthia Phillips, JPL
Kate Craft, APL
Chris German, WHOI
Sam Howell, JPL

August 2019 OPAG Meeting
Boulder, CO

The **Formation**, **Evolution**, and **Habitability** of Ocean Worlds in our Solar System and Beyond

Three unifying science themes:

1. How do ocean worlds form?
2. How do ocean worlds evolve?
3. What controls the habitability of ocean worlds? Are they inhabited?

A Europa exploration strategy would address all these questions!

Proposed Key Unifying Theme #1: How do Ocean Worlds form?

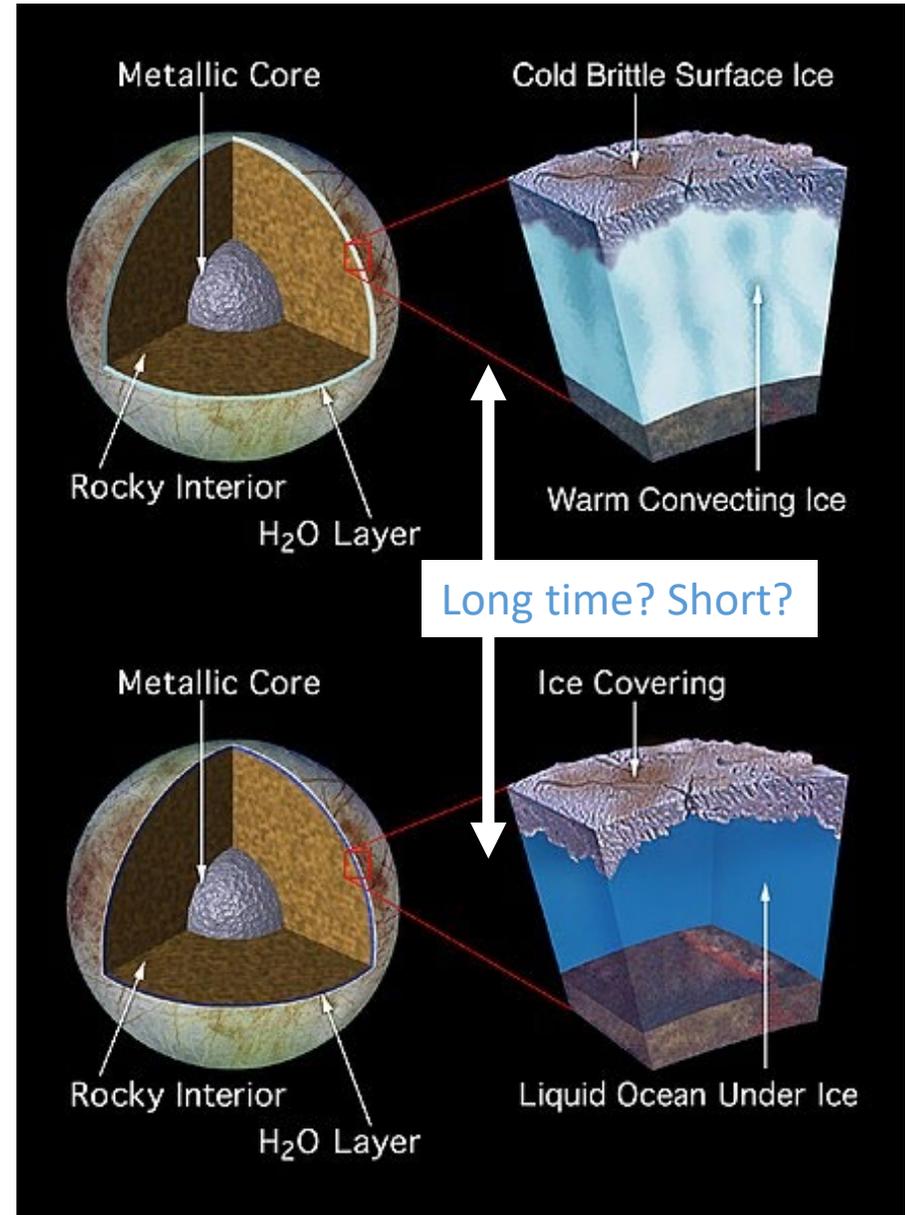
Priority Science Questions and Investigations

- How did Europa and its ocean **form**?
- What can the ice & water at Europa tell us about the **distribution of volatiles** through the solar system?
- How can understanding Europa's formation within the Jupiter system help us **understand exoplanets / exomoons** and formation of solar systems?



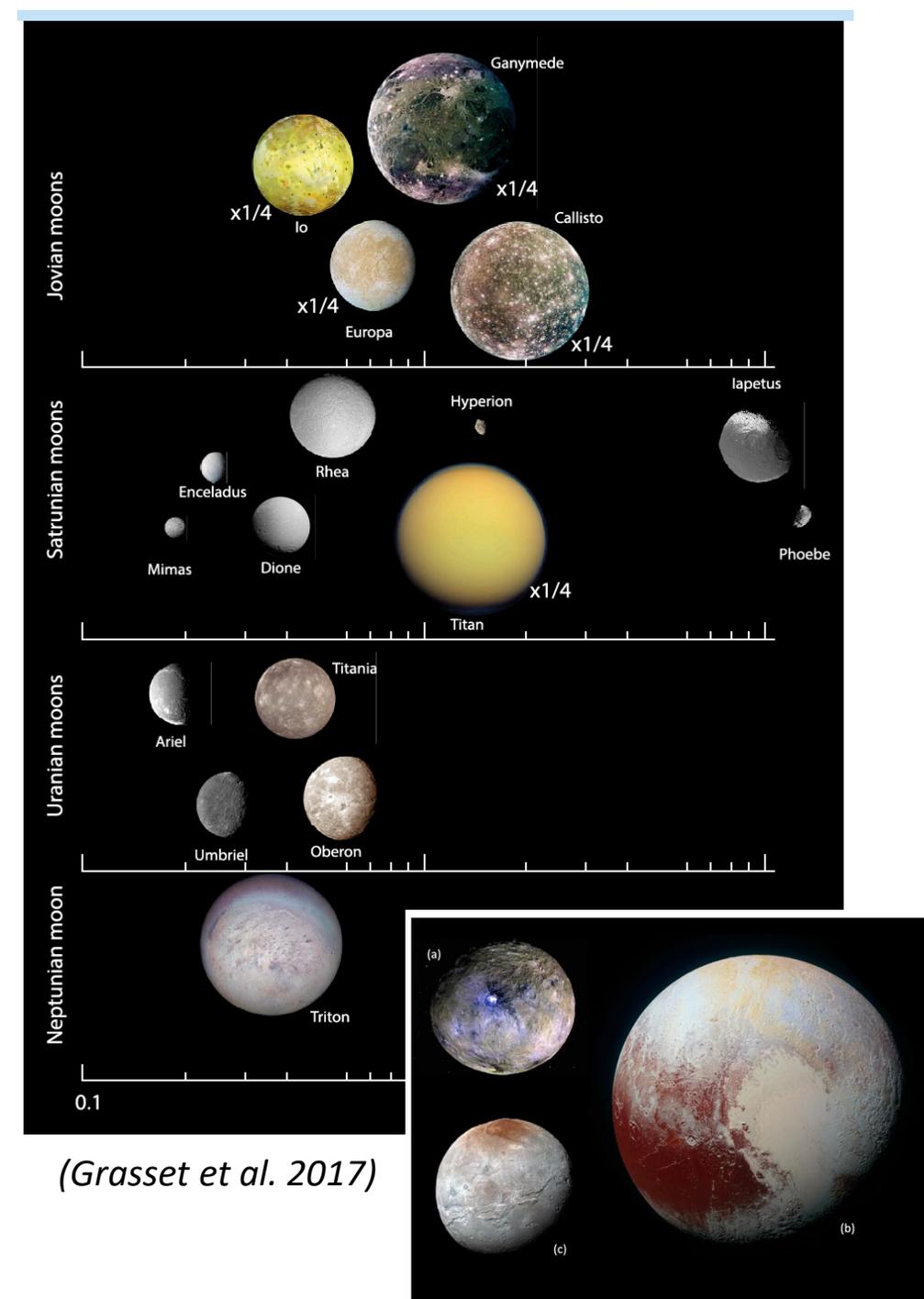
How did Europa and its Ocean Form?

- How does the water get out of the rock to form an ocean? Or is the water exogenic (i.e. from comets)?
- Timelines –When did the ocean world form? When did its ocean form?
 - Is Europa's ocean primordial?
 - How long can an ocean last?
 - Is there episodic thickening / thinning of the ice shell?
- Differentiation – how does the differentiation of volatile-rich silicates work?



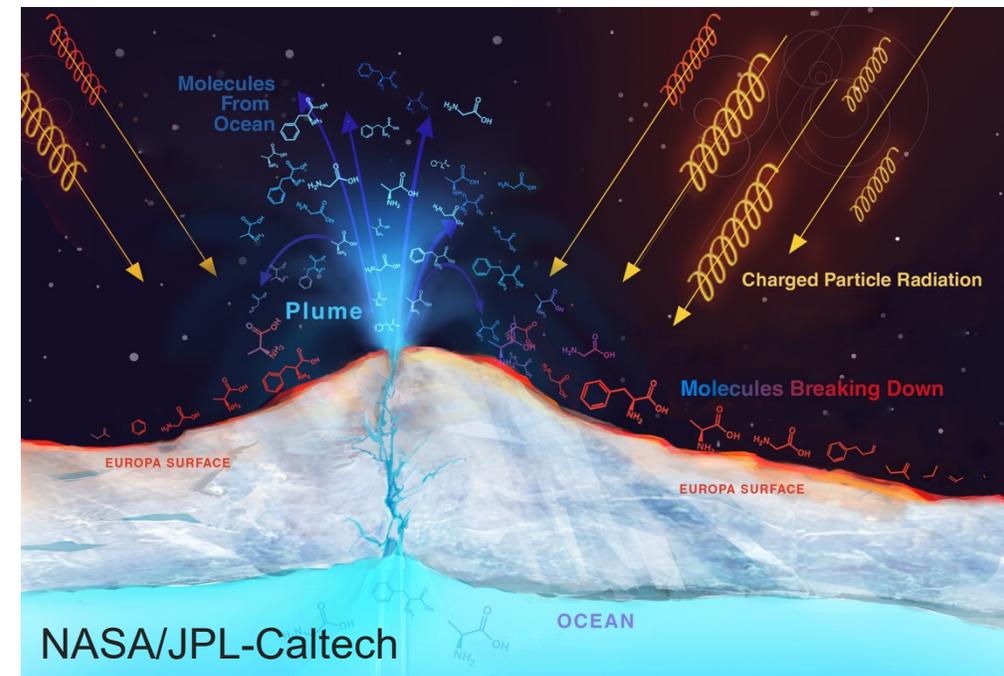
What can Europa tell us about the distribution of volatiles through the solar system?

- Through time: From early solar system to current
- Distribution of ices *geographically*
 - Volatiles found on Mercury -> Pluto, Europa as a data point
- How do cold, irradiated volatiles work?
- Europa is the first volatile-rich body outside the snow / water line
 - How did/does its interaction with Jupiter and other moons enable the retention of volatiles? Was it these interactions?



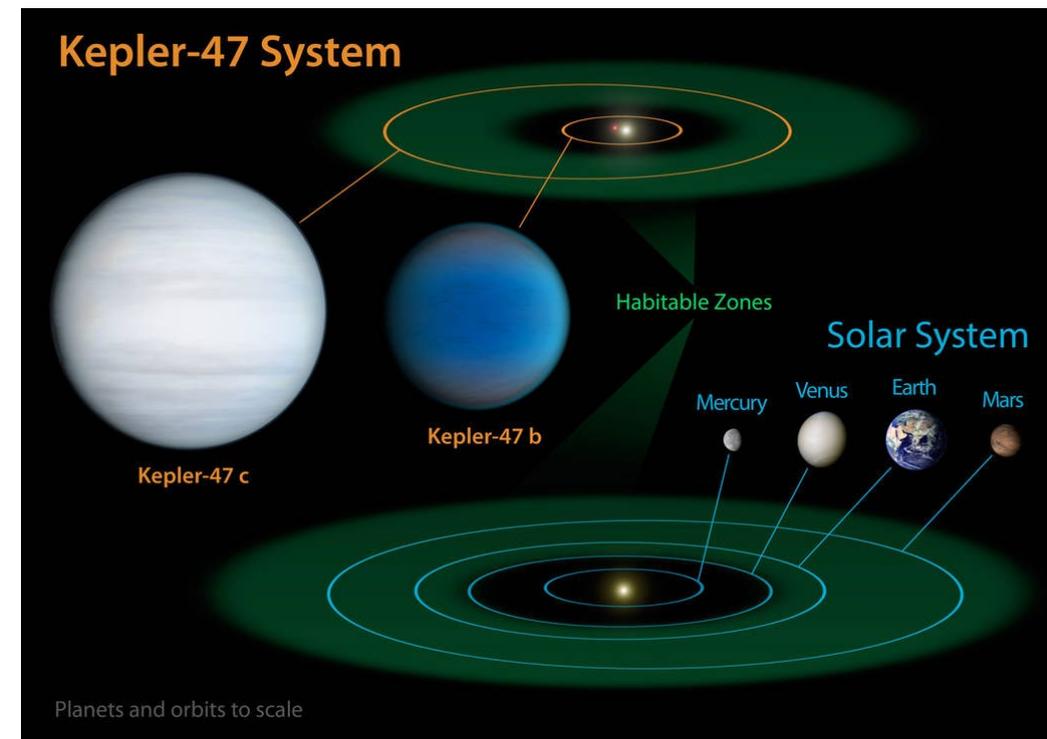
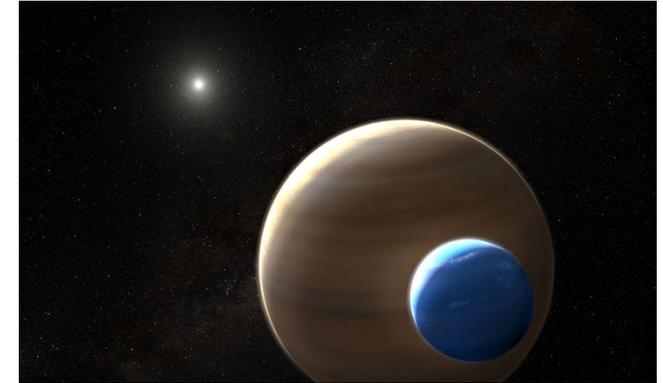
What can Europa tell us about the distribution of volatiles through the solar system?

- Through time: From early solar system to current
- Distribution of ices *geographically*
 - Volatiles found on Mercury -> Pluto, Europa as a data point
- How do cold, irradiated volatiles work?
- Galilean moons are the first volatile-rich bodies outside the snow / water line
 - How does Europa's interaction with Jupiter and other moons enable the retention of volatiles?



How can understanding Europa's formation within the Jupiter system help us understand exoplanets / exomoons and formation of solar systems?

- Understanding "Goldilocks" regions in exo-solar systems.
 - Finding ocean worlds in outer solar system helped us redefine the habitable zone
- Investigating ocean world formation and stability informs our research on exoplanet systems with bodies orbiting:
 - Multiple stars
 - Different star types
 - Gas giants /Ice Giants



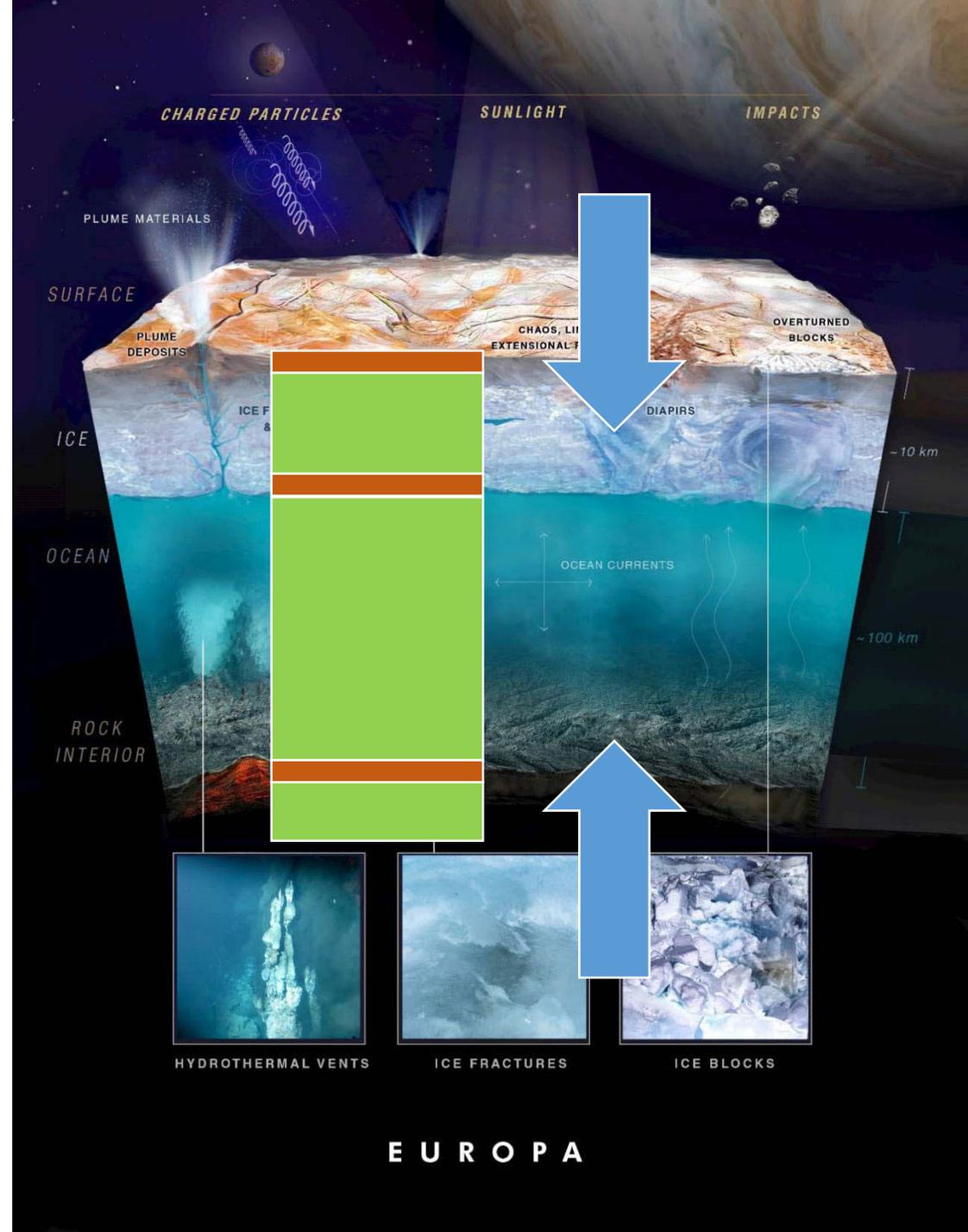
Proposed Key Unifying Theme #2: How do Ocean Worlds **evolve**?

Priority Science Questions and Investigations

What are Europa's key interfaces that permit and regulate thermal, physical, and chemical exchange?

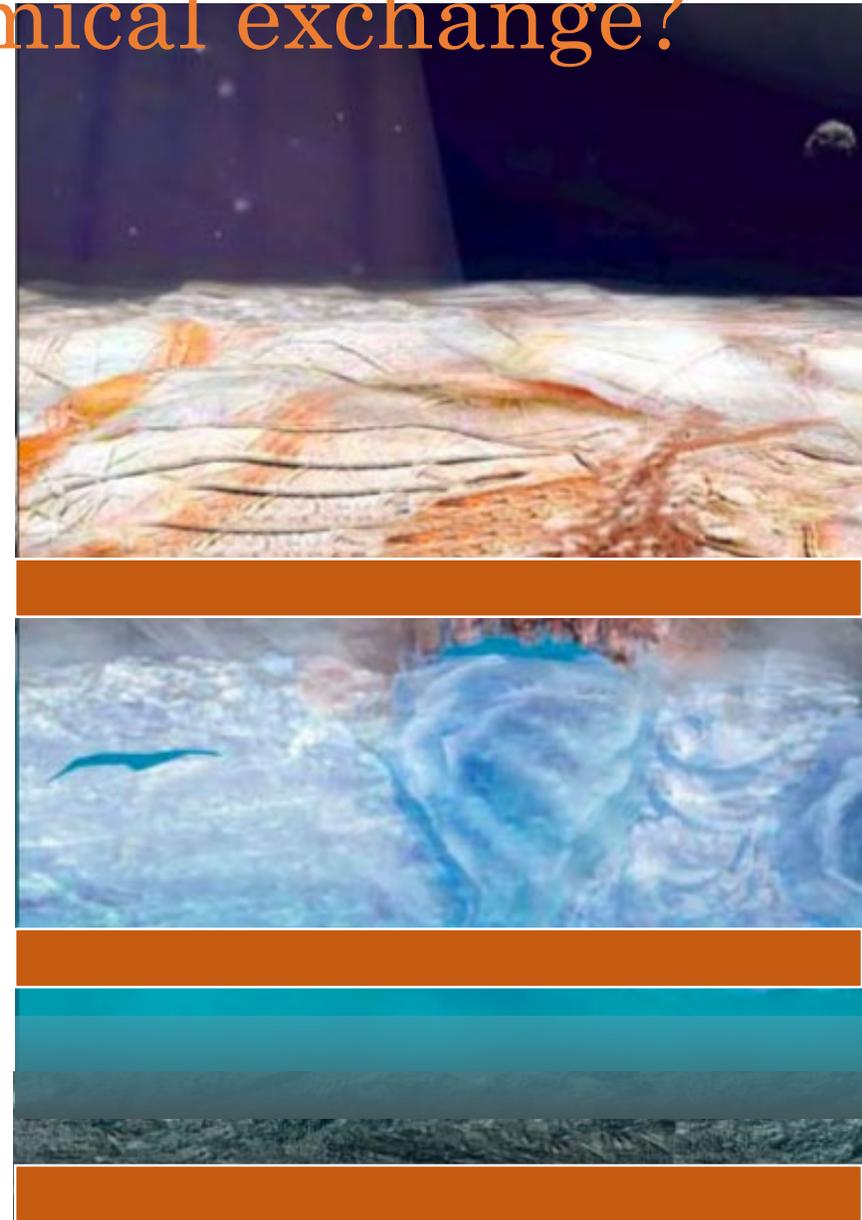
What are the governing processes internal to Europa's key geological layers: the ice shell, the ocean, and the rocky interior?

What are Europa's key sources of energy that power change within these layers?



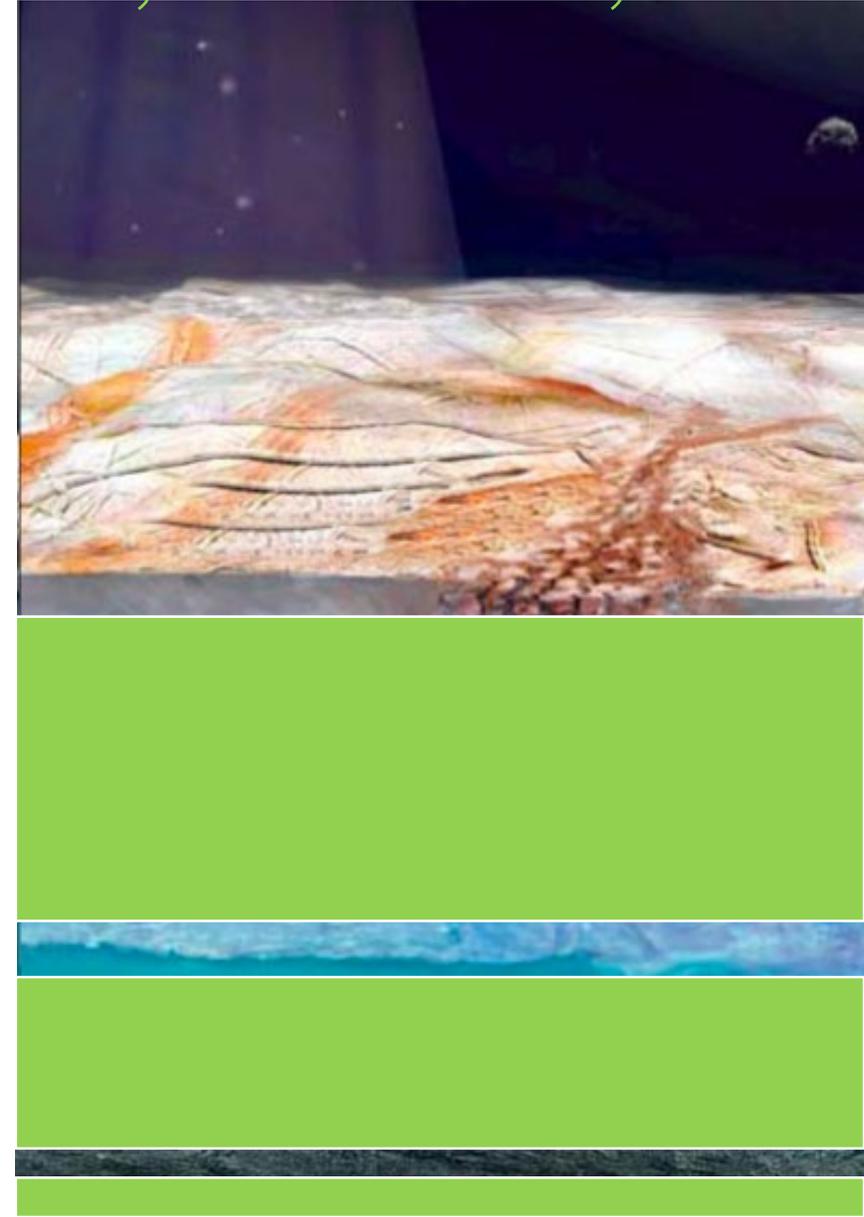
What are Europa's key interfaces that permit and regulate thermal, physical, and chemical exchange?

- How has the production rate and steady state concentration of oxidants on Europa's surface changed through time? What is it today?
- How has the production rate and steady state concentration of reductants on the seafloor/ocean of Europa changed through time?
- What is the REDOX potential at the ice ocean interface and seafloor, and how has this evolved through time?



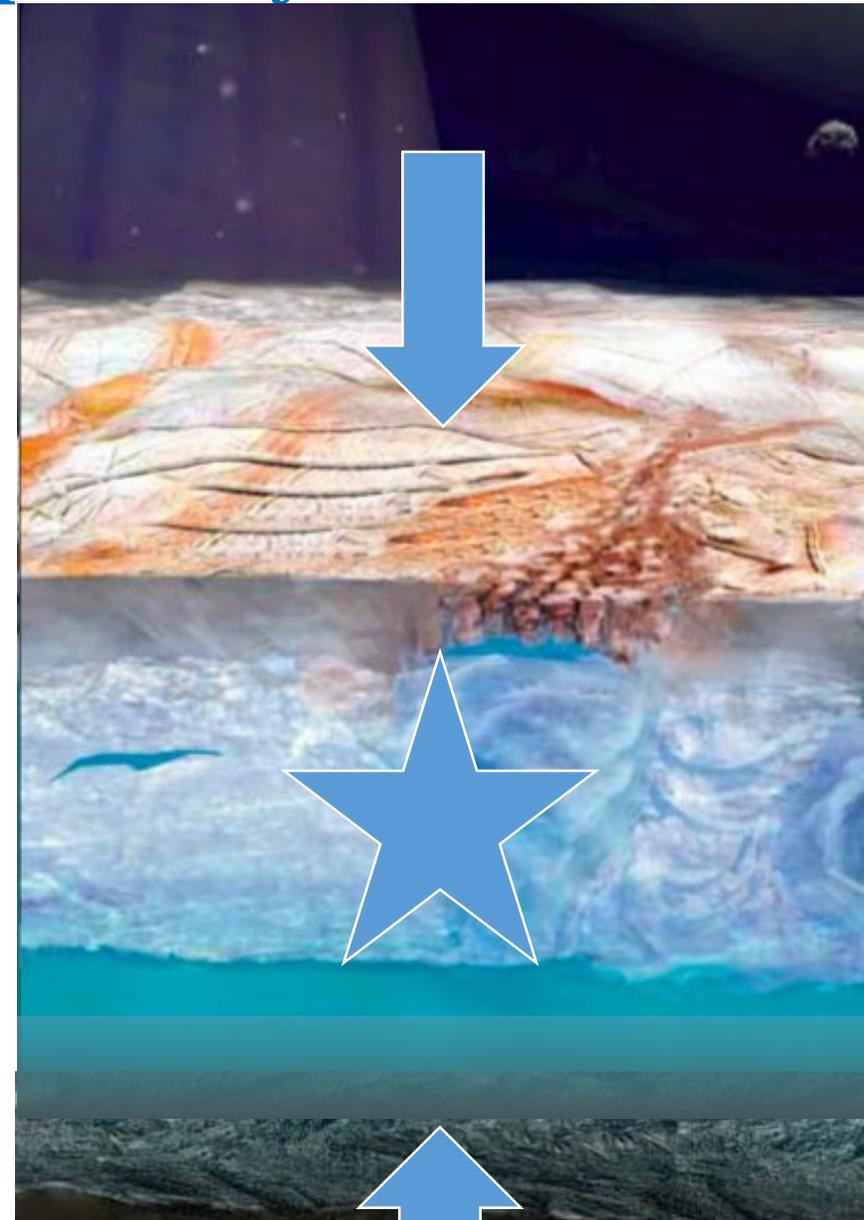
What are the governing processes internal to Europa's geological layers: the ice shell, the ocean, and the rocky interior?

- How have the thickness of the ice shell, the geodynamic state, and the strength of the icy lithosphere evolved through time?
- What is the circulation pattern and timescale of the ocean, and where and when might heterogeneities have been maintained?
- When was the silicate interior geophysically / volcanically active, and could activity persist today?



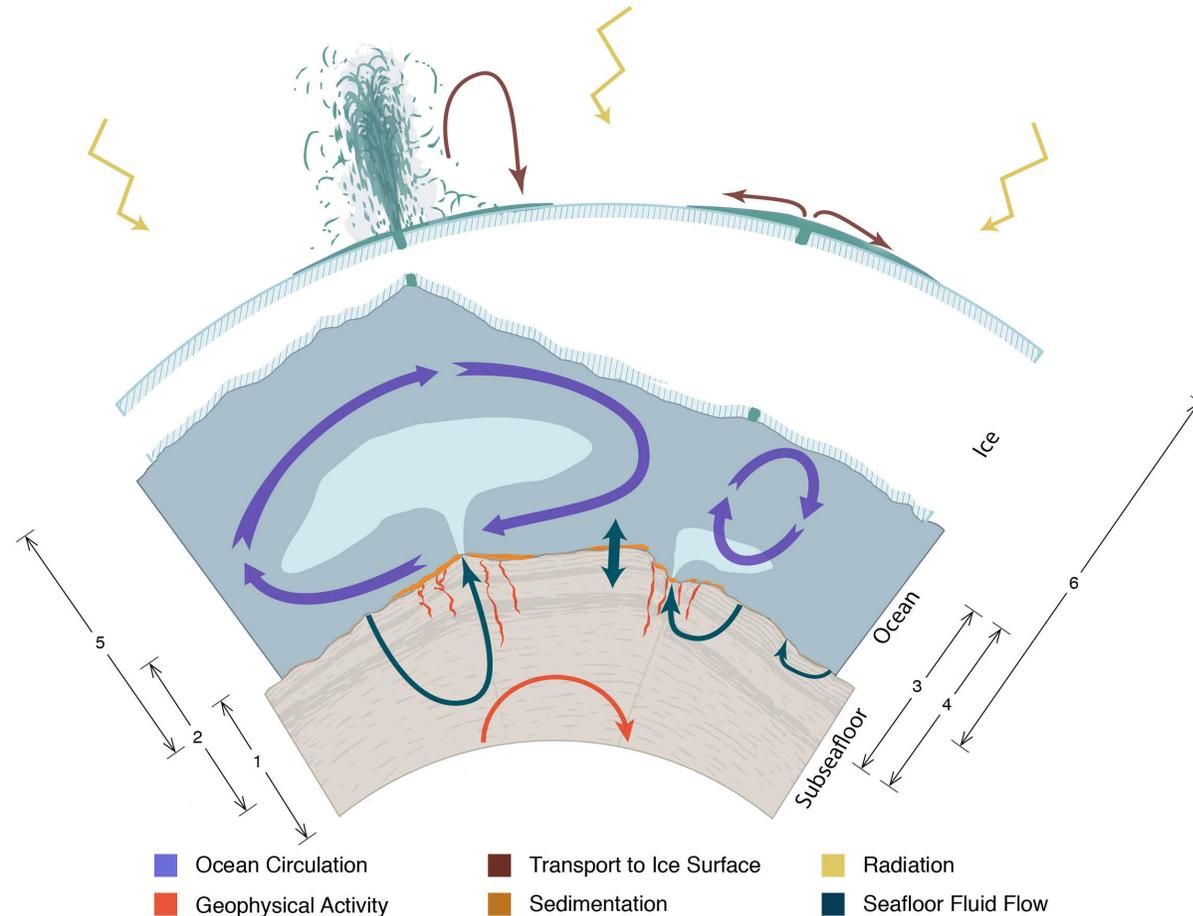
What are the key sources of energy that power change within Europa's solid and liquid layers?

- How has Europa's orbital forcing evolved through time, and how is orbital energy dissipated in the ice shell?
- What heat budget is available from the silicate interior?
- How does the ocean contribute to the heat budget, and what role does it play in heat exchange?



Theme #3:

What Controls the *Habitability* of Ocean Worlds (e.g. Europa)? Are they *inhabited*?



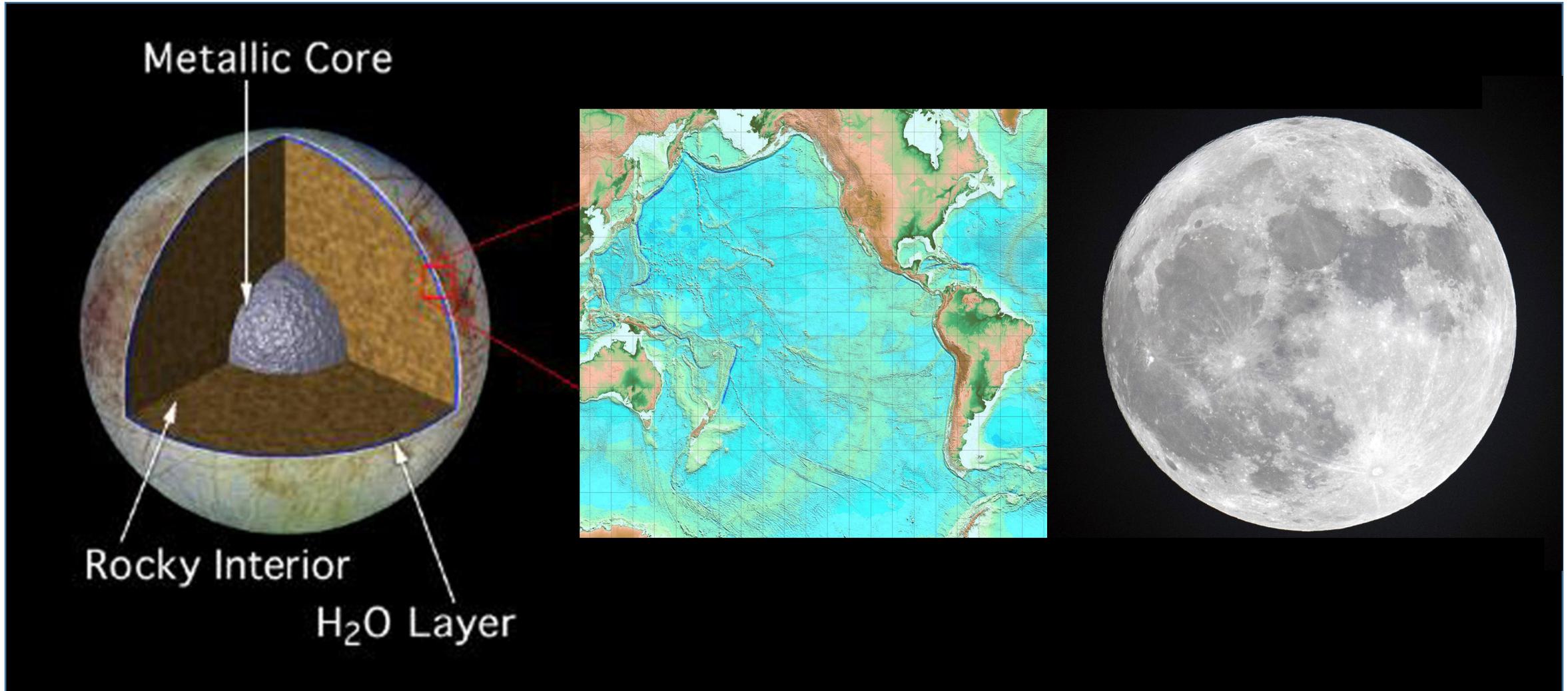
Mantra: Physics begets Chemistry; Chemistry begets *possibility* for Life

Proposed Key Unifying Theme #3: What Controls the *Habitability* of Europa?

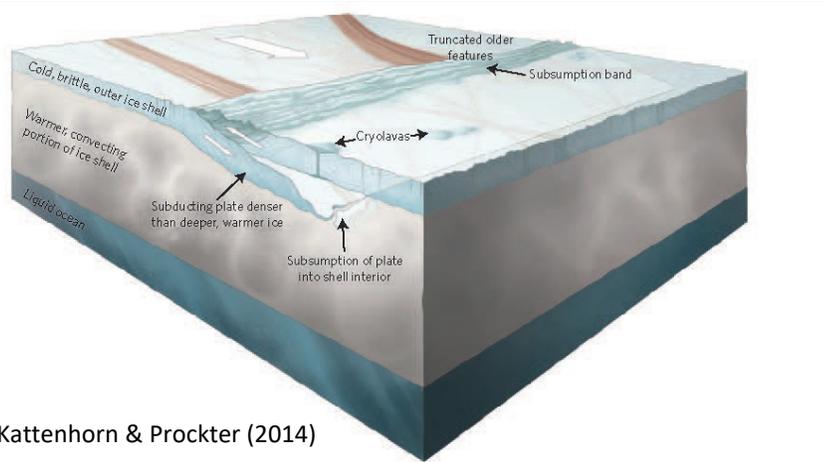
Priority Science Questions and Investigations that address Theme #3:

- #3.1 What are the geophysical and geochemical processes that need to have been active within the interior to render it habitable, energetically?
- #3.2 Where might the key locales be where energetic “oases” for chemosynthetic life could exist?
- #3.3 How might the functioning of Europa’s circulation systems contribute to the redistribution of life signatures and other diagnostic tracers?

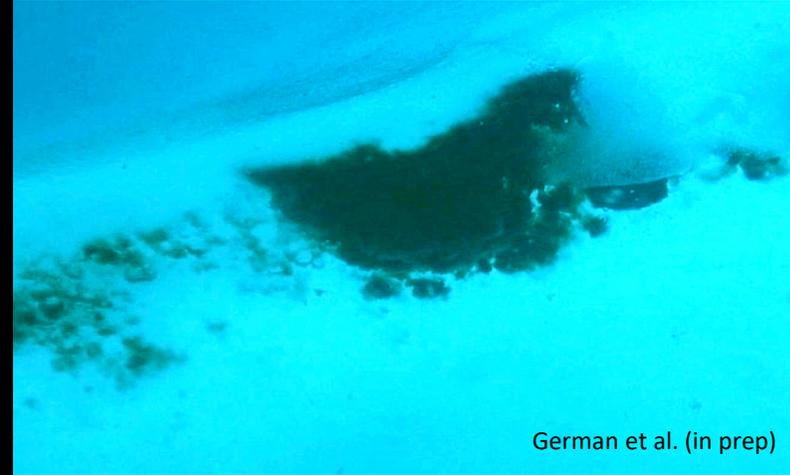
#3.1 What are the geophysical and geochemical processes that need to have been active within the interior of an ocean world like Europa to render it habitable, energetically?



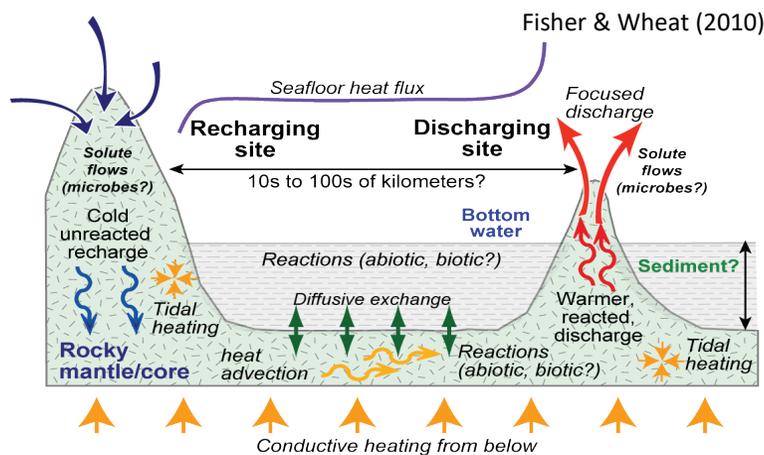
#3.2 Where might the key locales be where energetic “oases” for chemosynthetic life could exist?



Kattenhorn & Prockter (2014)



German et al. (in prep)

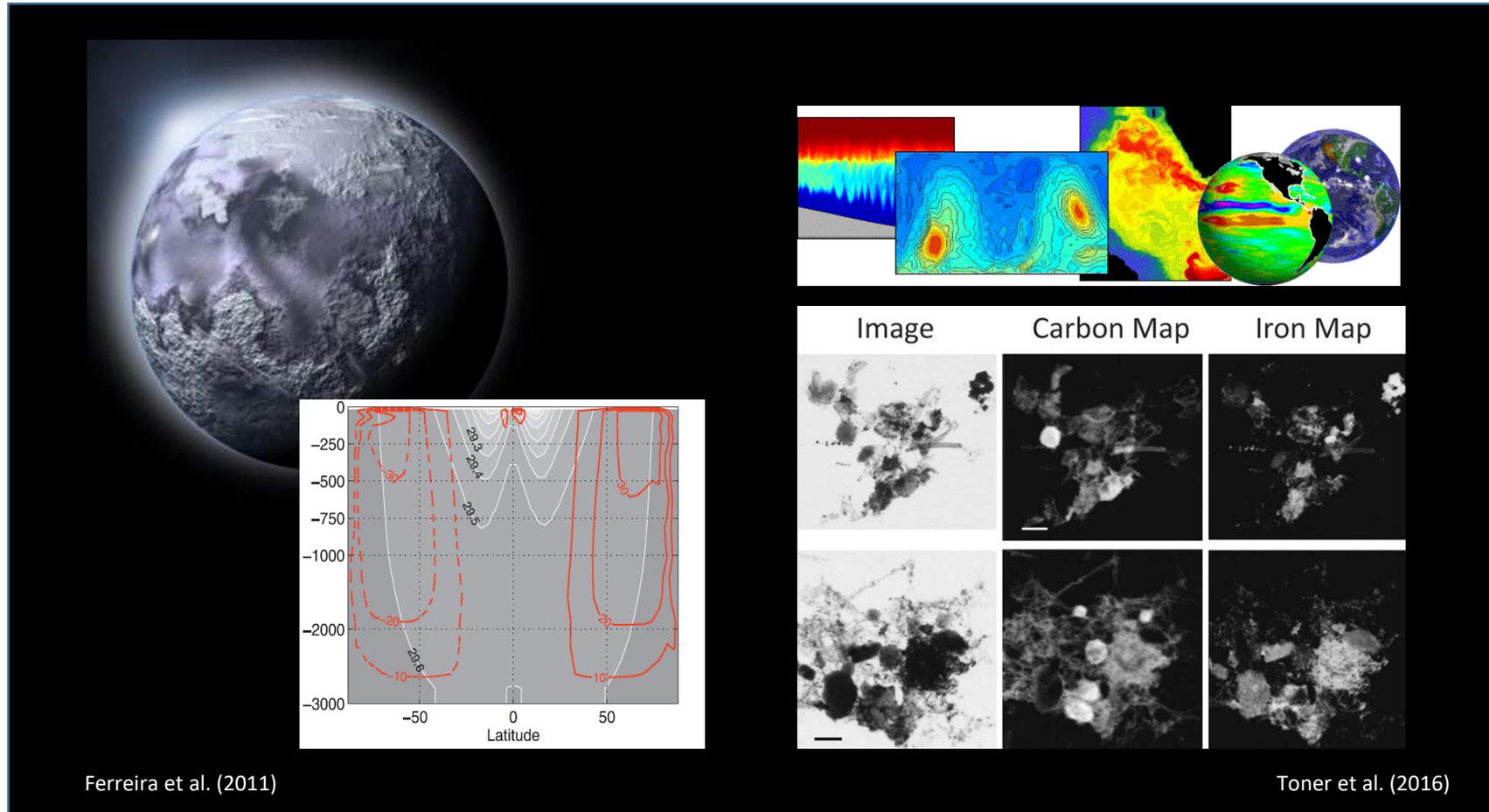


Fisher & Wheat (2010)



McDermott et al. (2018)

#3.3 How might the functioning of Europa's circulation systems contribute to the redistribution of life signatures and other diagnostic tracers?



Our Unifying Science Themes for Europa:

The **Formation**, **Evolution**, and **Habitability** of Ocean Worlds in our Solar System and Beyond

1. How do ocean worlds form?
2. How do ocean worlds evolve?
3. What controls the habitability of ocean worlds? Are they inhabited?

Europa Synthesis: Science Themes & Investigations

- **How do ocean worlds form?**
 - How did Europa and its ocean form?
 - What can the ice & water at Europa tell us about the distribution of volatiles through the solar system?
 - How can understanding Europa's formation within the Jupiter system help us understand exoplanets / exomoons and formation of solar systems?
- **How do ocean worlds evolve?**
 - What are Europa's key interfaces that permit and regulate thermal, physical, and chemical exchange?
 - What are the governing processes internal to Europa's key geological layers: the ice shell, the ocean, and the rocky interior?
 - What are Europa's key sources of energy that power change within these layers?
- **What controls the habitability of ocean worlds? Are they inhabited?**
 - What are the geophysical and geochemical processes that need to have been active within the interior to render it habitable, energetically?
 - Where might the key locales be where energetic "oases" for chemosynthetic life could exist?
 - How might the functioning of Europa's circulation systems contribute to the redistribution of life signatures and other diagnostic tracers?

Europa: Implementation plan

- **Integrated strategy** to address key cross-cutting themes, priority questions, and investigations for Europa
- 5 Methods
 - **Remote sensing** mission
 - **Surface** mission
 - **Subsurface** mission
 - **Laboratory** work
 - Theoretical **models**
- **Matrix** of which investigations are addressed by which methods
- Summary: **Systematic Europa Exploration Strategy**

Systematic Europa Exploration Strategy

- **Remote sensing: Europa Clipper**
 - Science Goal: Explore Europa to Investigate its Habitability
 - Remote sensing PLUS in situ observations
 - Reconnaissance: **Feed forward** to a future lander
- **Surface: Europa lander**
 - **Ground Truth** for remote sensing from previous missions
 - Science Goals:
 - Characterize the surface and subsurface.
 - Assess the habitability and potential for life
 - **Feed forward** to future subsurface exploration
- **Subsurface: Ice and ocean access probes**
 - Science Goals:
 - Characterize ice shell and ocean
 - Search for life
 - **Feed forward** to other ocean worlds

