GEO 325M Spring 2022

Class project: Two-phase convection in Europa's ice shell

Europa!

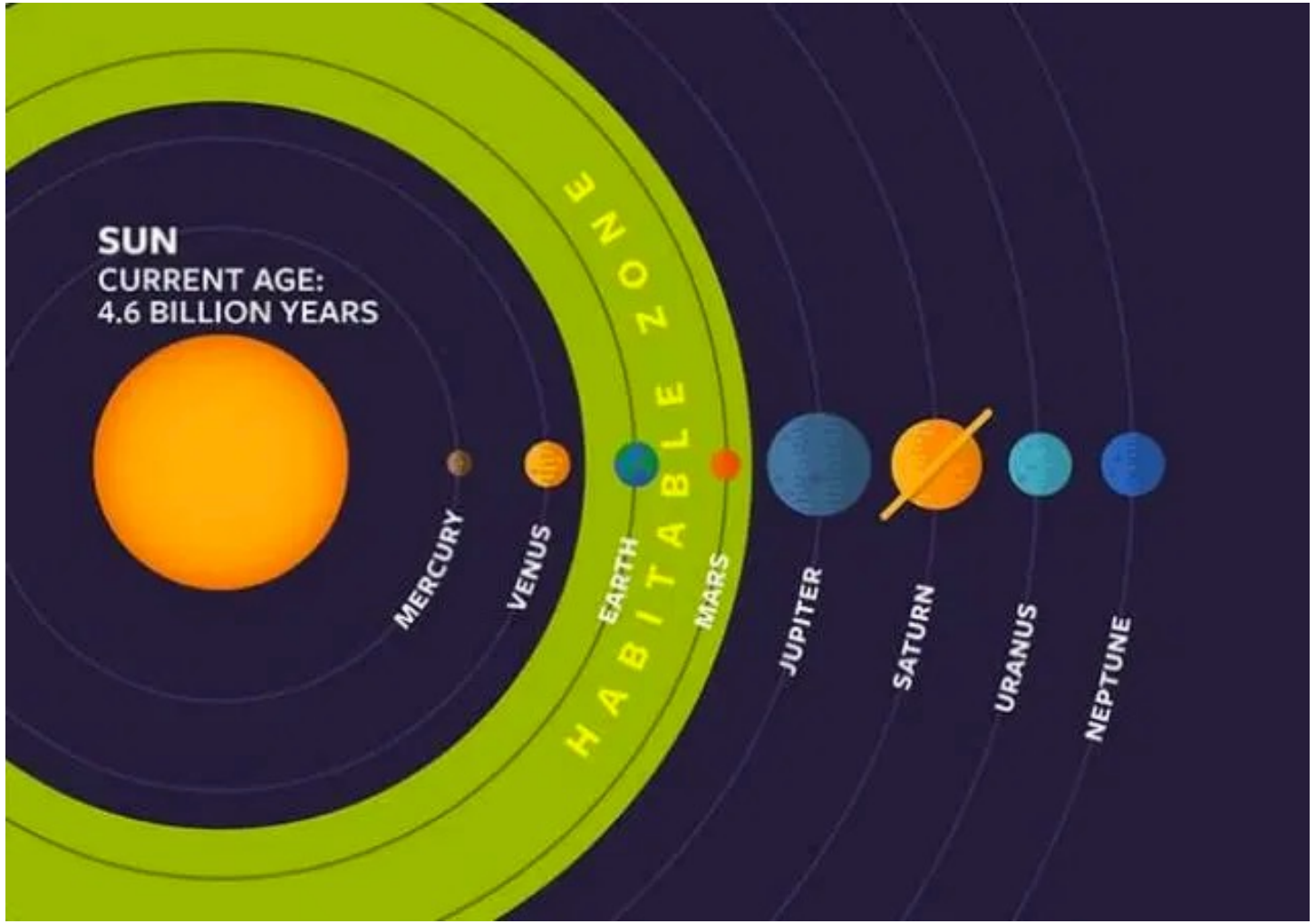
Wrong one (continent on Earth)

Correct one (moon of Jupiter)

Habitable zone

Sounds good, but is largely BS

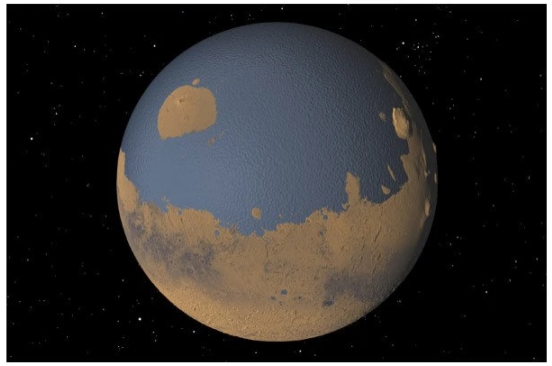
Habitable Zone (surface water)



Follow the water

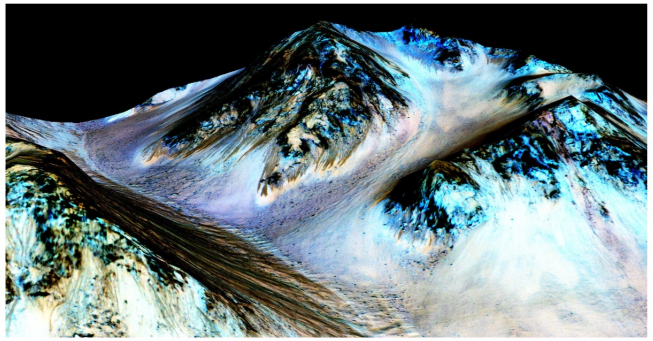
The New York Times

Ancient Mars Had an Ocean, Scientists Say

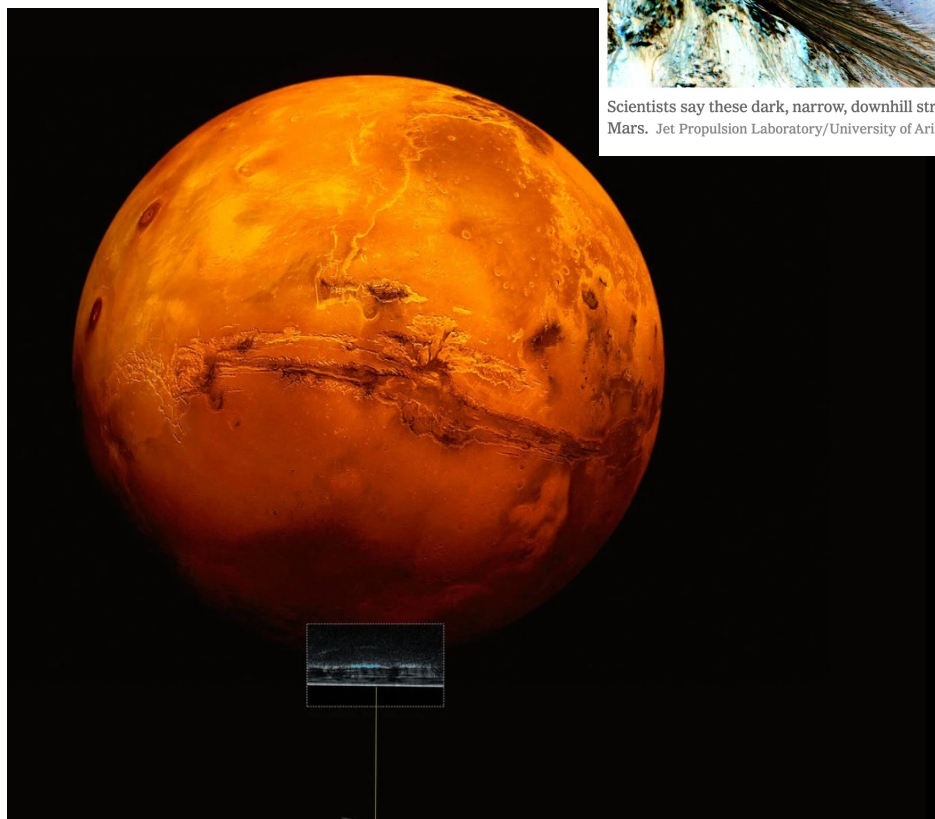


The New York Times

Mars Shows Signs of Having Flowing Water, Possible Niches for Life, NASA Says



Scientists say these dark, narrow, downhill streaks are evidence of flowing water on Mars. Jet Propulsion Laboratory/University of Arizona, via NASA



The New York Times Account

A Large Body of Water on Mars Is Detected, Raising the Potential for Alien Life

The discovery suggests that the liquid conditions beneath the icy southern polar cap may have provided one of the critical building blocks for life on the red planet.

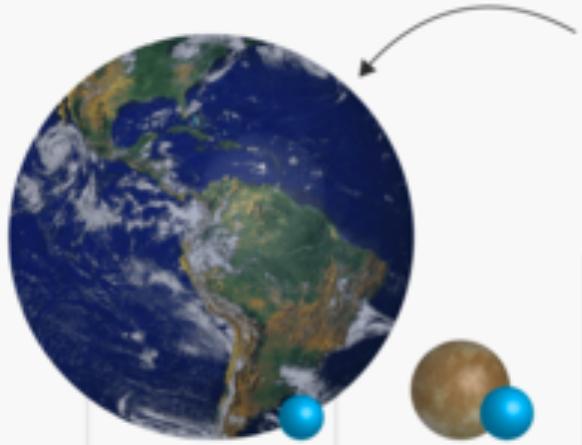
… but Mars is a pretty dusty place.

Introduction to Icy Ocean Worlds

Icy moons in the outer solar system

What if the water is not on the surface?

HOW THE SOLAR SYSTEM'S LARGEST OCEAN WORLDS COMPARE IN SIZE



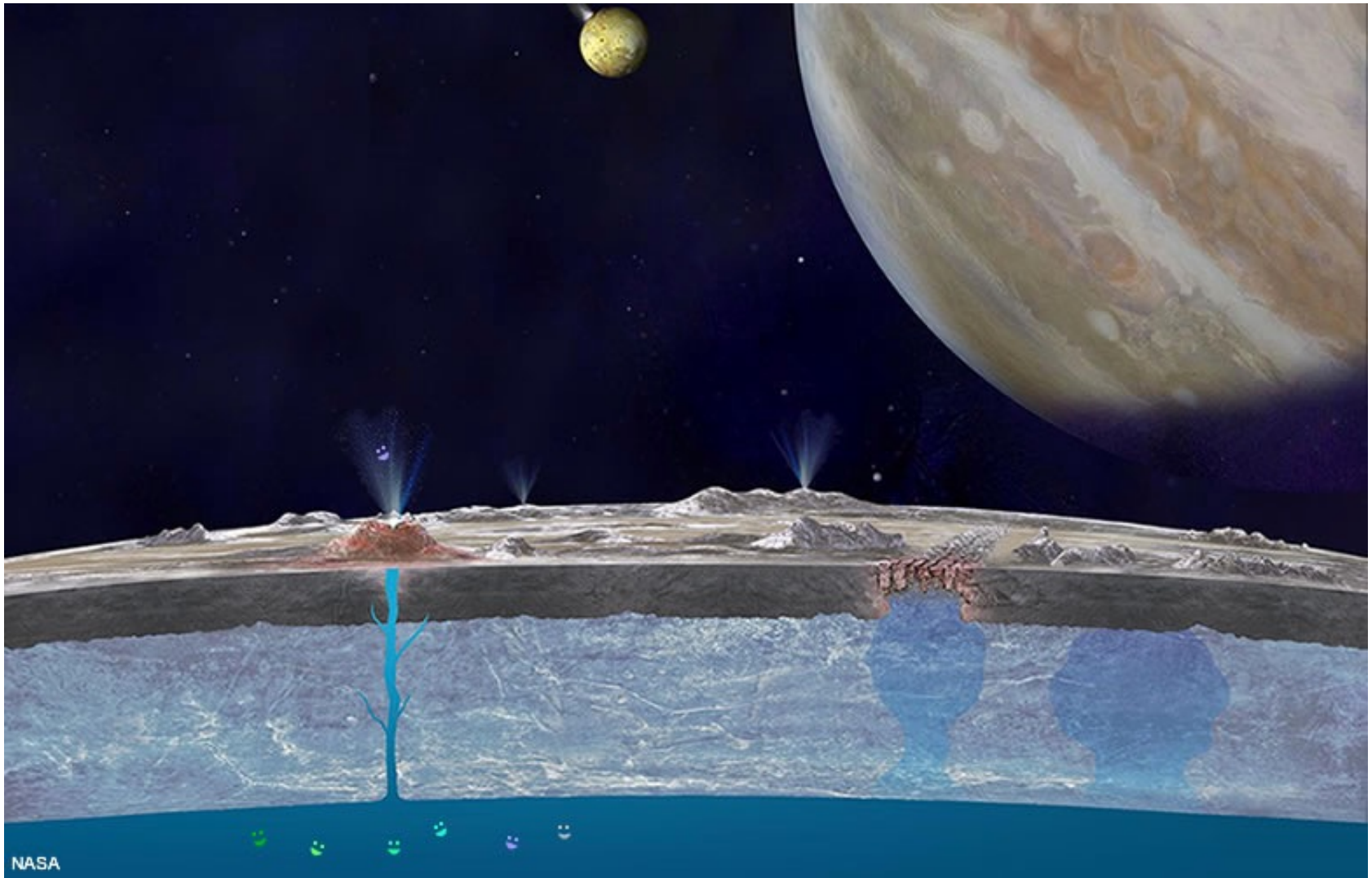
Earth has a surprisingly small amont of water compared to other worlds in the Solar System. Each measurement is the spherical radius of the world and its water (including ice):

ENCELADUS	DIONE	EARTH	EUROPA	PLUTO	TRITON	CALLISTO	TITAN	GANYMEDE
Water radius: 140 mi./ 220 km.	Water radius: 300 mi./ 480 km.	Water radius: 430 mi./ 690 km.	Water radius: 550 mi./ 880 km.	Water radius: 630 mi./ 1010 km.	Water radius: 730 mi./ 1170 km.	Water radius: 1,120 mi./ 1,800 km.	Water radius: 1,180 mi./ 1,890 km.	Water radius: 1,460 mi./ 2,350 km.
World radius: 157 mi./ 252 km.	World radius: 349 mi./ 561 km.	World radius: 3,959 mi./ 6,371 km.	World radius: 972 mi./ 1,565 km.	World radius: 738 mi./ 1,187 km.	World radius: 840 mi./ 1,352 km.	World radius: 1,498 mi./ 2,410 km.	World radius: 1,601 mi./ 2,576 km.	World radius: 1,635 mi./ 2,631 km.

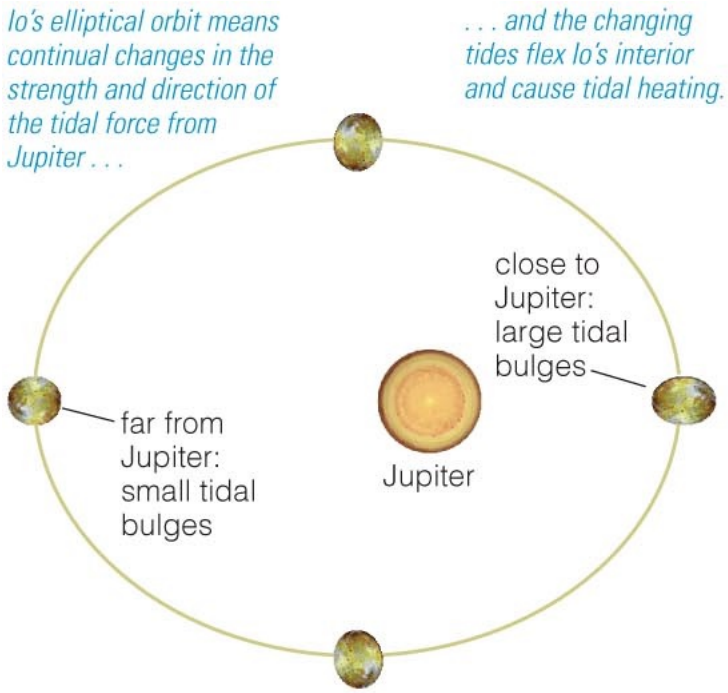
SOURCE: Steve Vance; NASA/JPL-Caltech

BUSINESS INSIDER

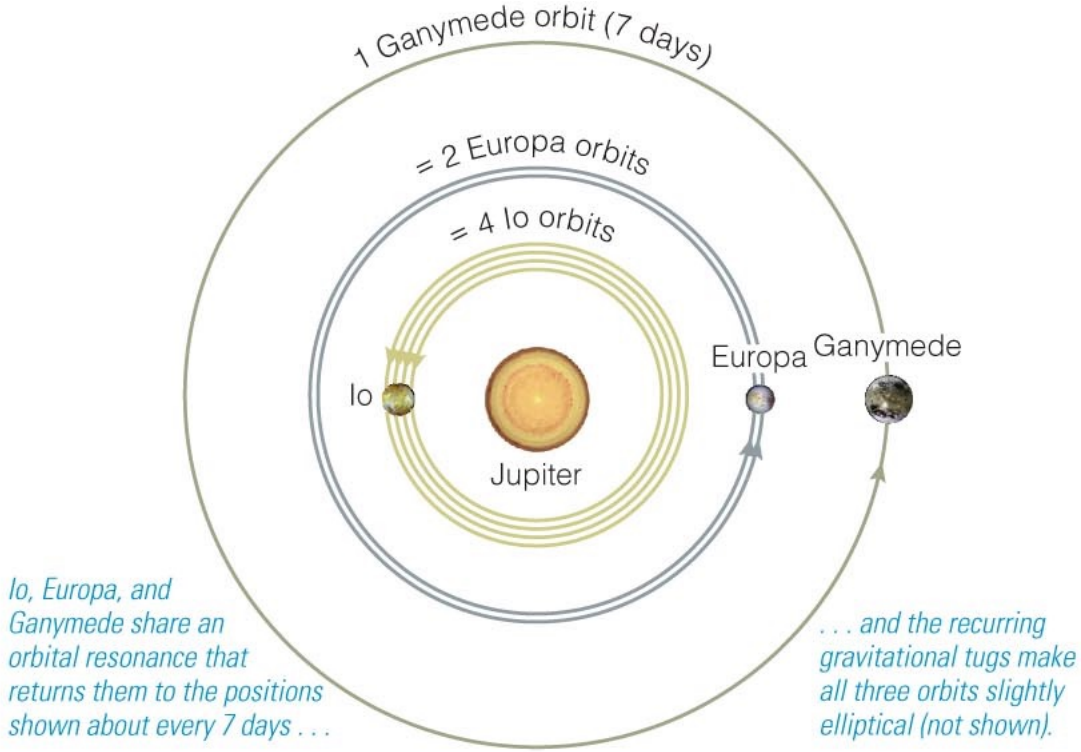
These are (thought to be) internal oceans!



Tidal heating of moons



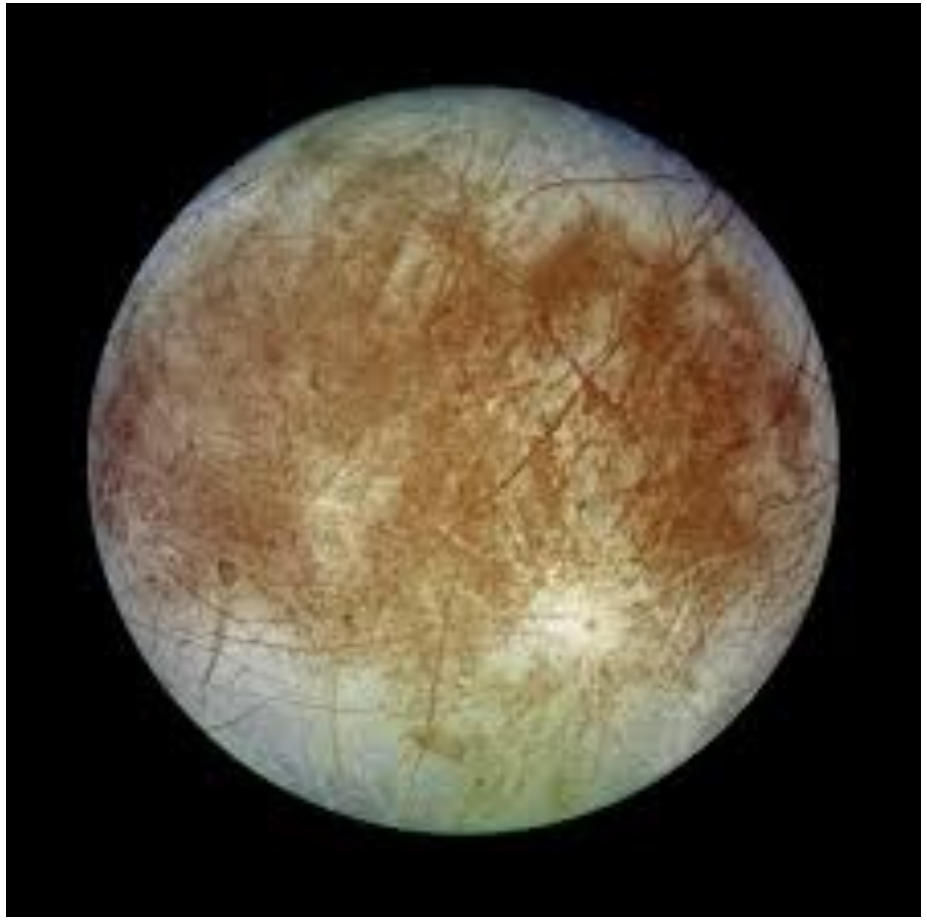
a Tidal heating arises because Io's elliptical orbit (exaggerated in this diagram) causes varying tides.



b Io's orbit is elliptical because of the orbital resonance it shares with Europa and Ganymede.

How do we know there is water?

Europa (Moon of Jupiter)

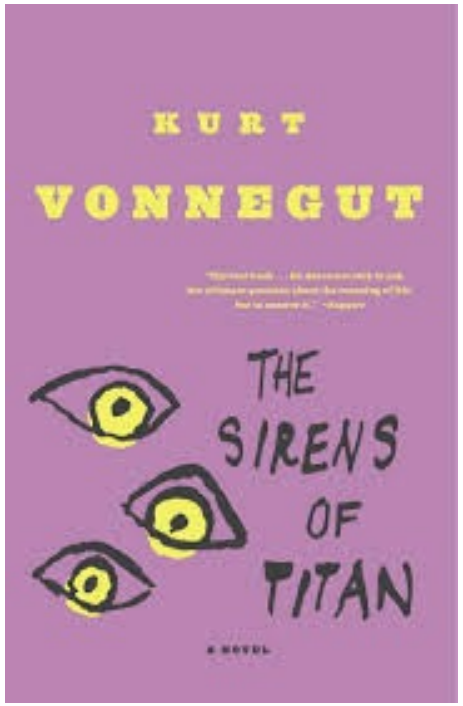


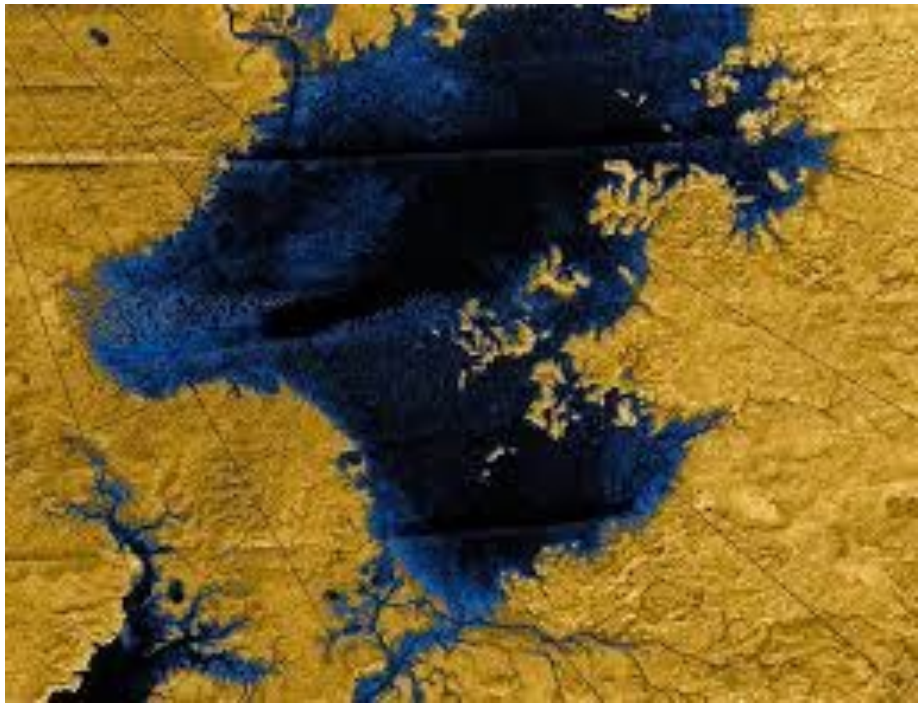
Three upcoming space missions!

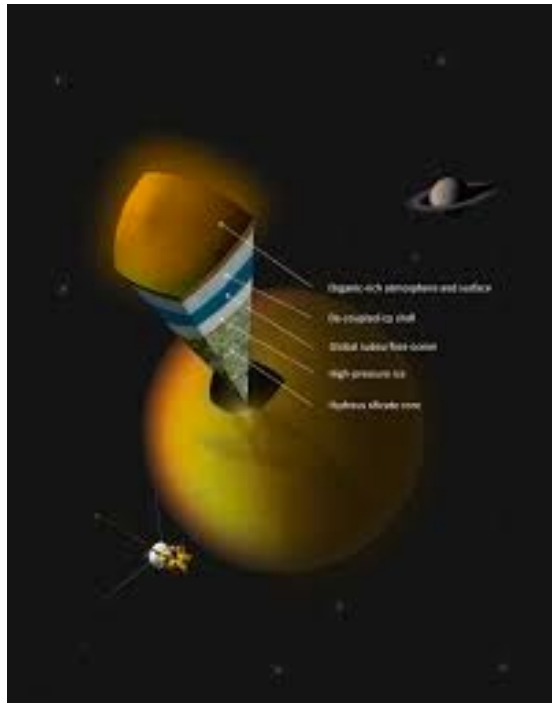
1. Europa Clipper (NASA - JPL): Europa
   https://www.jpl.nasa.gov/missions/europa-clipper/
   Launch: 2022, Arrival:
2. JUICE - Jupiter Icy Moons Explorer (ESA): Callisto and Ganymede
   https://sci.esa.int/web/juice
   Launch: 2022, Arrival: 2030
3. Dragonfly (NASA-APL): Titan
   https://dragonfly.jhuapl.edu/
   Launch: 2026, Arrival: 2034

$\Rightarrow$ Exciting area to get involved in now.

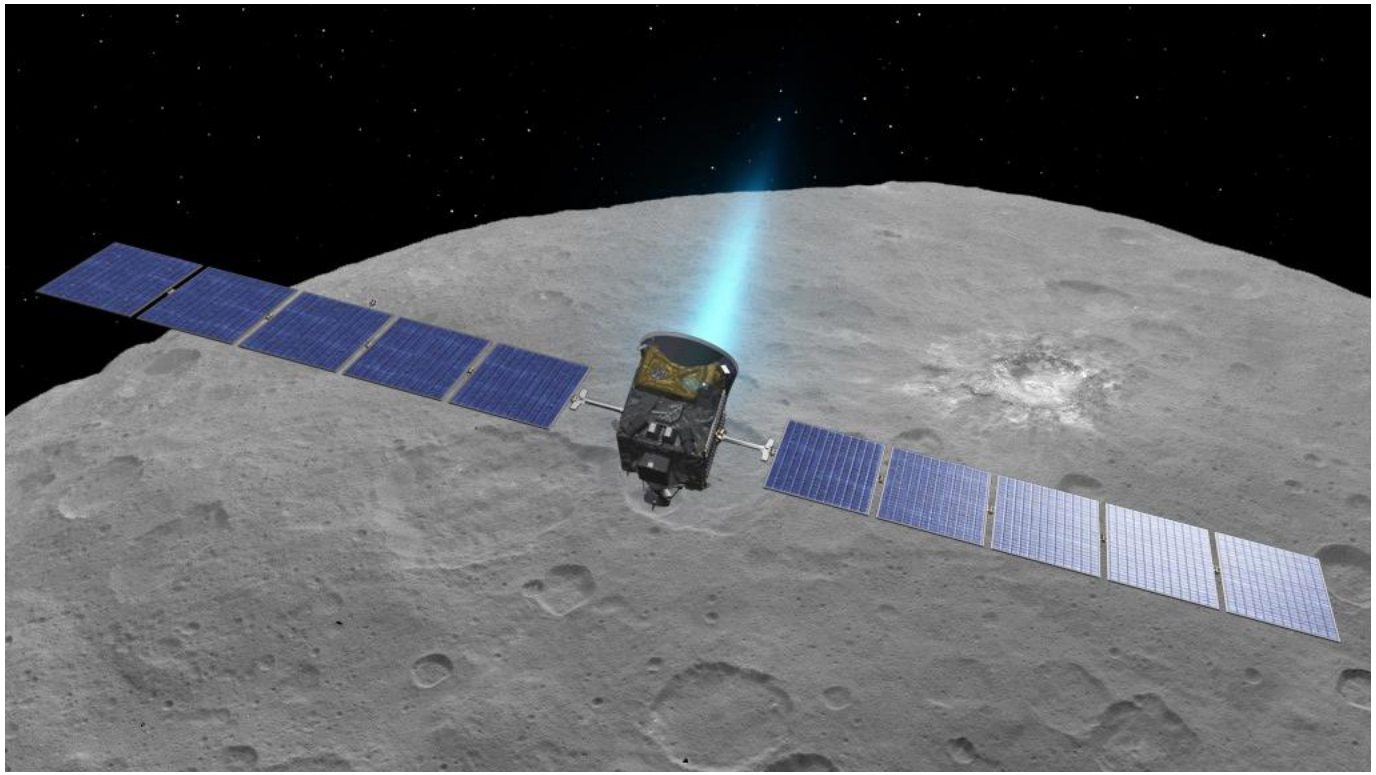
Titan







Just competed Dawn mission

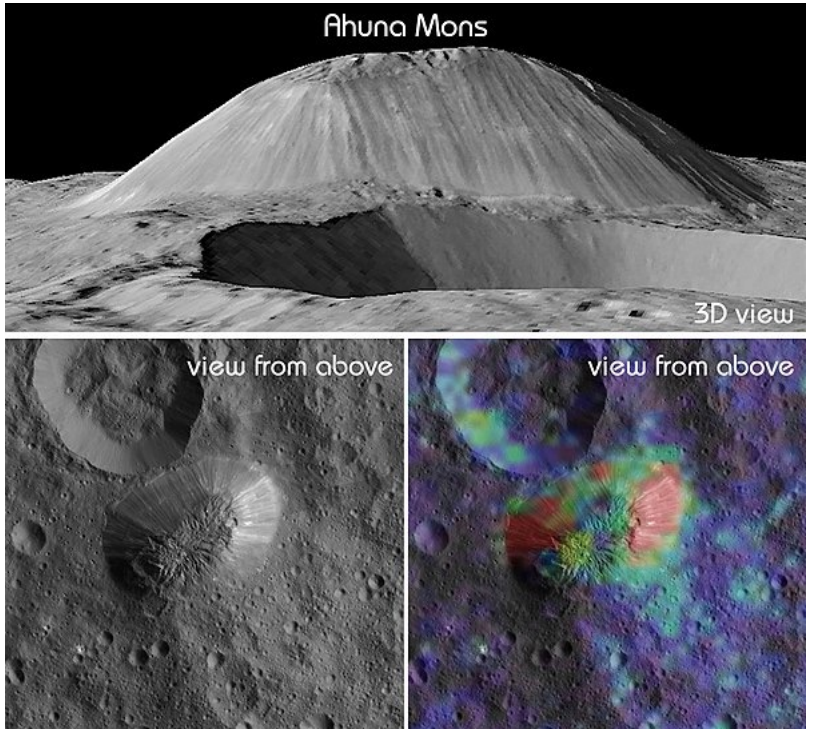


Ceres and Ancient Ocean World from the dawn of time?

Geologically recent activity!

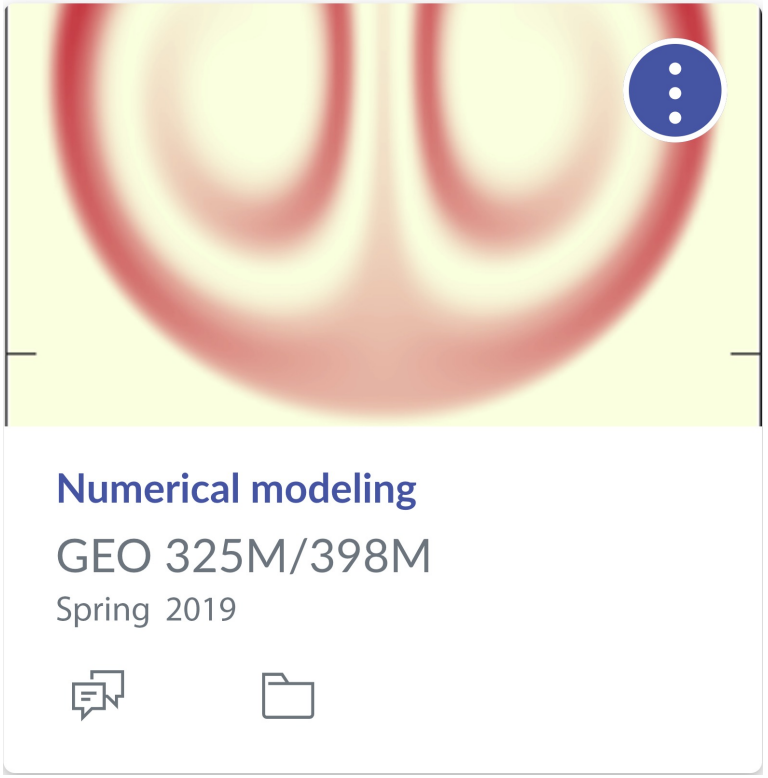
Occator crater

Ahuna mons



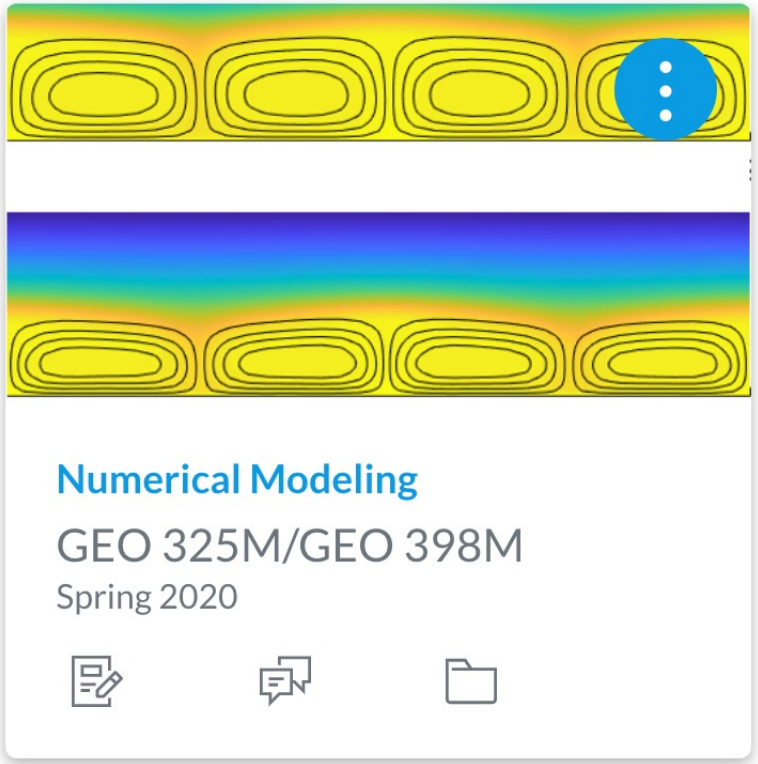
Results from the two past Europa projects

2019 – Melt Migration in stationary ice



Hesse et al. (2022) GRL in review

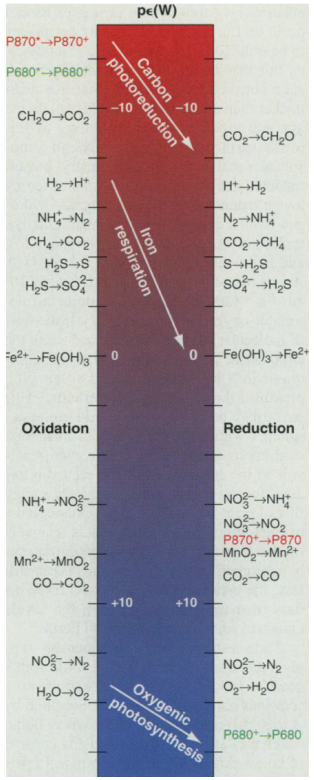
2020 – Ice shell convection



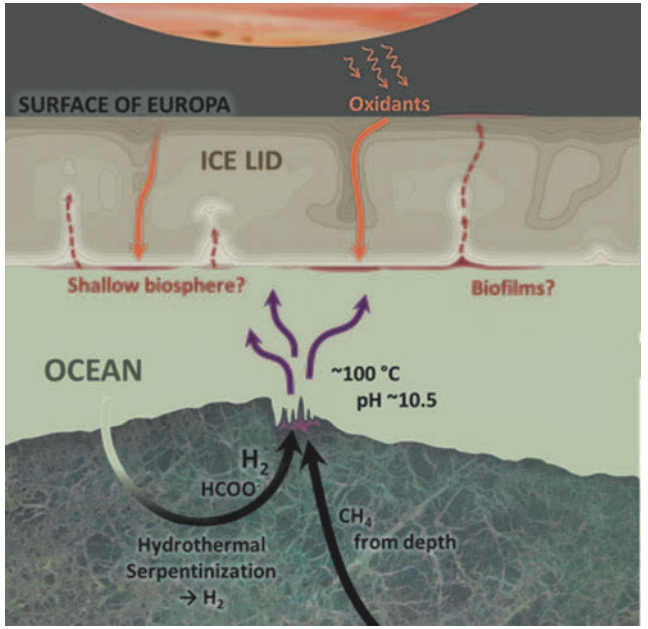
Carnahan et al. (2022) EPSL

Oxidant for Europa's ocean

Life exploits redox gradients

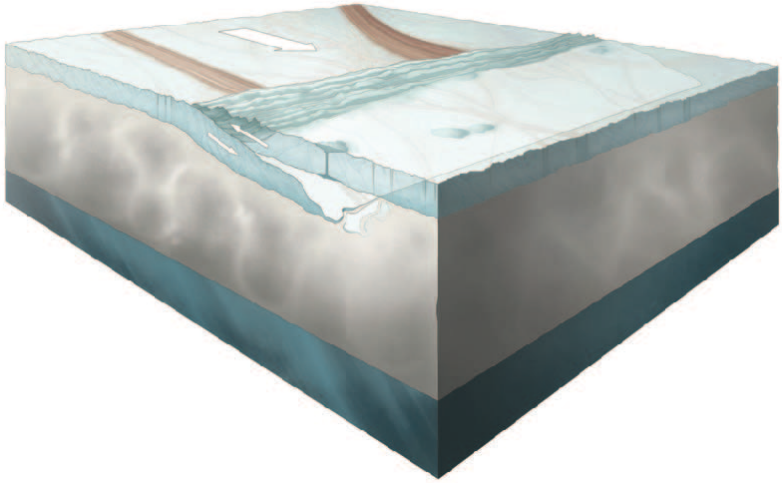


Oxidants from on the surface

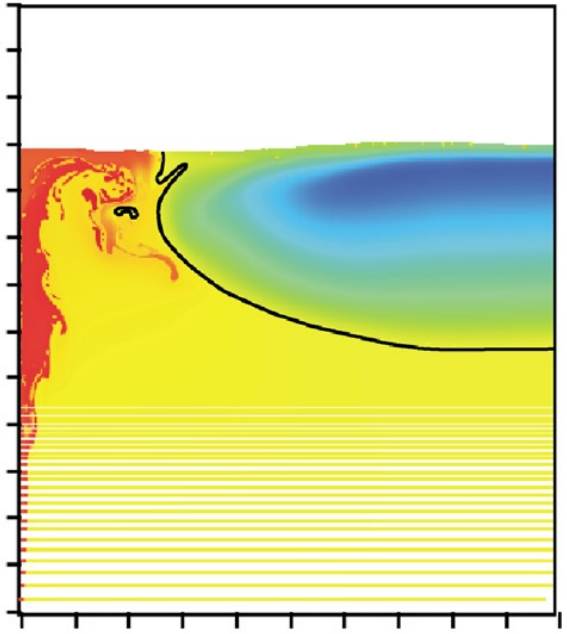


Transport processes

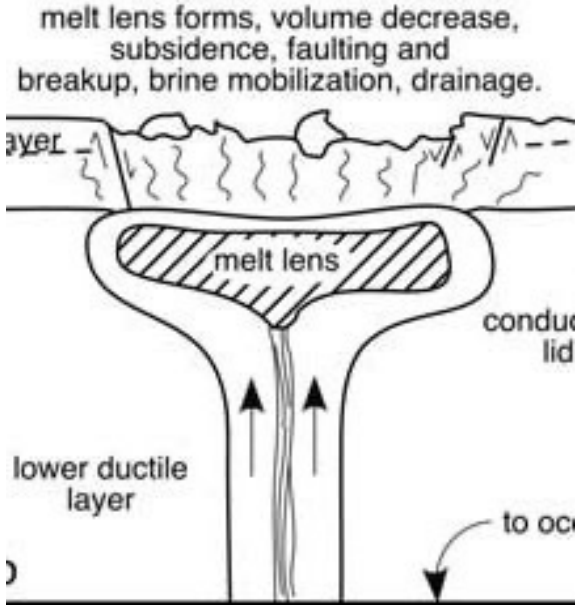
Subduction



Impact breaching

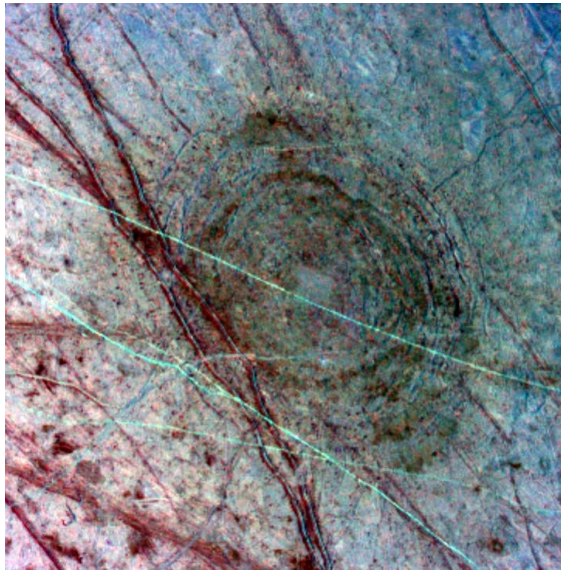


Melt drainage



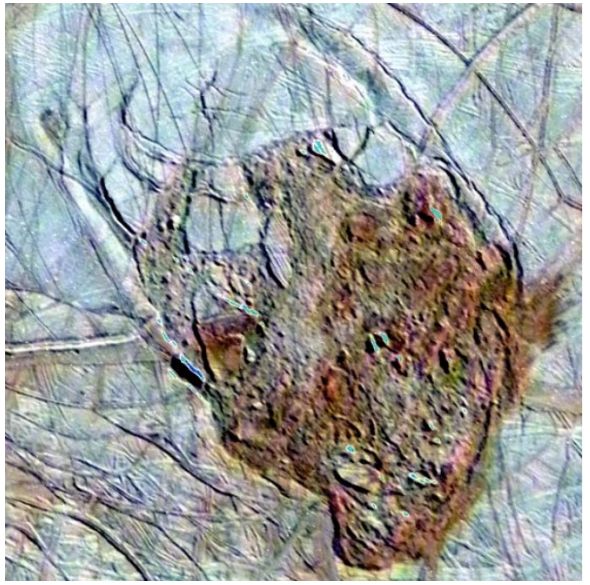
Evidence for near surface melting

Impacts

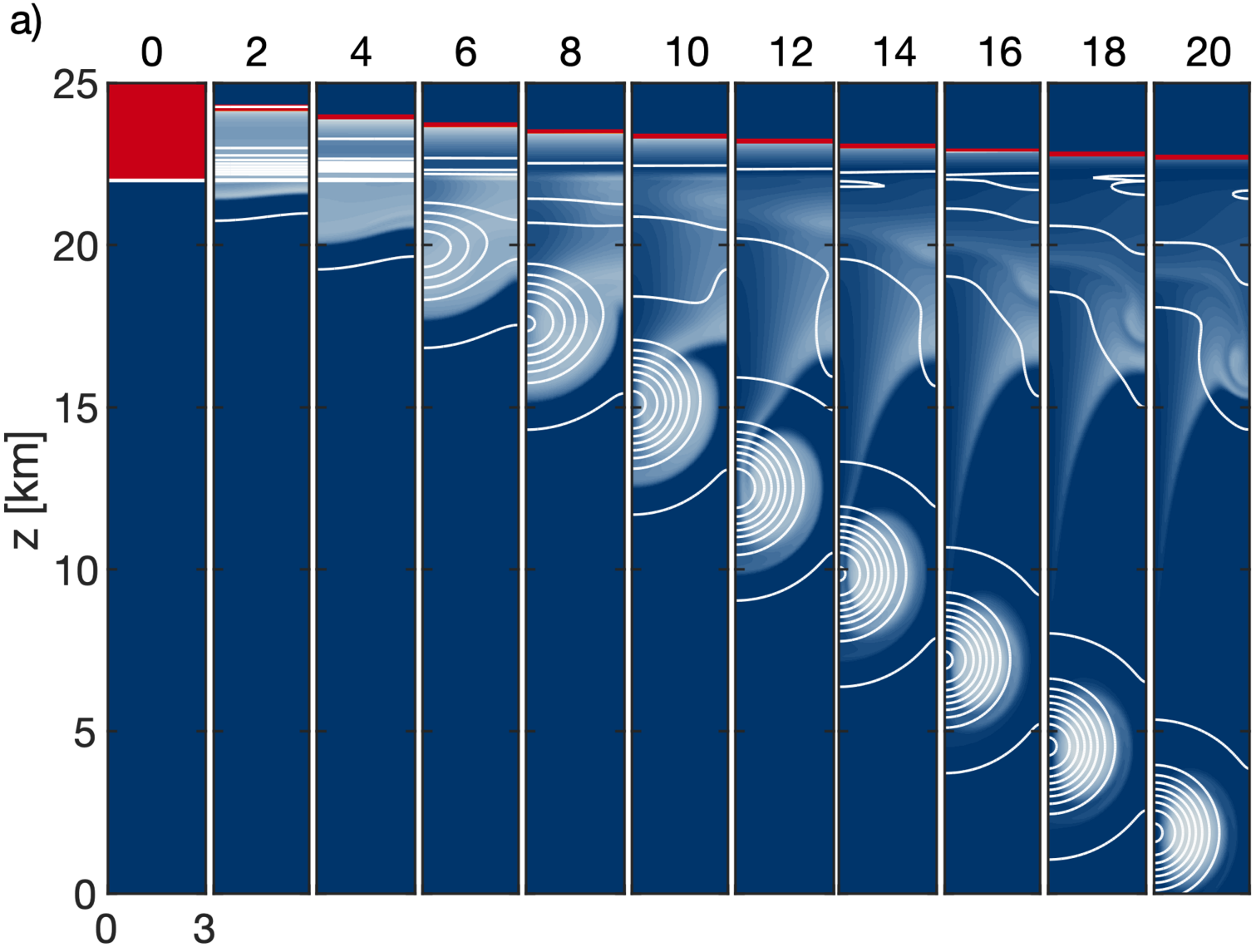


Pits & domes

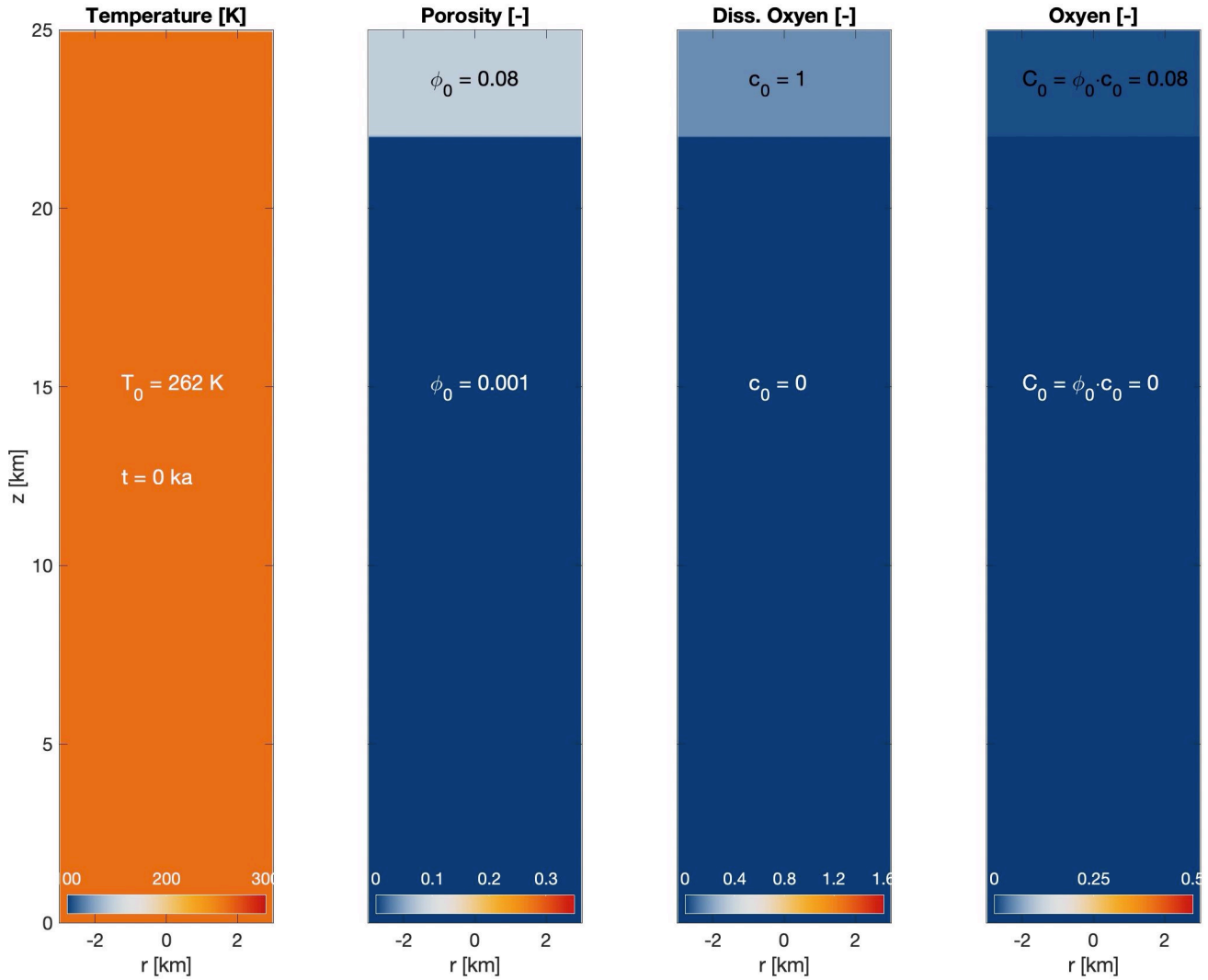
Chaos terrains



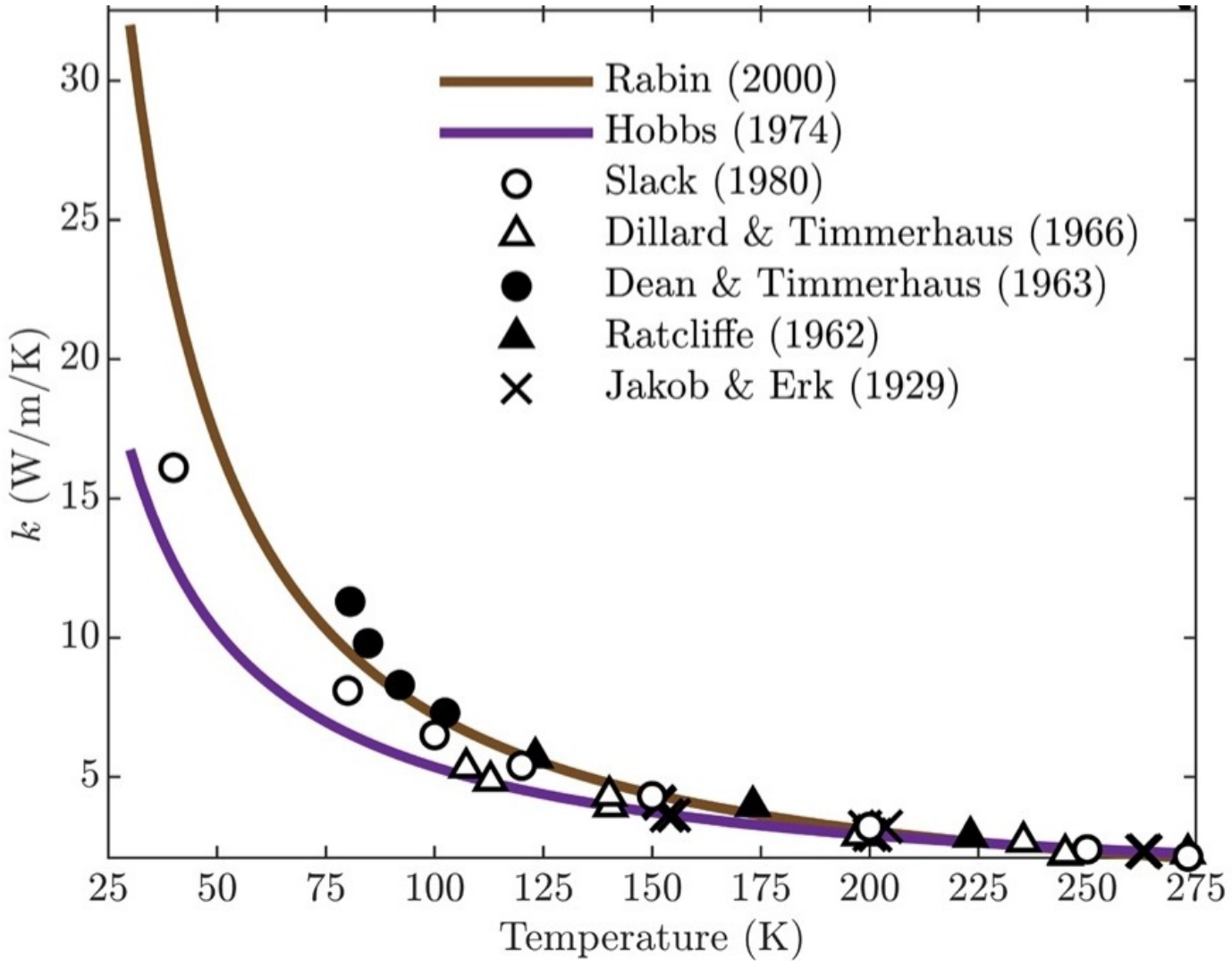
2019 – Melt migration with oxidant transport

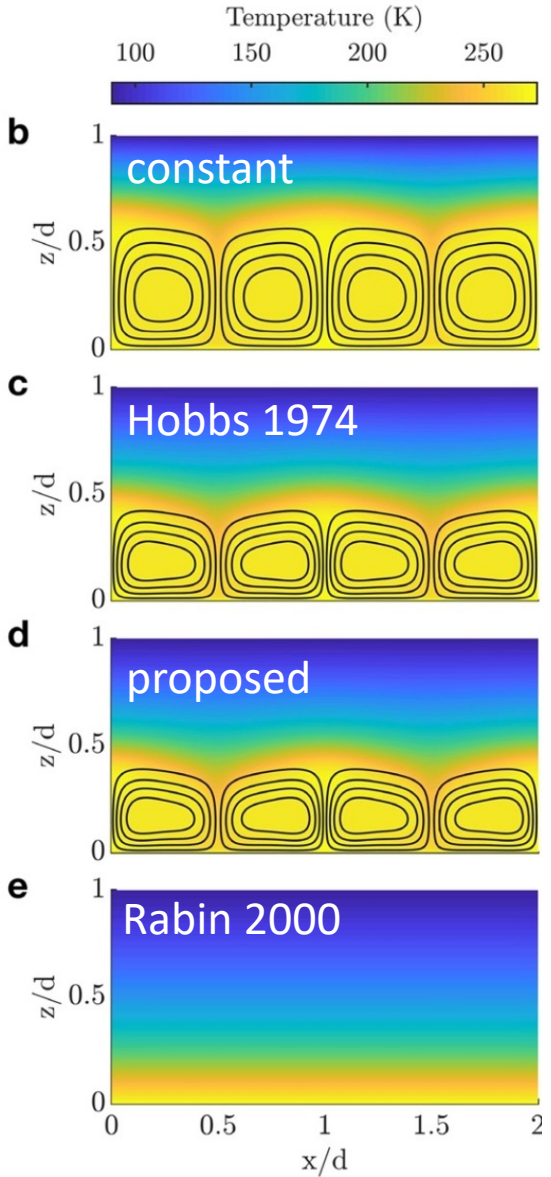


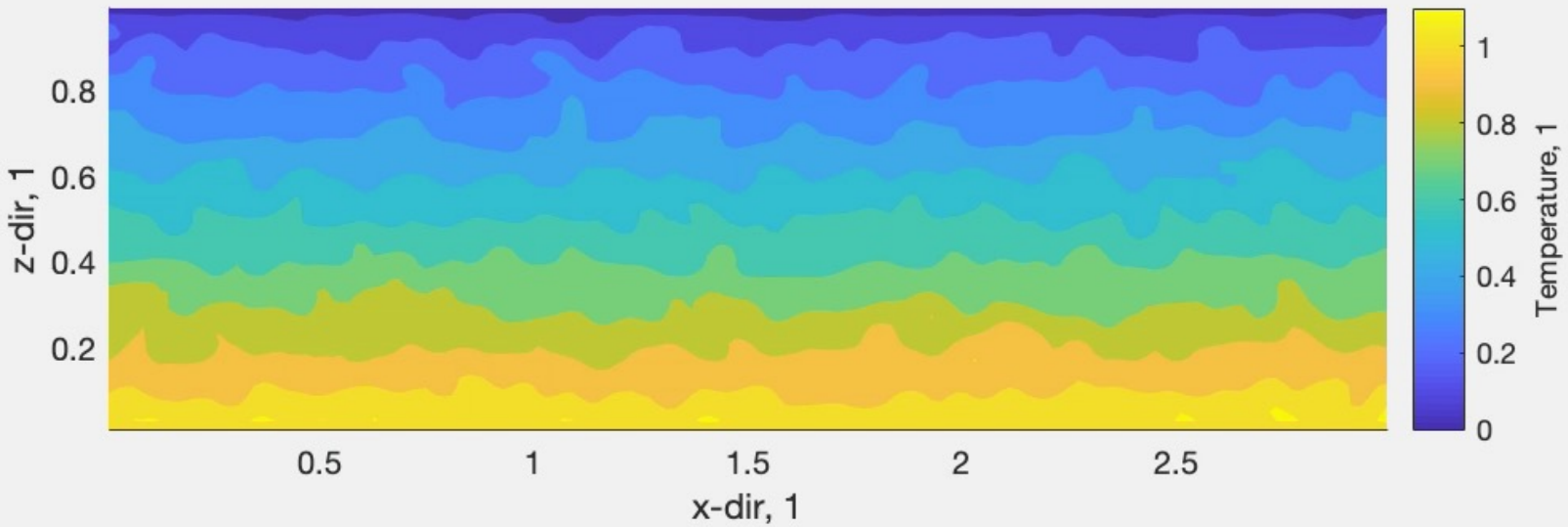
Animation of melt drainage



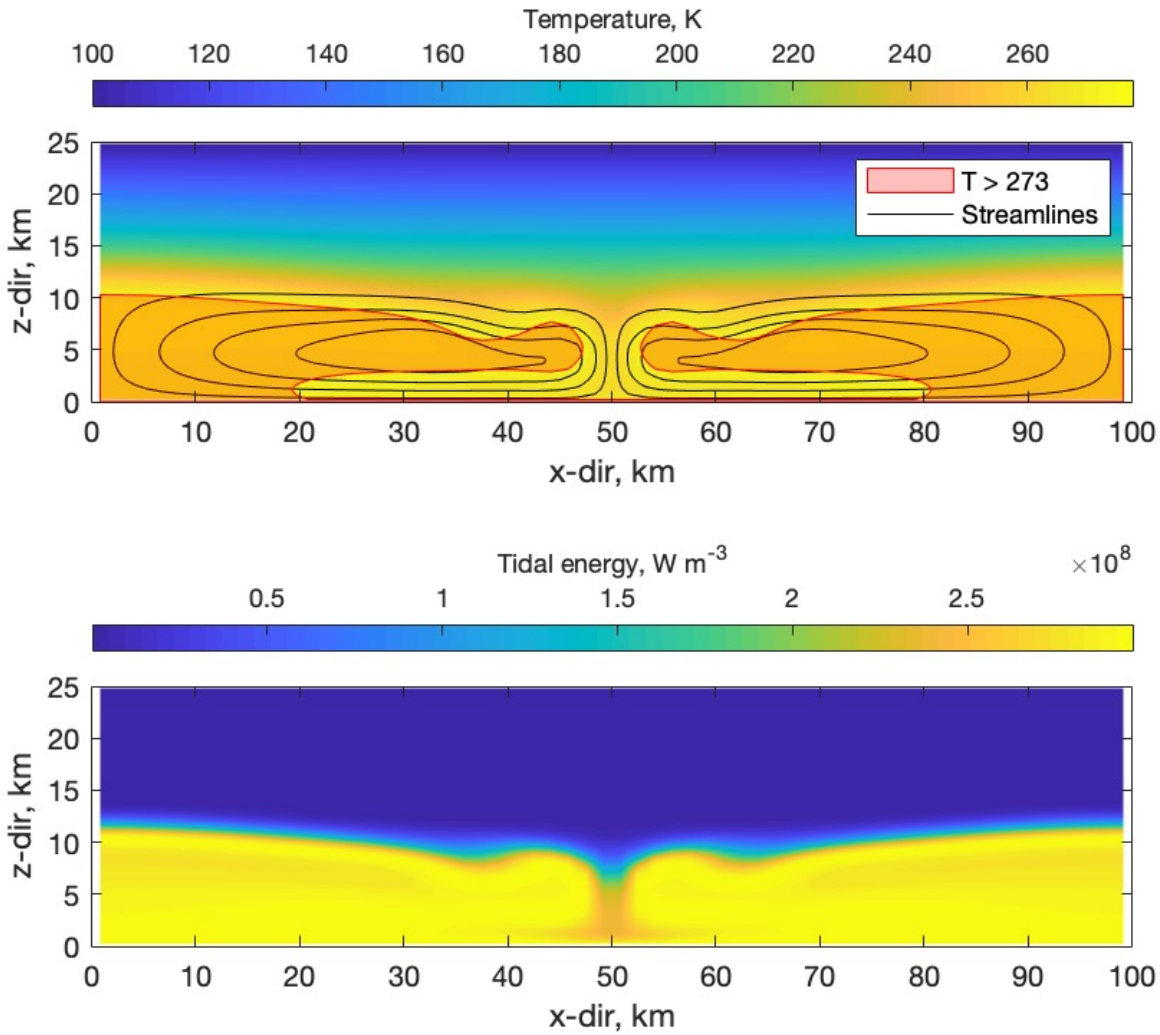
Ice convection with T-dependent conduction



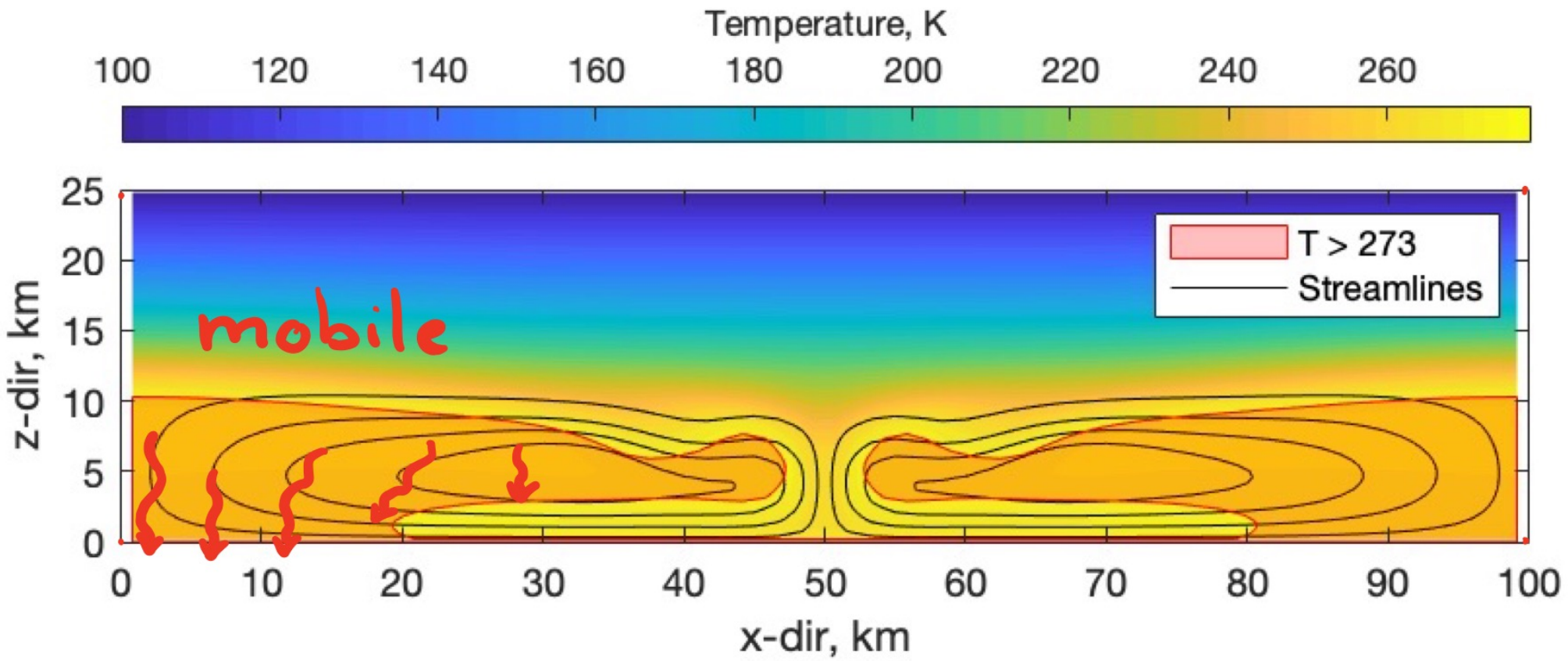



z-dir, 1
0.8
0.6
0.4
0.2
0.5
1
1.5
2
2.5
x-dir, 1
1
0.8
0.6
0.4
0.2
0
Temperature, 1

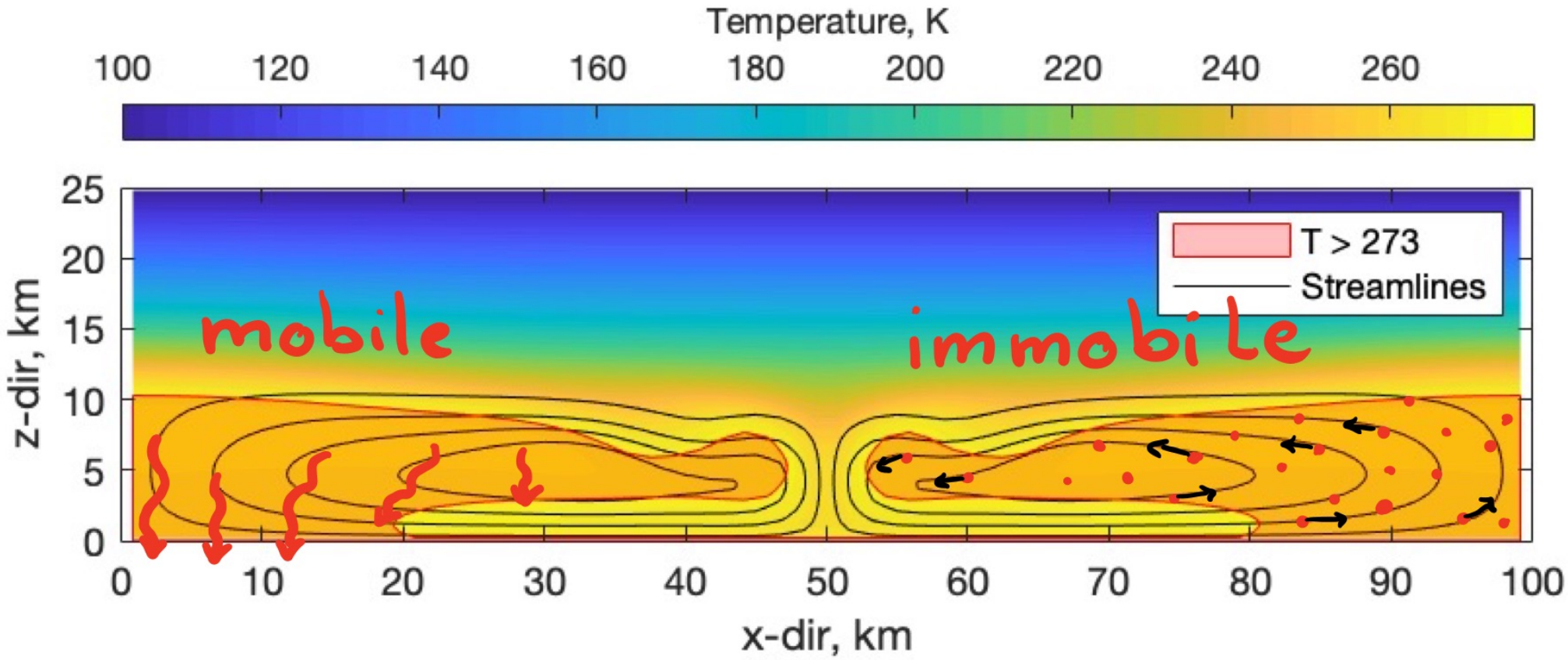
Next step: Combine melting + convection



Mobile melt – drainage – two-phase flow



Immobile melt



Affects: density, viscosity, tidal dissipation ⇒ ice shell composition and thickness.

Fully coupled ice convection+melt drainage

- Effect on ice shell thickness (access to internal ocean)
- Ice shell dynamics (mass transfer)
- Understand unexplained phenomena on Europa.

- Lot’s of work -> get started!