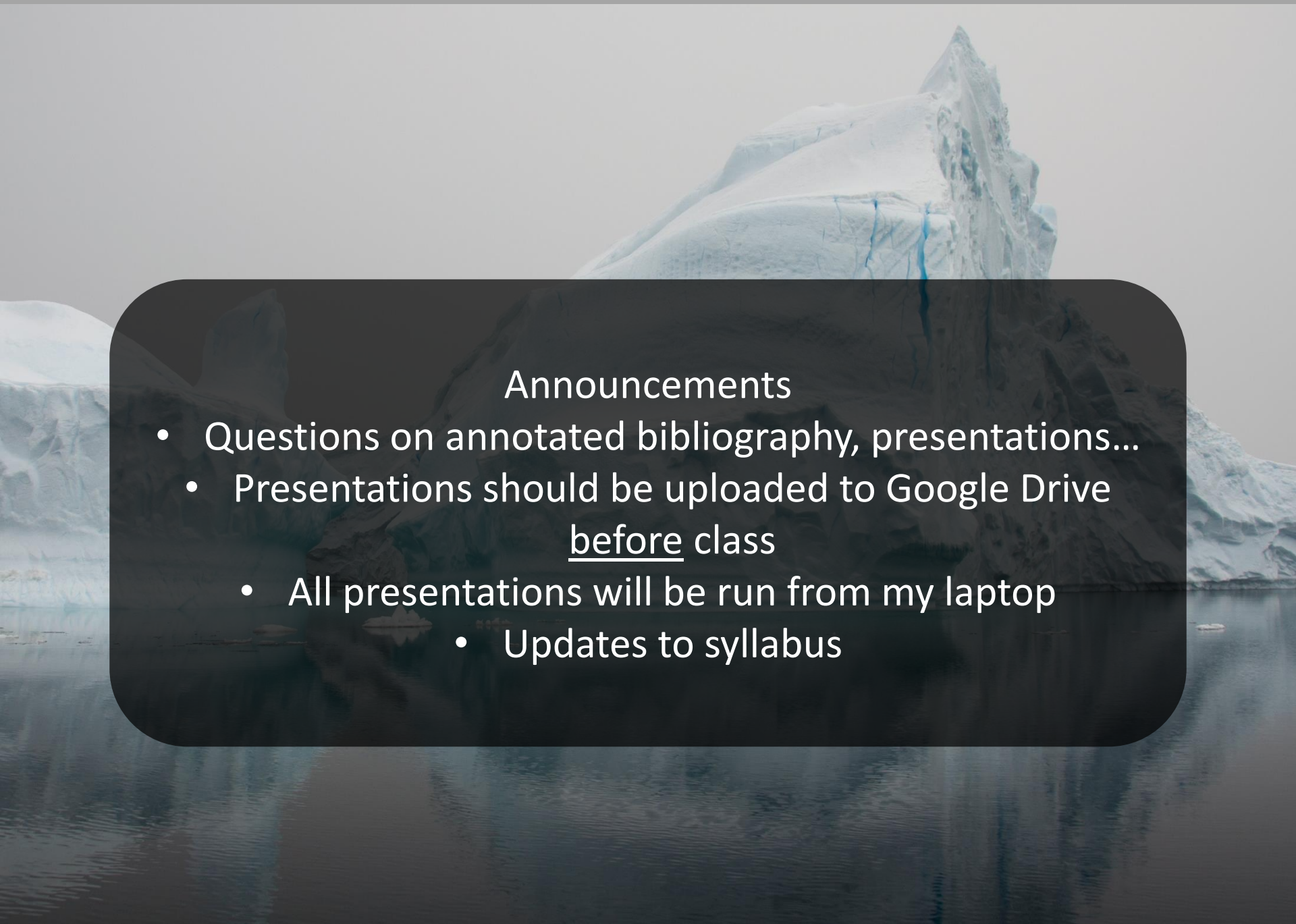
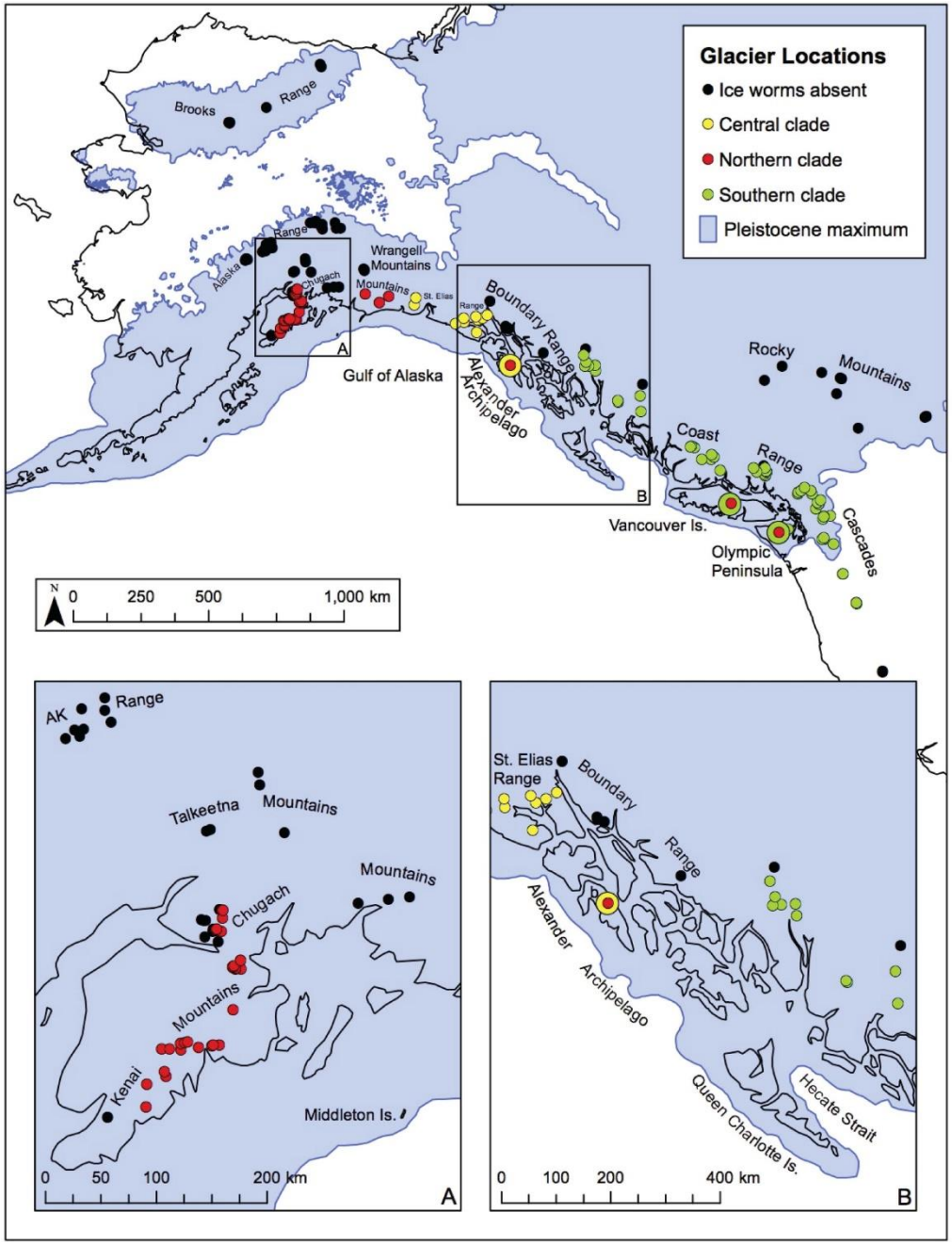
# Astrobiology and the cryosphere



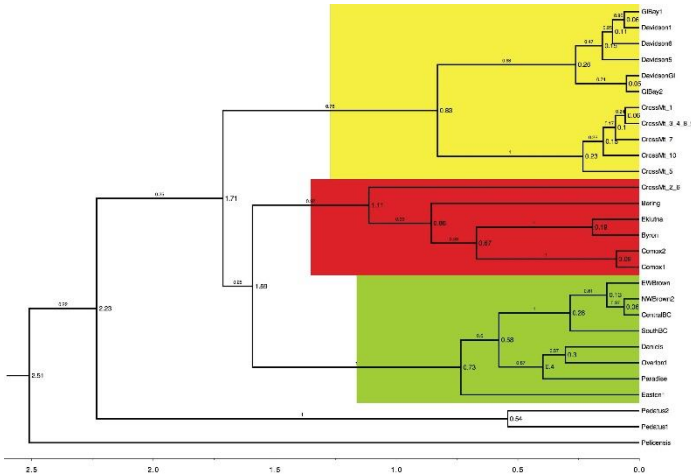
Announcements

- Questions on annotated bibliography, presentations…
- Presentations should be uploaded to Google Drive before class
- All presentations will be run from my laptop
- Updates to syllabus



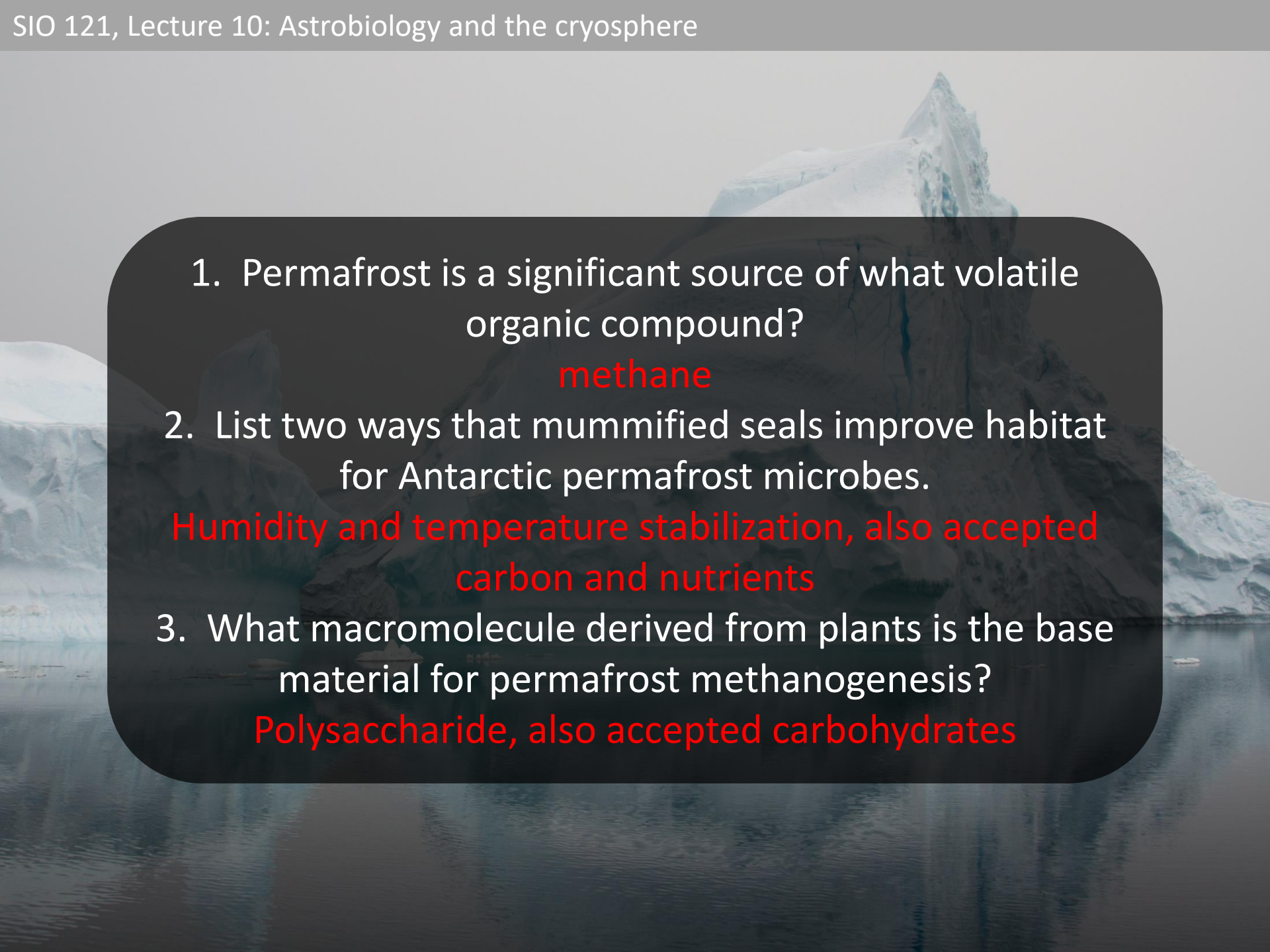

- *Mesonchytraeus solifugus* (northern clade)
- *Mesonchytraeus rainiernsis* (southern clade)

Hartzell et al., 2005



Dial et al., 2015

*Sinenchytraeus glacialis*
Liang, Y.L., 1979. A new genus and species of Enchytraeidae from Tibet. *Acta Zootaxonomica Sinica*, *4*, pp.312-315.



1. Permafrost is a significant source of what volatile organic compound?

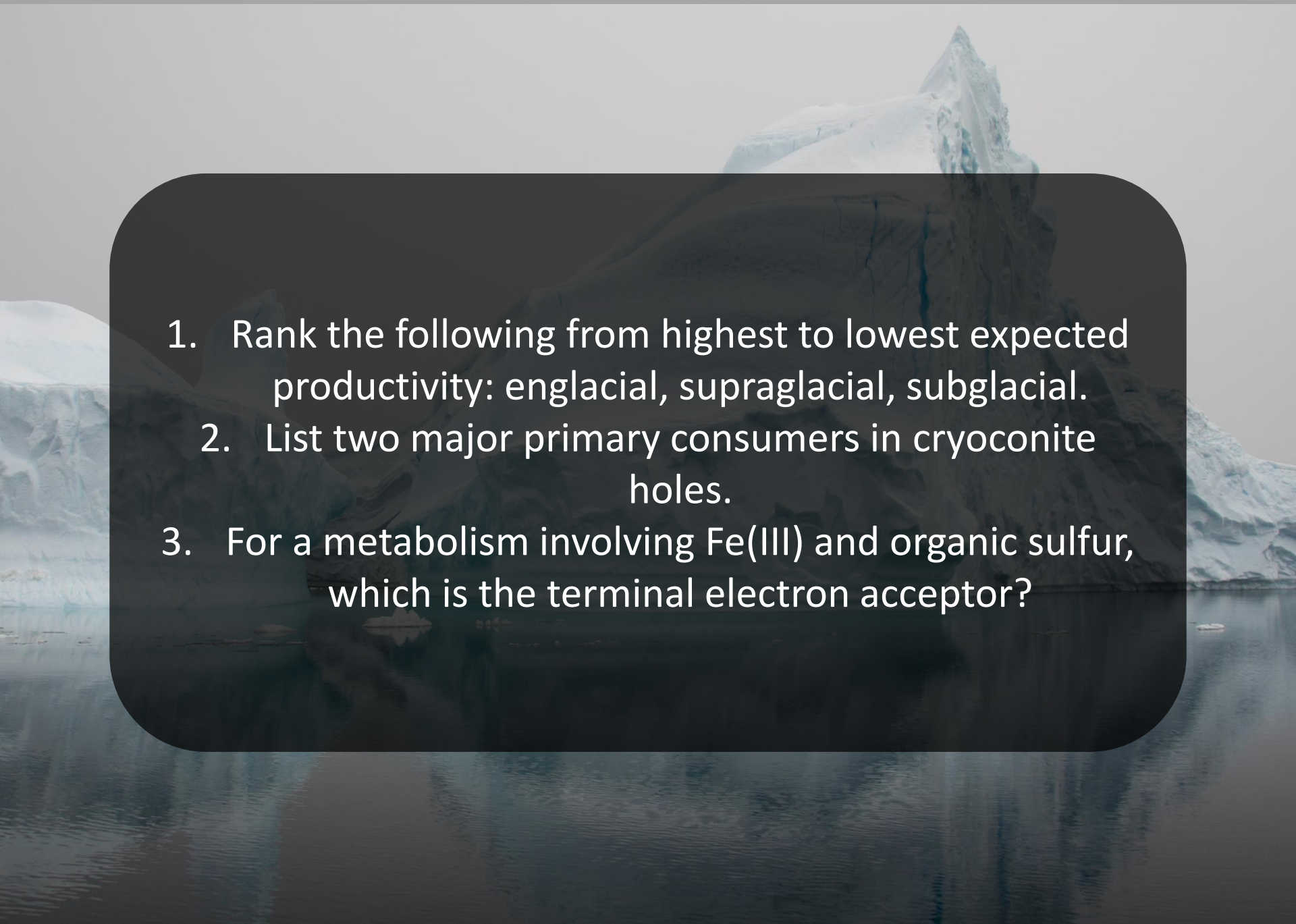
methane

2. List two ways that mummified seals improve habitat for Antarctic permafrost microbes.

Humidity and temperature stabilization, also accepted carbon and nutrients

3. What macromolecule derived from plants is the base material for permafrost methanogenesis?

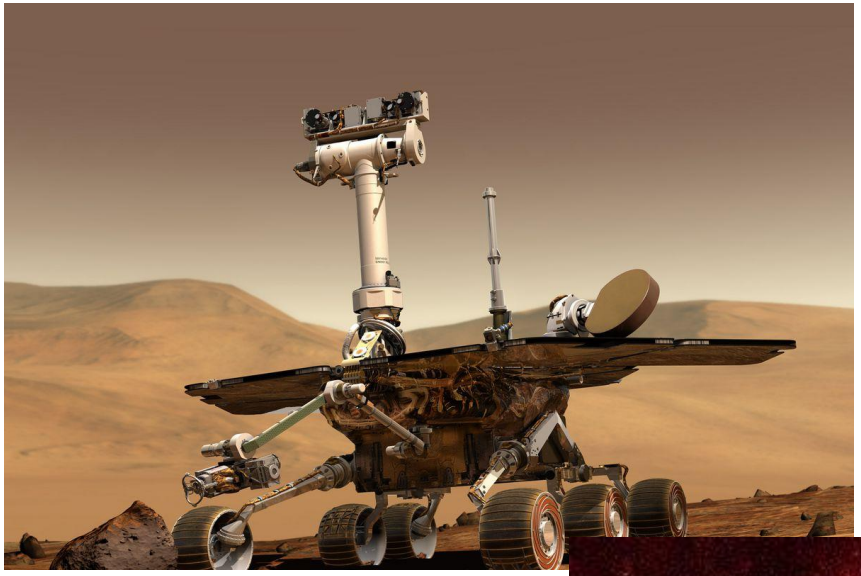
Polysaccharide, also accepted carbohydrates

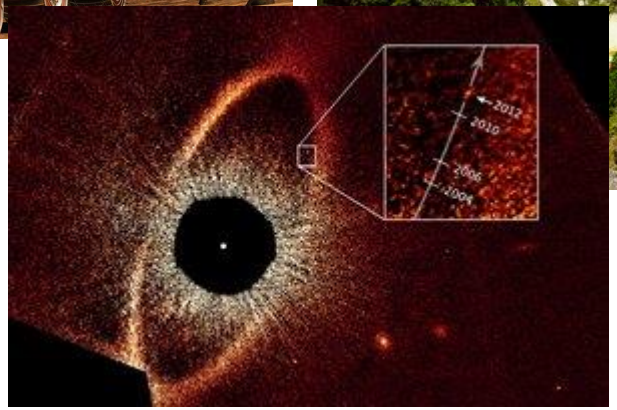


1. Rank the following from highest to lowest expected productivity: englacial, supraglacial, subglacial.
2. List two major primary consumers in cryoconite holes.
3. For a metabolism involving Fe(III) and organic sulfur, which is the terminal electron acceptor?

What is astrobiology? A brief recent history

- Astrobiology is the study of life in the universe, and is largely subdivided into two subfields:
  - Direct observations, or attempts to make direct observations within our solar system
  - More theoretical or hypothetical investigations of life outside our solar system





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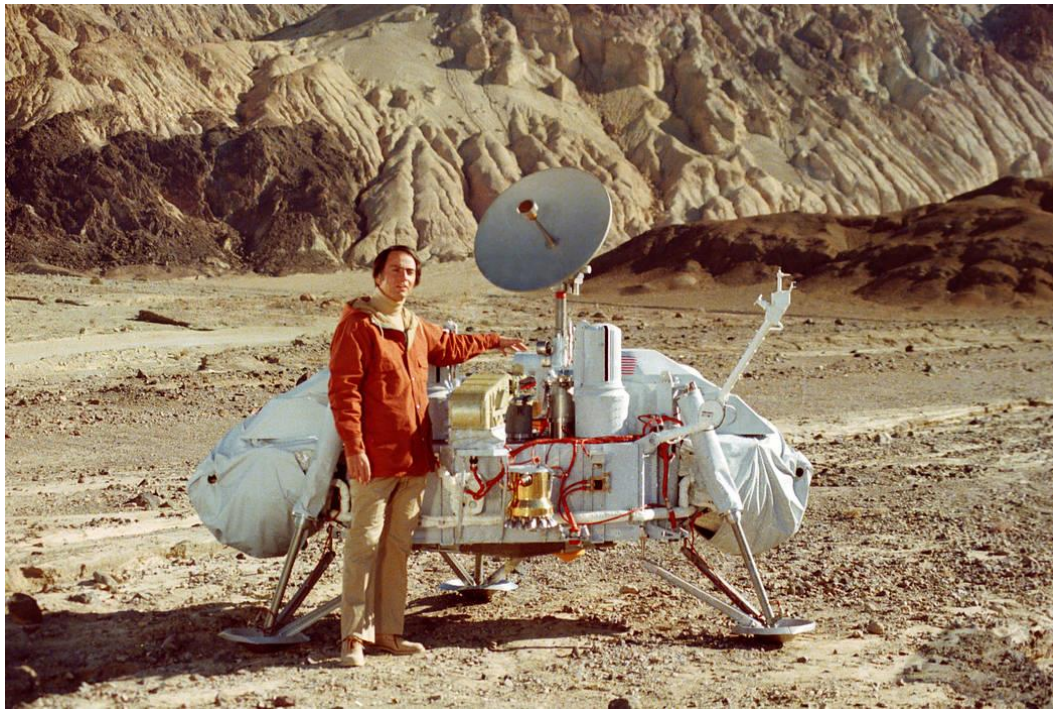
- The modern astrobiological era probably began with Viking, the first Mars rover in 1975

- In 1975 we knew very little about Mars, and less about the rest of the solar system
- No Hubble, no Keck Telescopes, no space shuttle, had only reached the moon 6 years prior…



Legendary cosmologist Carl Sagan with Viking model in Death Valley

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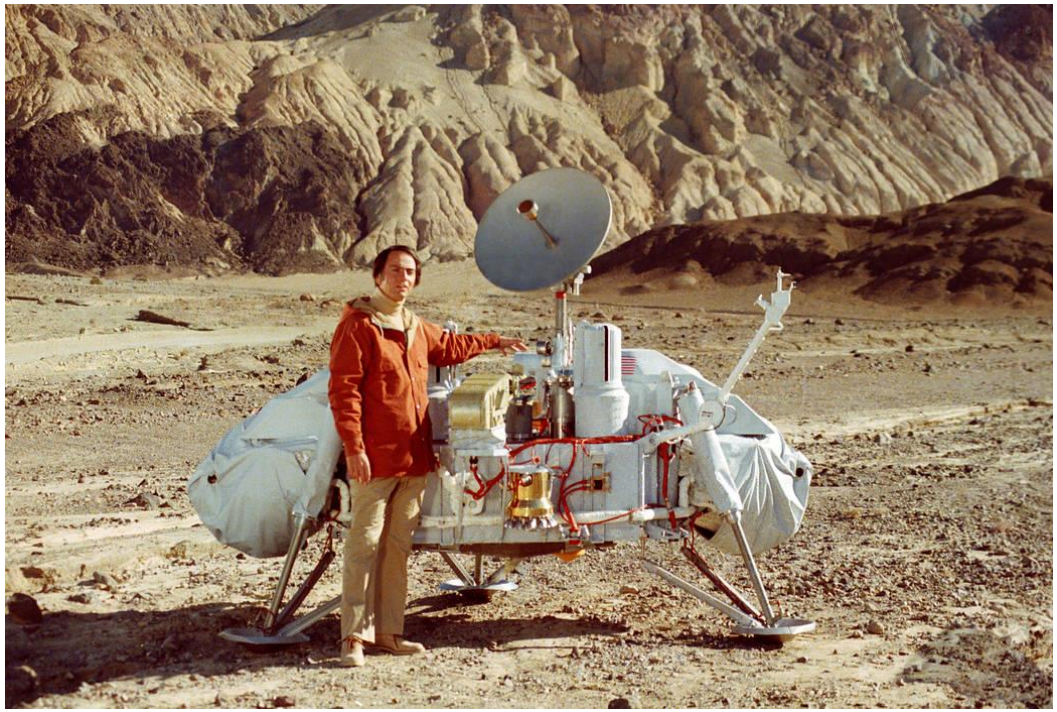
- Life detection experiments were similar to the production assays that we are familiar with
- Results were ambiguous, and remain debated today!



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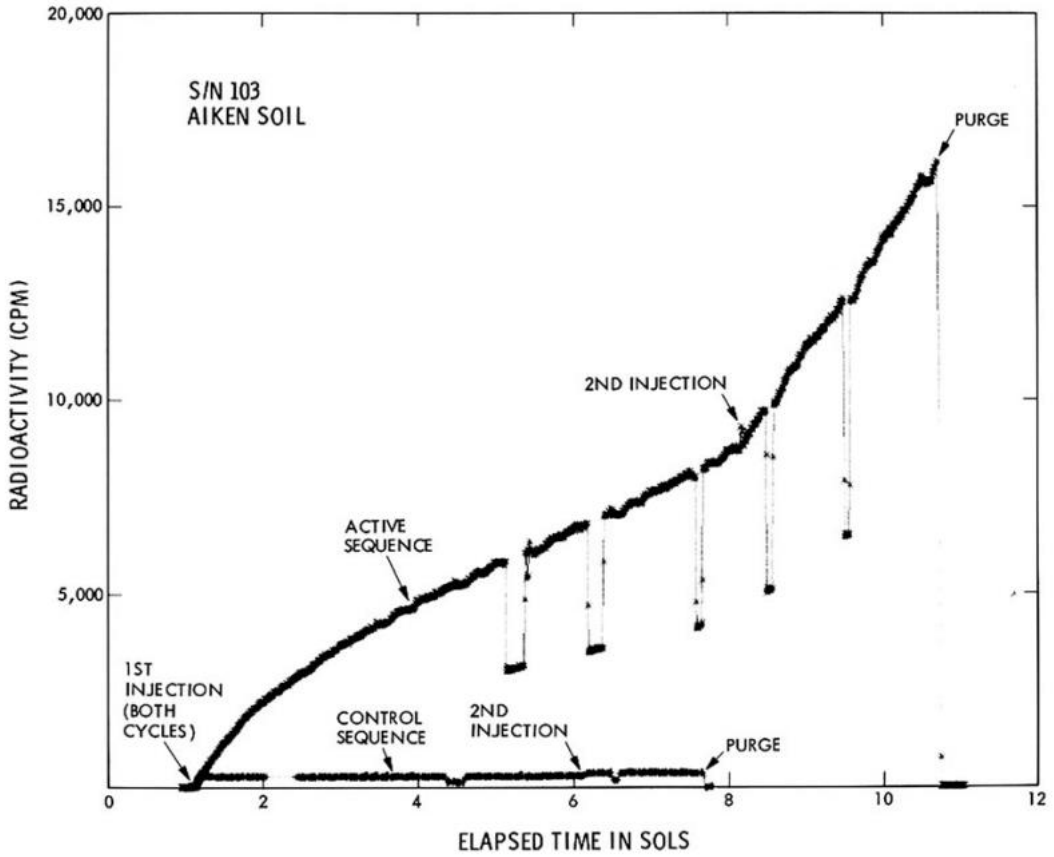


Levin and Straat, 2016

What is astrobiology? A brief recent history

- Following the ambiguity of the Viking mission there was a period of stagnation – finding life on Mars wasn't going to be easy, and no one understood what the next step should be
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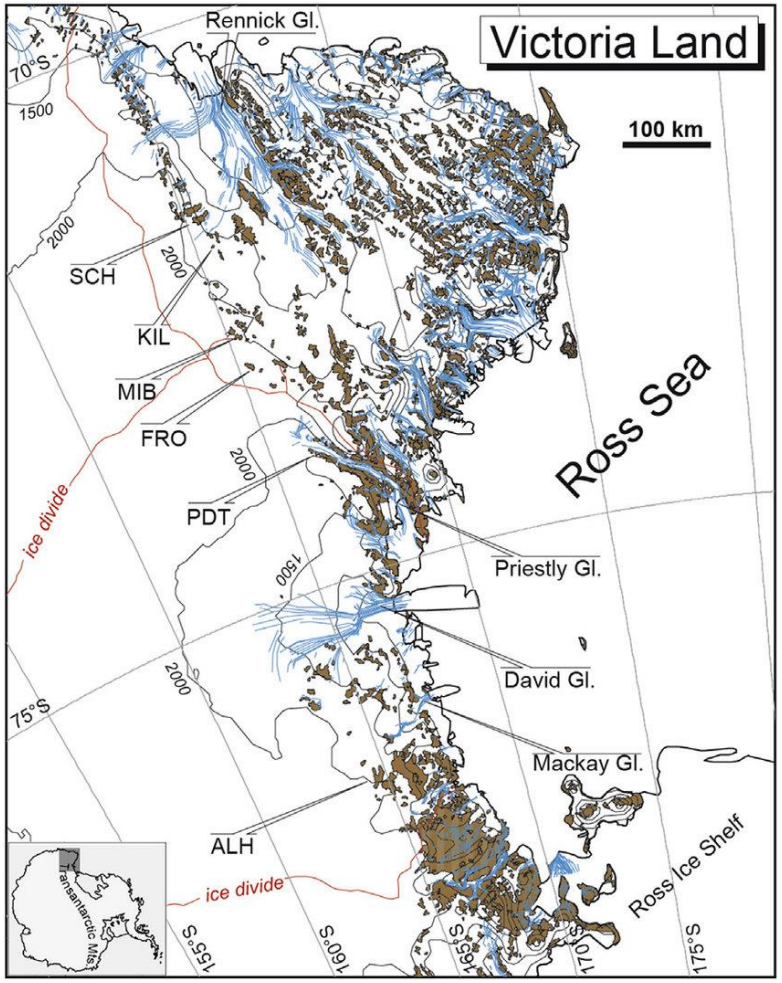

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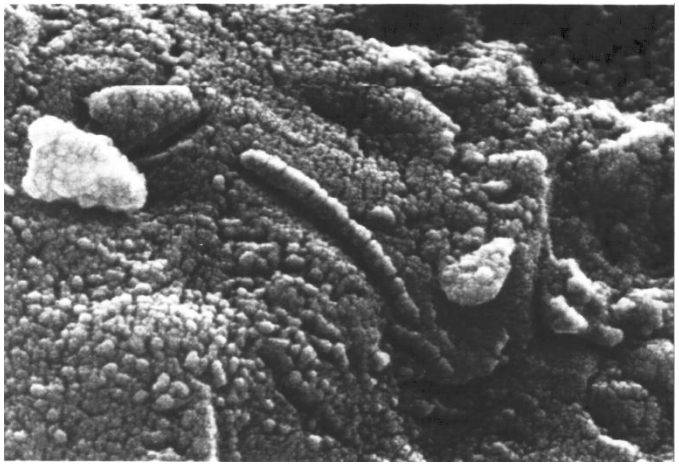
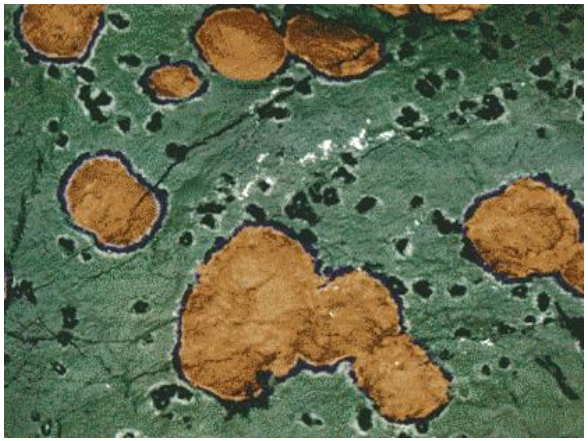


Putative microfossils



Carbon rich globules

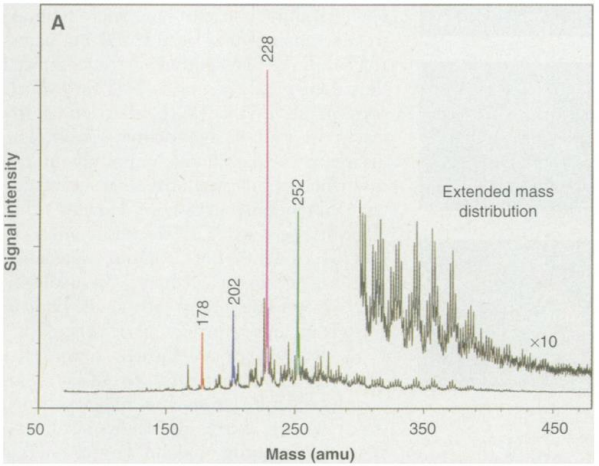



**Fig. 1.** (**A**) Averaged mass spectrum of an interior, carbonate-rich, fracture surface of ALH84001. The spectrum represents the average of 1280 individual spectra defining an analyzed surface region of 750 by 750 μm mapped at a spatial resolution of 50 by 50 μm. (**B** through **E**) PAH Signal intensity as a

Complex organics, specifically PAHs

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- All of which were subsequently debunked…

*American Mineralogist, Volume 86, pages 370–375, 2001*

LETTER

**A simple inorganic process for formation of carbonates, magnetite, and sulfides in Martian meteorite ALH84001**

D.C. GOLDEN,[1] DOUGLAS W. MING,[2,*] CRAIG S. SCHWANDT,[3] HOWARD V. LAUER JR.,[3] RICHARD A. SOCKI,[3] RICHARD V. MORRIS,[2] GARY E. LOFGREN,[2] AND GORDON A. MCKAY[2]

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[2]Earth Science and Solar System Exploration Division, Mail Code SN2, NASA Johnson Space Center, Houston, Texas 77058, U.S.A.
[3]Lockheed Martin, Mail Code C23, P.O. Box 58561, Houston, Texas 77258-8561, U.S.A.

Pergamon

Geochimica et Cosmochimica Acta, Vol. 60, No. 24, pp. 5149–5155, 1996

0016-7037/96 $15.00 + .00

PII S0016-7037(96)00383-3

**Magnetite whiskers and platelets in the ALH84001 Martian meteorite: Evidence of vapor phase growth**

JOHN P. BRADLEY,[1,2] RALPH P. HARVEY,[3] and HARRY Y. MCSWEEN JR.[4]

[1]MVA Inc. 5500/200 Oakbrook Parkway, Norcross, GA 30093, USA
[2]School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0245, USA
[3]Department of Geological Sciences, Case Western Reserve University, Cleveland, OH 44106-7216, USA
[4]Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996-1410, USA

**Petrological evidence for shock melting of carbonates in the martian meteorite ALH84001**

**Edward R. D. Scott, Akira Yamaguchi & Alexander N. Krot**

*Hawaii Institute of Geophysics and Planetology, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA*

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- All of which were subsequently debunked…
- And de-debunked. The debate continues.

**Chains of magnetite crystals in the meteorite ALH84001: Evidence of biological origin**

**E. Imre Friedmann*†‡, Jacek Wierzchos§, Carmen Ascaso¶, and Michael Winklhofer‖**

*Department of Biological Science, Florida State University, Tallahassee, FL 32306-1100; †Space Science Division 245-3, National Aeronautics and Space Administration Ames Research Center, Moffett Field, CA 94035; §Servei de Microscòpia Electrònica, Universitat de Lleida, 25196 Lleida, Spain; ¶Centro de Ciencias Medioambientales, Consejo Superior de Investigaciones Científicas, 28006 Madrid, Spain; and ‖Institut für Geophysik, Universität München, D-80333 Munich, Germany

**MINIREVIEWS**

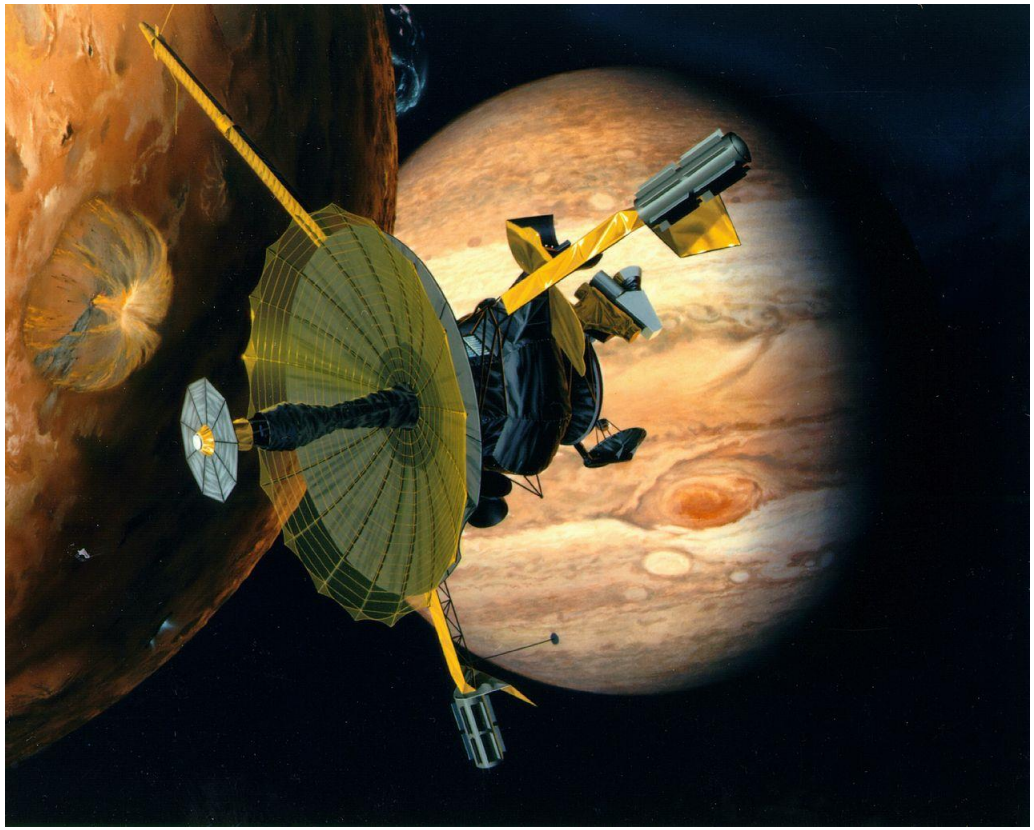
Magnetofossils from Ancient Mars: a Robust Biosignature in the Martian Meteorite ALH84001

Kathie L. Thomas-Keprta,[1]* Simon J. Clemett,[1] Dennis A. Bazylinski,[2] Joseph L. Kirschvink,[3] David S. McKay,[4] Susan J. Wentworth,[1] Hojatollah Vali,[5] Everett K. Gibson, Jr.,[4] and Christopher S. Romanek[6]

*Lockheed Martin[1] and National Aeronautics and Space Adminstration/Johnson Space Center,[4] Houston, Texas 77058; Department of Microbiology, Iowa State University, Ames, Iowa 50011[2]; Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125[3]; Department of Earth and Planetary Sciences, McGill University, Montreal, Quebec H3A 2A7, Canada[5]; and Savannah River Ecology Laboratory, University of Georgia, Aiken, South Carolina 29802[6]*

What is astrobiology? A brief recent history

- Concurrent with the debate about ALH84001 however, scientists began to get data back from the Galileo satellite, launched in 1989 to study Jupiter and its moons (arrived 1995)



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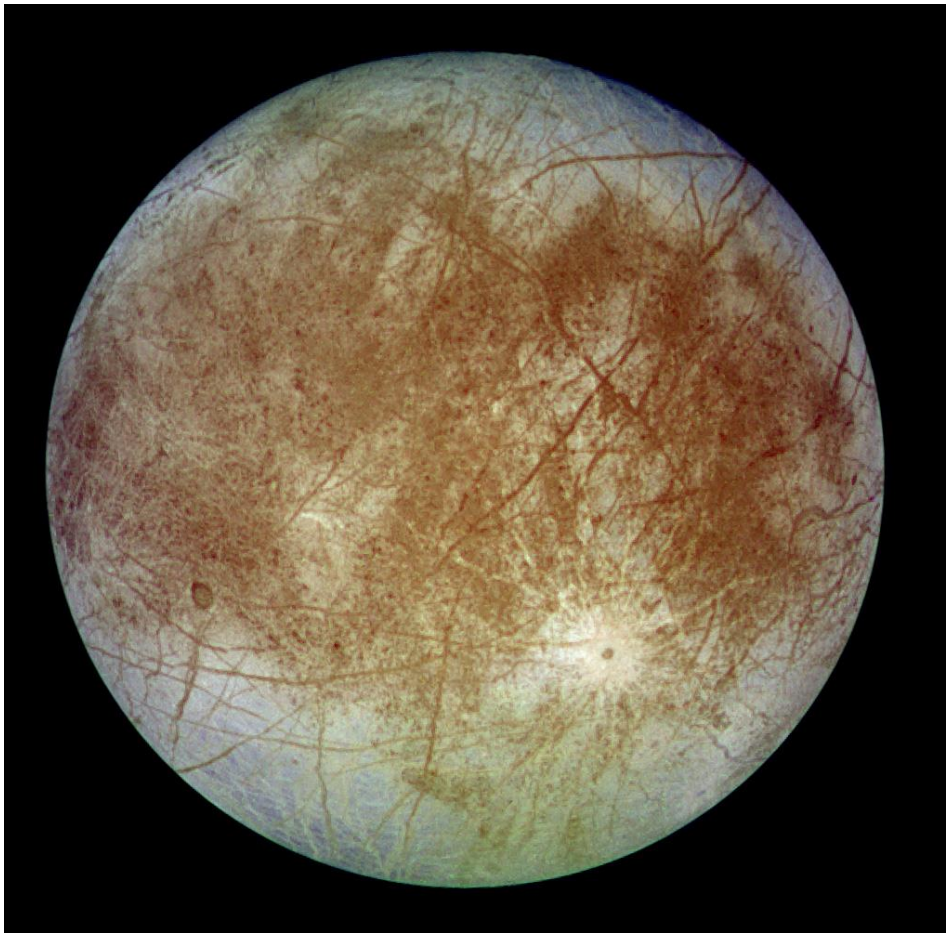
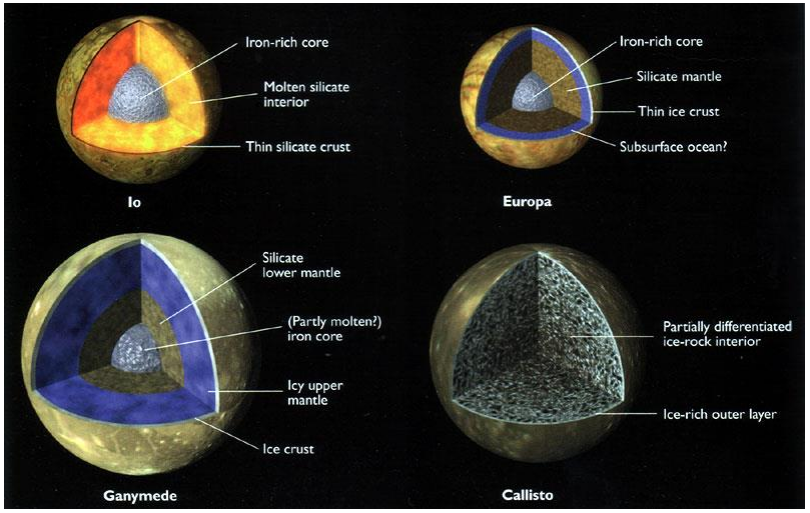
- Multiple lines of evidence (magnetic, gravity, surface features) pointed to liquid water ocean on the moon Europa



**Galileo Magnetometer Measurements: A Stronger Case for a Subsurface Ocean at Europa**

Margaret G. Kivelson,* Krishan K. Khurana, Christopher T. Russell, Martin Volwerk, Raymond J. Walker, Christophe Zimmer



## What is astrobiology? A brief recent history

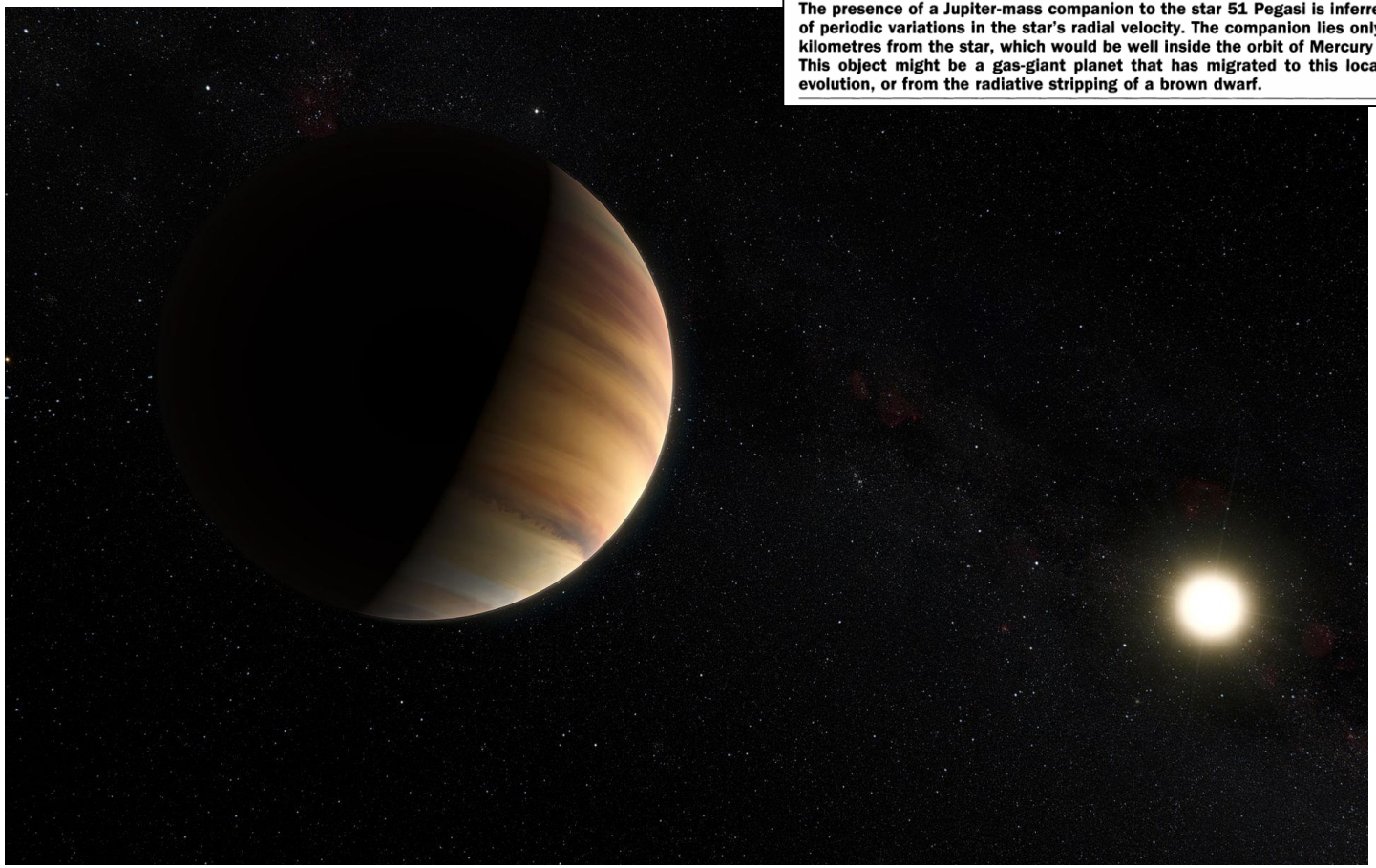
- Also at roughly the time of ALH84001, the first definitive observation was made of an exoplanet
- In the 23 years since there has been an explosion in the number of exoplanets discovered

**A Jupiter-mass companion to a solar-type star**

**Michel Mayor & Didier Queloz**

Geneva Observatory, 51 Chemin des Maillettes, CH-1290 Sauverny, Switzerland

**The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star's radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.**



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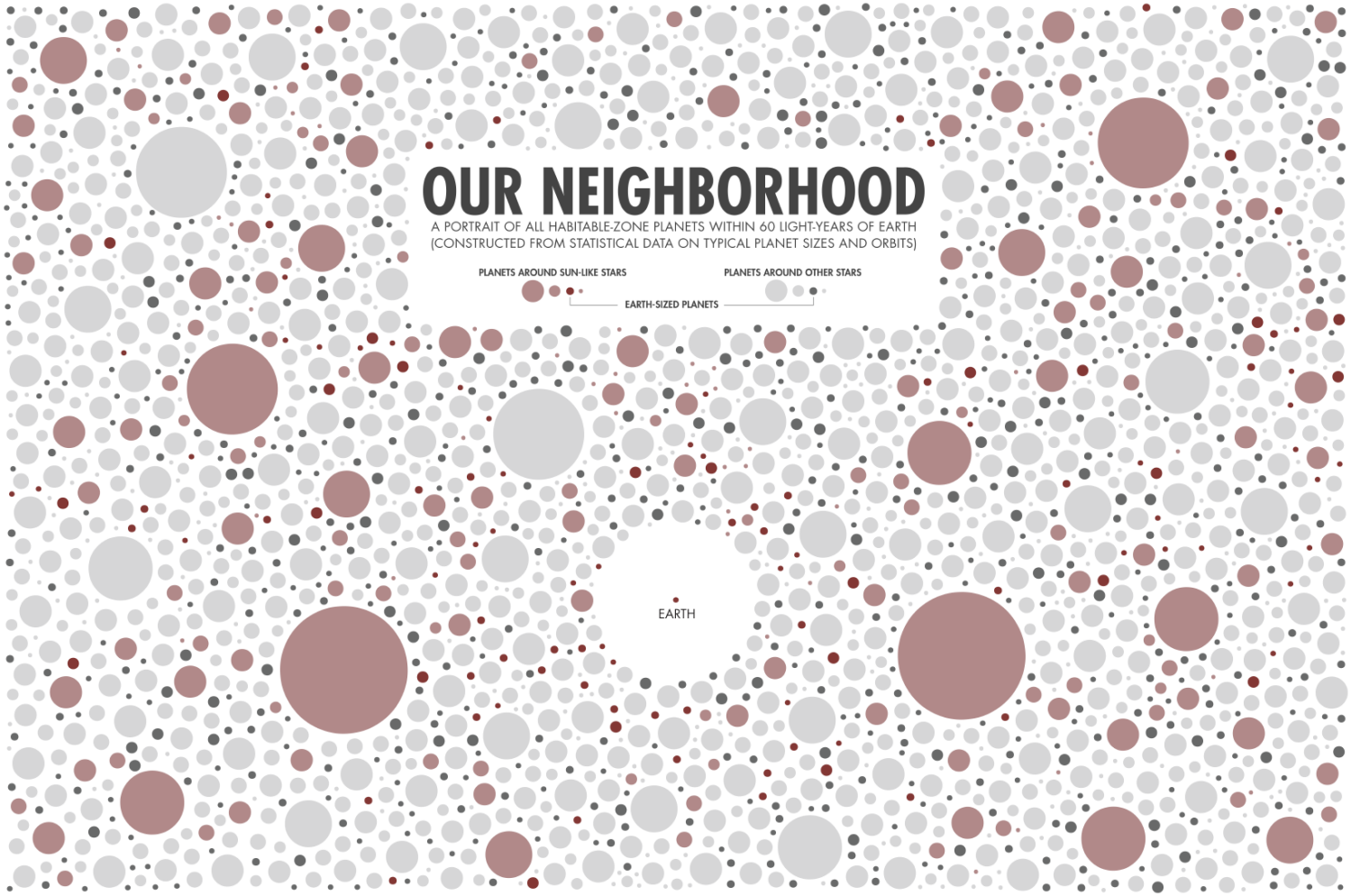
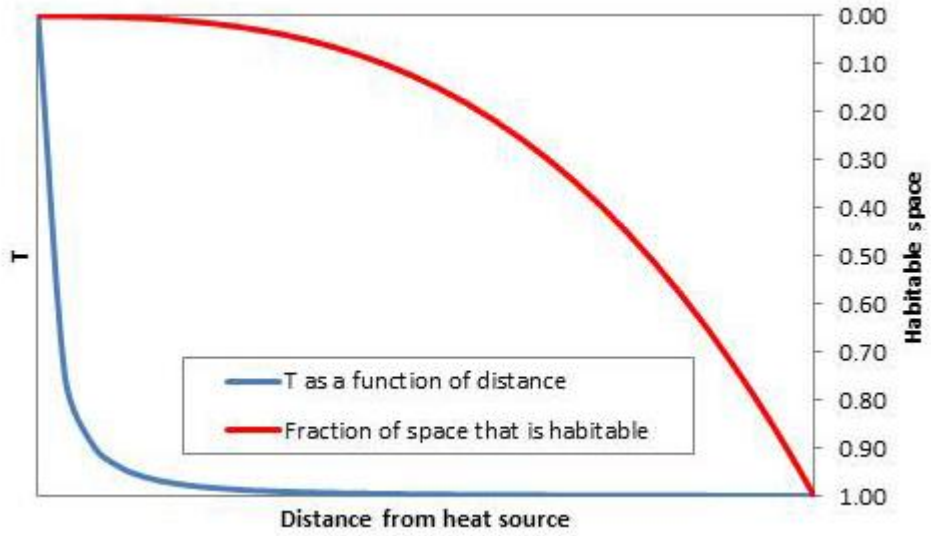



https://xkcd.com/1298

The modern study of life in the universe is predicated around these key points of knowledge:

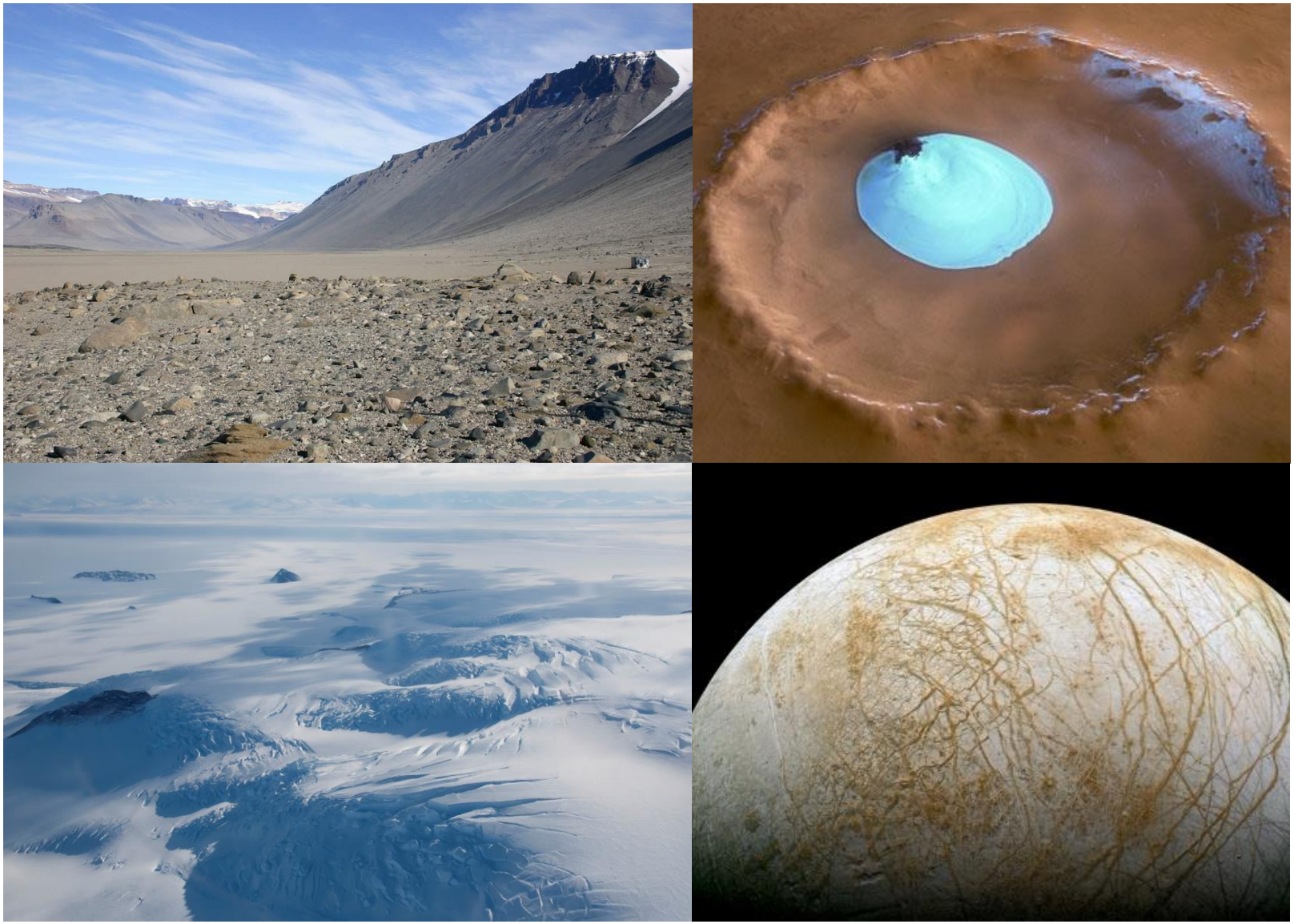
1. Liquid water is common in our solar system
2. The deep subsurface of Mars and the Europan ocean are plausibly similar to inhabited ecosystems on Earth
3. Planets (and moons) are ubiquitous features of solar systems in our galaxy

So what does this have to do with the cryosphere?



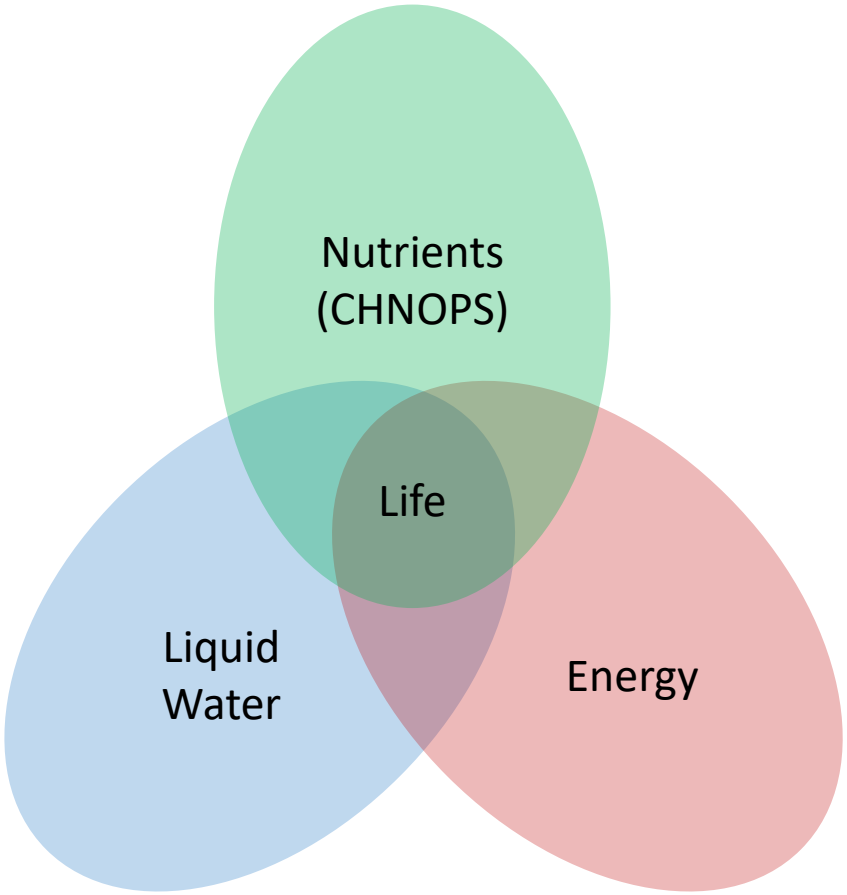

The universe is cold! The lower the temperature limit for life, the greater the space around a heat source it will occupy, and the greater our chance of finding it.

Given that the best potential extraterrestrial habitats are associated with ice, it makes sense to study frozen environments on Earth. We call these environments *analogs*.

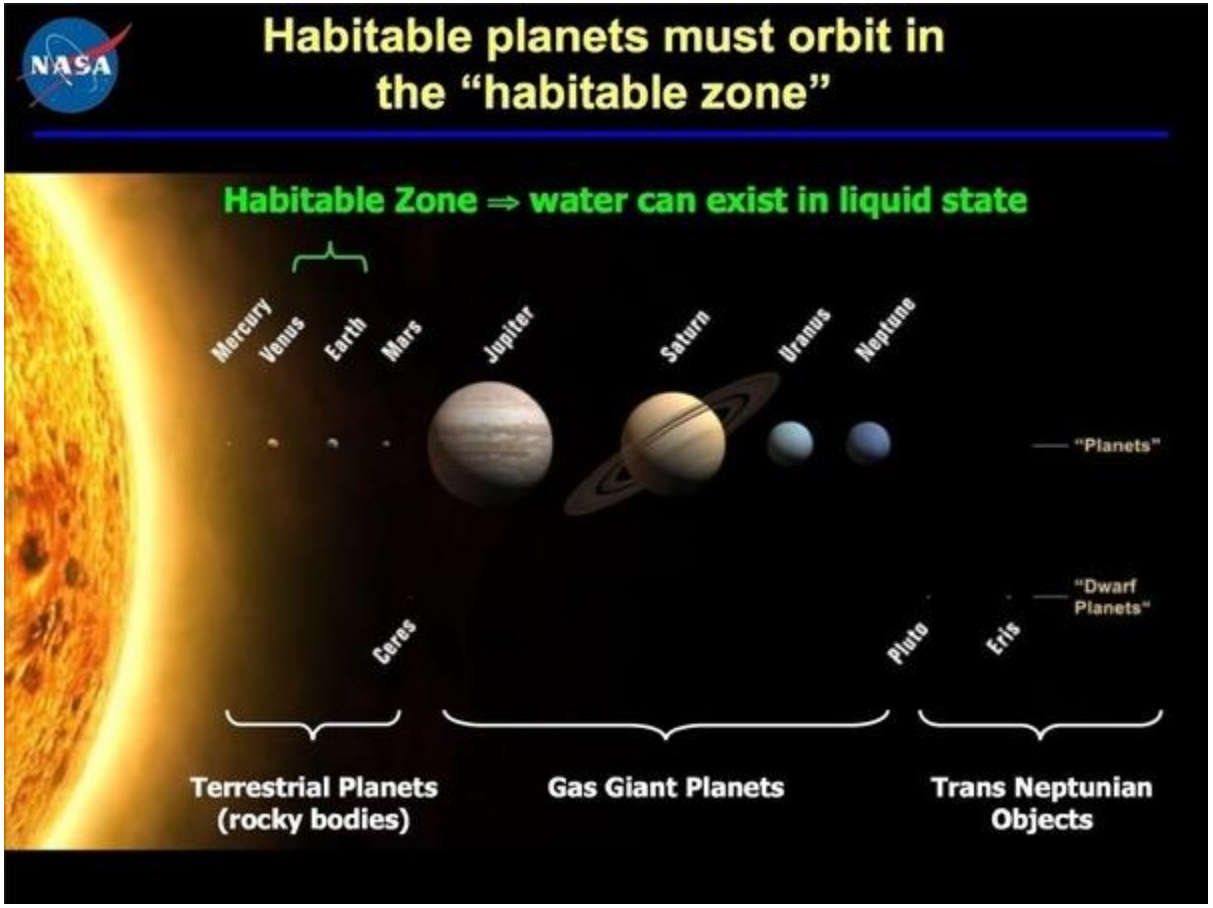


Understanding how (terran) life might be distributed in the universe

- If we can map the key requirements for life, we can identify those places where life might be found (the key requirements are…)
- In our solar system CHNOPS are widely distributed, so we are most interested in the distribution of liquid water and sources of energy



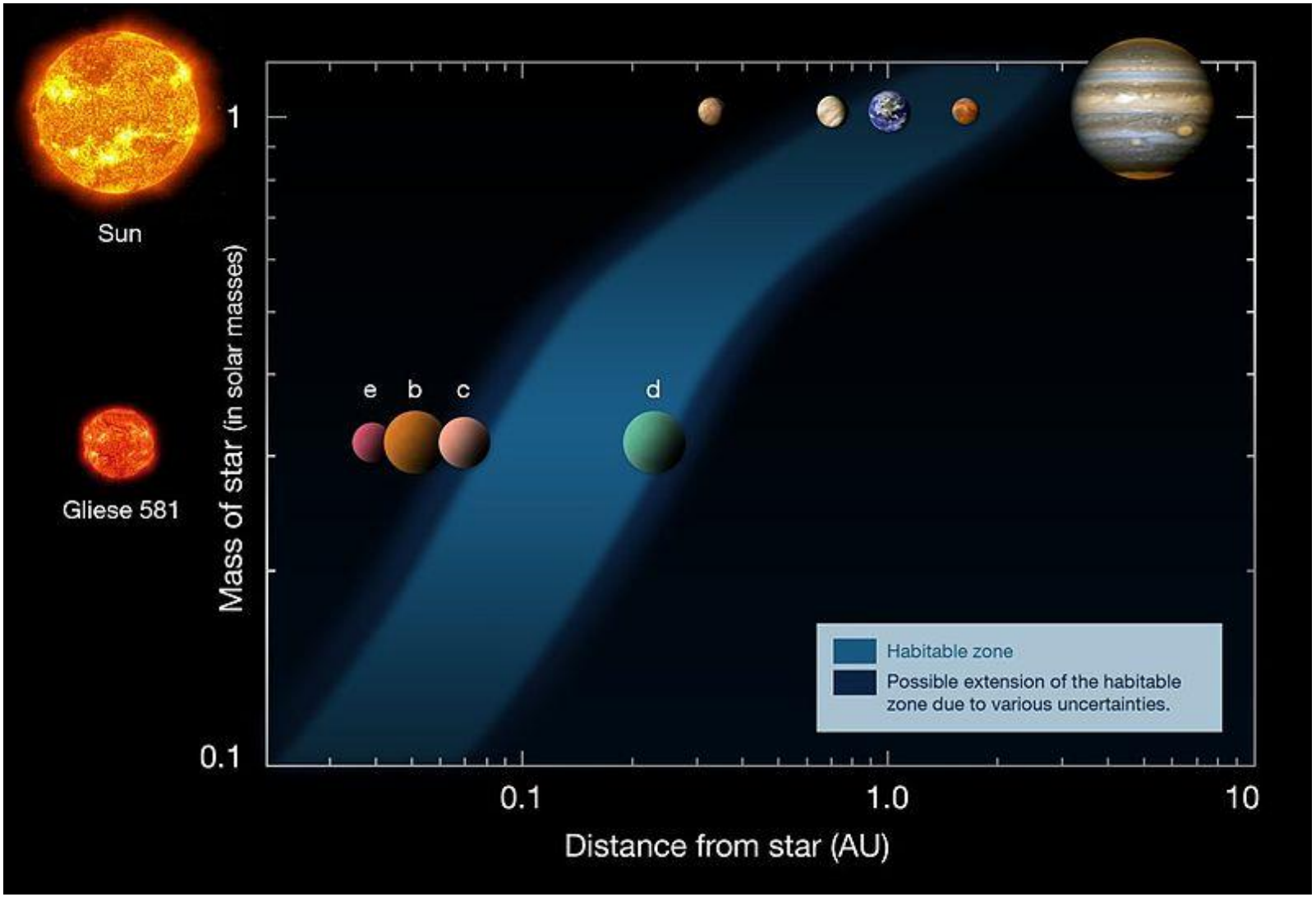
The habitable zone represents the classical view of how liquid water is distributed




- The habitable zone is the region around a star where water can exist in liquid state
- Q: Mars is firmly in the habitable zone but lacks liquid water at the surface, why?
- A: Too small, lost its atmosphere, no greenhouse effect to warm the surface

The habitable zone represents the classical view of how liquid water is distributed

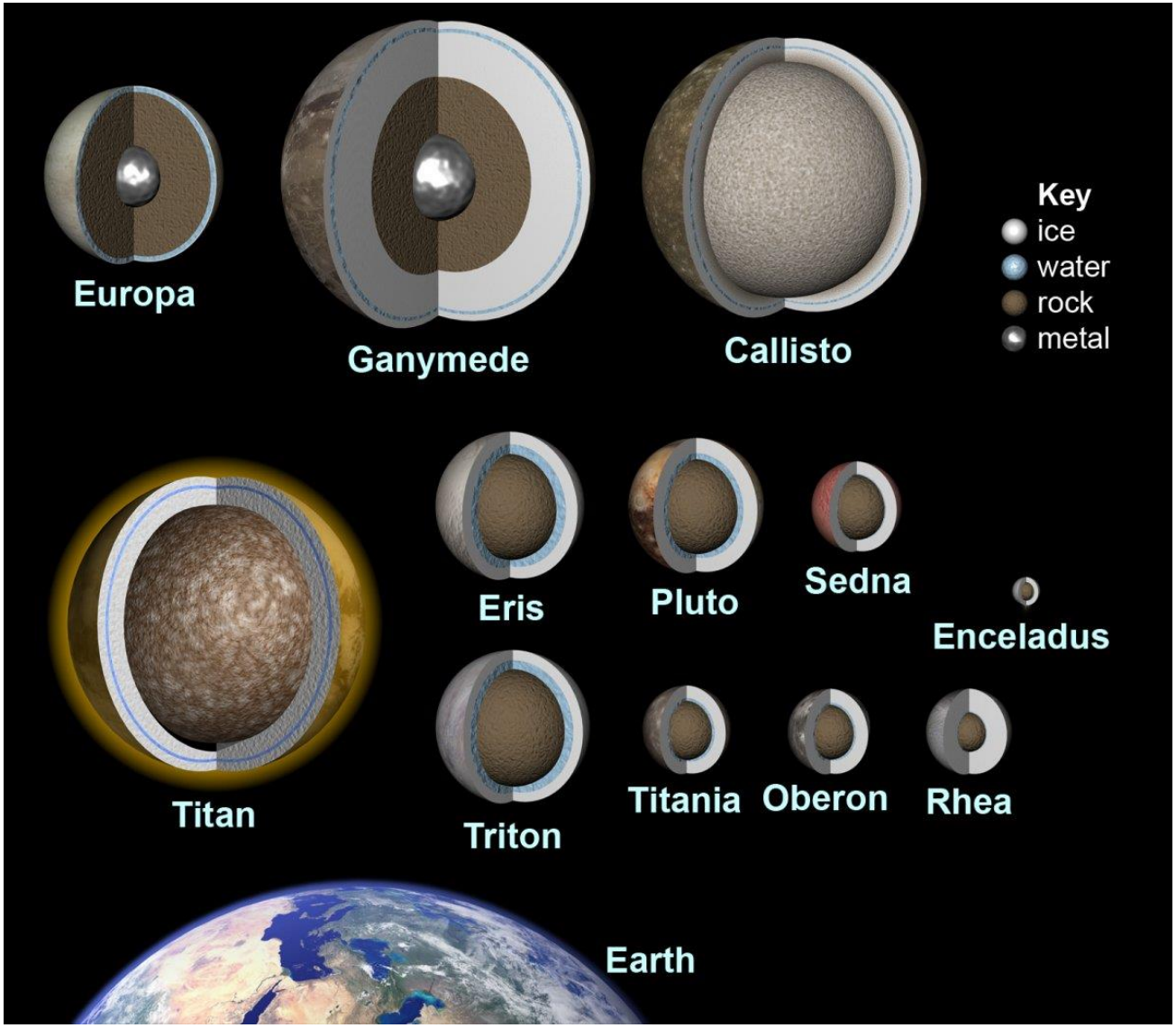
- Stars of different size/age will have different habitable zones



The habitable zone is not the only place that liquid water is found – it's actually pretty common in our solar system (note that all of these have lots of water ice)

<u>Moons</u>
Europa (Jupiter)
Ganymede (Jupiter)
Callisto (Jupiter)
Titan (Saturn)
Rhea (Saturn)
Enceledus (Saturn)
Triton (Neptune)
Oberan (Uranus)
Titania (Uranus)

<u>Trans-Neptunian Objects</u>
Sedna
Eris



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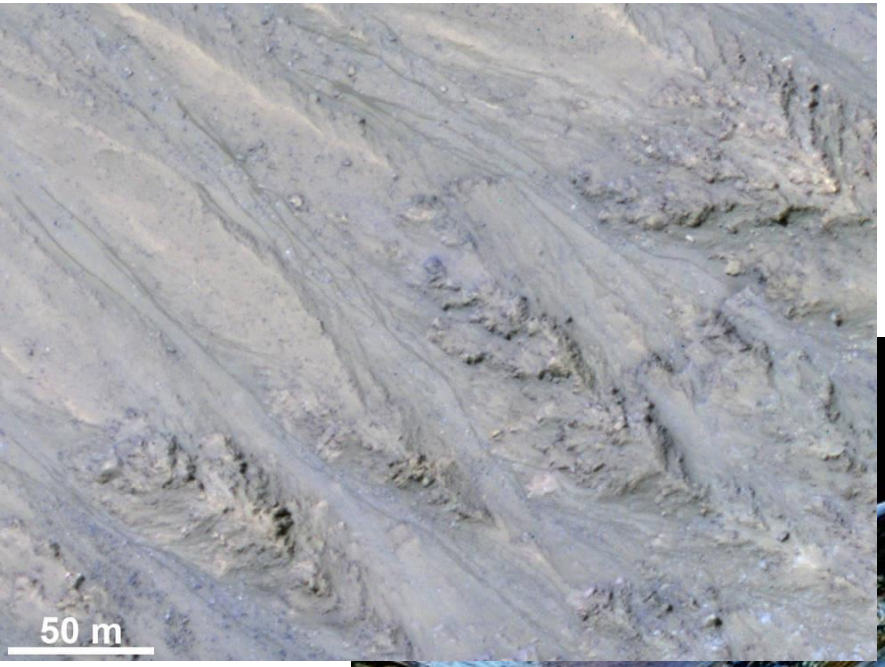
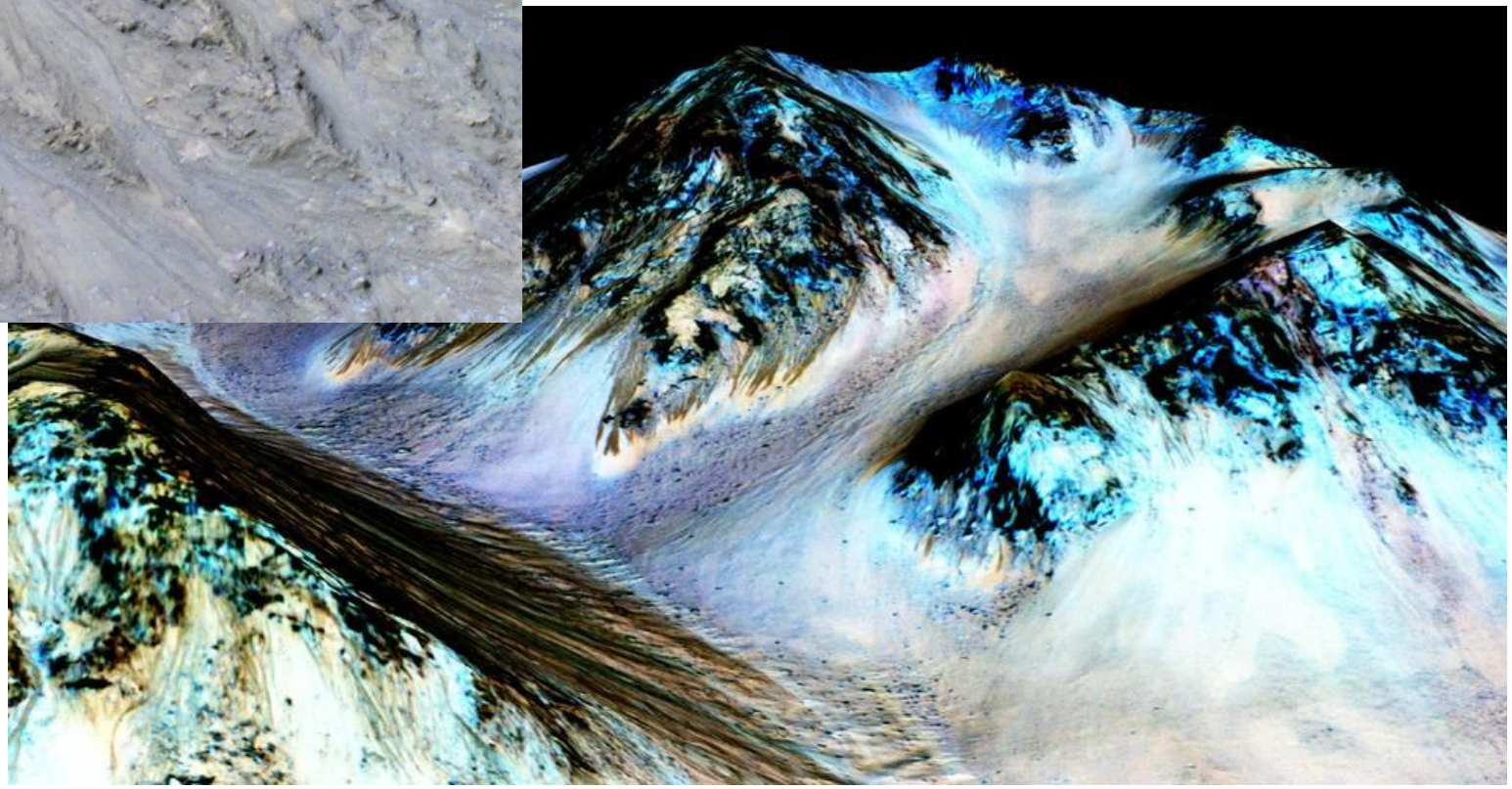
- Even Mars may have liquid water at times




- Highly controversial, could also be sand, but…
- Correlated to warm seasons
- Co-occur with hydrated salts



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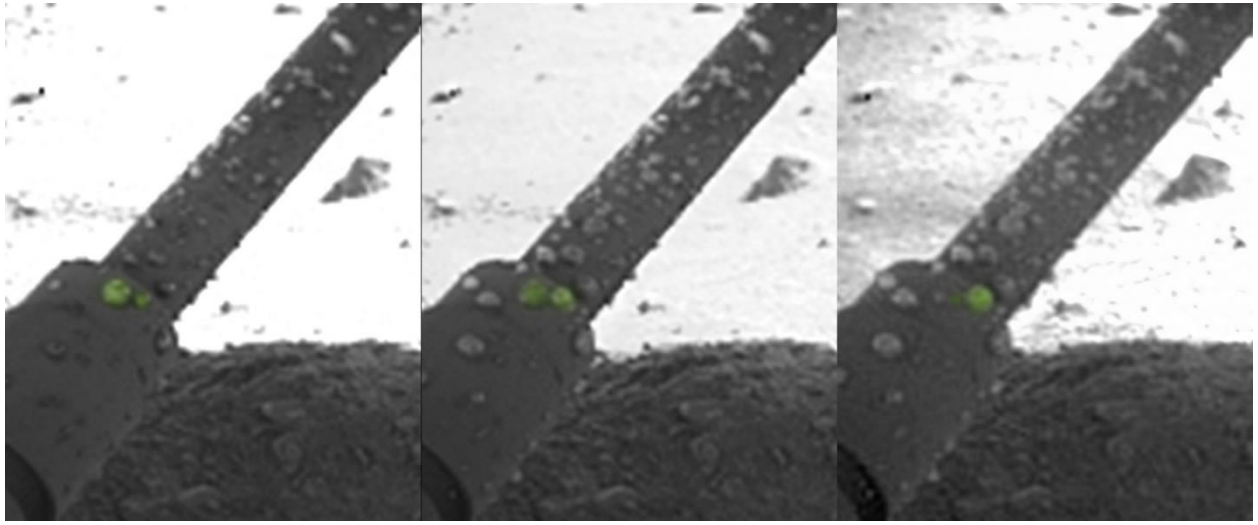
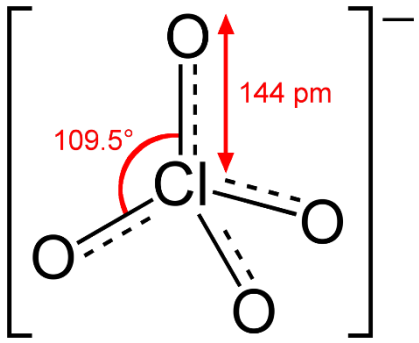


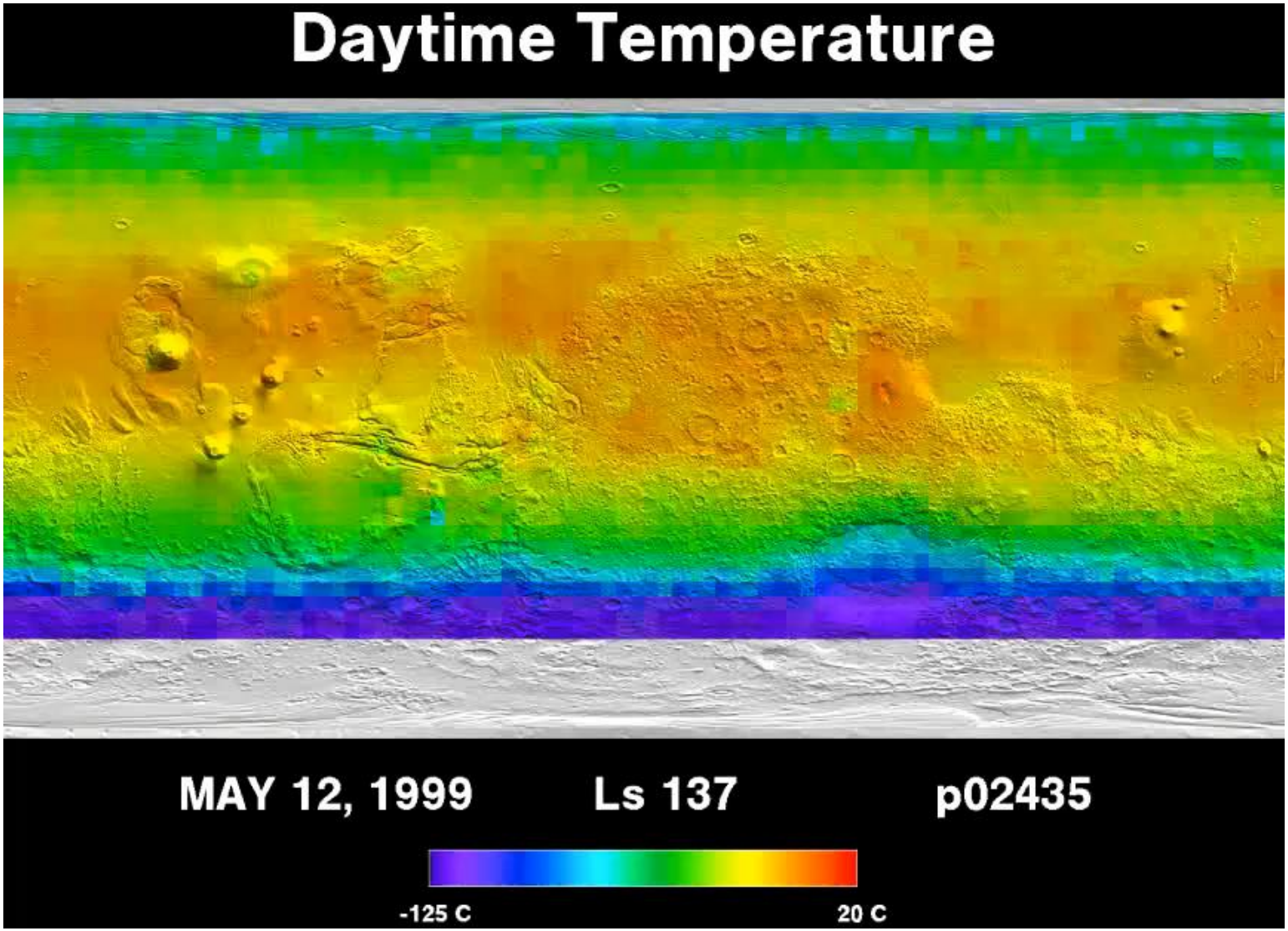
Q: What common substances lower the freezing point of water?
A: Salt – on Mars perchlorate salts do a great job




Eutectic: -67.15
Q: But what does this mean for biology?

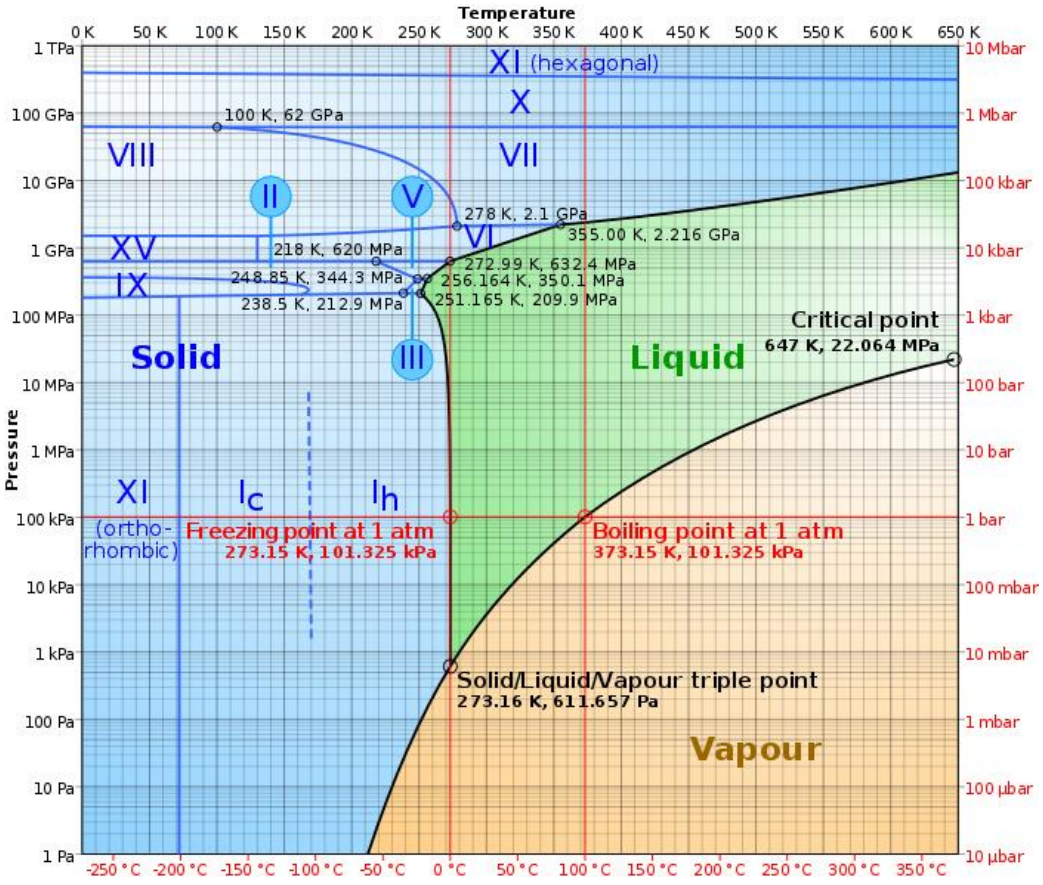
Putative liquid water on Mars Phoenix Lander

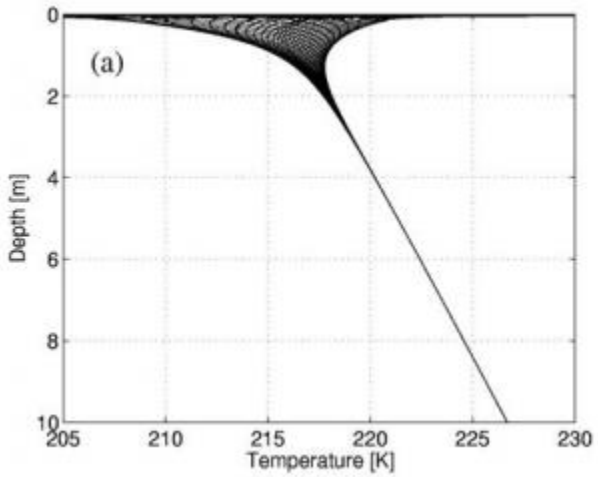
Mars surface temperatures from Themis spacecraft

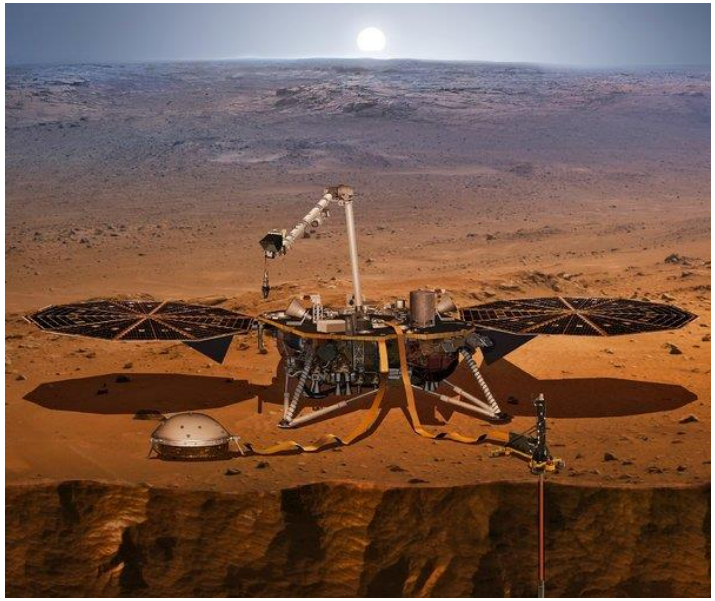


Atmospheric pressure of Mars: 6.0 mbar

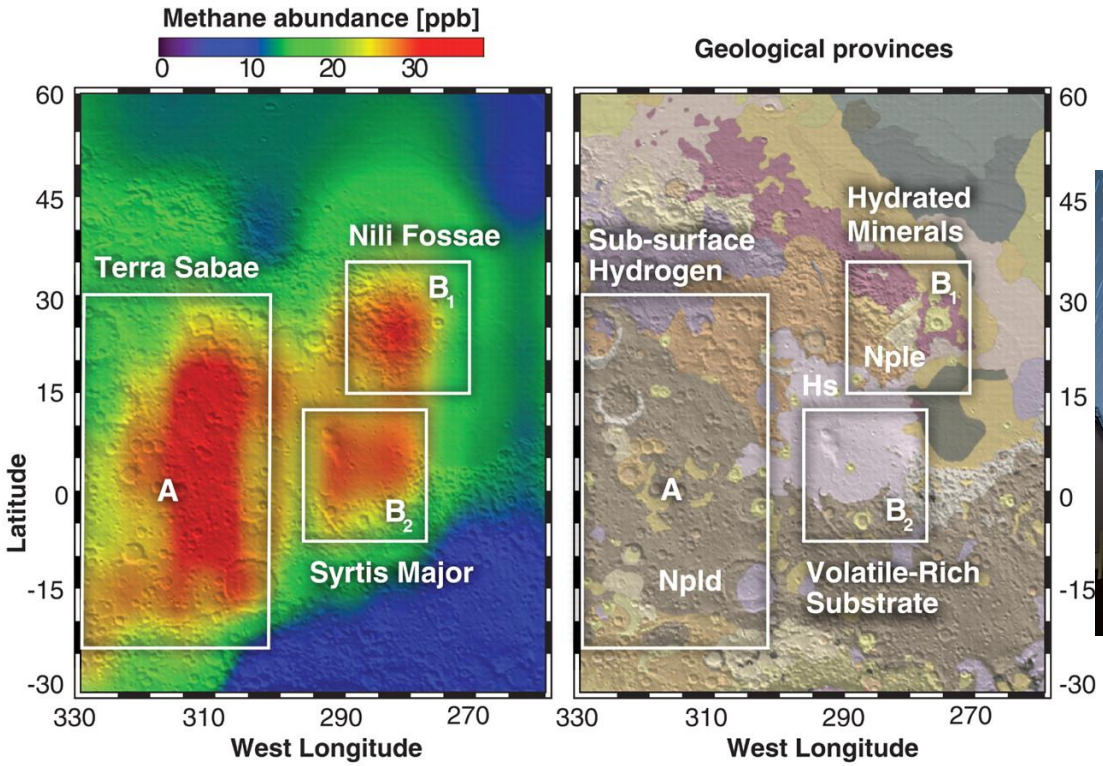
Q: At what atmospheric pressure is water not possible?



*Insight* lander (should launch shortly)

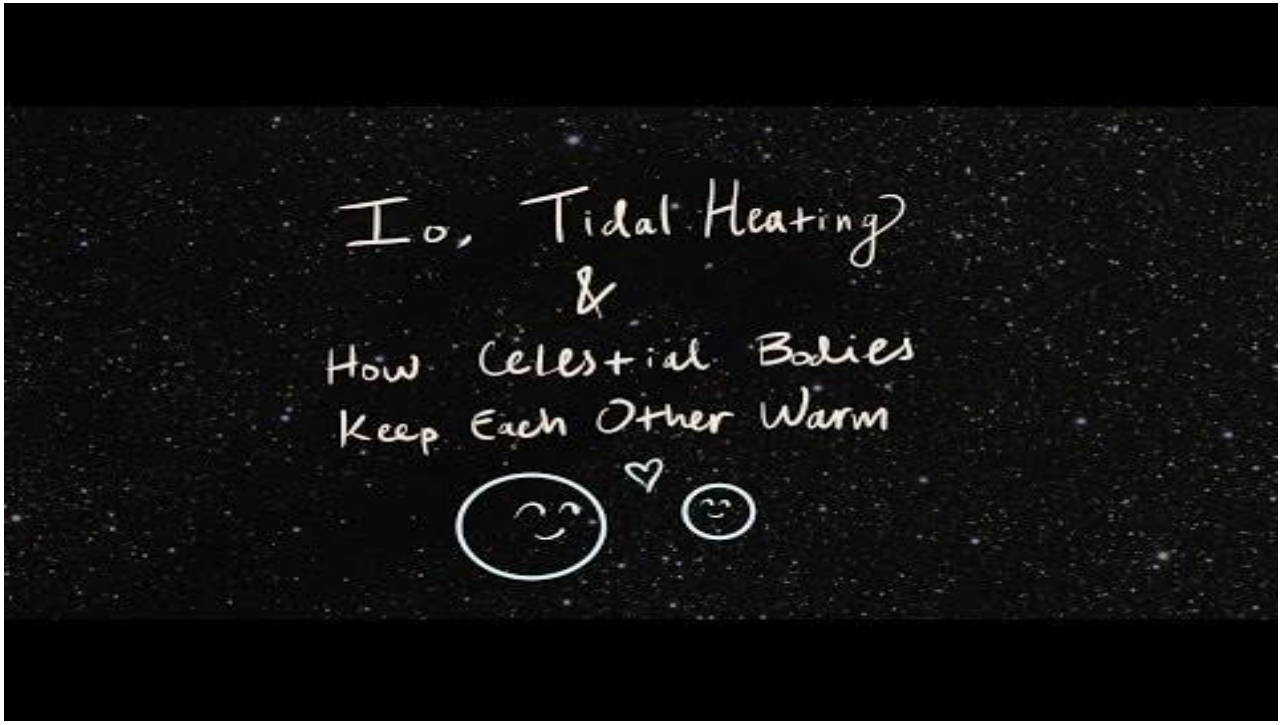



Mumma et al., 2009

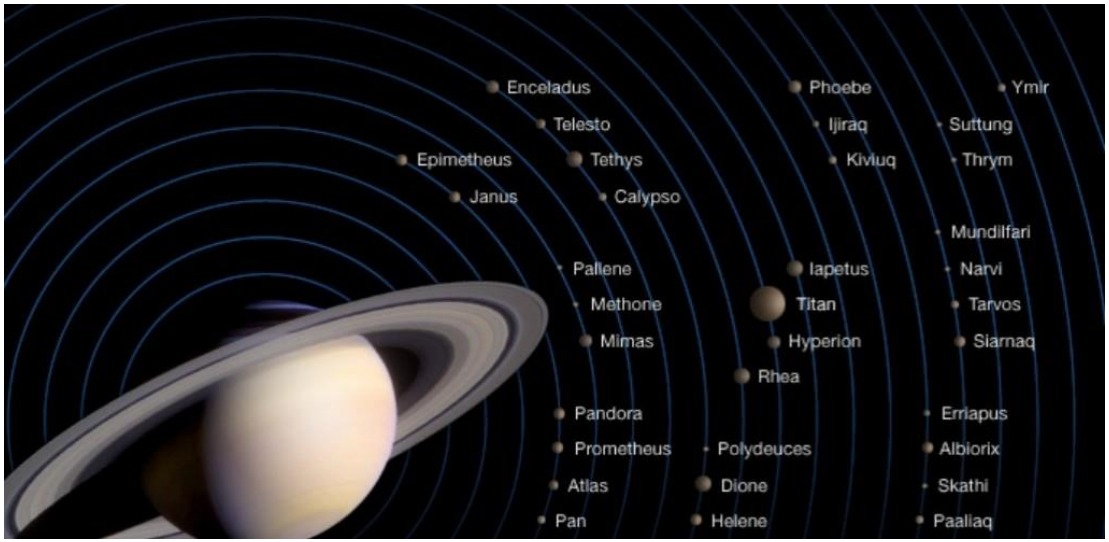
- There is a whiff of methane in the Martian atmosphere, and the residence time is predicted to be very, very short
- Some hints at a seasonal cycle
- Possible geological sources, but still implies an active hydrosphere which is critical for possible life!

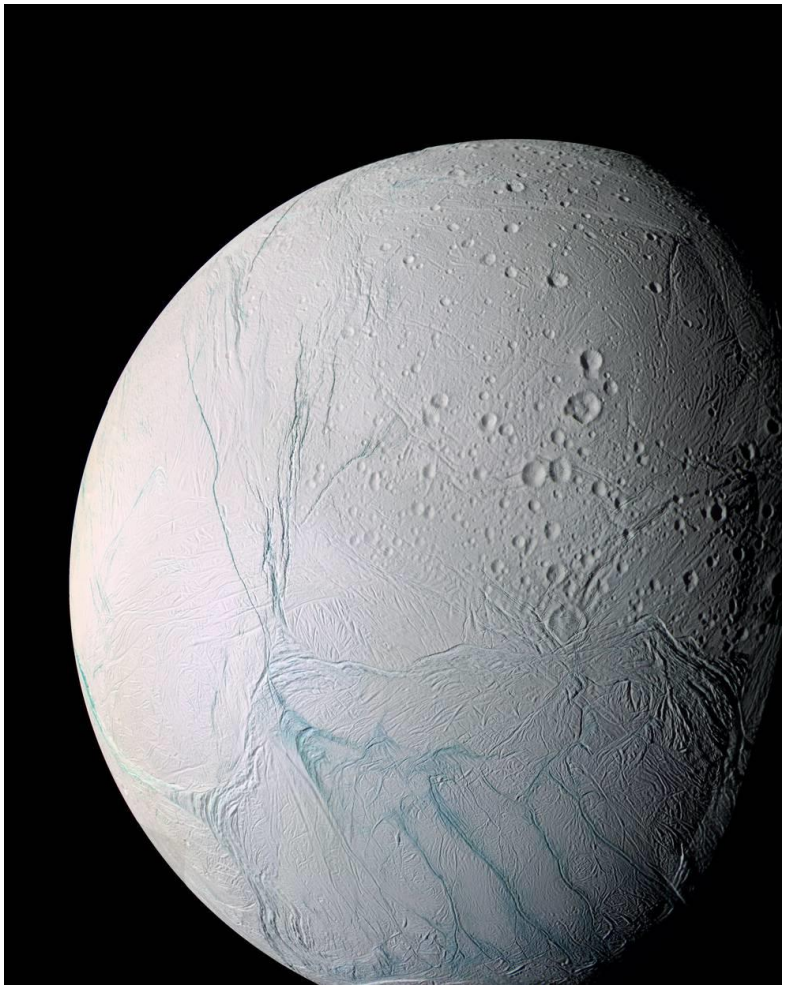
- The moons of the outer planets may be among our best opportunities to find *extant*, *independent* life (why?)
- Efforts are currently focused on Enceladus and Europa
- How do these bodies maintain a liquid ocean, given that they're so far from the sun?

- The moons of the outer planets may be among our best opportunities to find *extant*, *independent* life (why?)
- Efforts are currently focused on Enceladus and Europa
- How do these bodies maintain a liquid ocean, given that they're so far from the sun?

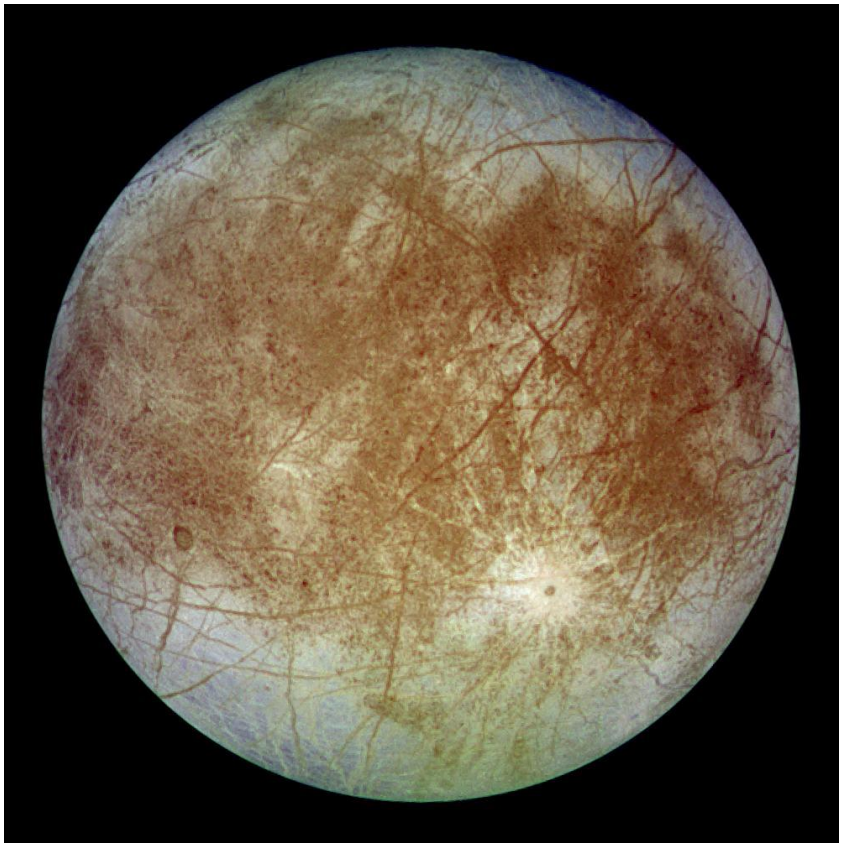


- The most notable feature of Enceladus is plumes of water emanating from the highly fractured south pole region
- The has fueled interest in trying to sample this material from spacecraft (very difficult)
- Otherwise, we know very, very little about Enceladus as it has never been the target of a major mission



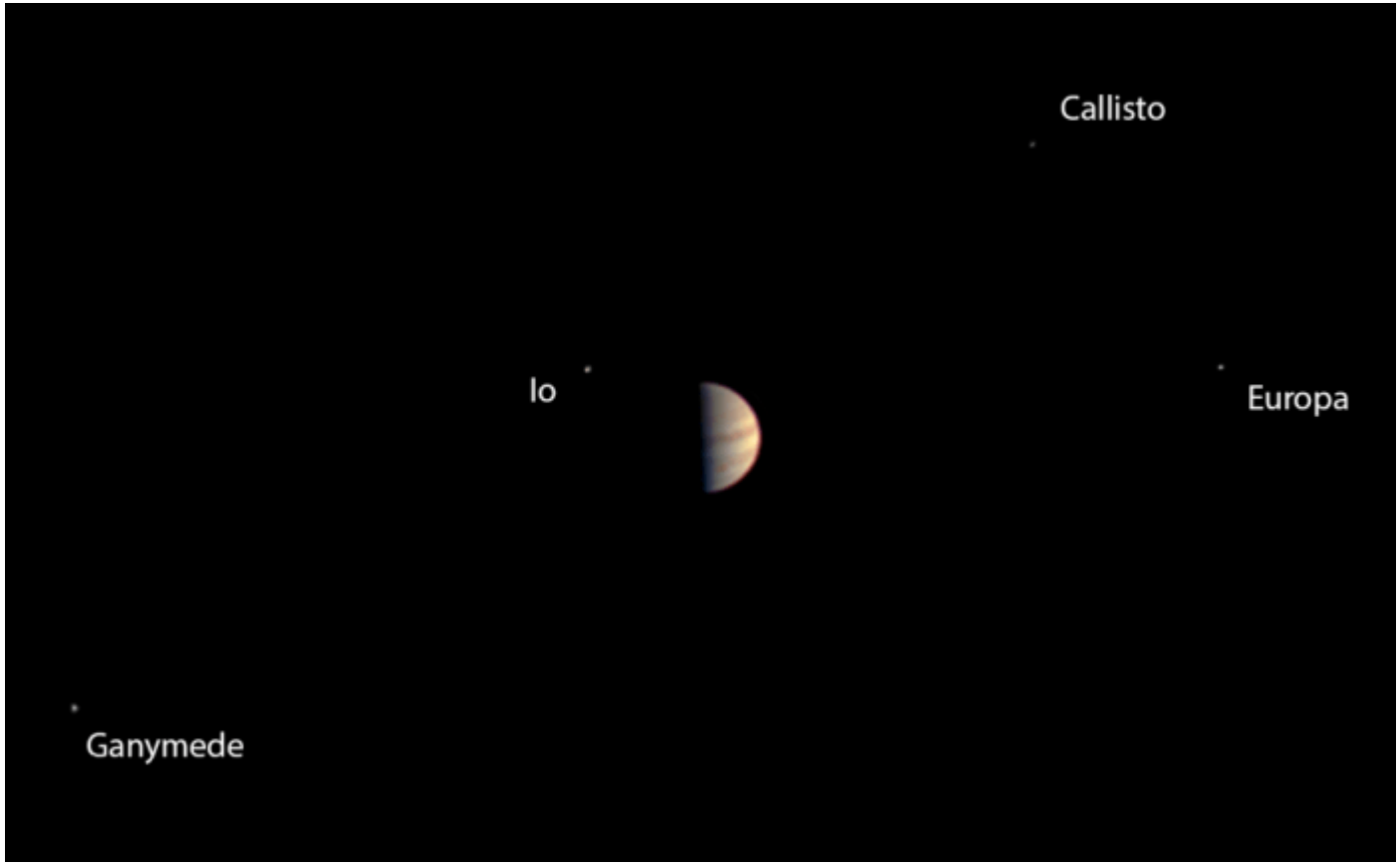



- We know a lot more (but still very little) about Europa
- Notable features of Europa include:
  - Oxidized, tectonically active ice shell
  - Liquid water ocean
  - Potential hydrothermal activity
  - Potential liquid water near the surface (within a few kilometers)



Oxidized ice shell

- Result of complex interaction between Jupiter, Io, Europa



Oxidized ice shell

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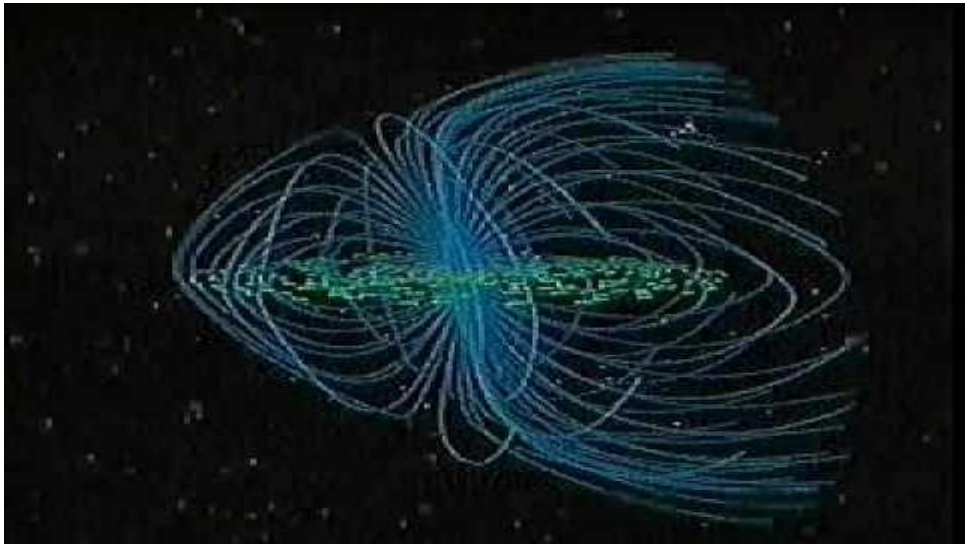
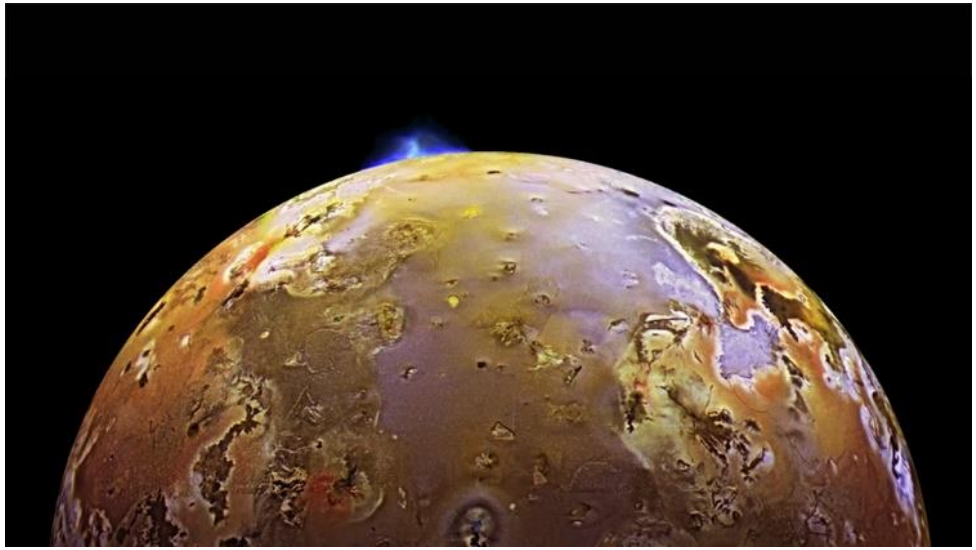
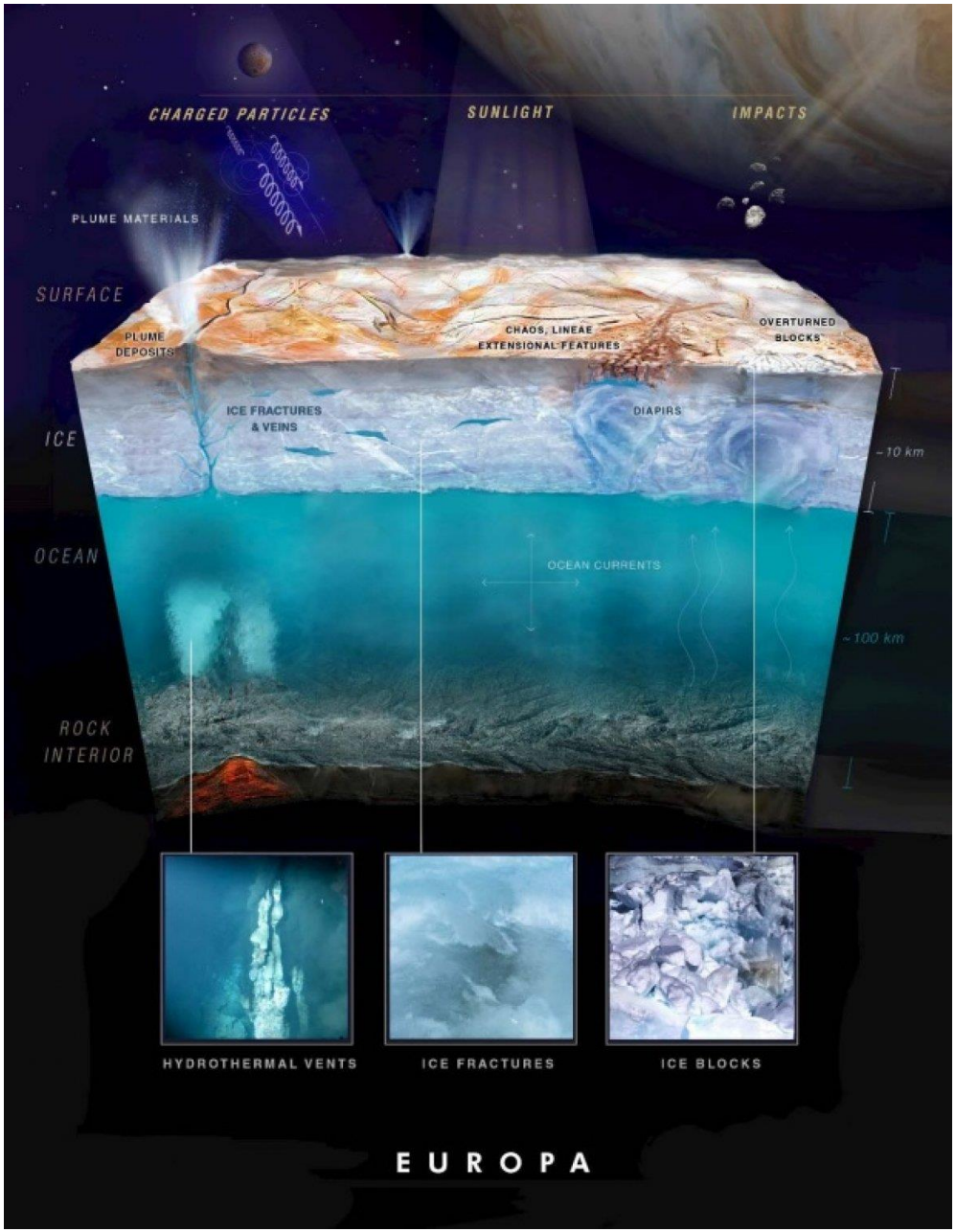


Oxidized ice shell

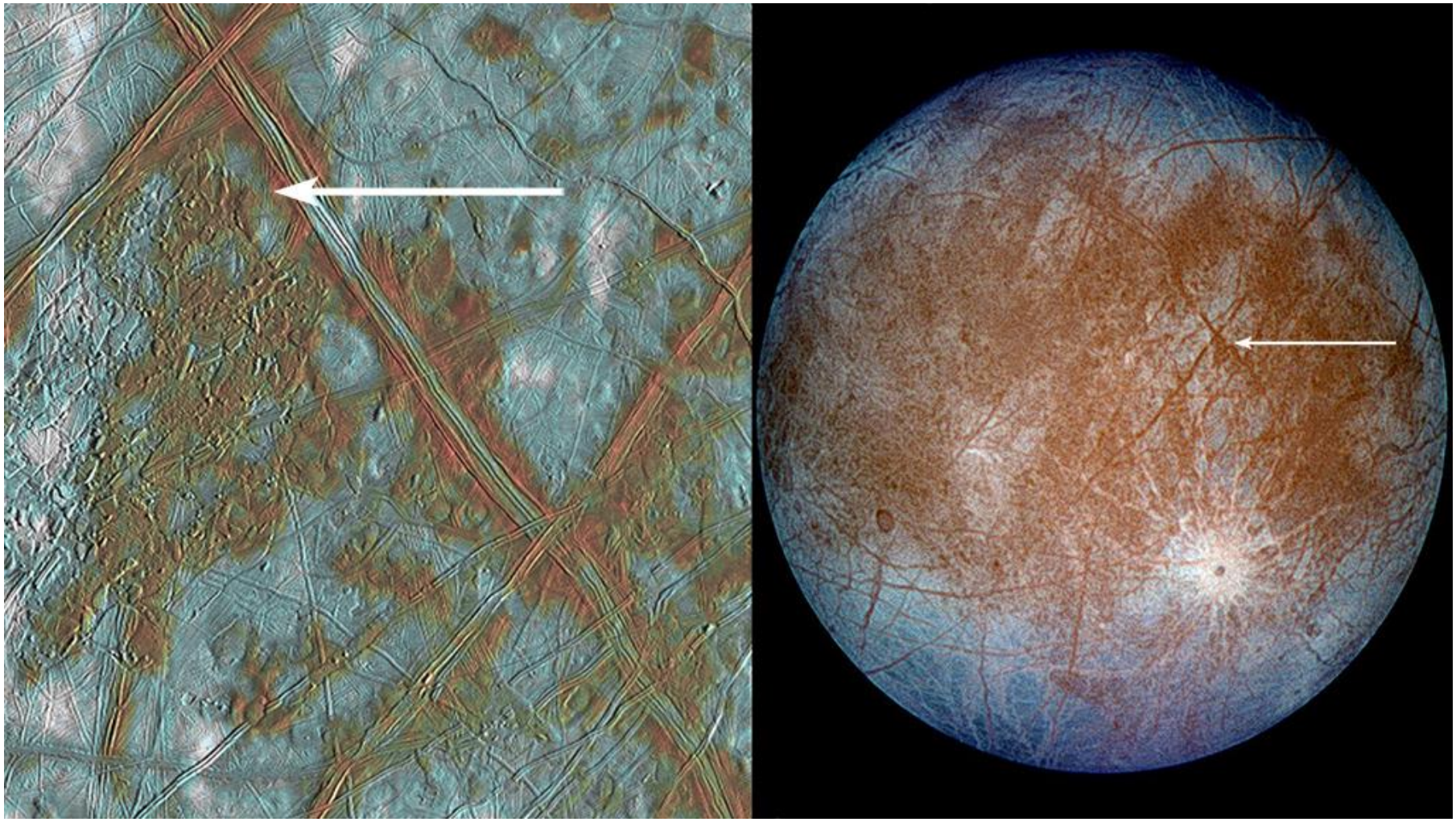
- Result of complex interaction between Jupiter, Io, Europa

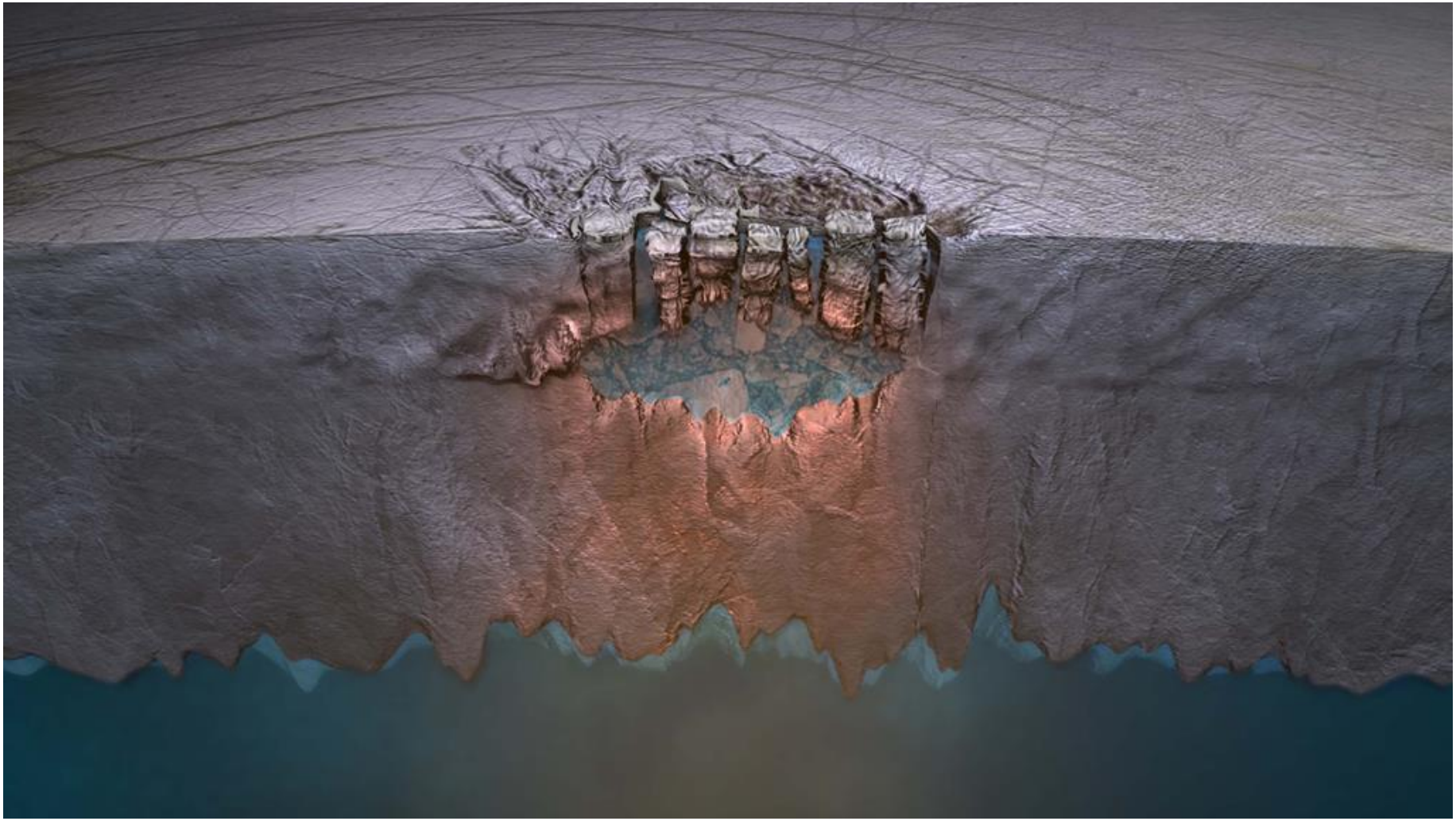


- Io is volcanic as a result of close proximity to Jupiter (tidal heating)
- Volcanic gases interact with Jupiter's radiation belt, become highly energized plasma
- Impact the surface of Europa, cleaving water and other molecules, and creating a diverse array of oxidized compounds, including free oxygen and sulfur
- Q: Why is this important?

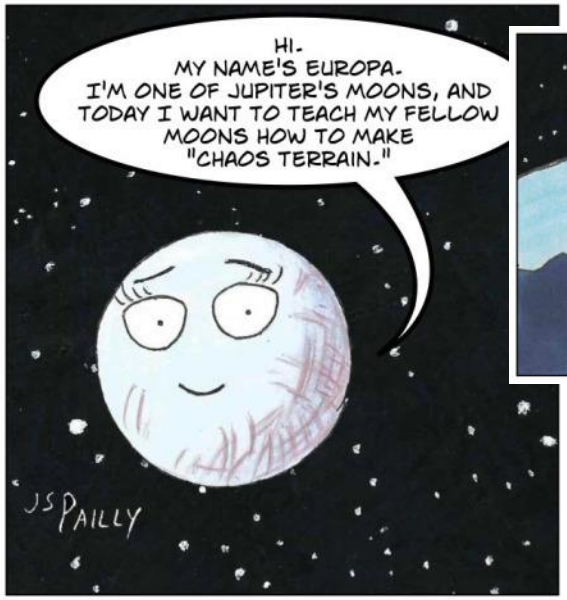

CHARGED PARTICLES
SUNLIGHT
IMPACTS
PLUME MATERIALS
SURFACE
PLUME DEPOSITS
CHAOS, LINEAE EXTENSIONAL FEATURES
OVERTURNED BLOCKS
ICE FRACTURES & VEINS
DIAPIRS
ICE
~10 km
OCEAN
OCEAN CURRENTS
~100 km
ROCK INTERIOR
HYDROTHERMAL VENTS
ICE FRACTURES
ICE BLOCKS
EUROPA

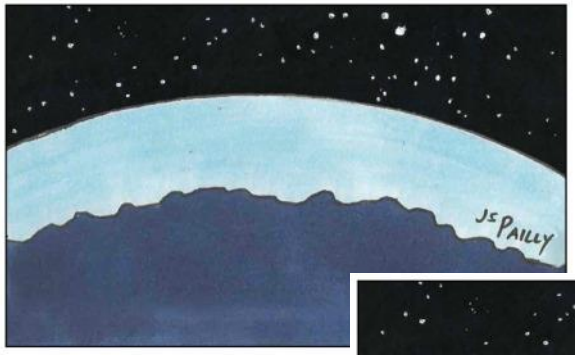
In addition to being oxidized, the ice shell is young and active, and may have subsurface liquid water features



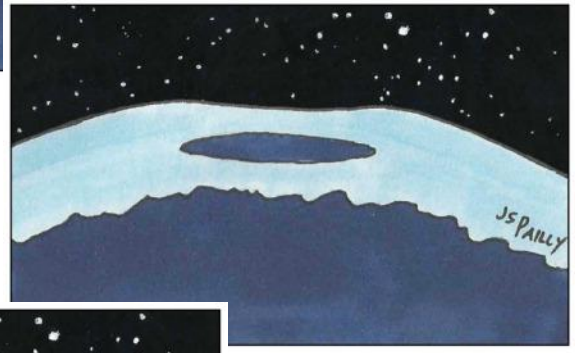


Schmidt et al., 2012



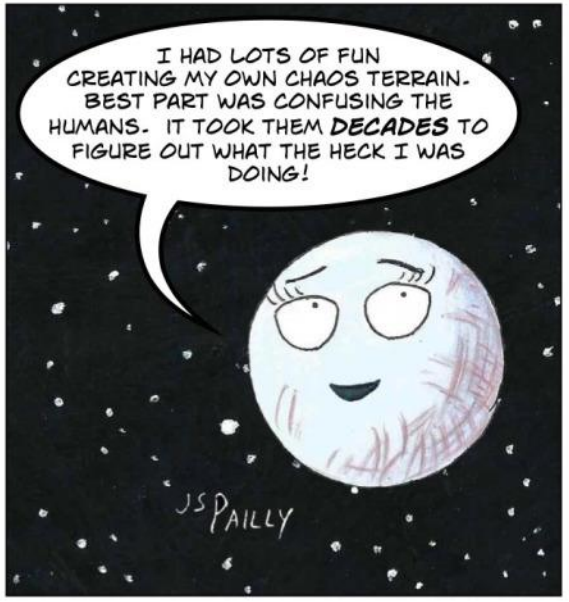

Geothermal heat sets up convection




Lens of salty water is trapped in ice, rises

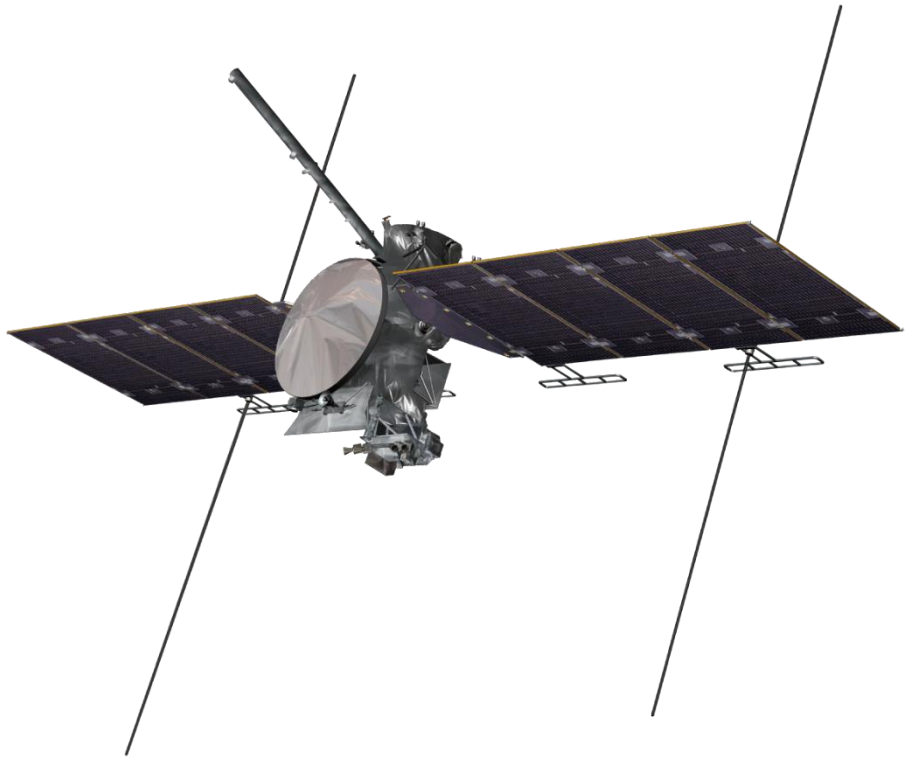

Volume loss (water denser than ice) causes surface to collapse


When lake refreezes expansion pushes ice back upwards

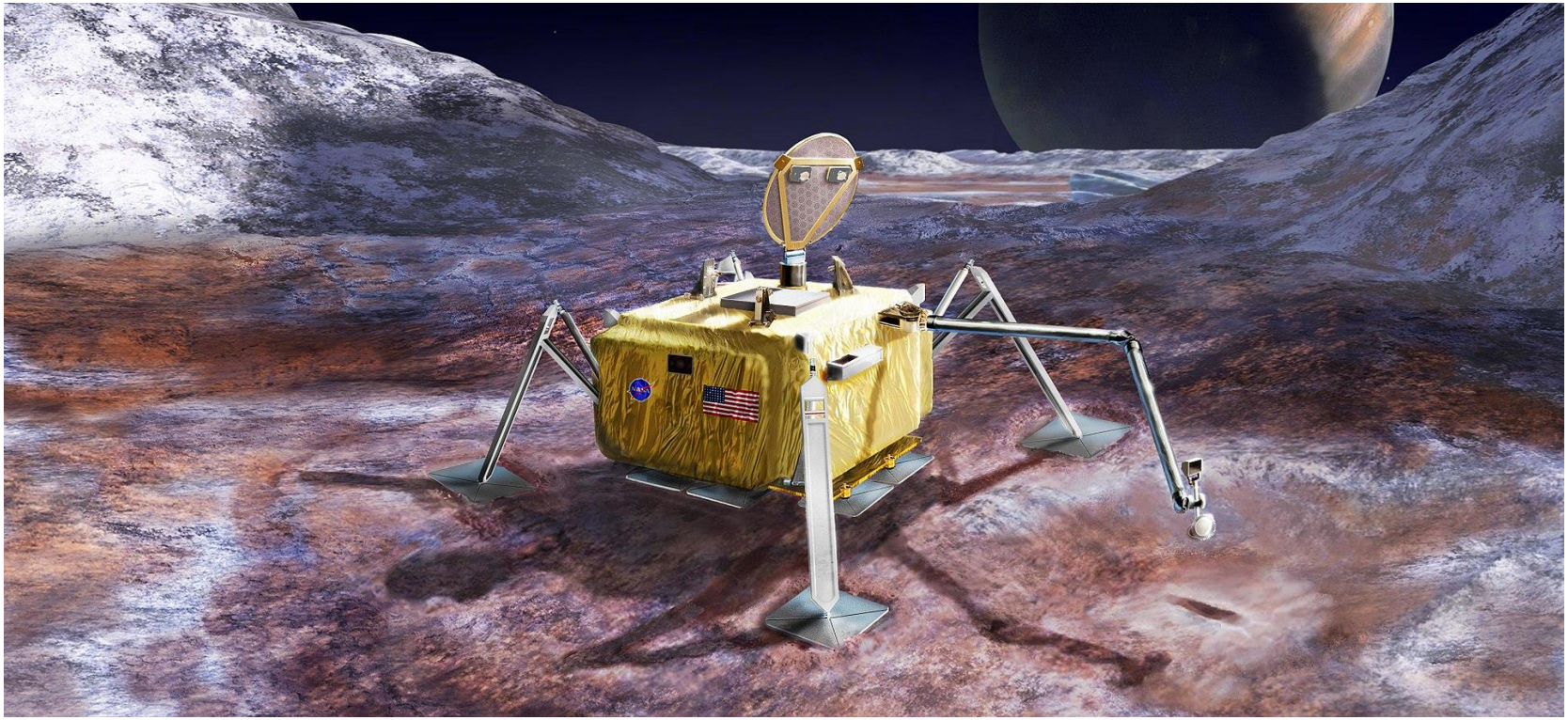



https://planetpailly.com/2015/08/21/sciency-words-chaos-terrain/

- There is incredible competition for “flagship” NASA missions, but Europa has emerged as a leading target in the search for life
  - Europa Clipper, set to launch 2022-2025
  - Series of flybys while in orbit around Jupiter
  - Expected cost > $2 Billion (and it’s not even orbiting!)
  - Will provide massively improved mapping of surface, ice penetrating radar, remote chemical analysis of surface, chemical analysis of (very thin) atmosphere



- There is incredible competition for “flagship” NASA missions, but Europa has emerged as a leading target in the search for life
  - Europa Lander, preliminary feasibility study completed last year
  - NASA instructed study team to go back to drawing board
  - Incredible technical challenges, unrealistic and uneven expectations between Congress, scientific community, public, massive $$$



- There is incredible competition for “flagship” NASA missions, but Europa has emerged as a leading target in the search for life
  - Europa Penetrator? Most scientists think we won’t have a definitive answer on the habitability of Europa unless we penetrate the ice shell
  - Decades away (if ever), but many people are working on this…