Life in a Cosmic Context

Session 5: Life in the Solar System

5th Workshop of the
Italian Astrobiological Society,

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(15.15-15.35)

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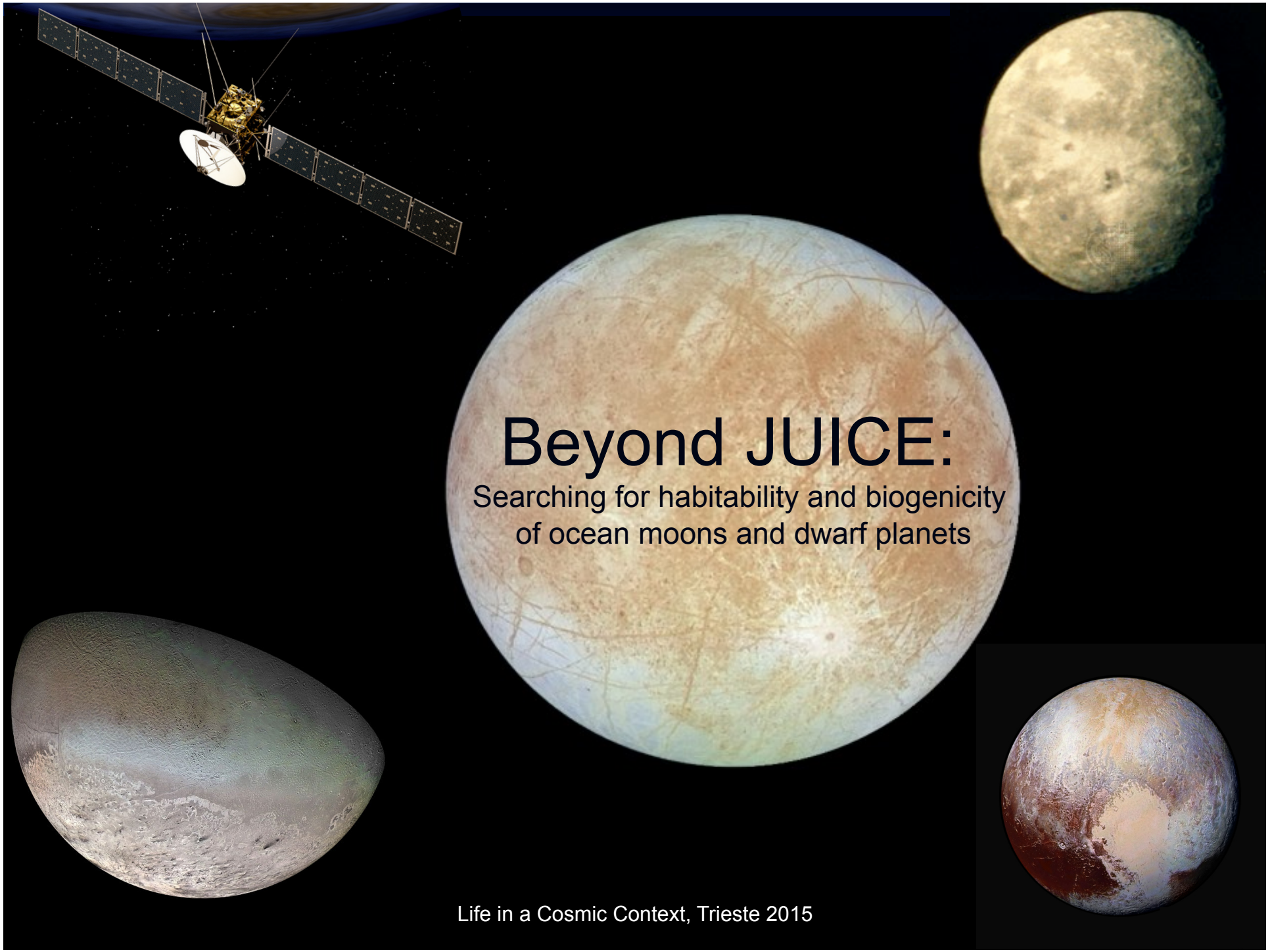

Beyond JUICE:

Searching for habitability and biogenicity of ocean moons and dwarf planets

Life in a Cosmic Context, Trieste 2015

Summary

1. Geochemistry: isotope fractionation

2. Habitability at the poles and in the Solar System

3. Searching for biogenicity from Galileo till JUICE

4. Searching for biogenicity in the post- JUICE era

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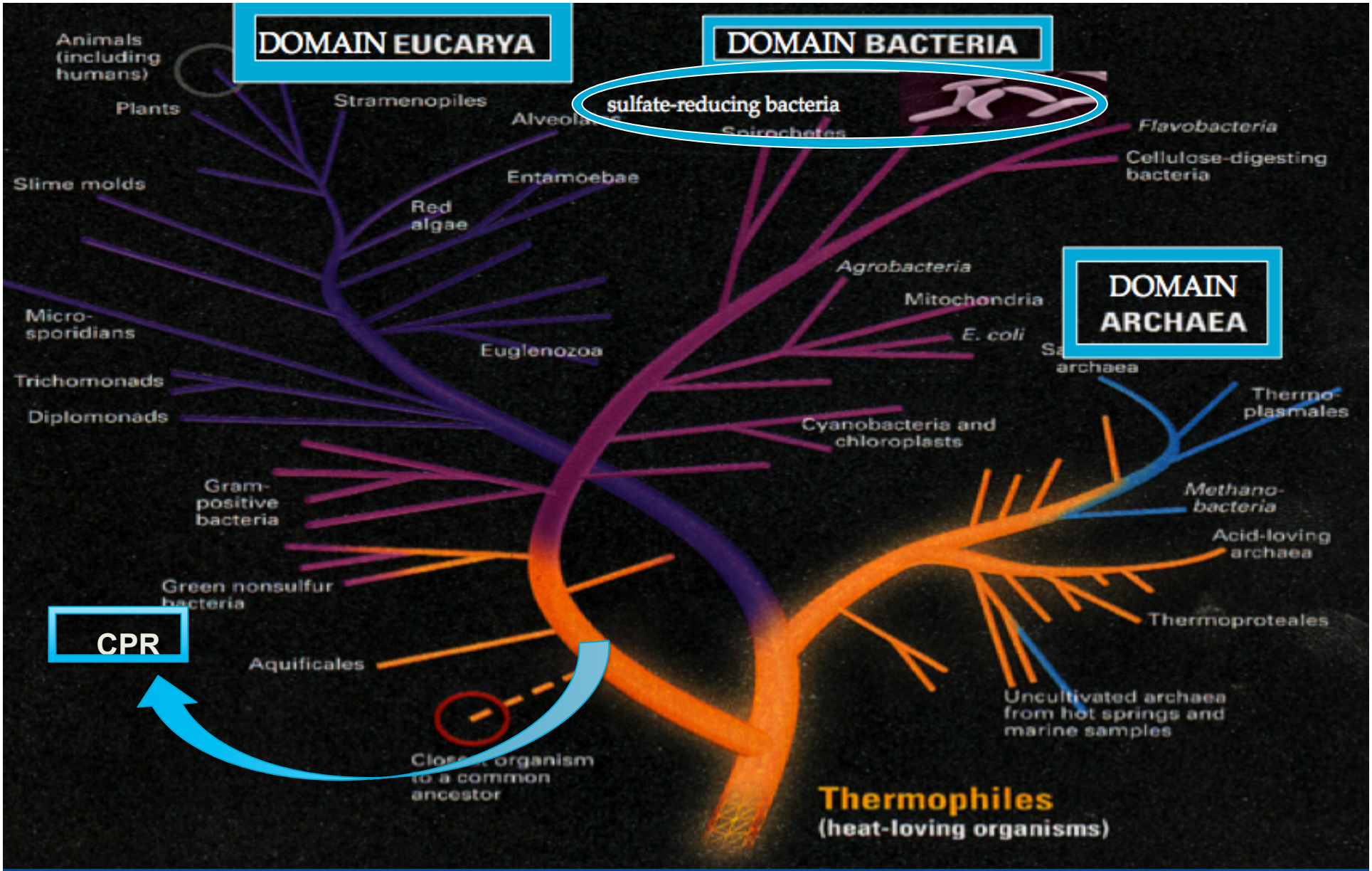


Could the properties of sulfate-reducing bacteria help us to identify biogenicity in the Solar System?

Isotopic fractionation

For the mix of ^{32}S and the less abundant isotope ^{34}S, a δ-parameter is defined in a given sample (sa, such as the product of sedimentation) with respect to a standard mix of isotopes "st") as :

$$\delta^{34}S = [(^{34}S/^{32}S)_{sa} / (^{34}S/^{32}S)_{st} - 1] \times 10^3 \quad \text{(CDM, } {}^{0}/_{00}\text{)}$$

We take as the standard (st) mix of isotopes what we find in a "Canyon Diablo meteorite" (CDM).

A crater in Canyon Diablo region (Arizona, USA) gives the name to the Canyon Diablo meteorite (CDM)

A 360 kg fragment of the meteorite has survived
(Muséum national d'Histoire naturelle in Paris)

What does the delta parameter tell you?

- *When the S isotope abundance in a sample is comparable to the mix of ^{32}S and ^{34}S in the CDM,*

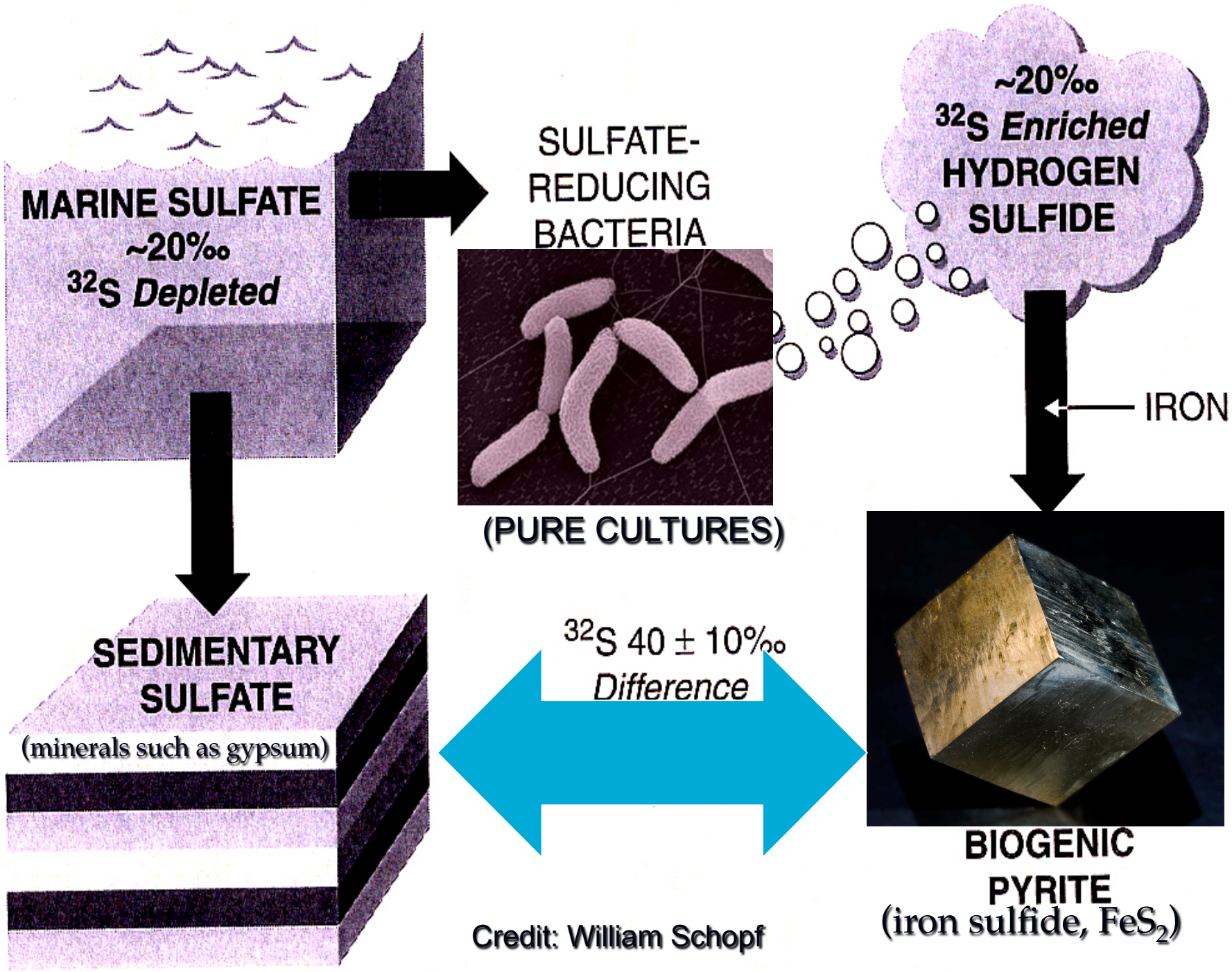
$$\delta^{34}S = 0.$$

- *When the (microbially altered sedimentary sulfide) sample has more abundant ^{32}S than in the mix of ^{32}S and ^{34}S in the CDM,*

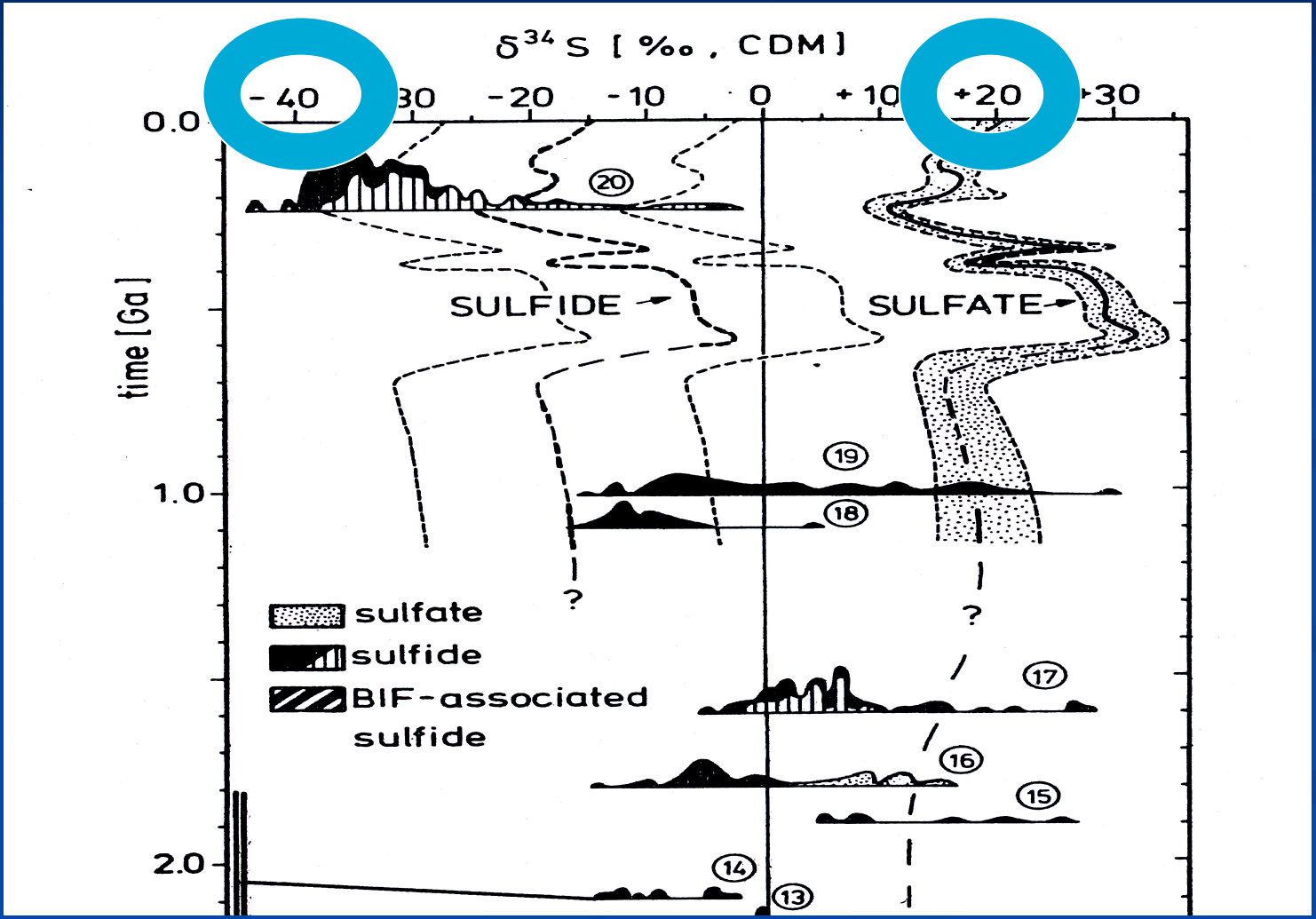
$$\delta^{34}S < 0.$$

- *When the (sedimentary sulfate) sample has more abundant ^{34}S than than in to the mix of ^{32}S and ^{34}S in the CDM,*

$$\delta^{34}S > 0.$$


MARINE SULFATE
~20‰
32S Depleted
SULFATE-
REDUCING
BACTERIA
~20‰
32S Enriched
HYDROGEN
SULFIDE
IRON
(PURE CULTURES)
SEDIMENTARY
SULFATE
(minerals such as gypsum)
32S 40 ± 10‰
Difference
BIOGENIC
PYRITE
(iron sulfide, FeS2)
Credit: William Schopf

The delta-34 function in a historical review of sedimentation on Earth

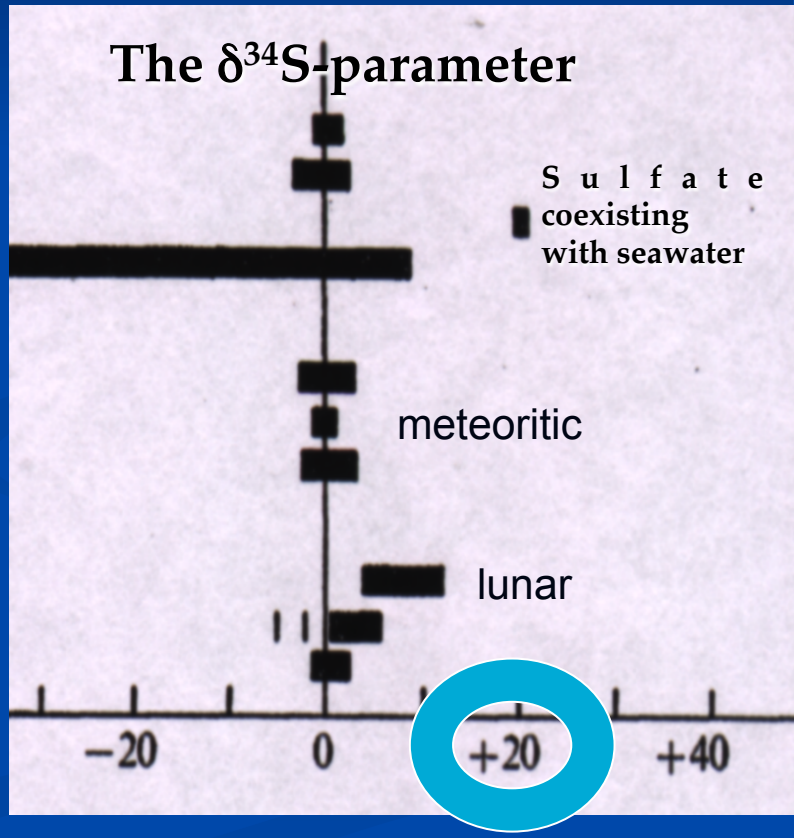


J.W. Schopf (1983). Earth's Earliest Biosphere, Princeton.

Sulfur fractionation in the Solar System

- Sulfur is known to be strongly fractionated by biogenic activity of sulfate reducing bacteria.

On Earth over - *40* ‰



Kaplan, I.R. (1975). Proc. Roy. Soc. Lond. B189, 183-211

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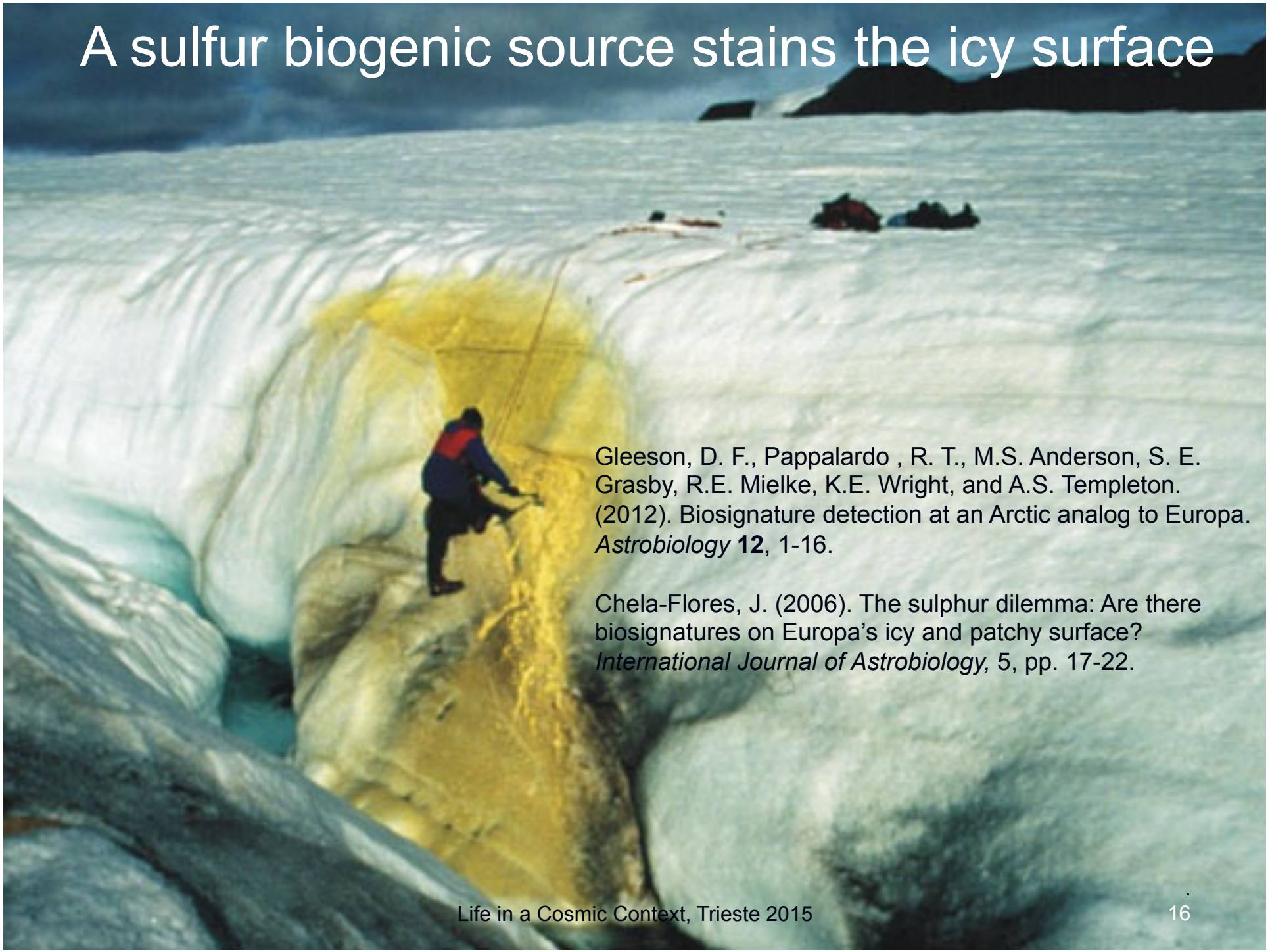
Habitability at the poles

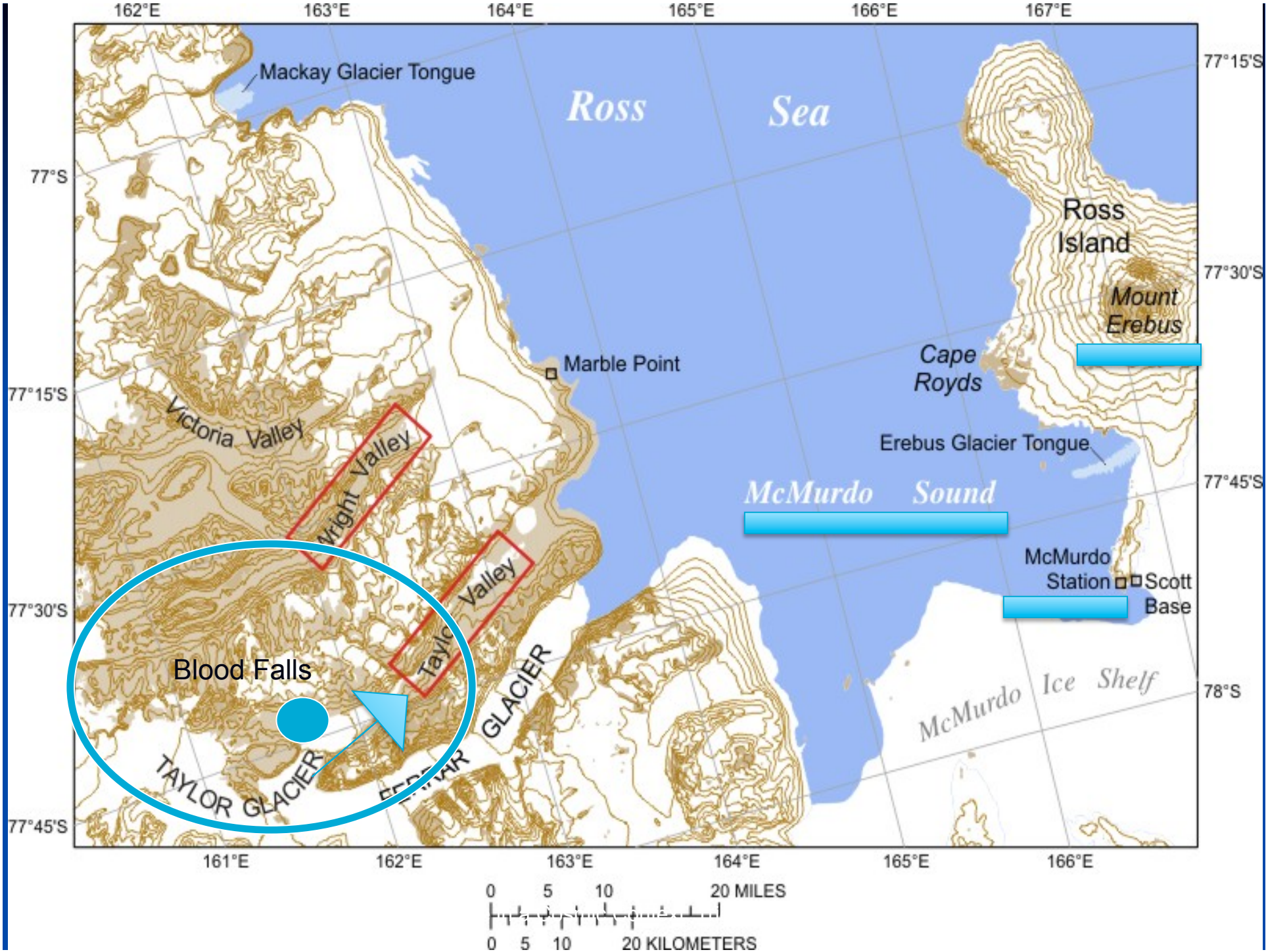
In northen Canada chemical elements stain icy surfaces

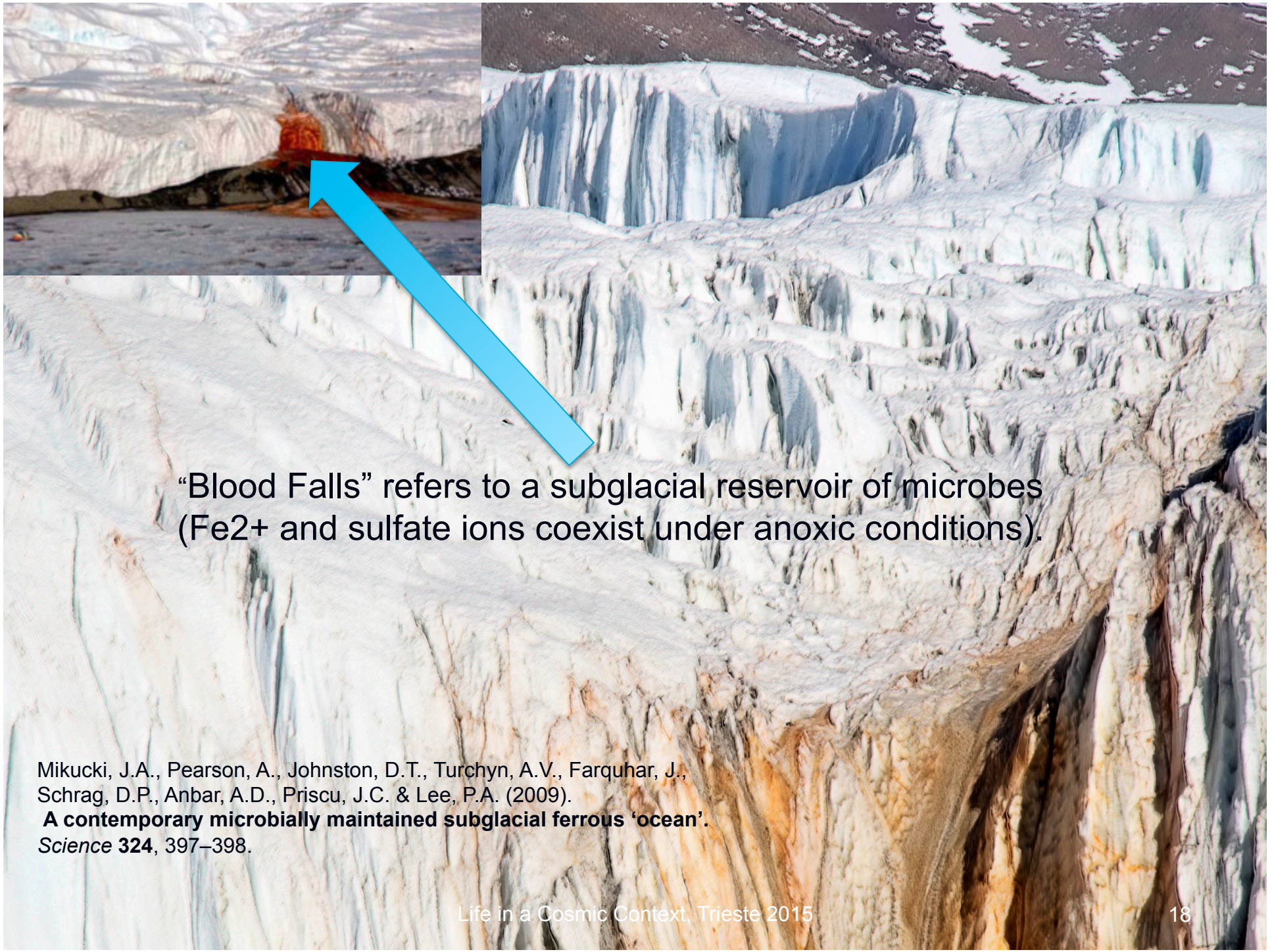
A sulfur biogenic source stains the icy surface



Gleeson, D. F., Pappalardo , R. T., M.S. Anderson, S. E. Grasby, R.E. Mielke, K.E. Wright, and A.S. Templeton. (2012). Biosignature detection at an Arctic analog to Europa. *Astrobiology* **12**, 1-16.

Chela-Flores, J. (2006). The sulphur dilemma: Are there biosignatures on Europa's icy and patchy surface? *International Journal of Astrobiology,* 5, pp. 17-22.


162°E
163°E
164°E
165°E
166°E
167°E
77°15'S
77°S
77°30'S
77°45'S
78°S
161°E
Mackay Glacier Tongue
Ross Sea
Ross Island
Mount Erebus
Cape Royds
Marble Point
Victoria Valley
Wright Valley
Taylor Valley
Erebus Glacier Tongue
McMurdo Sound
McMurdo Station
Scott Base
Blood Falls
TAYLOR GLACIER
GLACIER
McMurdo Ice Shelf
0 5 10 20 MILES
0 5 10 20 KILOMETERS

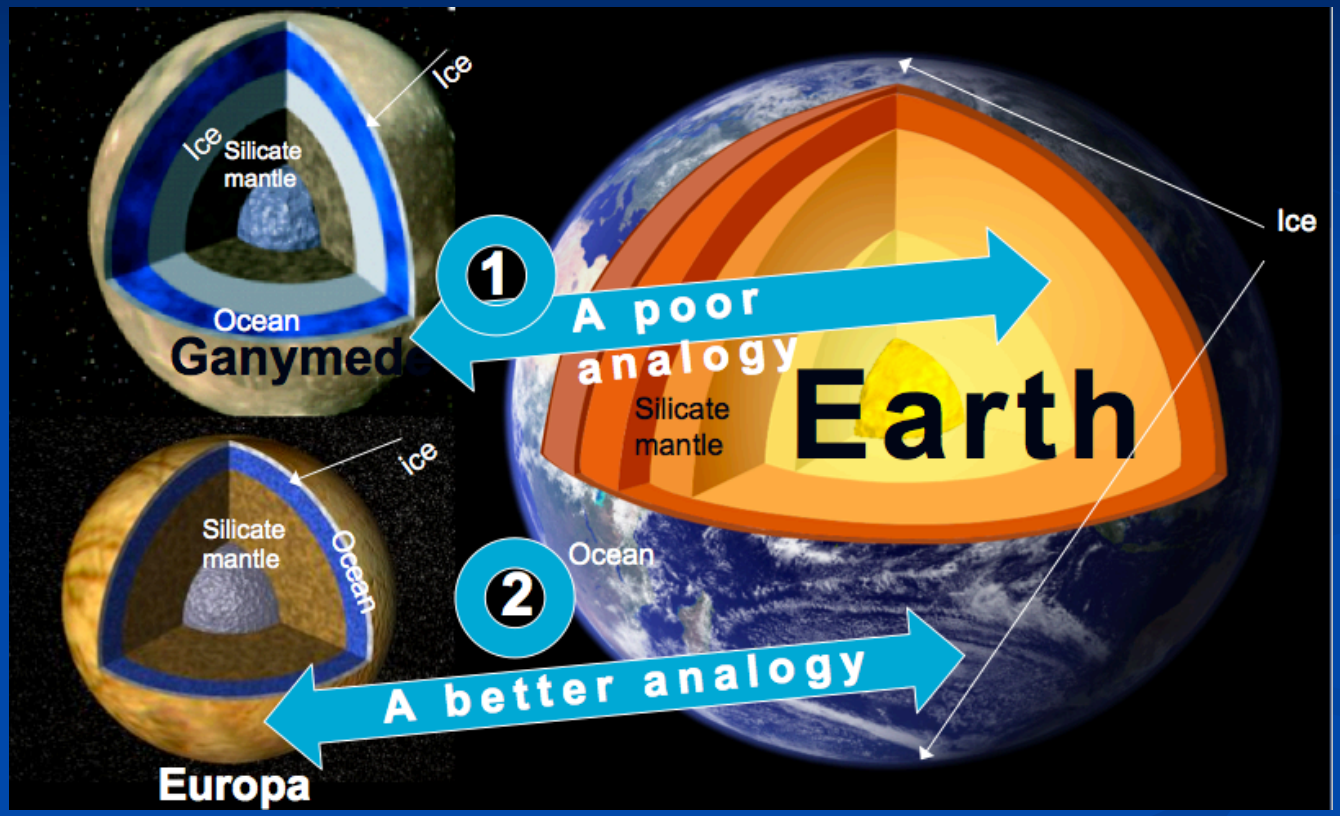


"Blood Falls" refers to a subglacial reservoir of microbes (Fe2+ and sulfate ions coexist under anoxic conditions).

Mikucki, J.A., Pearson, A., Johnston, D.T., Turchyn, A.V., Farquhar, J., Schrag, D.P., Anbar, A.D., Priscu, J.C. & Lee, P.A. (2009).
A contemporary microbially maintained subglacial ferrous 'ocean'.
Science **324**, 397–398.

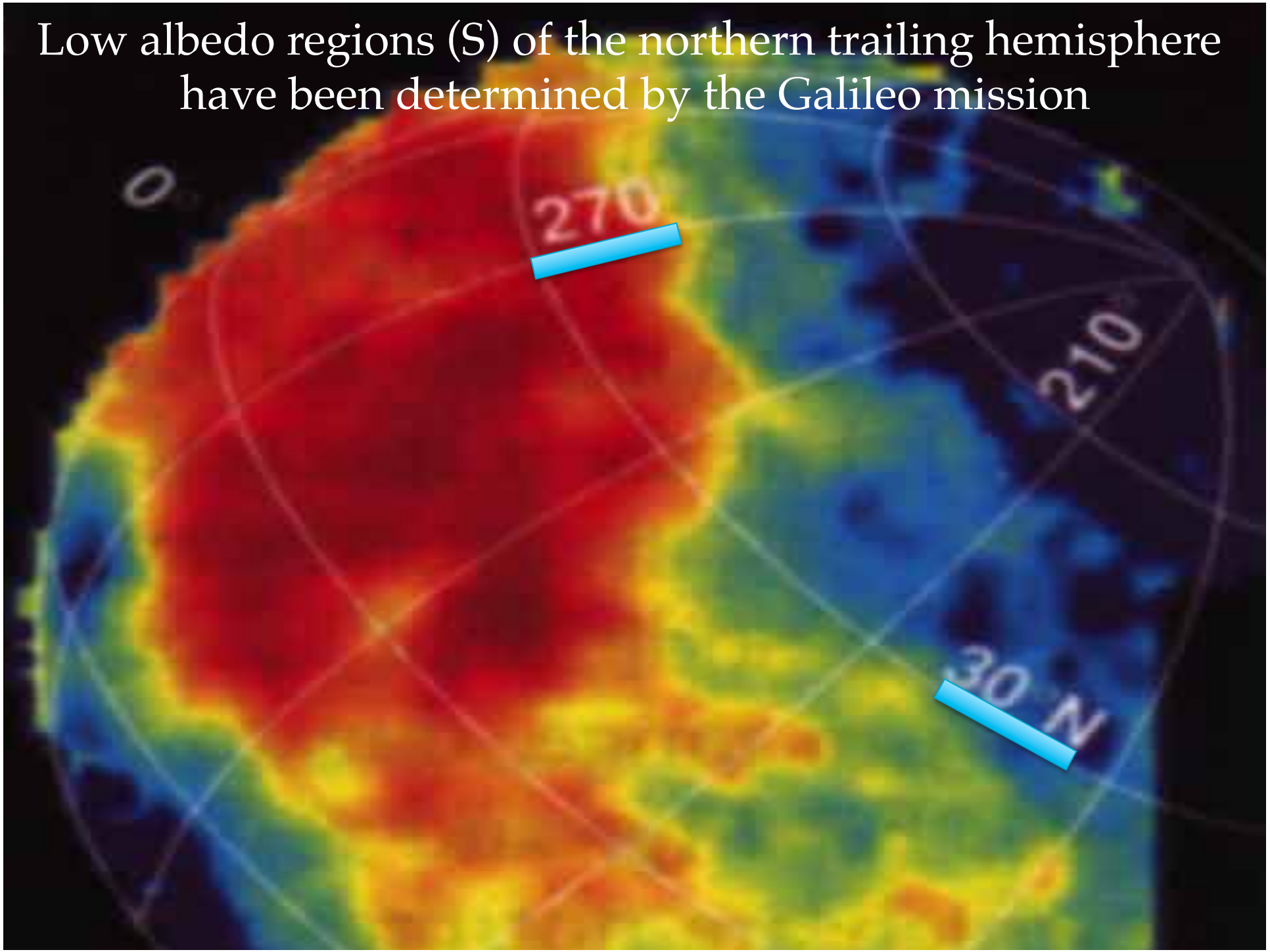
Habitability in the Solar System since Galileo

Is there a good analogy between the inhabited Earth and the habitable Galilean moons?

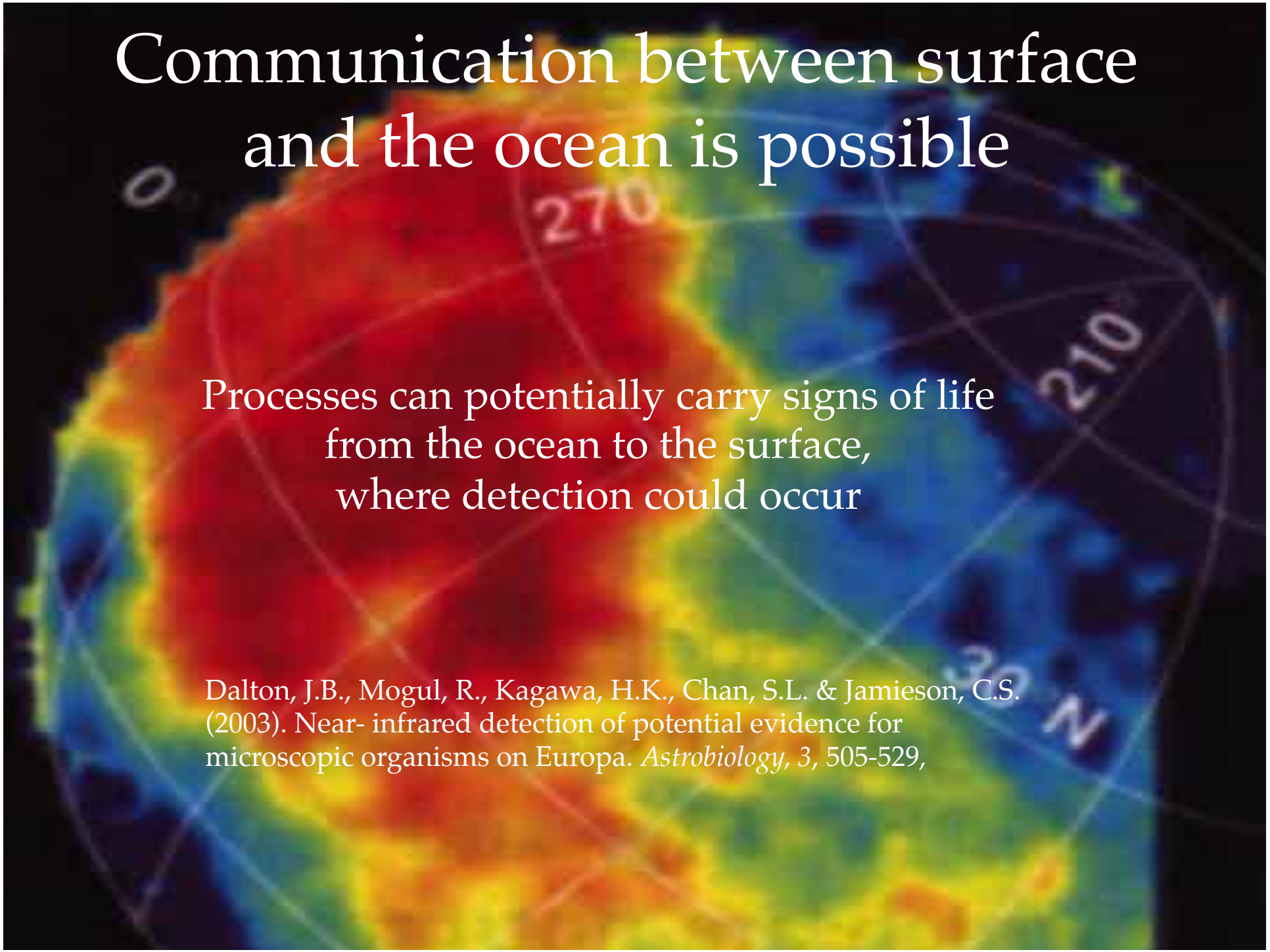


Chela-Flores, J. (2010). Instrumentation for the search of habitable ecosystems in the future exploration of Europa and Ganymede. *International Journal of Astrobiology* **9**, 101-108.

Low albedo regions (S) of the northern trailing hemisphere have been determined by the Galileo mission



Communication between surface and the ocean is possible



Processes can potentially carry signs of life from the ocean to the surface, where detection could occur

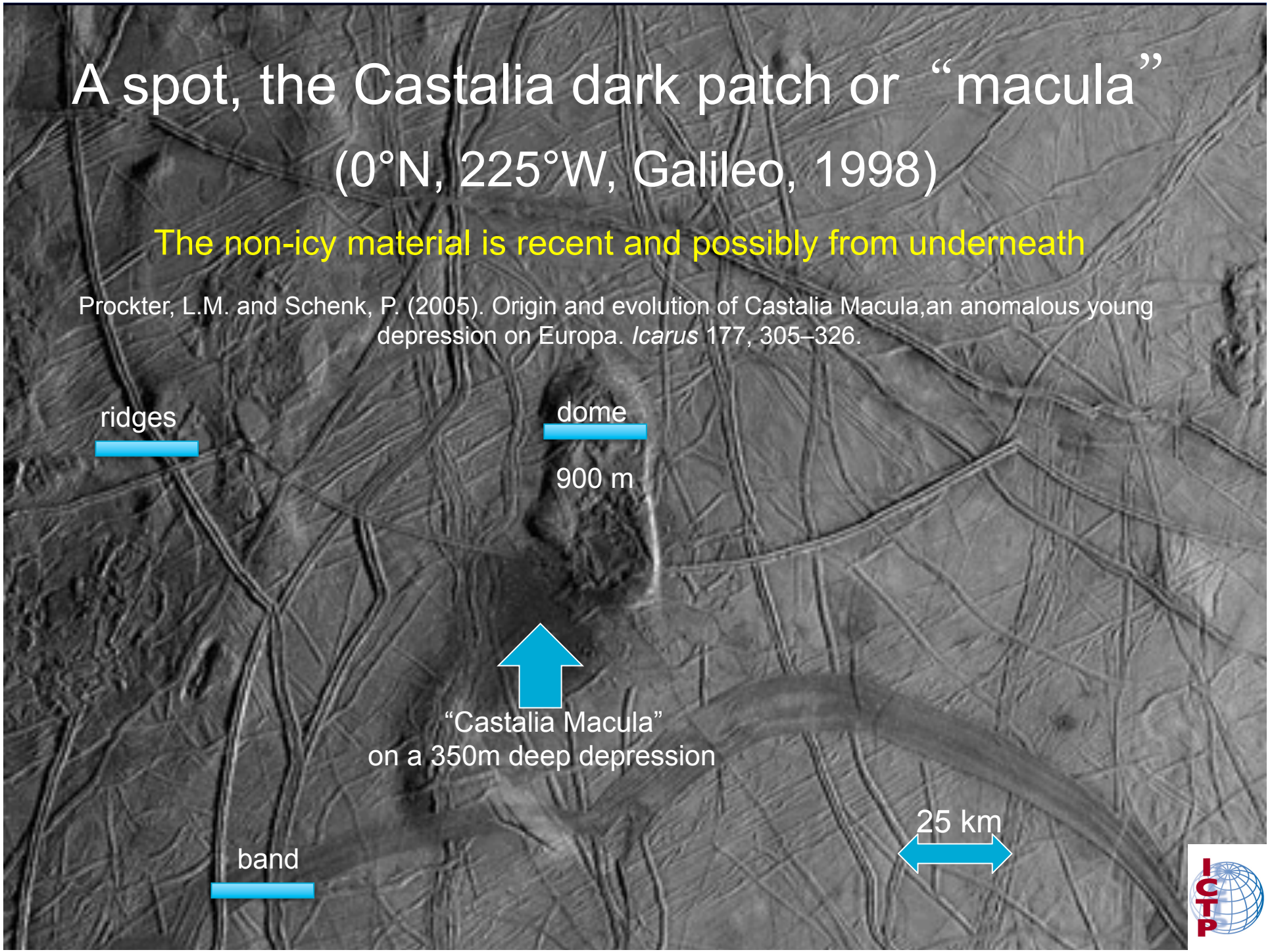
Dalton, J.B., Mogul, R., Kagawa, H.K., Chan, S.L. & Jamieson, C.S. (2003). Near- infrared detection of potential evidence for microscopic organisms on Europa. *Astrobiology, 3*, 505-529,

A spot, the Castalia dark patch or "macula"

(0°N, 225°W, Galileo, 1998)

The non-icy material is recent and possibly from underneath

Prockter, L.M. and Schenk, P. (2005). Origin and evolution of Castalia Macula,an anomalous young depression on Europa. *Icarus* 177, 305–326.



Signs of life can be transferred from the ocean to the icy surface suggesting tests with mass spectrometry (MS)

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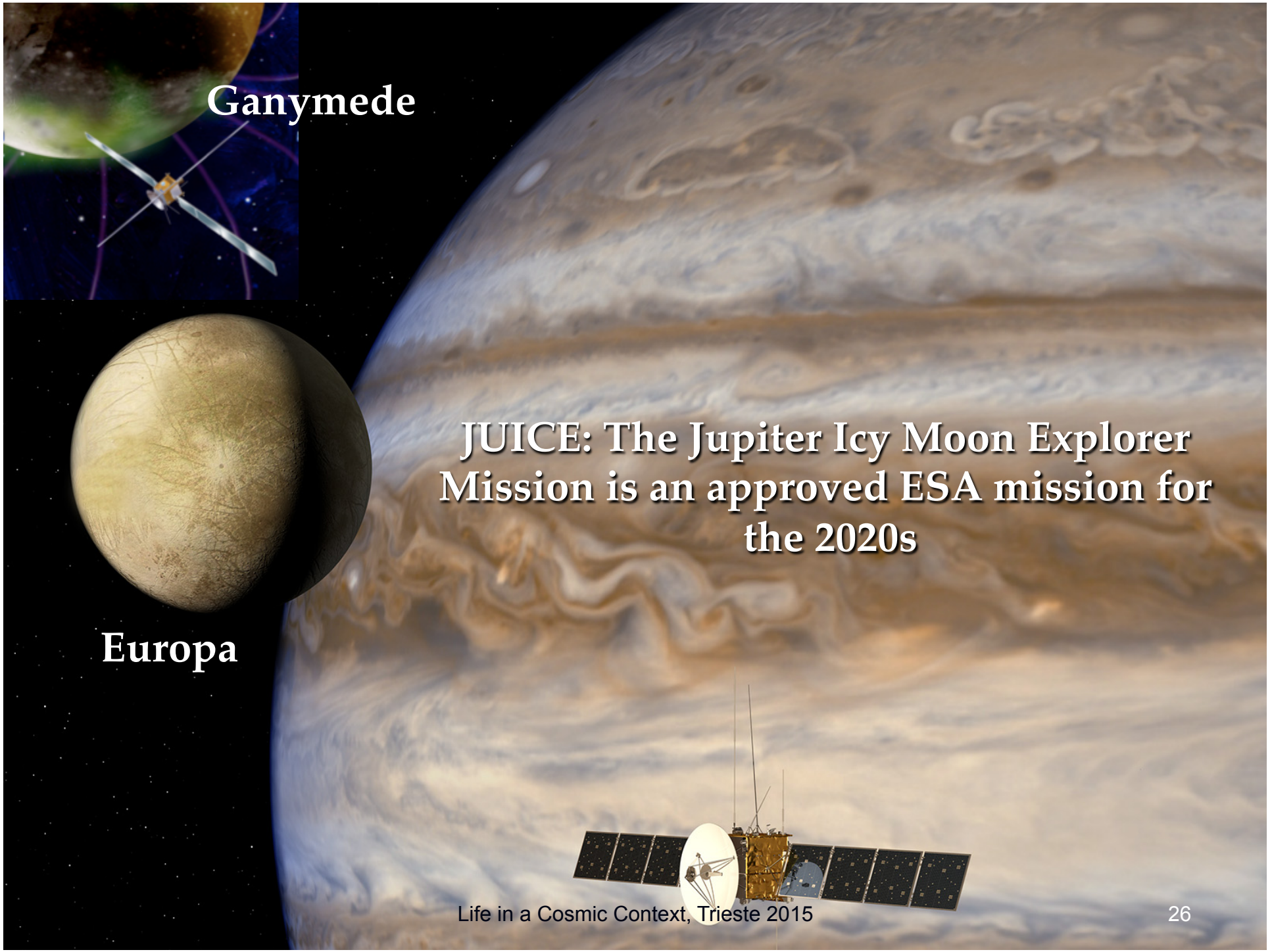

Ganymede
Europa
JUICE: The Jupiter Icy Moon Explorer Mission is an approved ESA mission for the 2020s

The JUICE scientific payload for Europa and Ganymede

- The instruments of the University of Bern have an impressive track record - a heritage - in the exploration of the Solar System.

- Improvements in their accuracy are possible by optimizing the laser ablation ion source conditions, and instrument sensitivity (private communication, 2015).

The JUICE scientific payload for Europa and Ganymede

JANUS: Jovis, Amorum ac Natorum Undique Scrutator, camera system

MAJIS: Moons and Jupiter Imaging Spectrometer
UVS: UV Imaging Spectrograph

SWI: Sub-millimetre Wave Instrument

GALA: Ganymede Laser Altimeter

RIME: Radar for Icy Moons Exploration

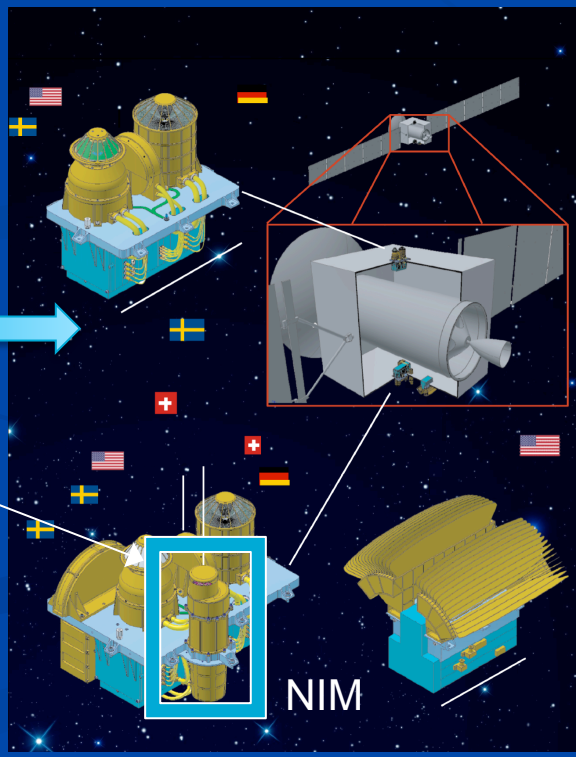
J-MAG: Magnetometer for JUICE

PEP: Particle Environment Package with a Neural Gas and Ion MS (NIM)

RPWI: Radio & Plasma Wave Investigation

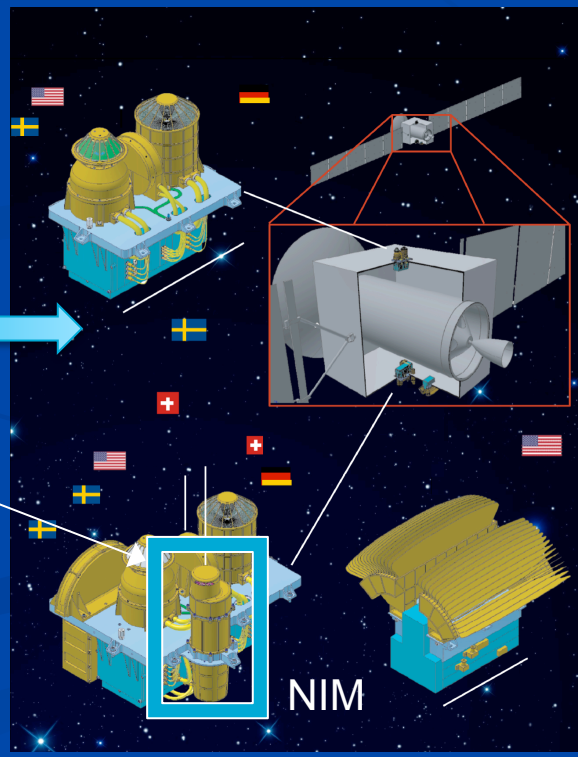
3GM: Gravity & Geophysics of Jupiter and Galilean Moons

PRIDE: Planetary Radio Interferometer & Doppler Experiment



The JUICE scientific payload for Europa and Ganymede

PEP: Particle Environment Package with a Neural Gas and Ion MS (NIM)



The PEP miniaturized instrument has significant advantages

- Mass spectra (MS) are easy to interpret [1].
- This instrument will conduct the first-ever direct sampling of the exospheres of Europa and Ganymede [2].

1. D. Abplanalp et al (2009). A neutral gas mass spectrometer to measure the chemical composition of the stratosphere. *Adv. Space Res.* **44**, 870–878.
2. P. Wurz et al (2014). Simulation of Callisto‘s exosphere as measured by JUICE/NIM. EPSC Abstracts 9, 596.

Tests of biogenicity

- The mass sulfur spectra for the Europa exosphere should be measured down to the per mill level [1,2].

- The accuracy for detection, or ruling out the presence of biogenicity on Europa, is a possibility with the PEP instrumentation in the foreseeable future [2].

1.Chela-Flores, J. Cicuttin A., Crespo, M. L. and Tuniz, C. (2015). *International Journal of Astrobiology* 14, 427-434.

2. Chela-Flores, J. and Kumar, N. (2008). Returning to Europa: Can traces of surficial life be detected? International Journal of Astrobiology , 7(3) 263-269 .

3. Marek Tulej et al (The University of Bern with the collaboration of the University of Sweden and the Swedish Natural History Museum), Astrobiology J. (2015) No 8, pp. 1-15.

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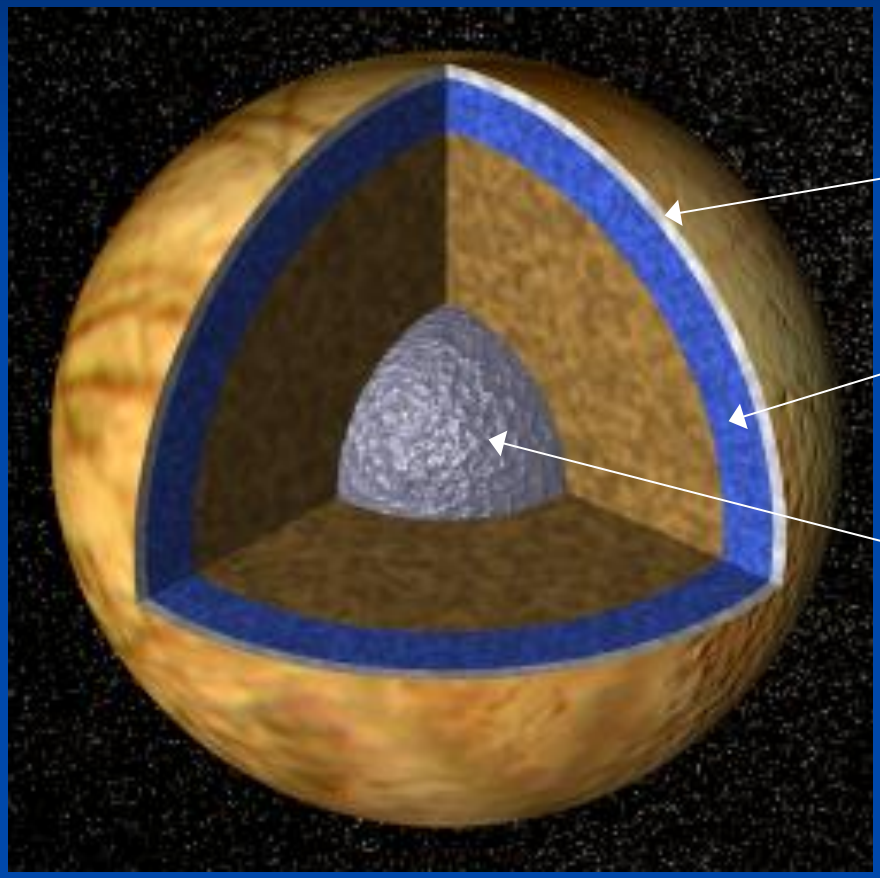
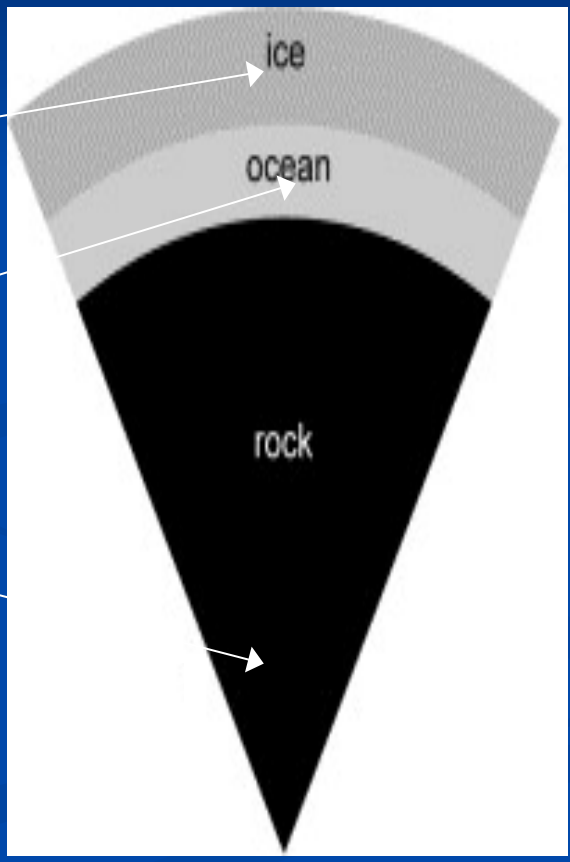
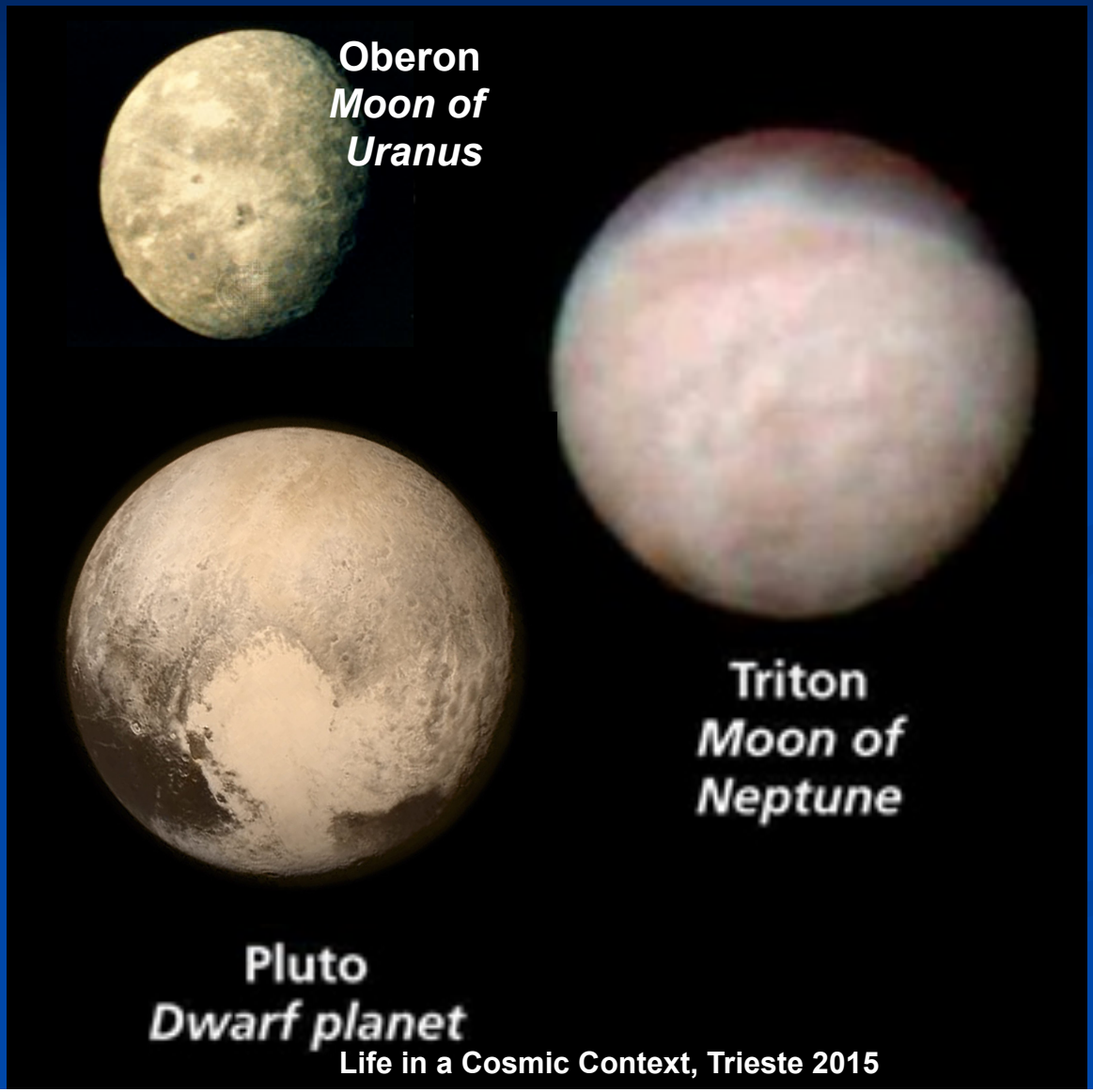
Modelling suggests that the Europa ocean may be a common feature in the outer Solar System





Possible oceans in trans-Saturnian worlds



How can we test habitability and biogenicity in the Solar System?

- In the outer Solar System:

  It is not feasible in the short term to seek directly for microfossils (biogenicity). But biogeochemical tests are not excluded in the future exploration.

Can we test biogenicity in the moons of Uranus, Neptune and beyond ?

- The ODINUS (and LOKI) Italian-led dual-planet concepts (Uranus and Neptune exploration) are on stand-by (private communication, 2015).

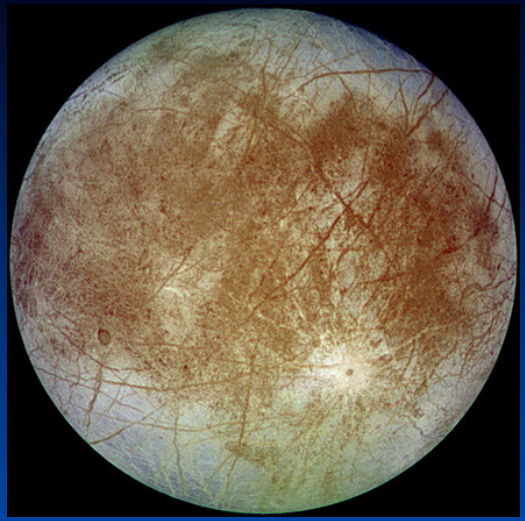
- In addition, single planet mission concepts are the Uranus Pathfinder (UP, Arridge *et al.*, 2012) and the Outer Solar System (OSS) mission (Christoph *et al.*, 2012).

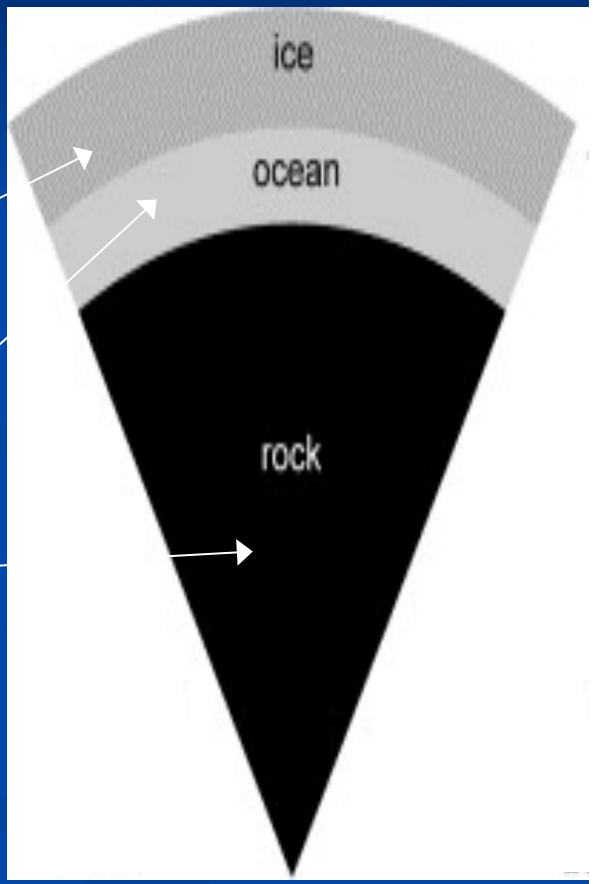
- Potentially, with such missions we could test biogenicity' all the icy worlds.

Are there traces of biogenicity up to the horizons of the Solar System?

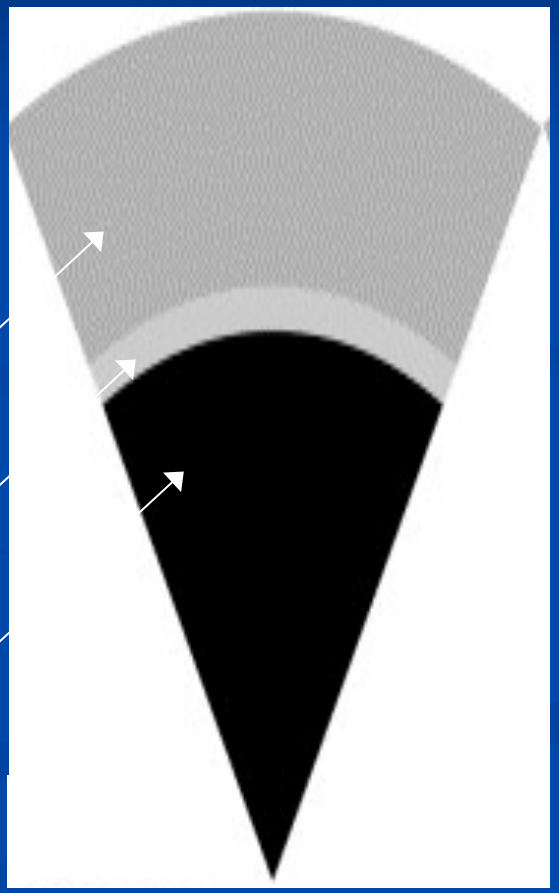
- Lewis at MIT (1971), Haussmann and co-workers in the German Aerospace Center (2006) have suggested that icy worlds of the outer Solar System may have internal oceans.
  - Some examples:
    - Europa (Jupiter),
    - Oberon (Uranus),
    - Triton (Neptune).
    - Pluto

Europa

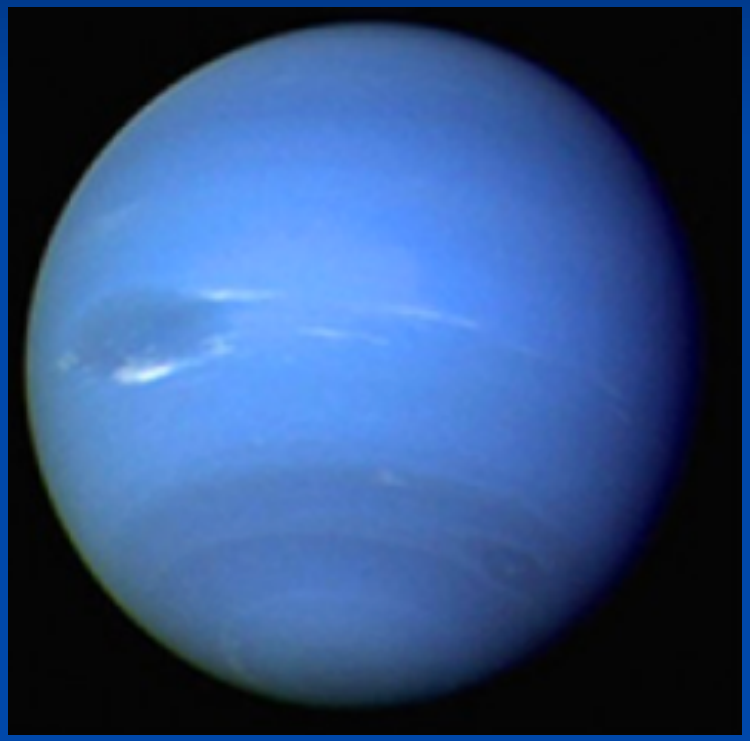


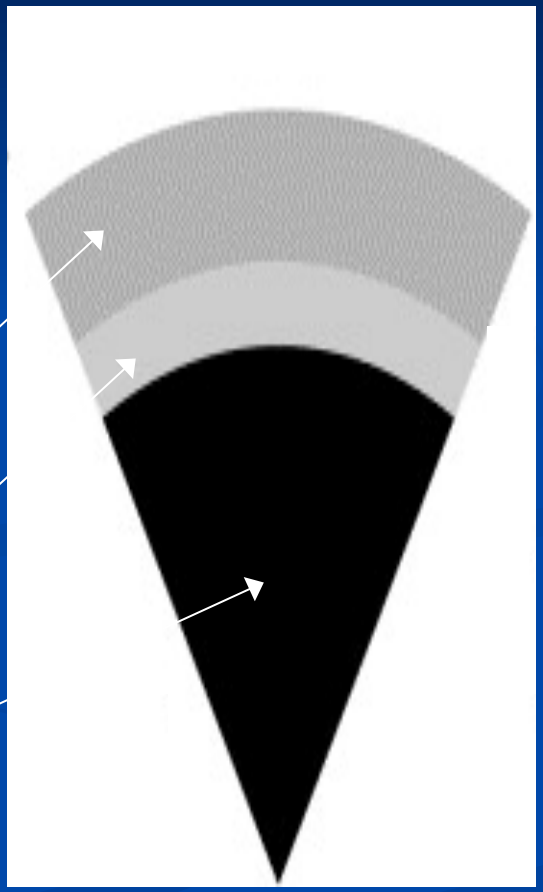


Oberon



Triton



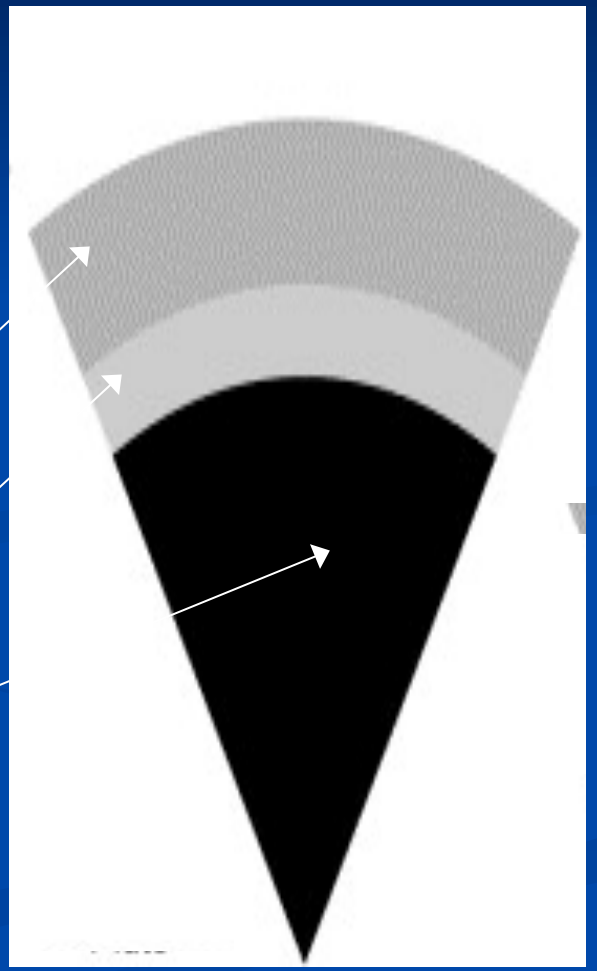


Pluto

227.7 km

137.1 km

830.2 km



Final comments

- With the already approved payloads for JUICE, tests for biogenicity on the Galileans are possible with miniaturized PEP instruments that can be improved before lauching in the early 2020s. .

- Beyond JUICE, these biogeochemical tests can be transferrred to the horizons of the Solar System.