

Life at the Extremes:

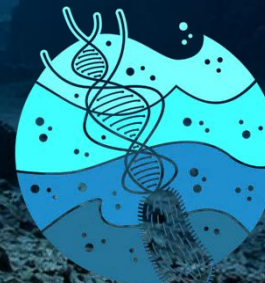
What Antarctic Microbes Reveal About
the Potential for Life in Ocean Worlds?

Prof. Dr. Amanda G. Bendia

+ *Instituto Oceanográfico USP*
Departamento de Oceanografia Biológica

+ *Marine Extremophiles Lab (ExtreMar)*
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EXTREMAR
LAB. Laboratório de
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ANTARCTICA

Life at the
Extremes



ANTARCTICA *Where are the limits of life?*

Soil, rocks and permafrost

Deep sea

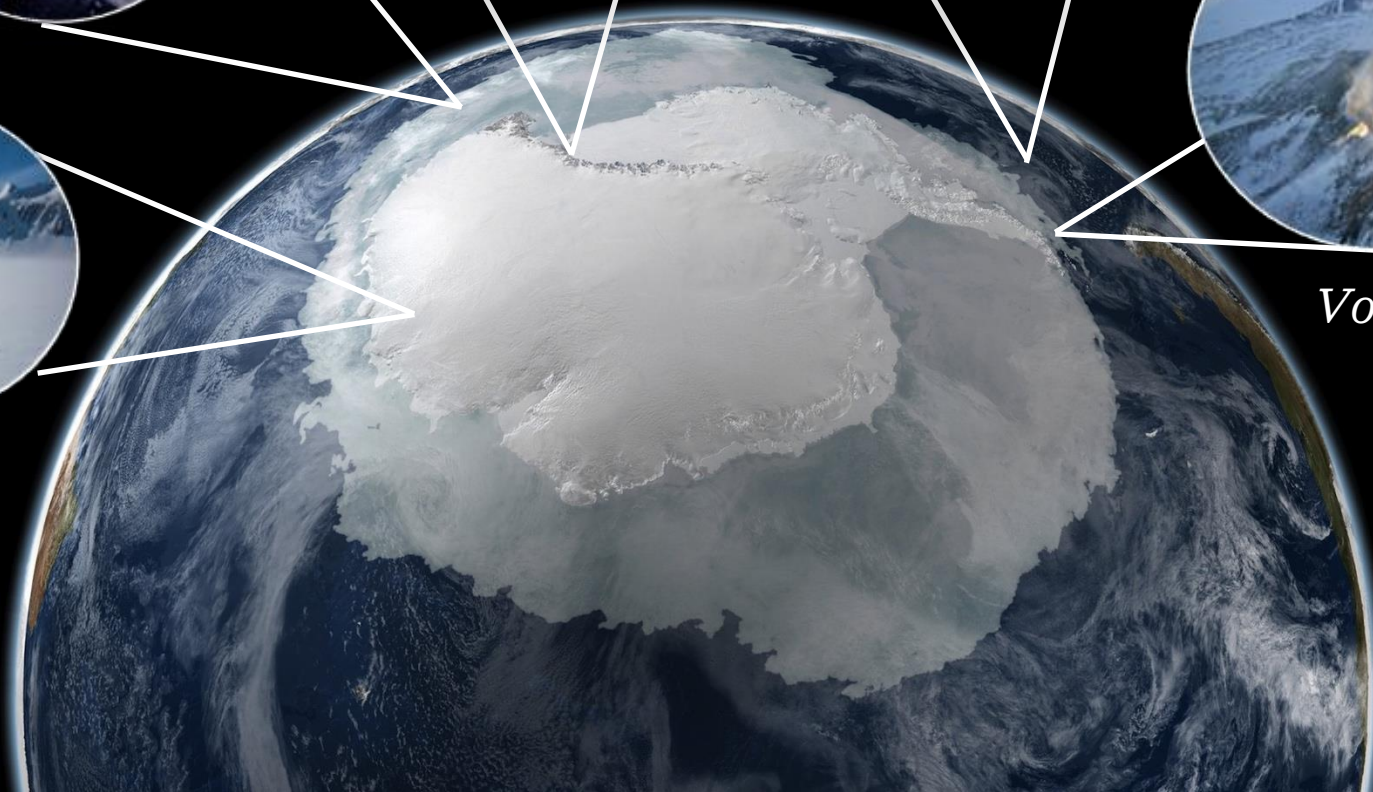
Ice (marine ice, ice shelf)



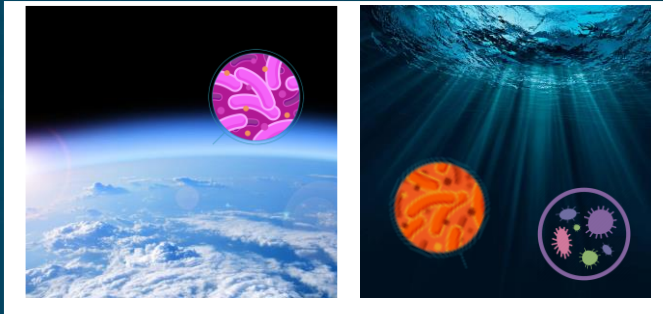
Volcanoes



Snow



The limits of life: **extremophiles**



an organism that is able to live
(or in some cases thrive) in
extreme environments

Notable prokaryotic extremophiles:

Bacteria



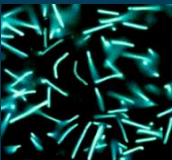
Deinococcus radiodurans

Radioresistant

15,000 Gy



Archaea



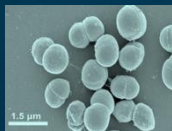
Methanopyrus kandleri

Hyperthermophile

122 °C



Bacteria



Planococcus halocryophilus

Psychrophile

-37 °C



Archaea



Picrophilus oshimae

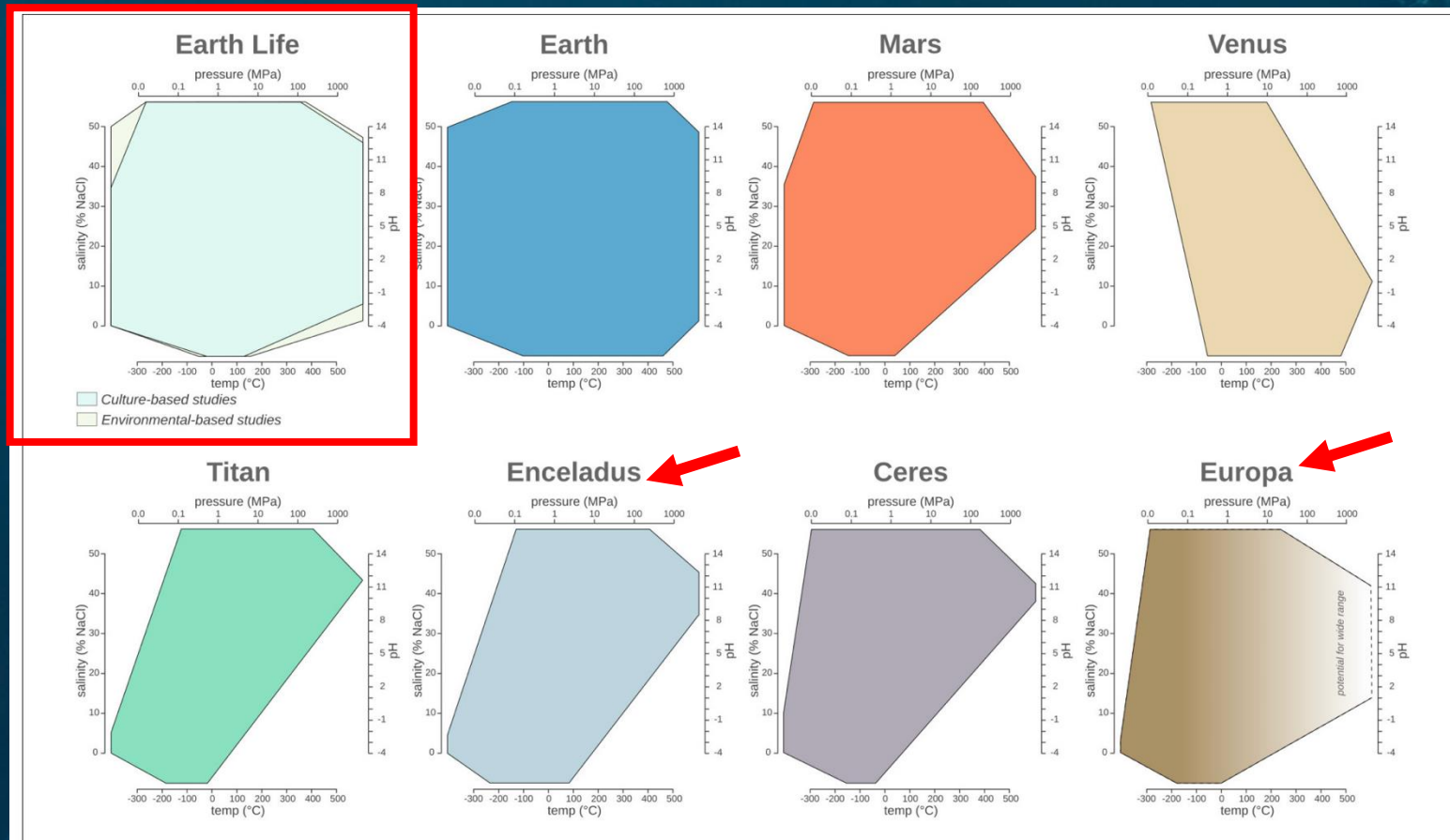
Acidophile

-0.06



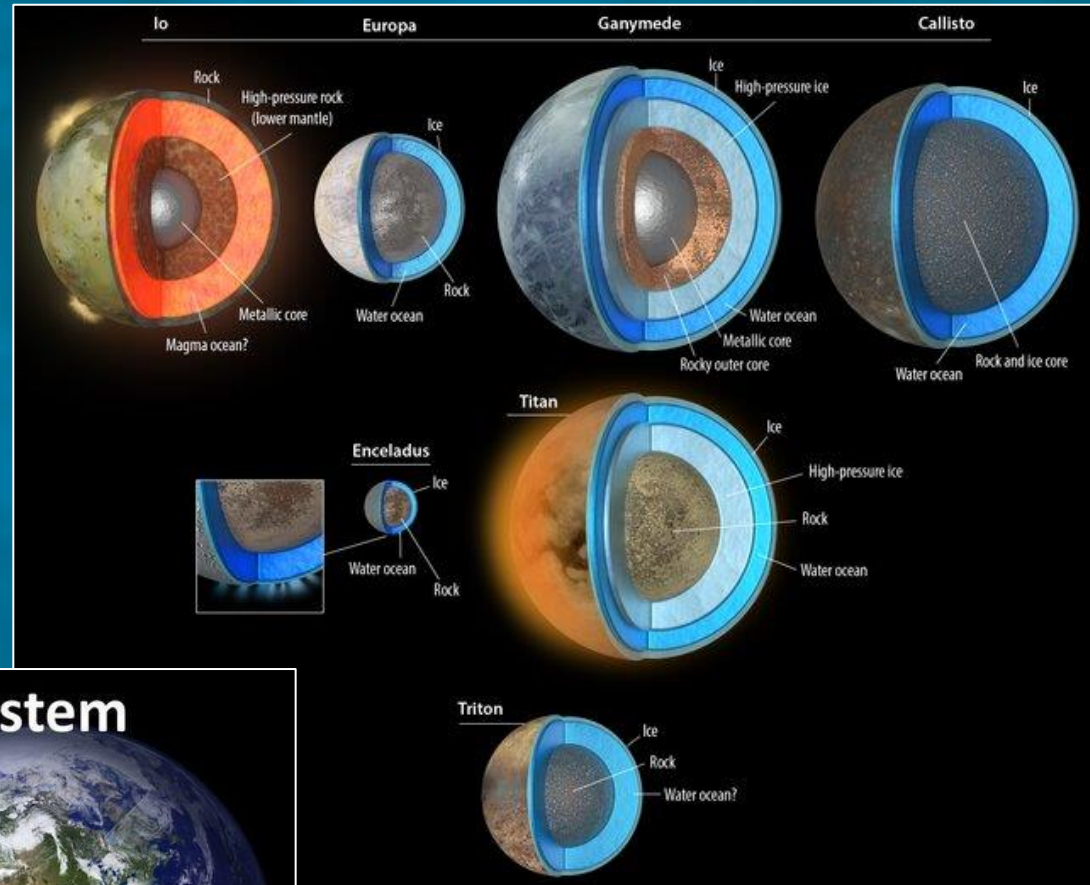
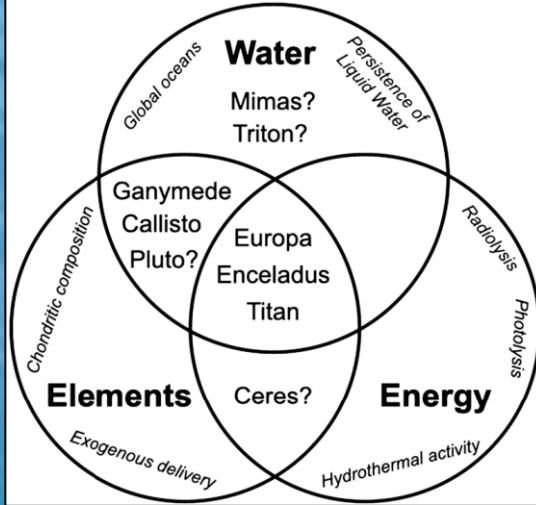
The limits of life: **extremophiles**

The **temperature**, **pressure**, **pH**, and **salinity** boundaries observed for life on Earth compared to the observed on planetary bodies

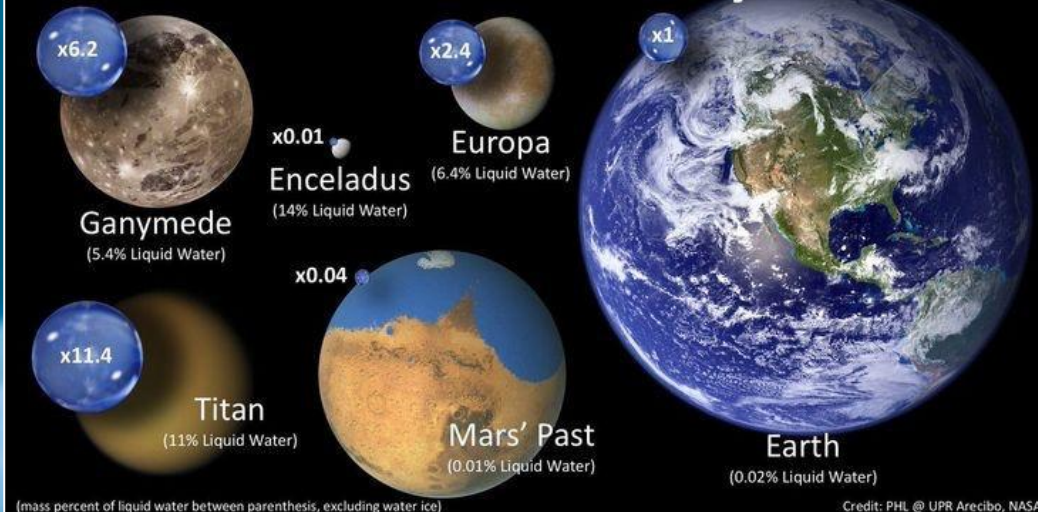


Ocean Worlds

Keystones of Habitability

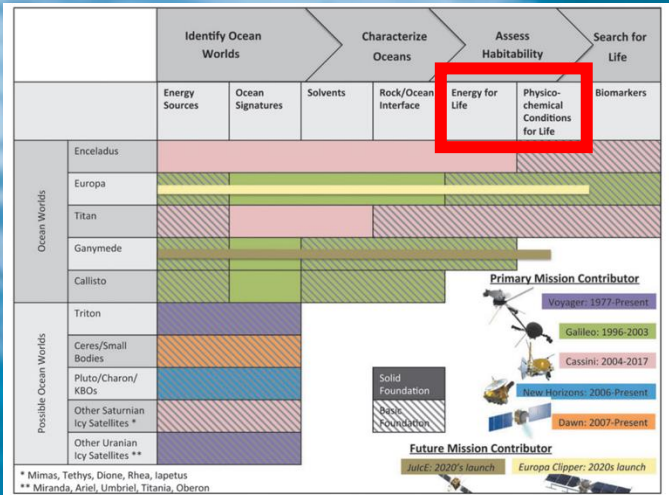


Oceans in the Solar System



Credit: PHL @ UPR Arcibo, NASA

Habitability of Ocean Worlds

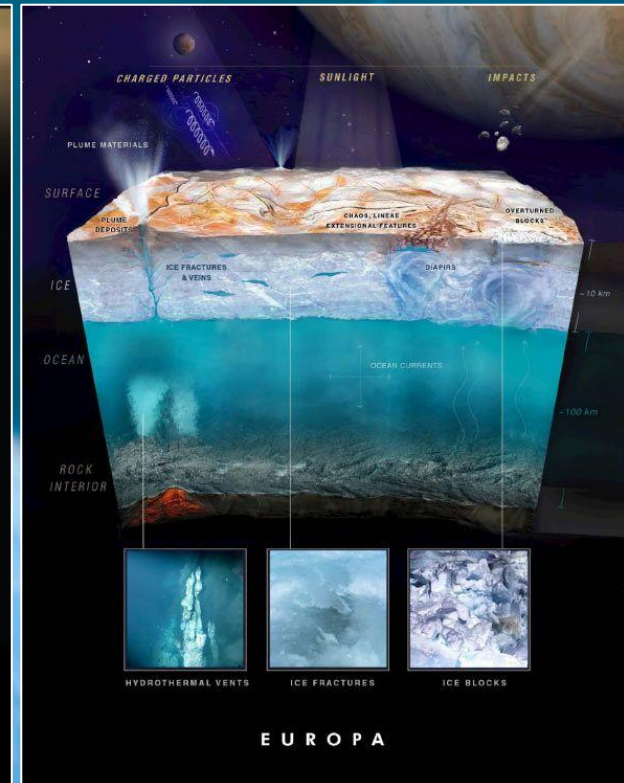
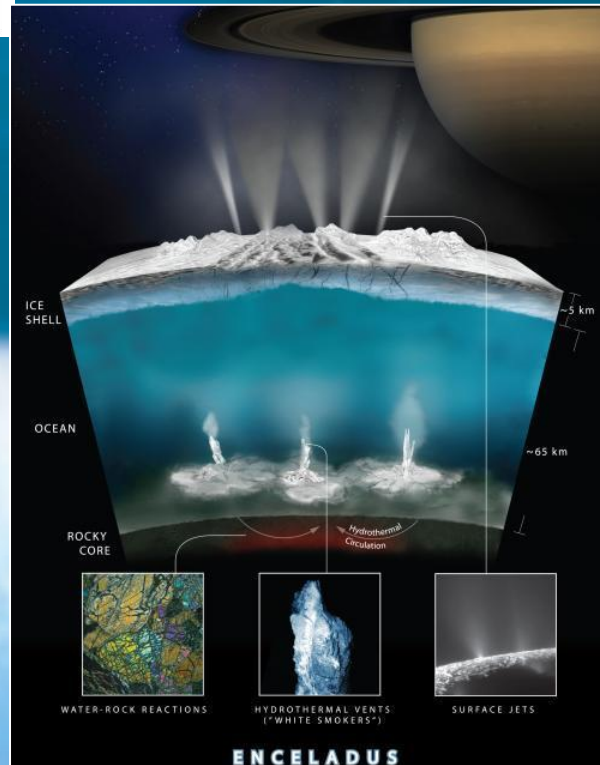
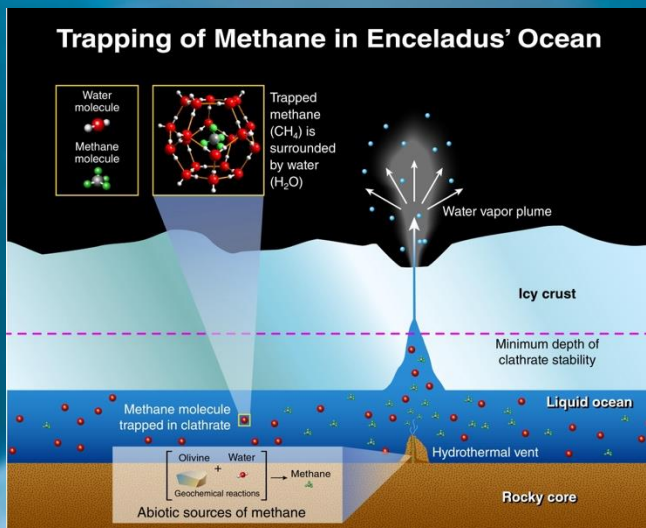


ASTROBIOLOGY
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 Mary Ann Liebert, Inc.
 DOI: 10.1089/ast.2018.1955

Forum Articles

The NASA Roadmap to Ocean Worlds

Amanda R. Hendrix (Co-Lead),¹ Terry A. Hurford (Co-Lead),² Laura M. Barge,³ Michael T. Bland,⁴ Jeff S. Bowman,⁵ William Brinckerhoff,² Bonnie J. Buratti,³ Morgan L. Cable,³ Julie Castillo-Rogez,³ Geoffrey C. Collins,⁶ Serina Diniega,³ Christopher R. German,⁷ Alexander G. Hayes,⁸ Tori Hoehler,⁹ Sona Hosseini,³ Carly J.A. Howett,¹⁰ Alfred S. McEwen,¹¹ Catherine D. Neish,^{1,12} Marc Neveu,¹³ Tom A. Nordheim,³ G. Wesley Patterson,¹⁴ D. Alex Patthoff,¹ Cynthia Phillips,³ Alyssa Rhoden,¹⁰ Britney E. Schmidt,¹⁵ Kelsi N. Singer,¹⁰ Jason M. Soderblom,¹⁶ and Steven D. Vance³



From Earth's Extremophiles to Ocean Worlds

Microbial insights to define habitability and guide the search for life in icy oceans

1. Study extremophiles in Earth analogs

How do they obtain energy, adapt and persist?



Hydrothermal systems



Subglacial environments



Deep-sea sediments



What do we learn?



Energy acquisition
(chemolithoautotrophy)



Metabolic diversity
(mainly anaerobic)



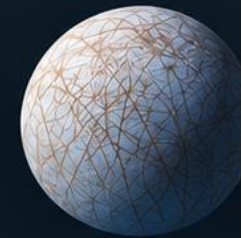
Adaptation strategies
(genomic and physiological)



Molecular biosignatures
(genes, pathways, metabolites)

Application to ocean worlds

Defining where and under what conditions life could exist



Europa



Enceladus



Titan



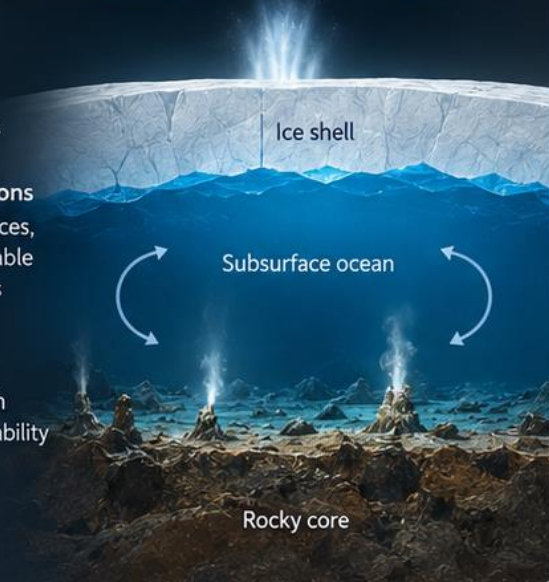
Where to look?
Subsurface oceans



Minimum conditions
Water, energy sources,
key elements, suitable
physical conditions



Can life persist?
Insights from Earth
to constrain habitability



Earth's extremes

Icy ocean worlds

Extremophiles as models for astrobiology

Organisms in pure cultures:

TABLE 3 | Limits of life as identified by (poly)extremophilic organisms in pure cultures.

Strain	Domain	Extremophile Type	Isolation ecosystem	Temperature (°C)	pH	Pressure (Mpa)	Salinity (%)	Water activity (a _w)	References
<i>Picrophilus oshimae</i> KAW 2/2	Archaea	Hypercidophile	Hot springs, Solfataras	47–65 (60) ^a	−0.06 –1.8 (0.7)	nr	0–20	nr	Schleper et al., 1995, 1996
<i>Serpentinomonas</i> sp. B1	Bacteria	Alkaliphile	Serpentinizing system (water)	18–37 (30)	9– 12.5 (11)	nr	0–0.5 (0)	nr	Suzuki et al., 2014
<i>Methanopyrus kandleri</i> 116	Archaea	Hyperthermophile	Deep-sea hydrothermal vent	90– 122 (105)	(6.3–6.6)	0.4–40	0.5–4.5 (3.0)	nr	Takai et al., 2008
<i>Planococcus halocryophilus</i> Or1	Bacteria	Halopsychrophile	Sea ice core	−15 –37 (25)	6–11 (7–8)	nr	0–19 (2)	nr	Mykytczuk et al., 2012, 2013
<i>Halarsenatibacter silvermanii</i> SLAS-1	Bacteria	Haloalkaliphile	Soda lake	28–55 (44)	8.7–9.8 (9.4)	nr	20–35 (35)	nr	Oremland et al., 2005
<i>Thermococcus piezophilus</i> CDGS	Archaea	Piezothermophile	Deep-sea hydrothermal vent	60–95 (75)	5.5–9 (6)	0.1– 125 (50)	2–6 (3)	nr	Dalmaso et al., 2016
Haloarchaeal strains GN-2 and GN-5	Archaea	Xerophile	Solar salterns (brine)	nr	nr	nr	nr	0.635	Javor, 1984

^aData presented as range (optimum) for each parameter. nr, not reported in the original publication. Current limits are highlighted in bold.

The majority of extremophile diversity is uncultivable or has not yet been cultivated!

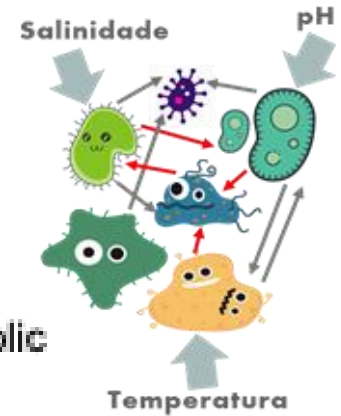
Looking for novel and uncultured Antarctic extremophiles: new models for astrobiology

- **Culture-dependent techniques**

- ↑ Understanding microbial physiology
- ↓ Only ~1% of microorganisms are culturable in lab conditions

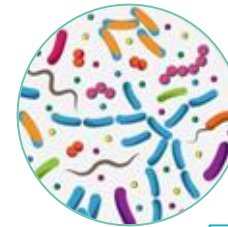
- **Culture-independent techniques**

- ↑ Understanding the "entire" microbial diversity in the environment
- ↓ We cannot affirm about their metabolic capabilities (only to know the metabolic potentials)



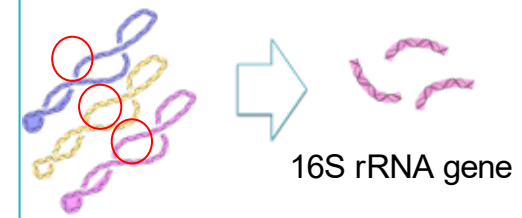
Describing microbial communities

Metatranscriptome/ Metaproteome	Flying	Driving	Bake	Eating	Sleeping
Metagenome	Pilot	Driver	Baker	Officer	Postman
Amplicon sequencing	Alejandra	Ricardo	Ben	Liliana	Jonathan

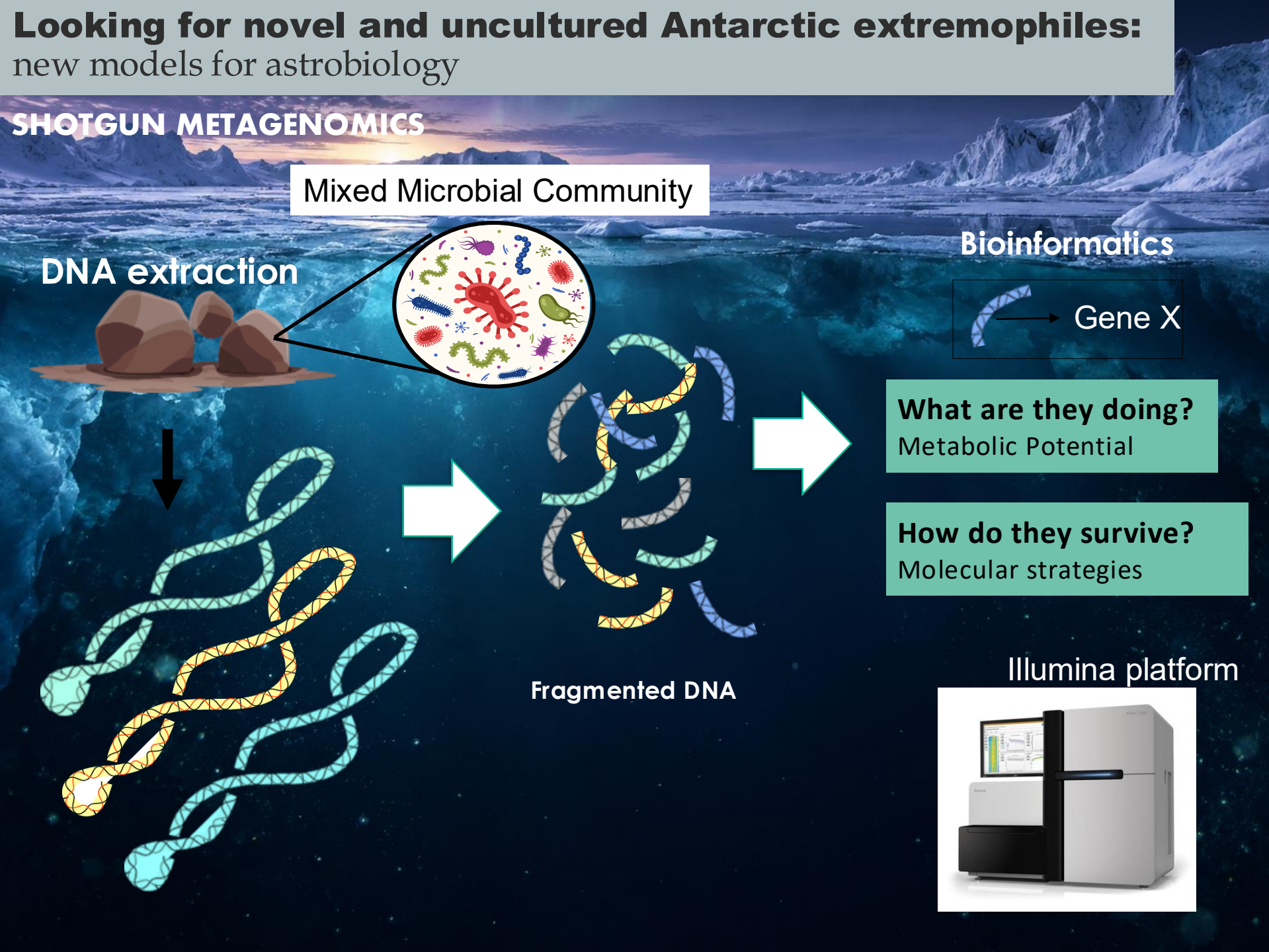


Microbial communities

Amplicon sequencing



Who?
is there?



RECOVERING EXTREMOPHILES' GENOMES WITHOUT CULTIVATION

Metagenome-assembled genomes (MAGs)

Mixed Microbial
Community



Extracted DNA



Illumina sequencing: reads

Reconstructed genomes
using bioinformatics tools



x millions/billions
genomes

Advantage:

- Description of extremophiles not yet cultivated
- Inference of new lifestyles and metabolisms for new taxonomic groups

x hundreds recovered
genomes

Exploring Antarctic microbial ecosystems: from the atmosphere to the deep sea

ATMOSPHERE



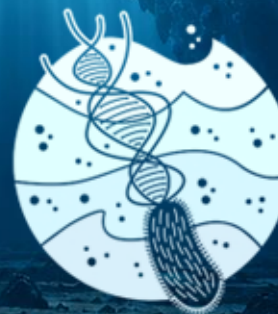
ANTARCTIC
INTERIOR SNOW



DECEPTION ISLAND



DEEP SEA



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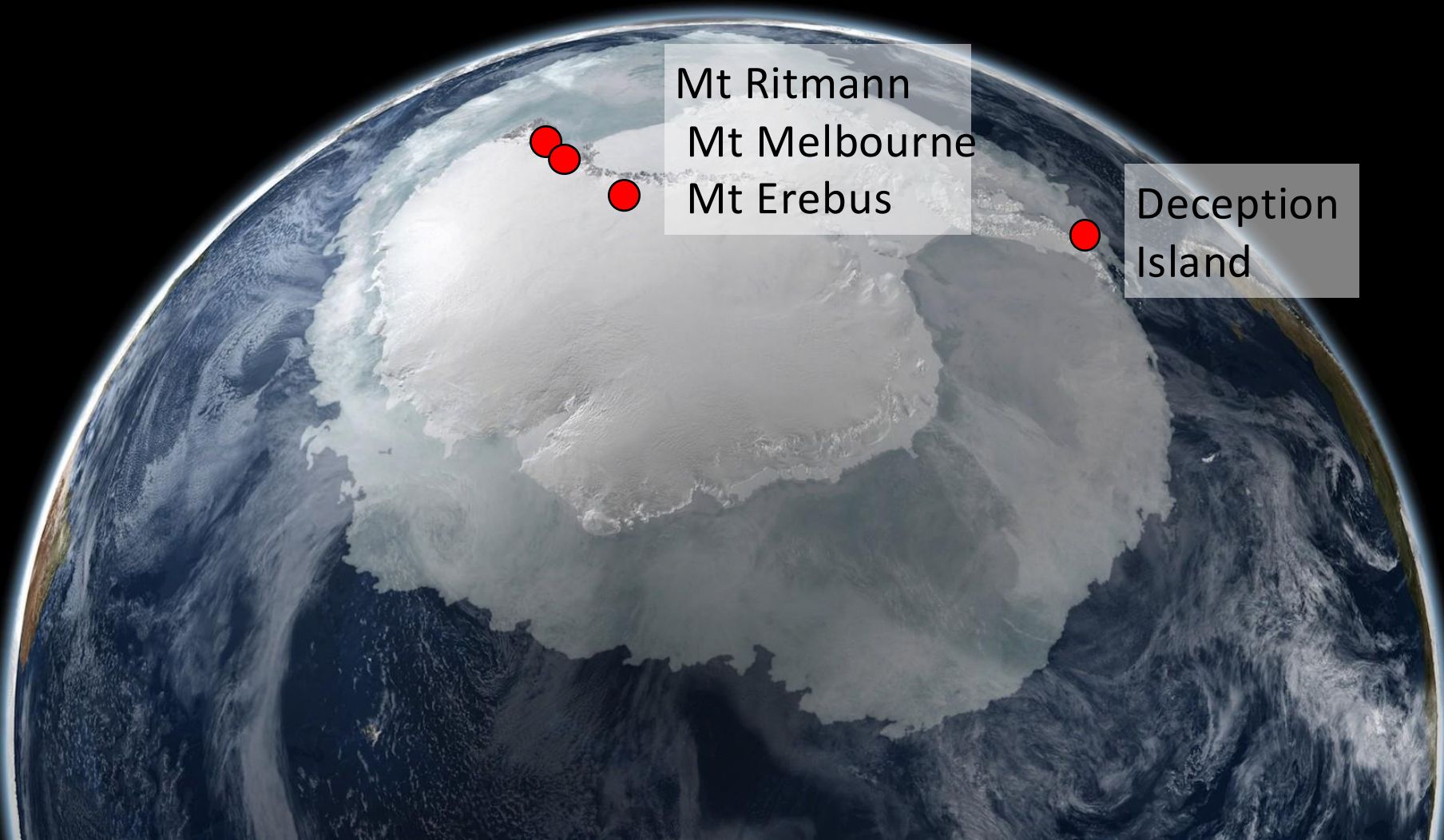
Deception Island volcano

South Shetland Islands, Antarctic Peninsula



ANTARCTICA

ACTIVE VOLCANOES



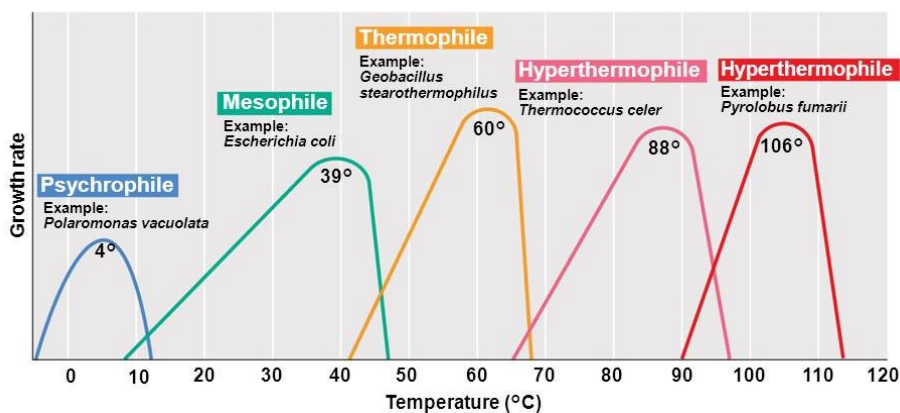
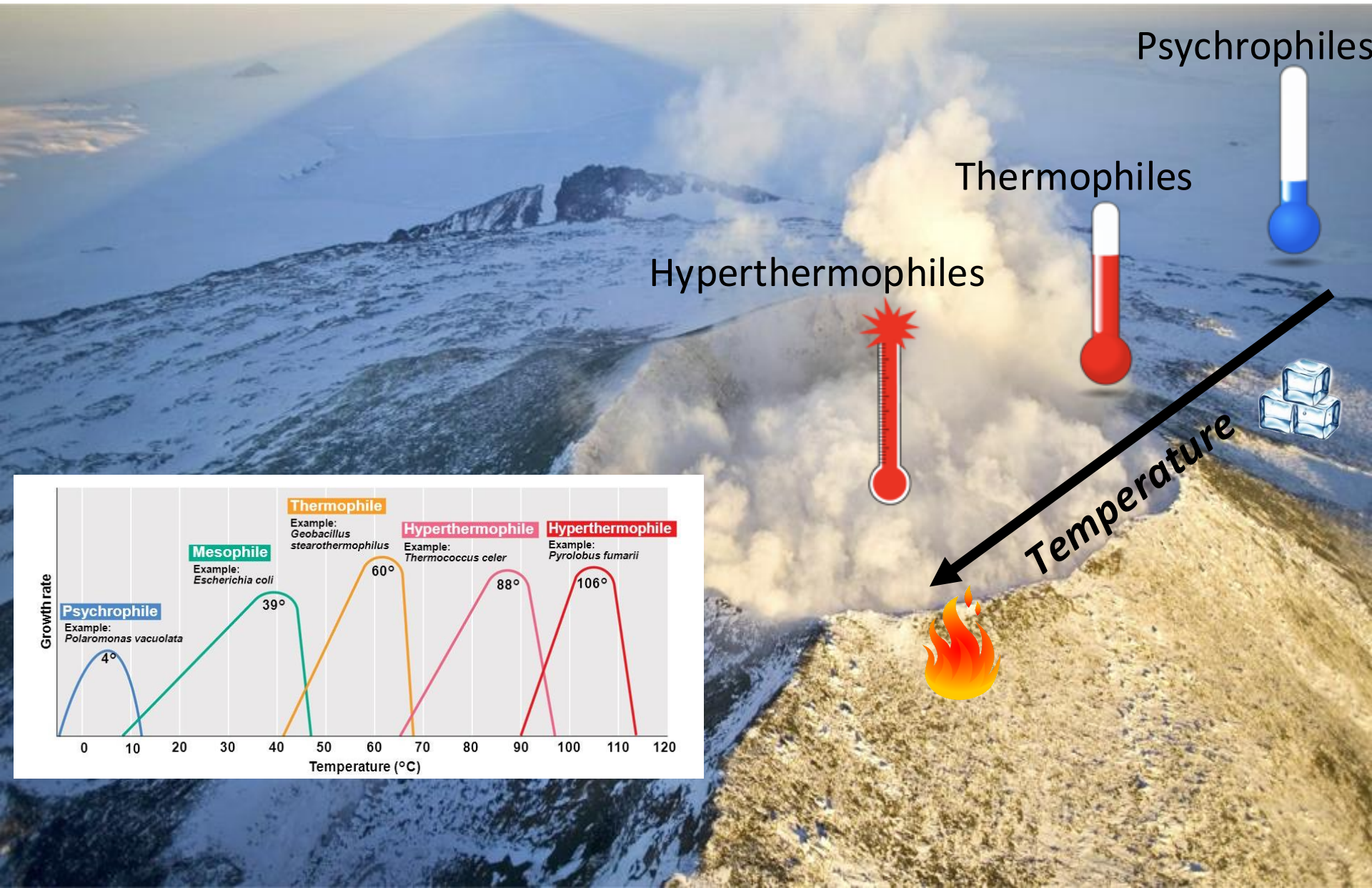
Mt Ritmann

Mt Melbourne

Mt Erebus

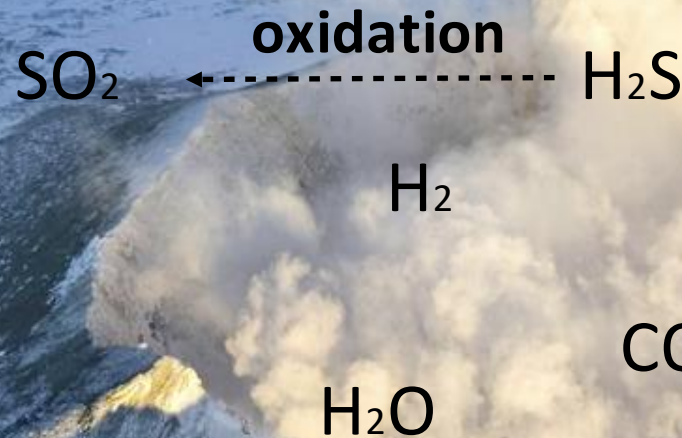
Deception
Island

Antarctic volcanoes: temperature gradient and the limits of life on Earth

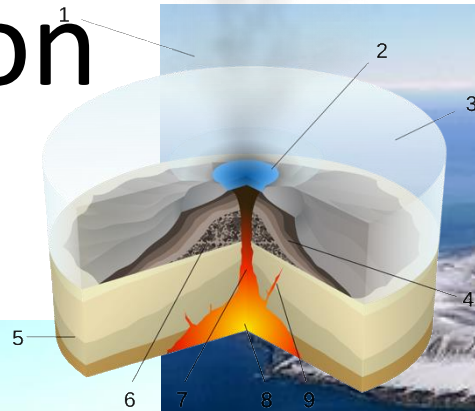


Antarctic volcanoes: geochemical gradient and the limits of life on Earth

Geochemical gradient:
Multiple forms of chemical energy
Different metabolisms
Chemosynthesis - Chemolithotrophs



Deception Island, Antarctica



Caldera entrance



SAMPLING IN ANTAR

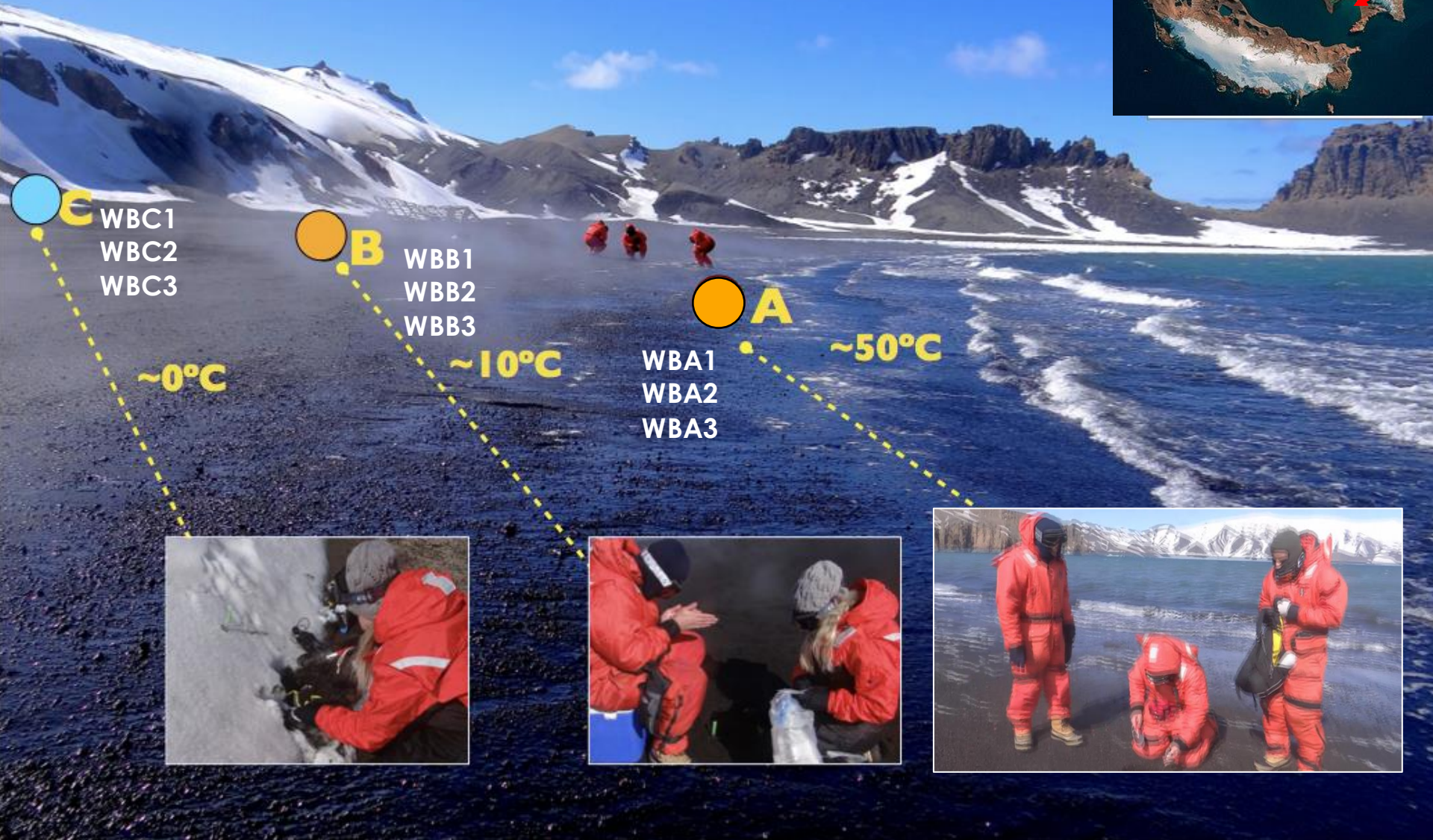
Brazilian Antarctic Program



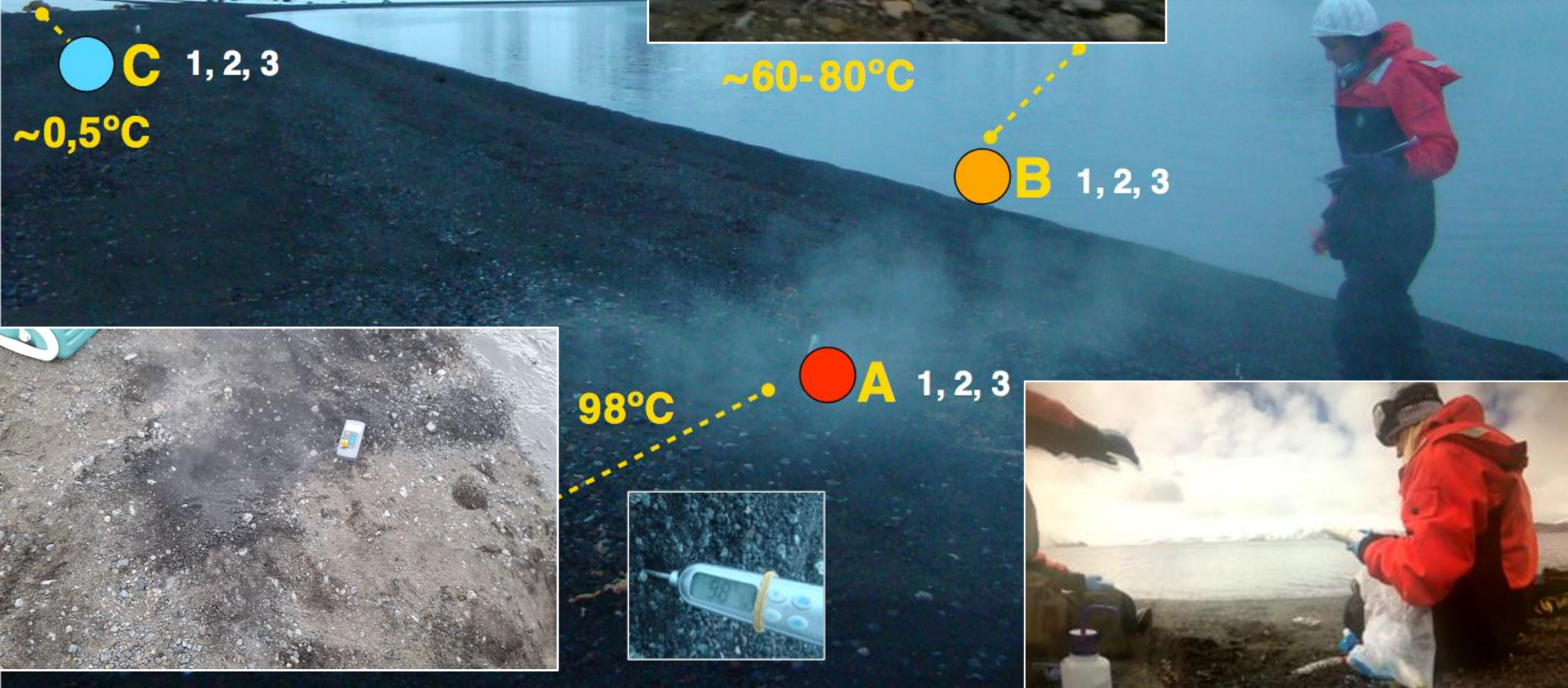
Brazilian Antarctic Station: Comandante Ferraz



Whalers Bay, Antarctica



Deception Island, Antarctica

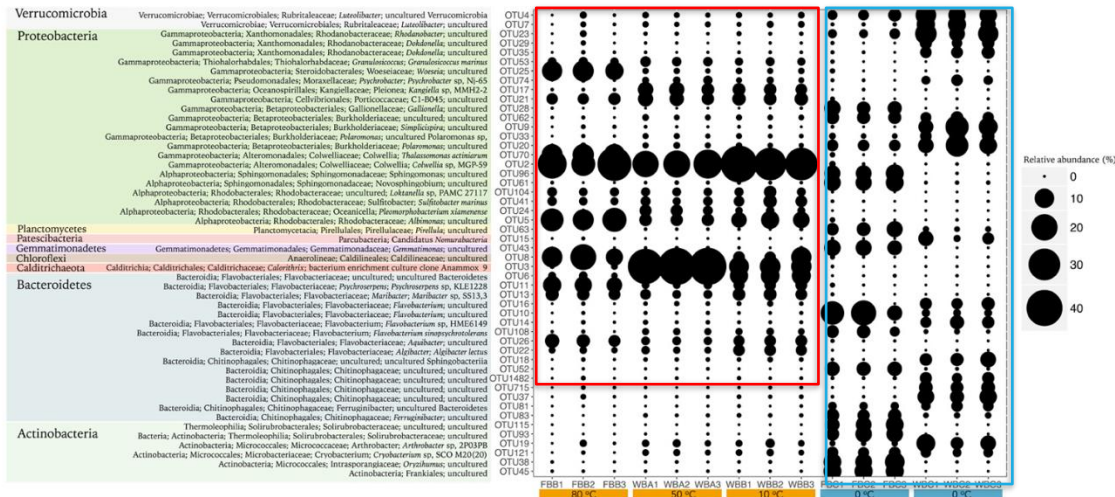




Who is there? Method: 16S rRNA sequencing

Diversity of Bacteria and Archaea in Deception Island

Bacteria

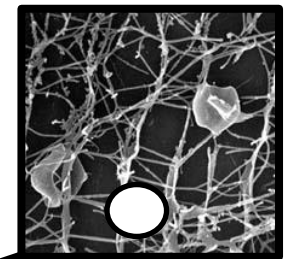
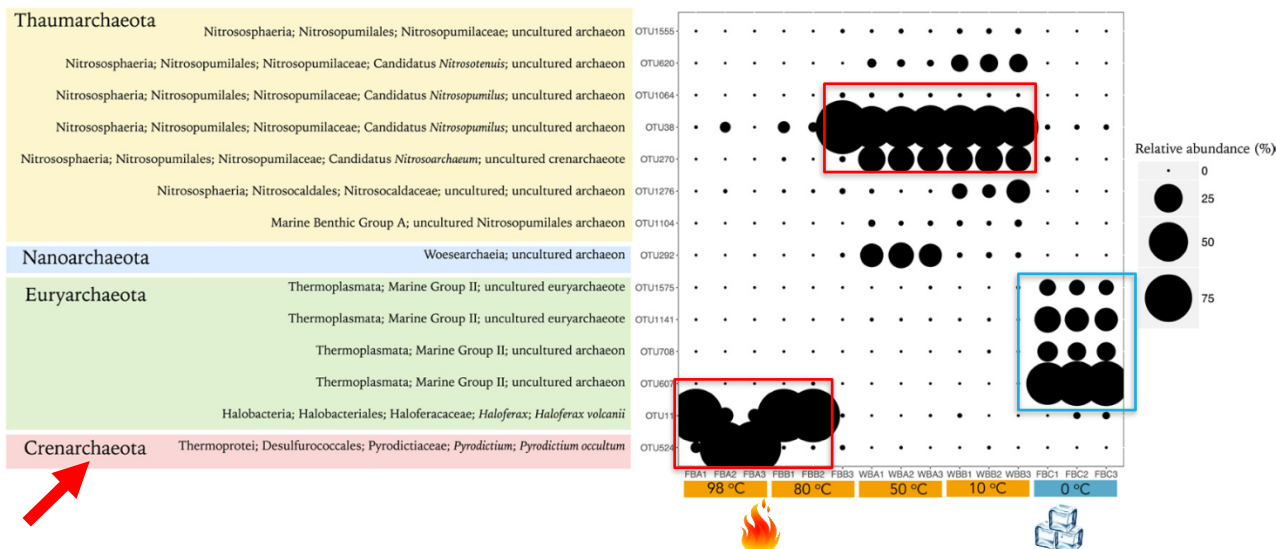


A Mosaic of Geothermal and Marine Features Shapes Microbial Community Structure on Deception Island Volcano, Antarctica

Amanda G. Bendia¹, Camila N. Signori¹, Diego Franco¹, Rubens T. Duarte^{1,2}, Brendan J. Bohannon³, Vivian H. Pellizari^{1*}

¹Oceanographic Institute, Universidade de São Paulo, Brazil, ²Universidade Federal de Santa Catarina, Brazil, ³Department of Biology, Institute of Ecology and Evolution, University of Oregon, United States

Archaea

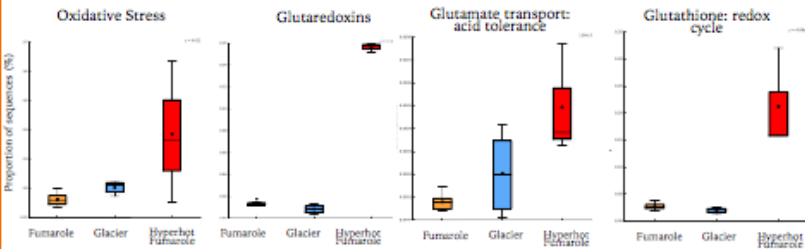


Molecular mechanisms of microbial adaptation in Deception Island

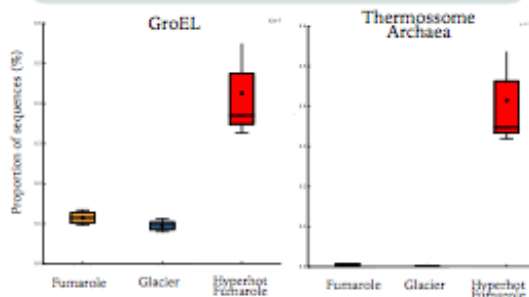
Fumaroles



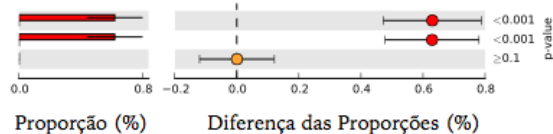
Oxidative stress



Heat-Shock Proteins



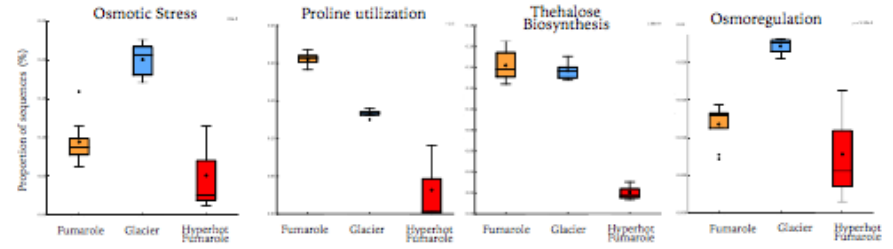
Reverse gyrase



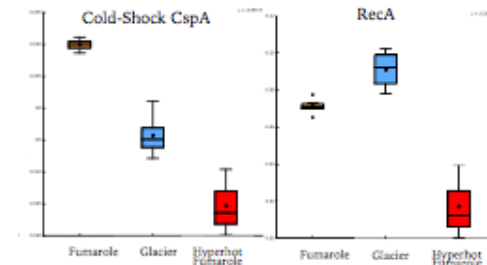
Glaciers



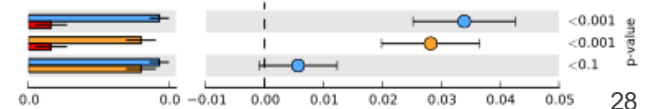
Osmotic stress



Cold-Shock Proteins



DNA repair:
photolyase



What are they doing? Method: Metagenomics

Bendia et al., 2021. Environmental Microbiology Journal

Metabolic potentials and their relationships with the biogeochemical cycles in Deception Island

Glaciers: nitrogen cycle (nitrification, denitrification) carbon cycle (photosynthesis, chemorganotrophy, and methanogenesis).



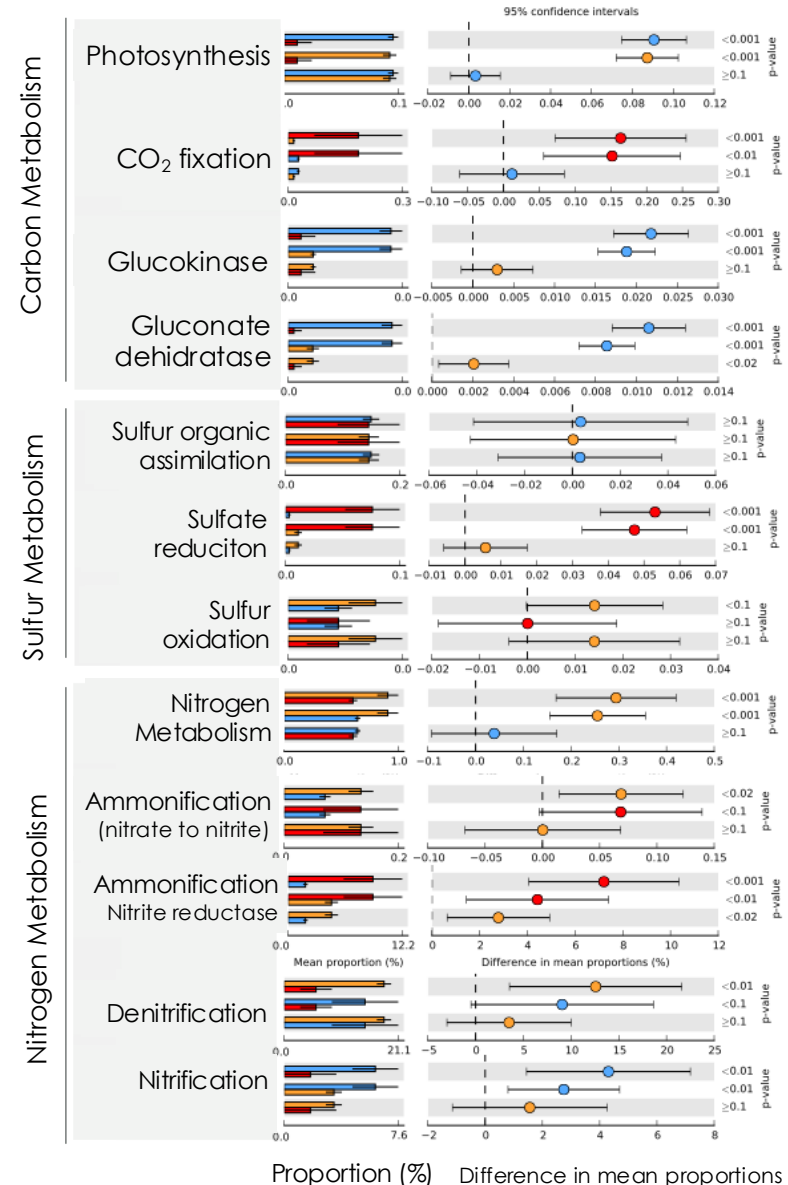
Fumaroles until 80 °C: nitrogen cycle (ammonification, nitrification, denitrification), carbon cycle (photosynthesis), sulfur cycle (sulfur oxidation).



Fumarole 98 °C: sulfur cycle, (sulfate reduction), carbon cycle (carbon fixation), nitrogen cycle (ammonification), chemolithotrophy.



Energetic metabolism



Metabolic and survival strategies of bacterial and archaeal genomes reconstructed through metagenomics

Energetic metabolisms

Stress response and DNA repair

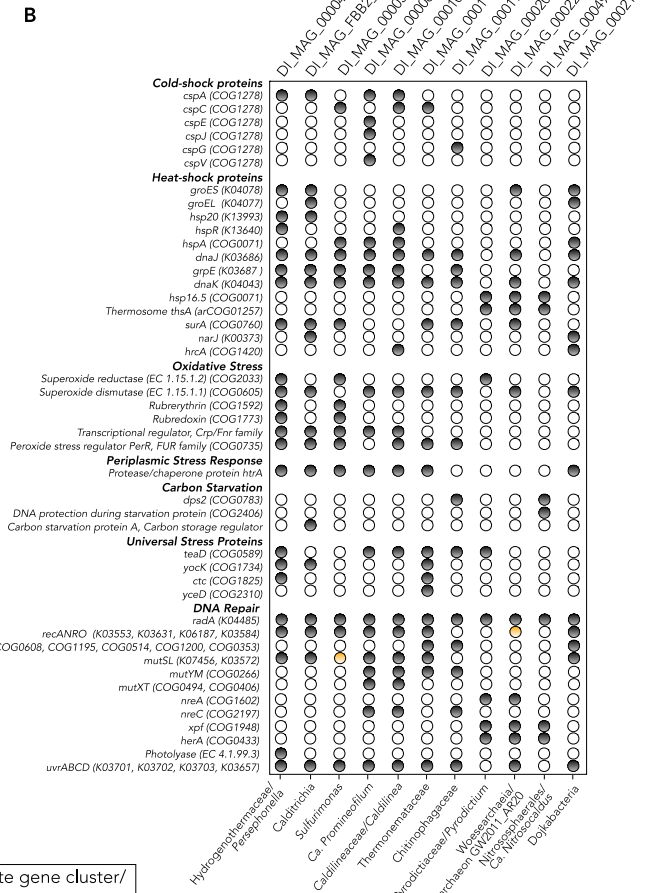
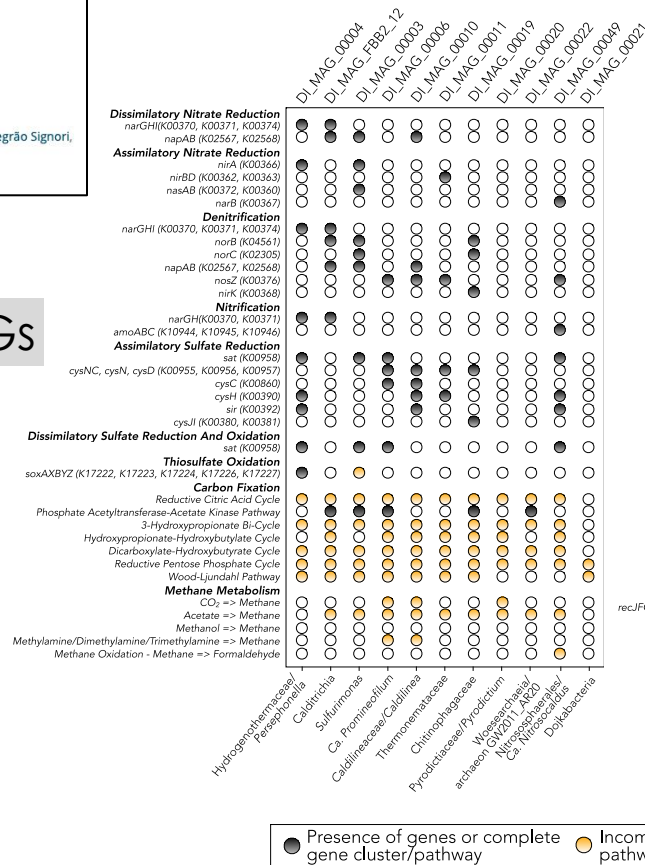
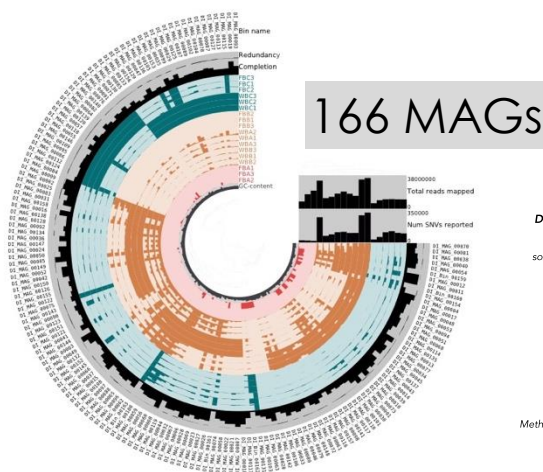
environmental
microbiology



Research article

Metabolic potential and survival strategies of microbial communities across extreme temperature gradients on Deception Island volcano, Antarctica

Amanda Gonçalves Bendia ✉, Leandro Nascimento Lemos, Lucas William Mendes, Camila Negrão Signori,
Brendan J. M. Bohannon, Vivian Helena Pellizari

First published: 09 July 2021 | <https://doi.org/10.1111/1462-2920.15649>

- First genome of this hyperthermophilic Archaea from Antarctica (Pyrodictiaceae family)
- Novel potential lifestyles, e.g. Woesearchaeia – reverse gyrase gene (typical of hyperthermophiles)
- Importance of MAGs approach to describe extremophilic lineages

Novel hyperthermophilic Archaea Method: Metagenomics

New genus/species within Pyrodictiaceae family: *Pyroantarcticum pellizari*

ISME Communications, 2026, 6(1), ycag080

<https://doi.org/10.1093/ismeco/ycag080>

Published: 27 March 2026

Original Article



Hot life in Antarctica: a novel metabolically versatile *Pyrodictiaceae* genus thriving at a volcanic–cryosphere–marine interface

Ana Carolina de Araújo Butarelli , Francielli Vilela Peres , Vivian Helena Pellizari , Amanda Gonçalves Bendia

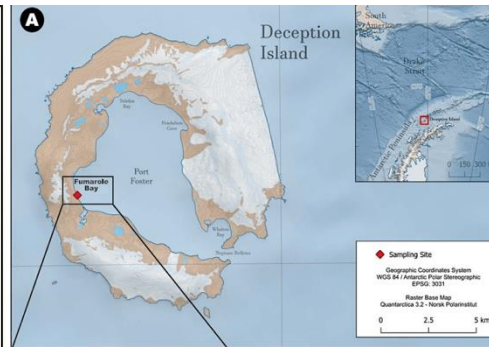
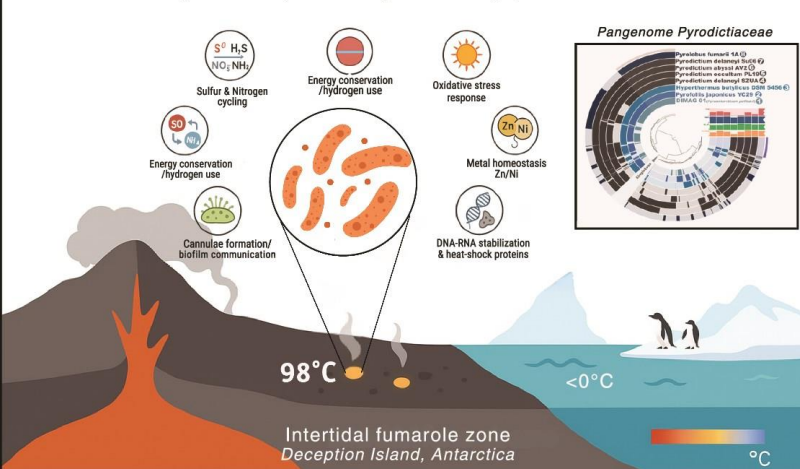
Department of Biological Oceanography, Oceanographic Institute, University of São Paulo, Praça do Oceanográfico, 191, São Paulo, SP 05508-900, Brazil

*Corresponding author. Department of Biological Oceanography, Oceanographic Institute, University of São Paulo, Praça do Oceanográfico, 191, São Paulo, SP 05508-900, Brazil. E-mail: amandagb@usp.br

Profa. Dra. Vivian Pellizari
IO-USP

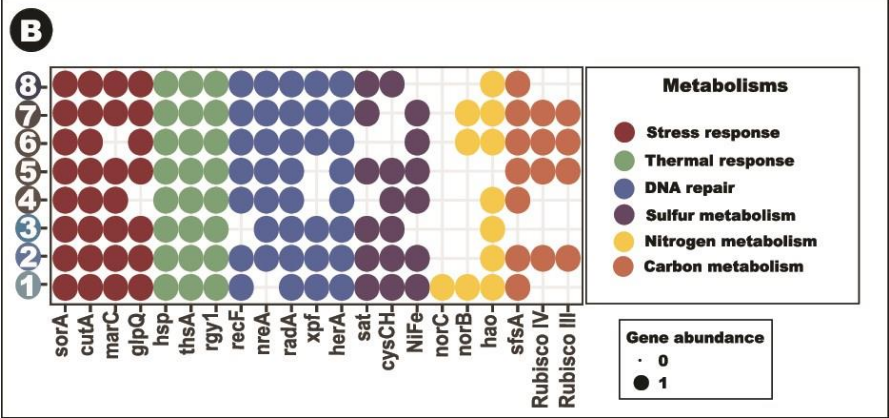
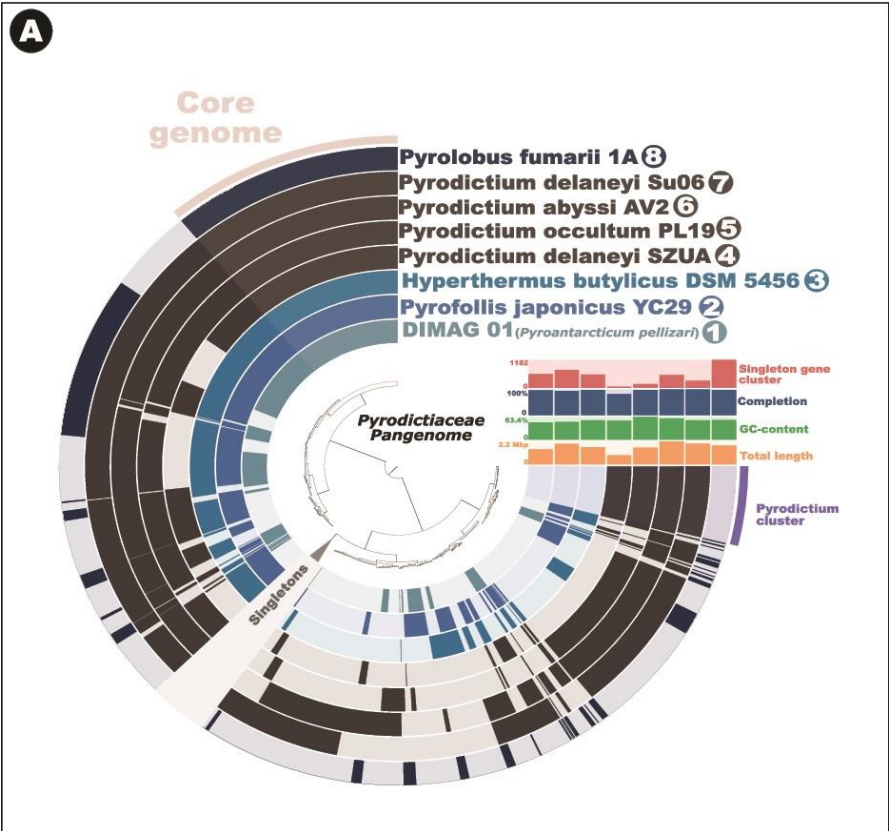
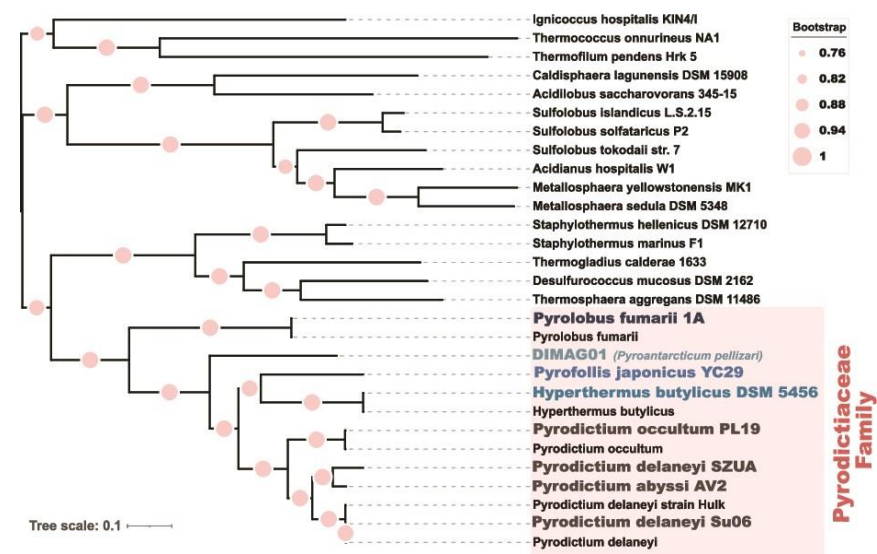


Candidatus *Pyroantarcticum pellizari* thriving at a volcanic–cryosphere–marine interface



Novel hyperthermophilic Archaea Method: Metagenomics

New genus/species within Pyrodictiaceae family: *Pyroantarcticum pellizari*



ISME Communications, 2026, 6(1), ycag080
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**Hot life in Antarctica: a novel metabolically versatile
Pyrodictiaceae genus thriving at a volcanic–cryosphere–marine
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Ana Carolina de Araújo Butarelli , Francielli Vilela Peres , Vivian Helena Pellizari , Amanda Gonçalves Bendia *

Department of Biological Oceanography, Oceanographic Institute, University of São Paulo, Praça do Oceanográfico, 191, São Paulo, SP 05508-900, Brazil

*Corresponding author. Department of Biological Oceanography, Oceanographic Institute, University of São Paulo, Praça do Oceanográfico, 191, São Paulo, SP 05508-900, Brazil. E-mail: amandagb@usp.br

SURVIVAL STRATEGIES OF UNCULTIVATED NANOARCHAEA/NANOBDELLOTA IN AN ACTIVE VOLCANO IN ANTARCTICA (DECEPTION ISLAND)

DPANN superphylum

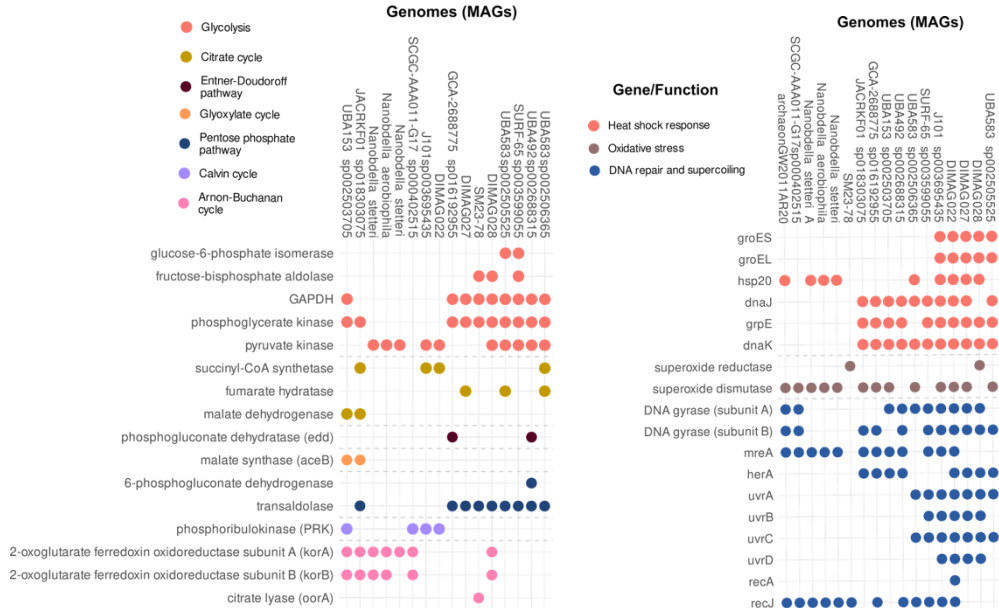
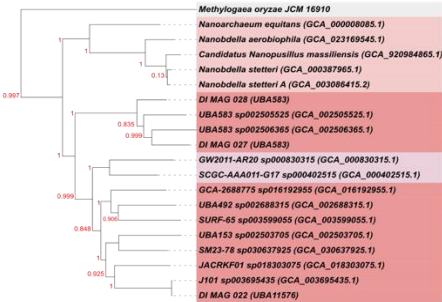
Are known for their diversity, reduced genomes, and symbiotic lifestyle

Ultra-small genomes, metabolic dependence on hosts, and adaptation to **extreme energy limitation** provide models for understanding the **minimal requirements for cellular life** in potentially habitable extraterrestrial environments.



Gabriela Elidio

MAG Code	GTD8-1k taxonomy 2025	Total length	Configs number	N50	GC content	Anvi'o		CheckM		Draft Quality
						Completeness	Redundancy	Completeness	Redundancy	
DL_MAG_022	d__Archaea; p__Nanoarchaeia; c__Nanoarchaeia; o__Woesearchaeales; f__UBA11576; g__J101; s__	1155662	40	83443	44,60%	78,40%	1,85	79,44%	0	Medium
DL_MAG_027	d__Archaea; p__Nanoarchaeia; c__Nanoarchaeia; o__Woesearchaeales; f__UBA583; g__UBA583; s__	874343	18	86500	27,10%	71,60%	0,62	74,30%	0	Medium
DL_MAG_028	d__Archaea; p__Nanoarchaeia; c__Nanoarchaeia; o__Woesearchaeales; f__UBA583; g__UBA583; s__	945169	22	99699	22,60%	73,46%	2,47	77,10%	9	Medium

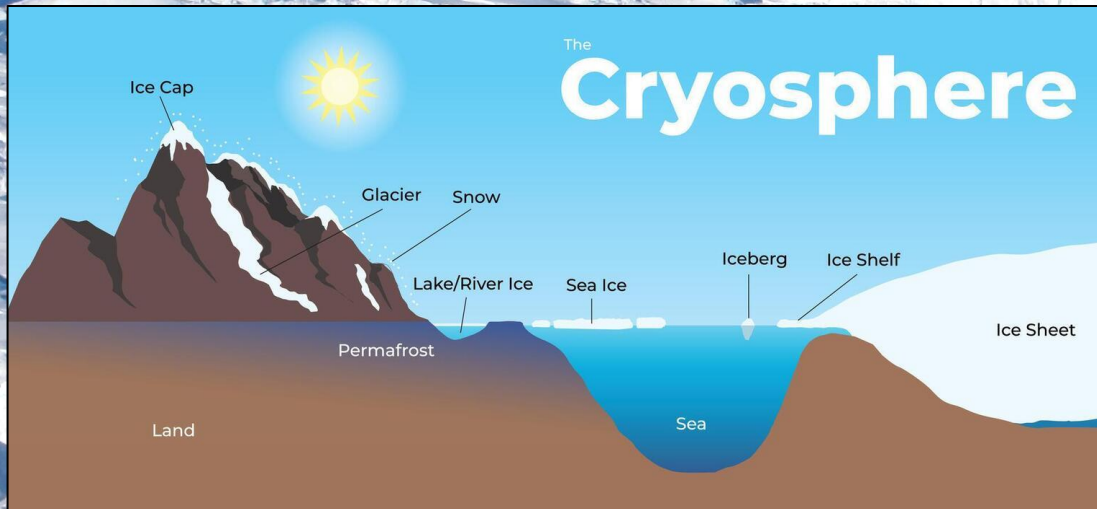


Functional Response Mechanisms

- DNA repair e recombination**
 - Genome stability
 - Recovery from UV/heat damage
- Oxidative stress enzymes**
 - Detoxify ROS
 - Prevent oxidative damage
- Heat shock proteins**
 - Refold denatured protein
 - Maintain protein function

Antarctic Cryosphere

Criosfera 1 (Brazilian Module)



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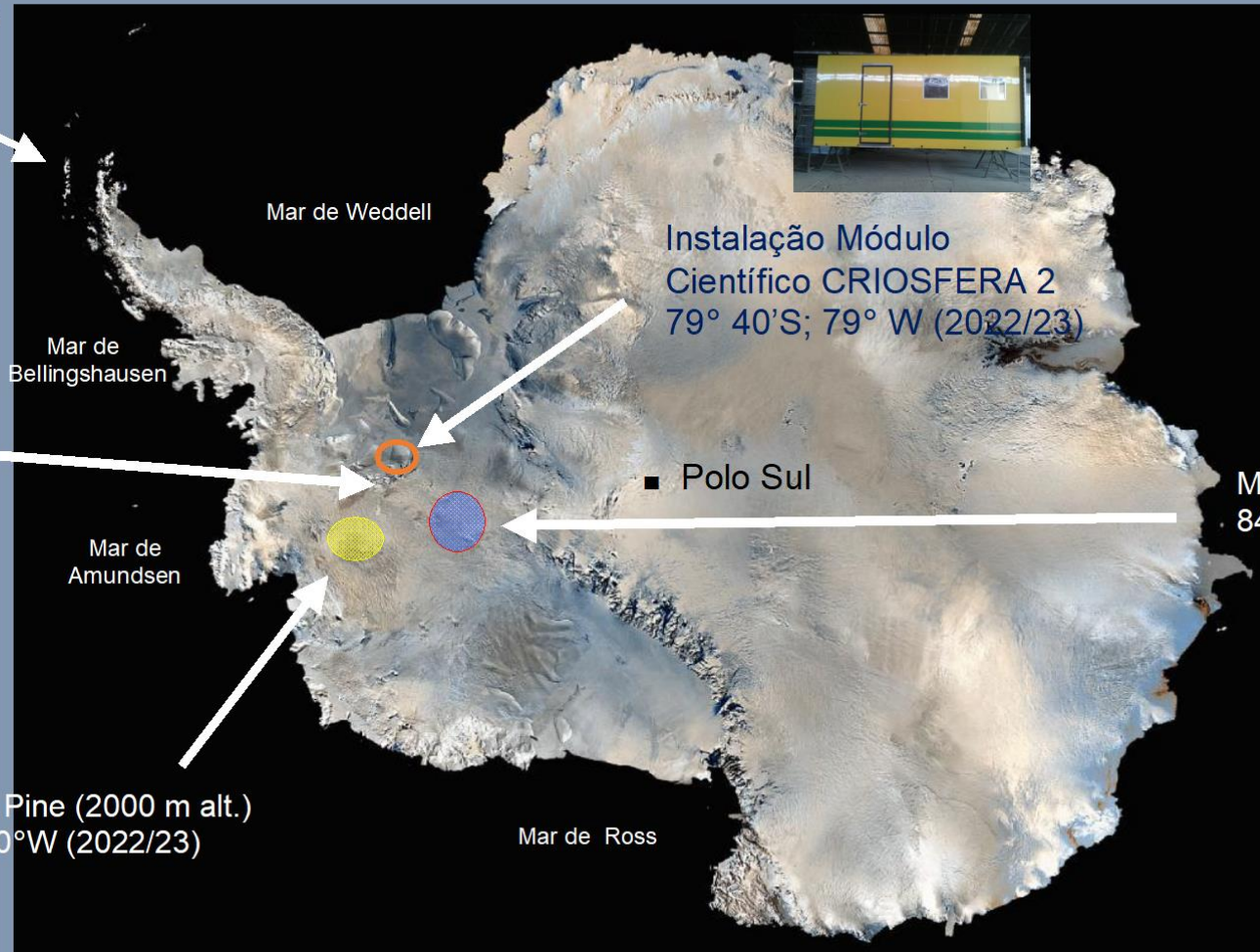


Antarctic Cryosphere

Criosfera 1 (Brazilian Module)

O Brasil na Antártica

Estação Antártica
Conte. Ferraz



Módulo CRIOSFERA 1
84°S (2011/12)



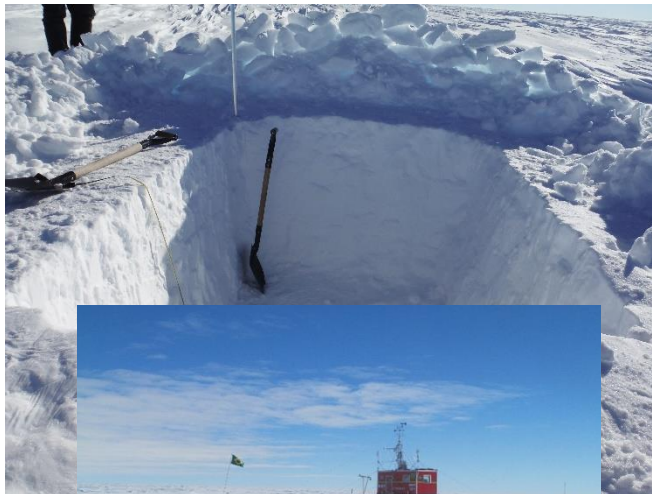
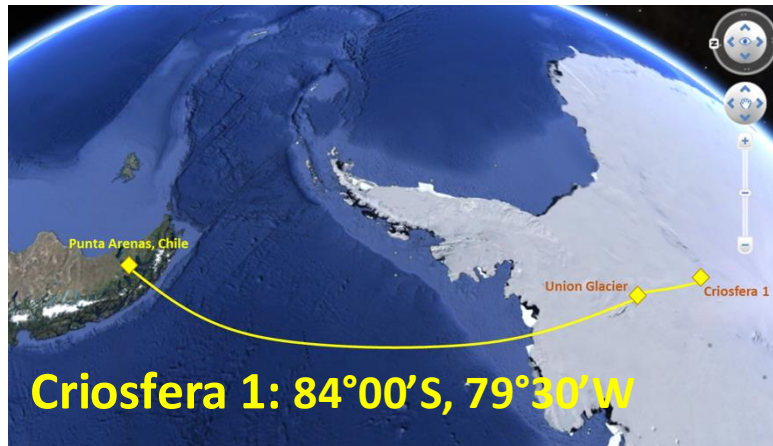
Fonte: Francisco Eliseu Aquino
CPC/UFRGS

Snow microbiome: Antarctic Continent

Criosfera 1/CrioLab1 – expedition – 2014

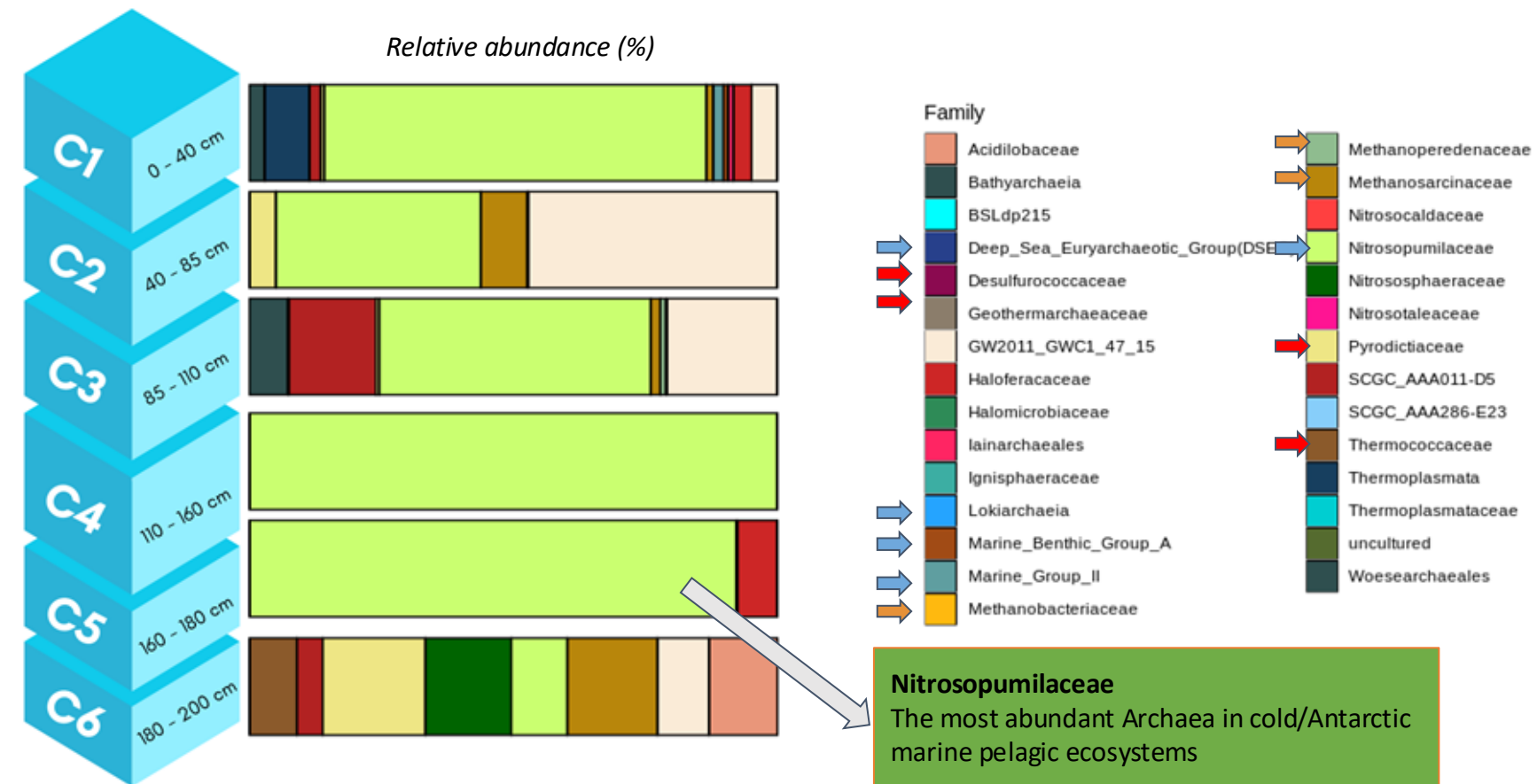
Prof. Heitor Evangelista UERJ

LECOM
Laboratório de Ecologia Microbiana



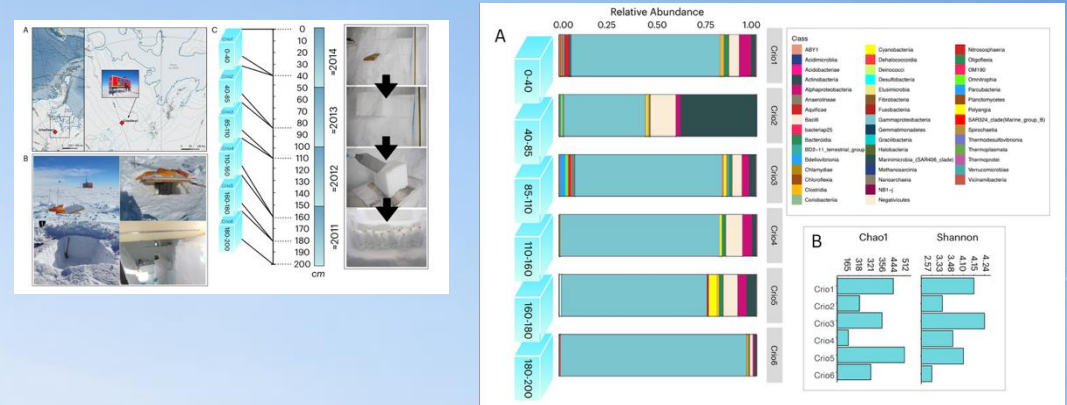
Marine Archaea in snow/firn layers from Antarctic continent interior

- Several marine archaeal groups (deep and surface waters)
- Methanogenic archaea
- Geo/hydrothermal systems

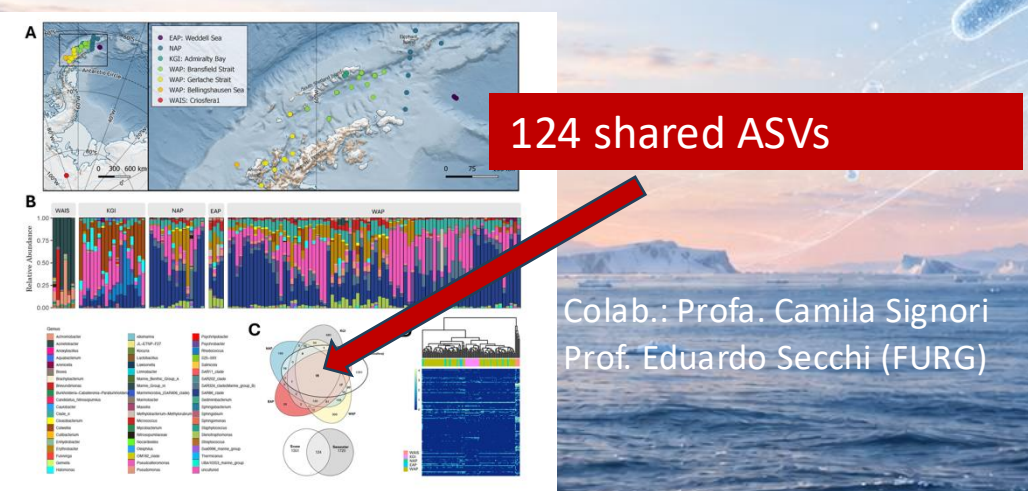


The prevalence of members that occupied such distant ecosystems as marine, hydrothermal and terrestrial ecosystems suggests a heterogeneity of the snow microbiome probably due to the **largely aeolian dispersion** over the Antarctic continent and the **long-time persistence of their genetic material**

Patterns of air mass incursions from Southern Ocean play a role on microbial dispersions into West Antarctic Ice Sheet



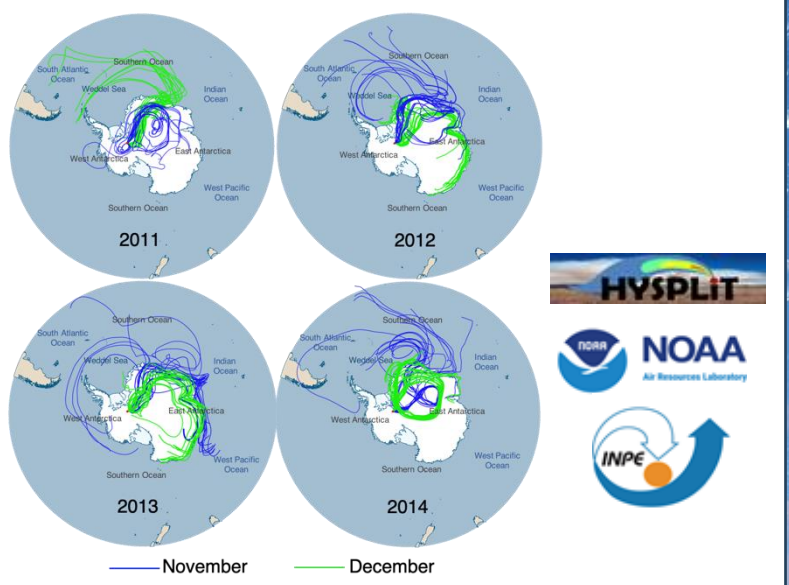
Surface Seawater vs. Antarctic snow/firn



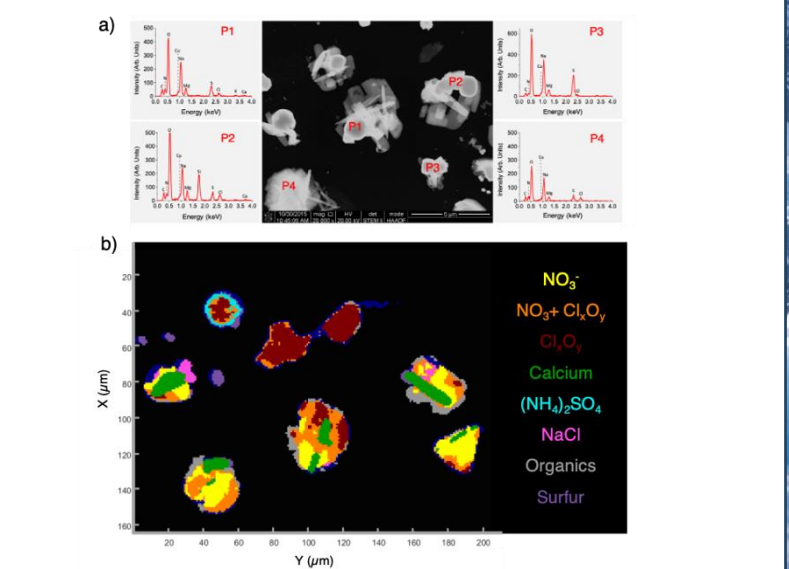
124 shared ASVs

Colab.: Profa. Camila Signori
Prof. Eduardo Secchi (FURG)

Backward air mass trajectories Prof. Dr. Heitor Evangelista UERJ

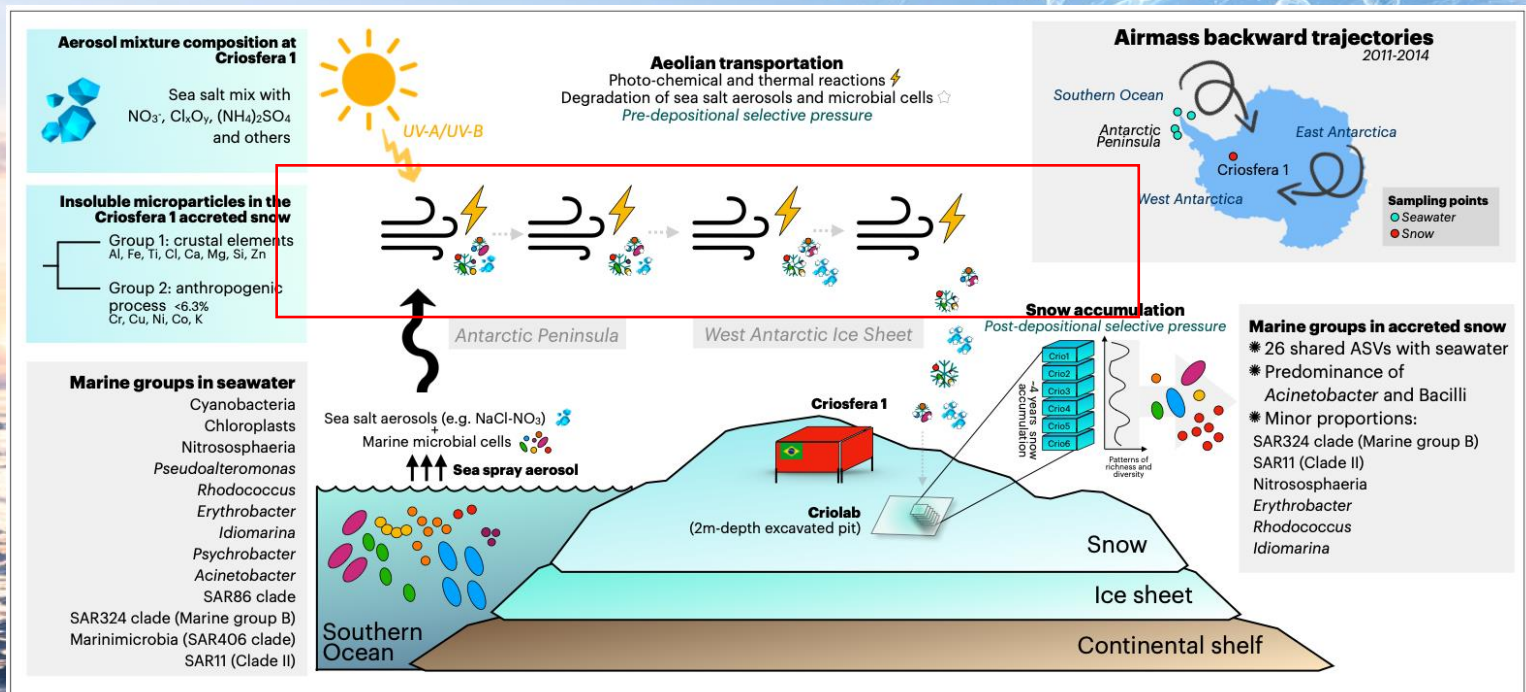


Marine bioaerosols near Criosfera1



Aerobiology over Antarctica and Astrobiology

- Previous results from our group identified the presence of marine microorganisms deposited in snow at the Criosfera 1 module, raising the hypothesis that these microorganisms could be transported through the atmosphere via bioaerosols from the Antarctic Peninsula to the continental interior.
- **How microorganisms can survive dispersal across extreme, cold, nutrient-poor, and highly irradiated environments.**
- The limits of microbial persistence and dispersal and may inform hypotheses about the **transport** and **potential establishment of life in icy extraterrestrial environments.**



AEROMICROANTAR: MARINE BIOAEROSOLS SAMPLING



NPo Almirante
Maximiano



EACF



Bioaerosol sampling to investigate extremophiles survival under atmospheric conditions

Operantares XLIII / XLIV – Operantar XLV (2024 – 2026)

Colab. Prof. Rodrigo Kerr e Eduardo Secchi (FURG)



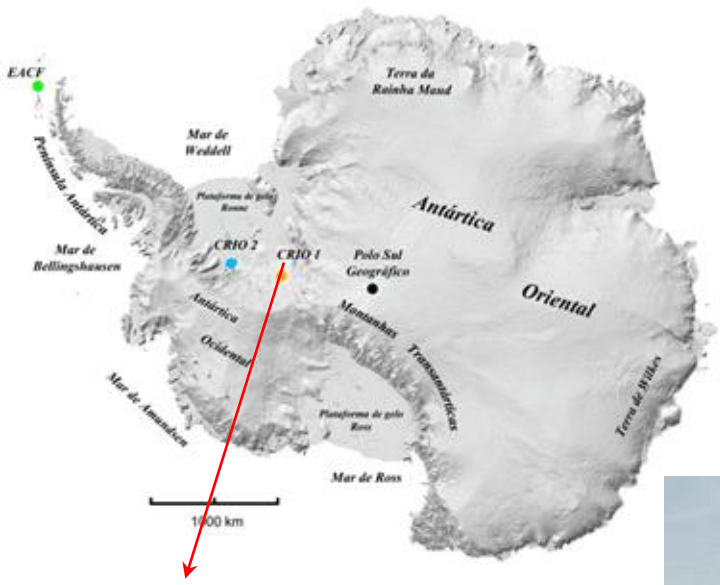
--- TRAJECTORY NP ALMIRANTE MAXIMIANO
◆ OCEANOGRAPHIC STATIONS
◆ AIR MEMBRANES EXCHANGES

AEROMICROANTAR
OPERANTAR XLIII - 5° Fase
MAP OF SAMPLING SITES - ANTARCTIC PENINSULA REGION



Snow sampling in the Ellsworth Mountains and at Criosfera 1 – Antarctic Continent Interior – 2025

Colab. Prof. Heitor Evangelista UERJ



Módulo Criosfera 1



Fotos: Heitor Evangelista (BBC) / Portal Geocracia



Ellsworth Mountains



Foto: Prof. Dr. Heitor Evangelista

ICCE – International Antarctic Coastal Circumnavigation Expedition – 2024/2025

Russian icebreaker Akademik Tryoshnikov

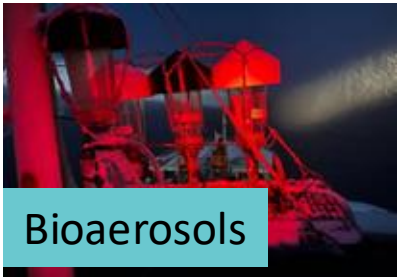
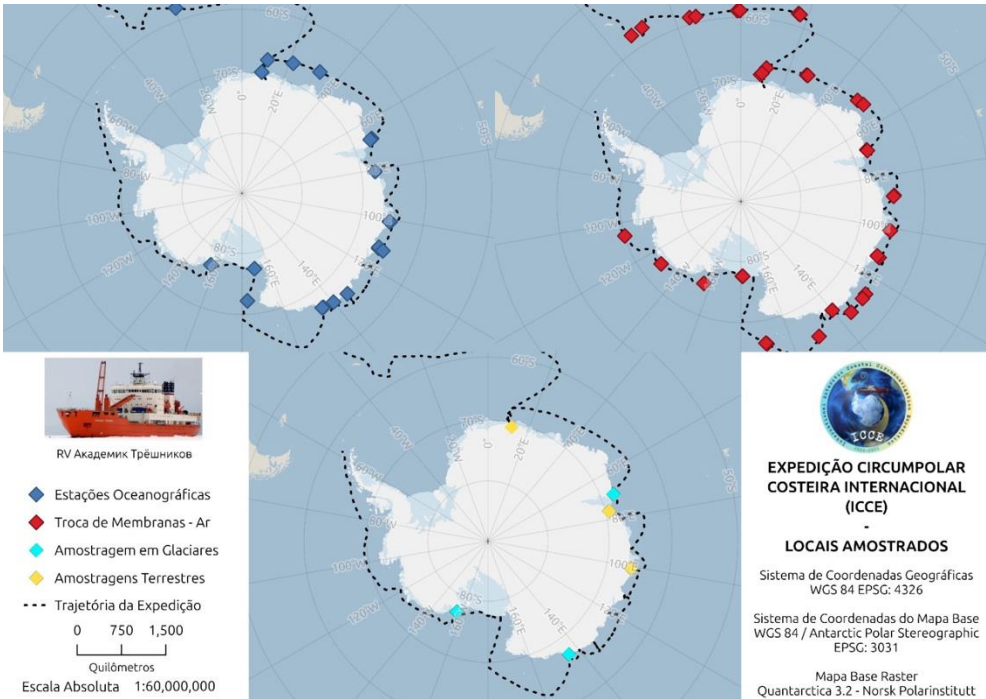
Colab. Prof. Jefferson Simões UFRGS



Sampling to investigate Antarctic extremophiles

Seawater, bioaerosols, snow, soil, and deep-sea sediments

International Coastal Circumpolar Expedition – ICCE



Seawater – surface to the deep sea









Deep Sea in Antarctica

Epipelagic
0 – 200 m

Mesopelagic
200 – 1,000 m

Bathypelagic
1,000 – 4,000 m

Abyssopelagic
4,000 – 6,000 m

Hadalpelagic
> 6,000 m

10 km

Seafloor

Sediment
layers

Subsurface
sediments
>1m

A new frontier for studying extremophiles: the subsurface and the limit



ARTICLE

<https://doi.org/10.1038/s41467-020-17330-1>

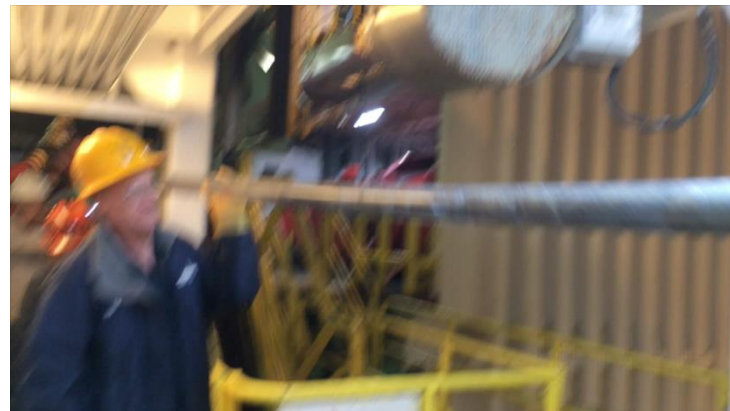
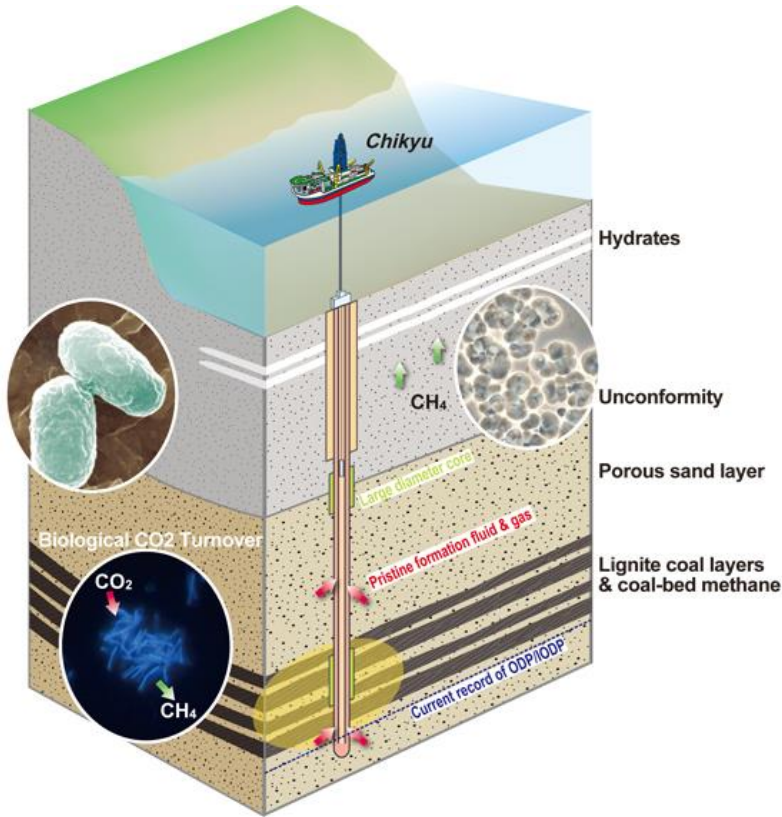
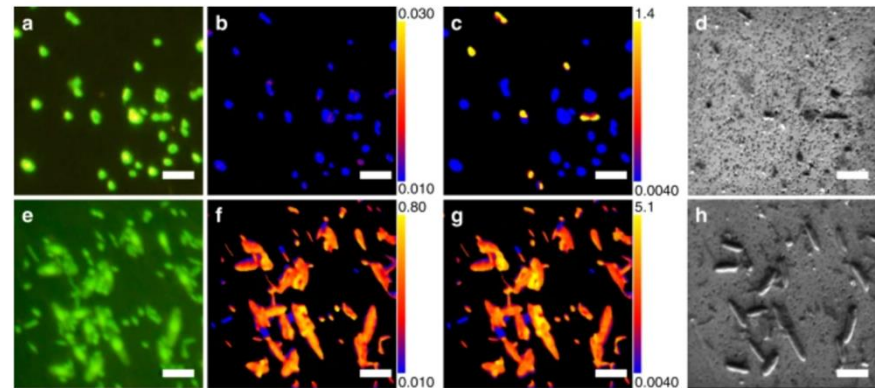
OPEN

Check for updates

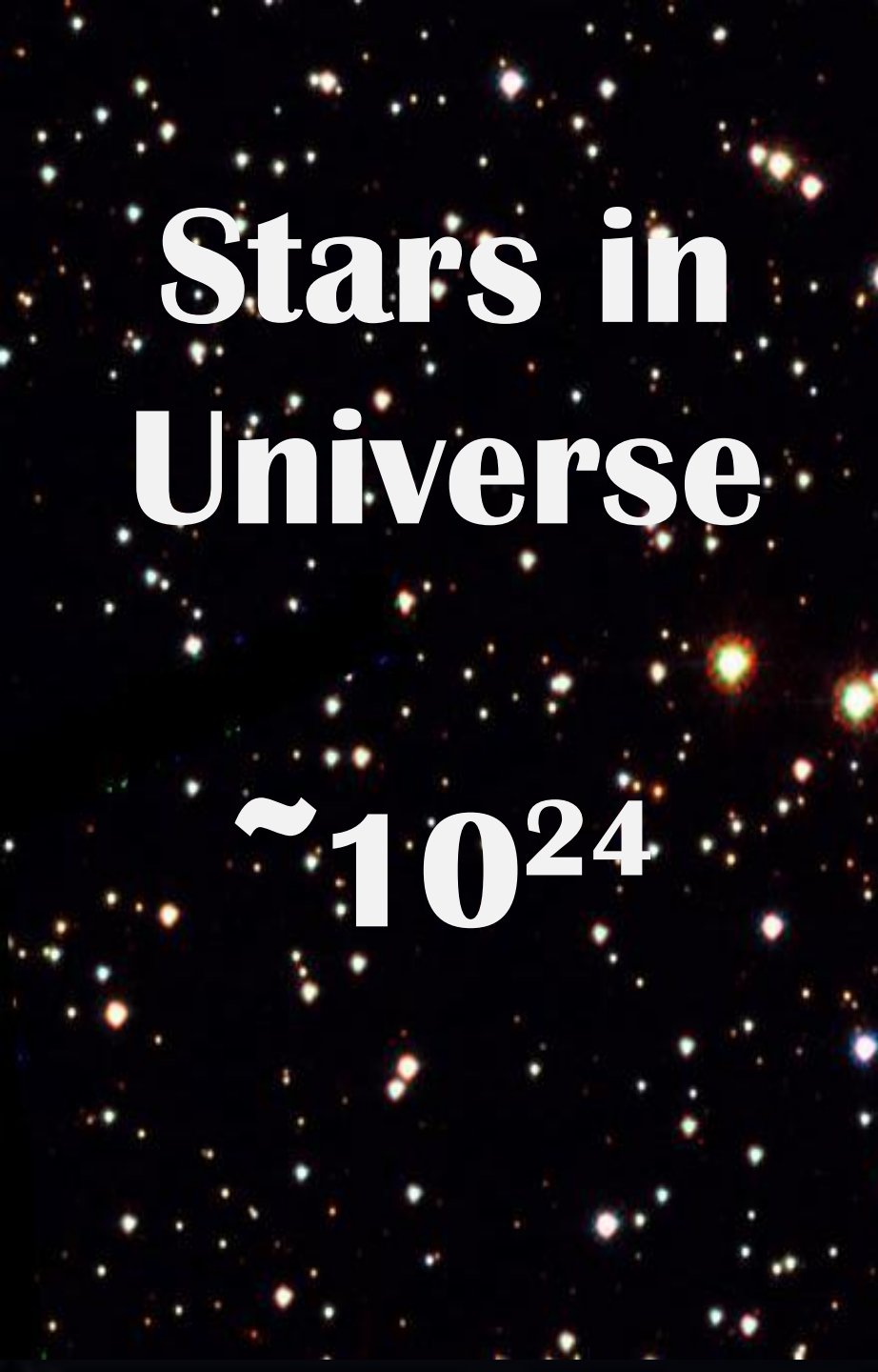
Aerobic microbial life persists in oxic marine sediment as old as 101.5 million years

Yuki Morono^{1,2}, Motoo Ito^{1,2}, Tatsuhiko Hoshino^{1,2}, Takeshi Terada³, Tomoyuki Hori⁴, Minoru Ikehara⁵, Steven D'Hondt⁶ & Fumio Inagaki^{1,2,7,8}

Fig. 1: ^{13}C and ^{15}N incorporation in representative microbial cells.



Pellizari, VH

A field of stars against a black background, with stars of various colors (white, yellow, orange, red) and sizes scattered across the frame.

Stars in Universe

$\sim 10^{24}$

A field of blue and green points representing subseafloor life. The top half is dark blue with small white and blue points, and the bottom half is a solid green with small yellow and green points.

Subseafloor Life

$\sim 10^{29}$

Hidden ecosystems: The marine subsurface

The **largest** and **most unknown** habitat for microbial life on Earth



high pressure
(deep sea)



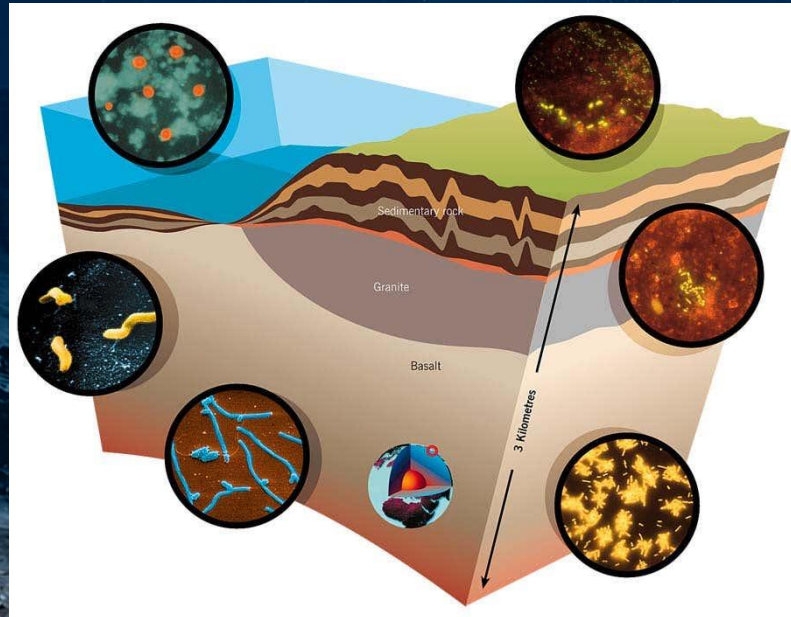
low and/or high temperatures



low nutrients



absence of light



Intraterrestrial Life (K. Lloyd)

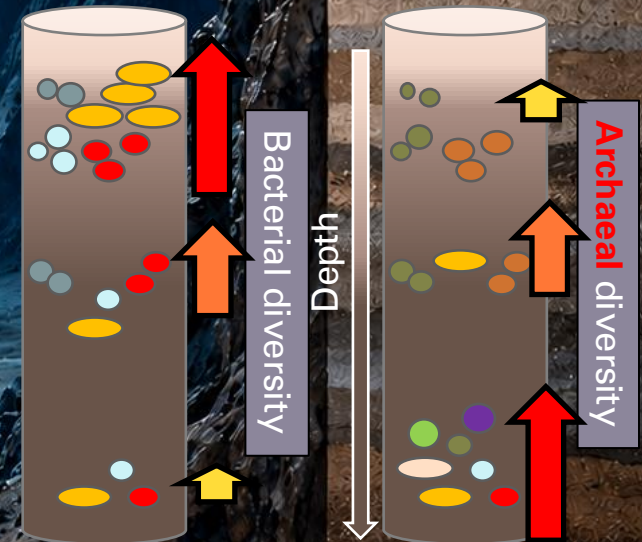
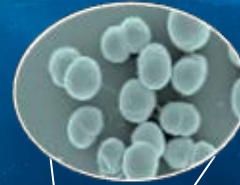


How **life** on Earth **survives** and **adapts** under subsurface conditions?

- **Intraterrestrial** extremophiles
- Chemoautotrophic growth
- Widespread microbial life (2 km deep in sediments/oceanic crust)
- Bacterial metabolism and growth rate decrease with depth

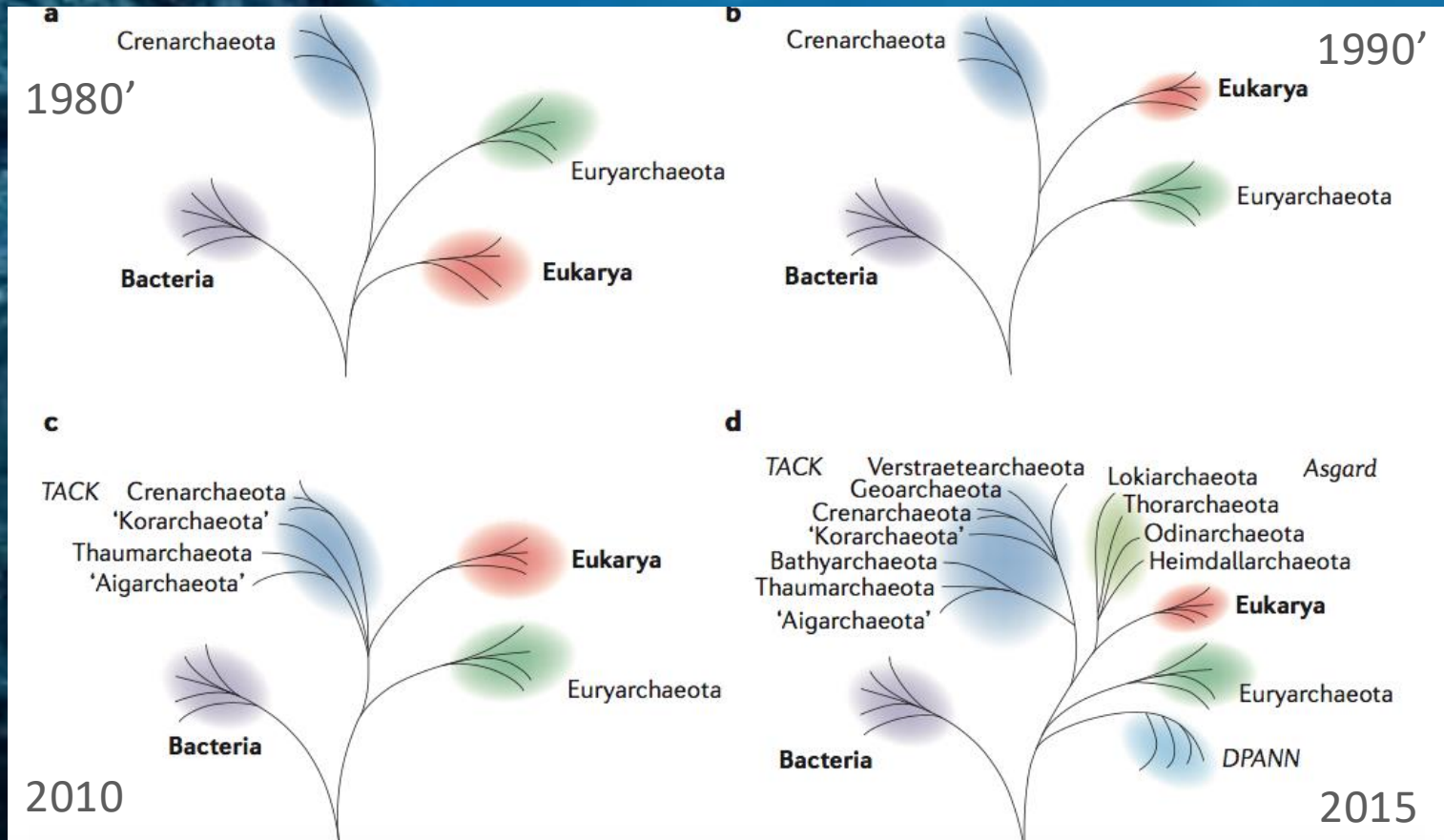
However...

- Diversity of **archaea** in the subsurface often **surpasses** that found the in surface
- **Underestimation of Earth's overall archaeal diversity**
- Subsurface ecosystems still poorly studied, notably for Archaea

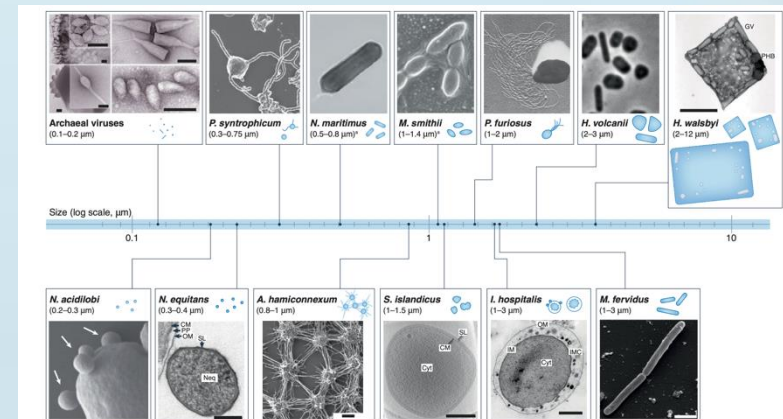
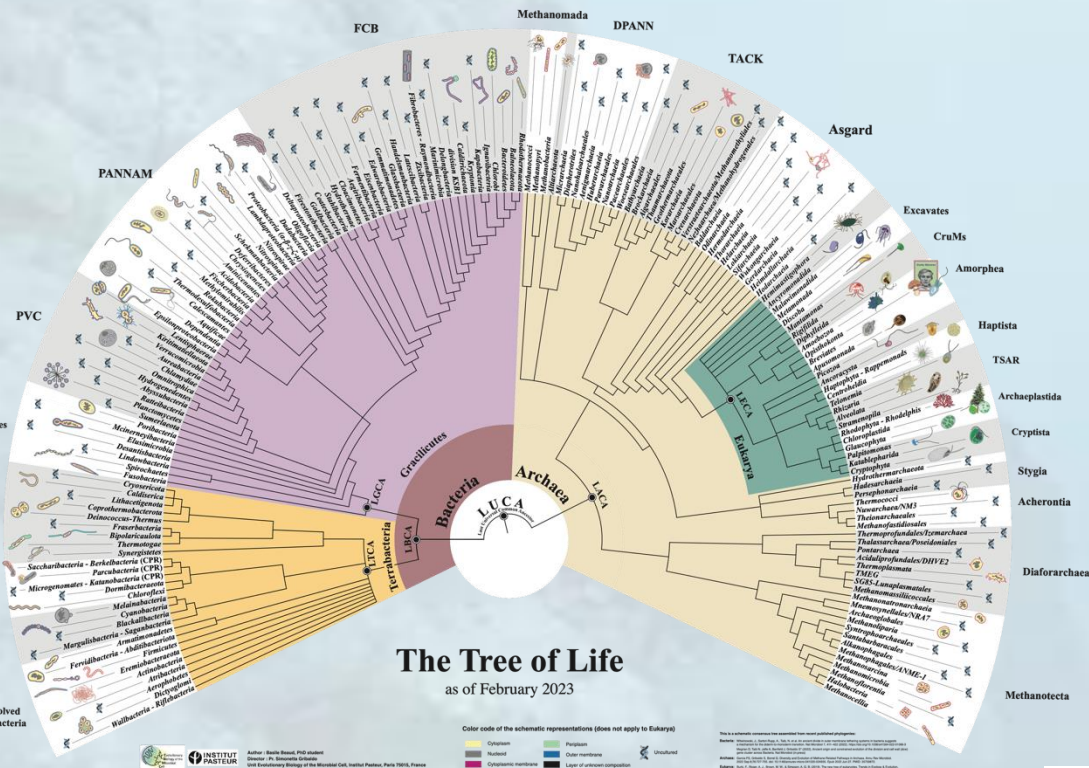


(Scheffer & Gieg, 2023; Hershey & Barton, 2018; Mullis, 2021)

DISCOVERING NOVEL ARCHAEOAL PHYLA AND SUPERPHYLA IN DEEP-SEA ECOSYSTEMS



DISCOVERING NOVEL ARCHAEAL PHYLA AND SUPERPHYLA IN DEEP-SEA ECOSYSTEMS



Review Article | Published: 17 October 2022

The cell biology of archaea

Marleen van Wolferen, Andre Arashiro Pulschen, Buzz Baum, Simonetta Gribaldo & Sonja-Verena Albers

Nature Microbiology 7, 1744–1755 (2022) | [Cite this article](#)

3407 Accesses | 135 Altmetric | [Metrics](#)

ASGARD AND THE ORIGIN OF EUKARYOTES AND

doi:10.1038/nature21031

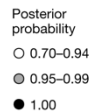
Katarzyna Zaremba-Niedzwiedzka^{1*}, Eva F. Caceres^{2*}, Jimmy H. Saw^{1*}, Disa Bäckström¹, Lina Juzokaite¹, Emmellen Vancaester^{1†}, Kiley W. Seitz², Karthik Anantharaman³, Piotr Starnawski⁴, Kasper U. Kjeldsen⁴, Matthew B. Stott⁵, Takuro Nunoura⁶, Jillian F. Banfield³, Andreas Schramm⁴, Brett J. Baker², Anja Spang² & Thijs J. G. Ettema¹

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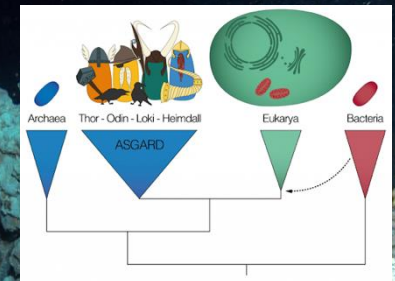
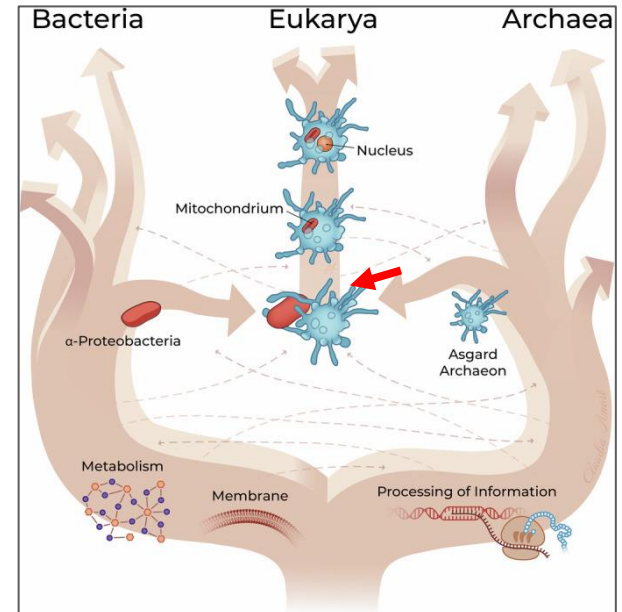
Ian M. Rambo, Marguerite V. Langwig, Pedro Leão, Valerie De Anda & Brett J. Baker

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Archaea and the origin of eukaryotes

Laura Erme, Anja Spang, Jonathan Lombard, Courtney W. Stairs and Thijs J. G. Ettema

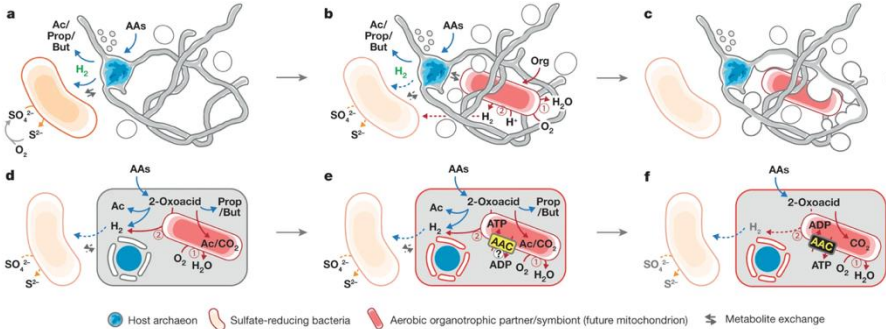


DISCOVERING NOVEL ARCHAEAL PHYLA AND SUPERPHYLA IN DEEP-SEA ECOSYSTEMS

ASCARD AND THE ORIGIN OF EUKARYOTES AND

Fig. 5: Proposed hypothetical model for eukaryogenesis.

From: *Isolation of an archaeon at the prokaryote–eukaryote interface*



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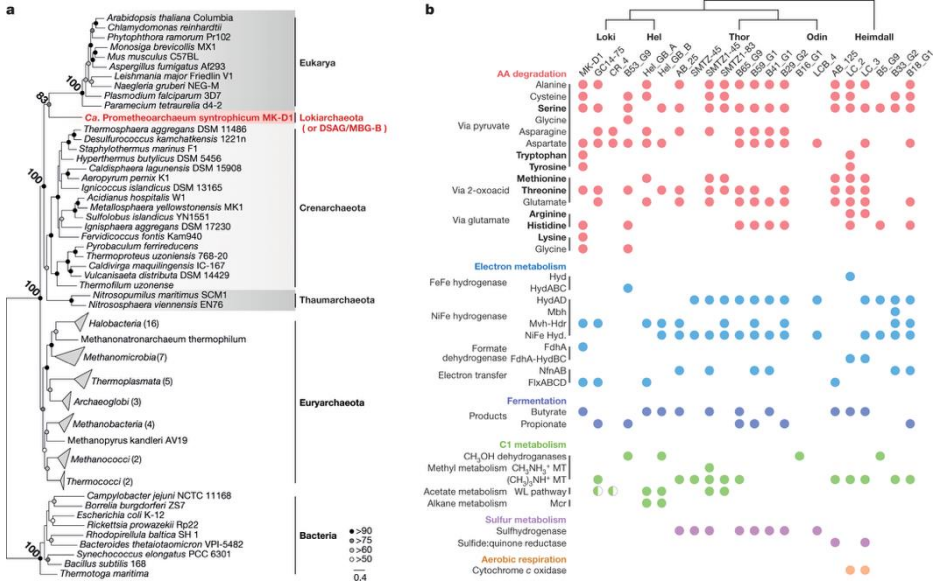
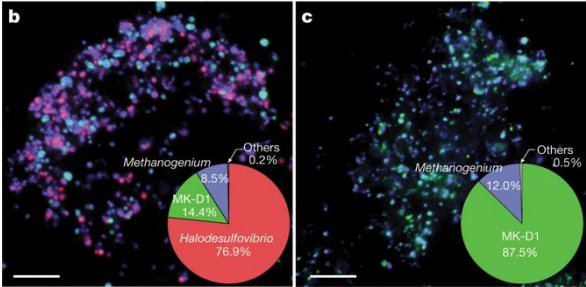
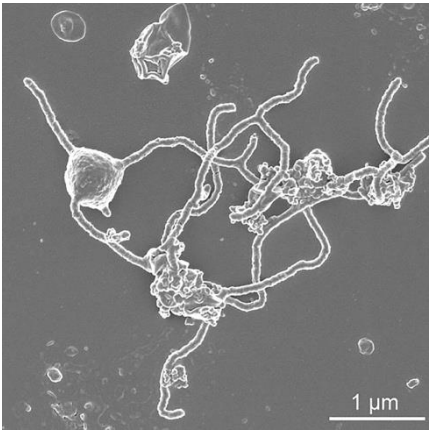
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Isolation of an archaeon at the prokaryote–eukaryote interface

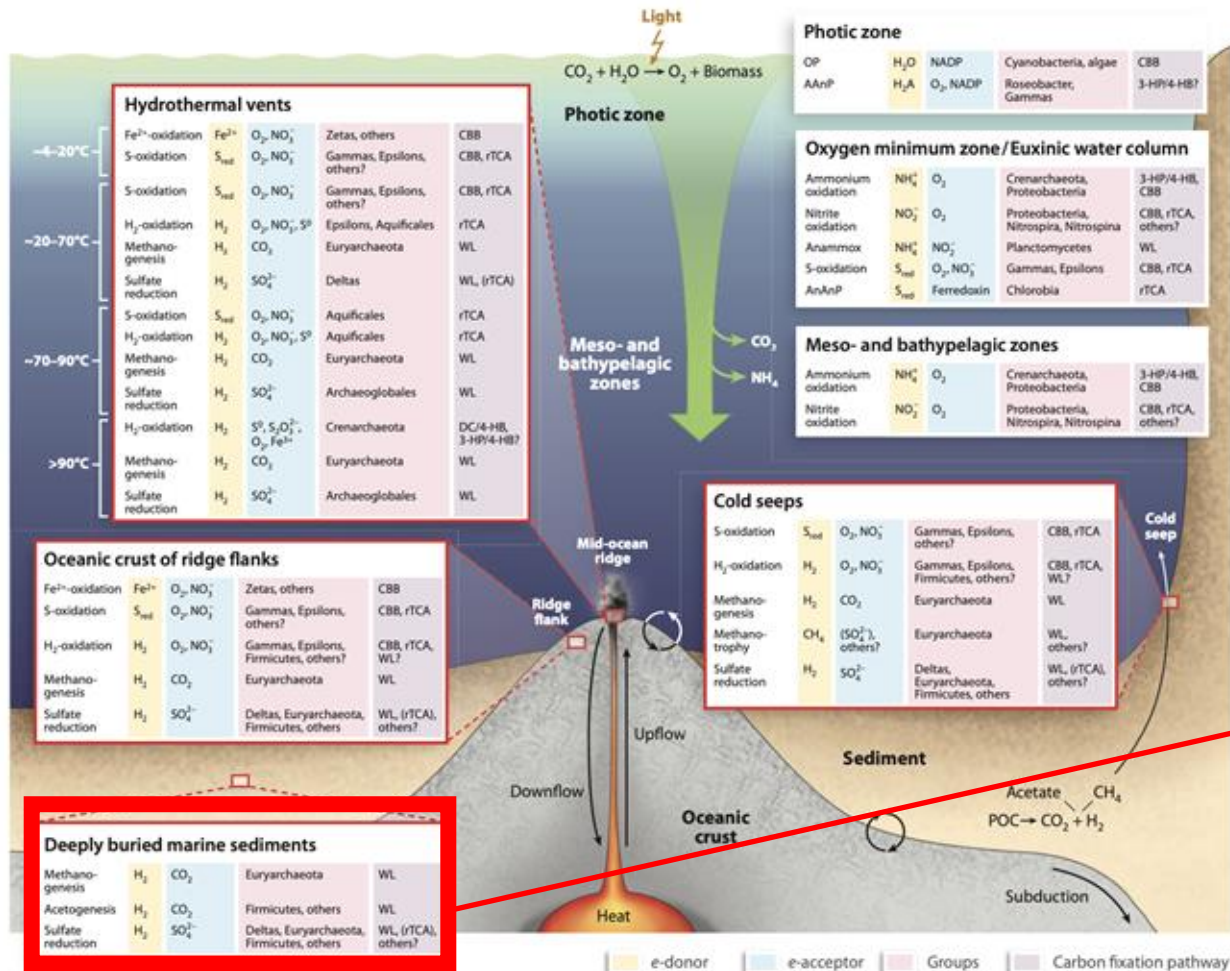
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[Nature](#) 577, 519–525 (2020) | [Cite this article](#)

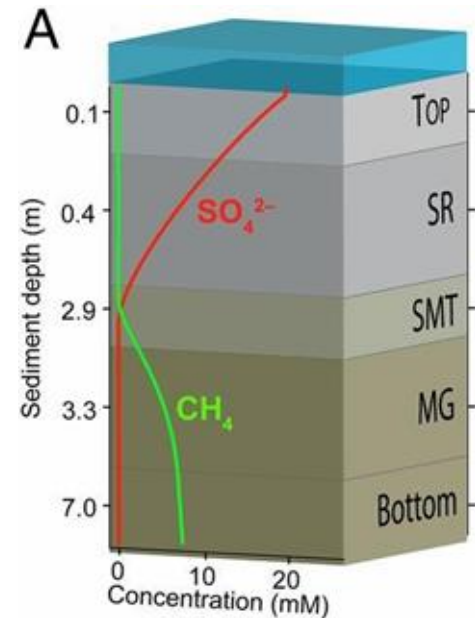


CHEMOSYNTHETIC METABOLISMS IN THE SUBSEAFLOOR

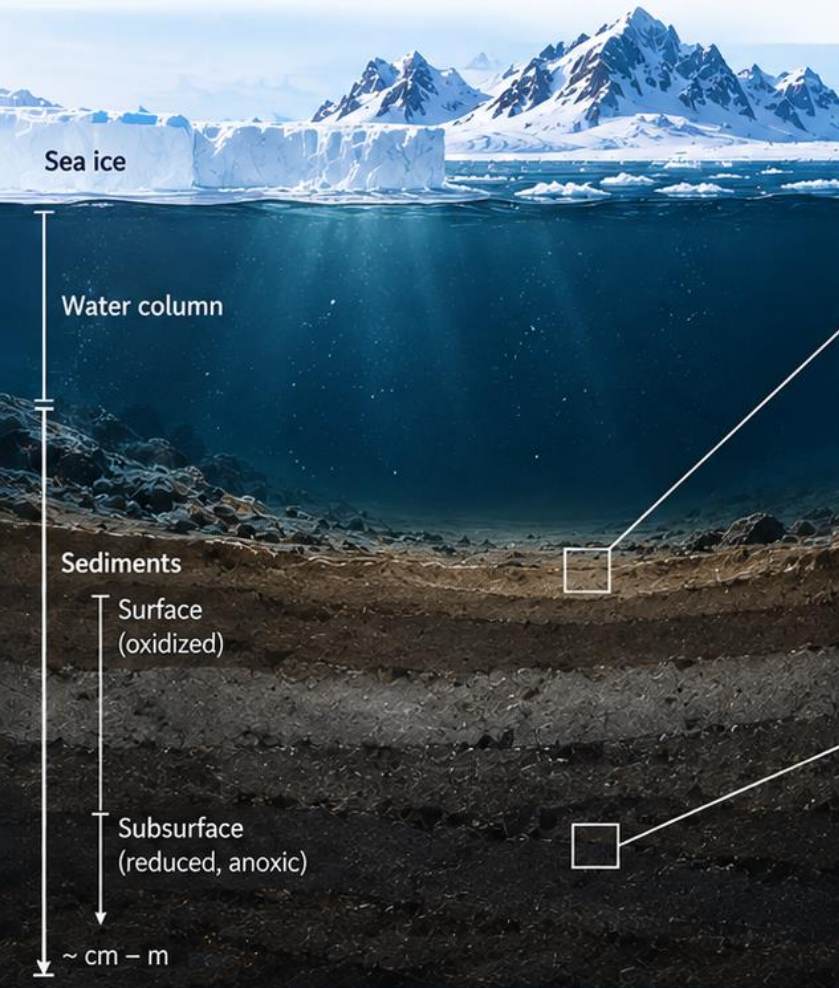
272 Hugler • Sievert



Sulfate-methane transition zone

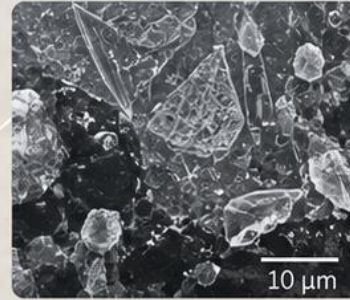


Microbial Metabolisms in Antarctic Deep-Sea Sediments



Surface sediments (oxic)

Higher availability of electron acceptors



Common metabolisms

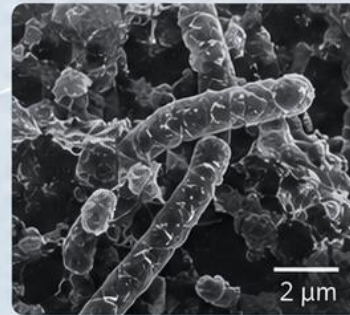
- Organic carbon degradation (aerobic)
- Nitrification
- Manganese and iron oxidation
- Sulfur oxidation

Electron acceptors

O_2
 NO_3^-
 $Mn(IV)$
 $Fe(III)$
 SO_4^{2-}

Subsurface sediments (anoxic)

Energy from reduced inorganic compounds



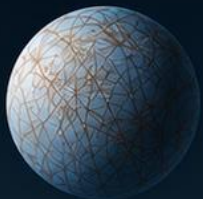
Common metabolisms

- Sulfate reduction
- Methanogenesis
- Anaerobic methane oxidation
- Iron and manganese reduction
- Other anaerobic pathways

Electron acceptors

SO_4^{2-}
 CO_2
 $Fe(III)$
 $Mn(IV)$
(no O_2)

Relevance for icy ocean worlds



Europa



Enceladus



Titan

- Subsurface oceans likely dominated by anoxic conditions
- Reduced compounds can fuel chemosynthetic life
- Similar metabolisms may sustain microbial ecosystems in icy ocean environments



Review

A Review on Hypothesized Metabolic Pathways on Europa and Enceladus: Space-Flight Detection Considerations

Jessica M. Weber*, Theresa C. Marlin , Medha Prakash, Bronwyn L. Teece , Katherine Dzurilla and Laura M. Barge



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Josep M. Trigo-Rodríguez,
Spanish National Research Council
(CSIC), Spain

REVIEWED BY
Alberto Robador,
University of Eastern California

Europa's ocean: potential for extraterrestrial chemoautotrophy

Emory G. Barrett and Richard A. Lutz*

Department of Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ, United States

Table 1. Predicted condition comparison between Enceladus and Europa based on modeling and spacecraft measurements. For the molecules and ions, this is a non-exhaustive list.

Condition	Enceladus	Europa
pH	Basic (8–11) [27,28]	Most likely acidic (~4–6), but not well constrained [29,30]
Pressure	1.5–10 MPa [31,32]	110–260 MPa [30,33,34]
Ice shell thickness	5–25 km (excluding south pole terrain) [31,35,36]	5–100 km [37,38,39]
Notable species	H ₂ , CO ₂ , NH ₃ , CH ₄ , organics, phosphates [11,12,13,14,40,41]	Mg ²⁺ , SO ₄ ²⁻ , CH ₄ , NH ₃ [29,42,43,44,45,46,47,48,49,50]

Hypothetical anaerobic metabolisms

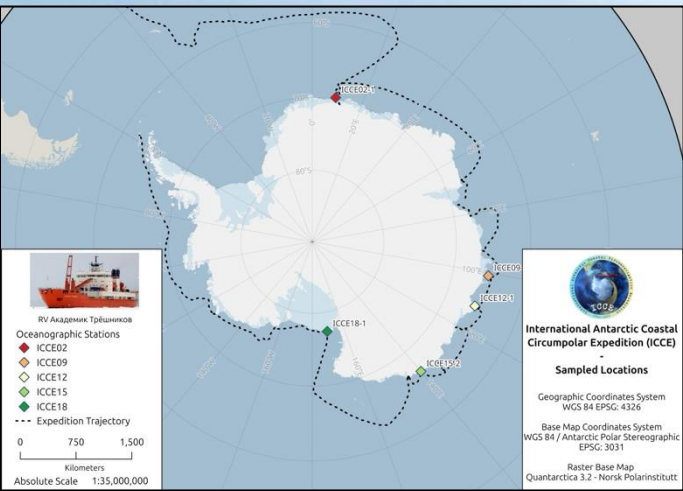
Methane oxidation (mainly Europa)

Methanogenesis

Sulfate Reduction

Sampling to investigate deep-sea Antarctic extremophiles

International Coastal Circumpolar Expedition – ICCE



- sampling_site
- Lazárev Sea
- Mawson Sea
- Dumont d' Urville Sea
- Dumont d' Urville Sea
- Ross Sea



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Início > Ciências > Expedição vai investigar impacto das mudanças climáticas no gelo e na biodiversidade da Antártida

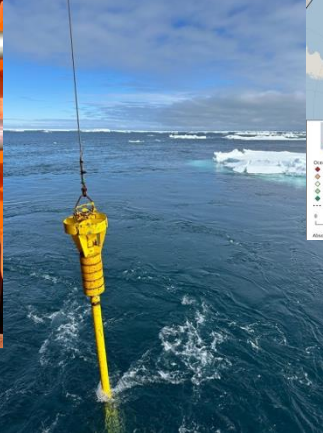
Expedição vai investigar impacto das mudanças climáticas no gelo e na biodiversidade da Antártida

Missão internacional, liderada pelo Brasil, vai percorrer mais de 20 mil quilômetros ao redor do continente antártico, a bordo de um quebra-gelo russo

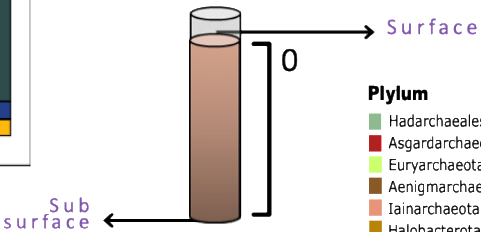
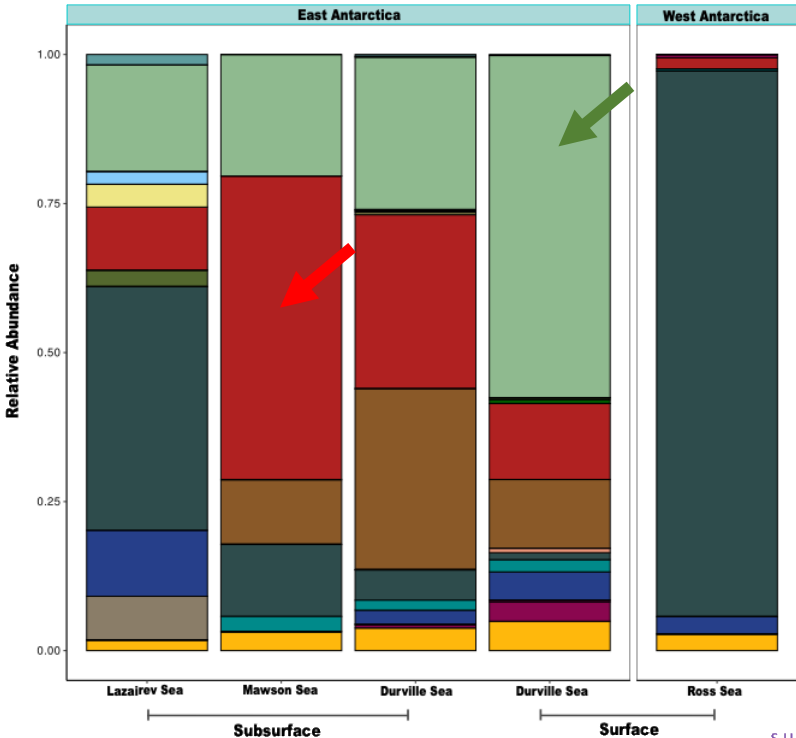
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Texto: Herton Escobar
Arte: Jornal da USP

Unveiling Extremophilic Archaea from Antarctic Deep-Sea Surface and Subsurface Sediments with Evolutionary Links to the Origin of Complex Life



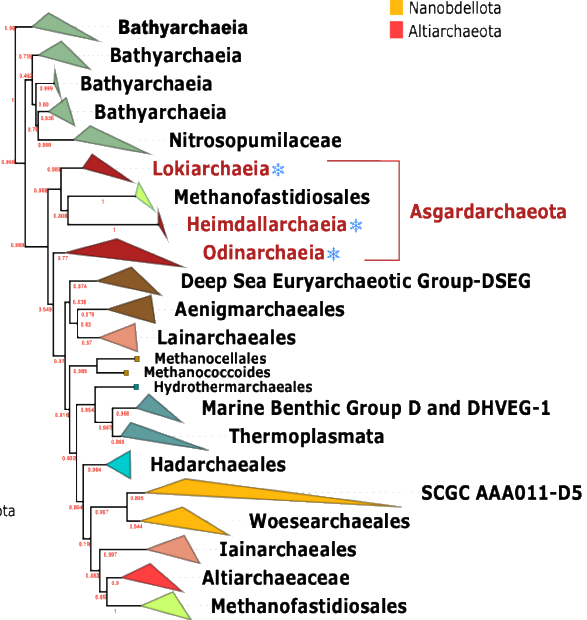
- Phylum**
- Hadarchaeales
 - Asgardarchaeota
 - Euryarchaeota
 - Aenigmarchaeota
 - Iainarchaeota
 - Halobacterota
 - Hydrothermarchaeota
 - Thermoplasmata
 - Hadarchaeota
 - Nanobdellota
 - Altiarchaeota



Tree scale: 0.1

Phylum

- Hadarchaeales
- Asgardarchaeota
- Euryarchaeota
- Aenigmarchaeota
- Iainarchaeota
- Halobacterota
- Hydrothermarchaeota
- Thermoplasmata
- Hadarchaeota
- Nanobdellota
- Altiarchaeota

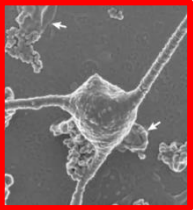


Gabriela Elidio
Master Student

**MAG: Archaea;
Asgardarchaeota;
Lokiarchaeia; CR-4;
SOKP01; SOKP01**

New results coming soon!

Antarctic Asgards!



Hooke Ridge hydrothermal vents – Bransfield Strait

Southernmost Hydrothermal área on Earth

Geo-Marine Letters (1999) 18: 277–284

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G. Bohrmann · C. Chin · S. Petersen · H. Sahling
U. Schwarz-Schampera · J. Greinert · S. Lammers
G. Rehder · A. Daehlmann · K. Wallmann
S. Dijkstra · H.-W. Schenke

Hydrothermal activity at Hook Ridge in the Central Bransfield Basin, Antarctica

1999



Earth and Planetary Science Letters 193 (2001) 381–394

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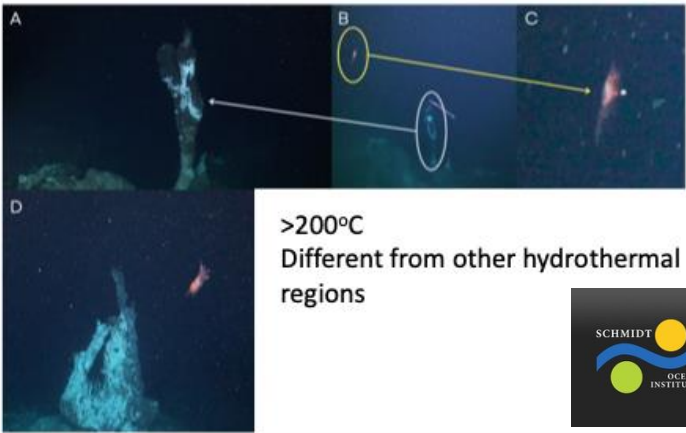
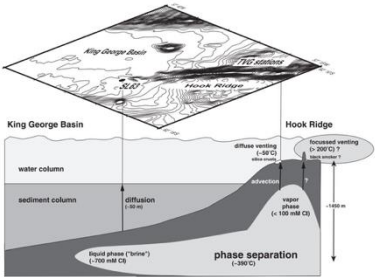
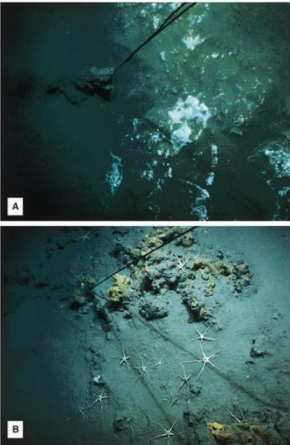
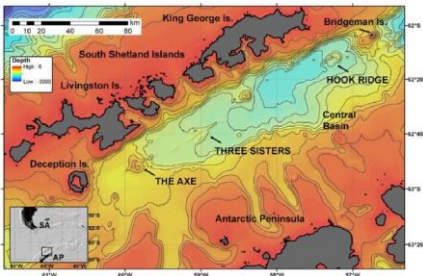
2001

www.elsevier.com/locate/epsl

Hot vents in an ice-cold ocean:

Indications for phase separation at the southernmost area of hydrothermal activity, Bransfield Strait, Antarctica

A. Dählmann^{a,*}, K. Wallmann^a, H. Sahling^a, G. Sarthou^{a,1}, G. Bohrmann^a,
S. Petersen^b, C.S. Chin^c, G.P. Klinkhammer^c



communications biology

A Nature Portfolio journal

2026

Article



<https://doi.org/10.1038/s42003-026-10780-1>

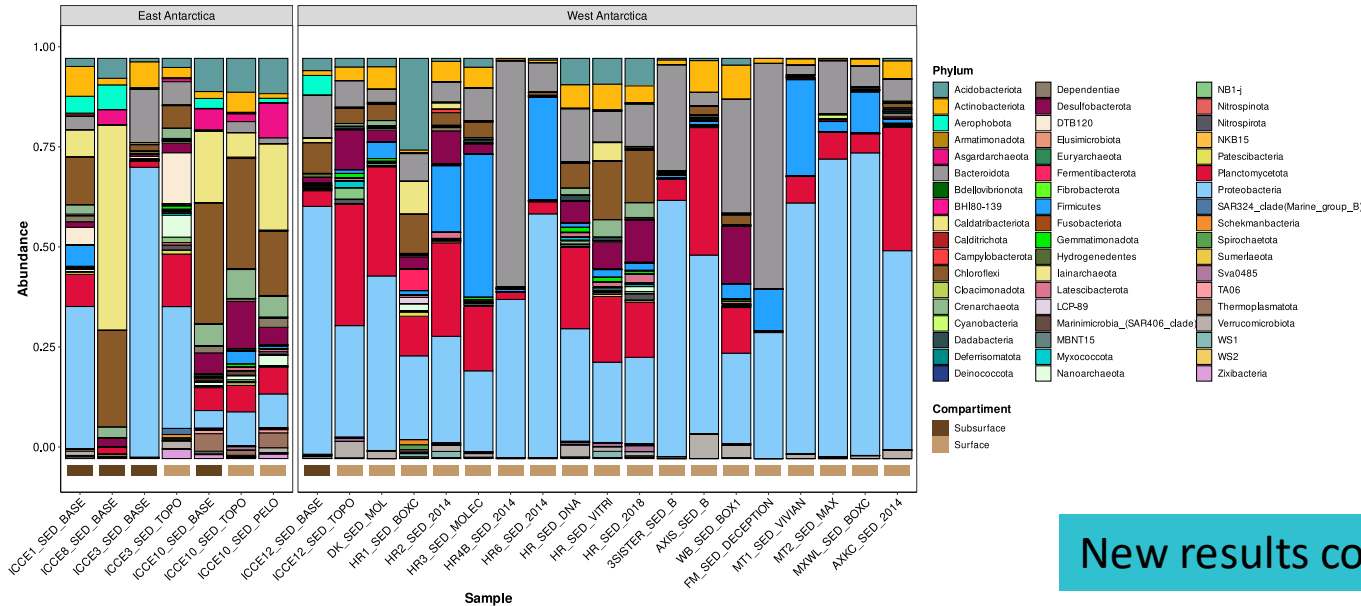
Deep Sea hydrothermal vent habitats support gravid Antarctic krill

Check for updates

Kim S. Bernard¹, Angelo F. Bernardino², Kristen N. Buck¹, Salvatore Caprara¹,
R. Ben Freiburger¹, Elizabeth Hogan³, Rachel L. Kaplan¹, Aaron Micallef⁴, Laura E. Moore¹,
Sarah Seabrook⁵ & Andrew R. Thurber⁴

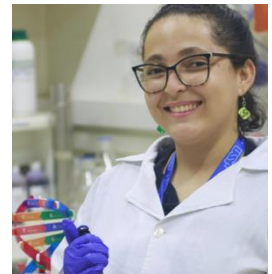
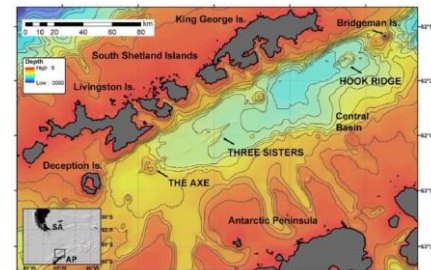
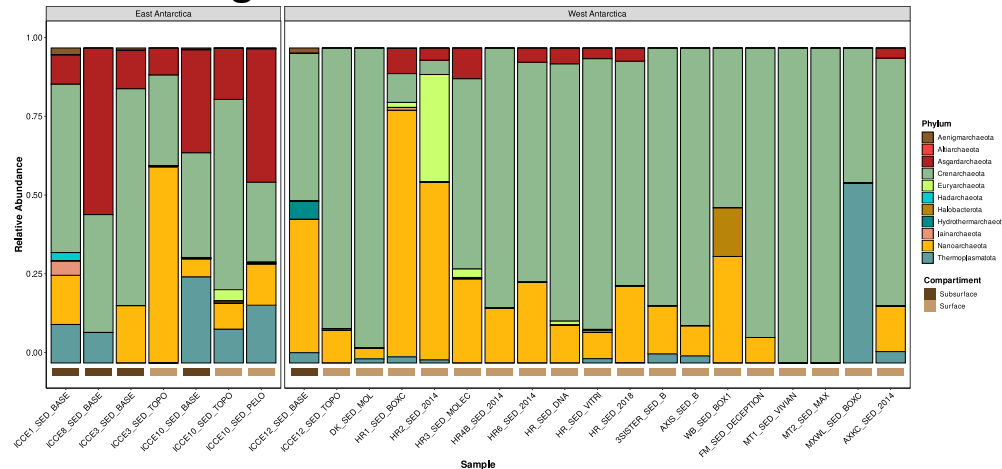
Unveiling Extremophiles from Antarctic Deep-Sea Surface and Subsurface Sediments

Around Antarctica



New results coming soon!

Hook Ridge



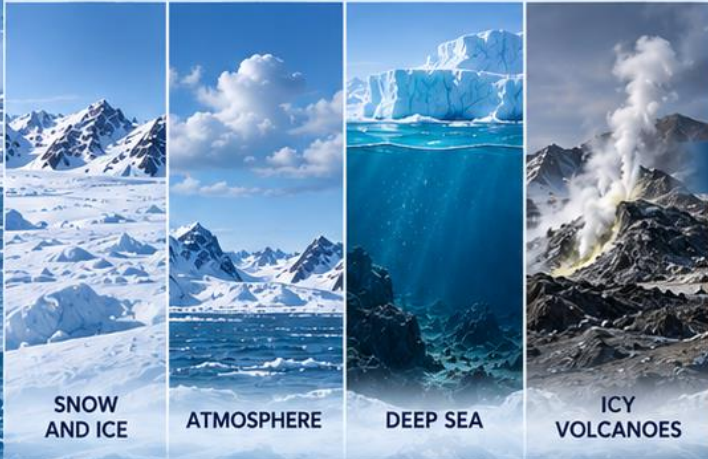
Gabriela Elidio
Master Student

What Antarctic Microbes Reveal About the Potential for Life in Ocean Worlds?

ANTARCTICA

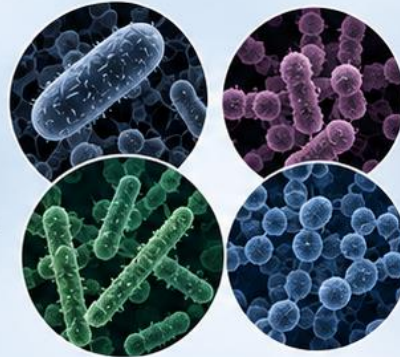
A NATURAL ANALOGUE

A diversity of geochemical environments that harbor extremophiles.



DIVERSE MICROBIAL LIFE

REFLECTING THE ENVIRONMENTS



COMMUNITIES | METABOLISMS | ADAPTATIONS

Driven by extreme conditions such as low temperature, high pressure, darkness and chemical energy sources.

OCEAN WORLDS

SIMILAR ENVIRONMENTS,
NEW OPPORTUNITIES



Antarctic habitats are diverse, and the metabolic diversity and adaptation of their microbial communities reflect these environments, helping us define **where — and **what** — to search for as evidence of life in ocean worlds.**



WHERE TO LOOK?

Ice-ocean interfaces
Seafloor
Subsurface environments
Plumes



WHAT TO LOOK FOR?

Metabolic products
Molecular biosignatures
Geochemical disequilibria



WHICH CONDITIONS CAN SUSTAIN LIFE?

Energy sources
Redox gradients
Liquid water
Temperature and pressure

Science outreach

Oceanographic Institute
University of São Paulo, Brazil



Exhibition “Microheroes of the Oceans”

Science in the streets of Brazil



**MICRO-HERÓIS
DOS OCEANOS**

Quantidade



Av. Paulista



Av. Paulista



Ask a Scientist



Women in Science: Soapbox
Science / Museum “do Amanhã”

Science outreach: schools

International Polar Week

APECS - Association of Polar Early Career Scientists

EMEE Olga Benário Prestes – Diadema/SP



PALAVRA DA MENTORA

Vozes de Permanência: Mulheres e Maternidade na Ciência Polar

Caros leitores e leitoras do Polos, escrever sobre mulheres e maternidade na ciência polar é, para mim, particularmente especial, pois falar sobre esse tema é falar sobre presença, permanência e transformação. No Programa Antártico Brasileiro (ProAntar) e na ciência polar, as mulheres têm desempenhado papel fundamental em todas as etapas: da formação de estudantes à liderança de projetos, da pesquisa em campo à produção de conhecimento que sustentam decisões estratégicas sobre as ciências polares. Há 14 anos, iniciei minha jornada na pesquisa Antártica durante o mestrado em Biologia na UFPA, e, em seguida, na doutorado em Microbiologia na UFPA. Hoje



Dra. Amanda Gonçalves Bendia
Universidade de São Paulo - Instituto Oceanográfico (IO-USP)

na foto inferior: Amanda foi assistente de monitoramento de biota

Podcasts – Átila Iamarino



Schools - 2026





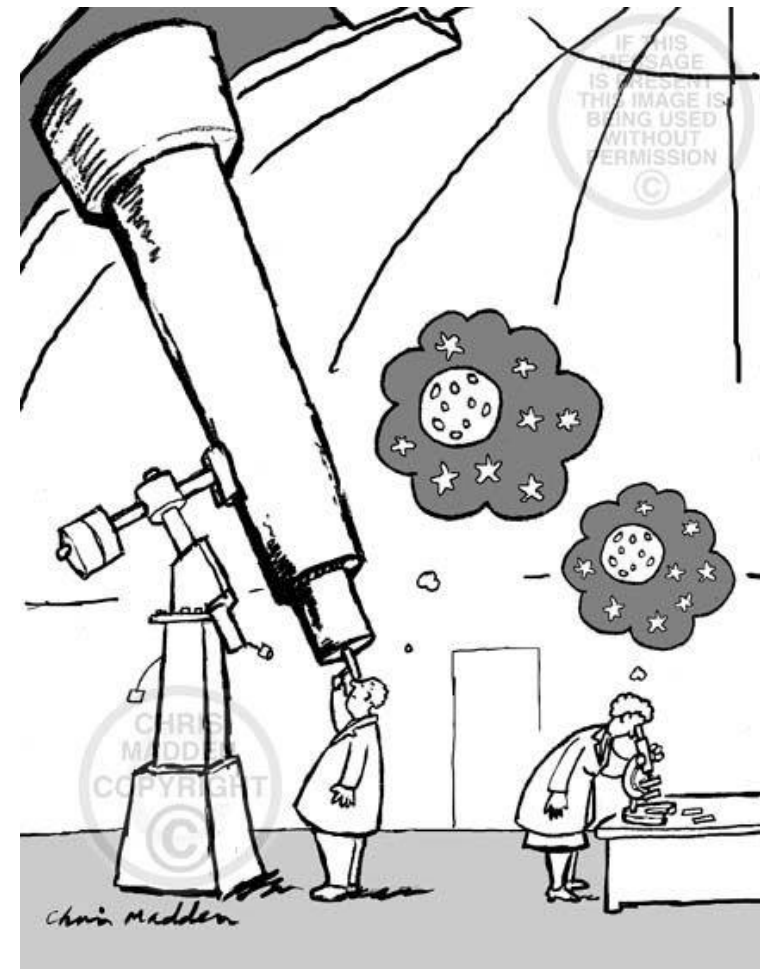
Sociedade
Brasileira de
Astrobiologia

<https://sbastrobio.org/>

sbastrobio.org



Livro gratuito em pdf:



People involved



Professors

- ✦ Prof. Dr. Vivian Pellizari (Microbiology, oceanography) - USP - IO
- ✦ Prof. Dr. Camila Signori (Microbial oceanography) - USP – IO
- ✦ Prof. Dr. Paulo Sumida (Biological oceanography) – USP -IO
- ✦ Prof. Dr. Michel Mahiques (Geophysics, geochemistry, oceanography) - USP – IO
- ✦ Prof. Dr. Luigi Jovane (Geophysics, geochemistry, oceanography) - USP – IO
- ✦ Prof. Dr. Douglas Galante (Geology, astrobiology) - USP - IGc
- ✦ Prof. Dr. Fabio Rodrigues (Chemistry, astrobiology) - USP - IQ
- ✦ Prof. Dr. Evelyn Sanchez (Geology, paleobiology) - UFVJM
- ✦ Prof. Dr. Alessandra Vasconcellos (Geology, speleology) – UFVJM
- ✦ Prof. Dr. Norberto Pepporine Lopes (Pharmacy) USP – FCFRP
- ✦ Prof. Dr. Rubens Duarte (Microbiology) – UFSC
- ✦ Prof. Dr. Heitor Evangelista (Atmospheric Sciences) UERJ

Researchers

- ✦ Dra. Flavia Callefo (Geology, paleobiology) - USP - IGc
- ✦ Dra. Francieli Peres (Microbiology) - USP – IO
- ✦ Dra. Natascha Bergo (Microbiology) - USP – IO
- ✦ Dra. Bianca Del Bianco (Microbiology) USP – ICB
- ✦ Dr. Julio Cezar Fornazier Moreira SENAI-ISI PA
- ✦ MSc. Ana Carolina Butarelli (Microbiology) - USP – IO
- ✦ MSc. Rebeca Lizárraga (Microbiology) - USP – IO

Postdocs

- ✦ Dr. Roberta Vincenzi
- ✦ Dra. Rayana Feltrin

Graduate students

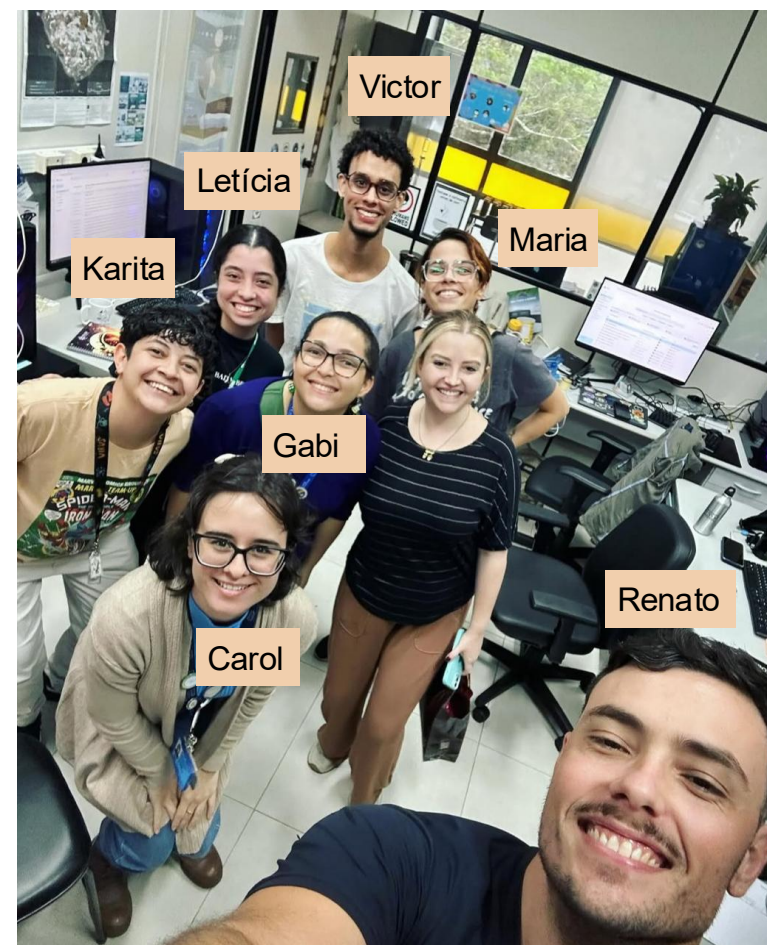
- ✦ Maria Eduarda Nascimento (PhD Student USP –IO)
- ✦ Carolina Targon Tiberio (PhD Student USP –IO)
- ✦ Gabriela Elidio (Master Student USP –IO)
- ✦ Karita Cristine (PhD Student USP – IO)
- ✦ Victor Roldão (Master Student USP – IO)
- ✦ Renato Gamba Romano (Oceanography USP – IO)
- ✦ Ana Brandão (PhD Student USP –IO)
- ✦ Nicola Sozza (Master Student USP – IO)
- ✦ Caio Augusto (Master Student USP – IO)

Undergraduate students

- ✦ Letícia Azaneth (ProAntar)
- ✦ Ana Venturin (ProAntar)
- ✦ Clara Corrêa (PUB-USP)
- ✦ Nayara (PUB-USP)
- ✦ Rebeca



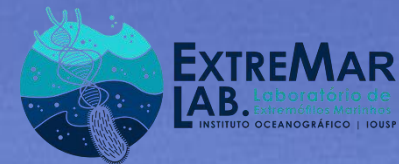
EXTREMAR
LAB. Laboratório de
Extremófilos Marinhos
INSTITUTO OCEANOGRÁFICO | IOUSP



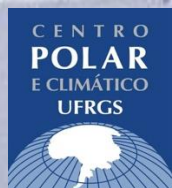
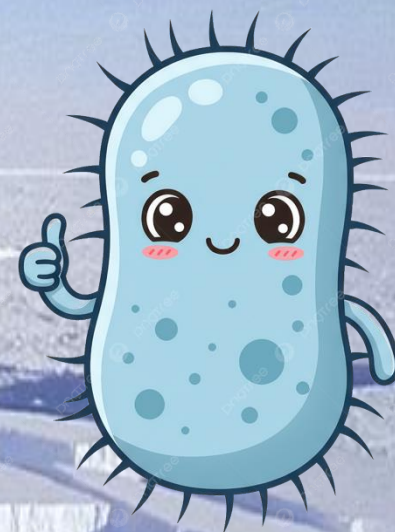
“Life will not be contained. Life breaks free. Life finds a way”

Dr. Ian Malcolm (Jurassic Park)

Obrigada!



***In memoriam
Rosa Gamba***



 @EXTREMAR_IOUSP