DAbG
Deutsche Astrobiologische Gesellschaft e.V.

GFZ

Astrobiology Across Scales: From Molecules to Worlds

10 Years of DAbG – Anniversary Workshop of the German Astrobiologial Society

11 – 13 October 2026
GFZ Helmholtz Centre for Geosciences, Potsdam

Topics – *Earth Analogues, Habitability, Extremophiles, Biosignatures, Prebiotic Chemistry, Origin of Life, Exoplanets, Space Missions & Technologies*

Abstract Deadline: 28 Juni 2026

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Image credit: NASA/Artemis II

10th Annual DAbG Workshop – Venue & Information

Address:

Telegrafenberg
Gebäude A71
14473 Potsdam

Important Information:

- **Workshop Dinner:** Monday, October 12, from 8:00 p.m. at the restaurant Da Pazzi (Berliner Straße 116 in 14467 Potsdam). The menu is à la carte, and each participant will pay individually.
- **City Center and Telegrafenberg Tours:** Please register until September 15 here: https://nuudel.digitalcourage.de/cfHs3Kcrcbgoqjfh
- **Photo and Video Notice:** Please be aware that photos and videos will be taken during the event. By attending, you consent to their use. If you do not wish to be included, please let the photographer or our organization team know.

List of participants in alphabetical order (as of Aug 27):

#	Surname	First Name	Affiliation
1	Arens	Felix	TU Berlin
2	Baqué	Mickael	FH Aachen
3	Bredehöft	Jan Hendrik	Universität Bremen
4	Capot	Timothee	TU Berlin
5	Carmona Ruiz	Marina	FU Berlin
6	Dannenmann	Marie	FU Berlin
7	de Vera	Jean-Pierre	DLR Köln
8	Degener	Stefanie	FH Nordwestschweiz (FHNW)
9	Digel	Ilya	FH Aachen
10	Eckhardt	André	Ruhr Universität Bochum
11	Fischer	Florian	TU Berlin
12	Glenn Ladd	Joseph	FU Berlin
13	Gopalan	Raghavan	AIP Potsdam
14	Heinz	Jacob	Universität Bremen
15	Henkel	Lukas	TU Berlin
16	Henn	Philipp	-
17	Khawaja	Nozair	FU Berlin
18	Kunja	Lasany Arfin	Chungnam National University
19	Liebermann	Ralf	-
20	Lv	Yuanyuan	TU Berlin
21	Mangelsdorf	Kai	GFZ Potsdam
22	Mayer	Christian	Universität Duisburg-Essen
23	Napoleoni	Maryse	FU Berlin
24	Noak (TBC)	Lena	FU Berlin
25	O'Sullivan	Thomas	FU Berlin
26	Oses	Rómulo	Universidad de Atacama, Chile
27	Postberg	Frank	FU Berlin
28	Radloff	Sarah	Universität Bremen
29	Riekeles	Max	TU Berlin
30	Santos	Berke	CNRS
31	Schad	Manuel	GFZ Potsdam
32	Schulz	Alina	Universität Heidelberg
33	Schulze-Makuch	Dirk	TU Berlin
34	Spohn	Tilman	DLR Berlin
35	Strehlow	Morgane	GFZ Potsdam
36	Tezak	Bruno	FU Berlin
37	Trixler	Frank	LMU München
38	Vilovic	Iva	AIP Potsdam
39	Wagner	Dirk	GFZ Potsdam
40	Waltemathe	Michael	Ruhr Universität Bochum
41	Zapf	Jürgen	-

10th Annual DAbG Workshop – Preliminary Programme

Sunday, Oct 11			
Oct 11	18:00	**Ice Breaker** at GFZ, Telegrafenberg, building A71	
Monday, Oct 12			
Oct 12	09:00	DAbG Board	*Opening remarks:* **10th anniversary of the DAbG**
Oct 12	09:15	Rómulo Oses	**Keynote:** *A Kaleidoscope of Extreme Environments: The Atacama–Puna Network of Natural Laboratories for Astrobiology and Planetary Science*
Planetary Habitability (Chairs: TBA)			
Oct 12	10:00	Tilman Spohn	*Plate Tectonics, Habitability and Life*
Oct 12	10:15	Florian Carlo Fischer	*Soil Microaggregates as Protective, Taxonomically and Functionally Distinct Habitats in Antarctic Soils: Implications for Mars*
Oct 12	10:30	Coffee & Tea Break	
Oct 12	11:00	Lasany Arfin Kunja	*Radiation Shielding for Future Habitation on the Surface of Mars and Moon*
Oct 12	11:15	Jacob Heinz	*A Reassessment of Perchlorate Toxicity for Microbes and Humans*
Oct 12	11:30	Felix Arens	*Small-Scale Mineralogical and Microbial Heterogeneity within a Fumarolic Alteration Zone, Furnas (Azores): Implications for Planetary Analogs*
Oct 12	11:45	Bruno Težak	*Experimental Investigation of UVC Shielding by Evaporitic Salt Crusts*
Oct 12	12:00 – 13:00	**Group Picture** + Lunch Break	
Oct 12	13:00	Yuanyuan Lv	*Water availability gates microbial ecosystem complexity from hyper-arid desert sediments to tropical soils*
Biosignatures and Space Missions #1 (Chairs: TBA)			
Oct 12	13:15	Kai Mangelsdorf	*Lipid Signals of Microbial Life in Soils and Specific Refuges in the Atacama Desert*

Oct 12	13:30	Sarah Radloff	*Investigation of halotolerant microorganisms and lipid biomarkers in hypersaline environments*
Oct 12	13:45	Coffee & Tea Break	
Oct 12	14:15 – 16:00	**Mitgliederversammlung**	
Oct 12	17:00 – 19:00	Potsdam City Center Tour	
Oct 12	20:00 – 23:00	**Conference Dinner** at Ristorante Da Pazzi Potsdam	
Tuesday, Oct 13			
Oct 13	09:00	Ilya Digel	**Keynote:** *The Physics of Living Matter, Astrobiological Discovery and Everything*
Biosignatures and Space Missions #2 (Chairs: TBA)			
Oct 13	09:45	Jean-Pierre de Vera	*Preparation for ExoMars and future balloon exploration missions: Mars analog field studies during GANOVEX XVI*
Oct 13	10:00	Michael Waltemathe	*Astrobiology and the Politics of Expansion: Human Futures on the Moon and Mars*
Oct 13	10:15	Dirk Schulze-Makuch	*What Type of Life Can We Expect on Mars?*
Oct 13	10:30	Coffee & Tea Break	
Oct 13	11:00	Max Riekeles	*The Evolving Detectability of Earth: Information & Detection Fronts*
Oct 13	11:15	Morgane Strehlow	*Membrane Lipids as Adaptive Stress Biomarkers: Insights from Antarctic Permafrost Bacteria*
Oct 13	11:30	Manuel Schad	*Potential relevance of Precambrian biogeochemical processes for the identification of life on Mars*
Oct 13	11:45	Berke Santos	*Evaluate the degradation of biosignatures under simulated Martian irradiation using a GEANT4 simulation tool and a Pelletron light-ion accelerator*

Icy Moons (Chairs: TBA)			
Oct 13	12:00	Frank Postberg	*Cassini CDA observes compositional segregation of Enceladus' ice grains from slow freezing and fragmentation of large oceanic droplets*
Oct 13	12:15 – 14:00	Lunch Break / **Telegrafenberg Tour (13:00 – 14:00)**	
Oct 13	14:00	Nozair Khawaja	*Exploring the Habitability of Ocean Worlds using Analogue Icy Moon Simulations (AIMS)*
Oct 13	14:15	Marie Dannenmann	*Detectability of biosignatures of a putative inhabitant of Enceladus oceanic surface*
Oct 13	14:30	Thomas R. O'Sullivan	*Molecular CRUMBLE: an automated quantum chemical package for exploring the fragmentation space of molecules*
Oct 13	14:45	Maryse Napoleoni	*Identification of Molecular Biosignatures in Antarctic Ices: Implications for Icy Moons Exploration*
Oct 13	15:00	Joseph Glenn Ladd	*Analogue Hydrothermal Processing of Carboxylic Aromatic Compounds on Enceladus*
Oct 13	15:15	Coffee & Tea Break	
Oct 13	15:45	Lukas Henkel	*TRIPLE Project LifeDetect: AstroBioNose – Search for habitability hotspots on Enceladus*
Oct 13	16:00	Timothee Capot	*TRIPLE Project LifeDetect: AstroBioNose – Simulation Software and Prototype Sensor Testing for Autonomous Ocean-World Exploration*
Prebiotic Chemistry (Chairs: TBA)			
Oct 13	16:15	André K. Eckhardt	*The Role of Glycolaldehyde Imine in Amino Acid and Sugar Formation*
Oct 13	16:30	Frank Trixler	*Silica nanofluids enable basic building blocks to form prebiotic RNA in water*
Oct 13	16:45	Christian Mayer	*Periodic temperature variation as an energy source for prebiotic chemistry*
Oct 13	17:00	(Lena Noack)	***TBC:** Automatic identification of environment-dependent disequilibrium gases as indicator for non-Earth-like biosignatures*
Oct 13	17:15 – End	DAbG Board	**Award ceremony:** Ralf-Möller-Gedächtnispreis & Best Talk *Closing Words*
Oct 13	*optional: After-show gathering*		

ABSTRACTS

A Kaleidoscope of Extreme Environments: The Atacama–Puna Network of Natural Laboratories for Astrobiology and Planetary Science

Oses, R. (1), Lavin, P. (2), Ferreira, C. (3) & Wagner, D. (4)

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(5) GFZ Helmholtz Centre for Geosciences, Section Geomicrobiology, Telegrafenberg, 14473, Potsdam, Germany; Institute of Geosciences, University of Potsdam, 14476, Potsdam, Germany.

The Atacama Desert and the adjoining Puna de Atacama–Ojos del Salado volcanic complex form an interconnected network of natural laboratories, each reproducing a distinct combination of extreme physicochemical conditions relevant to planetary habitability. Rather than a single analog site, this kaleidoscope spans hyperarid salt flats, endolithic gypsum and halite microhabitats, nitrate-rich oxidizing soils, high-UV altiplano plateaus, and the permafrost-fumarole gradient of the world's highest volcano (6,893 m). Each node hosts specialized extremophile communities—halophiles, psychrophiles, chemolithotrophs, and UV-shielded phototrophs—whose metabolic strategies and biosignature preservation patterns diverge according to local mineralogy, moisture pulses, and thermal regimes. This spatial heterogeneity allows researchers to test hypotheses on habitability limits, biosignature detection, and prebiotic chemistry across multiple extraterrestrial contexts simultaneously, including icy moons, ancient Mars-like terrains, and early-Earth analog settings, without restricting interpretation to a single planetary target. We synthesize two decades of multidisciplinary research—geomicrobiology, climatology, and astrobiological instrumentation—to argue that the Atacama–Puna network's true scientific value lies in its combinatorial diversity rather than in any isolated extreme. This positions Chile as a globally unique, integrated region for comparative astrobiology and planetary science, offering complementary environmental analogs for the diverse habitability scenarios anticipated across our Solar System and beyond.

Abstract

Title: Plate Tectonics, Habitability and Life

Authors: Tilman Spohn

Affiliations: DLR - Institute of Space Research, Ruherfordstrasse 2, 2489 Berlin

Plate tectonics is widely considered an essential factor in the habitability of Earth. The weathering of continental crust and the exchange of volatiles with Earth's interior help to maintain favorable climate conditions through the carbonate-silicate cycle and provide essential nutrients to the biosphere. The emergence of continents and their lateral motion during continental drift have furthered the evolution of life. However, plate tectonics may have emerged relatively late in Earth's history, after life began and proto-continents formed. During this time, habitability would have been independent of this tectonic mode. Estimates of when plate tectonics emerged range from the Archean to the early Phanerozoic, while LUCA has been dated to 4.2 billion years ago. Pre-plate tectonic modes may have included stagnant lid and squishy lid tectonics, which may thus have supported the biosphere for significant periods of geological time. During this time, the lid may have increased in mobility and plateness to eventually reach modern values. These tectonic scenarios may also apply to Earth-like exoplanets, though they may be difficult to infer. We can try to infer tectonic modes from exoplanetary observables using indirect evidence such as atmospheric composition, albedo variations and magnetic fields, all of which are challenging to observe.

Abstract

Soil Microaggregates as Protective, Taxonomically and Functionally Distinct Habitats in Antarctic Soils: Implications for Mars

Authors: Fischer, Florian Carlo[1], Khosravani, Pegah[3], Scholten, Thomas[3] and Wagner, Dirk[1,2]

[1] GFZ Helmholtz Centre for Geosciences, Section Geomicrobiology, Potsdam
[2] University of Potsdam, Institute of Geosciences, Potsdam
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Habitability in extreme environments is often controlled at the microscale. Even where bulk conditions appear hostile, differences in pore structure, mineral composition, water retention, and nutrient availability can create protected niches. Soil microaggregates, composed of mineral particles, organic matter, and microbial extracellular polymeric substances (EPS), can provide such spatially structured microenvironments.

Rover and lander data reveal potentially analogous features on Mars, including cohesive, hydrated regolith crusts in Jezero crater[1] and perchlorate-containing regolith clods at the Phoenix landing site[2]. Such aggregates may transiently attract and retain liquid water through processes such as salt deliquescence and could therefore represent potential microhabitats for life or sites for biosignature preservation.

Here, we investigated different aggregate-size fractions from Livingston Island, Antarctica, using 16S and 18S rRNA gene amplicon sequencing, metagenomics, and geochemical analyses. Analysis of bacterial and eukaryotic communities revealed distinct microhabitats among aggregate fractions. Metagenomic analyses further showed differences in functional potential, including nutrient cycling, stress adaptation, and mineral interactions. Smaller fractions contained more taxa associated with EPS production, indicating specialization toward traits that may support aggregate stabilization and water retention.

These findings provide a terrestrial framework for identifying potentially habitable and biosignature-preserving niches in Martian regolith.

References

1. Hausrath, E. M. et al. An examination of soil crusts on the floor of Jezero Crater, Mars. J. Geophys. Res. Planets 128, e2022JE007433 (2023).
2. Cull, S. *et al.* Concentrated perchlorate at the Phoenix landing site, Mars: Evidence for liquid brine. *Geophys. Res. Lett.* **37**, L22203 (2010).

Abstract

Radiation Shielding for Future Habitation on the Surface of Mars and Moon

Lasany Arfin Kunja[1], Yu Yi[2], Eojin Kim[3]

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The Moon and Mars are the primary targets for celestial bodies outside of the Earth for future human habitation. The radiation from the combination of galactic cosmic rays, solar particle events, and albedo radiation found on the planetary surface is a significant barrier to human habitation. Unlike Earth, the Moon and Mars does not provide appropriate protection for a potential habitable zone because of their lack of magnetic fields and incredibly thin atmospheres. In this case, we look at possible materials for housing protection on these planetary objects. We investigated a hybrid shielding concept that uses a second layer of hydrogen-rich radiation shielding materials in addition to an outer lunar regolith layer. This hybrid idea can reduce expenses and effort by utilizing in-situ regolith.

The shielding properties are investigated, and the radiation dose that astronauts experience is directly simulated using NASA's OLTARIS for overall radiation. We also used MULASSIS, a shielding simulation program created by ESA that is based on Monte-Carlo simulations and shows the shielding effectiveness of our habitation model for each radiation component. According to our research, polypropylene and lithium hydride offered the best shielding properties when paired with lunar or Martian regolith in the hybrid shielding housing concept.

Abstract

A Reassessment of Perchlorate Toxicity for Microbes and Humans

Heinz, J[1], Heeßel, E[1], Thibaud, L[1] and Verseux, C[1]

[1] Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Bremen, Germany.

Perchlorate salts are rare on Earth but are thought to be widespread on Mars, raising questions about their impact on putative Martian microorganisms and future astronauts. Recent research has clarified several misconceptions. First, the 0.4–0.6 wt.% perchlorate detected by the Phoenix lander represents concentrations in 1:25 regolith-to-solution mixtures rather than naturally occurring Martian brines. Stable brines formed by deliquescence or melting would likely contain much higher, near-saturated perchlorate concentrations. Second, perchlorate toxicity differs between humans and microbes. In vertebrates, perchlorate disrupts thyroid hormone synthesis by competing with iodide uptake, whereas microbial toxicity primarily results from its chaotropic properties and interference with cellular processes. Third, although perchlorate is thermodynamically a strong oxidant, it is kinetically stable in solution and is therefore often overestimated as a direct source of oxidative stress.

This presentation compares perchlorate concentrations expected on Mars with experimentally determined microbial tolerance limits. It also highlights recent findings on microbial stress responses and adaptation mechanisms, and discusses the implications of perchlorate-rich regolith for in situ resource utilization (ISRU) and potential health risks for future Mars astronauts.

Abstract

Title: Small-Scale Mineralogical and Microbial Heterogeneity within a Fumarolic Alteration Zone, Furnas (Azores): Implications for Planetary Analogs

Authors: Felix Leo Arens [1], Dirk Schulze-Makuch [1,2,3,4], Alexander Bartholomäus [2], Kai Mangelsdorf [5] and Dirk Wagner [2,6]

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The Azores are characterized by intense volcanic activity, creating unique environments such as fumarole sites. To investigate small-scale mineralogical and microbial heterogeneity within such a site, six visually distinct alteration phases were collected within a 30 cm radius at an active fumarole on São Miguel Island. Mineralogical profiling shows all samples share a primary advanced argillic alteration assemblage (alunite, alkali-feldspar, and quartz). However, striking macroscopic color variations suggest localized micro-environments, likely reflecting subtle variations in volatile flux or fluid pathways. To explore these micro-habitats, mineralogical data were paired with lipid biomarkers (PLFAs) and microbial community structure using a novel DNA separation technique targeting the living microbiome. Despite primary mineralogical similarities, significant biological partitioning occurred across the centimeter-scale micro-zones, with distinct microbial communities aligning with specific color phases and transitional signatures. This demonstrates that pronounced biogeochemical heterogeneity can be maintained over small scales, suggesting that micro-scale shifts in hydrothermal environments exert profound control on microbial colonization. Consequently, more emphasis should be placed on the physicochemical characterization of these micro-scale environments. These findings also have important implications for the search for life on Mars and other planetary bodies, as they suggest that potential biosignatures and habitable niches may occur at very small spatial scales that are not resolved by bulk sampling approaches.

Abstract

Title: Experimental Investigation of UVC Shielding by Evaporitic Salt Crusts

Authors: Težak, B[1,2] ; Riekeles, M[2,3] ; Schulze-Makuch, D[2]

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Text:

Present-day Mars is hostile to unshielded microorganisms because its thin atmosphere provides only limited attenuation of biologically damaging short-wavelength UV radiation at the surface. Evaporitic salts are astrobiologically relevant because chloride- and sulfate-bearing deposits are widespread on Mars, can form crusts and cements, and may attenuate UVC radiation while helping to preserve microenvironments and potential biosignatures. This research investigates evaporitic salt crusts composed of sodium chloride (NaCl) and gypsum ($CaSO_4 \cdot 2H_2O$), selected as practical chloride- and sulfate-bearing materials for controlled laboratory experiments relevant to Martian evaporitic settings.

First, thickness-controlled crusts with different NaCl mass ratios were fabricated and physically characterised by density, porosity, UVC attenuation, and scattering behaviour. Preliminary measurements show strong attenuation by all crusts, with gypsum-rich and mixed compositions generally providing stronger shielding than pure NaCl. The optical response is controlled not only by absorption but also by scattering, sample heterogeneity, and source geometry.

Second, the biologically relevant shielding effect was tested using plate-based UVC irradiation experiments with *Pseudoalteromonas haloplanktis*, a cold-adapted, halotolerant marine bacterium, placed underneath salt crusts. These experiments assess whether physical attenuation translates into improved survival. Third, ongoing work will examine the effect of UVC exposure on biosignature molecules, focusing on the pigment beta-carotene as a radiation-sensitive biomarker.

Water availability gates microbial ecosystem complexity from hyper-arid desert sediments to tropical soils

Yuanyuan Lv[1], Hans-Peter Grossart[2], Dirk Schulze-Makuch[1]

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[2] Leibniz Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany

Water underpins microbial life in soils, yet whether increasing water availability gradually enhances belowground microbial communities or instead opens threshold-like windows in which microbial ecosystem complexity can emerge remains unresolved. The hyper-arid Atacama Desert, temperate soils in Brandenburg, and the Amazon tropical rainforest together provide an ideal natural moisture gradient for testing this question. Across these ecosystems, microbial communities experience sharply contrasting levels of aridity, soil structure, nutrient supply, and climatic constraint. Here, we used phospholipid fatty acid (PLFA) analysis to quantify microbial biomass, diversity, and community composition, and combined threshold modelling, variation partitioning, and multivariate predictor selection to assess cross-biome microbial patterns, environmental controls, and field-capacity thresholds. We draw this inference from three converging lines of evidence: (i) microbial biomass, diversity, and community composition showed decoupled responses: biomass was highest in rainforest soils, α-diversity peaked in Brandenburg, and β-diversity was greatest in the Atacama; (ii) environmental controls differed strongly among ecosystems, shifting from soil texture and water-retention constraints in the Atacama to weaker carbon-related structuring in Brandenburg and stronger integrated edaphic–climatic–spatial control in rainforest soils; (iii) field-capacity thresholds were most evident in rainforest soils and were also expressed in Brandenburg, whereas Atacama communities showed only candidate but non-significant threshold signals. Overall, these results suggest that water availability imposes hierarchical control over microbial ecosystem complexity: constraining microbial persistence under extreme aridity, promoting biomass accumulation and community reorganization in wetter soils, and shaping local coexistence under high field-capacity conditions. Thus, water availability determines when, and in what form, microbial complexity emerges across biomes.

Abstract

Lipid Signals of Microbial Life in Soils and Specific Refuges in the Atacama Desert

K. Mangelsdorf[1], D. Wagner[1], A. Bartholomäus[1], C. Karger[1], D. Schulze-Makuch[1,2]

[1]GFZ Helmholtz Centre for Geosciences, Telegrafenberg, 14473 Potsdam
[2]Centre of Astronomy & Astrophysics, Technical University Berlin, Germany

The Atacama Desert is one of the driest and oldest deserts on Earth and due to its hyperaridity it is being discussed as an analogue for Martian conditions. Occasionally coastal fog and rare rain events associated with the El Niño phenomenon can transport water from the coast into the desert. After a rain event in 2015 we investigated Atacama soils and specific microhabitats (quartz hypoliths, gypsum crusts, halite nodules) for life marker signatures along a transect from the coast to the hyperarid core of the Atacama. As markers we used membrane phospholipids, remaining intact only in living microorganisms, and DNA. The highest amount of bacterial life was detected in the coastal area, where water availability is more frequent due to coastal fog. Further inland, the microbial life markers drastically decrease in amount and diversity indicating a shrinking and less active microbial desert community. Higher abundance of microorganisms in specific microhabitats within the desert point to the retreat of microbial life into specific niches where water, stored in crystalline structures, may be longer available. The data show that the Atacama core area is a transitory life habitat for microorganism, which are occupying desert soils and specific refuges under challenging environmental conditions.

200 words
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Abstract

Title: Investigation of halotolerant microorganisms and lipid biomarkers in hypersaline environments

Authors: Sarah Maria Radloff (1), Jacob Heinz (1), Cyprien Verseux (1)

Affiliations: (1) Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Germany

In astrobiological research, microorganisms isolated from extreme terrestrial habitats are frequently used to investigate microbial adaptations to conditions similar to those found in extraterrestrial environments such as on Mars. In addition, the characterization of biosignatures such as lipids can reveal information about the microbial composition and the preservation of biomolecules in these extreme environments. Our research is focused on halotolerant microorganisms, isolated from calcium chloride (CaCl2)-rich sediment samples from the Atacama Desert, Chile, and Don Juan Pond, Antarctica. Microbial isolates were investigated by morphology, microscopy and 16s-rRNA-gene sequencing. Furthermore, as potential biosignatures, intact polar lipids (IPLs) were extracted from sediment samples and investigated through Liquid Chromatography-Mass Spectrometry (LC-MS). Preliminary results revealed differences in microbial and lipid composition depending on soil depth and the sampling location. Ultimately, these analyses demonstrate that a shared stressor, such as $CaCl_2$, does not necessarily lead to convergent outcomes, but rather that microbial composition and lipid biosignatures remain highly dependent on specific environmental contexts.

Abstract

The Physics of Living Matter, Astrobiological Discovery and Everything

Digel, I.

Institute for Bioengineering, FB9, FH Aachen University of Applied Sciences, Jülich, Germany

Life is the only known form of matter that continuously maintains organization, stores information, adapts to changing environments and evolves complexity while operating far from thermodynamic equilibrium. Understanding the physical principles that enable such behavior is a central challenge of modern science and an essential prerequisite for the search for life beyond Earth. This keynote provides an *overview* of how concepts from molecular biophysics, microbial ecology and even selected aspects of neurophysiology can contribute to a more general understanding and better *detectability* of living matter. Extremophilic microorganisms are fascinating natural experiments that reveal strategies by which life preserves structure, function and information under severe physicochemical constraints. This perspective leads to the transition from terrestrial biology toward generalized concepts of life and recent developments in *agnostic* biosignature research. Particular attention is given to the integration of multiple independent observables into quantitative frameworks combining molecular, physicochemical, informational, ecological and planetary evidence. These ideas are reflected in current TRIPLE LifeDetect and ChemNav projects, including biomimetic navigation inspired by biological environmental sensing and chemotaxis.

Abstract

Preparation for ExoMars and future balloon exploration missions: Mars analog field studies during GANOVEX XVI

de Vera, J-PP[1], Hauber, E[2], Koglin, N.[3] and Witte, L[3]

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During the German Antarctic North Victoria Land Expedition (GANOVEX) XVI expedition to continental East Antarctica, Mars analog field investigations were carried out from the German Gondwana Station of the Federal Institute for Geosciences and Natural Resources (BGR) to test on one hand technology for Mars balloon probes with the goal to do short to long term investigations of the Martian atmosphere and the Martian surface. On the other hand, samples were also collected in extreme environmental conditions, for further biogeological investigations in ground-based Mars simulation facilities and on exposure platforms in space. Some of the samples will serve for training of the members of the ExoMars' Rosalind Franklin Rover during mission simulations. Particular the Co-I teams of the PanCam camera and Clupi camera instruments will benefit from these simulations. In this reference, important steps for systematic exploration were also the studies on terrestrial geomorphological analogues of permafrost landscapes on Mars. Impressions of the expedition and an outlook on upcoming work resulting from the field studies will be presented.

Abstract

Title: Astrobiology and the Politics of Expansion: Human Futures on the Moon and Mars

Authors: Waltemathe, M[1]

Affiliations: [1]Evangelisch-Theologische Fakultät, Ruhr-Universität Bochum, Bochum, Deutschland

While astrobiology has traditionally focused on the scientific search for life beyond Earth, renewed efforts to establish a sustained human presence on the Moon and Mars raise a range of political, ethical, and cultural challenges that extend beyond the natural sciences. This paper explores how contemporary human space exploration initiatives are shaped by historical narratives, ideological assumptions, and geopolitical ambitions. Drawing on perspectives from philosophy, theology, sociology, and political theory, it examines the persistence of concepts such as frontier expansion, *Manifest Destiny*, and colonial settlement within current discourses surrounding lunar and Martian exploration.

The analysis considers how narratives of "colonizing" other worlds and securing extraterrestrial resources may reproduce terrestrial histories of empire, extraction, and inequality. It further addresses the implications of increasing commercialization and geopolitical competition in space, raising questions about governance, justice, environmental stewardship, and humanity's collective responsibilities beyond Earth – not least focused on the role of science in an expansion programThis paper argues for greater critical reflexivity within astrobiology and related space sciences regarding the political imaginaries that underpin contemporary exploration agendas. Such reflection is essential not only for the ethical development of future space missions but also for informing astrobiological research itself on threats for its scientific foundation in light ofhow humanity conceptualizes, investigates, and ultimately inhabits extraterrestrial environments.

Abstract

What Type of Life Can We Expect on Mars

Schulze-Makuch D.[1-4] and Finster, K.[5]

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The detection of organic compounds by the Curiosity and Perseverance rovers — including thiophenes, aromatic hydrocarbons, and long-chain alkanes — strengthens the case for past, and possibly extant, life on Mars. If living organisms persist on Mars today, what form should we expect them to take, and where should we search? Mars's near-surface environment combines temperature swings from approximately −150°C to +25°C, extremely low water activity, ultraviolet (UV) irradiances of 26.9–42.3 W m^{-2} per day, and ionising radiation doses of 240–300 mSv yr^{-1} — conditions that would inactivate most terrestrial microorganisms within seconds to minutes of unshielded surface exposure. Yet life on Earth reveals extraordinary adaptive capacity. We propose five non-exclusive strategies by which putative Martian life could persist: (1) retreat to physically sheltered niches such as the subsurface or lava tubes; (2) alternating dormancy–activity cycles analogous to sporulation; (3) exploitation of hygroscopic salts for water acquisition via deliquescence; (4) biochemical adaptation to concentrated chlorate or perchlorate brines, ultra-low water activity, or alternative biochemistries; and (5) combinations thereof. We review quantitative constraints from Mars mission data, extremophile physiology, and Mars-analogue field studies that define the envelope of possibility for each strategy and identify the most tractable targets for future life-detection missions.

Abstract

The Evolving Detectability of Earth: Information & Detection Fronts

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The detectability of Earth by extraterrestrial observers is commonly discussed in terms of individual biosignatures or technosignatures. However, the distinction between the physical propagation of information and the practical ability to detect that information has received comparatively little attention. Here, we introduce a time-dependent framework that separates Earth's observability into two complementary concepts: information fronts and detection fronts. An information front is defined as the maximum distance to which a planetary signature has propagated at the speed of light since its emergence. In contrast, a detection front represents the maximum distance at which an observer with technological capabilities comparable to present-day humanity could realistically detect and interpret that signature. We apply this framework to key stages in Earth's history and astrobiological concepts, such as the presence of surface water, the Great Oxidation Event, the occurrence of atmospheric ozone and oxygen, the vegetation red edge, and modern technosignatures.

Using current and near-future observational capabilities as a conservative reference, we estimate detection fronts for different classes of planetary signatures and compare them to their corresponding information fronts. This framework provides a quantitative basis for linking planetary evolution, observational capability, stellar demographics, and interstellar exploration within a unified time-dependent model of planetary detectability.

Abstract

Membrane Lipids as Adaptive Stress Biomarkers: Insights from Antarctic Permafrost Bacteria

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Membranes are essential for bacterial survival, providing protection, mediating transport, and supporting energy generation. In cold environments and under varying pH conditions, bacteria must adapt to maintain their membrane fluidity. One important adaptation mechanism is the restructuring of the membrane polar lipids, especially the fatty acid side chains (PLFAs), through de novo synthesis or enzymatic modification. However, membrane lipid compositions are commonly characterized under standard laboratory conditions (28°C, optimal pH), potentially overlooking adaptive lipid changes expressed under environmental stress.

While investigating the PLFA composition of *Halpernia frigidisoli* (formerly *Chryseobacterium frigidisoli*, Bajerski et al, 2013), a bacterium isolated from Antarctic permafrost and cultivated under different temperature conditions (0 to 20 °C), Bajerski et al. (2017) showed the adaptive increase of 14-methyl-hexadeca-9,13-dienoic acid with decreasing cultivation temperature. Here, we investigated whether this fatty acid occurs also in related bacterial taxa from different environmental origins, and whether it can serve as a taxon-specific biomarker for the genus or the family. Our results show that the respective fatty acid is not species-specific but can also occur in related bacteria, suggesting a shared mechanism of membrane adaptation shaped by both phylogenetic affiliation and ecological context.

These findings improve our understanding of membrane adaptation in cold-adapted bacteria and demonstrate that lipid remodeling represents a flexible strategy for survival under low-temperature conditions. Consistent taxon-specific lipid signatures may provide valuable biosignatures for astrobiological exploration and support future efforts to detect past or present microbial life on Mars.

References

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Abstract

Potential relevance of Precambrian biogeochemical processes for the identification of life on Mars

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Identifying potential signatures for life is a difficulty inherent to Astrobiology and early Earth research. Both the Precambrian rock record (e.g. Banded Iron Formations; BIFs) and Mars as a target for identifying extraterrestrial life face limitations. These include low abundance and poor preservation of organic carbon and biomolecules, post-depositional alteration of mineral assemblages and similarity between abiotic and biological signatures.

Here I present the results of experimental work simulating early Precambrian environments and efforts in constraining potential biosignatures for life on early Earth. Co-cultivation of anoxygenic photoautotrophic Fe(II)-oxidizing and Fe(III)-reducing bacteria resulted in considerable alteration of primary Fe mineral assemblages, thus limiting their utility as potential carriers of biosignatures. However, analysis of the photoautotroph biomass for trace metals showed unexpected similarities with trace metal profiles preserved in BIFs, suggesting that bacterial trace metal profiles might be a diagnostic tool to identify bacterial metabolisms in the rock record.

Life has a profound influence on and shapes the environments where it is found. While photosynthesis is unlikely to have existed on Mars, trace metal signatures of chemolithotrophic microbes might be a promising avenue to identify life on Mars. Areas in chemical disequilibrium with steep Fe redox gradients might be of considerable interest.

Abstract

Evaluate the degradation of biosignatures under simulated Martian irradiation using a GEANT4 simulation tool and a Pelletron light-ion accelerator

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Following the loss of atmospheric pressure ~4 Ga ago, the Martian surface lost its liquid water and became exposed to Solar Energetic Particles (SEPs) and Galactic Cosmic Rays (GCRs), which penetrate the subsurface and degrade potential biosignatures of past life preserved in ancient rocks (Westall et al., 2015; Dartnell et al., 2007). Shielding at depth may nonetheless preserve organics over Gyr (Kminek et al., 2006), motivating the development of the ExoMars Rosalind Franklin rover and its 2 m drill (Altieri et al., 2023).

This work aims to assess the protective role of minerals in biosignature preservation by developing a GEANT4-based simulation tool that reproduces SEP/GCR irradiation of the Martian subsurface over several Gyr. The framework should compute depth-dependent dose profiles with varying atmospheric and regolith parameters, after initial validation against MSL-RAD data (Matthiä et al., 2016). The simulations will also guide the irradiation of analogue samples at the CEMHTI Pelletron light-ion accelerator, followed by in situ Raman analysis (Canizarès et al., 2022) and Ion Beam Analysis. A baseline simulation project has already been built and tested: mono-energetic protons at various energies, propagated through a Martian-like atmosphere and surface, yield energy deposition and stopping altitudes consistent with reference and benchmark data.

Cassini CDA observes compositional segregation of Enceladus' ice grains from slow freezing and fragmentation of large oceanic droplets

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Salt-rich ice particles, termed Type 3, are a major compositional group within Enceladus' plume and Saturn's E-ring, and are thought to represent (sub-)micron-sized, frozen aerosols from Enceladus' salty subsurface ocean (Postberg et al. 2009, 2011). Here we present new insights into the plume formation process based on an updated analysis of approximately 1,000 CDA mass spectra of individual salt-rich ice grains from Enceladus, typically ranging from approximately 0.5 to 5 µm in diameter. Analyzing the compositional diversity within the Type 3 group, substantial experimental and theoretical efforts aid in the inference of processes forming Enceladus' ice plume from the subsurface oceanic water table.

We find at least five basic compositional subtypes dominated by either NaCl, NaHCO3/Na2CO3, Na2HPO4/Na3PO4, NaOH or KCl/KOH. With the exception of hydroxides, these individual salts are rarely found together within a single ice grain. From our freezing experiments, we arrive at consistent boundary conditions and find that salt separation, in agreement with CDA observations, occurs as a consequence of salt mineral precipitation only within droplet sizes above ≈ 10 µm and freezing rates below ≈ 20 K/min. Supported by thermodynamic calculations and plume modelling, we suggest that oceanic spray droplets originally form with typical size of several 100 µm, containing a solution of the observed salt species. These are entrained in a slow gas flow causing slow freezing and separation of salts. Subsequently they are accelerated to speeds >100 m/s in narrow ice vents where frequent wall collisions lead to much smaller fragments mostly containing a single type of salt, matching CDA observations. The size distribution of ice grains observed in the plume by several Cassini instruments (e.g. Hedman et al. 2009) indeed matches results from high-velocity fragmentation experiments (Hauck et al. 2015, Burke et al. 2023).

Such a complex plume formation process bears several implications for constraining conditions in the ocean by plume observation and sampling. Previous studies have already established that the plume composition is spatially heterogeneous (e.g., Ershova et al. 2024) and that organic material across the ice grain population also varies significantly in composition (Postberg et al. 2018; Khawaja et al. 2019, 2025). Our results show that gradual cooling of ocean droplets in combination with wall collisions determine the final size distribution and provide an efficient chemical separation of both inorganic and organic oceanic constituents into differently composed ice grains ejected into Enceladus' plume. Future sampling missions can greatly benefit from this when inferring the ocean's composition and its habitability.

Abstract

Exploring the Habitability of Ocean Worlds using Analogue Icy Moon Simulations (AIMS)

Nozair Khawaja, Lucía Hortal Sánchez, Thomas R. O'Sullivan, Joseph Ladd, Quentin Betton, Maryse Napoleoni, Andreas Beinlich, Jon Hillier, Juergen Schmidt, Timm John, Frank Postberg

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Icy moons with subsurface oceans are prime targets in the search for habitable environments in the outer solar system. Saturn's moon Enceladus is of particular interest because of its active south polar plume that provides direct access to its subsurface ocean. The NASA/ESA Cassini-Huygens mission revealed a diverse inventory of chemical species including aromatic and aliphatic organic compounds, evidence for ongoing hydrothermal activity, and potentially habitable conditions. However, the extent to which these compounds are chemically altered during transport from the hydrothermally active rocky core through the ocean and into the plume remains poorly constrained.

The European Research Council Consolidating Grant Project, Analogue Icy Moon Simulations (AIMS), addresses this question through laboratory simulations representative of Enceladus' interior and investigates the chemical evolution of inorganic and organic molecules, as well as potential biosignatures, during their transport toward the surface. Here, we introduce the AIMS project in view of the current understanding of Enceladus' chemical inventory. The latest results from AIMS laboratory simulations provide new constraints on the origin of molecular species in the plume and improve the interpretation of spacecraft observations, supporting future life-detection missions to ocean worlds, e.g. ESA's L4 mission to Enceladus.

Abstract

Title: Detectability of biosignatures of a putative inhabitant of Enceladus oceanic surface

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Enceladus has recently been selected as the target of ESA's L4 mission. Biosignatures of a putative biosphere in its subsurface ocean could be detected by impact ionization mass spectrometers analyzing single ejected ice particles during flybys. These particles form at the oceanic surface. This surface environment may present key advantages for habitability including oxygen formed by radiolytic reactions and elevated concentration of accumulated organics. Additionally, due to its proximity to the site of ice grain formation, potential microbial inhabitants of this niche, may predominantly be enclosed in the particles and dominate detectable biosignatures.

We aimed to investigate the habitability of the ocean surface and the mass spectral detectability of biosignatures produced therein. We simulated impact ionization with laser desorption mass spectrometry. We grew a model organism, *Rhodonellum psychrophilum*, aerobically at 3°C in an Enceladus ocean simulant. In the mass spectra of the cells, we identified amino acids and fatty acids in biotic abundance ratios along with more complex compounds. We also observed a higher relative abundance of unsaturated fatty acids with lower growth temperature, representing a cold-adaptation.

Our results can guide the interpretation of data obtained from impact ionization mass spectrometers on current and upcoming space missions such as L4.

Abstract

Molecular CRUMBLE: an automated quantum chemical package for exploring the fragmentation space of molecules

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Text:

The construction of potential energy surfaces when exploring the dissociation of a molecule is often the most time-consuming step of a quantum chemical methodology. A large number of fragmentation pathways can be accessed in energetic processes, including radiolytic chemistry and impact ionisation of particles onto spaceborne mass spectrometers at hypervelocity, as performed by Cassini, Europa Clipper, and DESTINY+. Theoretical work on impact ionisation mass spectrometry has been conducted largely on a case-by-case basis. To the best of our knowledge, there is no general-purpose tool available for systematically surveying the fragmentation space of potential molecular biosignatures with quantum chemistry.

We introduce the Chemical Rupture Understanding via Molecular Bonding and Liberation Energetics (CRUMBLE) package, which computes the dissociation energies for all possible fragmentation channels of a given molecule. CRUMBLE runs on the ORCA quantum chemistry software and employs graph theory to enumerate all possible molecular fragments from a parent structure, with the option of exploring the isomeric ensemble for each. Fragment structures are stored in a library that is queried to reduce the computational expense associated with future runs. CRUMBLE is broadly applicable to any context in which the fragmentation space of a molecule is explored, including in many astrobiologically-relevant environments.

Abstract

Identification of Molecular Biosignatures in Antarctic Ices: Implications for Icy Moons Exploration

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Enceladus and Europa are key targets for astrobiology investigations. Onboard Europa Clipper, the SUDA instrument will provide the chemical composition of ejected ice grains, and can detect molecular biosignatures, such as lipids. The performance of SUDA strongly relies on analogue experiments using Laser Induced Liquid Beam Ion Desorption (LILBID), a method that simulates SUDA mass spectra. Environmental samples allow for a more realistic assessment of the detection capabilities of spaceborne instruments, as compared to experiments with prepared synthetic samples of well-defined compositions. Specifically, natural ice analogues from polar locations offer some of the most realistic representations of icy moons. However, polar samples have never before been analyzed with LILBID. We present the first analysis of natural ice analogues with LILBID combined with a detailed lipid characterization. Ice samples were collected from the Collins glacier on King George Island, Antarctica, where several environmental conditions are analogous to specific processes on ocean worlds. LILBID analysis were combined to data obtained from GC-MS, Raman and IR spectroscopy. Results on icy samples containing pink microalgae revealed key fingerprints of lipids adapted to cold temperatures, and highlight a novel assessment of the detectability of lipid biomarkers from icy moon analogues with spaceborne instrumentation.

Abstract

Analogue Hydrothermal Processing of Carboxylic Aromatic Compounds on Enceladus

Joseph Ladd[1], Lucía Hortal Sánchez[1], Thomas R. O'Sullivan[1], Marie Dannenmann[1], Maryse Napoleoni[1], Frank Postberg[1], Nozair Khawaja[1]

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Ice grains ejected by the ocean world Enceladus revealed a global subsurface salty liquid water ocean containing organic compounds and evidence of hydrothermal activity. A diverse suite of organic species have been detected. The coexistence of liquid water, organic material, and hydrothermal chemistry satisfies key criteria for habitability.

To investigate the origin of organic compounds on Enceladus, it is necessary to understand their evolution under conditions analogous to those within the subsurface ocean. We performed laboratory experiments using the ERC-CoG Analogue Icy Moon Simulations (AIMS) project's hydrothermal laboratory to simulate Enceladean hydrothermal conditions. The identification of low-mass organic compounds containing aromatic and carbonyl functional groups in Enceladean ice grains makes benzoic acid a suitable model in our study.

Prepared solutions of benzoic acid in an analog "Enceladus Ocean" were processed using the AIMS hydrothermal reactor. Mass spectra produced in the laboratory by the laser-induced liquid beam ion desorption (LILBID) technique serve as an analog for those obtained by spaceborne impact ionization mass spectrometers. Compositional analysis of hydrothermally processed and unprocessed benzoic acid was conducted using multiple analytical techniques.

Abstract

Title:

TRIPLE Project LifeDetect: AstroBioNose – Search for habitability hotspots on Enceladus

Authors:

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Text:

Putative hydrothermal vents on icy ocean worlds such as Enceladus are considered prime targets in the search for potentially habitable environments beyond Earth. Within the AstroBioNose project of the Technologies for Rapid Ice Penetration (TRIPLE) initiative, we investigate how established hydrothermal vent exploration strategies from marine geology and ocean sciences can be adapted for future missions to icy moons. This presentation focuses on the process of locating hydrothermal activity, drawing on decades of terrestrial experience in vent prospecting using physical, chemical, and geological indicators. We discuss how proven sensor technologies and search methodologies – including measurements of temperature, water chemistry, redox conditions, dissolved gases, and particle plumes – can be translated to the unique environmental conditions expected within Enceladus' subsurface ocean. The talk highlights the challenges of adapting these approaches to autonomous planetary exploration under extreme constraints and outlines a sensor concept tailored to the detection of hydrothermal systems as potential habitats for life. By transferring knowledge from Earth's oceans to extraterrestrial environments, AstroBioNose aims to support future life-detection missions to ocean worlds.

Abstract

Title:

TRIPLE Project LifeDetect: AstroBioNose – Simulation Software and Prototype Sensor Testing for Autonomous Ocean-World Exploration

Authors:

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Text:

Future exploration of ocean worlds such as Enceladus will require compact autonomous systems that can identify chemical and thermal anomalies linked to potentially habitable environments. This work presents AstroBioNose, a combined simulation and hardware testbed being developed to study anomaly detection strategies for a future under-ice exploration platform based on nano-scale autonomous underwater vehicle (nanoAUV). The simulation models an Enceladus-inspired underwater environment with hydrothermal vent fields, seafloor morphology, heat and chemical plume dispersion, AUV navigation, sensor readout visualization, and mapping of local gradients within a selectable mission volume. In parallel, a first prototype sensor system has been assembled using commercial off-the-shelf temperature, oxidation-reduction potential, conductivity, and pH sensing modules. To support controlled testing, a water-tub test bench is being designed and built using three stepper motors to position the prototype nose in X, Y, and Z. Two linear tracks control horizontal motion, while a moving vertical stage raises and lowers the sensor package. This setup will allow sensor readings to be automatically linked to their measurement locations, producing test data that can be compared with the simulation. Although experimental validation is still pending, the project establishes a practical software-hardware framework for developing compact astrobiology sensing concepts for future icy-moon exploration architectures.

Abstract

The Role of Glycoladehyde Imine in Amino Acid and Sugar Formation

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Simple imines are versatile intermediates in the construction of complex organic molecules and are thought to contribute to prebiotic chemical networks. Although imines are readily generated in solution from carbonyl compounds and ammonia or primary amines, many simple aldimines are intrinsically unstable under condensed-phase conditions. Formaldimine, the smallest aldimine, has been detected in the interstellar medium, but cannot be isolated on Earth because it rapidly oligomerizes or polymerizes when concentrated. Related hydroxy-substituted aldimines, including glycolaldehyde imine ($CH_2OHCHNH$), are particularly relevant because they may participate in pathways leading to sugars, amino acids, and other biorelevant compounds. However, experimental spectroscopic data for these transient species remain scarce, limiting reliable identification and mechanistic understanding.

This project aims to generate and characterize glycolaldehyde imine under well-defined cryogenic conditions and to clarify its role in prebiotic molecule formation. Glycolaldehyde imine will be produced by matrix-isolation photolysis of azidoethanol, enabling its infrared and UV/Vis spectroscopic observation. Complementary quantum-mechanical calculations will be used to calculate conformational preferences, vibrational spectra, and possible photochemical or thermal reaction pathways. The combined experimental and computational approach will provide reference data for glycolaldehyde imine and improve our understanding of imine chemistry in sugar and amino acid formation.

Abstract

Silica nanofluids enable basic building blocks to form prebiotic RNA in water

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The emergence of RNA is key to prebiotic chemistry as it paved the way for replication reactions and information storage. However, RNA polymerization is inhibited by water. Reported non-enzymatic RNA syntheses thus run under non-physiological conditions to circumvent the water paradox. This weakens their prebiotic plausibility in view of evolutionary conservation. Other weaknesses arise by using already complex biomolecules (nucleotides), and the formation of oligonucleotides with lengths far below the potential of developing functional sequence complexity.

We demonstrate that a prebiotic plausible one-pot synthesis of RNA is possible when performing it in aqueous nanofluids. Our approach thus overcomes the water paradox and requires only primitive molecular building blocks known to exist in meteorites. The median length of the resulting RNA of > 200 bp is significantly above the threshold of 100 bp needed for the potential to develop functional sequences towards encoding error correction enzymes for replication. Our achieved yield in RNA is substantially increased by the presence of amino acids, indicating a pre-enzymatic role in RNA synthesis. Prebiotic plausibility of our approach is further supported by its consistency with the principle of evolutionary conservation as it links conditions in ubiquitous nanogeochemical settings with intracellular environments via nanofluid phenomena.

Reference

Greiner de Herrera, A.; Markert, T.; Trixler, F. (2023) Temporal nanofluid environments induce prebiotic condensation in water; Commun. Chem. 6, 69. DOI: 10.1038/s42004-023-00872-y

Abstract

Periodic temperature variation as an energy source for prebiotic chemistry

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Periodic temperature variations can power chemical heat engines in accordance with the generalized Carnot principle. Such systems are commonly found in developing reaction networks or RNA evolution. Based on a given balanced reaction equilibrium, they absorb heat at higher temperatures and release it at lower temperatures. The difference between the two heat quantities is converted into chemical energy, which is partially conserved due to the slow kinetics at lower temperatures. Subsequent steps can then use this energy to drive uphill reactions.

For example, the effect of periodic temperature variation on RNA interactions is demonstrated using pairs of competing RNA duplexes as a simplified model system. These represent random base-pairing interactions between short RNA chains at the earliest stages of RNA evolution. The molecular interaction kinetics are simulated based on experimental thermodynamic data obtained by M. E. Christiansen et al. and the Eyring theory. The simulated time developments demonstrate the impact of shifting reaction kinetics and a state of continuous non-equilibrium. The product mixture that forms slowly at low temperatures releases chemical energy quickly at high temperatures, while the product mixture that forms quickly at high temperatures releases chemical energy slowly at low temperatures. In terms of heat flow and energy storage, the chosen model system represents a generalized Carnot engine, as would most similar reactions during RNA evolution. This provides a perpetual driving force for selection processes and creates ideal conditions for ongoing molecular evolution.

Abstract

Automatic identification of environment-dependent disequilibrium gases as indicator for non-Earth-like biosignatures

Authors:
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The search for life on planets beyond the solar system relies on the identification of robust biosignatures in exoplanetary atmospheres that can be detected with current or future space and ground observatories (such as JWST, ELT, HWO or LIFE). For a correct interpretation of the potential sources of biosignatures, we first need a solid understanding of the potential range of abiotically created atmospheres over a wide range of planetary parameters, including planetary composition, redox state, and atmospheric pressure and temperature conditions.

We then determine the gases that would be maximally out of equilibrium with the baseline atmosphere. For this, we developed a new chemical reaction model in Python that allows us to first define the chemical elements (so far limited to COHNSP, but arbitrarily extendable to more elements) and molecules of interest, and automatically derives the according network of all possible chemical reactions in the atmosphere together with the Gibbs energies of the equilibrium reactions. This allows on the one hand to calculate the equilibrium atmosphere based on the atmospheric elemental composition, and leads on the other hand to an automatic marking of gases that are most out of equilibrium with that atmosphere – i.e. potential biosignatures for non-Earth-like atmospheres.