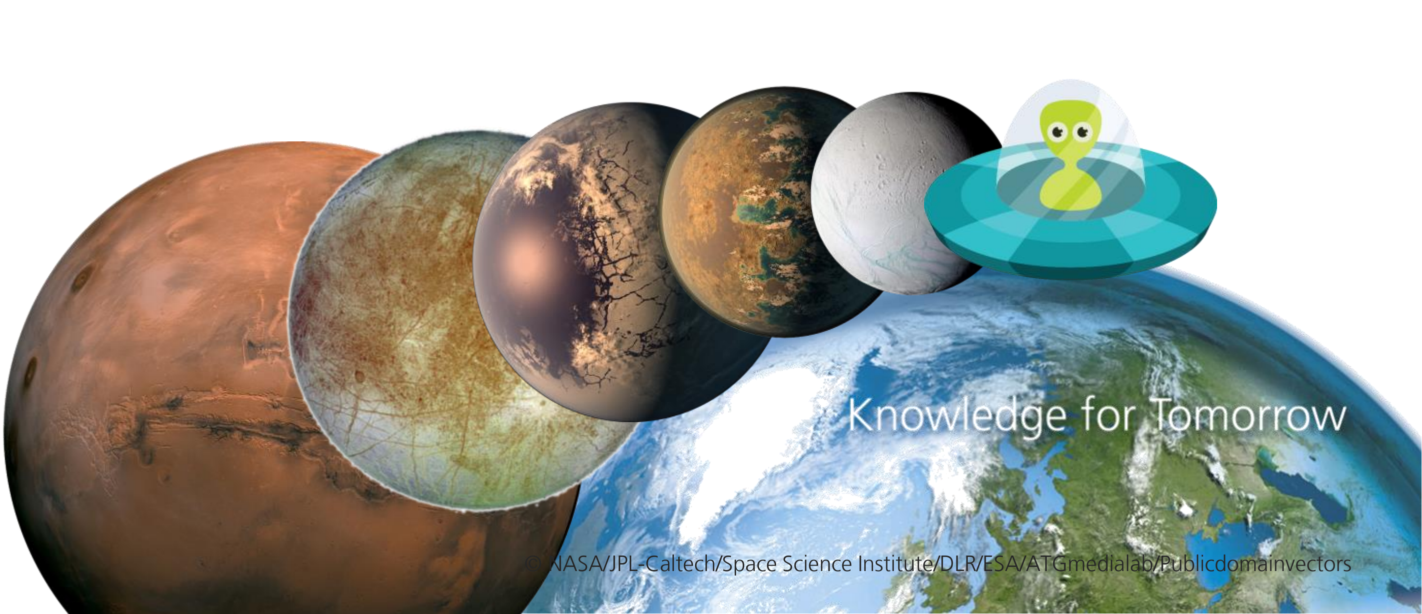
Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center

# The search for life in the Universe

7th annual workshop of the Deutsche Astrobiologische Gesellschaft e.V. (DAbG)

6 - 8 September 2023
DLR Berlin - Institute of Planetary Research

# BOOK OF ABSTRACTS



# Wednesday, September 6, 2023

## Welcome - Rotunde (1:00 PM - 1:30 PM)

| time | [id] title | presenter |
|---|---|---|
| 1:00 PM | [32] Welcome and Opening of DAbG 2023 | VORSTAND, DAbG<br>BAQUÉ, Mickael |
| 1:10 PM | [33] Welcome from the Director of the Institute of Planetary Research | Prof. RAUER, Heike |
| 1:20 PM | [34] Welcome from the head of the Planetary Laboratories Department | Dr HELBERT, Jörn |

## MARS - Rotunde (1:30 PM - 2:30 PM) Chair: Mickael Baqué

| | | presenter |
|---|---|---|
| 1:30 PM | [19] The Role of Perchlorate on the Habitability of Mars | HEINZ, Jacob |
| 1:50 PM | [25] Influence of (per)chlorate salts and regolith depth on the survival of microorganisms in simulated Mars-like conditions | FISCHER, Florian Carlo |
| 2:10 PM | [23] Exploring Past and Present-Day Habitable Environments in the Martian Subsurface | PLESA, Ana-Catalina |

## Coffee break - Rotunde (2:30 PM - 3:00 PM)

## HABITABILITY - Rotunde (3:00 PM - 4:40 PM) Chair: Jean-Pierre de Vera

| | | presenter |
|---|---|---|
| 3:00 PM | [7] A Stellar Oasis: K-Dwarfs are at least as viable for Photosynthesis as our Sun; Results from garden cress and cyanobacterium experiments | VILOVIC, Iva |
| 3:20 PM | [29] A focus on the physiological adaptations of the brine shrimp A. salina exposed to space simulated parameters: a new model for astrobiological studies. | MUSCARI TOMAJOLI, Maria Teresa |
| 3:40 PM | [11] Detection of phosphate in ice grains from Enceladus' ocean with general implications for habitability in the outer solar system | POSTBERG, Frank |
| 4:00 PM | [3] Is there a "Living Pulse" in Microorganisms? | SCHULZE-MAKUCH, Dirk |
| 4:20 PM | [24] The survivability of cyanobacteria on lunar rocks, their relevance for future space travel and possible causes for the changes in their cells | Mr BABEL, Timo |

## Poster session - Rotunde (4:40 PM - 6:00 PM)

| [id] title | presenter | board |
|---|---|---|
| **[2] A very universal biomarker: Life = Order + Complexity** | MAYER, Christian | |
| **[4] Metabolomic profiling of microbial-mineral interactions** | GFELLNER, Sebastian | |
| **[17] Influence of Mars-Relevant Minerals on the Thermal Stability of the Biomolecule NAD+** | ZEPF, Franziska | |
| **[20] Visual localization and 3D reconstruction as complement for astrobiological in-situ investigations** | IRMISCH, Patrick | |
| **[8] Temperature effect on a vesicle membrane obtained by an evolution experiment: A Theoretical Study** | DÁVILA GARVÍN, María J. | |
| **[26] Integrating Textured 3D Models from Drone Images into Virtual Reality for Planetary Analog Training: A Case Study from the 2023 Vulcano Summer School** | Dr RIEDEL, Christian | |
| **[10] Hydrothermal processing of triglycine and its detection in Enceladean ice grains** | HORTAL, Lucia | |

# Thursday, September 7, 2023

## HABITABILITY - Rotunde (9:30 AM - 10:30 AM) Chair: Solmaz Adeli

| time | [id] title | presenter |
|---|---|---|
| 9:30 AM | [5] Equivalent system mass of cyanobacterium production from Martian resources | Dr VERSEUX, Cyprien |
| 9:50 AM | [28] To move or not to move: The thermal and dynamic state of Europa's ice shell | RÜCKRIEMEN-BEZ, Tina |
| 10:10 AM | [9] Searching for planets with reducing atmospheric conditions | NOACK, Lena |

## Coffee break - Rotunde (10:30 AM - 11:00 AM)

## FIELD ANALOGS - Rotunde (11:00 AM - 12:00 PM) Chair: Dirk Wagner

| time | [id] title | presenter |
|---|---|---|
| 11:00 AM | [1] Vulcano (Italy): a planetary analog and training site with high astrobiological potential. | BAQUÉ, Mickael |
| 11:20 AM | [12] Polar Research: the bridge to Space Research | Dr DE VERA, Jean-Pierre Paul |
| 11:40 AM | [22] Microbial life in the Barrancas Blancas plain – a harsh mountain desert environment – in a Mars analog region of the high Atacama Andes (Chile) | MEDINA CARO, Diego |

## Lunch Break (12:00 PM - 1:00 PM)

## Lab Visits (1:00 PM - 2:10 PM)

***PASLAB (Planetary Analogue Simulation Laboratory), RMBL (Raman Mineral and Bio Detection Laboratory), PSL (Planetary Spectroscopy Laboratory)***

## FIELD ANALOGS - Rotunde (2:10 PM - 2:50 PM) Chair: Janosch Schirmack

| time | [id] title | presenter |
|---|---|---|
| 2:10 PM | [31] Field campaigns to analyse spectral characterisation of various volcanic material in NIR range; preparation for EnVision and VERITAS | ADELI, Solmaz |
| 2:30 PM | [21] Unveiling Microbial Communities in Terrestrial Deep Subsurface Environments along a Climate Gradient in Chile | HORSTMANN, Lucas |

## BIOSIGNATURES - Rotunde (2:50 PM - 3:30 PM) Chair: Jacob Heinz

| | | presenter |
|---|---|---|
| 2:50 PM | [6] Dirty Little Crusts for Science - Preparing Samples for BioSign | BREDEHÖFT, Jan Hendrik |
| 3:10 PM | [13] How to use Microbial Motility as Biosignature and Separate Cells from Martian Regolith Analogs | Dr SCHIRMACK, Janosch |

## Coffee break - Rotunde (3:30 PM - 4:00 PM)

## Jahreshauptversammlung - Rotunde (4:00 PM - 6:00 PM)

## Conference Dinner (7:00 PM - 10:00 PM)

# Friday, September 8, 2023

**BIOSIGNATURES - Rotunde (9:30 AM - 10:30 AM) Chair: Lena Noack**

| time | [id] title | presenter |
|---|---|---|
| 9:30 AM | [14] Simulating exoplanetary atmospheres in the laboratory: comparing experimental data with output from an atmospheric model | HOFMANN, Florence |
| 9:50 AM | [15] Uncertainty in phosphine photochemistry in the Venus atmosphere prevents a firm biosignature attribution | GRENFELL, John Lee |
| 10:10 AM | [16] Experiments for the Detection of Biosignatures in Irradiated Ice Grains with Europa Clipper's SUDA Mass Spectrometer | NAPOLEONI, Maryse |

**Coffee break - Rotunde (10:30 AM - 11:00 AM)**

**BIOSIGNATURES - Rotunde (11:00 AM - 12:00 PM) Chair: Cyprien Verseux**

| time | [id] title | presenter |
|---|---|---|
| 11:00 AM | [18] Effect of Sample Preparation in UV Irradiation Experiments on Potential Molecular Biosignatures | ENGEL, Alexander |
| 11:20 AM | [27] Mass Spectral Features of Enceladus' Organic Enriched Ice Grains: Plume Vs E ring | KHAWAJA, Nozair |
| 11:40 AM | [30] Laboratory Experiments on Earth and Detection of Organics by Cassini | CRADDOCK, Maxwell |

**Closing remarks and Prize ceremony - Rotunde (12:00 PM - 12:15 PM)**

# Contents

**FIELD ANALOGS / 1**

## Vulcano (Italy): a planetary analog and training site with high astrobiological potential.

**Author:** Mickael Baqué[1]

**Co-authors:** Alessandro Pisello [2]; Ana Lomashvili [3]; Clémentine Pelissier [4]; Dennis Dahlke [3]; Dirk Baumbach [3]; Frank Sohl [4]; Hugo Cordier [3]; Katrin Stephan [4]; Klaus Gwinner [4]; Kristin Rammelkamp [3]; Patrick Irmisch [3]; Roland Wagner [4]; Vikram Unnithan [5]

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The volcanic settings of the Eolian Islands, Italy, offer access to various types of volcanic terrains, with diverse morphology and mineralogy. The current signs of volcanic activity on the island of Vulcano, whose last eruption is dated to 1890, include e.g. the presence of large fumarole fields on ground and underwater. The dry landscape and easy access to layers of older and more recent volcanic material, in addition to the possibility of investigating secondary minerals, make this site a very promising analog for our neighbor planets: Mars and Venus. The active and acidic fumarolic sites could also be considered for early-Earth/Mars potential. For these reasons, Vulcano is a remarkable training site to test instruments, rovers, or data processing techniques for planetary exploration by comparison of field and lab data collected during this and previous field campaigns.
In the frame of the DLR SaiNSOR project, our main objectives for the 2023 campaign were the spectral characterizations of diverse lithologies and volcanic materials (from Venus to Mars analogues) with different field instruments: visible near infra-red (VNIR) reflectance, Raman spectroscopy, laser induced breakdown spectroscopy (LIBS), hyperspectral cameras, and drones. We also combined the spectral measurements with Integrated Positioning System (IPS) data –a multi-sensor system for localization, 3D reconstruction and inspection in unknown terrains –, a field documentation, and data pre-processing tools in order to produce a combined dataset of measurements to be reproduced in the lab and further integrated in a combined instrument concept. We also revisited sites measured in 2019 and 2022 to monitor changes and explored new localities on the Aeolian islands.
Finally, these extreme environments have a high astrobiological potential pertaining to the questions of life detection, using spectroscopy techniques, and habitability, looking at microbial colonization. Indeed, the identified extreme and unique environments present at Vulcano inform us on strategies and protocols on how to detect life elsewhere by applying a combined spectroscopy approach in the field, much like a rover would on another world, and comparing with lab measurements.

This work was supported by the German Aerospace Center Project SaiNSOR.

**Poster session / 2**

## A very universal biomarker: Life = Order + Complexity

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Terrestrial life is characterized by significant complexity combined with a high degree of order. Life needs complexity and order combined to develop functionality, exactly this functionality that life

uses to keep up its ordered state against the second law of thermodynamics. Essentially, life is a form of **self-sustaining complex order**. Consequently, the combination of complexity and order qualifies as a very general biomarker. All known life on Earth fits into a section defined by typical thresholds for complexity and order. The opposite is true as well: everything on Earth that fits into this section is either life itself or something that has been produced by life.

In the lab as well as in nature, it is quite easy to achieve order without complexity. Any crystallization process leads to states of high order. However, due to missing complexity, crystals have practically no functionality. Likewise, it is quite easy to achieve complexity without order. A random polymerization process may lead to copolymers of high complexity. However, due to missing sequential order, such random polymerization products have practically no functionality.

The most powerful process that leads to complexity combined with order is evolution. At a very early stage, molecular evolution leads to polymer chains of increasing complexity (defined by the length of the chain sequence) and increasing order (defined by the reliability and variability of the sequence). As an example, such a process is calculated based on a simplified RNA world model. The resulting data show the potential of the RNA evolution to reach states of high complexity and order.

References

Mayer, C. (2020) Life in the context of order and complexity, Life 10, 5.
Mayer, C. (2023) Order and complexity in the RNA world, Life 13, 603.

**HABITABILITY / 3**

## Is there a "Living Pulse"in Microorganisms?

**Authors:** Dirk Schulze-Makuch[1]; Marina Walther-Antonio[2]

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[2] *Mayo Clinic*

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A rhythmic pattern of motion due to breathing and circulation processes is observed within macroscopic organisms such as animals. The question is whether we could observe something like this –on a much smaller scale –also in microbial life forms. We know that there is motion within any type of cell from the myriad of internal processes and also at the cell boundaries when an organism interacts with its natural environment. Here we hypothesize that each microorganism has such a "living pulse", a rhythmic pattern that in principle can be detected by state-of-the-art technology (Walther-Antonio and Schulze-Makuch, 2023).
Experimental evidence that such a living pulse might exist comes from nanomechanical oscillators, which detect forces in the order of a piconewton and which were used to characterize living specimens and their metabolic cycles (Boisen et al. 2011). Cantilevers were used to investigate the activity of a cell's molecular motors and the particular vibrations of living *Saccharomyces cerevisiae* (Pelling et al. 2005). The measured force by nanomechanical oscillators in the order of a piconewton fares well with our theoretical considerations of the same order for the force required for one ion to go through a cellular membrane. If such a proposed "living pulse"exists, we suggest that it can be detected with state-of-the-art microscopy such as Stimulated Emission Depletion (STED) and Scanning Ion Conductance Microscopy (SICM), particularly if we compare dead cells as a control to living cells from the same species. One (of the many) challenges will be to distinguish the hypothetical "living pulse"from environmental noise. However, while environmental noise would travel from the outside of the cell to the inside, the opposite direction would be the case for the "living pulse". While we hypothesize that all living microbes will exhibit a living pulse, we expect the frequency and the magnitude to be different depending on the species just like it is the case for animals.
If the hypothesized "living pulse"can be detected, it would have far-reaching applications. It would be a universal biosignature independent of an organism´s specific biochemisty. It would be a tool to detect life in extreme environments on Earth and in extraterrestial locations, where we don´t know

whether it exists. It would also help us to ensure that life is not present where sterilizing conditions are critical, such as for planetary protection purposes, in the food-processing industry, and during medical procedures.

**References**

Boisen, A., et al. (2011) Cantilever-like micromechanical sensors. Rep. Prog. Phys. 74, 036101.
Pelling, A.E., et al. (2005) Time dependence of the frequency and amplitude of the local nanomechanical motion of yeast. Nanomedicine 1, 178-183.
Walther-Antonio, M. and Schulze-Makuch, D. (2023) The hypothesis of a living pulse in cells. Life 13(7), 1506; https://doi.org/10.3390/life13071506

**Poster session / 4**

## Metabolomic profiling of microbial-mineral interactions

**Authors:** Sebastian Gfellner[1]; Tetyana Milojevic[1]

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Chemolithoautotrophic organisms thrive under extreme conditions (e.g., high metal concentrations, high temperatures, and low pH) through redox-altering minerals by oxidizing inorganic molecules (e.g., iron, sulfur, and other reduced inorganic sulfur compounds). As the early planetary phases of Earth and Mars are similar, this metabolomic path makes these microbial organisms good candidates for astrobiological investigation. The molecular residues may differ owing to the different mineralogical compositions of Earth and Mars, which may result in a Mars-specific biopattern [1]. It is feasible to identify the biological substances of interest and validate their biogenicity by metabolomic and lipidomic investigations using different mass spectrometry methods. To trace the metabolomic profile of the extremely thermoacidophilic archaeon *Metallosphaera sedula*, we used a suite of mass spectrometry (MS) techniques, including electrospray ionization (ESI), Liquid Chromatography (LC) - MS, and matrix-assisted laser desorption ionization –Time of Flight (MALDI-ToF). *M. sedula*, a member of the archaeal order Sulfolobales, is extremely resistant to high temperature, low pH, and heavy metals and can be found in hot sulfur springs, volcanic regions, and acid rock drainages. Quinones, in addition to lipids, are chemotaxonomic indicators of archaeal cells, including information about mediating redox processes [2], showing that they could be used as diagnostic biomarkers in the Martian subsurface. In particular, thiophene-bearing quinones with thiophene heads and quinone tails are promising stable compounds for biosignature detection applications. These molecules have attracted the attention of scientists in connection with the discovery of sulfur compounds such as ethanethiol and thiophene in the Martian Gale Crater [3]. The emphasis is on similarities and differences in specific molecular sites (e.g., extra methylations), number of cyclizations, and changes in the integrated S-moieties. Our proposed research may provide a mechanism for successful analytical examination to determine the possible biogenicity of materials acquired and eventually recovered from Mars.

[1] Milojevic, T., Albu, M., Blazevic, A., Gumerova, N., Konrad, L., & Cyran, N., Frontiers in microbiology, 10, 1267 (2019)
[2] Elling, F. J., Becker, K. W., Könneke, M., Schröder, J. M., Kellermann, M. Y., Thomm, M., & Hinrichs, K. U., Environmental microbiology, 18(2), 692-707 (2016)
[3] Millan, M., Williams, A. J., Mcadam, A. C., Eigenbrode, J. L., Steele, A., Freissinet, C., … & Mahaffy, P. R., Journal of Geophysical Research: Planets, 127, 11 (2022)

**HABITABILITY / 5**

## Equivalent system mass of cyanobacterium production from Martian resources

**Author:** Cyprien Verseux[1]

**Co-authors:** Tiago Ramalho [2]; Emma Bohuon [1]; Nils Kunst [1]; Vincent Baumgartner [1]; Christiane Heinicke [1]; Guillaume Pillot [3]; Sven Kerzenmacher [3]; Marc Avila [1]

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Bioproduction systems that rely on diazotrophic, rock-weathering cyanobacteria for in situ resource utilization have been described as potential ways of increasing the sustainability of crewed missions to Mars. According to this concept, cyanobacteria would be fed with water mined from the ground; carbon and nitrogen sourced from the atmosphere; and the local regolith, from which it has been argued that they could extract the other necessary nutrients. They could then produce various consumables directly, such as dioxygen and dietary supplements, but also support the growth of secondary producers (plants or microorganisms) which could, in turn, generate a wide range of critical consumables.

While a fast-increasing body of work suggests that such systems could function, no thorough assessment of their cost-efficiency has so far been presented. This can be attributed to the paucity of data related to the physiological responses of cyanobacteria to factors which are critical to their cultivation on site, including: low total pressure; non-ambient partial pressures of carbon dioxide and nitrogen; and interactions with regolith, a source of both nutrients and toxic compounds. In this talk, we will present work performed toward such an assessment. We will give an overview of data collected for that purpose, including the effects on growth rates of changes in key atmospheric parameters or in the concentrations of regolith components; describe a mechanistic mathematical model that, relying (among others) on this data, can predict productivity and equivalent system mass (ESM) of cyanobacterium cultivation on Mars; and present ESM estimates for several cultivation scenarios.

These estimates are not definitive: we were limited by the many uncertainties that remain, notably on technologies that will become available and on specific mission parameters. However, they already provide insights that can guide development efforts: they underline areas where improvements would most improve cost-efficiency, such as that of the cultivation system's water efficiency; point out to adaptations of existing technology that are required for the system to be operated, aimed for instance at providing regolith-handling capabilities; and underline gaps in knowledge whose filling-in would enable much refined predictions, critical ones among which pertain to cyanobacterium-regolith interactions. Most notable may be the suggestion that development efforts are warranted: a breakeven can be reached, it seems, after only a few years of operation.

**BIOSIGNATURES / 6**

## Dirty Little Crusts for Science - Preparing Samples for BioSign

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**Co-authors:** Lina Brockmann [2]; Noah Felis [2]

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In the context of the search for life on other bodies of the solar system, much time has been invested in research and discourse about what constitutes a good biosignature. Ideally, we would want something that is unique to life (has no abiotic origin), is easily detectable and is not prone

to false positives (from *eg.* forward contamination). It seems to be consensus now that no single biosignature (apart from actually meeting an extraterrestrial organism) can fulfill all these criteria, and that we need to look at a bigger picture with different techniques to decide whether any signature qualifies as an identifier of past or present life.
In their 2015 Astrobiology Strategy paper, NASA has compiled a list of ten possible classes of biosignatures to look for.<sup>[1]</sup> One of those classes are organic molecules that play a role in Earthly biology. These seem to be a very good candidate for chemical biosignatures. One problem that could arise, however, is that the conditions on the surface of Mars, or Enceladus, or any other body of the solar system are much different from those inside a cell of an organism on Earth. Simple molecules that we find in all living cells could be broken down rapidly when exposed to vacuum, radiation, temperature extremes, or all of the above.
In order to understand the changes that chemical biomarkers undergo in these conditions, experiments are needed. One such experiment is the BioSign project hosted at DLR. In it, several biosignatures such as whole bacteria, fossils, sediments, various molecules and others will be irradiated with the full solar spectrum on the outside of the ISS.
In preparation of these experiments and to establish experimental protocols with regards to sample preparation and analysis, we present here first attempts to produce films of Riboflavin (Vitamin B2) in pure form or in different salt matrizes, the re-solvation of these films and finally quantification of the substance amount recovered throughout the whole process.
One of the easiest and surprisingly powerful techniques for quantification is UV/VIS spectroscopy. In the case of Riboflavin, which is distinctly colored and has an even stronger absorption in the UV, this is easily done by comparing spectra of solid films as well as solutions to a standard calibration curve. In order to increase specificity and prepare for eventual analysis of photolysis products, an analytical protocol using HPLC/MS was also developed.
Interestingly, the reproducible preparation of uniform solid films proved to be very challenging. Not only does the inclusion of different salt matrizes call for different preparation protocols, we also found out that the surface properties of the sample carrier material had an enormous effect on crystal deposition. This proves that there need to be individual developments of not only analytical protocols for different substances but also for every combination of target biosignature molecule and sample carrier surface.

There will be many more colored salt crusts, before we can fly to the ISS.

[1] L. Hayes (ed.), NASA Astrobiology Strategy 2015, Chapter 5.4 II

**HABITABILITY / 7**

## A Stellar Oasis: K-Dwarfs are at least as viable for Photosynthesis as our Sun; Results from garden cress and cyanobacterium experiments

**Author:** Iva Vilovic[1]

**Co-authors:** Dirk Schulze-Makuch [1]; René Heller [2]

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Light is the fundamental energy source for photosynthesis, enabling the synthesis of organic compounds. Over billions of years, photosynthetic organisms have profoundly transformed our planet into a diverse global ecosystem (1,2). Therefore, understanding an (exo)planet in the context of its stellar environment is an essential step in assessing its habitability. K-dwarf stars have gained a lot of attention in recent years as potentially offering the most bening stellar environment for putative life (3).

Here we present our results in which we investigate the viability of simulated K-dwarf radiation for phototrophic organisms. We used an LED solar simulator with a variable spectrum module which we adapted to emit radiation corresponding to a globally distributed light which would be received at the surface of a hypothetical planet in the habitable zone of a 4300 Kelvin K-dwarf star at a distance of ~0.44 AU. The resulting K-dwarf spectrum is shifted towards longer wavelengths and exhibits three times smaller fluxes overall. We exposed garden cress *Lepidium sativum* as well as the cyanobacterial strain *Chroococcidiopsis* sp. 029 to K-dwarf radiation for up to 14 days, and compared these responses to an exposure to solar radiation as well as completely dark conditions.

In summary, we find that despite a decreased red to far-red ratio (due to the relative shift of the K-dwarf spectrum towards longer wavelengths) and receiving only a third of the photons suitable for oxygenic photosynthesis (in the radiation range of 400 –700 nm), garden cress under K-dwarf radiation exhibits comparable visual growth, photosynthetic activity as well as water intake and dry mass accumulation as garden cress under solar conditions. Moreover, the cyanobacterium demonstrated a significantly more positive response to K-dwarf radiation, exhibiting both higher photosynthetic activities and culture growth. Neither organism exhibited photosynthetic activity without radiation, underscoring the significance of light for their survival.

**References**
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2. Kiang, N. Y. et al. Spectral signatures of photosynthesis. II. Coevolution with other stars and the atmosphere on extrasolar worlds. Astrobiology 7, 252–274 (2007).
3. Arney, G. N. The K Dwarf Advantage for Biosignatures on Directly Imaged Exoplanets. ApJL 873, L7 (2019).

**Poster session / 8**

## Temperature effect on a vesicle membrane obtained by an evolution experiment: A Theoretical Study

**Author:** María J. Dávila Garvín[1]

**Co-author:** Christian Mayer [1]

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Early cellular membranes may have emerged and survived harsh temperature, pressure, pH or ionic strength gradients, presumably occurring in diverse geological environments, such as pumice rafts, volcanic splash pools, submarine hydrothermal vents and subaerial springs [1-2]. A wide variety of thermotropic phases could appear in the amphiphilic membranes under these environmental conditions, thereby affecting the stability and functionality of the protocells. In this study, all-atom molecular dynamics simulations have been used to elucidate the effect of temperature on the properties of functionalized vesicle membranes. For this purpose, temperature changes from 358 K to 323K were established, based on the hypothesis postulated by Schreiber et al. [3]. A plausible prebiotic system was selected, constituted by a model membrane bilayer, an equimolar mixture of long-chain fatty acids and fatty amines, and short peptides, KSPFPFAA, previously identified in an evolution experiment [4]. Peptides tend to form the largest spontaneous aggregates at higher temperatures, therefore enhancing the pore formation process and the eventual transfer of essential molecules in a prebiotic scenario. Analyses also suggest that the peptide-amphiphilic molecules interactions affect the stability and the structural properties of the plausible prebiotic vesicular system.

References
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2. E. Camprubí, J.W. de Leeuw, C.H. House, F. Raulin, M.J. Russell, A. Spang, M.R. Tirumalai, F. Westall, The Emergence of Life, Space Sci. Rev. 215, 56, 2019.

3. Ulrich Schreiber, Oliver Locker-Grütjen, Christian Mayer, Hypothesis: Origin of Life in Deep-Reaching Tectonic Faults, Orig. Life Evol. Biosph. 42, 47, 2012.
4. Christian Mayer, Ulrich Schreiber, María J. Dávila, Oliver J. Schmitz, Amela Bronja, Martin Meyer, Julia Klein and Sven W. Meckelmann, Molecular Evolution in a Peptide-Vesicle System, Life 8, 16 (2018).

**HABITABILITY / 9**

## Searching for planets with reducing atmospheric conditions

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**Corresponding Author:** lena.noack@fu-berlin.de

Currently we do not yet know, if Earth did have a reducing atmosphere or not during the first few hundreds of Myrs of its history. However, this would have a strong impact, as shown in the Miller-Urey experiment and several follow-up studies, on prebiotic chemistry and therefore possibly the origin of life on Earth.

It has been recently suggested, that rocky planets being more massive than Earth (so-called super-Earths), may actually have even more oxidized mantles (and hence atmospheres) than Earth, which would strongly decrease the probability of prebiotic chemistry as we know it. However, more massive planets also experience a higher pressure and compressibility in their interior, which can strongly impact the differentiation efficiency of the planet, i.e. the extraction of iron from the mantle to the core. The result would be an iron-enriched and strongly reduced mantle, and an equally reduced atmosphere.

Here, first preliminary results from a new study following planet formation and differentiation from the magma ocean stage to the long-term evolution suggest, that the ability to form a core should decrease with planetary mass, which means that super-Earths may, after all, be more reducing than Earth, which would be reflected in their atmospheric composition and potential for prebiotic chemistry and life as we know it.

Acknowledgment: Funded by the European Union (ERC, DIVERSE, 101087755). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

**Poster session / 10**

## Hydrothermal processing of triglycine and its detection in Enceladean ice grains

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Evidence for water-rock interactions and hydrothermal (HT) reactions at the ocean-floor of Enceladus was found via the mass spectrometers onboard the Cassini spacecraft –the Cosmic Dust Analyzer and the Ion and Neutral Mass Spectrometer. Organic material of astrobiological interest, containing various moieties (N-, O- and aryl groups), was detected in ice grains coming from vents on Enceladus'south pole, as well as prebiotically relevant high mass fragments (mass > 200) and low mass (mass < 100) compounds.
These low-mass compounds, soluble and reactive, could provide building blocks for the synthesis of prebiotic monomers like amino acids (AA) under Enceladus hydrothermal conditions (EHTC). AAs play a distinct role in the origins of life on Earth - both as monomers and polymers like peptides or proteins and enzimes- and are key biosignatures for the identification of extraterrestrial life. Therefore, it is of investigating the hydrothermal processing (HTP) of AAs and peptides under EHTC is of great importance. A tripeptide of glycine, an AA relevant for astrobiology investigations, was studied in this work. Triglycine (GGG) formation is inhibited under conditions relevant to Enceladus' HT system, thus the detection of GGG, and its degradation products, in Enceladean ice grains may hint at biotic or hitherto unknown abiotic processes in the moon's interior.
The mass spectral appearance of GGG in ice grains after processing under EHTC (80 ℃, 80 bar; [GGG]=0.005 M; 1:20 peridotite-water) was investigated. Different solutions were prepared and HT processed for 2 and 4 hours: 1) GGG 2) GGG + Enceladus ocean simulant (EOS; pH=9, [NaCl]=0.1 M), 3) GGG + minerals, 4) GGG + EOS + minerals. This systematic methodology is adopted in order to assess degradation pathways of GGG during HTP.
Processed and unprocessed HT samples, were measured using laser-induced liquid beam ion desorption (LILBID), which accurately simulates hypervelocity impact ionization mass spectra of ice grains. Partial degradation of GGG in HT processed solutions 1 and 2 was identified, while 3 and 4 showed no signs of degradation. Spectral differences were found in solutions 1 and 2, hinting at NaCl having an effect on the degradation pathway of GGG. There was a lack of evidence for HTP found in spectra of solutions 3 and 4, which might indicate the mineral used for fulfils a preservative role.

**HABITABILITY / 11**

# Detection of phosphate in ice grains from Enceladus'ocean with general implications for habitability in the outer solar system

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Enceladus's subsurface global ocean (1) can be probed by sampling the gaseous and icy material the moon expels into its cryovolcanic plume and - even further out - into Saturn's E ring (2,3,4,5). Hydrothermal outflows supported by tidal heating (4,5,6), together with rich organic chemistry (7,8) imply that the moon appears to be one of most habitable places in our solar system. Among the elements C, H, N, O, P and S that are considered to be essential for life, all except phosphorous have either been identified (5,7,8) or - in the case of sulfur - tentatively detected (9). From these elements, P has by far the lowest cosmic abundance and is usually bound in poorly soluble minerals, limiting its bio-availability.
Here we present results from a re-analysis of mass spectrometric data from Cassini's Cosmic Dust Analyzer (CDA), showing strong evidence of sodium-phosphate salts in ice grains originating from Enceladus's subsurface ocean (10). We found a population of ice grains whose spectra clearly indicate the presence of at least two soluble sodium orthophosphates: $Na_3PO_4$ and $Na_2HPO_4$. We infer phosphate concentrations in the Enceladean ocean in the order of a few mM, about 1000-times higher concentrations than in Earth's seawater (10).
We carried out geochemical experiments and calculations showing how such high phosphate abundances can be achieved in the subsurface ocean. The driver enabling the abundant availability of

phosphate is the high observed concentration of dissolved carbonate species, which shift phosphate-carbonate mineral equilibria toward dissolution of phosphate minerals into Enceladus'ocean. We show that interactions between chondritic rocks and $CO_2$-rich fluids generally lead to conditions with high dissolved phosphate concentrations (10). Therefore, P-rich oceans would commonly occur in ocean worlds beyond the $CO_2$ snow line. This almost certainly applies to bodies at Saturn and beyond. It is, however, currently unclear if the Jovian moons formed under such favorable ($CO_2$ rich) conditions at low enough temperatures.

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**FIELD ANALOGS / 12**

## Polar Research: the bridge to Space Research

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In the last decade Polar Research in Germany became increasingly an important focus in Space Research activities, particularly in Planetary Research and Astrobiology. The reason is obvious, because the planets and moons in our Solar System, with a potential to be habitable and also being promising candidates for the search for life beyond Earth, are icy worlds. These icy conditions on those worlds show some analogies to the environment in the polar regions of our home planet Earth. Therefore, the Polar Regions on Earth are often used in Space Research for technology and operational tests as well as for environmental research investigations with probes (landers, rovers, melting probes) and their payloads under these extreme conditions. The tests include either topics of robotic exploration scenarios and crewed astronautic activities. A special trigger for these activities is the question about life and the search for life in the universe as well as investigations on searching for habitable niches on and in the extreme worlds in our solar system. The disciplines of natural sciences (what includes disciplines of geology, geomorphology, physics, chemistry and biology), using and developing the necessary technologies for the described extreme cold environments, are mainly driven by the astrobiological questions of the origin, the evolution and distribution of life in the universe. Examples about the German polar activities in space research will be presented to show perspectives how the journey through Polar Research could support investigations to reach the stars and their planets.

**BIOSIGNATURES / 13**

## How to use Microbial Motility as Biosignature and Separate Cells from Martian Regolith Analogs

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A major indicator for the presence of microbial life is motility, or the ability to move independently using metabolic energy. Motility can be observed and quantified by analyzing the trajectories of individual cells in microscopic videos and by comparing them with the movement of abiotic particles due to Brownian motion or drifts.
Using microscopy for detecting possible extraterrestrial organisms on Mars provides an efficient technique. However, there are major challenges that need to be overcome, such as a) separating potential cells from the regolith particles, b) stimulating potential cells to move, and c) automated in-situ analysis of microscopic images, which is essential for rapid and reliable identification of living cells. Here we will present our latest findings on all three aspects of this issue and derive recommendations for methodologies and instruments for a Mars mission.
Separating the potential microorganisms from the Martian regolith is a key challenge for detecting microbial life on Mars. Certain minerals or other compounds contained in the regolith may interfere with the detection or identification of living cells. Therefore, it is important to develop efficient and reliable separation methods that can extract microbial cells from the regolith without damaging them or compromising their viability. We have tested various separation methods using Martian analog regolith samples. These methods include physical methods, such as filtration, centrifugation, and sonication. We have evaluated their performance in terms of concentration, and viability of the extracted cells. We analyzed the motility with our novel tracking approach and investigated the implications of different separation steps on their motility behavior. Additionally, we examined stimuli (chemotaxis, temperature variation) that can be used to enhance the motility of specific bacteria. The goal is to find an agnostic substance, which works for many bacterial species and does not harm individual organisms. The tracking of small and simple cells like prokaryotes is an engineering challenge, because the objects to be tracked are close to the resolution limit of the microscope. We apply new tracking and identification methods that are based on a combination of image processing techniques, such as motion history images, region growing, background subtraction, adaptive thresholding, blob detection, particle filtering, and machine learning. These methods can handle large datasets of highly motile microorganisms with low signal-to-noise ratios, such as those obtained from natural environments or Martian analog samples.

**BIOSIGNATURES / 14**

## Simulating exoplanetary atmospheres in the laboratory: comparing experimental data with output from an atmospheric model

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Since the discovery of the first exoplanet, several thousand have been found, including some Earth-like planets. A new generation of space telescopes (e.g., James Webb Space Telescope and Transiting Exoplanet Survey Satellite) are now taking the search for potential extra-terrestrial life one step further. With these new missions, direct imaging of exoplanets and spectral resolution of reflected or transmitted light through their atmospheres becomes scientifically feasible. The possibility of detecting biosignatures indicative for life on other habitable planets allows the search for extra-terrestrial

life to go beyond our Solar System.
The correct interpretation of future exoplanetary spectra relies strongly on the understanding of atmospheric processes and possible chemical pathways. Given the large variety of exoplanets there is a pending need for theoretical and experimental atmospheric and astrochemistry studies.
With our new Planetary Simulation Chamber (PSC) at Freie Universitaet Berlin, we are capable of simulating a large set of atmospheric parameters, including pressure, temperature and various gas compositions characteristic for Earth-like planets. Triggering complex photochemical processes in the gas phase, the sample is exposed to solar radiation, including Lyman alpha, UV/VIS and particle radiation.
Most telescopes operate in the VIS/NIR range that corresponds to the fingerprint regions of interesting organic molecules. Our facility allows continuous spectroscopic monitoring of samples in the VUV, UV/VIS and NIR region and simultaneous mass spectroscopic analysis.
In collaboration with our partners at the DLR institute for planetary research, we compare experimental results from our chamber with output from their climate-chemistry model 1D-TERRA.
We expect to provide valuable insights in understanding complex chemical pathways in various, exotic atmospheres, which not only improve current atmospheric models but aid in the definition of a set of reliable and detectable biomarkers in exoplanet atmospheres.
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**BIOSIGNATURES / 15**

## Uncertainty in phosphine photochemistry in the Venus atmosphere prevents a firm biosignature attribution

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Context. The possible detection of phosphine (PH3) in the clouds of Venus has raised the question as to which processes could produce such large abundances of PH3. Previous studies suggested that abiotic processes including photochemical production cannot explain the claimed PH3 concentrations. However, the photochemistry of phosphorus-bearing species in the atmosphere of Venus is not well known.
Aims. We aim to assess the abiotic production of PH3 considering the effect of uncertainties in the chemical rate coefficients of phosphorus-containing reactions.
Methods. Using a photochemical column model, we simulated Venus-like conditions and varied the chemical rate coefficients with a Monte Carlo (MC) approach in order to estimate the associated error in the PH3 abundances throughout the atmosphere.
Results. Current uncertainties and missing data in photochemical rate coefficients lead to a variation of about six orders of magnitude in the modelled PH3 abundance on Venus, assuming photochemical production of PH3 from tetraphosphorus hexoxide (P4O6) pathways. Our results suggest an abiotically produced upper limit of 2 ppb PH3 between 50 and 60 km. These concentrations are in the range of a recent reanalysis of Atacama Large Millimeter Array (ALMA) data, suggesting planet-averaged abundances in PH3 of 1–4 ppb above 55 km. Future observations of phosphorus monoxide (PO) on Venus would be beneficial for increasing our confdence in assessing PH3 as a biosignature.
Conclusions. We conclude that due to the large uncertainties in phosphorus chemistry, even a firm detection of several ppb PH3 in the Venus atmosphere would not necessarily mean a biological origin.

**BIOSIGNATURES / 16**

# Experiments for the Detection of Biosignatures in Irradiated Ice Grains with Europa Clipper's SUDA Mass Spectrometer

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Ocean worlds, such as Jupiter's icy moon Europa, are key targets in the search for extraterrestrial life. One powerful approach involves searching for biochemical signatures at the molecular level - both specific biosignature molecules and their distribution patterns. These include amino acids and fatty acids, the latter being considered as universal biomarkers of extraterrestrial life [1], while amino acids are some of the simplest molecules that could be a biosignature.

NASA's upcoming Europa Clipper mission [2] will evaluate Europa's habitability. The SUrface Dust Analyzer (SUDA [3]) is the onboard impact ionization mass spectrometer, which will provide compositional analyses of water ice grains, potentially rich in organic material derived from the subsurface ocean. SUDA has the capability to detect and distinguish between abiotic organic molecules [4,5] and (microbial) biosignatures [6,7,8] in Europa's ice grains. However, if such signatures are indeed present in Europa's surface ice, they are exposed to Jupiter's harsh magnetospheric radiation and may thus be destroyed and/or modified by high-energy particles, mainly electrons [9]. It is therefore crucial to evaluate the impact of Europa's radiation environment on the preservation of biosignatures in its surface ice and on their detectability with spaceborne instruments.

Here, we assess the effects of electron irradiation on the mass spectral signatures of molecular biosignatures embedded in ice, as detectable by SUDA-type mass spectrometers. We irradiated amino acids and fatty acids in water ice with high-energy (10 MeV) electrons and recorded analogue mass spectra using Laser Induced Liquid Beam Ion Desorption (LILBID), a technique that accurately simulates SUDA-type mass spectra [10]. Samples were irradiated with doses from about 300 Gy to 3.5 MGy, i.e., exposure on the timescale of minutes up to a year on Europa's surface at 0.1mm depth [11]. The irradiation experiments were conducted at conditions similar to those experienced by Europa's surface ice (i.e., high vacuum and surface temperatures between 80 and 130 K). Samples consisted of (i) 4 amino acids (alanine, aspartic acid, glycine, lysine) at a concentration of 0.01 wt% for each amino acid, (ii) fatty acids at simulated abiotic concentrations (all fatty acids at the same concentration) and (iii) fatty acids at simulated biotic concentrations (increased abundances for even carbon number fatty acids, especially C16 and C18, as compared to odd carbon number fatty acids).

Preliminary results show characteristic signals can be identified from both amino acids and fatty acids even at the highest tested dose, indicating that these biosignatures can persist under Europan surface conditions over long periods of time and be still easily detectable by SUDA. The intensities of peaks corresponding to high molecular mass amino acids was found to decrease with increasing radiation dose, indicating that these compounds undergo destruction due to the radiation, but they decreased with a lower degree than expected. Results will be further discussed in the context of surface location and depth on Europa, drawing implications for the detection of organic biosignatures with space missions such as Europa Clipper and other future icy moon missions [12].

**Poster session / 17**

## Influence of Mars-Relevant Minerals on the Thermal Stability of the Biomolecule NAD+

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The search for signs of biological activity on Mars is among the main objectives of Mars exploration programs [1]. Here, molecular biosignatures, i. e. molecular traces of life such as biomolecules, are of particular interest. It has to be noted though that biomolecules are highly susceptible to alteration by extreme conditions on extraterrestrial bodies. On Mars specifically, such conditions include ionizing radiation, UV radiation, and strong oxidants in the regolith. Especially in early martian history, heat was also important. It was caused, for example, by intense volcanism in the Noachian and Hesperian periods (4.8–2.6 billion years ago). Given the susceptibility of biomolecules to chemical alteration under extreme conditions, a thorough investigation of stabilities, detection limits and alteration products of potential molecular biosignatures is crucial [2, 3]. In this context, one type of studies consists of Earth-based simulation experiments [2].
Given the above-mentioned long history of martian volcanic activity, we investigated the thermal stability of the biomolecule nicotinamide adenine dinucleotide (NAD+) and identified its decomposition products. A particular focus was on the influence of the mineral environment on the thermal decomposition. Five Mars-relevant mineral matrices were selected for the heating experiments: sodium chloride (NaCl), calcium sulphate ($CaSO_4$), basalt, the Martian regolith simulant JSC Mars-1A, and a mixture of JSC Mars-1A and sodium chloride. The solid residues of the thermolysis experiments were analyzed by infrared spectroscopy and X-ray powder diffraction.
Initial results include: (i) alteration and decomposition of neat NAD+ starts at around 200 ℃ and is preceded by a stepwise loss of crystal water between 100 and 180 ℃; (ii) exposure of a NAD+/NaCl mixture to temperatures above 180 ℃ first leads to the formation of sodium cyclo-triphosphate ($Na_3P_3O_9$); (iii) later (above 500 ℃) sodium diphosphate ($Na_4P_2O_7$) is formed. Diphosphate minerals are rare and cyclo-triphosphate minerals are apparently unknown, at least on Earth. Therefore, these oligophosphates may potentially serve as "secondary"biosignatures.

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**BIOSIGNATURES / 18**

## Effect of Sample Preparation in UV Irradiation Experiments on Potential Molecular Biosignatures

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The possibility of extraterrestrial life has fascinated humanity for centuries. Currently, a number of space research projects are at least partly dedicated to the search for life on other worlds such as Mars and Enceladus. Against this backdrop, terrestrial laboratory experiments simulating extraterrestrial physical and geochemical conditions that might alter molecular traces of life are important. Relevant physical conditions include irradiation by (UV-)light and heat exposure, among others [1]. Should life forms similar to those on Earth exist on other planets and moons, they may rely on biomolecules similar or even identical to the key molecules of life on Earth. A prominent example is amino acids [2], but several other, sometimes less obvious, biomolecules can also be considered here, for example the coenzyme nicotinamide adenine dinucleotide (NAD) and related molecules, which occur in all domains of life on Earth [3].

A common type of experimental studies in biosignature research deals with the stability of biomolecules and their decomposition products under UV irradiation conditions. However, also the effect of different procedures of sample preparation on the to-be-irradiated molecules per se needs to be considered. Procedures for sample preparation include, for example, solution casting, spin coating and sublimation. We will present results on (i) the effect of sample preparation on fundamental properties of amino acids, such as crystal size and crystalline modification [4], and (ii) how different solution casting parameters influence the UV-induced decomposition of 1 methyl¬nicotinamide chloride, a model compound for the redox-active nicotinamide moiety of NAD(P)+.

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**MARS / 19**

## The Role of Perchlorate on the Habitability of Mars

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Putative microbial life on Mars would encounter a severe scarcity of liquid water due to the prevailing freezing and hyperarid climate conditions. Interestingly, hygroscopic salts were discovered on Mars that enable water absorption from the atmosphere and lower the freezing point, potentially allowing the temporary occurrence of liquid briny water [1]. However, these brines contain high concentrations of salts, posing significant challenges for life, including high salinity, ionic strengths, and low water activity. Of particular interest are perchlorate (ClO<sub>4</sub><sup>-</sup>) salts, which are widespread on Mars [2] but rare in natural environments on Earth. Therefore, investigating the habitability of perchlorate brines and the effects of perchlorate ions on microbial cells through lab experiments is crucial. In this study, we summarize the results of our investigations into the perchlorate-specific stress responses of various organisms from all three domains of life (archaea, bacteria, and eukaryotes) and discuss their implications for the habitability of Mars.

As model organisms, we used *Planococcus halocryophilus* and *Escherichia coli* for bacteria, *Haloferax volcanii* for archaea, and *Debaryomyces hansenii* for eukaryotes. We employed various analytical tools, including growth experiments, fluorescence and scanning electron microscopy, and proteomics, to analyze the microbial stress responses. Microscopic analysis revealed that cells exposed to perchlorate stress often exhibited morphological changes, such as the formation of cell clusters in *P. halocryophilus* and *D. hansenii*, as well as cell filaments in *E. coli*. Growth experiments demonstrated that all tested organisms could adapt to higher perchlorate concentrations when repeatedly incubated with increasing amounts of perchlorate. Notably, the halotolerant yeast *D. hansenii* displayed the highest perchlorate tolerance at 2.5 mol/kg NaClO<sub>4</sub> (water activity a<sub>w</sub> = 0.926), although its tolerance to NaCl was even higher at 4.0 mol/kg (a<sub>w</sub> = 0.854) [3]. Proteomic investigations indicated that the chaotropicity of perchlorate (i.e., destabilization of biomacromolecules) likely contributed to *D. hansenii*'s decreased tolerance towards NaClO<sub>4</sub> compared to NaCl [4]. In response to the chaotropic stress, *D. hansenii* stabilized proteins through increased glycosylation and upregulated the biosynthesis and remodulation of the cell wall. Analyses of perchlorate-induced changes in the proteome of other investigated organisms are ongoing, with preliminary results showing only a limited overlap with the perchlorate-specific stress responses observed in *D. hansenii*. However, for both prokaryotes investigated thus far (*E. coli* and *H. volcanii*), the *de novo* inosine monophosphate (IMP) biosynthesis and purine metabolism appeared to play a crucial role in the metabolic perchlorate defense machinery, suggesting an increased requirement for nucleotide repair and stabilization. This might be due to chaotropic and oxidative stress resulting from perchlorate exposure.

The surprisingly high perchlorate tolerances of organisms like *D. hansenii* and the ability of various organisms to adapt to elevated perchlorate concentrations demonstrate that perchlorate in liquid solutions under ambient temperature is not as detrimental to life as often assumed.

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**Poster session / 20**

## Visual localization and 3D reconstruction as complement for astrobiological in-situ investigations

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Research in the field of astrobiology requires the study of geological and biological features in harsh environments, such as arid, cave or volcanic environments as analogs for Mars and Venus. Evaluation of in-situ measurements and laboratory analysis of samples are important for life detection and habitability characterization, but are limited if context information such as spatial relations are unavailable. Therefore, sampled data needs to be precisely localized in space and time, and to be prepared appropriately for further analysis and evaluation.
On this poster we present our progressing work on context generation for in-situ measurements with two exemplary use cases from our work at Vulcano, Italy. We use the Integrated Positioning System (IPS) as base localization platform, which is a camera-based multi-sensor system dedicated for localization, 3D reconstruction and inspections in unknown terrains. In the first use case, exploration of fumarole fields, we consider a thermal imaging camera that is attached to the IPS demonstrator. Each thermal image is localized in space and time and 3D thermal mapping provides context in the

form of thermal 3D models. In the second use case, investigation of volcanic outcrops, we seek to support in-situ spectroscopy measurements (e.g., Raman spectrometer, LIBS, VNIR reflectance) that function independently from IPS. We place optical markers to identify areas of interest and provide context in the form of their global position and detailed RGB 3D models.
With this poster we intend to motivate the use of such systems as complement for astrobiological in-situ investigations by discussing results and impressions from our participation at the Vulcano Summer School 2023. Vulcano, with its wide range of comparatively easy to reach and promising analog sites for Mars and Venus, is an ideal environment to test new methods and instruments in the field. Generally, we seek to support astrobiological, geophysical and planetary in-situ investigations.

**FIELD ANALOGS / 21**

## Unveiling Microbial Communities in Terrestrial Deep Subsurface Environments along a Climate Gradient in Chile

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The terrestrial deep subsurface is a vast and enduring habitat, representing one of Earth's most extensive and consistent ecosystems. Microorganisms thriving within the deep biosphere are pivotal in maintaining the planet's biodiversity and represent analogs for the search for life in extraterrestrial settings. However, our understanding of microbial colonization and persistence in Earth's terrestrial subsurface systems, particularly in igneous rocks like granite, remains limited. Unlike sedimentary rocks that form on the surface, granite systems lack autochthonously produced organics. Given this limitation, it remains unclear whether subsurface communities in granite receive photosynthetically produced carbon through transport along pore space and fractures or in situ-produced chemoautotrophic carbon.
This study aims to characterize a deep regional biosphere in Chile by sampling granite rock cores from three different sites, encompassing a climate gradient spanning from arid conditions in the north to humid conditions in the south. High-throughput DNA sequencing, combined with geochemical and mineralogical analysis of the samples, unveils the biodiversity of the deep biosphere at different depths.
The findings reveal a diverse microbial community in deep granites predominantly composed of organisms belonging to the phyla Proteobacteria, Actinobacteria, and Firmicutes. Several Amplicon Sequence Variants (ASVs) exhibit affiliations with iron cycling and heavy metal tolerant organisms (e.g., Aquabacterium sp., Pseudomonas stutzeri, uncultured Janthinobacterium sp.), indicating a highly specialized subsurface community experiencing significant selective pressure and remaining largely unaffected by ongoing surface processes.
Our study underpins the adaptability and resilience of deep subsurface communities colonizing the nutrient-limited underground. Future metagenomic analyses of our samples will further explore the functional potentials and, unravel how life might persist and adapt in extreme and nutrient-limited subsurface habitats on Earth and beyond. The outcome could enhance our understanding of the habitability of other celestial bodies and help to guide the direction of future astrobiology research.

**FIELD ANALOGS / 22**

## Microbial life in the Barrancas Blancas plain –a harsh mountain desert environment –in a Mars analog region of the high Atacama

# Andes (Chile)

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The Barrancas Blancas Plain (~5000 m a.s.l., 68°39' W, 27°02' S) in the high Atacama Andes of Chile is a unique place that combines the harsh characteristics of the mountain desert environment with the presence of ice-rich permafrost. This place is situated in a Mars analog region and is therefore considered to be a natural laboratory for the study of extremophilic microbes, aiming to understand life on and the potential for life beyond Earth. Due to seasonal changes, temporal lakes are created in this area which give us the opportunity to explore the effect of water on microbial life in a desertic environment. For this reason, we performed a sampling campaign to understand how microbial life can survive and thrive under these extreme conditions and what the role of the temporal lake is in shaping the microbial community. We sampled three transects along a moisture gradient, starting from soil pit 1 (P1) on the shoreline of the lake until P5, ~70 m away with apparent non-water interaction. We used a novel protocol to separate the living community (represented by intracellular DNA) from the dead or past communities (represented by extracellular DNA). Since this study focused on the potentially active microbial community, only the iDNA pool was considered. The results showed a clear separation between the water-affected samples from the reference site and a highly specialized microbial community, mainly composed of Proteobacteria, Gemmatimonadota, Actinobacteria, and Acidobacteria. We found that the 16S rRNA gene copy number and the ATP content have the highest values in the surface samples, particularly the P4 surface sample, at a third of the moisture gradient, which had the peak of activity. The correlation analysis indicated that these two parameters are positively correlated and negatively correlated with moisture. Additionally, co-occurrence network analysis revealed that the community is clustered into two major depth-dependent groups. The surface-related module 3 (M3) matched the ATP signal. Therefore, we expect that those ASVs might be involved in the metabolic functionality of the microbial community in this place. The study indicates that the temporal lake is a hotspot for life in this high-altitude desert, providing insights into how water shapes its specialized microbial community and controls the potential microbial activity.

**MARS** / **23**

# Exploring Past and Present-Day Habitable Environments in the Martian Subsurface

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Today, liquid water is not thermodynamically stable at the surface of Mars due to the low temperature and pressure conditions. However, liquid groundwater may still exist in the Martian subsurface [1, 2].

In this study, we use fully dynamical 3D thermal evolution models [3] to calculate the depth at which favorable conditions for liquid water are present, assuming that a global subsurface cryosphere exists on Mars today.

Some of the most important parameters that affect the depth of liquid water are the spatial variations of crustal thickness and crustal thermal conductivity, since the crust has a lower thermal

conductivity compared to that of the mantle and thickness variations can shift the groundwater table locally closer to the surface. The amount and distribution of heat sources, and the presence of mantle plumes, can introduce additional perturbations to the depth of groundwater. The surface temperature distribution and the presence of salts and clathrate hydrates considerably affect the depth and locations where subsurface liquid water may be stable. Hydrated magnesium (Mg) and calcium (Ca) perchlorate salts, whose presence has been suggested at various locations on Mars [4], may significantly reduce the melting point of water ice. In addition to thick regolith layers, clathrate hydrates, if present in the subsurface, would provide an insulating effect reducing the crustal thermal conductivity at least locally [e.g., 5].

Our results suggest that the Martian subsurface has had, and still has, the potential to enable deep environments with stable liquid groundwater. Combined with the analysis of geomorphological features at the Martian surface such as outflow channels, valley networks, deltas [6], sedimentary deposits [7], hydrated minerals [8], cementation [9], mineral veins containing, e.g., manganese oxides that require water [10], and maps of subsurface water ice [11], our models could deliver valuable estimates of the depth of liquid groundwater on past and present-day Mars providing key knowledge on the planet dynamics, evolution, and astrobiological potential.

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**HABITABILITY / 24**

## The survivability of cyanobacteria on lunar rocks, their relevance for future space travel and possible causes for the changes in their cells

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Cyanobacteria are ubiquitous in the world. They have successfully colonised both land and sea and were the first to oxygenate the atmosphere in what is known as the Great Oxidation Event (GOE) (1). Cyanobacteria are also the only prokaryotes capable of photosynthesis and are considered a pre-evolutionary stage of today's chloroplasts (2). This is predicted on the endosymbiont theory, which postulates that cyanobacteria have been taken up by other organisms and thus become today' s chloroplasts. In recent developments the interest in prokaryotes has increased with regards to space travel since they can be a reliable producer of materials with only minimal resources (3).
Based on the growing interest in prokaryotes we investigated growth behavior of cyanobacteria on moon rocks. Therefore, cyanobacteria were first isolated from the environment around the Heinrich-Heine University (HHU). For this purpose, cultures were taken from different terrestrial surfaces or aquatic habitats and selected for cyanobacteria with antibiotics.
Selected cultures were incubated on the lunar rock simulant EAC-1A. Under the conditions used in this study, cyanobacteria grow on the simulant. Especially the strain *Anabaena PCC 7120* (henceforth called *Anabaena sp.*) grew in medium without nitrogen as well as in medium without nitrogen and iron. These results indicate a benefit of the regolith of *Anabaena sp.* as the control without regolith grew little or not at all. Incubation with the regolith also altered the so-called heterocysts. These showed increased chlorophyll at different time points. Repeats of this experiment under same conditions showed the same results. Possible candidates of minerals in the regolith were tested to find out which one is responsible for the changes of the heterocysts.
Goals of further experiments are investigations if those cells are capable of photosynthesis and nitrogen fixation at the same time.
Acknowledgments:
I would like to thank Prof. Axmann to be able to do my PhD thesis at her institute. Also, I would

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**MARS / 25**

## Influence of (per)chlorate salts and regolith depth on the survival of microorganisms in simulated Mars-like conditions

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Liquid water, an essential compound for life on Earth, is not stable on the Martian surface, but the presence of hygroscopic salts like chlorates and perchlorates in the regolith could enable the formation of, at least temporarily, stable liquid brines[1]. In the near-subsurface, a thin regolith layer could prevent water sublimation, thus extending the lifetime of the brine [2]. Regolith layers can also shield microbes from harmful UV radiation, creating possibly favorable habitats for potential microbial life in the shallow subsurface. Our study aimed to understand how microbial survival in Mars-like conditions is influenced by (per)chlorate salts, water scarcity, UV irradiation, and regolith thickness. To achieve this, we conducted simulations using the Mars Environmental Simulation Chamber (MESCH) described by Jensen et al. (2008) [3]. The model organisms used in our experiments were *Debaryomyces hansenii* (a halotolerant yeast), *Planococcus halocryophilus* (a halotolerant and psychrophilic bacterium), and *Aspergillus niger* (a fungal spore former). Vegetative cells of *D. hansenii* and *P. halocryophilus*, as well as spores of *A. niger*, were suspended in their respective growth mediums with or without sodium (per)chlorate. Subsequently, 3 grams of the cell culture or spore solution, containing either 0.5 mol/kg $NaClO_4$, 0.5 mol/kg $NaClO_3$, or no additional salt, were inoculated into 30 grams of MGS-1 Mars Global Simulant and then placed in glass tubes with a depth of 15 cm. These glass tubes were transferred to the MESCH and exposed to simulated Mars-like conditions (constant temperatures of about -10 °C,6 mbar $CO_2$ atmosphere, and 2 hours of daily UV irradiation at 200-250 nm). Before and after exposure periods of three and seven days, the number of colony forming units (CFU) per gram of inoculated regolith and the water content at different regolith depths (0-0.5 cm, 1-3 cm, and 10-12 cm) were measured. CFUs were normalized to dry weight by subtracting the determined water content, allowing us to calculate the survival rates of the microorganisms. The low pressure conditions led to water evaporation from the top layers of the regolith. However, moisture was retained in the regolith at depths of 5 cm and below, with a residual water content of up to 95% (SD=15%) at 10-12 cm. This resulted in the crystallization of water ice at a depth of 10-12 cm, creating concentrated brines in samples containing sodium chlorate and sodium perchlorate, resembling potential brine conditions in the shallow subsurface of Mars. Interestingly, the survival rates of the three tested organisms were significantly higher in the $NaClO_3$ sample compared to the $NaClO_4$ sample. For instance, at a depth of 10-12 cm, *P. halocryophilus* displayed a survival rate of 95% (SD=13%) in the $NaClO_3$ sample, while no survival was observed in the $NaClO_4$ sample at 10-12 cm depth. These higher survival rates in chlorate salts underscore their critical role in the habitability of the Martian near-surface environment. Additionally, the regolith demonstrated its ability to shield against UV irradiation. The survival rates at 0-0.5 cm were at least 10% lower for all tested organisms than those at 1-3 and 10-12 cm.

**Poster session / 26**

## Integrating Textured 3D Models from Drone Images into Virtual Reality for Planetary Analog Training: A Case Study from the

## 2023 Vulcano Summer School

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In planetary exploration and analog studies, the fusion of diverse datasets and collaborative research outcomes from multidisciplinary teams presents an exciting yet complex challenge. This abstract outlines an approach to address this challenge, as demonstrated during the 2023 Vulcano Summer School on Vulcano Island, Italy. Vulcano Island's unique geological setting, characterized by an active volcano and extreme environments due to fumarolic activity, offers a compelling environment for researchers of different fields working on planetary analog studies [1,2]. During the Vulcano summer school, researchers from geology, geoinformatics, robotics, oceanography, and astrobiology conduct scientific experiments, test new technical equipment and procedures, and provide training for students and early career researchers [3].

Due to the interdisciplinary focus of the summer school's research teams, the associated research data generated during the field campaigns exhibit a remarkable degree of heterogeneity, reflecting the diverse research cultures and methodologies inherent to the respective research fields. Our focus lies in seamlessly integrating information from these diverse domains through generating and utilizing textured 3D models, subsequently incorporated into a virtual reality (VR) framework for planetary analog training. To that end, we performed drone flights in several locations where researchers conducted field experiments and employed open-source software [4] to create high-resolution data products such as orthophotos, digital surface models, and textured 3D models. In order to ensure consistent accuracy in the spatial representation of our data products, we measured ground control points using a differential GPS for accurate georeferencing.

Integrating textured models into a VR environment establishes a basis for immersive planetary analog training and opens doors to numerous applications that cover training, education, and outreach initiatives. It provides an interactive platform for users to engage with Vulcano Island's landscape and planetary analogs while synergizing diverse scientific findings that are connected to the Vulcano Summer School. We plan to further assess the potential in fostering collaboration, advancing knowledge transfer, and cultivating advanced research data management during the following field trips to Vulcano Island and the Summer School's collaborative efforts. To that end, our next steps involve developing precise use case scenarios based on the research projects working on Vulcano, eventually working towards a more advanced VR integration that leverages the full potential of this approach.

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**BIOSIGNATURES / 27**

## Mass Spectral Features of Enceladus'Organic Enriched Ice Grains: Plume Vs E ring

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Ocean worlds in the outer Solar System are prime targets for the search of life beyond Earth [1]. So far, Enceladus is the only extraterrestrial ocean world whose subsurface material was sampled by the Cassini spacecraft. Enceladus throws its subsurface material into space in the form of ice grains and gas from the moon's south polar region. Most of the ice grains fall back onto the surface and only a fraction of these grains leaves the moon's gravity and become a part of Saturn's E ring [2]. During it's entire mission, Cassini's Cosmic Dust Analyzer (CDA, [3]) frequently sampled ice grains in Enceladus'plume and Saturn's E ring. The detection of nanophase silica (SiO2; [4]) particles indicated hydrothermal activity at the sea floor, which further increased astrobiological potential of Enceladus.

Previous analyses of ice grains revealed a variety of organic species in E ring ice grains, which led to the discovery of complex (mass > 200 u) and simple (mass < 100 u) organic compounds [5,6]. This indicated rich organic chemistry in Enceladus's subsurface ocean e.g., Friedel Crafts and serpentinization reactions. The Cassini's flybys of Enceladus plume on the other hand provided an opportunity for CDA to sample freshly ejected subsurface oceanic material, particularly organic compounds. Here, we try a detailed compositional analysis of organic material in ice grains measured directly in the plume by CDA soon after they are ejected from the moon's South Pole during the flyby-E5 in 2008. Previously, CDA time of flight (ToF) mass spectra of these grains have only been assigned as Type 2 "the spectra of organic enriched ice grains", without a detailed compositional investigation of the organic species [7]. The spectra of these freshly emitted grains were recorded at fluxes of up to 5 s-1 at flyby speed 17.7 km/s, albeit with reduced mass resolutions and mostly ranges (2-120 u).

At this high speed, organic molecules in ice grains fragment more when impacting CDA's target, providing new insights of their molecular structures in comparison to previously sampled and analysed Type 2 spectra in E ring. Our results confirm the presence of aromatic and O-bearing species in the ice grains that were previously sampled in the E ring [5,6]. In addition, spectra of these freshly ejected organic-bearing grains also exhibit certain spectral features, which were not observed in the lower impact speed spectra of E ring ice grains.

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**HABITABILITY / 28**

## To move or not to move: The thermal and dynamic state of Europa's ice shell

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Europa's hydro- and cryosphere is of primary interest in the quest for habitable environments in the solar system (e.g., Coustenis & Encrenaz et al., 2013). The ice shell, which connects the potential subsurface ocean to the surface, may itself provide niches for life if liquid brine pockets can form and exist for extended periods of time. It is thus crucial to understand the dynamics of the ice shell in order to characterize transport of liquid brines within the ice shell or between ocean and surface. Recent work by Carnahan et al. 2021 and Harel et al. 2020 investigated the effects of temperature dependent thermal conductivity (k) as well as heat capacity (cp) and a complex composite rheology on convection in the ice shell. In this work, we build upon these previous efforts by combining the influence of both - varying thermodynamic parameters and complex rheology - in geodynamic simulations performed with the convection code GAIA (Hüttig et al., 2013). Instead of a temperature-dependent heat capacity, we investigate the effect of a temperature- and depth-dependent thermal expansivity (α), which is a crucial term in determining the buoyancy induced by temperature differences. We study the dynamic state (Nu-Ra scaling), the mechanical state (elastic thickness, deformation maps), and the thermal state (bottom and top boundary heat flux) of the ice shell for various setups (using both constant and variable α and k) and input parameters (ice shell thickness and grain size). Future steps will include the calculation of radargrams (cf. Kalousova et al. 2017) and gravity anomalies (cf. Mazarico et al., 2023) from our modeled thermal and dynamic states of the ice shell. Both quantities will be measured by the upcoming JUICE and Europa Clipper mission and provide a unique opportunity to align models with observations.

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**HABITABILITY / 29**

## A focus on the physiological adaptations of the brine shrimp A. salina exposed to space simulated parameters: a new model for astrobiological studies.

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Astrobiological studies are fundamental to understanding how extraterrestrial environments might alter the survivability of complex biological systems. An optimal biological model for space research would need to lower its metabolic rate, possess enhanced defenses against the space environment, and be able to survive prolonged periods of space flight [1]. The crustacean Artemia salina has interesting characteristics for space applications because in instances of adverse developmental circumstances, it generates cysts capable of entering cryptobiosis, possibly enabling it to endure even the harsh conditions prevalent on other planets like Mars. The aim of my research was to conduct preliminary experiments on physiological responses of nauplii (larval forms) of A.salina hatched after 72h of cysts'exposure to low atmospheric pressures that reproduce those of the Martian surface, by using a Mars simulator located at Parthenope University of Naples. After determining the hatching percentage, in vivo respiration was performed polarographically to obtain information on the whole metabolism of the larval forms. Subsequently, in vitro respiration was performed on nauplii homogenates using succinate and a mixture of pyruvate plus malate as electron transport chain-related substrates, in the absence and presence of ADP, to obtain information on mitochondrial functionality. ROS content [2], total antioxidant capacity [3], oxidative damage to lipids (HPs) and proteins (CO) [2], in vitro susceptibility to oxidants [4], lactate content [5], NADPH oxidase (NOX) activity [6] and mitochondrial complexes activity [4] were also performed. Low pressure exposure induced a significant increase in hatching rate and in vivo respiration, to which the increased NOX activity seems to contribute. This result suggests an improvement of the protective mechanisms of larvae exposed to low pressure, as suggested by the increased NOX activity of hemocytes in metamorphic transitions of larvae exposed to external stimuli [7]. Instead, mitochondrial respiration appears not to contribute to the increased in vivo respiration as suggested by the reduction during both basal and ADP-stimulated respiration, which may be explained by reduced Complex I activity of the mitochondrial respiratory chain. Moreover, the reduced lactate content also highlighted a decreased anaerobic pathway after low-pressure exposure. The reduced aerobic pathway can be responsible for reduced ROS content that parallels the reduced HPs level. Since ROS are regulators of antioxidant defense system, the enhanced susceptibility to oxidants observed after low-pressure exposure could be explained by the reduced ROS content. In conclusion, one hour of low-pressure exposure affects A.salina nauplii metabolism by inducing adaptations that are compatible with its survival, thus suggesting that it is suitable for further astrobiological studies.

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**BIOSIGNATURES / 30**

## Laboratory Experiments on Earth and Detection of Organics by Cassini

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Observations of Enceladus have shown water jets expelling from the surface. These jets originate from a subsurface ocean and formed Saturn's E-ring. Further observations of the plumes have led to the consensus that Enceladus likely holds a porous chondritic mineralogy, hydrothermal environments, and several building blocks necessary for the formation of life (e.g., HCN, NH3, CO2). Numerous research has documented the viability of synthesizing organic material in chondritic hydrothermal systems, which has given credence to life forming on chondritic ocean worlds. On Enceladus, a freezing phase is likely to occur during cycling at an overlying icy shell interface. As demonstrated by Miyakawa et al. (2002), this freezing phase is equally valuable in forming organic material. Aromatic hydrocarbon structures and amines have been investigated within Enceladean ice grains. However, no previous experiment has attempted to explain these organics or how a hydrothermal freeze cycle could affect chemical evolution and variety. Furthermore, previous experiments neglected abundant concentrations of phosphate (1-20 mM) which were recently calculated from geochemical modeling and surveying Type III (salt-rich) ice grains. Our research aims to simulate possible geochemical cycling scenarios within Enceladus and to identify organic compounds and processes that could exist within its ocean by laboratory analog experiments. We also plan to determine the role of phosphate in this organic synthesis.
We subjected mixtures similar in compositions revealed by Cassini to several temperature ranges, pH ranges, and maximum pressures thought to exist within Enceladus within a Au/Ti pressure vessel. During heating, sampling was taken in 24-hour intervals and stored at 4 °C until analysis. Afterwards, samples were frozen in temperatures and time periods ranging from -20 to -40 °C and 2 days to ≥8 weeks respectively. Cycling continued until neglectful sample amounts were left. Analysis was conducted through HPLC, UPLC, H1-NMR, P31-NMR, IC, and LILBID-MS.
Preliminary results showed a temperature-dependent darkening of solution and the formation of a wide array of amino acids (notably serine, histidine, glycine and alanine) and other organic compounds aligning with predicted pathways. HPLC indicated potential Strecker-cyanohydrin synthesis during long-term freeze phases from the formation of glycine and a peak that aligned with Histidine' s standard. Phosphate concentration and identity stayed consistent through all reactions. Thus, detection of phosphorus in a from other than orthophosphate or phosphite may be indicative of biological activity. LILBID-MS confirmed the detection of most HPLC amino acids (glycine, alanine, aspartate, and serine); however, some results were heavily impacted by Na+ and K+ concentrations. Additionally, some laboratory LILBID organic peaks aligned cautiously well with Type II (organic rich) spectra peaks from Cassini, yet Cassini's spectra could also be due to fragmentation of benzene or other carbon molecules. In future studies, we plan to incorporate a mineral phase consisting of chondrite relevant material and modify starting reactant concentrations to minimize the effects of positive salt ions on organic detection.

**FIELD ANALOGS / 31**

## Field campaigns to analyse spectral characterisation of various volcanic material in NIR range; preparation for EnVision and VERITAS

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One of the main objectives of the ESA EnVision and NASA VERITAS missions is to understand the evolution of Venus by characterizing the composition and origin of its major geological terrains. The best Venus' dataset comes from the VIRTIS instrument on-board Venus Express, which used a near-infrared sensor [1,2,3], because the dense CO2 atmosphere of Venus only allows observations

in narrow spectral windows around 1µm. It mapped the Venusian surface through atmospheric windows at 1.02, 1.10 and 1.18µm [4,5]. Although VIRTIS was not designed for this task, it provided new insights into Venus'evolution and history, such as the discovery of recent volcanic activity [6]. The Venus Emissivity Mapper (VEM) [8] will observe the surface of Venus through a broader wavelength range with five atmospheric windows including six bands. These will allow the spectral characteristics of the Venusian surface, as well as the type of lava and likely alteration processes. To prepare for these missions and deepen our understanding of the emissivity spectral characterisation of various volcanic rocks, we plan several field campaigns using in-situ measurements that emulate VEM and bring samples back for emissivity measurements at the Planetary Spectroscopy Laboratory of DLR-Berlin.

Vulcano in southern Italy: Field work in this area was planned as part of the Vulcano summer school [9] in 2022. Tectonically-controlled magmatic activity is the source of lava for Aeolian Islands and their alignment [10]. Vulcano rocks display diverse compositions from basalt to rhyolite, making this site an attractive analogue to Venus. The island also shows a strong fumarolic activity with very high temperatures. Our main goal was to characterize the spectra from the fresh and old volcanic rocks with different compositions using the spectral range of the VenSpec-M and VEM. See [11] for more information on this campaign.

Iceland: Reykjanes peninsula in Iceland with its very recent eruptions from the Fagradalsfjall volcano, is a prime analogue to Venus. The extended presence of recently erupted lava fields (2021, 2022, and 2023), with various textures (from aa to pahoehoe), as well as the local presence of fumaroles within the lava fields, constitute a prime analogue site. In August 2023, DLR and JPL plan an airborne radar data collection campaign over the Reykjanes peninsula accompanied by a field work. Our goal is to collect in situ spectral measurements and relevant samples for characterisation in the Venus Emissivity chamber of the PSL at DLR-Berlin. See [12] for more information and the prepared remote sensing project.

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