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Talks Session 6

16:00 – 16:40

KEYNOTE

Life in Extreme Environments: From Rio Tinto to the Ocean of Enceladus

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Life exists almost anywhere on Earth that liquid water is present. What can extremophiles teach us about the potential for life in habitable. but still challenging environments such as the ocean of Enceladus and possible hypersaline pockets in Europa? And what about those methane seas on Titan—how can one approach the question of their habitability

16:40 – 17:00, 1.9.2022

7

Getting closer to solar flares and coronal mass ejections

Harra L[1]
[1]Pmod/wrc & Ethz

Solar flares and coronal mass ejections are currently studied in exceptional detail with new spacecraft launched in the past 4 years which add to the existing fleet. These spacecraft get close to the Sun, and provide an exceptionally detailed view of all scales of activity on the Sun - from the formation of the solar wind to the trigger of large scale flares.

These observations of solar flares and coronal mass ejections allow us to probe what happens to create the environment that surrounds planets, and is a major influence on whether there can be life on other planets. We will summarise the latest developments in the understanding of solar activity, and the future developments that we expect in the coming years with the new missions.

8:45 – 9:05, 2.9.2022

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Heating planetary bodies with tidal interactions

Bagheri A, Khan A, Efroimsky M, Samuel H, Deschamps F, Giardini D
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Tidal evolution is playing a critical role in the development of the architecture of the solar and extra-solar systems. On the one hand, tides add a lot to the n-body interactions in these systems. On the other hand, tidal heating contributes greatly to the thermal processes and internal evolution of planets. Among the numerous examples of the working of tides in the solar system are: (1) the Martian moons Phobos and Deimos, which are migrating towards and away from its host planet, respectively; (2) the Jovian moon Europa with its subsurface liquid ocean; (3) the Saturnian moon Enceladus renowned for its water-rich plumes venting into space. Inarguably, tides and tidal heating are playing a major role in determining planetary habitability. Modeling tidal evolution of orbits and interiors thus becomes a key to our understanding the evolution and current state of planetary systems. We developed a tidal model applicable to describing highly eccentric orbits and higher-order spin-orbit resonances. The tidal model is combined with self-consistently built interior structure models, and is used to explore evolution of both rocky and icy planets and moons. We emphasize on the necessity of taking into account appropriate combined tidal and thermal evolution modeling for constraining the interior properties, and exterior architecture of the planetary systems. Our model has been employed to study, e.g., the orbital evolution of the Martian moons, the Pluto-Charon binary, exoplanet TRAPPIST-1e, and
the dwarf planet Gonggong. We show that the use of this tidal model is essential to obtain precise results. Specifically, we study the importance of the tidal heating in formation and maintaining the subsurface liquid oceans that can be potentially habitable.

9:05 – 9:25

21

Enabling the search for life in our solar system with 3D microscopy techniques

Serabyn E[1], Lindensmith C[1], Wallace K[1], Liewer K[1], Kim T[1], Oborny N[1], Nadeau J[2]
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The existence of life beyond the Earth can be investigated either spectroscopically, on exoplanets around nearby stars, or in situ, by sending probes to our own solar system's planets, moons and asteroids. In the latter case, in situ microscopic imaging of potential microbes is a promising possibility. Potential environments can range from ices and liquid water on outer solar system moons and asteroids, to shielded regolith and caves on Mars, to aerosols in the clouds of Venus. We will describe 3D microscopy techniques applicable to a variety of environments, including digital holographic microscopy and light-field fluorescence microscopy, that we have been developing to enable the search for cellular life in its native environment on such worlds. Our microscope systems have already been successfully deployed to a number of remote terrestrial sites.

9:25 - 9:45

48

Towards In Situ Amino Acid and Lipid Detection on Ocean Worlds using Laser Desorption Ionisation Mass Spectrometry

Boeren N[1,2], Ligterink N[1], Kipfer K[1], de Koning C[1], Keresztes Schmidt P[1], Gruchola S[1], Tulej M[1], Wurz P[1,2], Riedo A[1,2]

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The search for and detection of extinct or extant life outside of Earth is a major topic in space sciences. Finding signs of life on extraterrestrial Solar System Bodies could give us important clues of how life could form. Detection of signatures of life, so-called biosignatures, is therefore necessary, but remains a highly challenging task. Instrumentation should be flight-capable, posing several restrictions on weight, dimensions, and power usage. Detection capability should also not be limited to only one compound or group, but should be more broadly applicable to several groups of compounds that are relevant for life. High sensitivity is required as well to detect trace abundances.

Ocean Worlds, such as Europa and Enceladus, are highly interesting to search for signs of life, since all ingredients to form life (as we know it) are present [1]. Plumes, that spray out through cracks in the ice shells, could contain biosignatures, making in direct sampling of the ocean underneath possible. Several groups of compounds are listed as potential targets in the search for life, including amino acids and lipids. Amino acids are the building blocks of proteins, while lipids are involved in cell structure and function. Both are essential compound groups for life as we know it. Detection and identification of both groups is therefore of interest for future space exploration missions in the search for signs of life.

ORIGIN, standing for ORganics Information Gathering INstrument, is a novel prototype laser desorption mass spectrometer (LDMS) and has been designed for in situ space exploration missions [2]. The design is compact and robust and complies with the requirements for space instrumentation. The current setup consists of a nanosecond pulsed laser system and a miniature reflectron-type time-of-flight mass analyser (160 mm x Ø 60 mm) [3]. Sample material is desorbed and ionised and generated cations are separated in the mass analyser based on their mass-to-charge ratio (TOF principle), resulting in a single mass spectrum for each laser pulse.

Measurements of amino acid and lipid standards were performed to assess the capabilities of ORIGIN [2,4]. Standard measurement protocols were established and subsequently used in studies conducted to investigate sensitivity and limit of detection, optimal conditions for laser desorption, and influence of the sample holder substrate. In our contribution, we will discuss the setup, measurement procedures, and present and discuss our latest findings using the ORIGIN prototype. The implications of our results will be discussed with focus on the suitability of the presented technique for future space missions to Ocean Worlds in the search for signs of life.

References:

[1] Lunine J.I. (2017) Acta Astronaut., 131, 123-130.
[2] Ligterink N.F.W. et al. (2020) Sci. Rep., 10, 9641.
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[4] Boeren N.J. et al. (2022) to be submitted.

10:15 – 10:35

24

Microbial Mat Hosted Gypsum from a Sabkha in Qatar: Raman microscopy and microbial community analysis

Dittrich M[1], Diloreto Z[1], Shaharyar Ahmad M[1], Bontognali T[2], Al Saad Al-Kuwari H[3], Sadooni F[3]
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The sabkha environments of Qatar represent a unique opportunity to gain insight into the production and preservation of halophilic biomarkers similar to those that might have occurred on Mars. Sabkhas may be analogous to past evaporitic surfaces of Mars due to their arid location with elevated concentrations of salt, and increased insolation by low-wavelength radiation. Furthermore, sabkhas in Qatar host extensive assemblages of evaporitic minerals, including gypsum in close association with abundant and diverse hypersaline microbial communities.

Evaporitic minerals act as a refuge for extremophilic microorganisms in the extreme environments. Gypsum can offer protection against desiccation, rapid temperature fluctuations, and exposure to UV-radiation, while still allowing the penetration of electromagnetic radiation. On the other hand, gypsum could be a very effective medium for the preservation of biomarkers. Given the elevated levels of UV-radiation on the Martian surface, it is reasonable to postulate that surviving microorganisms would have produced UV-shielding pigments as a major component of their survival strategy. One such pigment of consideration is β-carotene due to its ability to repair damaged DNA and absorb UV-C radiation.

The aim of our work is to better understand the interactions of biomarkers, e. g., pigments that may be preserved within a gypsum matrix and to evaluate a potential of Raman microscopy to detect the biomarkers in gypsum crystals from extreme environment. To better understand the interactions of pigments or other biomarkers encapsulated in a gypsum matrix, sediment cores samples of buried microbial mats and gypsum from the Dohat Faishakh sabkha in Qatar were collected. These samples were evaluated using a combination of microbial DNA analyses to determine organisms present and their aptitude for producing biomarkers, as well as Raman spectroscopy to analyze biomarkers trapped within the gypsum mineral matrix. This study showed that organic material produced by in these environments is encapsulated within gypsum and able to be detected using standard Raman spectroscopic methods with little sample preparation.

10:35 – 10:55

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Implications for Early Earths and Biospheres from Studies of Subglacial Lakes in the Land of Fire and Ice

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"Extreme" environments provide intellectual inspiration and some ``ground truth" for discussions of conditions and events involved in the emergence and early evolution of a biospheres on Earth and other habitable worlds. Among the factors often considered in such discussions are the availability of chemical energy sources prior to an origin of phototrophy, and emerging feedbacks between biologically-mediated geochemical cycles in a nascent biosphere and climate. Ice-covered lakes are a subset of extreme environments that can offer insight into an ice-covered Earth under a fainter young Sun (and "snowball Earth" episodes) as well as ice-covered oceans in some satellites of giant planets. In Iceland, volcanic heat maintains several subglacial lakes under the Vatnajokull ice cap. These lakes are completely isolated from sunlight and mostly (but not completely) isolated from the atmosphere. Our exploration of these lakes over the past two decades has shown them to be near the freezing point, anoxic, and highly sulfidic, with chemistries that resemble hydrothermal fluids diluted by glacial melt. Moreover, we have detected and described an active microbial biome that is endemic to the lakes and unlike anything described in natural environments elsewhere. Unsurprisingly, we find that that taxa in this biome are related to organisms with established metabolisms able to use the sources of chemical energy in the lake water column, i.e. carbon dioxide, hydrogen, sulfur and (probably) the minor amount of oxygen released into the lake by melting glacial ice. More interesting is the structure of the community, which is dominated by only a few taxa, all bacteria. Unexpectedly, the dominant lithoautotrophic metabolism involving carbon dioxide and hydrogen is not methanogenesis, but acetogenesis. One of the dominant taxa in these lakes is not only capable of acetogenesis as an energy source, but uses this as a source of fixed carbon and is capable of nitrogen fixation as well. Even more surprising is the apparent absence of members of the Archaea, including all known lithotrophic methanogens, i.e. non-detection by multiple methods including metagenomics. The absence of methanogens and the dominance of acetogens (a situation hitherto undescribed outside of termite guts) could be related to specific environmental conditions, i.e. low temperatures and high hydrogen activity. The complete absence of archaea is much more mysterious, and (speculatively) may be related to high energy levels, or insolubility and unavailability of metal cofactors such as Fe in the presence of high sulfide. The enzymes involved in methanogensis and acetogensis appear to be ancient and evolutionarily related. Methane is an important greenhouse gas and a popular biosignature, while acetate would be highly soluble in oceans. On biospheres where conditions favor acetogenesis, such attributes would be absent, with implications for the climate and detection of life elsewhere.

10:55 – 11:15

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Metabolic signatures and biomass limits of an aerial biosphere in the clouds of Venus

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[1]Institute Of Astronomy, University of Cambridge, [2]Department of Earth Sciences, University of Cambridge, [3]Cavendish Laboratory, University of Cambridge, [4]MRC Laboratory of Molecular Biology

Life in the clouds of Venus, if present in sufficiently high abundance, must be affecting the atmospheric chemistry. It has been proposed that abundant Venusian life could obtain energy from its environment using three possible sulfur energy-metabolisms. These metabolisms raise the possibility of Venus's enigmatic cloud-layer SO2-depletion being caused by life. We couple each proposed energy-metabolism to a photochemical-kinetics code and self-consistently predict the composition of Venus's atmosphere under the scenario that life produces the observed SO2-depletion. Using this photo-bio-chemical kinetics code, we show that all three metabolisms can produce SO2-depletions, but do so by violating other observational constraints on Venus's atmospheric chemistry. This therefore enables us to place an upper limit on the maximum allowed biomass in Venus's clouds before the effect of life's energy-metabolism violates observational constraints on the atmospheric chemistry. We calculate the maximum possible biomass density of sulfur-metabolising life in the clouds to be 10^{-5} - 10^{-3} mg m^{-3}, under the assumption that cell maintenance power requirements are high in the extreme environment of Venus's acid cloud layer, compared to cell power requirements of life on Earth. The methods employed are equally applicable to predicting chemical signatures of aerial biospheres on Venus-like exoplanets, planets that are optimally poised for atmospheric characterisation in the near future.

Posters Session 6

9

Introducing the Cosmic Origins Of Life (COOL) model: a multi-scale, multi-physics framework for the emergence and survival of life in a hostile Universe

Kruijssen D[1], Longmore S[2]
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Our existence is arguably the biggest multi-scale astrophysics problem. Not only does it require a comprehensive understanding of the astrophysical processes enabling the emergence of life, but also of the processes that could end it. A comprehensive answer to the problem requires linking galaxy formation and evolution, star formation, stellar feedback, and the formation and evolution of planetary systems. We will present a unified "cosmic planet population synthesis" modelling framework named Cosmic Origins Of Life (COOL), which combines prescriptions for all of these processes to self-consistently predict the emergence and persistence of habitable planets and Earth-like life across cosmic history. COOL connects state-of-the-art models for the formation of galaxies, stellar clusters, stars, and their planetary systems, accounting for the multi-scale, multi-physics environmental dependences between these. In addition, it accounts for a wide range of cosmic hazards, including the external photoevaporation and dynamical disruption of protoplanetary discs by nearby stars, dynamical perturbations of planetary systems by stellar encounters, the impact of supernova explosions and GRBs on planets, and asteroids showers, including their dependences on the evolving galactic environment. By self-consistently following stars and planets as they form and evolve within the galactic environment, the model determines the occurrence rate, proximity and magnitude of these hazards for each planetary system. Using this model, we will show which astrophysical threats are the most likely to impact both the solar system and planetary systems in general, as a function of their stellar mass, age, chemical composition, and location. These insights help to answer if we live in the most fertile, benign, and suitable galactic environment and stellar system compared to other galaxies and host stars.

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Exploring the role of extremophiles for the formation of Mg-rich carbonate minerals

Al Disi Z[1], Zouari N[1], Dittrich M[1,2], McKenzie J[3], Al-Kuwari H[1], Bontognali T[1,4,5]
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Mg-rich carbonate minerals, (e.g., dolomite - (Ca,MgCO3) are a common constituent of ancient sedimentary sequences. Studies conducted in the field of geobiology have shown that microbial activity promote the formation of Mg-rich carbonates at low temperature, which implies that some occurrences of such minerals in the geological record may represent a biosignature. This hypothesis is of great interest in the field of research studying the evolution of early life on Earth and for the search of life on other planets. Indeed, dolomite often occurs in Archean rocks in association with putative microbially induced sedimentary structures, and Mg-rich carbonates that likely formed at low temperature have been identified by orbital spectral analysis on Mars (e.g., Marginal Carbonates at Jezero Crater). Here, we present the results of laboratory precipitation experiments that have been conducted with extremophilic microbes isolated from the sabkhas (i.e., salt flats) of Qatar. Specifically, we tested how the presence of cells and extracellular polymeric substances (EPS) with specific functional groups influence the mol% Mg of carbonate minerals that form through evaporation of seawater. We show that high Mg calcite with a mol% of Mg of 45 ± 1.2 precipitates in the presence of EPS or bacterial cells. Instead, a mol% of maximum 35 ± 1.8 was detected in parallel control experiments conducted under identical conditions but in the absence of organic molecules. These results provide insight that allows for better linking Mg-rich carbonates and extremophilic microbes.

Keywords: Bacterial cells, EPS, Functional groups, Protodolomite.

901

Microbial sulfur cycling in lacustrine sediments from a mid-Proterozoic Ocean analogue

Paula Rodriguez[1], Jasmine Berg[2], Longhui Deng[2], Hendrik Vogel[3], Mark A. Lever[2] , Cara Magnabosco[1]

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Lake Cadagno (Ticino, Switzerland) is one of the few sulfidic, meromictic lakes in Europe and is frequently cited as an analogue to the Proterozoic ocean. The water column of the lake contains ~ 2 mM of dissolved sulfate, a concentration 10 times higher than most freshwater basins. However, since the lake's formation following deglaciation, the bottom layer of the water column has undergone redox transitions from oxic, to periodically anoxic, to euxinic. These redox transitions are reflected in the sedimentary record of the lake. Thus, Lake Cadagno sediment constitute an ideal natural setting to study the co-evolution of sediment geochemistry in the subsurface with its associated biosphere. Here, we investigated the potential role of microorganisms in biological sulfur cycling on a 13.5 kyr sediment succession from Lake Cadagno. We sequenced the dissimilatory sulfite reductase beta subunit gene (dsrB) from sediment samples encompassing the last 10 kyr of sediment deposition and found that microorganisms from the class Deltaproteobacteria dominate the organic matter-rich surface sediments above the sulfate-depletion zone. Reconstruction of Deltaproteobacteria genomes from surface sediment metagenomes identified the complete set of genes to perform canonical dissimilatory sulfate reduction (DSR). In contrast, in mid-column, sulfate-poor sediments, 44% to 98% of the dsrB gene sequences belong to representatives from Dehalococcoidia and Anaerolineae, from the phylum Choloroflexi. Together, these results indicate that active sulfur cycling is occurring in surface and deep lacustrine sediments, although the biochemical mechanisms are still unclear. Further genome-resolved analyses will provide new insights into the role of microbial populations in the biogeochemical sulfur cycling in Lake Cadagno.

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Size-dependent cataclastic hydrogen gas production

Andrew Acciardo [1], Claudio Madonna[1], Cara Magnabosco[1]

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Over 70% of Earth's prokaryotes live in the subsurface. These microorganisms can utilize various electron donors. The simplest of these electron donors is molecular hydrogen, which is thought to have been used by primitive life forms during the earliest stages of life on Earth. In the subsurface, hydrogen can be generated through a variety of water-rock reactions including radiolysis, serpentinization and cataclasis. Cataclastic hydrogen production occurs via a mechanoradical reaction between water and silicate rocks that have been crushed or fractured. To understand the influence of grain size in the mechanoradical production of hydrogen and to calculate an estimate for global cataclastic hydrogen production on Earth, we carried out a series of water-rock reactions with varying sizes of granite rock grains. Grain size distributions of rocks have been shown to decrease as a result of seismic activity, a process which is thought to play a role in earthquake instability. Thus, it is important understand how these size distributions control the level of hydrogen produced and consequently the fates of the microbial communities living within the rocks. Samples of Rotondo granite from a borehole drilled in the Bedretto tunnel in Ticino, Switzerland were hydraulically crushed, milled, and vacuum-sieved into three size-fractions. After initiating the reaction in anoxic glass vials, the headspace was tested to determine hydrogen gas concentration using gas chromatography. After twenty hours of incubation, the 45-63 μm, 90-106 μm, and 125-150 μm size fractions showed net hydrogen production of 142.34±31.34, 103.62±16.75, and 16.93±1.78 nmol g-1 rock, respectively. Control samples with either no rock or no water showed only trace levels of hydrogen. Additional experiments using different lithologies and types of water are also being performed and will help illuminate the influence of mechanoradical hydrogen production for life on Earth as well as potential life on planets and moons in our solar system and beyond.

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CLUPI/ExoMars, The Search for Past Life on Mars

Jean-Luc Josset[1] and the CLUPI Science Team

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The main goal of the ExoMars rover mission is the search of life on Mars. The Mission was planned to be launched in September 2022 before to be postponed (in 2028 ?) due to the suspension of collaboration with Russia.

The scientific objectives of the ESA ExoMars rover mission are to search for traces of past or present life and to characterise the near-sub surface. Both objectives require study of the rock/regolith materials in terms of structure, textures, mineralogy, and elemental and organic composition. The key point of the ExoMars rover is the capability to drill the surface of Mars up to 2m under the surface and to collect samples to be in-situ analysed.

The ExoMars rover payload consists of a suite of complementary instruments designed to reach these objectives.

CLUPI, the high-performance colour close up imager, part of the science payload on board the ExoMars Rover plays an important role in attaining the mission objectives: it is the equivalent of the hand lens that no geologist is without when undertaking field work. CLUPI is a powerful, highly integrated miniaturized (<900g) low-power robust imaging system, able to sustain very low temperatures (–120°C). CLUPI has a working distance from 11.5cm to infinite providing outstanding pictures with a color detector of 2652x1768x3. At 11.5cm, the spatial resolution is 8 micrometer/pixel in color. The optical-mechanical interface is a smart assembly that can sustain a wide temperature range.

Given the time and energy expense necessary for drilling and analysing samples in the rover laboratory, preliminary screening of the materials to chose those most likely to be of interest is essential. ExoMars will be choosing the samples exactly as a field geologist does – by observation (backed up by years and years of field experience in rock interpretation in the field). Because the main science objective of ExoMars concerns the search for life, whose traces on Mars are likely to be cryptic, close up observation of the rocks and granular regolith will be critical to the decision as whether to drill and sample the nearby underlying materials. Thus, CLUPI is the essential final step in the choice of drill site. But not only are CLUPI's observations of the rock outcrops important, but they also serve other purposes. CLUPI, could observe the placement of the drill head. It will also be able to observe the fines that come out of the drill hole, including any colour stratification linked to lithological changes with depth. Finally, CLUPI will provide detailed observation of the surface of the core drilled materials collected up to 2m under the surface when they are in the sample drawer at a spatial resolution of about 15 micrometer/pixel in color.

A brief review of the science objectives of the ExoMars mission together with the observation modes of the instrument will be described, showing importance of CLUPI capabilities to provide information, significantly contributing to the understanding of the geological environment and could identify outstanding potential biofabrics of past life on Mars.

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The Bedretto Underground Laboratory for Geosciences and Geoenergies: a new experimental laboratory for studying the extent and prevalence of subsurface life

Cara Magnabosco, Andrew Acciardo, Bernard Brixel, Marian Hertrich, Hansruedi Maurer, Stefan Wiemer, Domenico Giardini

[1] *ETH Department of Earth Sciences,*

The Bedretto Underground Laboratory for Geosciences and Geoenergies is located within the ~5km long Bedretto Tunnel in Ticino, Switzerland. The tunnel was originally excavated as part of the construction logistics of the Furka Base Tunnel and traverses the Gotthard Massif, encountering up to ~1.6 km of granitic overburden. In 2018, the ETH Zürich Department of Earth Sciences began developing the Bedretto Underground Laboratory for Geosciences and Geoenergies (BULGG) in collaboration with the Matterhorn Gotthard Bahn and, in 2021, the first borehole dedicated to the study of subsurface life in BULGG was drilled. This presentation will provide an overview of BULGG research activities that are improving our understanding of the physical and chemical controls on the extent and prevalence of subsurface life. Key findings include the influence of electron acceptor availability on microbial diversity, decrease in microbial population sizes with depth and deformation of the host rock, and response of microorganisms to subsurface transport and mixing. The continued development of experiments and this facility by ETH and others will enable us to make more informed predictions about the potential for life on other planets and design missions to explore other subsurface worlds.