Geoscience for understanding habitability in the solar system and beyond Furnas

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Abstract book

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Habitability of hyperarid Atacama Desert soils as an analog for the search of life on Mars

Alessandro Airo[1], Felix Arens[2], Christof Sager[2], and Dirk Schulze-Makuch[1,3]

[1]Center for Astronomy and Astrophysics, Astrobiology Group, Technical University Berlin, Berlin, Germany, [2]Department of Earth Sciences, Freie University Berlin, Berlin, Germany, [3]SETI Institute, Mountain View, CA, USA

The habitability of modern Martian soils remains poorly understood. However, the recent discovery of shallow subsurface water ice by the Phoenix Lander and the observation of Recurring Slope Lineae assumed to be associated with deliquescence processes suggest that microorganisms might be able to thrive in Martian soils if conditions are most favorable. The extremely low water availability in Martian soils is one the main obstacles for life to flourish, making hyperarid desert soils on Earth an ideal Martian analog for investigating the limits of life as we know it. Previous microbiological studies of hyperarid Atacama Desert soils show that the biological activity is close or even below the detection limit. However, depending on the soil type and the local environmental setting the habitability and consequently the microbial activity can vary. We have investigated the habitability and biota of five one-meter soil profiles representing a range of microhabitats present in the Atacama Desert. Our results show that the habitability of these microenvironments partially depend on the depositional setting, salt content, fog frequency, and the presence of seismically-driven boulder movement. The habitability of extraterrestrial soils (e.g. on Mars) are expected to be similarly dependent on surface processes such as earthquakes and the availability of water. Hence, our data provides guidance for identifying those soil types on Mars that are most promising for the search of life.

What is the role of the planetary magnetic field in the evolution of the planetary atmosphere?

Igor Alexeev[1], Elena Belenkaya[1], Vladimir Kalegaev[1], David Parunakian[1], Aleksandr Lavruchin [1], Marina Blohina[1], Sergey Bobrovnikov[1], Maxim Khodachenko[1,2]

[1]Federal State Budget Educational Institution of Higher Education M.V.Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Moscow, Russia, [2]Space Research Institute, Graz, Austria

An universal model of planetary magnetosphere have been constructed. The scaling ratio for the magnetospheric size depending on the planetary dipole and on the distance to the Sun have been received. We are discussed the condition for plasma disk forming in the Jupiter or Saturn magnetospheres. The effective dipole moment, which stopped the solar wind, can be enchancement in several times compare to original planetary dipole. It results in the more habitability protection by magnetic field in the course of the planetary evolution. In the last years a observational estimation of the plasma exchange between the magnetosphere and ionosphere and atmosphere have been made for the Earth's case. This estimation demonstrated that most part of the ionospheric ions return to the atmosphere after their escape with polar wind in the polar cap region. The role of the Joule heating polar region by closure the field-aligned currents in the polar ionosphere in the planetary energy balance have been discussed.

The obliquity of icy satellites with internal global oceans

Rose-Marie Baland, Marie Yseboodt, Tim Van Hoolst
Royal Observatory of Belgium

Much progress has been made in recent years in modeling the obliquity of synchronous icy satellites with an internal global ocean sandwiched between a solid interior and an icy shell. Obliquity depends sensitively on the interior of the satellites, notably the properties of the ocean, and obliquity measurements are important to assess the habitability of bodies like Titan or Ganymede, as they help to constrain the satellite's interior and ocean.

The obliquity is the angle between the rotation axis and the normal to the orbital plane. In the same way as for the Moon, synchronous satellites are expected to be in a Cassini state, an equilibrium rotation state. If there were no internal ocean, the external torque exerted by the parent planet on the oblate figure of the satellite would lead to a fixed obliquity in the case of an orbital ascending node uniformly precessing in space.

Because of the internal ocean, the internal layers are differently affected by the external torque, so that their spin axes can have different obliquities. This misalignment gives rise to internal gravitational and pressure couplings that tend to restore, but without achieving, the alignment. The measured obliquity of Titan is not consistent with the predicted solid body obliquity and is evidence of a subsurface ocean. It moreover requires the ocean density to be at least about 20% above that of pure water, indicating a high level of enrichment in salts. Future obliquity measurements (e.g. with JUICE) for Europa, Ganymede, and Callisto can provide independent evidence of the existence of internal oceans and help constrain them.

Additional physical processes affecting the obliquity include the variations of the orbital precession rate, which leads to a time-variable obliquity, the tidal deformations induced by the parent planet and the flow inside the internal ocean. We will include all these elements in a new obliquity model to improve the interpretation of obliquity measurements in terms of the interior and possible habitability.

Microbial isotopic biosignatures and biomineralization to unveil biosphere-hydrosphere-geosphere interactions

Nolwenn Callac [1;2;3], Olivier Rouxel [4], Céline Rommevaux-Jestin [5], Françoise Lesongeur [2] and Anne Godfroy [2].

[1]Stockholm University, Department of Geological Sciences and Bolin Centre for Climate Research, SE-106 91, Stockholm, Sweden; [2]Ifremer, Laboratoire de Microbiologie des Environnements Extrêmes, UMR6197, 29280 Plouzané, France; [3]Université de Bretagne Occidentale, UEB, IUEM, Laboratoire de Microbiologie des Environnements Extrêmes UMR 6197 place Nicolas Copernic, 29280 Plouzané, France; [4]University of Hawaii, Department of Oceanography, 1000 Pope Road Honolulu, HI 96822, USA; [5]Laboratoire Géobiosphère Actuelle et Primitive, CNRS, IPGP, Sorbonne Paris Cité, Univ Paris Diderot, UMR7154, Paris, France

Since the Early Earth until modern time, the deep ocean chemistry had changed, in particularly in term of iron (Fe) and sulfur (S) species and concentrations. The Fe and S biogeochemical cycles have been strongly associated, since the Early Earth. Three main periods corresponding to their respective change in concentrations and speciation have been described. Thus the ocean was assumed to be anoxic and ferruginous during Archean; to be anoxic and sulfidic during the Proterozoic and to be oxic with sulfates since the Phanerozoic. However, the role of the biotic and/or abiotic processes, involved in the evolution and shaping of these two elements cycle remains quite unexplored, as well through the geological time that in the various reservoirs, i.e. the hydrosphere and the geosphere. In order to investigate the biosphere-hydrosphere-geosphere interactions during the Early Earth, we have explored both the Fe and S chemistry, isotopic fractionation and mineral alterations in a modern deep sea hydrothermal systems which are considered as analogue of the Early Earth environments. Thus, we highlighted that entire S and Fe cycles can function at high temperature and under anaerobic conditions. We demonstrated that these biogeochemical cycles are linked, via both microbial metabolisms and/or chemical reactions between sulfide and iron compounds. Regarding the Fe isotopic signature, we have shown that it is quite difficult to distinguish the biotic Fe isotopic signature, linked to hydrothermal endemic thermophilic iron-reducer microorganisms, from the abiotic one. Consequently, the Fe isotopic signature as a proof of biosignature should be used with caution and other proxies has to be associated. Ours in situ colonization experiments, through colonization modules deployed in hydrothermal sediments, have revealed the presence of nano-crystals of pyrite and barite only in the biotic colonizers and associated to organic maters, while micro-crystals of pyrite and barite were observed in biotic and abiotic colonizers. These observations suggest that nano-crystals were directly formed or induced by microbial activities while micro-crystals were solely the result from inorganic processes. Consequently, the study of Early Earth analogues, might give some insights about how life had interacted with the geosphere and its evolution through geological time.

Astrobiology and Society in Europe Today

Klara Anna Capova[1],[2] Erik Persson[2]

[1]Department of Anthropology, Durham University, UK [2]Pufendorf Institute for Advanced Studies, Lund University, Sweden

In this paper, presented by the White Paper lead authors on behalf of the WG5 History and Philosophy of Astrobiology, the prefinal version of the joint Astrobiology and Society in Europe Today will be introduced. The talk gives a brief overview of the structure and contents of the latest version of the white paper, that is Version 5. During the talk, we will discuss the societal implications of astrobiology research in the European context and the timely role of an organised initiative in astrobiology policy as well as astrobiology communication.

The evolution of atmospheric composition on the early Earth

David Catling[1], Joshua Krissansen-Totton[1]

[1]Department of Earth and Space Sciences/Astrobiology Program, University of Washington, Seattle, WA. USA

Changes in the organic and inorganic components of the carbon cycle would have affected key gases in Earth's early atmosphere (O2, CO2, CH4 and N2), and are linked to the evolution of life. Atmospheric O2 is tied to burial of organic carbon in the context of evolving global redox fluxes. Atmospheric oxidation rapidly removes CH4, so pCH4 inversely correlates with pO2. Precambrian pN2 would have also been affected by pO2 because oxidative weathering of continental organics releases nitrate, which denitrifiers use to make N2. In contrast, pCO2 is more closely tied to climate and weathering.

Evolving O2, CH4 and N2 levels can be understood by considering global redox conservation. The biosphere on its own cannot change Earth's net global oxidation state because every biologically generated oxidant is accompanied by a mole-equivalent reductant. Instead, a net atmospheric redox shift requires that these redox products couple differentially to geologic fluxes. Four key global redox fluxes describe the system and oxidized the surface environment by removing reductants: (1) an oxidizing flux caused by escape of hydrogen to space; (2) an oxidizing flux of O2 associated with the long-term burial of organic carbon (or sulfide derived from sulfate); (3) the efficient consumption of O2 by reducing gases and aqueous cations (combining subaerial volcanic and metamorphic gases, seafloor volcanism, and seafloor oxidation); and (4) an O2 consumption flux in oxidative continental weathering. A model using these fluxes plausibly explains three states: anoxia with high CH4 and low pN2 before 2.4 Ga; an oxic but low-O2 middle Proterozoic; and a high O2, high pN2 state in the Phanerozoic. Results indicate that mid-Proterozoic O2 should have been buffered by geologic emissions of (seafloor) reductants, while a dominant O2 sink from continental weathering characterizes only the Phanerozoic. Increasing Precambrian O2 levels can also be linked to growth in pN2.

The history of pCO2 is constrained by the carbonate-silicate cycle including seafloor weathering (see abstract by Krissansen-Totton et al.). But pCO2 is linked to redox evolution through global mean temperatures and thus CH4 (greenhouse) levels.

The extent to which such atmospheric evolution applies to Earth-like exoplanets remains to be determined. But the key principles of redox conservation and crustal weathering sink for CO2 ought to be universal, and so studying a different planet - the early Earth – provides some insight.

Evolution of Pluto's Interior

S. G. Coulson [1,2], M. K. Wallis [2] and N. C. Wickramasinghe [2,3]

[1]. Pembroke College, University of Oxford, Oxford OX1 1DW, UK [2]. Buckingham Centre for Astrobiology, The University of Buckingham, Buckingham MK18 1EG, UK [3]. International Research Centre, University of Peradeniya, Peradeniya 20400, Sri Lanka

The flypast of Pluto by the New Horizon probe in July 2015 has greatly increased our knowledge of the Pluto-Charon system. Initial studies of the observations made by the New Horizon suggests that surface of Pluto is active, and may have contained liquid volatiles. Observations of Charon's equatorial extensional tectonic belt hints at the freezing of a former water ice ocean inside Charon in the distant past. Other evidence found by New Horizons indicates Pluto could well have an internal water-ice ocean today.

We develop an analytical model for the temperature distribution inside Pluto which indicates that radioactive heating could have formed a small internal lake with a radius 10 km soon after its formation (1×10^9 years ago). Radioactive heating would not be sufficient to maintain a pure water-ice lake up to the Charon impact event (1×10^8 years ago); however, a sufficient mix of organic impurities within the ice has the potential to prevent freezing.

Global Archean geodynamics and onset of plate tectonics evidenced by 142Nd

Vinciane Debaille [1], Ashlea N. Wainwright [1]

[1]Laboratoire G-Time, Université Libre de Bruxelles, 50 avenue F.D. Roosevelt, 1050 Brussels, Belgium

Short-lived chronometers record very ancient differentiation events that can later only be modified by subsequent re-mixing. As such, 142Nd signatures observed in Archean rocks can be related to ancient differentiation events within the first 500 Myr of Earth history, and have been subsequently re-mixed by mantle convection in modern-day samples (e.g. [1]). So far, present-day samples display no 142Nd anomaly (e.g. [2]). As such it is supposed that the homogenization of the mantle has been achieved regarding that isotope. The discovery of a 7 ppm anomaly in 2.7 Gyr old rocks from the Abitibi greenstone belt also indicates that the homogenization of the mantle was not fast, despite intense mantle convection when the Earth

was hotter in the Archean [3]. This paradox has been interpreted as relating to a stagnant-lid tectonic regime with only scarce and short episodes of subduction [3]. When observing the record of 142Nd in the most ancient samples, large disparities exist with geographic locations. The largest positive variations are found in the Isua Greenstone Belt (e.g. [1, 4]), while at the same period, very small positive variations are recorded in the Yilgarn craton, Australia [1] and negative ones in the Nuvvuagittuq Greentsone Belt, Canada [5]. Of a similar age, the Barberton Greenstone Belt, South Africa [6], has no 142Nd anomaly while small negative anomalies are also found in Isua [7]. Finally, our recent results in the West African Craton, Mauritania, also find no 142Nd anomaly, hence suggesting the African continent does not sample any ancient event. Such a geographic diversity is intriguing and could be interpreted in terms of the onset of plate tectonics at the global scale or not, on Earth. Indeed, because of the geographic scale, it could either mean that the Earth did not differentiate homogeneously, or that the terrestrial mantle did not remix homogeneously [1]. The second case could be related to localized conditions for plate tectonics. By investigating other cratons, we will distinguish between the two scenarios, and their implications.

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General overview talk on planetary habitability and geophysical interactions

Veronique Dehant [1], Tilman Spohn [2]

[1]Royal Observatory of Belgium, Belgium [2]DLR-Berlin, Germany

Extraterrestrial life would probably be based on organic chemistry in a water solvent. The stability of liquid water at the surface of a planet defines a habitable zone (HZ) around a star. In the Solar System, it stretches between Venus and Mars. Depending on details of the models, Venus may have been in the habitable zone in the early solar system when the Sun was less luminous. Geological evidence suggests water on early Mars but whether Mars has been habitable is still debated.

We believe that the presence of water at a planet surface is strongly influenced by the planetary interior and atmosphere evolution. In order to understand more deeply habitability, we study planetary evolution and dynamic processes, e.g. internal dynamo, magnetic field, deep interior evolution, atmosphere, plate tectonics, mantle convection, volcanism, thermal evolution, meteorite impacts and erosion etc. These dynamic processes modify the planetary surface conditions, the possibility to have liquid water, the thermal state, the energy budget and the availability of nutrients. We show that the dynamics and the interrelation between interior and atmosphere is very important for understanding habitability, as an introductory talk of this workshop.

Tidal heating in the Trappist-1 planets

Vera Dobos[1,2], Amy C. Barr[3]

[1]Konkoly Thege Mikl\'os Astronomical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, H–1121 Konkoly Thege Mikl\'os \'ut 15-17, Budapest, Hungary [2]Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, H–9400 Csatkai Endre u. 6-8., Sopron, Hungary [3]Planetary Science Institute, 1700 E. Ft. Lowell, Suite 106, Tucson, AZ 85719, USA

The recent discovery of seven roughly Earth-sized planets orbiting the low-mass star TRAPPIST-1 has vaulted this system to the forefront of exoplanetary characterization. The planets orbit the star with semi-major axes $< 0.1AU$, and orbital periods of a few Earth days. Given their proximity to the star, and the star's low mass and low luminosity, the surface of each planet has a moderate temperature (from 160 to 400 K), consistent with solid surfaces composed of water ice and/or rock. The planets' orbits are in a near mean motion resonance, which maintains their eccentricities, raising tidal forces in the bodies that heat their interiors by tidal dissipation. Tidal heating may be an important energy source that can significantly increase the temperature of planets and satellites.

We use a model that balances heat production by tides with heat loss by conduction and convection to constrain tidal heating rates for each of the Trappist-1 exoplanets. We construct simple interior models for each planet based on its mean density, and knowledge of the physical properties of ice, rock, and metal. We determine how the interior of the planet responds to tidal forcing, by calculating the Love number k2, which describes how a planet's gravitational potential changes in response to tidal forces. We calculate the expected tidal heat flux on each planet, and discuss the consequences on habitability and the geophysical state of the planet (e.g., potential for volcanism).

The magmatic processes making habitable worlds

Fabrice Gaillard, Guillaume Richard, Malcolm Massuyeau
ISTO, Université d'Orléans-CNRS, France

Capturing the chain of processes making habitable worlds is a requirement to resolve the fascinating issue of the Earth's unicity. Observing exoplanets strikes the imagination by reasoning on the size and the stellar endowment of the planets and information on the atmospheric signature of exoplanets will certainly become a ground-breaking field. The terrestrial planets of our solar system also constitute valuable and observable benchmarks and, as such, they display a great diversity in surface chemistry telling us that size and solar endowment must be considered together with a variety of other processes. These processes are mostly ancient, telluric phenomena that erected the initial status of the planets and triggered subtle changes producing the bifurcation toward sterile, episodically habitable or definitively habitable worlds. Among these telluric phenomena, magmatism is one of the most important and it is twofold, the emerged and immersed parts. The emerged magmatism constitutes the volatile pipelines connecting the mantle to the planetary surface. C-O-H-S-N species can be delivered to the surface if the P-T-redox conditions of mantle melting make it possible. Several melting routes that will be reviewed here can prevent degassing of C or S. The immersed magmatism involves stagnant melt in the mantle that most likely induces weakening. The melting regime that produces stagnant melt is related to mantle volatiles producing minute amount of melts. The stagnant melting regime occurs in the region of the Earth's LVZ and it may play a critical role in the establishment of a low viscosity layer enabling the shifting of plates. We will present here an analysis of these magmatic processes and whether they can account for the diversity of surficial conditions found in terrestrial planets.

Early large impacts and the evolution of Venus

Cedric Gillmann[1], Gregor Golabek [2], Paul Tackley [3], Sean Raymond [4]
[1]Royal Observatory of Belgium, [2]University of Bayreuth, [3]ETH Zürich, [4]Laboratoire d'Astrophysique de Bordeaux

During the end of the accretion, the so-called Late Veneer phase, while the bulk of the mass of terrestrial planets is already in place, a substantial number of large collisions can still occur. Those impacts are thought to be responsible for the repartition of the Highly Siderophile Elements. They are also susceptible to have a strong effect on volatile repartition and mantle convection. We study how Late Veneer impacts modify the evolution of Venus and its atmosphere, using a coupled numerical simulation. We focus on volatile exchanges and their effects on surface conditions. Mantle dynamics, volcanism and degassing processes lead to an input of gases in the atmosphere and are modeled using the StagYY mantle convection code. Volatile losses are estimated through atmospheric escape modeling. It involves two different aspects: hydrodynamic escape (0-500 Myr) and non-thermal escape. Hydrodynamic

escape is massive but occurs only when the solar energy input is strong. Post 4 Ga escape from non-thermal processes is comparatively low but long-lived. The resulting state of the atmosphere is used to the calculate greenhouse effect and surface temperature, through a one-dimensional gray radiative-convective model. Large impacts are capable of contributing to (i) atmospheric escape, (ii) volatile replenishment and (iii) energy transfer to the mantle. We test various impactor compositions, impact parameters (velocity, location, size, and timing) and eroding power. Scenarios we tested are adapted from numerical stochastic simulations (Raymond et al., 2013). Impactor sizes are dominated by large bodies (R¿500 km). Erosion of the atmosphere by a few large impacts appears limited. Swarms of smaller more mass-effective impactors seem required for this effect to be significant. Large impactors have two main effects on the atmosphere. They can (i) create a large input of volatile from the melting they cause during the impact and through the volatiles they carry. This leads to an increase in atmosphere density and surface temperatures. However, early impacts can also (ii) deplete the mantle of Venus and (assuming strong early escape) ultimately remove volatiles from the system, leading to lower late degassing and lower surface temperatures. The competition between those effects depends on the time of the impact, which directly governs the strength of atmospheric losses.

Studying the extraterrestrial flux to Earth: what can we learn from the terrestrial impact cratering record?

Steven Goderis

Vrije Universiteit Brussel

Although micrometeorites ($< 2mm$) dominate the extraterrestrial flux to Earth (40,000 tons/yr), impacts of km-sized objects affect Earth's evolution much stronger. Impactors with diameter in between 600 m and 5 km that are thought to cause global catastrophes, still occur once every 0.1 to 1 million years [1]. Currently, approximately 190 terrestrial impact craters are known, ranging from 13.5 m to 160 km for the collapsed transient crater [2]. This number reflects the geological activity on our planet and correlates regionally to the available geological knowledge. As terrestrial impact structures are often modified by erosion, their identification primarily relies on the occurrence of shock metamorphic effects or geochemical and isotopic anomalies induced by the contamination of impact melt rocks and ejecta material with meteoritic matter. These terrestrial structures provide ground truth data on the geologic effects of impacts and the subsurface structure of impact craters on other terrestrial planetary bodies (e.g., the Moon or Mars). They can also be used to further improve crater formation models. The destructive consequences of high-velocity impacts on the terrestrial ecosystem became apparent through the work of [3], who linked the Cretaceous-Paleogene (K-Pg) mass extinction event 66 million years ago to the impact of an asteroid larger than 10 km in diameter (cf. summary in [4]). To date, the K-Pg boundary event remains the only recognized mass extinction that coincides with a large impact event. Many more impacts of similar or larger size have occurred during Earth's history without a substantial influence on life, and often also without dramatic changes in the global geological record, or such links remain the subject of debate. The environmental outcome of impact events resulting from asteroid break-up events punctuating Earth's geologic past range from local to global scales. Short-term effects include thermal radiation, blast-wave propagation in the atmosphere, crater excavation, earthquakes, and tsunamis, while long-term consequences comprise the ejection of dust and climate-active gases into the atmosphere [6]. Impact cratering may not only be destructive in nature, as impact cratering may have created hydrothermal systems in the Archean (or even before) crust inducing environmental conditions (H2O, heat, metals) favorable for prebiotic synthesis and perhaps organism diversification [5].

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Interpreting Spectra of Exoplanetary Atmospheres: A Review of Atmospheric Retrieval

Kevin Heng

Center for Space and Habitability, University of Bern, Switzerland

The study of the atmospheres of exoplanets has come of age in the past decade. Astronomers have progressed rapidly from measuring the transit depths of close-in (fractions of an AU) gas giants (hot Jupiters) in broad wavebands to establishing spectrophotometry as a robust technique for inferring the presence of molecules in the atmospheres of transiting exoplanets with sizes down to that of Neptune's. The Wide Field Camera 3 (WFC3) onboard the Hubble Space Telescope is now routinely used to detect the presence of water in transiting exoplanets. In parallel, astronomers have devised techniques to direct image (i.e., photometrically separate the exoplanet from its star) the thermal emission from gas giants on orbits of tens to hundreds of AU, and take their spectra. In principle, both techniques may be eventually applied to Earth-sized exoplanets to remotely infer the chemical inventory of their atmospheres. On the theoretical front, astrophysicists are borrowing and generalising a technique from the Earth remote sensing and Solar System communities known as atmospheric retrieval: inferring the atmospheric chemistry and temperature-pressure profile from inverting the measured spectra. A key challenge is that we do not have in-situ measurements or high-resolution imaging for exoplanets, which necessitates that we invest our efforts into carefully understanding the physics and chemistry we are inserting into our retrieval models. I will review the progress of this subfield of exoplanetary science, starting from the first introduction of retrieval into our literature in 2009. I will discuss a set of challenges associated, separately, with applying atmospheric retrieval to transiting and directly imaged exoplanets. I will use the HR 8799 system, which hosts four directly imaged gas giants with measured spectra, as a "real life" case study where atmospheric retrieval is applied to real data. Specifically, the elemental abundances of carbon and oxygen may be extracted from the measured spectra, which in turn allows us to infer the posterior distributions of the carbon-to-oxygen ratio and set constraints on the formation history of these exoplanets. Finally, I will look to the future and discuss the state of the art for identifying and detecting biosignature gases. I will finish up this keynote talk with a plug for my recently published textbook entitled, “Exoplanetary Atmospheres: Theoretical Concepts and Foundations” (Princeton University Press).

Impact of life on feedbacks cycles in Earth’s evolution

Dennis Höning, Tilman Spohn

Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany

Major shifts in Earth’s evolution led to progressive adaptations of the biosphere. Particularly the emergence of continents permitted efficient use of solar energy. In contrast, effects of the emergence and evolution of life on the Earth’s system are much less certain. A link is provided by biologically enhanced weathering rates of silicate rock (Schwartzman and Volk, 1989). Weathering rates are crucial to the evolution of plate tectonics planets in various respects. On one hand, weathering is an important component in the long-term silicate-carbonate cycle, which stabilizes Earth’s climate. In this context, the biologically enhancement of weathering rates has been argued to extend the lifespan of the biosphere (Lenton, 2002). In addition, the dissolution of rock enhances the rate of surface erosion and thus the flux of sediments into subduction zones. This establishes a potential link to the deep interior. Stably bound water within subducting sediments not only enhances partial melting but further affects the mantle rheology. The mantle responds by enhancing its rates of convection, water outgassing, and subduction. Altogether, to understand how surface life feeds back on the interior evolution of Earth requires the investigation of the intertwined feedback cycles including the growth of continental crust and the hydration of Earth’s mantle.

Particularly important are self-reinforcing mechanisms associated with continental growth that can cause a non-linear behavior in Earth’s evolution. A temperature rise below insulating continents and an increased subduction rate of sediments with the emergence of continents cause an increasing continental production rate with an increasing volume of continental crust. Analyzing the strengths of positive and negative feedbacks show that positive feedbacks are sufficiently strong to cause a bifurcation in the continental growth system. In a phase plane spanned by continental coverage and (upper) mantle water concentration, three fixed points emerge of which two are stable and an intermediate point is unstable with respect to continental coverage and located at present-day Earth values. In other words, the present-day Earth fraction of emerged continents is not a necessary result for Earth-sized plate tectonic planets in general. Rather, the fraction of emerged continents depends on initial conditions (e.g., initial mantle water budget, initial mantle temperature, initiation time of plate tectonics) as well as on the weathering rate. Reducing the weathering rate, i.e. simulating the evolution of the Earth without its biosphere, enlarges the zone of attraction of the stable fixed point with small continents and a dry mantle. It thus becomes increasingly likely for the planet to evolve into a water-world scenario with hardly emerged continents (Höning and Spohn, 2016).

This presentation gives an overview of long-term Earth system feedback cycles from the surface to the deep interior where life acts as an important component in creating and sustaining an habitable environment. In addition, we discuss whether this concept could be used to search for life on planets beyond our solar system.

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Early Life Traces and Evolution, & Implications for Astrobiology

Emmanuelle J. Javaux

University of Liège, Belgium

The search for life on the early Earth or beyond Earth requires the characterization of biosignatures, or "indices of life". These traditionally include fossil chemicals produced only by biological activity, isotopic fractionations of elements indicative of biological cycling, biosedimentary structures induced by microbial mats such as stromatolites, and microstructures interpreted as morphological fossils. However, these traces can in some cases also be produced by abiotic processes or later contamination, leaving a controversy surrounding the earliest record of life on Earth. Looking for life beyond Earth is even more challenging, in situ on other rocky bodies, or by remote sensing in exoplanet atmospheres.

Geobiological studies can improve our understanding of preservational environments and taphonomic processes, abiotic processes and products, and help us to develop a multidisciplinary approach to establish the biogenicity, endogenicity and syngeneity of these in situ biosignatures or the possible biogenicity of atmospheric signatures. This research also documents steps in biological and biochemical innovations, the emergence and rise of biological complexity, and their possible environmental and or ecological causes. Combining minimum ages of fossil biosignatures with molecular phylogeny permits to produce molecular clocks, that provide dating of branching events and important biological innovations, and allow predictions for the evolution of former and later clades or metabolisms.

Resolving these issues is critical if we want to understand in which conditions life may originate (habitability), evolve, and what are the interactions between planet and life. These interactions leave traces or biosignatures that provide a rationale to tentatively define ways to look for life on Earth or in extraterrestrial environments. The future missions ESA EXOMARS 2020 and NASA MARS 2020 are now developed based on these early Earth approaches.

This keynote talk will present examples from the Archean through the Proterozoic recording crucial steps in the evolution of life to illustrate the results and challenges of this multidisciplinary approach, and discuss implications for the search of extraterrestrial life.

Formation of habitable planets

Anders Johansen
Lund University

Planets form in protoplanetary discs around young stars as dust and ice particles collide to form larger and larger bodies. I will present a coherent theory framework for the formation of planetary systems, including habitable planets. Dust grows to pebbles by coagulation and deposition of volatile ices, but the continued growth to planetesimals is hampered by the poor sticking of mm-cm-sized pebbles. Planetesimals can nevertheless form by gravitational collapse of pebble clumps concentrated in the turbulent gas through the streaming instability. The subsequent growth initially occurs by planetesimal-planetesimal collisions, but the accretion rate of pebbles dominates the growth from 1000-km-sized protoplanets to form terrestrial planets and the solid cores of gas giants, ice giants and super-Earths.

Possible methane outgassing scenarios from clathrates on Mars and atmospheric transport modelling

Özgür Karatekin[1], Elodie Gloesener[1], Orkun Temel[2], Véronique Dehant[1]
[1]Royal Observatory of Belgium, Brussels, Belgium, [2]von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium

Methane has been shown to vary with location and time in the martian atmosphere, with abundances of up to tens of parts-per-billion by volume (ppbv). Since methane is short-lived on geological time scales, its presence implies the existence of an active, current source of methane that is yet to be understood.

In this study, the destabilization of subsurface reservoirs of clathrate hydrate as a possible geological source of methane is investigated. Present-day maps of clathrate stability zone variations are shown for clathrates trapping different fractions of methane. Then, a gas transport model is used to determine the CH4 flux at the surface due to the diffusion of different plausible methane volumes released by clathrate hydrates at variable depths under the martian surface. Finally, the transport of the released methane spike into the atmosphere is simulated using the PlanetWRF model.

Robust constraints on the climate and ocean pH of the early Earth using a geological carbon cycle model

Joshua Krissansen-Totton[1], Giada Arney[2], David Catling[1]

[1]Department of Earth and Space Sciences/Astrobiology Program, University of Washington, Seattle, WA, USA [2]NASA Goddard Spaceflight Center, Greenbelt, MD, USA.

Constraining surface conditions on the early Earth is an important prerequisite to understanding the long-term habitability of Earth-like planets. The geological carbon cycle must play a role in controlling Earth's climate and ocean pH on long timescales. Generally, a thermostat based on weathering of continental silicates is thought to buffer Earth's climate against changes in insolation. However, there is considerable uncertainty over the efficiency of this feedback, and so debate remains over the climate and ocean pH of the early Earth. Estimates of average Archean temperatures vary widely from below freezing to over 350 K. Ocean pH estimates similarly range from highly acidic to highly alkaline. Finally, there is uncertainty over the extent to which seafloor weathering acts as a carbon sink, moderating climate and buffering ocean pH. Previously, some authors have suggested that early seafloor weathering was so efficient that the Hadean and early Archean climates were characterized by widespread glaciation.

To better constrain surface conditions and the operation of these feedbacks, we applied a new geological carbon cycle model to all of Earth history. Our model tracks continental and seafloor weathering, outgassing, carbonate burial, and ocean chemistry. The latter enables the parameterization of seafloor weathering kinetics. The model has been validated over the Cenozoic and Mesozoic where abundant proxy data are available. To extend the model to the Precambrian we took a conservative approach by iterating over a broad range of assumptions about Earth's internal evolution, continental growth, biogenic enhancement of weathering, and the temperature/CO2-sensitivity of weathering. Consequently, the uncertainties in our final model outputs are large, but they likely bound the true evolution of Earth's carbon cycle.

We find that the early Earth was probably temperate (270-310 K). The combined buffering effects of continental and seafloor weathering preclude hot Archean temperatures. This is true even for extreme scenarios with no Archean land because temperature-dependent seafloor weathering will still buffer climate to temperate values. We also find that ocean pH evolved monotonically from 6.4-7.5 at 4.0 Ga to moderately alkaline modern values. Seafloor weathering is an important feedback, but not as efficient as previously assumed, and so it does not cause a Snowball early Earth. Our conclusions are robust to uncertainties in model parameters.

The need for an ethics of planetary sustainability

Andreas Losch
University of Bern, Center for Space and Habitablity & Theological Faculty

The concept of sustainability is widely acknowledged as a political guideline. Economic, ecological, social and cultural aspects of sustainability are already under discussion. Current space mining efforts demand that the discussion become a broader one about "planetary sustainability", including the space surrounding Earth. To date, planetary sustainability has mainly been used with reference to Earth only and I will extend it here, elaborating on a similar NASA initiative. This article (1) sketches the contemporary economic-political initiatives which call for a special reflection of Earth's location in space, and then (2) discusses the meaning of the concept of sustainability in this context. Next, (3) I relate the discussion to the issue of planetary protection, before, (4) finally, presenting a philosophical and theological perspective that seems particularly able to broach the issue of the multiple dimensions of sustainability in this context. This is the concept of constructive-critical realism. My discussion concludes with (5) a summarizing outlook.

Comparative study of circulation regimes of terrestrial planets' atmospheres

Pedro Machado[1], Thomas Widemann[2], Ruben Gonçalves[1], Gabriella Gilli[1]
[1]Institute of Astrophysics and Space Sciences, Portugal, [2]Observatoire de Paris - LESIA, France

Understanding our Solar System Planetary Atmospheres is a significant step forward for paving the way for future studies of atmospheres of Extrasolar Planets. Notably, Venus and Mars are natural comparative laboratories to investigate diversity of circulation regimes of terrestrial planets' atmospheres. In this context, comparative studies are essentials to understand the evolution of climate of our Earth, both in the past and in the future. Notably, Venus and Mars are natural comparative laboratories to investigate diversity of circulation regimes of atmosphere of terrestrial planets. Venus for example, is Earth's closest sibling but it has ended up with a radically different climate. Venus atmospheric science is thus increasingly important in an era in which we are trying to understand the divergent evolutionary outcomes for terrestrial planets, whether we are considering the future of our Earth or the habitability in other planetary systems. We will present a study based on large scale and small scale processes going on the middle/upper atmosphere of Venus and Mars combining wind measurements and 3D model simulations. Venus is a slowly rotating planet with a dense atmosphere. The mechanisms for the generation and maintenance of superrotation are still unclear and no model has been able to successfully reproduce its circulation in decades (Lebonnois 2013). A proper monitoring of Venus winds is crucial towards a full understanding of this phenomena. With this aim, we intend to conduct a synthesis effort that could provide important constraints on atmospheric models. In Venus's mesosphere (65-85 km), visible observations of Doppler shifts

in solar Fraunhofer lines have provided the only Doppler wind measurements near the cloud tops in recent years (Machado et al. 2014, 2017). We will present wind measurements based on VLT/UVES and CFHT/ESPaDOnS observations (around 70 km), wind measurements based on Akatsuki space probe data (and ESA's Venus Express archive data) with cloud tracking methods (from 48 km till 70 km), using an improved version of a cloud tracking tool based on phase-correlation between images. The objective of this work is to help constrain the planetary atmospheric characterization, and to take a step forward in the comparative studies of terrestrial planets.

Terrestrial planets and Super-Earths: similar bodies? An origin perspective

Alessandro Morbidelli, Sean Raymond

CNRS, Observatoire de la Cote d'Azur and Laboratoire Astrophysique de Bordeaux

Super-Earths, particularly those with a bulk density similar to that of our planet, are often considered as scaled-up versions of our Earth. But our planet is not just characterized by a mass and a radius. A specificity of our planet is that it formed slowly, over tens of millions of years. Thus it formed mostly after the disappearance of the protoplanetary disk of gas, via a sequence of giant impacts. The precursors of the Earth, the planetary embryos, which formed within the disk lifetime, were small. They had a mass presumably smaller than that of Mars. Thus, they did not migrate significantly while in the protoplanetary disk.

The super-Earths are more massive than our planet and they are much closer to the central star. Some of them may have migrated from the outer parts of the disk and thus they are probably more similar to Neptune than the Earth. But also the rocky super-Earths may have formed differently from our planet. In fact, if more mass is available in the system as to form more massive planets in the end, the planetary embryos grow faster and bigger as well. Thus, they start to be affected by orbital migration. Migration in turns affects strongly the accretion process. We predict that close-in super-Earths formed mostly within the proto-planetary disk lifetime. Their growth was dominated by the accretion of small particles, and giant impacts have been rare. Primitive atmospheres are likely.

It is unclear whether this different accretion path leads to chemical and geophysical properties different from those of our Earth, impacting their capability to sustain life even if they are emplaced in the end in the so-called "habitable zone"

The link between mantle convection, atmosphere evolution and surface habitability - from the Solar System to exoplanets

Lena Noack[1], Attilio Rivoldini[2], Tim Van Hoolst[2], Caroline Dorn[3] and Antoine Rozel[4]

[1]Freie Universität Berlin, Germany, [2]Royal Observatory of Belgium, [3]University of Bern, [4]ETH Zurich

The Earth is only one out of three planets in the HZ of the Solar System - with Mars and Venus at the boundaries. Both planets lack active plate tectonics, a global magnetic field and (at least in the case of Mars) active volcanism. Planets like Mars without plate tectonics and no or only limited volcanic events (and thus limited outgassing potential of greenhouse gases) are not able to build up a dense CO2 atmosphere. At the outer boundary of the HZ, the greenhouse effect would not be strong enough to ensure liquid surface water and the planets may not be considered as habitable at their surface. Venus, lying at the inner boundary of the HZ, has a dense CO2 atmosphere and is not habitable. If the planet were to be at the outer boundary of the habitable zone or if some of the CO2 from the atmosphere would have been extracted by weathering and carbonate formation (for example via a global plate-tectonics-driven carbon cycle similar to Earth), Venus might have been a habitable planet - at least in its past.

The comparison between Earth, Mars and Venus shows that the rocky mantle of terrestrial planets can shape their possible surface habitability via different internal processes like plate tectonics and volcanic activity. Similar feedback mechanisms between interior and surface are thought to exist on rocky exoplanets, even if they may have different chemical compositions.

Here we study the effect of the planet interior of stagnant-lid planets in the habitable zone on the formation of a secondary atmosphere through outgassing that would be needed to preserve surface water. In general, we find that volcanic activity and associated outgassing in one-plate planets is strongly reduced after the magma ocean outgassing phase, if their mass and/or core-mass fraction exceeds a critical value (which depends on the mantle composition). As a consequence, the effective outer boundary of the habitable zone is then closer to the host star than suggested by the classical habitable zone definition, setting an important restriction to the possible surface habitability of massive rocky exoplanets, assuming that they did not keep a substantial amount of their primary atmosphere and that they are not in the plate tectonics regime.

The impact of the host star and of geophysical processes on the habitability of exoplanets

Heike Rauer
Institute for Planetary Research, DLR

The search for Earth-like planets in the habitable zone of stars has become a central focus of research. However, understanding whether a planet could indeed be potentially habitable requires a deep knowledge of the geophysical processes driving the key elements for habitability. To gain a better understanding of These processes, the evolution of Earth is often taken as a reference case for the interaction of atmosphere, geology and biological processes. Such processes will also take place on terrestrial exoplanets, but are much harder to constrain without in situ information. Furthermore, terrestrial planets around other types of stars, or young planetary systems, may experience much harsher space weather conditions which can impact habitability as well as the presence of biosignatures. We will review recent results of model simulations studying the atmosphere-interior-biosphere interaction as well as the planet-star interaction and their impact on habitability of exoplanets orbiting different types of stars (solar-like and cool M dwarf stars). We will also discuss which habitability indicators in the atmosphere of extrasolar planets exist and their detectability with future instruments.

The role of communication in science and astrobiology

Arianna Ricchiuti, Pierluigi Catizone
Planetario di Bari Sky-Skan

Misinformation is the activity of spreading misleading and non-objective information in order to deceive someone's opinion about a person, a situation or a fact. Misinformation can be particularly dangerous in science. A great effort has been done and it is still going on by Italian scientists and communicators in order to suffocate the movement who states that vaccines cause autism. A lack of scientific education and false but easy-to-believe stories lead many parents not to vaccinate their children and exposing them to terrible diseases. That it why it is necessary to give people correct and reliable information about every field of science. Science communication plays a key role in order to fight against misinformation, but it can have other important roles.

First, to point out how useful scientific research can be even when it seems useless (like space exploration). Second, to make science something interesting, friendly and suitable for everyone; third, to make people understand scientists are firstly moved by passion, curiosity and the desire of knowledge. Not every single thing a scientist does is necessarily "useful" to someone or something. As astrobiologists, we want to study the origin and evolution of life in the universe and we want to find extraterrestrial life. That is just because we are passionate, because we feel a connection with the universe.

The language used in science communication is essential and it must vary respect to the type of audience (children, general public, specialists) and event (birthday, conference, entertainment show). A communicator or a researcher should carefully choose the strategies to make his activity charming, so he can plan a power point presentation or take advantage of the full-dome technology of planetariums which allows people to feel involved and carried away by the images. A Planetarium can be particularly suitable to talk about astrobiology, for example to represent how the Earth was when the first form of life emerged or to picture molecules and chemical reactions. In order to stay in close contact with people, a science communicator can use simple and common objects to represent difficult issues: a stone can become a meteorite and a little ball can become a bacteria. This is very successful especially when we are dealing with kids. On the other side, some specific occasions require professional instruments like telescopes for astronomical observations.

"A good communication is made of 20% of what you know and 80% of what you feel about what you know."

Origin and evolution of the terrestrial nitrogen atmosphere

Manuel Scherf[1], Helmut Lammer[1], Maxim Khodachenko[1], Igor Alexeev[2], Colin Johnstone[3], Manuel Güdel[3], Lin Tu[3], Marina Blokhina[2], Elena Belenkaya[2], John Tarduno[4], Herbert Lichtenegger[1], Yuri Kulikov[5]

[1]Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2]Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia, [3]Institute of Astrophysics, University of Vienna, Vienna, Austria, [4]Department of Earth and Environmental Sciences, University of Rochester, Rochester, USA, [5]Polar Geophysical Institute, Russian Academy of Sciences, Murmansk, Russian Federation

The present-day terrestrial atmosphere, as dominated by the volatile elements nitrogen and oxygen, is providing a habitable environment for a diverse range of lifeforms. However, simulations of the terrestrial paleo-magnetosphere as well as of the solar wind induced atmospheric ion-pickup escape ~4 billion years ago (Scherf et al. 2017, Lichtenegger et al. 2010) are indicating that during the harsh conditions of the Hadean and early Archean eons a nitrogen-dominated atmosphere would not have been able to survive, but would have been eroded within a few million years due to the high EUV flux and the strong solar wind of the early Sun (Tu et al. 2015, Johnstone et al. 2015). In addition, these results are suggesting that the present-day nitrogen-dominated atmosphere has its origin during later stages of the geological history of the Earth, whereas for the late Hadean and early Archean, CO_2 can be considered as the dominating atmospheric constituent. Supported by several different studies of the ancient atmospheric composition and pressure, as well as of the different $^{14}N/^{15}N$ isotope fractionations of the terrestrial mantle and atmosphere, we are proposing that the nitrogen-dominated atmosphere started to build up during the Archean eon and slowly evolved from a low-pressure atmosphere via outgassing of N_2 into the present-day habitable environment. Important environmental conditions for this evolution and its interconnections will be discussed within this presentation. This includes the role of the paleo-magnetosphere and of plate tectonics; the evolution of the solar EUV flux, as well as the essential role of lifeforms on the sustainability of a nitrogen-dominated atmosphere.

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Habitability of Many Worlds and the Adaptability of Life on Earth

Dirk Schulze-Makuch [1,2], Alessandro Airo [1], and Janosch Schirmack [1]

[1]Astrobiology Group, Center of Astronomy and Astrophysics, Technical University Berlin, Hardenbergstr. 36, 10623 Berlin, Germany, [2]SETI Institute, Mountain View, CA 94043, USA

All life on Earth uses the same fundamental biochemistry, but even within that constrain the adaptability of life to a versatility of environments is enormous. The adaptability results from the coevolution of the biosphere and the geosphere during the natural history of our planet and seems to require an active recycling mechanism such as plate tectonics. Some of the physicochemical parameters encountered on Earth exceed the ability of life to adapt, but most lie within the adaptability range of Earth's biota. Certain parameters such as water activity seem to be close to the limit of biological activity, which is readily observable in hyperarid deserts on Earth. Can these limits be expanded on other solar system bodies such as Mars or Titan? A much wider range of environmental parameters certainly exists on planetary bodies within and beyond our Solar System and the question arises which set of environmental parameters would still allow the origin and persistence of life. In a first analysis we identify some of the critical parameters such as temperature, pressure, and water availability, which are relatively well constrained in regard to the adaptability of life as we know it. In a next step we outline the range of possible environments for a diverse set of alien planets and moons, which we categorize according to Planetary Environment Types (PETs) to inform us about their potential habitability. Some of these types are present in our Solar System, others are thought to exist beyond our Solar System. At this time our results are limited to Earth-type life, particularly in regard to the use of solvent (water) and energy source (light and chemical compounds).

Apatite geochemistry coming to the rescue for evaluation of Martian abiotic environment composition

Ewa Słaby[1], Hans-Jürgen Förster[2], Richard Wirth[2], Alicja Giera[1,2], Łukasz Birski[1], Izabela Moszumańska[1]

[1]Institute of Geological Sciences, Polish Academy of Sciences, Warsaw, Poland, [2]Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum GFZ, Potsdam, Germany

Apatite from Martian meteorites is frequently used to show volatiles/fluid content in Martian mantle and crust. This mineral has structurally bonded OH, F and Cl. As a behavior of all of them is predictable during magma evolution, degassing, and partitioning into fluid, the data on apatite geochemistry may allow us to assign precisely its crystallization to particular environment and at the same time to recognize the environment chemistry. Especially the information about composition of crustal fluids circulating in Martian crust is important to diagnose the abiotic environment and the possibility of its transition to conditions conducive to life. To get relevant data on crystal structure and geochemistry each apatite domain needs careful examination. F-rich, however containing Cl and OH groups, apatite is consistent with crystallization from mafic magma. During degassing, Cl strongly partitions into the exsolved fluid, whereas F remains in the melt. Thus apatite crystallizing from degassed melt is pure fluorapatite. Cl and OH rich apatite crystals are results of postcrystallization reaction with fluids. We present apatite case study from NWA 2975 shergottite. Three types of apatite have been recognized: magmatic, crystallizing after degassing and apatite indicating influence of Cl-rich crust assimilation. The possibility of using data to show mantle/crust volatiles/fluid composition is shown. Magmatic apatite brought data on degree of Martian mantle hydration. The obtained data also allow us to verify the suitability of apatite in reconstruction of abiotic crustal environment.

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On the habitability of a stagnant-lid Earth

Barbara Stracke[1], Nicola Tosi[1,2], Mareike Godolt[1,2], Thomas Ruedas[2,3], John Lee Grenfell[1], Dennis Höning[1], Athanasia Nikolaou[1,2], Ana-Catalina Plesa[1], Doris Breuer[1], Tilman Spohn[1]

[1]Institute for Planetary Research, German Aerospace Center (DLR), Rutherfordstr. 2, 12489 Berlin, Germany, [2]Technische Universität Berlin, Department of Astronomy and Astrophysics, Hardenbergstr. 36, 10623 Berlin, Germany, [3]WestfälischeWilhelms-Universität Münster, Institute of Planetology,Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Plate tectonics is considered a fundamental component for the habitability of the Earth. Yet whether it is a recurrent feature of terrestrial bodies orbiting other stars or unique to the Earth is unknown. The stagnant lid may rather be the most common tectonic expression on such bodies.

To understand whether a stagnant-lid planet can be habitable (i.e., host liquid water at ist surface), we model the thermal evolution of the mantle, the volcanic outgassing of H_2O and CO_2, and the resulting climate of an Earth-like planet lacking plate tectonics.

We use a 1D model of parameterized convection to simulate the evolution of melt generation and the build-up of an atmosphere of H_2O and CO_2 over 4.5 Gyr. We then employ a 1D radiative-convective atmosphere model to calculate the global mean atmospheric temperature and the boundaries of the Habitable Zone (HZ).

The evolution of the interior is characterized by the initial production of a large amount of partial melt accompanied by a rapid outgassing of H_2O and CO_2. The maximal partial pressure of H_2O is limited to a few tens of bars by the high solubility of water in basaltic melts. The low solubility of CO_2 causes instead most of the carbon to be outgassed, with partial pressures that vary from 1 bar or less if reducing conditions are assumed for the mantle, to 100–200 bar for oxidizing conditions. At 1 au, the obtained temperatures generally allow for liquid water on the surface nearly over the entire evolution. While the outer edge of the HZ is mostly influenced by the amount of outgassed CO_2, the inner edge presents a more complex behavior dependent on the partial pressures of both gases.

At 1 au, the stagnant-lid planet considered would be regarded as habitable. The width of the HZ at the end of the evolution, albeit influenced by the amount of outgassed CO_2, can vary in a non-monotonic way depending on the extent of the outgassed H_2O reservoir. Our results suggest that stagnant-lid planets can be habitable over geological timescales and that Joint modelling of interior evolution, volcanic outgassing, and accompanying climate is necessary to robustly characterize planetary habitability.

Habitable planets in mupti-planet systems

Ewa Szuszkiewicz

Faculty of Mathematics and Physics and CASA, University of Szczecin, POLAND

There are more than 600 known multiple planet systems. They are characterized by a remarkable variety of structures and dynamical behaviours. This gives a real possibility of studying life-bearing planets. Habitable conditions will be investigated for some of the most interesting systems taking into account not only the requirement of the existence of liquid water on the planet surface, but also for an internal heat that is sufficient to drive plate tectonics.

Coupled evolution of the core, mantle and lithosphere over billions of years: our current state of understanding

Paul Tackley

ETH Zurich Institute fuer Geophysik, Department of Earth Sciences, Switzerland

Convection of the rocky mantle is the key process that drives the evolution of the interior: it causes plate tectonics, controls heat loss from the metallic core (which generates the magnetic field) and drives long-term volatile cycling between the atmosphere/ocean and interior. Cycling of water and carbon dioxide between the atmosphere/ocean and interior is a key process that is thought to regulate habitability; thus plate tectonics is often considered necessary for planetary habitability. At the same time, the volatile content of the surface environment, particularly the presence or not of liquid water, is thought to have a large feedback on the interior, for example by influencing of the existence or not of plate tectonics.

Unfortunately, plate tectonics is still not well understood; other terrestrial planets like Venus and Mars instead have a stagnant lithosphere. Furthermore, Earth may not have had plate tectonics early on. Thus, one key topic of investigation is the possible tectonic modes of terrestrial planets and how their appearance depends on planet size, surface environment, internal temperature, internal heating rate, history, etc. For example, our recent models indicate that variations in crustal thickness caused by partial melting are important in facilitating plate tectonics, and have been ignored in previous analyses. Here the current state of knowledge will be reviewed.

Large terrestrial planets likely started off with partly or mostly molten with global magma oceans; processes occurring during the freezing of these include outgassing and the possible development of compositional layering, which affect both the atmosphere and the interior for a long time period. Large planets take longer to cool so if, as is likely, large terrestrial planets (super-Earths) started off molten then it is likely that their deep interiors are still very hot and active.

Finally, published "box models" for the long-term cycling of volatiles between the surface environment and the deep interior will be reviewed.

Photodegradation of selected organics on Mars

I. L. ten Kate [1], A. Boosman [1], T. Fornaro [2], H. E King [1], K. A. Kopacz [1], M. Wolthers [1]

[1]Dept. of Earth Sciences, Utrecht University, the Netherlands, [2]INAF-Astrophysical Observatory of Arcetri, Italy

At least as much as $2.4 \times 106kg$ of unaltered organic material is estimated to be delivered to the Martian surface each year. However, intense UV irradiation and the highly oxidizing and acidic nature of Martian soil cause degradation of organic compounds. Here we present first results obtained with the recently developed PALLAS facility at Utrecht University. PALLAS, the Planetary Analogues Laboratory for Light, Atmosphere, and Surface Simulations, is a $50 \times 50 \times 50cm$ stainless steel vacuum chamber, equipped with a turbo pump to create and maintain atmospheric pressure. This facility is specifically designed to simulate planetary and asteroid surface conditions to study the photocatalytic properties of relevant planetary minerals. Samples were placed on a cooling table in the beam spot of a solar simulator equipped with a water filter to remove residual heat (LOT-Oriel, 450 W UV enhanced Xe, 180-900 nm). Experiments were carried out at 20 °C and -55 °C in vacuum (10-7 mbar) and Mars-like atmospheric conditions (10 mbar CO2) for 24-48 hours. Before and after exposure the samples were analysed with Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS) and Raman Spectroscopy, enabling direct probing of the effects of the exposure to the Martian conditions, as the samples holders can be placed directly in the DRIFTS and the Raman. Our results tentatively show degradation of several compounds and preservation of others. Photocatalysis is a process known to effectively degrade organic compounds. Previous work has shown that several organic species can be photo-oxidized on very common minerals, such as olivine. Our results indicate that some minerals are more effective catalysts whereas others aid in the preservation of organic compounds. Furthermore, some of the compounds tested appear to be more stable than others. Further studies are underway to better understand the chemistry underlying these results.

New evidence for recent geologic activity on the surface of the Moon

Adomas Valantinas[1] and Kjartan Munster Kinch[1].

[1]Niels Bohr Institute, University of Copenhagen, Øster Voldgade 5-7, 1350 Copenhagen, Denmark

The conventional understanding of the Moon states that it is a differentiated but currently a geologically ‘dead’ body. Most of the lunar mare volcanism took place 4-3 Ga ago and basin related extensional tectonics ended 3.6 Ga ago with some degree of contractional tectonics up to 1.2 Ga [1-4]. However, with the help of high resolution images provided by NASA’s Lunar Reconnaissance Orbiter a number of geologically young structures have been recently identified by various workers. Evidence for basaltic volcanism in the past 100 Ma has been proposed from the observations of so called Irregular Mare Patches (IMPs) [5]. A number of surface tectonic expressions such as small graben and lobate scarps were found to be also $< 100Ma$ [6-8]. In our work, we analyze several contractional lunar wrinkle ridge systems which are thought to be manifestations of global stress fields along nearside maria edges [9]. Results from stratigraphic relationships and the lack of large superimposing craters suggests that all wrinkle ridges in our study regions are at least Copernican (i.e. $< 1.1Ga$ in age). We derive model ages from crater size frequency distributions which result in ages all below 30 Ma. Analyzed lunar wrinkle ridges appear morphologically crisp and include various degrees of pristine rocky outcrops. The latter supports the evidence that they are geologically young because estimates of lunar surface boulder obliteration rates imply that rock populations are fully destroyed in 300-1500 Ma [10-13]. These results suggest that there might be active and long lasting crustal weakness in the lunar nearside due to antipodal impact at the South Pole Aitken basin [14].

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Seeding Life, Punctuating Evolution – How impact processes affected planetary evolution

Kai Wünnemann

Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science

The evolution of planets and life has been influenced by collisions throughout the history of our planetary system. The violent bombardment of the primordial planets affected their thermal evolution, which is crucial for the formation of habitable worlds. Comets and carbonaceous chondrites may have been important sources of water and pre-biotic molecules delivering key ingredients for the formation of an atmosphere and biosphere. However, the delivery of volatiles by impacts that may have significantly contributed to the growth of atmospheres is counteracted by impact-induced atmospheric erosion. The current state of research to quantify the source and loss processes due to impacts is mostly based on numerical modelling and will be summarized in the presentation. In addition to the fact that impacts shaped the evolution of planets and how earth evolved into a habitable world, the origin of life on earth may be also a consequence of impact: the “Lithopanspermia” hypothesis considers the transfer of life-seeded rock fragments ejected from one planetary body by impact and then delivered through space to another planetary body as meteorites. Brecciation and impact melting of the target may have led to long-term surface and subsurface hydrothermal activity and may have provided a perfect habitat for the origin of life and its continued evolution, in particular during the early Achaean time. However, large impacts also pose a significant threat for developed biospheres through catastrophic environmental consequences. For example, the 65 Ma Chicxulub impact event caused one of the most pronounced mass extinctions in Earth history. Both the positive and negative consequences of impacts on the evolution of life have been explored by laboratory analogue experiments and numerical models. By means of computer simulations of the Chicxulub impact event it will be discuss how these simulations constrain the ensuing catastrophic environmental effects of the KPg impact. Laboratory experiments and complementary numerical models provide constraints on the conditions required for the survival of bacteria during interplanetary transfer. The presentation aims at summarizing the current understanding how the planet's collision history affected the evolution of lithospheres, atmospheres, and biospheres.

Posters

EMPA and LA ICP-MS studies of apatite crystals from Archean Barberton Greenstone Belt.

Łukasz Birski[1], Ewa Slaby[1], Klaus Simon[2], Alicja Giera[1, 3], Izabela Moszumańska[1], Aivo Lepland[4,5,6], Axel Hofmann[7]

[1]Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Warsaw, Twarda 51/55, 00-818 Warsaw, Poland, e-mail l.birski@twarda.pan.pl; [2]Department of Geochemistry, GZG of Georg-August-University, Goldschmidtstrasse 1, 37077, Göttingen, Germany [3]Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum GFZ, Telegrafenberg, 14473 Potsdam, Germany [4]Geological Survey of Norway, NO-7491, Trondheim, Norway [5]Department of Geology, Tallinn University of Technology, Ehitajate tee 5, 19086, Tallinn, Estonia [6]Center for Arctic Gas Hydrate, Environment and Climate, Arctic University of Norway, Langnes, 9037 Tromsø, Norway [7]Department of Geology, University of Johannesburg, Auckland Park 2006, Kingsway & University (APK campus) Johannesburg, South Africa

The studies of Archean abiotic environments are crucial for understanding the origin of Life. The examinations of Archean apatite Ca10(PO4)6(OH,Cl,F)2, investigated as a source of information on volatiles on Early Earth, may help us understand how it happened. Unfortunately, since analyzed apatites are very old, with a long history of secondary alterations and transformations it is crucial to point out which of investigated apatite crystals preserved primordial signature of the environment of their origin. Analyzed by LA ICP-MS and EMP samples from Barberton Greenstone Belt (3.5 – 3.2 Ga) can be divided into 3 groups. First group is represented by unaltered apatite crystals of ultramafic origin. Predominantly these are Cl-enriched hydroxyapatites with Cl concentration of about 1 wt.%. Normalized to chondrite profiles of REEs concentrations are relatively flat with slightly increasing concentrations of LREEs. Second group is represented by apatite crystals of sedimentary origin. EMP analyses revealed that these crystals are Cl-depleted hydroxy-fluorapatie with variable F:OH ratio. Their REEs profiles, normalized to chondrite, are flat with positive Eu anomaly. Last group is represented by hydrothermally altered apatite. It has to be noticed that apatite crystals from both sedimentary and ultramafic environments can be found in this group. EMP analyses show that they are definitely fluorapatite. Their REEs profiles present a wide range of shapes. Some are only LREEs depleted whereas others depleted in both, LREEs and HREEs. Moreover, in some cases crystals from a single sample can be divided into two populations basing on REE profiles. Future research of apatite crystals of first group can give us information about the concentration and evolution of volatiles in Archean mantle. Investigations of second group can be used to examine to what extend apatite preserve primordial sedimentary signature of its origin and signature of secondary alterations.

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Oxygen isotope composition of apatite as a tool for paleoenvironmental and astrobiological studies

Alicja Giera[1,2], Michael Wiedenbeck[2], Johannes Glodny[2], Ewa Slaby[1]

[1]Institute of Geological Sciences, Polish Academy of Sciences, Warsaw, Poland, [2]GFZ German Research Centre for Geosciences, Potsdam, Germany

Apatite Ca10(PO4)6(F,Cl,OH)2 is the most common phosphate mineral in geological environments and it is also the main component of bones and tooth enamel. The oxygen isotopic composition of biogenic apatite has been widely used for reconstructing marine paleotemperatures via measurements of the 18O/16O ratio in fossils (e.g. Joachimski et al. 2009). Even apatite reaching back to the ancient Barberton Greenstone Belt (3.2-3.5 Ga) in South Africa has proved useful for estimating the temperature of the Archaean ocean (Blake et al. 2010). Moreover, the 18O/16O ratio in apatite has been proposed as a potential biomarker for life on Mars (Greenwood et al. 2003). The determination of 18O/16O is commonly conducted using gas source mass spectrometry, which requires up to a few milligrams of sample material. In the case of very small samples, the in situ analysis by secondary ion mass spectrometry (SIMS) is a more suitable analytical tool, requiring under a nanogram of total sample mass. However, SIMS is hampered by the lack of homogeneous reference materials (RMs) required for quantitative measurements. Durango apatite from Mexico has been commonly used as a RM, but recent research has shown that it can have significant intra- and inter-crystalline variations in $\delta 18O$ up to 2 ‰(Sun et al. 2016), rendering Durango of little use for SIMS calibration. The aim of the research we report here is to develop a suite of well-characterized, homogeneous reference materials for the measurements of $\delta 18O$ in apatite. We have tested 32 samples acquired from mineral collections using both isotopic (SIMS, GS-IRMS) and chemical methods (EPMA, SEM-EDS). Our goal is to characterize a set of apatite crystals with 0.1 ‰repeatability of 18O/16O measurements which are available in quantities allowing us to provide this material to all laboratories, making the data they generate traceable.

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Ground and space based cloud-top wind velocities using CFHT/ESPaDOnS (Doppler velocimetry) and VEx/VIRTIS (cloud tracking) coordinated measurements

Ruben Gonçalves[1], Pedro Machado[1], Thomas Widemann[2], Javier Peralta[3], J.-F. Donati[4], David Luz[1]

[1]Institute of Astrophysics and Space Sciences, Portugal, [2]LESIA-Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique, Observatoire de Paris, France, [3]Institute of Space and Astronautical Science - Japan Aerospace Exploration Agency (JAXA), JAPAN, [4]Laboratoire Astrophysique de Toulouse, France

We present wind velocity results based in the measurements of the horizontal wind field at the cloud top level of the atmosphere of Venus, near 70 km altitude in the visible range on the dayside. The purpose is to characterize the zonal and meridional wind latitudinal behaviour and profiles on hour and day timescales. The technique developed over the last decade [Machado et al. 2017] is based on solar lines Doppler velocity in the light scattered by cloud top particles in motion. The study was undergone in coordination with ESA's Venus Express cloud tracking measurements. Our 2014 observations focused on the wind field at latitudes 60°S-60°N, while VEx/VIRTIS privileged southern latitudes poleward of 45°S in search for zonal and meridional wind circulation patterns. ESPaDOnS and the sequential technique of visible Doppler velocimetry has proven a reference technique to measure instantaneous winds. These measurements are necessary to help validating Global Circulation Models (GCMs), and to extend the temporal coverage of available datasets. The ground-based observations in the base of this project are critical in their complementarity with Venus Express data, which was recently decommissioned, and they are expected to play the same role during the ongoing Akatsuki mission. Our analysis technique shows unambiguous characterisation of the zonal wind latitudinal, local time profile and its temporal variability. We will also present a latitudinal profile of the meridional wind measured along both hemispheres, in the mid-latitudes range.

An analysis of the stationary points of the [C6, H4, N]-anionic potential energy surface

Jan Hrušák, Ivana Paidarová, Jan Žabka

J. Heyrovský Institute of Physical Chemistry vvi, Academy of Sciences of the Czech Republic, Dolejškova 3, 182 23 Praha, Czech Republic

The electron spectrometer (ELS) part of the Cassini plasma spectrometer (CAPS) on board the Cassini spacecraft detected heavy negative ions, long chained N containing hydrocarbons, in the deep (<1400 km) ionosphere of Titan [1,2]. An unexpected feature of the negative ions was their notably high mass (up to $\approx 14000 amu/q$), while the positive ions were detected up to 350 amu/q. Vuitton et al. [3] have theoretically investigated the formation mechanisms for negative ions at Titan based on laboratory studies. They conclude that dissociative electron attachment to neutral

molecules (mainly HCN) leads to the formation of negative ions with the main ions being CN- and C3N-. Further, it ia proposed that these negative ions are precursors to the aerosols observed at lower altitudes in Titan's atmosphere. In the present study we aim on the description of all the relevant stationary points of the [C6, H4, N]- anionic potential energy surface (PES) with the ultimate goal to understand the entire

CC-CN- + CH3-CC-H → [C6, H4, N - intermediates]- → fragments / products

reaction. The relative stabilities were calculated at the CCSD(T)/aug-cc-PVQZ//MP2/aug-cc- PVTZ level of theory using the GAUSSIAN09 program package. MP2/aug-cc-PVTZ calculated harmonic frequencies were used for characterization of the minima, the corresponding transition states, and the reaction products. In order to maintain the immense complexity of these calculations the [C6, H4, N]- PES, which is very rich on stationary points (416 identified and characterized so far), was divided into subsections of chemically reasonable molecular patterns. The starting addition reactions are

CC-CN- + CH3-CC-H → NC-CC-C(CH)CH3- → CC-CN-C(CH)CH3- → HC-C4-CH3-

These pathways were investigated separately including all the possible fragmentation channels. The sizable electron affinity of [C6, H4, N]- allows very rich anionic chemistry. Surprisingly, the cyclic CH3-C4H–CN- and CH2-C4H2-CN- intermediates were found to play a key role in the reactions. The overall energetics will be rationalized in terms of these different molecular families and compared with the results of energy resolved mass spectrometry experiments.

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Cold and thin but liquid - microscopic water and its habitability aspects on Mars

Akos Kereszturi [1], Bernadett Pal [1], Maria-Paz Zorzano [2,3], Javier Martin-Torres [3,4]

[1]Research Centre for Astronomy and Earth Sciences, Budapest, Hungary, [2]Centro de Astrobiologia (INTA-CSIC), Madrid, Spain, [3]Luleå University of Technology, Luleå, Sweden, [4]Instituto Andaluz de Ciencias de la Tierra (UGR-CSIC), Granada, Spain

Based on theoretical argumentation and some observations, microscopic liquid brines could be present on Mars. The candidate minerals (like perchlorates and chlorides) might produce liquid by deliquescence during night time hours. Based on climate model computations and orbital humidity observations at most (but not all) past missions' landing sites, microscopic brine could have emerged ephemerally. Analysing the conditions by climate model at ExoMars rover's primary landing site at Oxia Planum, the best annual period based is found to be between Ls 115–225, and (in) at Local Time 2–5, after midnight; while using REMS data (meteorology station onboard Curiosity) two short periods centred at Ls 20 and 270 are plausible candidates as RH maximizes that time.

Although such liquid has extreme characteristics, its relevance for astrobiology should be evaluated, especially regarding water trapping issues, and its emergence under past climates that differ from the current one because of the tilt of the rotational axis. The existence of such liquid will be detected for the first time by the HABIT instrument, which is located onboard the ExoMars rover. This instrument will analyse several habitability related issues, including humidity, the potential role of regolith on daily and annual H2O migration, the emergence of liquid water on hygroscopic minerals and UV radiation. Among these issues the characteristics of night time liquid water will be overviewed and presented, supported by the COOP-NN-116927 project of NKFIH.

Cycles of the landscape genesis on Moon and the evolution of crater landscapes

Serhii Kyryliuk, Olena Kyryliuk

Yuriy Fedkovych Chernivtsi National University, Ukraine

The study deals with the exploration of landscape structure of the lunar impact-explosion craters and its evolution using a morphometric analysis. The scheme of cycles of landscape genesis on Moon in response to the main geological periods (Pre-Nectarian, Nectarian, Imbrian, Eratosthenian, and Copernican) is suggested. The scheme has two levels: 1) morphostructural level reflects the formation of global holistic parts of the Moon landscape sphere formed in the result of the complex and continuous interaction of the landscape factors: bombarding of lunar surface by small bodies together with supplementary geodynamical processes that played a key role in the mega-relief structures; 2) morphosculptural level concerns the establishment of the characteristic landscape features within the structural elements of Moon under the influence of weathering processes. The obtained landscape and morphometric models of lunar craters of basic Moon geologic periods (Pomortsev (Dubiago P), Yerkes, Picard and Menelaus) demonstrate the level of evolution of the main Moon landscape types. To get the comparative morphometric indices determinative of the evolution moment, standard deviation is applied. The original axiomatic concept was used to build landscape models. The concept is aimed at the generation of the unified scheme of search for the surface elementary units and the following classification and interpretation. The application of axiomatic concept in such a way contributes to the classic landscape theory while enables landscape modeling without the contact with the natural body. The concept is significant for the case taking into account the simplicity of the Moon surface. The model contains three positions: 1) the surface image is stable or invariant with stable peculiarities of geometric figures and the formed knots on the surface; 2) landscape properties are seen separately from the geometric form of the surface that involves transition from specific to abstract; 3) elementary form is identified with elementary geometric figures (circle, square, and triangle) that leads to distinguishing invariants and its knots. The holistic images – geosystems are possible to reproduce while moving

the figures in the space. According to the theory of symmetry, the number of such movements is rather limited that contributes to the rapid detection of all the groups of movements and formation of its combinations. Accordingly, the scheme of the impact-explosion craters' landscape structure and its evolution on the basis of landscape models is produced.

Earth and Venus: Planetary evolution and habitability

Pauli Laine

University of Jyvaskyla

In our Solar System Earth and Venus are very similar at planetary level. Venus has sometimes even named Earth's twin because they both have similar size, density, surface composition and have cloudy atmosphere. There are also some differences between these planets. Venus is about 30% closer the Sun than Earth. Venus has retrograde rotation (opposite to Earth's) of 243 days, longer than its's orbital period, 225 days. The most striking difference is the atmosphere, 90 times more dense than Earth, and it contains 96.5% CO2, compared to 0.04% on Earth. These planets' orbits are within the habitable zone (for the existence of liquid water). What caused these two planets to evolve very differently? Could Venus have evolved to more Earth-like state? Could Earth end up to similar state that Venus is today? This presentation will review these important questions in the light of astrobiology and Earth's future.

Exo-Kuiper belts and water deliverable to planets

Jean-Francois Lestrade

Observatoire de Paris - CNRS

The Far-IR Observatories Herschel and Spitzer have discovered a few hundreds exo-kuiper belts around main sequence stars in the solar neighborhood and the total masses of their icy planetesimals have been modelled. A few have been angularly resolved and their radii direcly measured. In addition, a few exo-asteroidal belts are known. The ice and hydrated minerals of the planetesimals provide a reservoir of water deliverable to the inner planetary of the system. We study how star encounters, in the early evolution phase of these systems when they are still embedded in the open cluster of their birth, can trigger comet showers to deliver water to the planets.

Learning The Limits of Earth Life

Julie Nekola Novakova[1,2], Tomas Petrasek[1,3], Jaroslav Kousal[4]

[1]Department of Geophysics, Faculty of Mathematics and Physics, Charles University, [2]Laboratory of Evolutionary Biology, Department for History and Philosophy of Science, Faculty of Science, Charles University, [3]Institute of Physiology, Academy of Sciences of the Czech Republic, [4]Department of Macromolecular Physics, Faculty of Mathematics and Physics, Charles University

Extremophile organisms provide a valuable insight into life's adaptations on various conditions, indispensable for evolutionary biology, biotechnology, astrobiology and many other fields. They provide us with the only reasonable anchor of how to assess habitability of other celestial objects. However, for many of them, we only know their limits in a few dimensions of all the possibilities within environmental conditions, which could cloud our judgment in estimating that a given environment is habitable. For example, we know of several hundred halophiles from various taxa, but for most of them, we don't possess the knowledge of their tolerance toward radiation (let alone different types of radiation) and temperature changes (while many halophiles are tolerant either toward cold, or hot conditions, less is known about the full range of most of them). These would be of great benefit e.g. for estimating the habitability of environments on Mars (where low water availability, high salt activity, radiation, low temperatures and substantial temperature changes play a role), or the risks of its contamination by our spacefaring activities.

For all fields connected to extremophiles, but astrobiology in particular, it would be desirable to know various extremophiles' limits in terms of all dimensions of the "environmental space" (e.g. temperature, salinity, acidity/alkalinity, metal content, biogenic elements' availability, pressure, radiation tolerance, dessication tolerance). Most environments outside of Earth considered as potentially habitable (some areas of Mars, subsurface oceans of icy moons, cloud deck of Venus, "deep hot biosphere" of Earth and perhaps other objects) would require polyextremophile life from our point of view. For most tested species, however, we know limits only in one or two dimensions.

We are working on an educational brochure that could be used in schools or children's science courses. It will introduce the topic of extremophiles in general plus specific examples, accompanied by colored ink illustrations, and highlight the question of search for life in space and its challenges. A draft of the brochure will be available by the poster. It will be prepared in English and Czech. If successful, it could be accompanied by more educational materials including interactive ones. By learning the limits of Earth life, we can promote more in-depth knowledge about Earth's environments and history and other celestial bodies' geology, and we can also make more educated guesses about the chances of life elsewhere, which is important for both research and outreach.

Young Enceladus: Implications for Habitability

Tomas Petrasek[1], Julie Nekola Novakova[1]
[1]Charles University, Prague

Studies of the Saturn system have recently suggested a tantalizing possibility that some of its moons, including the ocean-bearing Enceladus, are not primordial (4,6 Ga old), but formed much later (Asphaug and Reufer, 2013). They probably post-date the Late Heavy Bombardment (Movshovitz et al., 2015), and perhaps accreted as late as 0.1 - 1 Ga ago (Ćuk et al., 2016). This scenario perhaps makes it easier to explain the amount of energy released by the South Polar Terrain on Enceladus, but also has consequences for astrobiological potential of this body. In our poster, we will estimate the consequences of recent formation in several domains, including the availability of energy from accretion, tides, radioactivity and chemical reactions, the challenge of fast origin of life and stability of the environment. We suggest that the recent formation of Enceladus should not make it less promising for astrobiological exploration - even if life did not arise there (yet), it may offer us a glimpse into the very process of biogenesis. In the future, exploration of Enceladus (as well as the other, presumably older ocean worlds) may put meaningful constraints on the theories of life origin and the timing of the process.

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