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Early Stars and Stellar Environments
Oral Presentations

The UV radiation environment in the Solar System

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The UV radiation environment in the Solar System is dominated of course by the Sun. Since the early Sun radiated more intensely in the short wavelength range, the influence of this radiation to the early planets and to the formation of early planetary atmospheres as well as to the evolution of life on Earth and possibly other planets has to be considered in detail. This can be done by comparing the Sun with Solar-like stars at different ages. Young stars clearly show strongly enhanced and strongly varying UV radiation. In addition to that, the occurrence of coronal mass ejections that influence the particle environment of early planets has to be taken into account. In the optical wavelengths the present Sun is variable at only small amplitudes (a few 1/1000); however, this variability increases to orders of magnitude in the UV range, thus influencing the high atmospheric layers of the Earth. Results from satellite measurements are presented and overviewed and implications to the complex climate system on Earth are discussed.

Setting a scene: before another Earth will be found

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The increasing number of extrasolar multi-planet systems, their diversity, and dynamical complexities provide a strong motivation to study the evolution and stability of such systems. One of the most important features connected with planetary system evolution is the occurrence of mean motion resonances, which may relate to conditions at the time of or just after the process of formation. We investigate orbital resonances expected to arise when a system of two planets, with masses in the range 1–4 Earth masses, undergoes convergent migration while embedded in a gaseous disc. Using hydrodynamic simulations we find that the planets can become locked in a first-order commensurability for which the period ratio is $(p+1)\colon p$, with p being an integer, and migrate together maintaining it for many orbits. Relatively rapid convergent migration, as tends to occur for disparate masses, results in commensurabilities with p higher than 2. However, in these cases some resonances show long-term instability. Instead, when the convergent migration is slower, such as occurs in the equal mass case, lower p commensurabilities such 3:2 are obtained, which show much greater stability. There is already one known example of a system with nearly equal masses in the several Earth-mass range, namely the two pulsar planets in PSR B1257+12, which are intriguingly, in view of the results discussed here, close to 3:2 commensurability. Future detection of other systems with masses in the Earth-mass range that display orbital commensurabilities will give useful information on the role and nature of orbital migration in planet formation.

Poster Presentations

Effects of stellar X-ray emission on planet atmospheres

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X-ray emission is a pretty common characteristic of almost all the stars including young stellar objects (YSOs), the latter being copious sources of X-rays with luminosities that span in the range $L_X \approx 10^{29}-10^{30}$ erg sec^{-1}, or up to $\sim 10^4$ times the X-ray luminosity of the active Sun. Evaluation of the changes in the X-ray emission[1] shows that the number of harder X-ray photons decay more rapidly in time than the softer X-ray photons. Using Solar-type stars of the Pleaides cluster, in the 1–10 keV range, X-ray photons at the Earth were three orders of magnitude higher when the Sun was as young as the Pleiades cluster ($\sim 10^8$ years). We investigate the irradiation of an exoplanet by treating the radiative transfer of X-rays in detail. A discussion is presented of the slowing down of fast electrons in a partly ionized gas mixture of H, H_2 and He (the planet atmosphere) with a varying ratio of H to H_2 and a fixed fraction of He. The mean energies and yields for ionization, electronic excitation, dissociation and vibrational excitation, as well as the heating efficiencies are calculated for fractional ionizations from 0 to 0.1. This analysis shows that, at the dawn of the Solar System, the top layers in the atmosphere of a gaseous planet might have reached extremely large temperatures.

Activity of nearby main-sequence G, K and M stars: a determining factor for planetary habitability

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Stellar activity can have major consequences for the habitability of nearby terrestrial planets. In view of forthcoming habitable planet finding missions such as Darwin (ESA) and TPF (NASA), a detailed knowledge of the activity characteristics of possible target stars is essential for the design of these missions. While flaring activity on other stars has been studied for years, there is still a major lack of information on their coronal mass ejection (CME) activity, because CMEs are only directly observable on the Sun. We are currently planning to investigate the CME activity of nearby single main-sequence G, K and M stars, taking into account the association of decametre radio type II bursts and CMEs on the Sun. Two observational campaigns are planned in the near future for implementation of this task. The radio observations will be carried out at the UTR-2, the World's largest decameter array, of the Institute of Radio Astronomy of the Ukrainian Academy of Sciences in Kharkov, Ukraine. Simultaneous observations in the optical range (UBVRI photometry) are also planned and will be carried out at the Astronomical Institute of the Slovak Academy of Sciences in Tatranská Lomnica, Slovakia. We present a general description of our project, as well as statistics of our target lists.

Evolution of high-energy irradiance and particle emission of low-mass stars: effects on planetary habitability

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The results from the 'Sun in Time' program suggest that the coronal X-ray–EUV emissions of the young main-sequence Sun were ~100–1000 times stronger than those of the present Sun. Similarly, the transition region and chromospheric FUV–UV emissions of the young Sun are expected to be 20–60 and 10–20 times stronger, respectively, than presently. In the entire XUV interval from 1 to 1200 Å, we find that the Solar high-energy flux was about three times the present value 2.5 Gyr ago and about six times the present value about 3.5 Gyr ago (when life arose on Earth). In summary, compelling observational evidence indicates that the Sun underwent a much more active phase in the past. The enhanced activity revealed itself in the form of strong high-energy emissions, frequent flares and a powerful stellar wind. Such energy and particle environment certainly had an impact on the genesis and evolution of Solar System planets and planetary atmospheres. Because lower mass stars are especially common and hence may host habitable planets, progress in this direction has started by expanding the 'Sun in Time' program to time sequences of the high-energy emissions, wind and flare activity of low-mass K and M stars. Because of the low luminosities, their 'habitable zones' can be quite close to the host stars. The initial studies of K and M main-sequence stars have revealed that they have very strong coronal/chromospheric XUV emission fluxes compared with Solar-type stars with similar rotation periods or ages. A profound knowledge of the activity characteristics of these late-type stars is therefore of great importance in view of future space missions dedicated to the search for potentially habitable planets such as COROT, Eddington and Darwin/TPF.

The case of superhot Jupiters

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Although there is a general standard scenario of planet formation, there are some details and specific areas that raise doubts and questions. The migration of planets is one such problematic process. In this work we investigate the migration process under some special circumstances. Based on the standard model of Classical T Tauri stars, we simulate a special case of disk–planet interactions. It is generally believed that these stars possess strong magnetic fields, which truncate their protoplanetary accretion disks, forcing the accreted material to flow along the field lines. We consider a central star of one Solar mass surrounded by the non-self-gravitating, thin accretion disc. Our disk is truncated at a distance of 0.057 AU from the central star. We put a planet in the gap between the star and the disk at an initial radius of 0.055 AU. The protoplanet evolves under the gravitational interaction of the central star and the protoplanetary disc. The acceleration from the disc is expected to cause the migration of the protoplanet. We have investigated two cases in which the value of density was chosen so that the initial disc mass was 10 and 100 Jupiter masses. For each disc mass we computed three models with different values of the protoplanet mass: 0.5, 1.0 or 2.0 Jupiter masses. The main aim of our work was to investigate the evolution of the planet's orbit due to the torque exerted on it by the truncated protoplanetary disc. The planet orbiting at the inner edge of the disc excites a set of trailing spiral density waves. The gravitational interaction between the spiral wave pattern and the planet leads to a torque acting on the planet and inducing its migration into the magnetosphere. As the planet migrates towards the central star, the amplitude of the spiral waves and the torque from the disc decreases. Therefore, the migration of the planet slows down. Our simulations lead to the following conclusion: inside the accretion disc, the more massive planets migrate faster, which results in their smaller distance from the central star after a given period of the evolution. This is in qualitative agreement with mass–orbital radius correlation suggested by Mazeh.

Habitable Zones and Planetary Habitability

Oral presentation

How common is complex life in the Milky Way?

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An integrated Earth system model is applied to calculate the habitability for primitive (unicellular) and complex (multicellular) life of terrestrial planets in extrasolar planetary systems. The model is based on the global carbon cycle mediated by life and driven by increasing stellar luminosity and plate tectonics. The primitive and complex life forms differ in their temperature and CO_2 tolerance. While complex life is more vulnerable against environmental stress, it amplifies weathering processes on a terrestrial planet. The model allows us to calculate the average number of Earth-like planets harbouring primitive and complex life by estimating the habitable zone for both life forms and using the formation rate of Earth-like planets in the Milky Way. We find that the number of planets bearing complex life is at least two orders of magnitude lower than the number for primitive life forms.

Are all the planets in our Solar System experiencing recent global warming and what does it mean?

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Some global warming scenarios on Earth have indicated that anthropomorphic greenhouse gas emissions are affecting climate worldwide. However, while this is certainly a contributing factor, greenhouse gas emissions are not the primary cause of the recent warming trend. Observational evidence from a variety of spacecraft along with Earth-based telescopes show marked changes in the climate of the planets Earth, Mars, Jupiter, Saturn, Neptune, Uranus and Pluto that indicate a possible Solar System-wide warming event is taking place. The entire Solar System moves through the local interstellar medium (LISM) of our galaxy. This interstellar medium contains both low-density and high-density molecular clouds and cloudlets. As the Solar System follows its orbit around our galaxy it can encounter these extremely dense cosmic clouds and cloudlets. This would allow the flow of neutral hydrogen gas from the LISM into the Solar System affecting Solar output and cause the protective magnetic field of our Sun (called the heliosphere) to contract and initiate unusual climate changes on the planets, icy moons and rings. By comparing recent observations to those made of the outer planets by the Voyager 1 and 2 spacecraft it is evident the Solar System is undergoing a dramatic environmental change. Some of Earth's most devastating mass extinctions may have been caused by global warming and ice age events initiated by passage through low-density and high-density interstellar clouds and cloudlets. From the Late Cretaceous period to the Eocene 55 million years ago, there were no polar ice caps and tropical flora and fauna were found above the Artic Circle. Newly acquired data from the Arctic Circle indicate that the sea ice there could be completely gone in less than 100 years.

The impact of galactic cosmic rays through the magnetospheres of different extrasolar planets

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Usually, planetary habitability is associated with the existence of liquid water on the planetary surface. While this is a necessary condition for life as we know it, this condition is far from sufficient, especially for planets close to their host star, and additional aspects have to be studied. One of these aspects is the impact of galactic cosmic rays through the planetary magnetosphere. We show that close-in extrasolar planets in the habitable zone of low-mass stars are synchronously rotating with their host star because of the tidal interaction. For such gravitationally locked planets, the rotation rate is determined by the orbital period, leading to rotation rates that are much lower than those expected for planets not subject to tidal locking. This results in a relatively small magnetic moment. For example, an Earth-like extrasolar planet, tidally locked in an orbit of 0.2 AU around an M star of 0.5 Solar masses (i. e. within the region where liquid water is expected to be stable on the planetary surface), has a rotation rate of 2% of that of the Earth. This results in a magnetic moment of less than 15% of the Earth's current magnetic moment. Therefore, such a close-in extrasolar planet is not protected by an extended Earth-like magnetosphere, and cosmic rays can reach almost the whole surface area of the upper atmosphere. Primary cosmic-ray particles, which interact with the atmosphere, generate secondary energetic particles, creating a so-called cosmic-ray shower. For moderate surface pressures, some of these particles can reach the planetary surface. We suppose that, under such pressure conditions, biological systems on the surface of different extrasolar planets at close-in orbital distances can be strongly influenced by secondary cosmic rays.

On the habitability of an Earth-like exoplanet exposed to the intensive stellar CME activity

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Low-mass M- and K-type stars are much more numerous in the Solar neighbourhood than Solar-like G-type stars and therefore represent potential targets for star selection of Darwin and TPF-C/I terrestrial exoplanets search programs. Because the orbital distance of the habitable zone (HZ) of low-mass stars its much closer to the host star compared with the Sun, Earth-like exoplanets will be effected by tidal-locking, which results in weaker intrinsic magnetic moments, high energetic particle exposure, high X-ray and γ-ray exposure, dense stellar winds and coronal mass ejections (CMEs) impacts. We focus only on the effects of the interaction of CMEs with the atmospheres/magnetospheres of Earth-like exoplanets at orbits inside the HZ of low mass M-stars, and extrapolate the existing knowledge regarding Solar CME activity to the exosolar case of low-mass active stars. Our study indicates that the difference of the mass flux between strong and weak CMEs is not as important as the difference between strongly and weakly magnetized Earth-like exoplanets. Our results show that for weakly magnetized Earth-like exoplanets, the atmosphere is strongly affected by the incoming CME plasma flow. CMEs can compress the magnetospheres of such planets down to atmospheric levels, where the ionized compounds of the atmosphere build an ionopause obstacle.

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The results of our study indicate that CMEs can erode an atmosphere equivalent to a pressure of about 1 bar at an Earth-like exoplanet orbiting of a low-mass M-star at 0.05 AU, after 40 Myr, resulting in a loss of about 25 bar after 1 Gyr. For weakly magnetized Earth-like exoplanets at orbital distances of about 0.1 AU, an atmosphere of about 1 bar and 5 bar is eroded by CMEs after 200 Myr and 1 Gyr, respectively. An atmosphere of about 1 bar can be lost at weakly magnetized Earth-like exoplanets after 1 Gyr at orbital distances of about 0.15 AU. Stronger magnetized Earth-like exoplanets have larger magnetospheres so that their atmospheres are protected from hitting CMEs and related atmospheric erosion.

Results of the First Workshop on the Habitability of Planets Orbiting M Dwarf Stars

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M dwarf stars comprise about 75% of all stars in the Galaxy. They are extremely long-lived and although much smaller in mass than the Sun, they dominate the stellar mass function. We have re-examined what is known at present about the potential for a terrestrial planet forming within, or migrating into, the habitable zone close to the star. We conclude that M dwarf stars may indeed be viable hosts for planets on which the origin and evolution of life can occur. Although the classic circumstellar habitable zone for M stars is $\sim 1/10$ the width of that of G stars, and there are a number of processes that may limit the duration of planetary habitability to periods far shorter than the lifetime of the M dwarf star, it makes sense to include M dwarf stars older than ~ 1 Gyr in programs that seek to find habitable worlds and their inhabitants.

Methanogenic archaea from Siberian permafrost: fit for Mars?

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Evolution of life on Earth started 3.5 Ga ago, when living conditions on Mars were similar to those on early Earth. Hence, it is legitimate to assume that life emerged on Mars as well as on early Earth. The current ESA mission Mars Express determined water on Mars, a fundamental requirement for life, and the presence of CH_4 in the Martian atmosphere, which could only originate from active volcanism or from biological sources. These findings implicate that microbial life could still exist on Mars. One possibility for survival of Martian primitive life might be subsurface lithoautotrophic ecosystems. Comparable environments exist in the permafrost regions on Earth. Despite the unfavourable life conditions, permafrost is colonized by high numbers of viable microorganisms, including methanogenic archaea. The capability of these organisms to grow under lithoautotrophic conditions, whereby energy is gained by the oxidation of H_2 and CO_2 is the only carbon source under strictly anaerobic conditions, tolerance to low temperatures and long-term survival under extreme conditions of permafrost make methanogens the most suitable keystone organism for the investigation of possible Martian life. Within the scope of DFG Priority Program '*Mars and the Terrestrial Planets*' we study the tolerances of methanogens under the extreme life conditions of terrestrial or extraterrestrial permafrost (Mars simulation). The borders of growth influenced by desiccation, temperature extremes, radiation and high salt concentration were analysed for the methanogenic archaea in pure cultures as well as in their natural environment of Siberian permafrost. First results represent high survival potential under these extreme conditions. Significant CH_4 formation appeared even by incubation with saturated salt solution (0.02 nmol $CH_4\ h^{-1}\ g^{-1}$), radiation dose 5000 J m^{-2} (0.8 nmol $CH_4\ h^{-1}\ g^{-1}$), desiccation (13.06 nmol $CH_4\ h^{-1}\ ml^{-1}$) and subzero temperatures (0.04 nmol $CH_4\ h^{-1}\ ml^{-1}$).

Possible habitats for life in the Venusian environment? Can the Venus Express payload answer?

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The Venusian conditions are unique in the Solar System. Venus has a dense CO_2 atmosphere, is volcanically active, and has plenty of energy sources such as light, UV radiation, volcanic activity and chemical energy from atmospheric disequilibria conditions. Its surface conditions are sufficiently hot for sterilization and volcanism injects highly toxic gases, which in the absence of unbound water can accumulate in the atmosphere. The Venusian surface is constantly regenerated by volcanism and any possible fossil record from early Venus history in which oceans existed on its surface is almost certainly destroyed. Its upper atmosphere lays bare to Solar radiation with only carbon dioxide to act as a confirmed EUV filter. Any possibility of life was considered irrational before extremophile bacteria were discovered in dark undersea hot sulphur rich volcanic vents on Earth. However, some regions of the Venusian clouds might show conditions similar to the Earth surface and could be a habitat of thermophilic microbial life similar to that observed on Earth. A synergy between the different instruments of the Venus Express payload, the SPICAV spectrometer and the VMC camera in a first step, and the spectrometers VIRTIS and PFS in a second step, will probe the actual environmental conditions of the cloud region. Given these observations we will be able to analyse whether the environmental conditions of the cloud layer would make it a possible habitat for extant microbial life. The instruments will shed light on the availability of nutrients, water, types of energy sources, atmospheric dynamics and organic chemistry.

Passing of the Solar System through the dense interstellar gas clouds and a planetary habitability

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In its motion through the Milky Way Galaxy, our Solar System passes through the clouds with high interstellar gas density. Even if the density of the local interstellar medium increases up to only ~ 10 H cm^{-3}, the heliosphere can be effectively suppressed within 10 AU due to increased interstellar gas pressure. Such events have probably occurred thousands of times in the Earth history. We show the possibility of global glaciations of the Earth due to accretion of interstellar dust into the upper atmosphere of the Earth at the encounters of the Solar System with the dense giant molecular clouds. The passages of the Solar System through moderately dense interstellar clouds can cause a dramatic increase in the flux of the anomalous component of cosmic rays (ACRs) along with an increased flux of galactic cosmic rays (GCRs). ACR and GCR radiation produces high concentrations of NO_x in stratosphere, which in turn destroy the ozone layer. As a result, the biosphere experiences dramatic impact of UV-B radiation. Here we also report the results of simulations for a high rate injection of interplanetary dust particles from the Kuiper belt into the region of terrestrial planets due to an effective gas drag in the interstellar clouds. We consider the complex impact of encounters with interstellar clouds on the biosphere and climate of the Earth, Mars and terrestrial-like planets of other planetary systems, including 'mass extinction' on the Earth, 'sterilization' of the Martian surface and a habitability of terrestrial-like planets.

Extremophile cryptobiotic communities in cold and hot deserts

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As was emphasized by Pócs *et al.*[1,2], cryptobiotic crust communities dominated by cyanobacteria, developing on rock or on bare earth surfaces, can be analogues of possible Martian life forms. The evidence for the presence of temporarily fluid water of the Mars surface is increasing[3–6]. A theory for the biotic origin of dark dune spots in the subarctic belts of Mars was elaborated on by Horváth *et al.*[7–10] and Gánti *et al.*[11]. The survival ability of cyanobacteria among Martian conditions has been under testing since recently by chamber experiments in several laboratories. Thorough studies on the cryptobiotic crust communities in the cold deserts of Antarctica, in the hot deserts of the Sahara and the hot semideserts of central and western parts of Australia were carried out by the authors. The components of these cyanobacteria-dominated communities were identified and the structure of the communities is described. The study of the cryptobiotic crusts revealed various adaptations and defending mechanisms of these extremophile communities against wide temperature changes, intensive UV irradiation and long-term desiccation. Similar adaptations can serve the long-term survival and short-term revival and life activities of the supposed Martian organisms.

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Lightning-induced astrobiological potential of rare gas–grain medium: where and when in Solar System

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Following Miller experiments, lightning is now considered as a possible energy source for the synthesis of biochemical compounds both in Earth's atmosphere and in the atmospheres of others bodies of the Solar System. Lightning in gas–grain mediums cannot be the only energy source for the synthesis of biochemical compounds. For prebiotic chemistry, this has the important consequences that the plasma of these discharges will have the properties of dusty plasma, owing to the presence of charged micrometre-sized particles (0,1, …, 10 μm). The purpose of this paper is the attempt to estimate the influence of the parameters of gas–grain medium on such a lightning-induced astrobiological potential. As a basis for these estimations, we use the parameters of sprites (lightning in Earth's mesosphere) and assume that discharges with such properties happen in gas–grain medium. We should consider the number of discharges, quantity of matter in the area of discharges and energy, which dissipates at discharges. It is evident that the frequency of usual lighting and its energy dissipation at discharge make it a basic candidate for the role of an energy source for synthesis in the atmosphere. It is also likely that sprites will occur. Sprites are highly structured mesospheric lightning that occurs above thunderstorms. Their energies are approximately 10–50 MJ (the energy of typical lightning on Earth is 500 MJ). Sprites can extend about 40 km in the horizontal and vertical directions and can occupy atmospheric volumes of about 104 km^3. The strongest usual lighting in the Earth's atmosphere takes a volume of less than 0.0001 km^2. Even if we take into account the fractal structure of sprites, this is seven or eight orders of magnitude more than the volume of usual lightning. The quantity of matter in a sprite constitutes approximately $10^5 - 10^6$ tons. At discharge in usual lightning, the quantity of matter is approximately 10^2 tons. In my opinion, this difference provides evidence for the higher astrobiological potential of sprites in comparison with usual lighting. It is possible to tell that the density of the rare gas–dusty atmosphere, which corresponds to the density of the Earth's atmosphere at altitudes 70–90 km (pressure 0.04–0.001 Torr), will be such that the additional capabilities for prebiotic chemistry will be apparent. Where do (or did) such conditions exist? At present, the atmospheres of comets and Mars are most similar. However, there is the problem of a lack of electrical activity in these atmospheres. The same problem exists for the assumption about discharges in the atmosphere of early Earth (pressure about 1 Torr).

Signs of water runoff and its relation to possible living organisms on Mars

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Possible water-related slope structures on Mars were analysed and classified into three groups: gullies, dark slope streaks and seepages. The last group was analysed regarding their location, morphological and morphometrical characteristics. The seepage characteristics were analysed in order to elucidate to what extent they could be the result of liquid water seepage below the seasonal water-ice/carbon-dioxide frost cover. The authors' conclusion is that the structures are probably formed under the action of liquid water resulting from the Solar insolation and solid-state greenhouse effect of the frost. These locations are of high potential importance for astrobiological research on Mars. A theory for possible Martian life forms in the dark dune spots has been developed. We sketched the following life cycle of the possible Mars surface organisms (MSOs): in winter the first rays of sunlight activate the MSOs, they start to warm up and melt the H_2O ice around them, while above them sublimation of CO_2 on the top of the frost is accelerated. Later MSOs begin to grow and reproduce in the water melted by them. Complete defrosting of the water-ice cover stops shielding the MSOs and water also immediately evaporates on this unprotected region, hence the life conditions of MSOs cease and they desiccate. Therefore, despite the adverse conditions, the hypothetical MSOs could dwell below the surface ice, in the upper water-rich layers of the dark dune field. Melting of water ice in the uppermost layer of the dune subsurface, triggered by the life activity of MSOs above, may contribute to the observed traces of liquid water associated with the dark dune spots seepages.

Implications for the radiation environment of the early Earth based on early to mid Archaean microfossils

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Modelling of the radiation environment of the early Earth[1] indicates that the amount of DNA-weighted UV radiation reaching the surface of the early Earth was about a thousand times the present value (worst-case scenario). This amount of radiation is deleterious to the long-term survival of microorganisms. However, the most-ancient, well-preserved sediments in 3.3–3.5 Ga-old rock formations from the Pilbara and the Barberton greenstone belts[2–4] contain the fossil remains of well-developed microbial biofilms and mats that developed on the surfaces of shallow water sediments and even on the surfaces of beach (littoral) sediments. The mat-forming microorganisms were healthy when fossilized (by silicification) and showed no morphological signs of stress. They were obviously capable of surviving (for at least short periods of time) in a subaerial environment, despite the supposedly deleterious UV radiation environment of the early Earth. These observations raise questions about the modelled UV flux on the early Earth. Either the flux was not as high a calculated, or there were a variety of factors that decreased UV radiation to the surface, such as high amounts of aerosols and volcanic/meteoritic dust in the atmosphere, and possibly a certain amount of ozone produced by photo-dissociation of water vapour in the atmosphere. A rapid gene repair mechanism on the part of the microorganisms would have been an additional necessity.

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Poster presentations

Europa's radiation and energetic particle induced exosphere: remote determination of surface materials from a Europa orbiter

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We study the intense radiation and particle interaction with the surface of the Jovian satellite Europa and model its sputter-induced exosphere. At present only a couple of exospheric species have been identified: Na and K from the decomposition of hydrated minerals, oxygen from the dissociation of water-ice molecules and most likely water, SO_2 and CO_2. We investigate whether a detailed study about the Na/K ratio in Europa's exospheric environment will lead to a better understanding about the up-welling of subsurface ocean material. We suggest that Europa's exosphere should contain many other sputtered molecular species. This is very interesting, especially because organic material from the subsurface ocean could be transported via cryovolcanism to the surface. We show that such material could easily be sputtered to altitudes, where it could be detected by the particle detectors of an orbiting spacecraft.

Aqueous acidic environments on Mars (I): ancient Mars

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Evidence for liquid water on ancient Mars is compelling. It has been explained by invoking controversial solutions based on warming the atmosphere with greenhouse gases or in local thermal energy sources. We show here that enhanced loading of the Martian aqueous solutions allowed the metastability of acidic liquid water on the surface, albeit with Mars' global mean temperatures remaining somewhat below the freezing point of pure water, experiencing neither global nor punctual warm conditions. The freezing point depression of the aqueous solutions is a function of pressure and chemical composition. We assumed that the partial pressure of CO_2 on early Mars would be 1.5–2 bars[1]. In our equilibrium model, variable quantities of solutes have been added to the initial pure liquid water, as high abundances of Fe, Mg, and the salt-forming elements S, Cl and Br in Martian soils is firmly established for all five sites visited by landers with appropriate analytical capabilities. These results have recently been extended: by the discovery of remnants of ancient acidic brines[2] derived from the alteration of the mafic crust favouring the formation of sulphates relative to carbonates and other salts[3]; by discoveries of widespread sulphate deposits from orbital observations[4]; by even higher sulphate and chloride concentrations in outcrop materials at Meridiani Planum[5]; and by significant traces of bromides in igneous rocks at Gusev Crater[6]. Thus, our model is built on the current knowledge of Martian surface composition based on Mars Lander data, indicating that any Martian early hydroshere was probably acidic and more salty than that of early Earth (up to twice as salty as modern terrestrial oceans[7]). The role of solutes as a way to depress the melting point, and to permit liquid on the Martian surface for temperatures below 273 K, has been considered by several pioneering studies[8–11]. However, these studies focused on the present climate system, and set forth very dense liquids, thick eutectic brines with a high viscosity, inconsistent with the shape and morphology of the valley networks, outflow channels and gullies, which suggest rapid fluvial flow rather than the slow, halting movement of low-temperature cool molasses. As such, the saturated solution hypothesis has remained just that, in part because pre-Mars Global Surveyor observations were unable to unambiguously determine the extent and quantity of surface evaporite deposits on Mars. Current *in situ* and orbital surface investigations are now able to better determine the mineralogical composition of surface and subsurface salts, thus allowing watery solutions to be modelled that can account

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for a complete hydrological cycle. These acidic weathering fluids can remain in a liquid state for temperatures well below the freezing point of pure water. Their stability against freezing explains how supercold, acidic and salty solutions of variable extent have been sustained for long times on the surface throughout the entire geological history of a basically cold Mars. From a biological perspective, terrestrial high acidic and salty waters hold a phylogenetically wide array of microorganisms[12]. Whether favouring an autotrophic or heterotrophic origin of life on our planet, similar conditions of increased salinity[7,11], high acidity[13,14] and low temperature[15] were prevalent on early Earth. The possibility of life surviving the subsequent driest periods is challenging.

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Aqueous acidic environments on Mars (II): modern Mars

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The discovery of the ferric sulphate mineral jarosite in Meridiani Planum, a near-equatorial region of Mars, indicates that a complex diagenetic history has occurred, including inundation by shallow acidic surface water, evaporation and desiccation. After jarosite precipitation, an arid environment must have prevailed, as jarosite becomes unstable and rapidly decomposes to ferric oxyhydroxides in the presence of new liquid water. However, it still remains an open question whether jarosite was formed in ancient times, with no subsequent aqueous alteration during perhaps billions of years, or whether it has been formed in a more recent period of water stability[1,2]. Several factors illustrate that considering Meridiani jarosite as an ancient mineral assemblage may pose severe problems. If jarosite formed in place millions or billions of years ago, not only the chemical but also the physical environmental parameters at Meridiani must have been remained strictly constant during the entire time for jarosite to be metastable. This scenario does not agree with our current knowledge about Mars. Very recent weathering processes of rock materials exposed at the Martian surface includes: (1) important changes in the near-surface water reservoirs, and in atmospheric composition and pressure, due to large excursions in planetary obliquity[3] and/or continuing extensive volcanism[4,5]; (2) planet-wide[6] and specifically equatorial[4] glacial activity; (3) wind activity, which includes dust particle transport, wind streak formation and mantling of the soil[7], as reported for Meridiani[8]; and (4) small-diameter and fresh craters, with impact-related crushed layers mantling previous deposits, suggesting local exposure ages of the surface as recent as 1 My, as dated for Meridiani[9]. Any alternative explanation considering these same physical weathering mechanisms as trigger agents for environmental changes leading to the exhumation of ancient buried assemblages, must resolve how delicate jarosite can resist ice-related chemical weathering, destructive global storms removing uppermost deposits, or, in particular, impact temperatures and pressures. Thus, the only reasonable conclusion after analysing Meridiani mineralogy is that jarosite has been formed in a very recent, virtually contemporary, transient acidic wet environment. The contribution of water at that time was likely not a continuous body the size of the sulphate-bearing unit that extends over regional scales (up to 3×10^5 km^2)[10,11], but shallow and heterogeneously localized ponded brines remaining liquid at temperatures well below 273 K. Moreover, the presence of unweathered basalt in the same location along with jarosite[1,2,8] indicates that liquid water was present only transiently in Meridiani at the time when jarosite was assembled. As the sulphur-enriched soil described in Meridiani requires a vast amount of long-term stable acidic water to be formed, it is likely to have occurred in more ancient times, when sulphuric acid exhalated from volcanic eruptions combined with water to corrode Martian rocks and produce acidic waters around the planet[12]. Over this previous sulphatic surface, little amounts of water have been flowing episodically assembling the jarosite observed in Meridiani, both in Eagle and Endurance craters as well as in rocks exposed at Anatolia trough. This interpretation has profound implications for the ongoing debate about the age of the water-related geology at Meridiani. It is possible that part of the described mineralogy reflects recent supercold episodes of local acidic brines. In fact, minor amounts of water seem to have been flowing recently between rocks and ponding deep into craters in Meridiani, as suggested by the Mars Exploration Rover Opportunity explorations in Endurance crater. As episodic aqueous processes also occurred at Meridiani several billions of years ago, varying amounts of shallow surface water may have been recurrently ponding there (and even on other Martian locations) during a major portion of Mars history. From a biological perspective, terrestrial high acidic and salty waters hold a phylogenetically wide array of microorganisms[13]. In the Earth, microorganisms have evolved to accommodate to a variety of extreme conditions: dessication, supercold, salty and acidic. Active bacterial communities that derive energy from iron and sulphur compounds in areas covered by glaciers and thick permafrost[14,15] could serve as analogues to search for iron–sulphur based ecosystems living at extremely low temperatures in acidic subterranean brines in Mars.

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Europa's surface and subsurface ocean: astrobiological implications

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Speculations about life in the subsurface ocean of Europa is a driving force for the future space exploration of this Galilean satellite. Our study examines possible energy sources relevant for life in such an ocean, expected chemical compounds in the ocean and theories about the thickness of Europa's ice shell. Further, we study the possibilities for transporting ocean-material via cryovolcanism to Europa's surface and study its impact to the surface chemistry, which is heavily effected by the radiation and particle environment of Jovian's magnetosphere. Finally, we discuss surface areas, which are interesting for the search for life on Europa and the implications for radiation induced limiting environmental factors for habitats.

Possible existence of terrestrial planets on horseshoe orbits in habitable zones of exoplanetary systems

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We have studied three real exoplanetary systems, HD 4208, HD 23079 and HD 28185, through computer simulations. In each of these, a single giant planet is known to exist on a nearly circular orbit inside the habitable zone of the system. In each of these systems we have assumed an Earth-like small planet moving around the central star locked to the motion of the giant so that the orbit is a special astrocentric orbit known as a horseshoe orbit. In the simulations the orbital semi-major axis has been varied around the semi-major axis of the giant planet's orbit within $\Delta a = \pm 0.2$ AU and the inclination between the orbital planes has been varied from 0° to 20°. The numerical method used for the simulations is direct integration of the orbit with modified Wisdom–Holman algorithm and the stability analysis is based on the Lyapunov times that are calculated via direct code differentiation. As a result, we have found that these orbits do not seem to exist in all planetary systems, but also that this kind of special motion can make a terrestrial planet stay inside the habitable zone with a Jupiter-like giant planet maybe even long enough to allow life to evolve.

Reactivation of possible dormant biology by the onset of convection in the ice shell of Europa

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Europa's chaos and lenticulae are frequently considered as being among the youngest geological features of Europa. These features may have been originated in relation to thermal diapirs linked to convective upwellings. Convection (and diapirism) starts if the ice shell is thicker than a critical value (with details depending on the dominant ice rheology, grain size and intensity of tidal straining). Following to the onset of convection, isotherms in the stagnant lid (the thermally conductive, cold and essentially immobile lid above the actively convective layer) become shallower due to the higher convective heat flow, which should be additionally increased by tidal dissipation in the warm convective layer. Previously to the onset of convection, possible biological forms living in, or close to, the shell/ocean interphase could result trapped and dormant in ice, due to satellite cooling and thickening of the ice shell. Some biological substances are used to optimize cellular functioning under low water activity conditions, such as low-temperature and high-osmotic conditions. Trehalose is an example that is frequent in halophilic microorganisms, which could be present on Europa. This kind of compound can reduce the water melting point to ~ 230 K, a temperature similar to that at the stagnant lid base. Thus, isotherms shallowing posterior to the onset of convection could cause an event of reactivation of dormant biological forms close to the base of the stagnant lid. The onset of thermal diapirism would have similar effects, moreover as diapirs are near to the melting temperature: chaos and lenticulae features are, therefore, places where signature of bio-antifreeze substances might be found.

Prebiotic Chemistry
Oral presentations

Infrared spectra of a species of astrochemical interest: aminoacrylonitrile (3-amino-2-propenenitrile)

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Ammonia readily reacts on cyanoacetylene in the gas phase or in a solvent to form the Z- and E-isomers of aminoacrylonitrile (3-amino-2-propenenitrile). This kinetically stable enamine presents interest for its possible presence in the interstellar medium, the comets and the atmospheres of planets including the primitive Earth. B3LYP/6-311+G(3df,2p) and G2 calculations indicate that the imine isomer is significantly less stable than the corresponding enamine. DFT and G2 calculations indicate that the Z-isomer of aminoacrylonitrile lies around 8.0 kJ mol^{-1} lower in energy than the E-isomer. The infrared spectra of the aminoacrylonitrile, both in the gas and condensed phases, were recorded in the range 500–4000 cm^{-1}. The compound presents a very low vapour pressure at room temperature. So, a cell of 96 m was necessary to record the infrared spectrum in the gas phase. Consistently with the theoretical calculations, the imine and the E-isomer of the enamine have never been detected in the infrared spectrum of a gaseous sample and only the Z-isomer has been observed. With a neat sample in the condensed phase, infrared spectra of 1:1 and 20:1/Z:E mixtures were recorded. The comparison of these data with the spectrum of the Z-isomer in the gas phase allowed us to deduce the infrared spectrum of the E-isomer. The E–Z isomerization takes place through a torsion around the C=C bond. A possible mechanism involving a previous enamine–imine tautomerism must be discarded because it implies a much larger barrier than the direct isomerization process. Consistently, the presence of a deuterium atom has not been observed on the sp^2 carbon of the products of distillation of a 1:1/E:Z mixture of the $NCCH{=}CHND_2$.

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The synthesis of organic compounds in the late stages of stellar evolution

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Recent theories on exogenous delivery often rely on gas-phase organic molecules in the proto-stellar molecular cloud as a source of primordial material for the origin of life on Earth. What has not been considered is the possibility of the transport of carbonaceous solid-state compounds from stars to the pre-Solar nebula. Since solids are much more likely than gas-phase molecules to have survived the formation of the Solar System, their presence may have much greater impact on the prebiotic chemical evolution on Earth. Recent observations by the Infrared Space Observatory (ISO) have found evidence of the rapid synthesis of complex organic molecules in the late stages of stellar evolution. The chemical synthesis begins with the formation of acetylene, the first building block of benzene, in carbon stars. In the following proto-planetary nebulae stage, emission features corresponding to stretching and bending modes of aliphatic compounds are detected. When these objects evolve to become planetary nebulae, aromatic C–H and C–C stretching and bending modes become strong. These results show that complex carbonaceous solid-state compounds can be produced in a circumstellar environment over a period of only a few thousand years[1,2]. Isotopic analysis of meteorites and interplanetary dust collected in the upper atmospheres has revealed the presence of pre-Solar grains similar to those formed in evolved stars. This provides a direct link between star dust and the Solar System and raises the possibility that the early Solar System was chemically enriched by solid-state ejecta from evolved stars and planetary nebulae[3].

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RNA viruses as models for early replicons

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It is believed that the early life forms were based on RNA (or RNA-like) molecules. It is possible that the pools of short RNA-replicons, each containing minimal or no coding capacity, replicated by common replication machineries and undergoing strong sequence variation via high recombination and mutation rates, may have had several similar molecular features and survival strategies as concurrent RNA viruses and viroids. It can be postulated that the early RNA replicons were involved in the early replication function, and also mediated other necessary functions and molecular interactions. The replicons had to function as templates both for the replication and for translation. The translation initiation had to be (fairly) protein-independent and the replication mechanism had to copy the entire replicons, including their terminal sequences. The replicons had to have potential for efficient genetic recombination and evolution. Similar molecular functions and features occur commonly also in many present-day RNA viruses. Both the early replicons and the current viruses and viroids are fully heterotrophic for all their molecular building blocks: viroids and viruses solely utilize biomolecules (nucleotides, amino acids and energy compounds) synthesized by their hosts, and apparently the early replicons utilized the biomolecules synthesized by their environment. In their life styles and genomic structures they both are minimalists, that is, they code only very limited functions. The most reduced virus genomes code only for their replicase enzyme, the protective coat protein and a protein for interaction with the host; viroids do not code for any protein products. Presumably the first translatable RNA replicons encoded for short and very simple polypeptides, maybe initially with structural or chaperone function. Several viral structures and features may be considered as potential functional models for the early RNA-based life forms.

Irradiation by radioactive minerals in impact craters: 1. Preferred sites for fixation of methane, carbon concentration and detection of organic molecules

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Irradiation can cause the polymerization of simple organic molecules, causing an increase in complexity and the concentration of carbon. This has been suggested as a mechanism that could have occurred on the early Earth, involving irradiation from radioactive (uranium, thorium) minerals, including monazite, zircon and uraninite[1]. Could this process occur in hydrothermal systems in impact craters, which have been suggested as likely sites for prebiotic chemistry and primitive evolution? In terrestrial craters, it is difficult to assess whether complex organic molecules can be created from abiogenic compounds because abundant biogenic materials are already present, but we can assess if (i) crater environments can support concentration of carbon by radioactive minerals, albeit from biogenic sources, (ii) carbon concentration can occur in both target rock and crater-fill sediments, and (iii) carbon is concentrated where it would otherwise be undetectable. These ideas were tested in the Lockne Crater, Sweden, as the Swedish crystalline basement and sedimentary cover rocks are uranium-rich and the target rock included organic-rich sediments. Petrographic studies show that carbonaceous polymers have precipitated around radioactive minerals in each of granitic and impact breccia matrix, and resurge deposits, in the Lockne Crater. Nodules up to 400 μm consist of mixtures of carbon with uranium oxide or uranium/thorium silicates. These results show that where radioactive minerals are present in the target rocks for craters, they are preferred sites both for carbon concentration and for our detection of organic molecules. The carbon in the Lockne Crater nodules is almost certainly derived from pre-existing organic matter of biological origin. However, if the irradiation process could be responsible for prebiotic chemistry, the likely starting material would be methane. There are several documented occurrences of carbonaceous polymers in uranium deposits elsewhere that are attributed to a methane source, characterized by very light carbon isotope compositions. Carbon isotope measurement is therefore a technique to detect the fixation of methane, to form more complex organic molecules, in impact craters and elsewhere. It is possible that carbonaceous polymers in the Vredefort Impact Structure, South Africa, represent such irradiation products of methane.

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Deep UV Raman investigations of meteoritic and biological samples

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We report about the great capabilities of deep UV Raman experiments to investigate meteoritic and biological materials. If the Raman excitation occurs within an electronic resonance band of a material, the scattering cross-section can be enhanced as much as 10^8.Many organic and inorganic materials have strong absorption bands in the deep UV and exhibit resonance enhancement of characteristic Raman bands coupled to the deep UV absorption band. In addition to the resonance enhancement, another major advantage of deep UV Raman spectroscopy is that no fluorescence interference exists when excitation is provided at wavelengths below 250 nm. This provides complete spectral separation of Raman and fluorescence emission bands resulting in high signal-to-noise measurements. Furthermore, the Raman cross section itself is dependent on the excitation wavelength to the inverse fourth power resulting in higher Raman intensity with shorter wavelength laser excitation leading to a reduction in acquisition time needed to record Raman spectra with a good signal-to-noise ratio. In addition, the size of the sampling spot for micro-Raman imaging experiments is proportional to the wavelength of the laser beam, and therefore a much better spatial resolution for Raman mapping experiments is achieved when the excitation laser has a shorter wavelength. Raman mapping was performed on the SAU 060 Shergottite Mars meteorite. Excellent, florescence-free Raman spectra were obtained. The distribution of different minerals on the surface was determined. It has to be noted that the absence of the D band (~1300 cm^{-1}) from the measured graphite spectrum indicates a high degree of crystallinity for graphite in the SAU 060. This is not observed usually in this type of meteorite since the shock processes that the stone was exposed to create more disordered phases. In addition to meteorites, biological samples were also investigated. The excitation in the UV region leads to selective resonance enhancement of macromolecules such as DNA/RNA and proteins. With this information it is possible to determine the GC value of a cell (ratio of guanine and cytosine to all DNA bases). Twenty-eight strains from 10 bacterial species were measured with UV-micro-Raman spectroscopy. In combination with a support vector machine an average recognition rate on strain level of 97.5% could be achieved.

Radiation and prebiotic chemistry on Titan: from laboratory models to Cassini–Huygens observations

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Since the discovery on Titan of a dense atmosphere, mainly made of N_2 with several per cent CH_4, by Voyager 25 years ago, many laboratory works (experimental as well as theoretical) have been developed to study the organic chemistry involved in this atmosphere and, more generally, the prebiotic chemistry likely to occur in this exotic environment. Indeed, the far UV photons from the Sun and energetic electrons from Saturn's magnetosphere are able to dissociate the main constituents of Titan's atmosphere and to produce many organic compounds in the gas and aerosol phases, including several of the key compounds involved in terrestrial prebiotic chemistry such as HCN and HC_3N. In addition to methane, 12 organic compounds – hydrocarbons and nitriles (including HCN and HC_3N) – have already been detected in Titan's atmosphere from Voyager and from observations from the ground or from Earth-orbiting observatories. With the arrival of the Cassini–Huygens mission, new data are now available from the Cassini orbiter experiments and the Huygens probe *in situ* measurements. These new and systematic observations are a fantastic tool to study the prebiotic-like processes – many of which are induced by radiation – occurring today in Titan's environments. They already show the high complexity of the chemistry occurring in the atmosphere, and the essential role of aerosols. Organic chemistry seems also to occur on the surface and probably in the internal structure of the satellite, with the key role of the methane cycle, similar in many aspects to the water cycle on the Earth. Several of these Cassini–Huygens data will be presented and their implication in our understanding of Titan's prebiotic and radiation induced chemistry will be discussed.

Cyanobutadiyne (HC≡C—C≡C—C≡N): preparation, characterization, photochemical synthesis, chemistry

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The family of compounds which associates one or several CC triple bonds and only one carbonitrile substituent plays a particular role in astrobiology. As an example, the biggest compound detected in the IM is $HC_{11}N$. The first one of this family, the cyanoacetylene (HC≡C—C≡N), has been observed in the atmosphere of Titan, in the IM and in comets. The cyanobutadiyne (2,4-pentadiynenitrile) has been detected in the IM, in comets and appears in numerous laboratory simulations of Titan's atmosphere. Up-to-now, it has never been prepared in pure form. We have synthesized cyanobutadiyne by reaction of 1,3-butadiynyltri-n-butylstannane with p-toluenesulphonylcyanide. It has been characterized by ^1H and ^{13}C NMR spectroscopy and high-resolution mass spectrometry (HRMS). Thanks to our synthesis of the cyanobutadiyne, traces of this molecule can be easily detected by ^1H NMR spectroscopy in various mixtures of compounds. Thus, as an example, we showed that photolysis of cyanoacetylene with acetylene at 185 and 254 nm leads to the formation of cyanobutadiyne. On the other hand, the addition of N,N-dimethylamine, ammonia or t-butanethiol on cyanobutadiyne only occurs via a 1,6-nucleophilic addition to give the corresponding adduct.

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Poster presentations

Cosmological neutrinos: can they contribute to molecular homochirality?

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The origin of biological homochirality is one of the most fascinating problems linked to the origin of life[1]. The discovery of an excess of L-amino acids in the Murchison meteorite[2], as well as the observation of infrared circular polarization from the Orion OMC-1 star-formation region[3], have reinforced the idea of an extraterrestrial origin of biological homochirality, although appropriate mechanisms involving polarized light in the necessary wavelength range are still speculative. Universal mechanisms such as weak parity-violating (P-odd) processes are of particular interest in the origin of extraterrestrial homochirality. Such interactions can lead to an energy difference between enantiomers of a chiral molecule, estimated to be between[4] 10^{-16} and 10^{-21} eV. Here we examine another universal process: cosmological neutrinos interacting with the electrons of chiral molecules. A speculation was made in a recent paper about a possible enantiomeric discrimination produced by supernova antineutrinos[5]. We use the known theoretical result of the split in energy of the two helicity states of an electron in the cosmic neutrino bath due to weak charged currents[6,7]. An estimation of this energy split for the case of a single electron in chiral molecules yields a small value of the order of[8] $10^{-26\ eV}$. This value is amplified by the contribution of all the molecular electrons having helicity and other possible mechanisms. This analysis explores a P-odd process not yet estimated in the context of enantiomeric discrimination, contributing to research completeness of all possible universal mechanisms involved in molecular chiroselection.

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Spatio-temporal homochirality through intense replication and competition

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The emergence and spreading of chirality on the early Earth is considered by studying polymerization models of early replicating molecules with auto-catalytic behaviour such as peptide nucleic acids[1,2]. The spreading of chirality on the early Earth is modelled by solving a set of reaction–diffusion–advection equations based on the polymerization model. It is found that effective mixing of the early oceans is necessary to reach the present homochiral state[3]. The possibility of introducing mass extinctions into the model by modifying the emergence rate of life is discussed[4].

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Protein subunits and their role in the evolution of life

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There is some evidence that modern proteins could have been formed as a result of various processes of gene fusion, in which primitive and very simple genes, containing the instructions for producing the ancient proteins, have fused together in the course of evolution giving rise to more and more complex macromolecules. Inside proteins one can indeed isolate some 'subunits', which could be the relics of these ancient proteins. Apart from multidomain structures, which are linked with the latest stages of evolution, there are other subunits, like for instance the so-called motifs, which appear with identical structural configuration patterns in different proteins. These configurations are extremely stable with respect to changes in the sequence of amino acids and their existence can hardly be explained as a simple matter of chance, but rather one would say that they are the result of divergent evolution starting from a common ancestor. Recently, the existence of even smaller subunits has also been proposed, called 'loops', consisting of 25–35 amino acid residues, which appear as a major mode in the loop size distribution in crystallized proteins[1]. In this contribution, the possibility of observing these loops, as well as other possible subunits, in crystallized proteins will be investigated.

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Which compounds are formed when a meteorite enters the terrestrial atmosphere? Flash-vacuum thermolysis of amino acids

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When a meteorite enters the terrestrial atmosphere, it is allowed to heat up to about 600 °C on average. Several amino acids, compounds usually proposed as the building blocks of life, have been detected in many meteorites. So we wonder whether molecules could be formed by amino-acids thermolysis. Amino acids were thermolysed in flash-vacuum thermolysis (FVT) conditions. We observed many products in the thermolysis of amino acids. Aldehydes, ammonia, carbon monoxide, water, imines and pyrrole are the most frequently formed products. Aldehydes and ketones formed by thermolysis of amino acids with an alkyl side chain could explain why these compounds are detected at the same time as their corresponding amino acids in several meteorites. Consequently, the presence of aldehydes and ketones found in meteorites cannot be considered as proof that they are precursors of amino acids. On the other hand, the easy formation of five-membered rings containing a nitrogen atom like pyrrole and pyrroline allow us to imagine the formation of porphyrins or porphyrinogens by reaction with the numerous aldehydes found in these thermolyses. The study of the chemistry of the thermolysis products dissolved in water is currently under progress in our laboratory. Many other products have also been detected, which suggests the themolysis of amino acids might have been the source of an important molecular diversity during the epoch of high bombardment.

Life in Extreme Radiation Environments
Oral presentations

TL dose measurements on board the Russian segment of the ISS by the 'Pille' system during Expedition-9 and -10

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The most advanced version of a thermoluminescent (TL) dosimeter system ('Pille-MKS') developed by the KFKI Atomic Energy Research Institute (KFKI AEKI) and BL-Electronics, consisting of 10 CaSO4:Dy bulb dosimeters and a compact reader, was successfully installed onboard the ISS in October, 2003. The Pille-MKS dosimeter system is applied for the routine and EVA individual dosimetry of astronauts/cosmonauts as part of the service system as well as for on-board experiments and operated by the Institute for Biomedical Problems (IBMP). It is unique providing accurate and high-resolution TL dose data already onboard the space station, which became increasingly important during the suspension of the Space Shuttle flights. In accordance with the common Russian–American working document ISS 8 IDRD, seven dosimeters are located at several places of the Russian segment of the ISS and read out once a month, two dosimeters are dedicated for EVAs and one dosimeter is kept in the reader and read out automatically every 90 minutes. During particular events like coronal mass ejections hitting Earth, incidental measuring campaigns are intercalated with frequent readouts. In this paper we report results of dosimetric measurements made aboard the International Space Station during Expedition-9 and -10 using the Pille portable TLD system and compare them with our previous measurements on the ISS.

Endolithic microorganisms in dolomite rock in the Swiss Alps

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The pore space in rocks is an ideal environment for microorganisms in extreme terrestrial habitats. Endolithic phototrophic microorganisms form a distinct visible band a few millimetres below the surface of the rock. We characterized this endolithic population from dolomite in the

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Swiss Alps with spectroscopical, optical and molecular methods. The light intensity at the site of the organismic layer amounts for 1–5% of the surface illumination. Reflection spectroscopy across the band reveals pigments with *in vivo* absorption maxima at around 720, 680, 625 and 500 nm, indicating the presence of eukaryotic algae, cyanobacteria and green phototrophic bacteria. Electron microscopy and1-photon/2-photon laser scanning microscopy identify various cyanobacteria of coccoid or filamentous morphology. Coccoid species often form colonies embedded in pigmented sheaths. Thick layers of exopolysaccharides protect the organisms against environmental stress such as light, UV and lack of water. Cloning the 16S rDNA from total endolithic DNA resulted in over 80 different clones, the 16S rDNA sequence of most of them not registered in data libraries. Besides heterotrophic bacteria from many groups, clones belonging to the Crenarcheota and to eukaryotic amoebae were found. A cluster of Chloroflexus-like sequences confirmed the presence of green bacteria. We conclude that the small zone of endolithic microorganisms underneath the rock surface is a nearly closed ecosystem harbouring a broad variety of physiologically different species. It may be an excellent analogue for extraterrestrial life.

Response of a phototroph to a simulated Martian UV flux and implications for cryptoendoliths on early Earth

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Dried monolayers of *Chroococcidiopsis* sp. 029, an extremophilic endolithic phototroph, were exposed to a simulated Martian surface UV and visible light flux. After 5 min, 99% loss of cell viability had occurred and there were no survivors after 30 min. However, this survival was approximately 10 times greater than that previously reported for *Bacillus subtilis*, perhaps accounted for by the screening effect of cellular components. We show that under 1 mm of rock, *Chroococcidiopsis* sp. could survive (and potentially grow) under the high Martian UV flux if water and nutrient requirements for growth were met. In isolated cells biomolecules remained intact hours after viability was lost. Reduction of esterase activity by 99% required 1-hour exposure and 99% loss of autofluorescence required at least 4 hours. However, cell morphology was not changed and DNA was still detectable by DAPI staining after 8-hour exposure (equivalent to approximately 1 day on Mars at the equator). Under 1 mm of simulant Martian soil or gneiss, no significant effect of UV radiation on esterase activity or autofluoresence was measured after 4 hours. These results show that under the intense Martian UV flux the morphological signatures of life can persist long after viability, enzymatic activity and pigmentation has been destroyed by intense UV radiation. Finally, the global dispersal of viable, isolated cells of even this extremophilic, desiccation-resistant, ionizing radiation resistant microorganism on Mars is unlikely as in a desiccated state they are killed quickly by unattenuated UV radiation, with implications for planetary protection. These results show how cryptoendolithic habitats could have provided refugia from extreme conditions for life on early Earth.

Radiobiological effects at low temperature and their relevance to astrobiology

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In the search for life beyond the Earth, liquid water has been defined as one of the prerequisites for the appearance and persistence of life, because of its many life-supporting characteristics: (i) as a diffusion milieu, (ii) as a selective solvent, (iii) as a clay producer, (iv) by supporting the structures of the polymers, (v) as a driver for chemistry, and (vi) as a heat dissipater. Therefore, the requirement for liquid water being permanently available at a planet's surface has been used for defining habitable zones around main sequence stars. Water is also a reaction partner in radiobiological processes. Upon irradiation of biological systems, the energy of ionizing radiation is absorbed in the water molecules of the cells producing either ions or radicals. In particular the highly reactive free radicals may interact with essential biomolecules, such as cellular DNA, causing mutations, transformations or inactivation of the cells. The degree of this indirect radiobiological damage depends on the degree of hydration of a biological system and the diffusion rate of the radicals. This diffusion rate of the radicals is dependent on temperature. At very low temperatures the radicals are immobilized. The $OH^\bullet$ and $O_2H^\bullet$ radicals start diffusion at 100–135 K and become fully mobile at 135 K. The $H^\bullet$ radicals start migration at temperatures above 10 K and are almost fully mobile at 77 K. Hence, at low temperatures (10–135 K) the $H^\bullet$ radicals, by migrating to the immobile $OH^\bullet$ and $O_2H^\bullet$ radicals, are capable of recombining with them. The result is an increased radiation resistance of the biological objects upon irradiation at low temperatures. Compared to samples at room temperature, the radiation resistance of objects at low temperature can increase up to a factor of 100. This fact is especially important when assessing the radiation exposure of microorganism in permafrost, where they have been exposed to the natural radiation for more than one million years. In this case, doses of several kGy are estimated. This high radiation resistance of microorganisms at very low temperatures also has astrobiological implications when considering that permafrost and ice as well as high radiation doses are common features in our Solar System (planets and their moons, comets, asteroids) and probably in the whole universe.

Cosmic ray and UV radiation exposure over the Martian history: astrobiological implications

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The evolution of the Martian atmosphere and evidence of the existence of an ancient hydrosphere are of great interest in studies regarding the evolution of the planet's water inventory and the search for life. Although the Martian climate is at present too cold and the atmosphere too thin so that liquid water cannot be stable on the surface, there are now many indications that the situation was different in the past. Several observations of the networks of valleys in the crater-rich areas of the southern hemisphere suggests that Mars had once a significant hydrologic activity and therefore a denser CO_2 atmosphere with surface pressure levels between 1–5 bars. The presentation gives an overview of the latest studies in the evolution of the Martian atmosphere in relation to the surface exposure of cosmic rays and UV radiation. We studied with a theoretical model the atmospheric flux of cosmic-ray-induced particles on the Martian surface by solving Boltzmann equations governing the propagation of protons, neutrons, muons and pions at the present thin and a denser ancient Martian CO_2 atmosphere. We also evaluated the influence of an intrinsic magnetic field on the magnitude of the surface flux of charged particles on the ancient Martian surface. Furthermore, we discuss astrobiological implications due to the modelled cosmic ray fluxes on the early Martian surface.

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Plant seeds as model vehicles for panspermia

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The origin of life on Earth is often explained as imported (panspermia) or having arisen on Earth from basic chemicals (spontaneous generation). We examine the plausibility of panspermia, using terrestrial models capable of resisting conditions found in space. Our choice of organisms is based on experiments showing that plant seeds are suitable space travellers, e.g., they are completely resistant to UV (254 nm) that is 105 times the dose that that kills the most resistant bacterial spores. Flavonoids in the seed coat are essential to UV resistance. Seeds also resist space vacuum and temperature extremes. We do not suggest that life was transferred to Earth via modern plant seeds, but rather that seeds demonstrate the capacity of life, seen in terrestrial models, to resist space conditions.

Preliminary investigation of the effect of proton and gamma radiation on fluorescent dyes for applications in astrobiology

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The Specific Molecular Indications of Life Experiment (SMILE) instrument is designed to utilize specific recognition elements for the detection of organic biomarkers on astrobiology missions, initially to Mars. One of the proposed methods of detection is an antibody assay utilizing fluorescently labelled antibodies. This approach is being validated through a series of experiments to determine whether the reagents used in this detection system will survive exposure to the typical levels of solar and galactic radiation encountered during a six-month transfer to Mars. We report the results of exposing two fluorescent dyes, fluorescein and Alexa Flour® 633, to an approximation of the proton, helium ion and gamma components of the radiation that would be encountered if the dyes were transported to Mars in an unshielded instrument, and also large over-exposures. Although some methodological issues will be highlighted and need to be resolved in on-going work, both dyes clearly retained their fluorescent properties, importantly peak emission and absorption wavelengths and intensities, after each of these radiation treatments. We therefore conclude that these fluorophores appear suitable for astrobiology missions to Mars pending future investigation of other radiation conditions, and suggest that other structurally similar fluorophores are likely to retain their fluorescent properties after exposure to these levels of proton, helium ion and gamma radiation.

Mutagenicity tests on bacterial cultures using exceptionally radioactive heavy mineral beach sands: irradiation or chemistry?

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Short-term irradiation effect of naturally radioactive (i.e. U-, Th-rich) detrital minerals on microbial life is an area that has hitherto received very little attention. Previous studies have demonstrated that natural radioactivity may have a detrimental effect on plants growing in high background radioactivity areas in Kerala, SW India, as well as on bats dwelling in abandoned underground mines of primary monazite ores in Namaqualand, Western Cape, South Africa. In spite of the fact that the evidence presented in these works is by no means unambiguous, little is known about similar effects of natural radioactivity on bacterial organisms *per se*. We undertook experimental work that utilized exceptionally monazite (Th)-rich mineral sands collected from the coast of Espirito Santo, Brazil, and to a lesser extent U-rich materials from the Oklo natural nuclear reactor, Ghana. The potential of such materials in inducing increased mutagenicity on *E. coli* cultures (both self-repair and non-self-repair strains) was repeatedly examined using the established tryptophan reverse mutation assay. The results indicate that at least on a short-term scale (1–3 days), the monazite-rich sands do not cause any obvious increases in mutation. In fact, it is likely that the high phosphate content of these sands may act as a 'fertilizer' for the bacteria, thus causing accelerated growth rather than increased mutation. On the other hand, the Oklo samples displayed clearly toxic (lethal) effects on both *E. coli* cultures as well as on *Chroococidiopsis* cultures, the latter known for their particularly high resistance to radioactivity. Chemical effects on bacteria with short doubling time may therefore overshadow those of radioactivity in natural environments. These results bear important implications in terms of the evolution of microbial life forms on the early Earth, as evidence from the Precambrian geological record suggests the existence of near-surface environments where radioactive minerals would also have been (at least locally) present in anomalously high amounts (e.g. uranium-enriched auriferous conglomerates of the late Archaean Witwatersrand Supergroup, South Africa).

Preliminary investigation of the effect of proton and gamma radiation on antibodies for applications in astrobiology

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The Specific Molecular Indications of Life Experiment (SMILE) instrument is designed to utilize specific recognition elements for the detection of organic biomarkers on astrobiology missions, initially to Mars. One of the proposed methods of detection is an antibody assay utilizing fluorescently labelled antibodies. This approach is being validated through a series of experiments to determine whether the reagents used in this detection system will survive exposure to the typical levels of Solar and galactic radiation encountered during a six-month transfer to Mars. We report the methodology and results of exposing a representative recombinant antibody fragment to an approximation of the proton, helium ion and gamma components of the radiation that would be encountered in an un-shielded instrument, and also large over-exposures. Although some methodological issues will be highlighted and need to be resolved in on-going work, initial results indicate that antibodies retain a proportion of their activity after each of these radiation treatments. We therefore conclude that this representative antibody appears suitable for astrobiology missions to Mars pending future investigation of other radiation conditions, and furthermore suggest that other antibodies are likely to retain their specific molecular recognition characteristics after exposure to these levels of proton, helium ion and gamma radiation.

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Poster presentations

Biological effects of secondary cosmic rays on Earth's surface

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We report experimental evidence for the irreversible biological effects of secondary cosmic rays on the Earth's surface produced by energetic Solar particle events. Cell fusion, the appearance of gigantic nuclei, multiple lesions of genetic and cellular matter and local radiation effects were observed in continuous cell lines. These biological changes were correlated to ground-level enhancements of high-energy particles. The effects are similar to those characterized with neutron and hadron irradiation in laboratory and spacecraft experiments. Our findings show that Solar particle events can yield qualitatively new irreversible states in living systems and may therefore be more influential in biological evolution than previously thought. Moreover, the morphogenetical diversity of the cell structures, which formed under the secondary cosmic ray exposure, demonstrates a new mechanism for the reorganization of genetic material on the early Earth, during a period of more intense Solar activity.

Field experiments with UV bio-dosimeters over north polar areas

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Due to the existence of open magnetic field lines over the polar areas, the stratospheric ozone concentration can be highly reduced. Recent multi-satellite observations revealed that high-energy Solar particle events caused by Solar storms during late October 2003 to January 2004 enhanced the production of NO_x (NO and NO_2) radicals at high northern latitudes from March through July 2004. This NO_x production was accompanied by the reduction in ozone of more than 60% compared to undisturbed conditions. We show that the geographical location of the research stations of the Kola Scientific Centre at the Kola Peninsula and Spitsbergen offer a good opportunity for studying the radiation effects on bio-systems and biological radiation damage by increased Solar UV radiation. To quantify the biological risk due to environmental UV radiation it is reasonable to weight the Solar spectrum by the spectral sensitivity of the DNA damage taking into account the high DNA sensitivity at the short wavelength range of the Solar spectrum. Various Solar UV-sensitive biological dosimeters have been developed, e.g. polycrystalline uracil thin layer. These are usually simple biological systems or components of them. Their UV sensitivity is a consequence of the DNA damage. We show that biological dosimeters applied for long-term Solar UV monitoring are promising tools for the assessment of the biological hazard in Arctic areas. For comparing Solar UV-induced DNA damage between high latitudes in Arctic regions with observations in central and southern Europe we started measurement campaigns during 2004 at the facilities of the Polar Geophysical Institute of the Russian Academy of Sciences in Barentsburg/Spitsbergen (78° N) and Apatity and Lovozero (68° N) and a drifting Iice station near the North Pole. We present the first preliminary results of these field experiments obtained during the heavy Solar particle storm in 2003–2004 and discuss planned future experiments.

Modelling the Martian subsurface radiation environment

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Unlike Earth, Mars and most small bodies (all comets and most asteroids) in the Solar System are unprotected from Solar and cosmic radiation by a global magnetic field. There is evidence, however, from the recently discovered crustal magnetic anomalies that Mars was magnetized ~4 billion years ago. We investigate the extent to which the Martian present and past atmosphere and surface layers attenuate the radiation environment and the potential effect on life. The damaging effect of ionizing radiation is one of the prime limiting factors on the survival of life in potential astrobiological habitats. The Martian topsoil is thought to have been rendered completely sterile by oxidizing conditions created by UV radiation, but the penetration of high-energy particles far exceeds this depth. A computer model of radiation penetration has been built using Geant4, a simulation toolkit for particle physics. This model tracks the propagation of low/high-energy primary particles, and the generated secondary cascades, through both the Martian atmosphere and regolith in order to calculate the radiation flux as a function of depth underground. Both cosmic galactic rays (CGRs) and Solar energetic particles (SEPs) are considered. The deflection of lower-energy charged particles by the magnetic anomalies is also modelled. The persistence times of living cells, metabolically dormant spores and organic molecule biomarkers at different depths can then be calculated. Comparison of this radiation map to other astrobiologically relevant data, such as distribution of permafrost water, geothermal hotspots and locations of methane seepage, will determine the most likely refuges of subsurface Martian microbes. Such analysis will be invaluable in the planning of sample-return missions.

Extreme Database: search for extreme life

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The Extreme Database holds information on extremophile organisms, currently from the archaeal domain only. Archaea, from a Greek adjective meaning ancient and/or primitive[1], are characterized by prokaryotic cells, membrane lipids predominantly isoprenoid glycerol diethers or diglycerol tetraethers and ribosomes containing an archaeal type of rRNA[1–4]. A description of the Extreme Database, as a Microsoft Access database, is provided, followed by the divulgation of the Website, where any user can have access to it at the Internet address http://www.astrobiology-portugal.tk. The Extreme Database is a useful tool to any astrobiologist who wishes to find information about extremophiles. Although still under construction, all of the information can be easily retrieved. The Website's interface allows the use of a simple search engine that searches through the entire database for keywords, the information about each microorganism is displayed in a table with the following topics/columns: genus, species, other designations, type of extremophile, other characteristics (including shape (coccus, rodshaped, etc.), size, Gram stain and G+C content), growth parameters, metabolism, location and references. The Website interface

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also allows advanced search on Archaea microorganisms specifying the search to the later topics mentioned.

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Radioresistant archaea

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The most radioresistant hyperthermophilic archaea isolated to date are *Thermococcus gammatolerans*, *Thermococcus marinus* and *Thermococcus radiotolerans*[1]. They resist high levels of gamma-irradiation: 30 kGy (*Thermococcus gammatoleran*)[2], 20 kGy (*Thermococcus marinus*) and 30 kGy (*Thermococcus radiotolerans*)[1]. Their gamma-radiation survival curves are presented. These three microorganisms, from domain archaea, are hyperthermophiles, with an optimal temperature for growth of 88 °C, obligately anaerobic heterotrophs that utilize yeast extract, tryptone and peptone as a carbon source for growth. Elemental sulphur or cystine is required for growth and reduced to hydrogen sulphide[1,2].

Radiation on Earth[3]

Over the last 4 billion years, Earth's radiation level has been 0.05–20 rad year^{-1} (1 rad = 0.01 Gy). This radiation dosage is inferior to the lethal dose for the radioresistant microorganisms described here.

- However, can radioresistant microorganisms survive Martian conditions?
- Are radioresistant microorganisms good candidates to live on Mars?
- Does Mars present habitats with the potential for radioresistant microorganisms?

Mars data

High-energy charged particles from free-space reach the outer Martian atmosphere due to the weak intrinsic magnetic field on Mars. On the other hand, these radiation fluxes are attenuated by the Martian atmosphere[4]. As the lower atmosphere has a composition of about 95.3% carbon dioxide, 2.7% nitrogen and 1.6% argon[4,5], protection against galactic cosmic rays (GCRs) and Solar flares is provided. GCRs are atomic nuclei that suffered acceleration to very high energies outside our Solar System[4]. The Martian surface environment results then from the interaction of Solar particle events (SPEs) and GCRs with the Martian atmosphere and surface materials. Various charged ions are reduced in size and other particles (neutrons) are produced from these interactions. The impact with the surface of Mars produces a backward flux of neutrons reaching a few hundred millielectronvolts[6].

Radiation on Mars[7]

GCRs. These reach a maximum of 0.2 Gy year^{-1} (20 rad year^{-1}) for a 25 g cm^{-2} depth, decreasing to 5×10^{-4} Gy year^{-1} at a 700 g cm^{-2} depth.

Natural radioactivity. The estimated radiation dose is 10^{-3}–10^{-4} Gy year^{-1}.

Solar ultraviolet (UV) radiation. This kills microorganisms and destroys organic molecules above and on the Martian surface.

X-ray radiation. This is insignificant compared to UV radiation as its energy is mostly dissipated in the atmosphere.

SEPs. Radiation dose is up to 0.6–0.7 Gy year^{-1} (an average for the upper 10 cm of Martian soil).

Effect on hypothetical Martian microrganisms[7]

It is possible to conclude that, apart from the most superficial layer exposed to UV radiation, Martian subsurface can eventually constitute a safe niche for active life. However, for life in a dormancy state, sterilization would happen at a 20 g cm^{-2} depth in less then 30 000 years (mainly by SEP and UV radiation). Radioresistance can be trained in Martian conditions[3]. The hypothesis is based on the astronomical theory of Martian climate oscillation and calculations of the radiation levels on Mars' surface. Hypothetical Martian life would accumulate a large radiation dose during the periods of cold climate when it would be in a dormancy state. During the periods of warm climate, there would be time for rebuilding its population, taking advantage of the mild climate and the presence of liquid water (in subsurface layers of soil and/or ice). Martian microorganisms could acquire radioresistance only in several millions years. Pavlov *et al.*[3] suggests that the polar regions are the most promising places for detection of living microrganisms on Mars. Indeed, Mars exhibits habitats with the potential for the presence of radioresistant microorganisms, similar to what has been found on Earth.

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Simulation of the Martian surface UV radiation in experiments with emphasis on molecular biophysics

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The majority of biological UV effects are due to photochemical reactions in nucleic acids, DNA or RNA, which constitute the genetic material of all cellular organisms and viruses. Protein or lipid effects generally play a minor role, but are also relevant in some cases. UV radiation can induce wavelength-specific types of DNA damage. At the same time it can also induce the photo-reversion reaction of a UV-induced DNA photoproduct of nucleic acid bases, the pyrimidine dimers. Intense UV-B and UV-C radiation, experienced on early Earth and present-day Mars, has been revealed to be harmful to extremophile bacteria and spores. Following this, more laboratory simulations are vital in order to investigate and understand UV effects on organic matter in the case of Mars. We have designed a radiation apparatus that simulates the anticipated Martian UV surface spectrum between 200 and 400 nm (UV-C to UV-A). The system comprises an UV-enhanced xenon arc lamp, special filter-sets and mirrors to simulate the effects of the Martian atmospheric column and dust loading. Under the influence of UV radiation, photo-reversion reactions occur simultaneously, thus the additivity law of the effect of the various

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wavelengths is not applicable. For studying the impact of photoreversion on the Martian surface, experiments were carried out with special interference filters, which block the UV outside wavelength regions that are not relevant for dimerization–monomerization.

Resistance of *Arabidopsis thaliana* seeds to deleterious conditions found in the space

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The chances of life being transported from one body of our Solar System to another or beyond are determined by the ability of organisms or parts of organisms to withstand the hostile space environment, including high-energy electromagnetic radiation, cosmic rays, temperature extremes, space vacuum, desiccation and microgravity. We tested the resistance of plant seeds (*Arabidopsis thaliana*) to different parameters of the space environment: UV, vacuum and ionizing radiation. The UV radiation is one of the most deleterious parameters in space, where the full spectrum of Solar UV light is present. The level of Solar UV that reaches the Earth's surface is high in the UV-A (320–390 nm) and decreases sharply in the UV-B (280–320 nm) due to the absorption by the stratospheric ozone layer. However, UV radiation in space includes extremely high energy: UV-C (190–280 nm) and VUV ($\lambda \leqslant 190$ nm). Germination of wild type Arabidopsis seeds was not reduced by exposure to vacuum, ionizing radiation and UV-C ($\lambda = 254$ nm), dose of 2.28×10^5 kJ m^{-2}. However, germination of mutant deficient in flavonoids was inhibited by UV 254 nm, at doses that were 100 times lower than those applied to wild-type seeds. Removal of the seed coat from the embryos of both the mutant and wild type increased the sensitivity to UV light. Using synchrotron light, we found that flavonoids have the same UV absorption spectrum as DNA, even in the VUV. We also determined UV absorption spectra of other UV-screening compounds, isolated from evolutionary distinct groups of organisms. We conclude that flavonoids in the seed coat provide the major protection against UV radiation. Flavonoids appear to be ideal sunscreens for protecting DNA against Solar UV light encountered in space.

Interplanetary Transfer of Life and Experiments in Earth Orbit

Oral presentations

Artificial Martian meteorites

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The STONE-1 experiment, flown by ESA, was designed to test whether Martian sedimentary material could survive terrestrial atmospheric entry. A basalt (inflight control), a dolomite (sedimentary rock) and artificial Martian regolith were embedded into the ablative heat shield of Foton 12. The collected entry samples were analysed for their chemistry, mineralogy and isotopic compositions by a European consortium. Modifications due to atmospheric infall were tested by reference to the untreated samples. The dolomite sample was retrieved intact, although reduced to a depth of about 30% of its original thickness, suggesting that some Martian sediments could, in part, survive terrestrial atmospheric entry from space. Some kinetic isotopic fractionation accompanied the thermal degradation of the dolomite during re-entry, as evidenced by bulk isotopic measurements on different zones of the residual carbonate. The silica 'fusion crust' from the associated sample holder exhibited a significant degree of isotopic exchange with atmospheric oxygen during re-entry[1]. When analysing the three oxygen isotopes, an interesting mass-independent isotopic fractionation during thermal decomposition *in vacuo* of naturally occurring carbonates of calcium and magnesium was observed[2]. The STONE-5 experiment will allow investigation of the chances for survival of simple life forms transported by meteorites when entering the atmosphere of the Earth. A sandstone (a sedimentary rock), a dolerite (an igneous rock) and a gneiss (a metamorphic stone) from Antarctica carrying endolithic cyanobacteria have been embedded in the heat shield of FOTON M2 launched on 31 May 2005. The three rocks have been loaded with bacterial *Bacillus subtilis* spores, fungal *Ulocladium atrum* spores and dessicated cyanobacteria *Chroococcidiopsis*.

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AMINO, PROCESS and UV-olution: investigation of solid/gas heterogeneous chemistry of organic compounds in space via Foton and the space station

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AMINO, PROCESS and UV-olution are three experiments selected to be flown on the EXPOSE facility on the International Space Station, or on the BIOPAN facility during the next FOTON M3 space capsule mission. The goal of our experiments is to improve our knowledge of the chemical nature and evolution of organic molecules involved in extraterrestrial environments with astrobiological implications. Similar experiments implemented in space so far were carried out in vented cells exposed to Solar UV. For the first time, sealed exposition cells will be used, which will allow us to study chemical evolution in the gaseous phase as well as heterogeneous processes (degradation of solid compounds and release of gaseous fragments). Those cells are currently under development in France with CNES support. Three kinds of experiment will be carried out. The first will deal with comets and are related to the Rosetta mission, the second will deal with Titan and are related to the Cassini–Huygens mission, and the third are related to the search for life-related organic compounds on Mars.

- Concerning comets, we plan to study the photodegradation of high molecular weight organic compounds, which might be responsible for extended sources: polyoxymethylene, hexamethylenetetramine, HCN polymers and carbon suboxide polymers.
- Concerning Titan, we plan to expose the main gaseous compounds of Titan's atmosphere ($N_2 + CH_4$) to the full Solar spectrum and study the production and evolution of Titan's aerosols analogues (tholins), including isotopic fractionation between gas and solids.
- Our Mars related activities will be devoted to studying the stability of organic compounds at the Martian surface: we plan to expose (alone or in a Martian soil analogues) molecules that are candidates to be biomarkers resistant in the Martian environment.

From supernova to consciousness: evolution of iron-binding compounds. Part 2: human brain

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Iron plays an important role in the human body. Two-thirds of the total amount of iron (4 g) is located within haemoglobin. Most of the remaining iron is located in the liver, spleen, heart and brain. Iron in the liver, spleen and heart is distributed homogenously. This is not the case for the brain. There are specific areas of the brain in which the concentration of iron is very high. These areas, globus pallidus (GP), substantia nigra (SN) and hippocampus (Hip), also play a very important role in the mechanisms of movement control and memory. The main iron storage compound in the brain is ferritin. Ferritin is composed of a protein shell with an iron core. The size of the iron core in the brain is much smaller (about 3.5 nm) than the size of the iron core in the liver (about 7 nm). The iron compound in both cores is ferrihydrite: the mineral which is also present in meteorites. The protein shell is composed of two types of chain: L (light) and H (heavy). These chains play different roles: H-chains are related to the metabolism of iron and its quick oxidation, while L-chains are responsible for the safe storage of iron within the core of ferritin. These different structures of the human brain were investigated by three methods: Mössbauer spectroscopy, electron paramagnetic resonance (EPR) and ELISA. The concentration of iron, assessed by Mössbauer spectroscopy, was the highest in GP (300 ± 40 µg/g wet tissue) and the lowest in Hip (80 ± 20 µg/g wet tissue). The concentration of iron in SN was 160 ± 20 µg/g wet tissue. The size of the EPR signal showed a similar trend, although the significance of this finding is not completely obvious. ELISA studies demonstrated that the ratio of H/L chains is similar in GP (5.8 ± 1.6) and SN (5.0 ± 1.6) and different in Hip (15.4 ± 8.6). These results suggest that the metabolic processes involving iron are different in the investigated tissues.

Chance of nucleic acid molecules to survive extraterrestrial UV radiation

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Space is a hostile environment for life, where ultra-high vacuum and short-wavelength ultraviolet radiation are known to have the most deleterious effects. For the investigation of the Responses of Organisms to the Space Environment, the 'ROSE' scientific consortium was set up. The experiment 'Phage and Uracil Response' (PUR) will be accommodated in the EXPOSE facility of the ISS. The structural/functional damage of bacteriophage T7/isolated T7 DNA exposed to simulated extreme environmental parameters in space was investigated during the Experiment Verification Tests (EVTs). Thin layers of bacteriophage T7/isolated T7 DNA were exposed to vacuum (10^{-6} Pa), to monochromatic (254 nm) and polychromatic (200–400 nm) UV radiation. Using neutral density (ND) filters dose–effect curves were performed in order to define the maximum doses tolerated, and we also studied the effect of temperature fluctuations in vacuum. We obtained substantial evidence that DNA lesions (e.g. strand breaks, DNA–protein cross-links, DNA–DNA cross-links) accumulate throughout exposure. Bacteriophage T7 can be used as biological dosimeter, therefore total DNA damage was determined by quantitative PCR using 555 bp and 3826 bp fragments of T7 DNA. The structural/chemical effects were analysed by spectroscopic and microscopical methods. Characteristic changes in the absorption spectrum, in the electrophoretic pattern of DNA and the decrease of the amount of the PCR products have been detected indicating the damage of isolated and intraphage DNA. Specific endocucleases were used to determine the amount of some typical photoproducts. For 254 nm UV radiation at higher doses, lesion frequency was less than expected, which could be explained by an equilibrium process. This phenomenon has to be further investigated and enhanced by other factors (e.g. by self-shielding of thicker layers or by the presence of protective meteorite powder) could contribute to the survival of DNA.

The experiment MARSTOX on Foton M-2

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For the study of the responses of organisms to the space environment and for the future exploration of Mars as another planet which has had the potential for the evolution of life, the survivability of terrestrial resistant microbial forms, spores of the bacterium *Bacillus subtilis* as well as cells of the bacterium *Deinococcus radiodurans*, exposed to different subsets of the extreme environmental parameters in space and on Mars (vacuum, simulated Martian UV climate, shielding by different Martian soil analogue materials) was investigated in the BIOPAN facility of the European Space Agency onboard of the Russian Earth-orbiting Foton M-2 satellite. This satellite was launched with a Soyuz-U rocket from Baikonur, Kazakhstan, on 31 May 2005. The landing is scheduled for 16 June. The basic questions addressed in the experiment MARSTOX on FOTON M-2 are as follows. (i) To what extent are different Martian soil analogues able to protect bacterial spores against the effects of UV radiation in vacuum? (ii) What are the effects of different mineralogical characteristics (grain size, dust versus compact material) on the efficiency of protection by Martian soil analogues? (iii) Are there (photo-)toxic effects of different Martian soil analogues in intimate contact with bacterial spores during UV exposure? (iv) Can *D. radiodurans*, a non-spore forming bacterium, survive the same harsh environmental conditions as *B. subtilis* spores? After exposure in space the survival as well as the mutation induction will be analysed in the laboratory together with parallel samples from the corresponding ground control experiment performed in the space simulation facilities of DLR. The results of this experiment will provide new insights into the adaptation to environmental extremes on Earth or other planets that define the principal limits of life and at the same time bear the potential for the evolution and distribution of life.

Adaptation of the lichen *Rhizocarpon geographicum* to harsh high altitude conditions: relevance to a habitable Mars

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The bipolar epilithic lichen *Rhizocarpon geographicum*, which grows at high mountain regions (e.g. Sierra de Gredos, Central Spain) with continental climate, has been systematically studied in the natural environment (Plataforma de Gredos at 2000 m altitude) as well as under simulated space conditions at the space simulation facilities of the DLR. The lichen system was also onboard the Foton M1 within the BIOPAN facility of ESA, which exploded during launching in October 2002. Parts of BIOPAN, including the LICHEN experiment were recovered after the winter in the North of Russia. The reflight of the LICHEN experiment is scheduled for May 2005. The sensitivity of the photosynthetic system (PSII) to the different environmental conditions (dryness including vacuum treatment, high-temperature fluctuations, high UV intensity) was fluorometrically measured with a MINI PAM (Walz, Germany). The lichen *Rhizocarpon geographicum* was extremely resistant to the harsh natural environment of the high mountains as well as to the simulated space conditions. Even the lichens of the failed BIOPAN mission showed high photosynthetic activity after recovery, whereas the lichen *Xanthoria elegans*, which was also part of the LICHEN experiment, was completely inactivated. We have shown that an intact cortex was essential in protecting the photobiont against desiccation and intense UV radiation. Because of its high resistance to environmental extremes, the lichen *Rhizocarpon geographicum* seems to be an ideal model system for studying its survival on the surface of rocks in the Martian environment. We therefore propose to expose this epilithic lichen on its substrate (granite rock) to simulated Martian conditions with emphasis on atmospheric pressure and composition, temperature fluctuations and the spectrum and intensity of the UV radiation climate on Mars. We will determine the photosynthetic activity after different periods of exposure. The results will contribute to the estimation of the habitability of the surface of Mars, which is relevant for the planning of search for life experiments as well as for planetary protection efforts.

Poster presentations

From supernova to consciousness: evolution of iron-binding compounds. Part I: meteorites

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The cosmic distribution of chemical elements has an evident maximum for iron. Iron nucleuses are very stable. They are created inside a star's core and are spread all over space during supernova explosions. Meteorites are composed mostly of iron-binding compounds. The meteorites called chondrites are the most primitive samples we have of the material that evolved into our Solar System. By the technique of radioactive dating, it has been shown that the chondrites all crystallized 4.6×10^9 years ago. The most typical minerals present in ordinary chondrites are olivine, pyroxene, kamacite and troilite. The last two minerals (kamacite and troilite) are only created under cosmic conditions. These minerals could be the source of the information about parent bodies of the meteorites[1,2]. In weathered meteorites new mineralogical phases emerged. Mössbauer spectroscopy is the best technique for the identification and investigation of iron-binding compounds present in meteorites. Using Mössbauer spectroscopy our presentation will show the evolution of iron-binding compounds from primary to transformed minerals under different cosmic conditions. One of the secondary minerals is ferrihydrite, which is also present in the human brain. Iron in the human brain plays an important, but not fully understood role.

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Ecological and economic considerations for sustainable biogenerative life-support systems for Mars

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We present an economic and ecological discussion about some alternative practical bioregenerative life-support systems on Mars. In these comparisons, we will weight the possibility of using local Martian resources (CO_2, water and light energy) against transportation of resources from the Earth. We will consider the growth requirements of different life-support species, and possible ecological or functional risks associated with different life-support alternatives. The discussion is largely based on published information of the MELISSA project, and other test programs using higher plants as life-support organisms. First, we discuss species and ecological functional groups needed to run a life-support system. These include, for instance, primary producers, decomposers, nitrifying organisms and pollinators. Then we consider the growth requirements of the different species in ecologically functional elements, their mutual interactions, and also how they mediate the circulation of the nutrients, primarily C, N, O and water. Next, we estimate the need of materials and supplies for establishing and maintaining the growth facilities for these alternative life-support systems. We aim to estimate the economic and ecological cost of transporting the raw materials from Earth to Mars for different life-support systems. We also discuss the potential of the survival of various organisms on the Martian surface, and posing a contamination risk for Mars. We will also address the total polluting effects of various life-support systems. The sustainability and durability of these semiclosed ecosystems in Marian environment will be also discussed.

Tolerance of fungal and fern spores against simulated space environment

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Our part of the experiment SPORES on EXPOSE deals with the long-term exposure of fungal (*Trichoderma koningii*) and fern spores (*Athyrium filix-femina* and *Dryopteris filix-mas*) in space. After return to Earth the survival of the spores and DNA changes will be examined. At this time ground simulation experiments at the space simulation facilities of DLR in Cologne are carried out. The parameter UV radiation was combined with vacuum or argon atmosphere, respectively. The artificial meteorite material, MRTE-2 TRE Ele' (accepted Mars soil simulant) was mixed with fungal spores for testing the protective effect of shielding the radiation. After exposure the viability of spores was tested by staining with ethidium bromide. The used artificial meteorite material MRTE did not protect the spores. Nevertheless the results showed that the natural spore cluster formation of *Trichoderma koningii* protects the spores effectively against UV radiation by shielding. For the detection of mutations AFLP (amplified fragment length polymorphism)-analysis was carried out with the DNA of single spore cultures. Both parameters, space vacuum and UV radiation, showed an altered fingerprint pattern. Furthermore, DNA analysis comet assay (single-cell gel electrophoresis) was established and optimized for quantification DNA damage[1]. First experiments with fungal protoplasts treated with gamma radiation (0–50 Gy) showed high resistance and a clear correlation between degree of damage and fragmentation of DNA.

Can Martian biota survive extreme heating during transfer via meteorites from Mars to Earth?

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Throughout its history Mars has exchanged surface rocky material with Earth via Martian meteorites. However, transfer of biota with Martian meteorites is only plausible if Martian microorganisms could have somehow survived episodic extreme-heating events. At the moment of asteroidal impact into Martian surface (when Martian meteorite is produced) rock temperature sharply increases. Similar heating is expected upon entry of the meteorite into the upper Earth's atmosphere. In both cases the duration of heating is very short ~10 seconds. Note that prior to both extreme heating events Martian microorganisms should have experienced a low atmospheric pressure, desiccating and freezing conditions: Martian surface conditions and space vacuum. We have developed a special forevacuum experimental chamber to model the whole sequence of extreme events which hypothetical Martian biota should have experienced during transfer to Earth via Martian meteorites. We are studying the resistance of bacteria against the short heating pulses (<30 seconds) in the range of 100–400 °C at low atmospheric pressure down to 0.01–0.001 mbar. Surprising preliminary result: desiccated bacteria (*Escherichia coli*, *Pseudomonas aeroginosa*, *Streptococcus aureus*) are able to survive short high-temperature pulses up to 250 °C if they are at very low atmospheric pressure without water vapour and oxygen. The same pulses absolutely sterilize the same bacteria at atmospheric pressure. As a result, hypothetical Martian bacteria could have survived the high-temperature heating pulses at the ejection of Martian meteorites from Mars and entry into Earth's atmosphere.

Human Exploratory Missions
Poster presentations

Respiratory burst as a biomarker for immunomodulatory effects of space-flight conditions

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Long-term missions in space are a challenge for the human immune system. The effects of space-flight conditions on the mammalian immune system are an important subject for risk assessment while planning manned long-term missions. The impairment and alteration of immune functions caused by space-flight conditions have been reported for short-term missions. Here we describe a test system intended for investigating long-term effects, namely of cosmic radiation and microgravity, on mammalian phagocytes, which will be tested on the International Space Station within the Project TRIPLE LUX. The respiratory burst is a crucial event in phagocytes aimed at the destruction of ingested particles. It can be stimulated by zymosan or phrbol-myristate-acetate. The reactive oxygen species produced during the respiratory burst can easily be detected by the chemiluminescent reagent luminol. The intensity of the light signal is directly related to the strength of the respiratory burst. We further developed this test system for polymorphonuclear leukocytes purified from sheep blood as well as for the murine monocyte cell line NR8383. We have already used this test system for the detection of immune modulating effects of hydrocortisone and cadmium on the respiratory burst. Hydrocortisone in concentrations between 10^{-4} and 10^{-9} mol/L showed an immune stimulating effect after zymosan treatment. An immunosuppressive effect was observed for Cd^{2+} in concentrations between 10^{-4} and 10^{-7} mol/L. The results show that the luminol-based chemiluminescence is a reliable method for the future study of space-flight effects on mammalian phagocytes.

General Aspects
Oral presentations

Space exploration and 'protection of the environment' issues

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Three new, important problems are to be taken into consideration: (1) the radiation risk (not the radiation hazard!) is increasing together with the application of more and more sophisticated technology in space exploration; (2) the risk of contamination of different kinds of planetary surfaces also increases during space exploration; (3) there is a certain risk of underestimating the habitability of planetary surfaces outside the 'classical habitable zone' (since there is no proof yet that there is no indigenous life on celestial bodies outside the habitable zone defined by the possibility of liquid water on their surface). A realistic risk assessment, based on information gathered by planetary probes, should be initiated on all three issues before manned space exploration starts on different planets. In January 2004, President Bush has namely initiated a bold strategy of space exploration in the Solar System. Since that time NASA has changed its structure and policy giving space exploration plans a definite priority. Supposing that this new policy will be supported by the President and Congress in the years to come, astronauts might land on the Moon and build lunar bases around 2010–2020 and probably explore Mars in person between 2015 and 2030. Besides the difficult technical, medical and financial problems to be solved before these expeditions, a clear vision is also needed with respect to the relation of astronauts to their alien planetary environment. Do they have the right and authorization to modify fundamentally the surface of independent celestial bodies, contaminate their new environment with terrestrial microbes or change the niches of (potential) Martian life forms by their surface activity? Taking into account that the present space exploration policy of NASA is just the beginning of a much broader and fundamental endeavour versus the colonization of the Solar System, a 'protection of the Solar System environment policy' must be discussed previously by the participants of this venture leading to a treaty or governmental agreement on the relation of future visitors and settlers from Earth to their planetary environment. Such an agreement would be important also from the point of view of future possibilities of astrobiological research on Mars and on other celestial bodies.

Astrobiology at university level: teaching experience from Finland

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Astrobiology (http://fan.utu.fi) has been taught in Finland since 2001 at the university level, first as a combination of a basic course and a seminar course. More recently, we have expanded our teaching curriculum into a minor subject composed of astrobiology related courses

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from different departments of natural sciences (astronomy, biology, chemistry, biochemistry, geology, medicine, bioinformatics; http://www.sci.utu.fi/astrobiologia/). In general, astrobiology courses are highly interesting for both students and teachers. We can still encounter some potential problems. The highly non-uniform background of the students coming from a wide variety of classical disciplines means that matters trivial to some students may be new and quite difficult to others. One has to find a common language and level of understanding. For this we aim at minimizing the jargon used in each discipline with every new concept explained. A potential practical problem is the size of classes, at least during the basic courses, as they tend to draw large numbers of students. The teacher has to put his/her classical field into a new perspective of astrobiology and find the aspects that are relevant to astrobiology. This can be quite challenging for a scientist established deeply in one's own field. We have found that initially having a large number of teachers is advantageous and later on a smaller number of teachers with increased self-education may be more suitable for the sake of coherence. We are also participating in the multi-institute International AstroBiology Course Network for European collaboration in education. We will review our experience in this expanding education. In general, our experience in astrobiology teaching has been very rewarding and positive.

Other
Poster presentations

The effect of terrestrial magnetic anomalies on biodiversity and on preservation of extant and extinct form of life

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In order to study how magnetic field anomalies affect the biodiversity and the preservation of extant and of extinct forms of life, two such zones (with positive and negative magnetic values) were chosen. The main European magnetic anomalies are situated in Krivoi Rog (Ukraine) with negative magnetic field and in Bohemian Massif (Germany) with positive magnetic value, higher than normal. Generally, these anomalies correspond either to old orogenic zones (as for the Bohemian Massif) or with important iron ores hosted by Achaean formations (e. g. Krivoi Rog), and finally with the rift type or oceanic floor structures preserved within Precambrian formations (e g. north-east Russia and south-west Finland). The samples were collected from both places as well as from similar places from geologic/geographic point of view but having a normal geo-magnetic environment. Chemical characterization of rocks, using XPS Spectrum, magnetic measurements in the temperature range 4.2–300 K and external magnetic fields up to 9 T, as well as palinological analyses were made. Palinological samples were collected from Velka niva-Lenora swamp (Czech Republic). High magnetic values of the Bohemian zone are due to the presence of the magnetically charged rocks in the subsurface containing the mineral magnetite. Recorded magnetic susceptibility values in the first 200 cm of the peat swamp of the Velka niva-Lenora are low due to the high content of organic matter, which leads to a dilution of the magnetic materials. Pollen diagrams, based on sediments from the peat swamp of the Velka niva-Lenora (13°55′E, 48°53′N) Sumava Mountains, the Czech Republic, show the development of vegetation in the area since the Atlantic period (ca 8000 B.P.). Stands of *Pinus sylvestris*, *Picea abies* with *Betula* sp., *Alnus* sp. and some *Corylus avellana* covered this place between around 8000 and 3000 B.P. Since 3000 years ago until now *Abies alba* and *Fagus sylvatica* emerged and dominated the natural forests. Human impact influenced the vegetation, the *Poaceae* pollen being well expressed in the pollen diagrams. Under natural conditions some species were probably admixed with other taxa (such as *Quercus*, *Fraxinus*, *Tilia*) and thus possibly represented by low percentages in pollen records. Vegetation is dominated by the arboreal ecosystems. This location is characterized by a moderate woodland diversity, in terms of the number of taxa and the genetic diversity within the taxa.

Fossil *Gallionella* microbes in ancient subsurface habitats from tertiary basalts of eastern Iceland

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Filamentous fabrics are common in many geological settings representing ancient subsurface environments, mainly cavities in volcanic rocks and oxidized ore deposits[1]. Tertiary plateau basalts of eastern Iceland frequently host fracture- and cavity-infills consisting of chert-like silica with additional Fe hydroxides, hematite and Fe-rich clays (in tholeiitic basalts) while zeolites dominate in olivine basalts. The low-T hydrous precipitates frequently contain filamentous fabrics interpreted as microbialites[1–3]. Such occurrences are present on a regional scale. Detailed mapping of cherts in the Breiddalur area (64°50′N, 14°20′W) has demonstrated the confinement of such occurrences to certain levels in the volcanic stratigraphy and the association with flow sequences related to a central volcano. In addition to filamentous features, the common occurrence of twisted stalks resembling the extracellular products of the modern iron oxidizing bacterium Gallionella has been recognized. Gallionella-like stalks typically are 3–5 μm wide and several 100 μm long. Splitting of stalks probably due to cell division has been observed. The association of *Gallionella*-like stalks with filaments and Metallogenium-like structures is taken as evidence for a biological origin of the latter features. The common occurrence of cherts containing biosignatures in the Breiddalur area demonstrates that basaltic sequences affected by hydrous alteration have a good potential to host quantitatively important and qualitatively excellent biosignatures.

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Kinetic parameters of uracil dosimeter in simulated extraterrestrial UV radiation

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We discuss experimental data obtained as follows: radiation sources applied were Mars simulator, Solar simulator and high-power

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deuterium lamp, the wavelengths were adjusted by interference filters (200BP10, 210BP10, 220BP10, 230BP10, 240BP10, 250BP10, 260BP10, 270BP10, 280BP10, 290BP10, 300BP10, 310BP10, 320BP10) and the irradiances were measured by OL754 spectroradiometer. The photo-reverse effect depends highly on the wavelength of the exposed radiation. Shorter wavelength UV radiation of about 200 nm is strongly effective in monomerization, while the longer wavelengths prefer the production of dimerization. In the case of polychromatic light, like in space or on a planetary surface that is unprotected by an ozone layer, the two processes run in parallel. We could demonstrate experimentally, for the case of a uracil thin-layer, that the photo-reaction process of the nucleotides can be both dimerization and the reverse process: monomerization. These results are important for the study of Solar UV effects on organisms in the early terrestrial environment as well as for the search for life on Mars since we can show that biological harmful effects can also be reduced by shorter wavelength UV radiation, which is of importance in reducing DNA damage provoked by wavelengths longer than about 240 nm. Our earlier results showed that dimerization of the pyrimidin base uracil can be described by first-order kinetics, and this reaction gives the possibility to determine the dose of the UV source applied. This work is a theoretical and experimental approach to the relevant parameters of the first-order kinetics.

Irradiation by radioactive minerals in impact craters: 2. An example from the Lockne impact crater, Sweden

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The Lockne impact crater is located in central Sweden and was formed around 455 Ma ago. The impactor was emplaced in a Proterozoic crystalline basement (mainly Revsund Granite) overlain by a sedimentary cover (mainly dark bituminous shales, limestone and seawater)[1]. The basement was extensively fractured and brecciated as a result of the impact. This impact breccia, referred to as the Tandsbyn Breccia, consists of clasts of granite sometimes in a fine-grained and dark matrix. The matrix is composed of granitic material with traces of organic matter. The organic material includes migrated hydrocarbons and carbon-rich shale fragments, but is also concentrated in aggregates (nodules) together with uranium/thorium-rich radioactive minerals (including uraninite, monazite). Most likely the organic matter is derived from the carbon- and uranium-rich bituminous shale of the target. The uranium could be derived from the shale or from the granite itself. Uranium enrichment is common in the bedrock of Sweden. No uranium-rich bitumen nodules were detected in the Revsund Granite in the area directly outside the crater, i.e. they seem to be specifically associated with the crater. The deposition of the organic component could be a result of fracture-controlled fluid flow at any time after impact, for example during the Caledonian Orogeny. Another scenario would be that the organic component was carried and deposited by hydrothermal fluids circulating in the crater after impact. However, the impact-related hydrothermal activity was most likely only active in the inner crater[1]. This study implies that when radioactive minerals are present amongst the target rocks for impact craters, they are a preferred site for carbon concentration, and for our detection of organic molecules.

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DNA damaging effects of heavy ion and X-ray irradiation of *Bacillus subtilis* spores

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Spores of *Bacillus subtilis* are highly resistant to a variety of treatments, including wet and dry heat, desiccation, UV and oxidizing agents such as hydrogen peroxide. There are a number of factors involved in spore resistance, including the desiccation and mineralization of the spore core and decreased spore permeability to damaging chemicals. The saturation of spore DNA provides protection against DNA base loss due to wet heat (i.e. depurination) and DNA single-strand breakage caused by desiccation and X-ray treatment. In 1997, Kunst *et al.*[1] published the complete genome of *Bacillus subtilis* 168. Although much is known about the process of sporulation and of the mechanisms responsible for dormancy and resistance of bacterial spores, relatively little is known of the gene activation of germinating spores after DNA-damaging treatments such as heavy ion treatments. The heavy ion irradiation (He 150 MeV/n, Si 400 MeV/n and Fe 500 MeV/n) were performed at the Heavy Ion Medical Accelerator (HIMAC) at the National Institute for Radiological Sciences in Chiba, Japan (HIMAC project 17B463). For studying the effects of the irradiation with heavy ions, ions in a broad LET range (2–200 keV μm^{-1}) were used. The spores survival after irradiation up to 500 Gy was determined by their colony formation ability, for dose–effect correlation as a basis for following genetic investigations. Starting with the gene induction of X-ray treated spores, measured by using DNA microarrays, preliminary data show that there are many known and unknown up-regulated genes involved in the DNA repair during spores germination. Spores can survive even high doses of X-ray irradiation up to 0.5 kGy and they are still vital (~40% survival), but there is measurable DNA damage, which influences the physiological behaviour against specific antibiotics. Irradiated spores are more resistant against antibiotics such as rifampicin by order of a magnitude. This mutagenic effect (i.e. base pair substitution) is based on amino acid change in the *rpoB* gene. The beta subunit of RNA polymerase exhibits a unique spectrum of effects on growth and various developmental events, including sporulation and germination. Many DNA-repair mechanisms are currently known, but there are still unknown genes that could play an important role in the spore DNA repair such as, for example, the over 1000 '*y*-genes'. For comparing the transcriptional profiles of X-ray with heavy ion treated spores, further genetic studies including DNA microarray experiments are in progress (correlating with the different types of applied ions).

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Carbon isotopic enrichment in Titan's tholins: implications for Titan's aerosols

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Since the discovery of the main composition of Titan's atmosphere, many laboratory experiments have been carried out to mimic its chemical evolution, and in particular the formation of the haze particles of this atmosphere. Indeed the solid products obtained during these simulation experiments, often named Titan's tholins, are supposed to be analogues of Titan's aerosols and many studies have already been achieved on these tholins. In this study, we were attached to the possible isotopic fractionation of carbon during the processes involved in the formation of Titan's tholins. This poster aims to present the first results obtained on the isotopic ratios of $^{13}C/^{12}C$ measured on aerosols synthesized in a laboratory. Measures of $^{\delta 13}C$ leaded both on laboratory aerosols and on the initial gas mixture (N_2/CH_4 (98:2)) used in the simulations have shown a deficit of ^{13}C in comparison with ^{12}C in the aerosols synthesized, compared to the initial gas mixture.

Experimental silicification of bacteria: support for identification of terrestrial and extraterrestrial microbial signatures

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The earliest life forms known to date (> 3 Gyr) were preserved due to the precipitation of dissolved silica on cellular structures (silicification). In order to better understand silicification mechanisms, a simulated silicification experiment was undertaken. Our purpose was to fossilize microorganisms that could have lived in the estimated early Archaean conditions (atmosphere without oxygen, $T > 60\,^{\circ}C$, oceans slightly acid). A preliminary experiment with the strain *Methanococcus jannaschii* (methanogenic Archaea), demonstrated its potential for good preservation during the fossilization process. This is the first experimental fossilization of a methanogenic Archaea strain. We focused on a time-study of the morphology of the silicified cells. SEM and TEM observations showed that fossilization takes place very quickly (less than 24 hours after immersion in the silicifying agent) and occurs while the cells are still alive. The main morphological structures of the microorganisms (cell envelope and cytoplasmic wall) could still be seen 1 month after the beginning of the experiment, indicating the potential for good preservation of microorganisms. This preliminary experiment is being followed up by a more detailed study that includes more precise identification of the biogeochemical signature left by fossilized microorganisms in the mineral matrix. This experiment provides valuable insight into the silicification and preservation processes of the kind of microorganisms that could have existed on the early Earth. Knowledge of these mechanisms can be helpful for the search and the identification of microfossils in both terrestrial and extraterrestrials rocks, and in the particular case of Mars. Environmental conditions on early Mars were, in many respects, similar to those of the early Earth. Thus, life could possibly have appeared on Mars. Given its simplicity, it may have similarities to life on Earth (e.g. thermophilic, anaerobic, autotrophic microorganisms). Silicification experiments can therefore help in the identification of possible fossilized Martian microorganisms.