



ABSTRACTS OF PRESENTATIONS

MONDAY 12, Morning session

Nader Haghighipour

The Unique Unifying Power of Research on the Origin of Life and its Existence in the Universe

José Cernicharo

Molecules in space, from cold dark cores to high mass star forming regions

Sun Kwok

Relationship between stellar synthesized complex organics and solar system organics

Complex organics are now known to be present in meteorites, comets, asteroids, interplanetary dust particles, and planetary satellites in the solar system. Recent infrared spectroscopic studies of stars in the late stages of evolution have found evidence for the rapid synthesis of organic compounds with mixed aromatic-aliphatic structures. These organics are ejected into the interstellar medium and distributed throughout the Galaxy. The possibility that the early solar system had inherited stellar organics will be discussed.

References : Kwok, S. The Synthesis of Organic and Inorganic Compounds in Evolved Stars, *Nature*, 430, 985 (2004) ; Kwok, S. and Zhang, Y. Mixed aromatic/aliphatic organic nanoparticles as carriers of unidentified infrared emission features, *Nature*, 479, 80 (2011) ;Kwok, S. Complex organics in space: from Solar System to distant galaxies, *A&A Rev.*, 24, 1-27 (2016)

Dimitris Stamatellos

Young protoplanetary discs and their role in planet formation and evolution

Stars are born with discs that during their initial stages of formation are relatively massive, asymmetric and they are being fed with material from their parent clouds. Recent ALMA observations of the disc of the young star HL Tau have revealed the presence of multiple dust and gas gaps. These gaps may be carved by planets, and since HL Tau is an extremely young object (less than 1 Myr old), this raises the exciting possibility that planets and planetary systems may form much faster than it has been previously thought. Therefore, their formation may be sensitive to the early properties of discs while they are still forming in collapsing molecular clouds. We will present radiative hydrodynamic simulations of self-gravitating discs forming in collapsing clouds and discuss their observational signatures. We will examine whether the conditions for chondrule formation may be met in the spiral arms induced by gravitational instabilities in young discs. Finally, we will discuss how young proto-planets may evolve in such discs.

Hideaki Fujiwara

Dust in Warm Debris Disks

Debris disks around main-sequence stars, or "extrasolar zodiacal lights," are expected to be related to the stability of minor bodies and, potentially, to the presence of planets around stars. Recent high-sensitivity observations in the mid-infrared allow us to investigate the properties of warm dust grains in the inner region of debris disks, which should have a more direct link to the formation of terrestrial planets than the low-temperature dust that has been

previously studied. Here we report the results of our survey of warm debris disks based on photometric measurements at 18 micron taken from the AKARI/IRC All-Sky Survey data. We have identified a number of debris disk candidates with bright mid-infrared excess emission above the stellar photosphere. We find that A stars and solar-type FGK stars have different characteristics of their debris disks. We also show the results of our follow-up observations of the warm debris disks in the mid- and far-infrared, and discuss their nature.

Sin-iti Sirono

Sintering of icy dust aggregates and its effects on collision

In the outer region of a protoplanetary nebula, the main component of dust grains is ice. Because ice sublimates at low temperatures, ice molecules migrate to a neck between adjacent grains to minimize the total surface area. This process is called sintering. The mechanical properties of an icy dust aggregate change greatly due to sintering. I conducted numerical simulations of collisions between sintered dust aggregates. It was found that the collisional outcomes changes from sticking to bouncing or breakup with sintering. Sintering prevents growth of an aggregate. Planetesimals (and probably planets) cannot be formed in the region where sintering proceeds. Fragments are produced in a collision of sintered dust aggregates. The symmetric pattern observed in a protoplanetary disk HL Tau is well explained by sintering

MONDAY 12, Early afternoon session

Thomas Henning

Chemistry in protoplanetary disks

Manuel Güdel

Conditions for habitability: young stars and their environment

The formation of (Earth-like) life on planets requires a set of conditions that are to a large extent determined by the stellar and planetary environment. Among the most crucial conditions figure a stable atmosphere and temperature ranges that allow liquid water oceans to form and to remain present on long timescales. Such conditions are not easily met given the complex and variable environmental properties of young stars. Among the most important factors to determine the early formation of planetary habitable conditions are the long-term evolution of the stellar output from optical radiation to the X-rays, the strength of the stellar ionised wind, the rate of coronal mass ejections, and the presence of high-energy particles; furthermore, small bodies in the evolving young planetary system have both supporting and deteriorating effects. I will discuss the role of the stellar environment and the star itself for planetary habitability and will in particular emphasise the "initial conditions" in the epoch of star and planet formation.

Theresa Lüfting

Young stars magnetic fields and their influence on the habitability of surrounding planets

The atmosphere formed on a young planet and its habitability critically depends on the properties of its host star - in particular the evolution of stellar rotation, winds and of the related magnetic activity are of crucial importance. The magnetic field of a star is the essential driver of activity, of ionization, photodissociation, chemistry, and winds in the stellar environment. Thus these fields have an enormous impact on the atmospheres and the magnetospheres of surrounding exoplanets. Modelling of stellar magnetic fields and their winds is extremely challenging, both from the observational and theoretical points of view. The recent groundbreaking advances in observational instrumentation and a deeper theoretical understanding of magnetohydrodynamic processes in stars enable us to model stellar magnetic fields and winds - and the resulting influence on surrounding planets - in more and more detail. In this presentation we will address questions on the formation and habitability of environments in (young) stellar-planetary systems in the light of stellar magnetic activity. We will discuss, how magnetic fields and winds are assessed observationally with relevant techniques such as Zeeman Doppler Imaging, field extrapolation, and wind simulations. We explore and present in particular a sample of prototypical young Suns, coupling the whole system, from the stellar surface to winds launched by the magnetic field, the atmospheric erosion of a surrounding early Earth due to this activity and winds, and the planetary magnetosphere as a shielding and protecting source.

Hideko Nomura

CO gas depletion and formation of organic molecules in protoplanetary disks

Protoplanetary disks are the natal place of planets and ALMA observations are now revealing the physical and chemical structure of planet forming regions in the disks. Understanding chemical components of gas, dust and ice in the disks is essential to investigate the origins of materials in the planets. In the talk, I shall report our recent ALMA Band 7 observations of CO isotopologue lines from the protoplanetary disk around TW Hya. The result shows a significant decrement in CO gas throughout the disk even inside the CO snowline, indicating freeze-out of gas-phase CO onto grain surfaces and possible subsequent surface reactions to form larger molecules. Complex

organic molecules could be efficiently produced in the observed CO gas depleted regions. Actually, methanol has been detected towards the TW Hya, whose abundance relative to water is consistent with that of comets in our Solar system.

MONDAY 12, Late afternoon session

Yoko Kebukawa

Carbonaceous meteorites and the origins of organic matter

Carbonaceous meteorites contain wide variety of organic matter. The origins of the organic matter are still subject to debate. One hypothesis is synthesis of organic matter during meteorite parent body aqueous processing starting from simple molecules such as formaldehyde and ammonia. Hydrothermal experiments of water solutions containing a mixture of formaldehyde, glycolaldehyde and ammonia showed that various amino acids including α -, β - and γ -amino acids up to five carbons were produced simultaneously with macromolecular organic solids similar to the chondritic insoluble organic matter (IOM). One-pot aqueous processing from simple ubiquitous molecules can produce a wide variety of extraterrestrial organic matter from amino acids to macromolecular IOM in hydrous planetesimals.

Hervé Cottin

Comets organic content and astrobiology, (re)assessment for comet 67P after the Rosetta mission

Comets are commonly regarded as objects with a prime astrobiological importance. They are reservoirs of a large amount of material considered as necessary for the origin of life: water and organic molecules. While the measurement of the D/H ratio in the water of comet 67P established in the early stages of the Rosetta mission that comets such as 67P are probably not a source of water on Earth, the nature and amount of the organic content of comet 67P is progressively revealed through the complementary measurements of ROSINA, COSAC, PTOLEMY and COSIMA instruments. The detection of glycine and phosphorous atoms in the atmosphere of the comet have demonstrated the presence of so called "prebiotic" ingredients. However, it takes certainly much more than this to feed the chemical evolution toward the origin of life on a planet. The organic content of comet 67P, as revealed by the Rosetta spacecraft, will be reviewed. The part that comets could have played in the origin of life on Earth will be discussed with regard to this inventory and in the light of recent advances in prebiotic chemistry.

Grazina Tautvaišienė

CNO abundances in stars of open clusters as tracers of stellar life

Carbon, nitrogen, and oxygen are key elements in stellar formation and evolution, and their abundances should also have a significant impact on planetary formation and evolution. Recent spectroscopic studies showed that stars hosting planets are relatively more metal-rich than those without planets. Differences of chemical composition of primordial clouds or stellar self-enrichment are competing scenarios to explain that. Investigations of stars in open clusters may reveal peculiar objects since the initial composition of stars in a cluster was the same. Using high-resolution spectra we determined the CNO abundances and C/N ratios for red giant branch stars in a sample of open clusters. We compare our results with recently developed stellar evolution models which take into account various scenarios of material mixing in stellar atmospheres.

Ji-Wei Xie

Orbits of Planetary Systems: an Eccentricity Dichotomy, a Common relation and the Prevalence of Circular Orbits

The nearly circular (mean eccentricity $\langle e \rangle \sim 0.06$) and coplanar (mean mutual inclination $\langle i \rangle \sim 3$ deg) orbits of the Solar System planets motivated Kant and Laplace to put forth the hypothesis that planets are formed in disks, which has developed into the widely accepted theory of planet formation. Surprisingly, the first several hundred extrasolar planets (mostly Jovian) discovered using the Radial Velocity (RV) technique are commonly on eccentric orbits ($\langle e \rangle \sim 0.3$). This raises a fundamental question: Are the Solar System and its formation special? The Kepler mission has found thousands of transiting planets dominated by sub-Neptunes, but most of their orbital eccentricities remain unknown. By using the precise spectroscopic host star parameters from the LAMOST observations, we measure the eccentricity distributions for a large (698) and homogeneous Kepler planet sample with transit duration statistics. Nearly half of the planets are in systems with single transiting planets (singles), while the other half are multiple-transiting planets (multiples). We find an eccentricity dichotomy: on average, Kepler singles are on eccentric orbits with $\langle e \rangle \sim 0.3$, while the multiples are on nearly circular ($\langle e \rangle = 0.04^{+0.03}_{-0.04}$) and coplanar ($\langle i \rangle = 1.4^{+0.8}_{-1.1}$ deg) orbits similar to the Solar System planets. We also show that Kepler multiples and solar system objects follow a common relation $\langle e \rangle \sim (1-2) \times \langle i \rangle$ between mean eccentricities and mutual inclinations. The prevalence of circular orbits and the common relation may imply that the solar system is not so atypical in the galaxy after all. For more details, please check the paper <https://arxiv.org/abs/1609.08633>

TUESDAY 13, Early morning session

Axel Hofmann

Early Earth surface processes 3.5 to 3.0 Ga ago

The Archaean geological record of the Kaapvaal Craton, South Africa comprises world-famous volcano-sedimentary successions that have provided key data for the understanding of surface processes on the early Earth. The Mesoarchaeon Dominion, Pongola and Witwatersrand Supergroups are the oldest continental cover successions of flood basalts and fluvial to shallow-marine sediments. These rocks provide a well-preserved record up to 3.0 billion-years-old of diversified life, contain proxies for atmospheric and ocean composition and host the largest gold deposit known. Stratigraphic architecture and lithofacies characteristics are not unlike much younger epicontinental volcano-sedimentary successions. Farther back in time, the Barberton greenstone belt, 3.5 to 3.2 Ga in age, has emerged as one of the most important Palaeoarchaeon geological sites worldwide in which to study the nature and processes of early Earth history. Palaeoarchaeon greenstone belts are direct evidence for non-tectonic processes on Earth, reflecting secular evolution of the Earth mantle and crust. They are characterised by submarine, predominantly mafic volcanic rocks that are interstratified or tectonically interleaved with volcanoclastic, siliciclastic and chemical sedimentary rocks of marine to terrestrial environments. Gold, nickel and iron form important ore deposits in greenstone belts, reflecting specific enrichment processes. The volcano-sedimentary successions have recorded very different physico-chemical conditions of the ancient Earth surface, and are the prime target for the study of the co-evolution of the atmosphere, hydrosphere, and biosphere.

Hervé Martin

Was the growth of Earth continental crust continuous or episodic? Implications for the evolution of life

Until recently, researchers considered that partial melting of Mid-Ocean Ridge Basalts (MORB) generated Tonalite-Trondhjemite and Granodiorite (TTG) suites that are the main components of the Archaean continental crust. Melting took place at high-pressure, in a hot subduction environment. However, recent geochemical modelling and experiments of basalt melting preclude MORB as a plausible source for TTGs. They rather indicate that TTG formed by melting of a source rich in elements such as K, Rb, Ba, Th, U, La, very similar to oceanic plateau basalts. On the other hand, the growth of continental crust appears as being episodic; it proceeded by "super growth events", (at ~4.2, ~3.8, ~3.2, ~2.7, ~1.8, ~1.1 and ~0.5 Ga), which is inconsistent with the continuous and regular crustal growth expected for a subduction driven process. Several authors proposed that in subduction environments, the descending residual slabs accumulate at the 660-km seismic discontinuity. When the amount of stored oceanic crust exceeds a threshold, it suddenly sinks into the lower mantle as a cold avalanche, which induces the ascent of a mantle plume, giving rise to the emplacement of huge amounts of oceanic plateaus. However, melting of an oceanic plateau does not appear as a realistic process for TTG genesis. Actually, modern oceanic plateaus can contain small volumes ($\leq 5\%$) of felsic magmas whose composition drastically differs from that of TTGs. In Iceland, the interaction between mantle plume and the Mid-Atlantic ridge results in an abnormally (Archaean-like) high geothermal gradient. Even in this favourable context, it is unable to reproduce the TTG trace element signature. Consequently, oceanic plateaus are not suitable environments for the genesis of the Archaean continental crust. A realistic alternative to this scenario consists in the subduction of the oceanic plateaus. A present day analogue of this process can be found in Ecuador, where the Carnegie ridge that is an oceanic plateau resulting of the Galapagos hot spot activity, subducts under the South American plate. There, TTG-like magmas are generated, and, in addition, the magmatic productivity is several times greater than in the other part of the volcanic arc. Consequently, it appears that subduction of oceanic plateaus can account not only for the episodic crustal growth, but also for the huge volumes of magma emplaced during these episodes. These later correspond to volcanic crisis, where not only huge amounts of magma are produced, but also where enormous volumes of ashes and gas were injected into the high atmosphere. These conditions are able to significantly modify the climate or more globally the environment of Earth's surface, which can have a great impact on the evolution of early life.

Benjamin Charnay

3D modeling of climate, carbon cycle and photochemistry on the early Earth

Oxygen isotopes in marine cherts have been used to infer hot oceans during the Archean with temperatures between 60°C and 80°C. Such climates are challenging for the early Earth warmed by the faint young Sun. The interpretation of the data has therefore been controversial. I will present results concerning the climate and carbon cycle of the early Earth at 3.8 Ga using a 3D GCM coupled to a carbon cycle model. We find that CO₂ partial pressures of around 1 bar could have produced hot climates given a low land fraction and cloud feedback effects. However, such high CO₂ partial pressures should not have been stable because of the weathering of lands and oceanic basalts, producing an efficient stabilizing feedback. Our results therefore favor cold or temperate climates for the late Hadean and early Archean. Finally, I will show results on the photochemistry on the early Earth performed for the first time with a 3D GCM.

Barbara Stracke

On the habitability of a stagnant-lid Earth

Whether plate tectonics is a recurrent feature of terrestrial bodies orbiting other stars or is unique to the Earth is unknown. The stagnant-lid may rather be the most common tectonic mode through which terrestrial bodies operate. Here we model the thermal history of the mantle, the outgassing evolution of H₂O and CO₂, and the resulting climate of a hypothetical planet with the same mass, radius, and composition as the Earth, but lacking plate tectonics. We employ a 1-D model of parameterized stagnant-lid convection to simulate the evolution of melt generation, crust production, and volatile extraction over a timespan of 4.5 Gyr, focusing on the effects of three key mantle parameters: the initial temperature, which controls the overall volume of partial melt produced; the initial water content, which affects the mantle rheology and solidus temperature; and the oxygen fugacity, which is employed in a model of redox melting to determine the amount of carbon stored in partial melts. We assume that the planet lost its primordial atmosphere and use the H₂O and CO₂ outgassed from the interior to build up a secondary atmosphere over time. Furthermore, we assume that the planet may possess an Earth-like ocean. We calculate the atmospheric pressure based on the solubility of H₂O and CO₂ in basaltic magmas at the evolving surface pressure conditions. We then employ a 1-D radiative-convective, cloud-free stationary atmospheric model to calculate the resulting atmospheric temperature, pressure and water content, and the corresponding boundaries of the habitable zone (HZ) accounting for the evolution of the Sun's luminosity with time but neglecting escape processes. The interior evolution is characterized by a large initial production of partial melt accompanied by the formation of crust that rapidly grows until its thickness matches that of the stagnant lid so that the convecting sublithospheric mantle prevents further crustal growth. Even for initial water concentrations in excess of thousands of ppm, the high solubility of water in surface magmas limits the maximal partial pressure of atmospheric H₂O to a few tens of bars, which places de facto an upper bound on the amount of water that can be delivered to the surface and atmosphere from the interior. The relatively low solubility of CO₂ causes instead most of the carbon contained in surface melts to be outgassed. As a consequence, the partial pressure of atmospheric CO₂ is largely controlled by the redox state of the mantle, with values that range from a few up to tens of bars for oxygen fugacities between the iron-wüstite buffer and one log-unit above it. At 1 AU and for most cases, liquid water on the surface is possible, hence the planets considered would be regarded as habitable although the atmospheric temperature may be well above the temperature limits for terrestrial life. The inner edge of the HZ depends on the amount of outgassed H₂O and is located further away from the star if no initial water ocean is assumed. The outer edge of the HZ is controlled by the amount of outgassed CO₂, hence by the assumed redox state of the mantle and its initial temperature.

TUESDAY 13, Late morning session

Ramon Brasser (+S. J. Mojzsis, S. C. Werner, S. Matsumura and S. Ida)

Late veneer and late accretion to the terrestrial planets

It is generally accepted that silicate-metal ('rocky') planet formation relies on coagulation from a mixture of sub-Mars sized planetary embryos and (smaller) planetesimals that dynamically emerge from the evolving circumsolar disc in the first few million years of our Solar System. Once the planets have, for the most part, assembled after a giant impact phase, they continue to be bombarded by a multitude of planetesimals left over from accretion. Here we place limits on the mass and evolution of these planetesimals based on constraints from the highly siderophile element (HSE) budget of the Moon. Outcomes from a combination of N-body and Monte Carlo simulations of planet formation lead us to four key conclusions about the nature of this early epoch. First, matching the terrestrial to lunar HSE ratio requires either that the late veneer on Earth consisted of a single lunar-size impactor striking the Earth before 4.45~Ga, or that it originated from the impact that created the Moon. An added complication is that analysis of lunar samples indicates the Moon does not preserve convincing evidence for a late veneer like Earth. Second, the expected chondritic veneer component on Mars is 0.06 weight percent. Third, the flux of terrestrial impactors must have been low to avoid wholesale melting of Earth's crust after 4.4~Ga, and to simultaneously match the number of observed lunar basins. This conclusion leads to an Hadean eon which is more clement than assumed previously, with a feeble bombardment and a functioning hydrosphere. Last, after the terrestrial planets had fully formed, the mass in remnant planetesimals was 0.001 Earth mass, lower by at least an order of magnitude than most previous models suggest. Our dynamically and geochemically self-consistent scenario requires that future N-body simulations of rocky planet formation either directly incorporate collisional grinding or rely on pebble accretion.

Miguel Angel Montoya-Pérez (+Karina Elizabeth Cervantes de la Cruz, José Luis Ruvalcaba Sil)

Characterization chemical and morphological of olivine barred chondrule and meteorite classification by nondestructive spectroscopy techniques

Ever since asteroids were discovered, they've been seen as remains of the planetary formation (Dameo and Carry, 2014), that's the reason why the processes that created the Solar System are registered in them, the same way we can read Earth's history from geological registry. Chondrites are classified according to their chemical constitution and the petrological characterization of their components (Van Schmus and Wood, 1967). Chondrules are what characterize chondrites. Particularly barred olivine chondrules are made out of dendritic olivine crystals forming a

texture of a single-plate dendrite. Cervantes de la Cruz (2009) experimental work suggests that the BO type chondrules width depends on the precursor material's partial or total fusion and this is directly proportional to the amount of energy under which they were formed. The purpose of the work is to characterize barred olivine chondrules of the Allende chondrite based on the morphological study of their bars' width and their mineralogical composition. The results obtained show that the bars' width present a values ranging from 5 μm to 10 μm . On the other hand, the chemical and mineralogical analyses, based on the SEM and microRaman results, indicate the chondrules' bars are composed of olivine rich in magnesium. In some cases they can be present in clinopyroxenes zones and other accessory minerals such as plagioclase. We also present the implementation of the total chondrule analysis method based on the X-ray fluorescence (XRF) analysis using the SANDRA portable equipment at the Investigation and Conservation of Cultural Patrimony National Science Laboratory (LANCIC-IF) in Mexico City. Furthermore, this method allows a preliminary classification of the metallic meteorites based on its Fe and Ni content present.

Zan Peeters

Large inclusions of organic carbon in meteorites: an application for nanoSIMS in Astrobiology

One crucial step in the origin of life on Earth is the accumulation of the building blocks of life. Multiple sources may have contributed to the final pool of chemical building blocks, both terrestrial and extraterrestrial. The analysis of organic matter (OM) contained in certain types of meteorites (carbonaceous chondrites), may help us understand what cache of building blocks, small soluble molecules such as amino acids as well as larger chunks of insoluble organic matter, was available at the time of the origin of life on Earth. Meteoritic organic matter has been extensively studied in the past in its extracted form. After dissolving away the surrounding meteoritic material (metals, silicates, sulfides) in strong acids, the insoluble organic matter (IOM) could be extracted. This was used to measure the elemental and isotopic composition, some chemical structural information, and the degree of alteration. The results, however, could only describe the bulk average of the IOM. By extracting the IOM, all spatial information and any sign of heterogeneity within the meteorite was lost. In our experiments, we focus on measuring the composition of meteoritic OM in situ, without destroying the surrounding matrix. We have used the nanoSIMS (nanometer-scale secondary-ion mass spectrometer) to map the carbon and nitrogen content of an area of the Murchison meteorite. Meteoritic OM was thought to occur as a sub-micrometer, fine-grained material dispersed within the matrix. We found that it can also occur as larger (up to 10 micrometer) inclusions and veins of pure organic matter. We then use a range of analytical tools (FIB, TEM, XANES, and again nanoSIMS) to investigate the morphology, elemental, chemical, and isotopic compositions of the different inclusions. The results show that there is a lot of heterogeneity amongst the various inclusions within one meteorite, and sometimes even within one inclusion. These findings have implications for both the origin of the meteoritic OM and the contributions to the pool of chemical functionality available to the nascent life on Earth.

Kota Naito

Statistical study on micrometer-sized organic inclusions in meteorites

Carbonaceous chondrites are meteorites that contain up to 7 wt% carbon. The organic matter that resides within these meteorites may have contributed to the building blocks for life through extraterrestrial delivery. Hence, investigating meteoritic organic matter is crucial for enhancing our understanding of the origin of life in the Solar System. In this study, we have used a new approach for analysing organic matter in carbonaceous chondrites. We used the NanoSIMS 50L to map large surface areas of four carbonaceous chondrites, SaU 290 (CH3), Murchison (CM2), GRA 95229 (CR2), and QUE 99177 (CR3) in 12C2, 12C13C, 12C14N, and 12C15N to search for organic inclusions. We then used image analysis software (SourceExtractor) to automatically detect organic inclusions in the collected image data. The output from SourceExtractor (coordinates, counts, area, ellipticity, etc. of each detected inclusion) was post-processed by our own homemade software to perform statistical analysis on the large number of inclusions that were extracted. The results show distinct trends in various properties of the organic inclusions between meteorites from different classes. For example, the size distributions of organic inclusions in the two CR chondrites are both highly skewed towards small-sized inclusions (<300 nm²), whereas the inclusions detected in the CH3 chondrite show a higher proportion of larger sizes (300-600 and 600-900 nm²); the distribution of the CM2 chondrite lies somewhere in between. We conclude that our novel method for automated organic inclusion detection can effectively extract large numbers of organic inclusions from NanoSIMS data and apply statistical analysis, to discover trends and differences between classes of meteorites.

TUESDAY 13, Early afternoon session

Takeshi Takegawa

Evidence of early life at >3.7 Ga Isua Supracrustal Belt in Greenland: its implication to origin of life

Some graphite contained in the 3.7-billion-year-old metasedimentary rocks of the Isua Supracrustal Belt (ISB), Western Greenland, is depleted in 13 C and has been interpreted as evidence for early life. However, it is unclear whether this graphite is primary, or was precipitated from metamorphic or igneous fluids. We discovered new graphitic schists in the northwestern part of ISB. We analyze the geochemistry and structure of graphite in the

discovered schists. Raman spectroscopy and geochemical analyses indicate that the schists are formed from clastic marine sediments that contained ^{13}C -depleted carbon at the time of their deposition. Transmission electron microscope observations show that graphite in the schist occurs as nanoscale polygonal and tube-like grains, in contrast to abiotic graphite in carbonate veins that exhibits a flaky morphology. Furthermore, the graphite grains in the schist contain distorted crystal structures and disordered stacking of sheets of graphene. The observed morphologies are consistent with pyrolysis and pressurization of structurally heterogeneous organic compounds during metamorphism. We thus conclude that the graphite contained in the Isua metasediments represents traces of early life that flourished in the oceans at least 3.7 billion years ago. Proto-arc model has been proposed to explain tectonic evolution of ISB (1). Tourmaline has been discovered from various locations in ISB, suggesting local enrichment of boron (2, 3). A part of biogenic graphite in ISB is associated with tourmaline. This finding implies that the early life was living in semi-closed, shallow and alkaline oceans enriched in borate, developed on "proto-arc" tectonic setting. Such shallow, potentially evaporitic, and borate-rich oceans are ideal to promote chemical evolution of ribose and RNA on the Hadean Earth (4).

References: (1) Nutman et al., (2015) *Geol.Soc.Lond.*, 389, 113, (2) Grew et al. (2015) *GCA*, 163, 156, (3) Mishima et al. (2015) *OLEB*, DOI10.1007/s11084-015-9474-x, (4) Furukawa et al. (2013) *OLEB*, 43, 353, (4) Nitta et al. (2015) *OLEB*, DOI 10.1007 /s11084-015-9472-z.

Yiliang Li

Looking for a new biomarker for the earliest oxygenic photosynthesis on Earth

From Archean to the early Palaeoproterozoic (~3.8-2.5 Ga), the deleterious short-wavelengthed ultraviolet radiations (UVRs), including Ultraviolet C (UVC, 200-280 nm) and most of Ultraviolet B (UVB, 280-315 nm) were able to penetrate the atmosphere and reached the surface of the Earth. Primitive photosynthetic microorganisms had to cope with this harsh surficial environment in order to harvest solar energy. It is known that some cyanobacterial species have developed sheath pigments on the cell exterior, such as scytonemin, to filter Ultraviolet A (UVA, 315-400 nm) as a living strategy. We investigated the properties of UVR absorbing by scytonemin and its structural derivatives, including two putative precursors and the oxidized/reduced transformations. We find that scytonemin and its derivatives have significant absorptions in the UVC region, which suggests the very surface the Earth could be habitable for Archean life with sheath pigments without the need for an atmospheric UVR shield.

Sally Potter-McIntyre

Progressive diagenetic alteration of macro- and microscopic biosignatures in ancient springs and spring-fed lacustrine environments

Biosignatures can be preserved via microbial enhancement of mineral precipitation during deposition and/or early diagenesis. Preservation of any type of microbial fossil or chemical or textural biosignature depends on the degree of alteration during diagenesis. Microbial carbonates have been extensively examined in modern systems; however, little is known about the transformation of biosignatures during diagenesis over geologic time. Mineralogical and morphological biosignatures in modern spring deposits are compared with the Quaternary (100-400ka) and Jurassic examples to show how these biosignatures are altered during diagenesis. These successively older carbonate microbialites provide a novel opportunity to investigate how macroscopic features diagnostic of spring deposits and microscopic biosignatures are progressively altered and preserved on geologic time scales. Ten Mile Graben, UT, USA hosts a cold spring system that is an exceptional site to evaluate diagenetic alteration of biosignatures due to the presence of modern springs with actively precipitating microbial mats and a series of progressively older tufa terraces (<400ka) preserved in the area from the same spring system. A Jurassic laminated carbonate deposited in a restricted hot spring-fed hypersaline lake environment (similar to Mono Lake, CA) within the upper part of the Brushy Basin Member of the Morrison Formation is also exposed in Ten Mile Graben. The data highlight two distinct methods of biosignature formation: 1. microbial metabolic activity induces mineral precipitation in a solution with nearly undetectable amounts of reactants, and 2. minerals nucleate on charged cell surfaces. Microbes also produce trace fossils by creating an environment conducive to mineral precipitation and, in turn, the presence of these minerals help preserve these features. Although organic matter may decompose in oxidizing near-surface conditions, this study shows that some microbial body fossils and trace fossils such as honeycomb textures can persist due to encasement by iron (oxyhydr)oxides and/or by entombment via Ostwald ripening of carbonates. This field site preserves an excellent record to understand the taphonomy of macroscopic and microscopic biosignatures preserved in discrete time slices in the geologic record. Recognizing spring-fed, biogenic tufas is crucial for astrobiological research and the search for life on Mars.

TUESDAY 13, Late afternoon session

Daniele Pinti

Noble gas and nitrogen isotopes from inclusions of the > 3.8 Ga Nuvvuagittuq Belt, Northern Quebec

The Nuvvuagittuq greenstone belt is a volcano-sedimentary sequence located on the eastern coast of Hudson Bay (Ungava Peninsula, Northeastern Superior Province of Canada). The belt is composed of gabbroic intrusions,

volcano-sedimentary silicic rocks and banded iron formation (BIFs), enclosed by 3.66 Ga tonalitic gneiss. Rocks are metamorphosed to amphibolite facies and zircon U-Pb ages give a minimum age of 3.75-3.82 Ga to the belt. A deficit in ^{142}Nd compared to the terrestrial Nd standard found in mafic amphibolites suggests that the emplacement age could be as old as 4.3 Ga, making this belt one of the oldest rock units on Earth. Characterization of the fluids in silicic rocks and BIFs, identified by previous works as chemical precipitates in seawater, might give precious constraints on the Earth superficial conditions in Late Hadean, following the Late Heavy Bombardment. Analyses of noble gas isotopes and nitrogen isotopes were carried out on a suite of rocks of the belt including ultramafic intrusions, silicic rocks, tonalite gneiss, BIFs and amphibolites. The ^4He , ^{22}Ne , $^{36,40}\text{Ar}$, $^{84,86}\text{Kr}$ and $^{129,131,132,134,136}\text{Xe}$ were analyzed on a quadrupole mass spectrometer (QMS) at GEOTOP. The $^{15}\text{N}/^{14}\text{N}$ ratio (reported as R15N and normalized against the air ratio) was measured with a QMS at Osaka University. Interestingly, anomalies of ^{86}Kr and heavy Xe isotopes and their relationship with argon isotopes ($^{40}\text{Ar}/^{36}\text{Ar}$) suggests the occurrence of two fluids in the rocks. The first is modern contamination with noble gas isotopic composition similar to present atmosphere. The second is an old fossil fluid component isolated longtime to have produced rare fissionogenic anomalies of Kr and Xe. Preliminary results of nitrogen isotopic data in a few samples show the same trend, with the modern component having a R15N close to 0‰, i.e. modern atmosphere, and an older component showing also a very light R15N value around +3‰. Previous work on Archean rocks suggested that the R15N value of superficial reservoirs on Earth (hydrosphere+atmosphere) did not change during eons and the R15N could have been $\pm 2\%$ around the present day atmospheric value of 0‰. If the R15N values are pristine would indicate that in the early Archean or even Hadean, the Earth was protected by a strong magnetic field. In the absence of such magnetic shielding, atmospheric dinitrogen would have interacted with charged particles from the solar wind, resulting in N isotope fractionation, as observed in the atmosphere of Mars.

Jean Pierre Bibring
Mars and Earth co-evolution

Julio Fernández
Impacts of giant comets and asteroids on Earth. An assessment of their relative contribution to the overall impact rate

The Earth has been subject to a steady bombardment of minor bodies throughout its lifetime. Most of the impactors are asteroids coming from the main belt. Comets coming from the Oort cloud or the trans-neptunian belt constitute a minor fraction (a few percent) of the collisional population of bodies with diameters $D > 1$ km. Yet, comets are found to have a greater contribution among the largest impactors ($D > \sim 10$ km) so, in terms of large impacts that may cause severe disruption of Earth's climate and extant mass extinction, large comets may be of some significance, and might even become dominant in some scenarios. The largest sky surveys of the last two decades have provided a much better knowledge of the populations of small bodies coming to the terrestrial zone, and of the more distant populations (e.g. Centaurs) that might evolve into Earth-crossing orbits and become potential impactors. The aim of this presentation is to re-evaluate the size and size-distribution of the populations of Oort cloud comets, Halley-type comets and Jupiter-family comets that are or may become Earth-crossers to assess the impact history of large comets with the Earth and compare it with that from asteroids. These results will be also compared with the impact cratering record on Earth and the layers of molten droplets, or spherules, formed as a consequence of megaimpacts.

Jaganmoy Jodder
Probing into the Palaeoarchaean record of the Singhbhum Craton (India) in search for vestiges of life older than 3.5 Ga.

Archean greenstone belts of the Kaapvaal craton, South Africa, and Pilbara craton, Western Australia, have been investigated comprehensively to elucidate the origin of early life. Arguments to establish an indisputable trace of biological life have led to several decades of research on these areas. Bonafide microfossils and microfossil assemblages, such as reworked microbial mats [1], organic-walled microfossil assemblages [2, 3], and filamentous microfossils [4] have been documented from different Palaeo-Mesoarchaeon volcano-sedimentary successions of both cratons, allowing a valuable insight into early life on Earth. In this work, we evaluate and appraise a well-preserved record of early life from the 3.51 Ga Palaeoarchaeon greenstone belt of the Singhbhum Craton, India and compare it with the Buck Reef Chert (3416 Ma), Barberton greenstone belt, South Africa, and the Strelley Pool Chert (3426 Ma), Western Australia. The Singhbhum craton has an Archean geological history remarkably similar to the Kaapvaal craton. The oldest rocks currently known in the Singhbhum craton include 3.5 Ga old TTG gneisses and greenstone belts. The Daitari greenstone belt of southern Singhbhum has experienced only low-grade metamorphism and includes a well-perpetuated submarine volcano-sedimentary succession of mafic-ultramafic rocks and intercalated banded cherts and iron formation. Felsic volcanoclastic rocks dated at 3.51 Ga [5] allow direct comparisons with the lower portions of the Onverwacht and Nondweni groups of the Kaapvaal craton. Conventionally, sedimentary chert units have been examined in the Palaeoarchaeon to understand the nature and association of carbonaceous matter. Sedimentary chert horizons of the Daitari belt overly sea-floor alteration zones and host signatures for the oldest habitat of early life in the form of well-retained carbonaceous matter. Carbonaceous matter recognized within the various chert units can be categorized based on its occurrence,

association and also its concentration of carbonaceous aggregates. The carbonaceous matter is preserved as: (1) composite carbonaceous grains, (2) reworked carbonaceous clasts, and (3) finely laminated carbonaceous layers. The carbonaceous matter within the chert of the Daitari belt shows textural, morphological and diagenetic similarities with the well-studied carbonaceous matter from the Buck Reef Chert and Strelly Pool Formation [6, 7]. Field, petrographic, and geochemical studies suggest primary biogenic processes for the origin of carbonaceous matter present within the chert horizons from Daitari. The Palaeoarchaeon rock record provides glimpses of an active biological niche, highlighting its importance in the search for new traces of life and understanding early Earth processes. The volcano-sedimentary succession of the Singhbhum craton may hold the key to several unsolved riddles of the past, including early geobiological constraints, depositional environments and tectonic settings related to the emergence of Earth as a habitable planet around 3.5 Ga.

WEDNESDAY 14, Early morning session

Jorge Vago, by Jean Pierre Bibring
Search for life signatures on Mars

Jesùs Martínez-Frías

Ethics and space exploration: from geoethics to astroethics

Advances in science and technology have increased considerably in the past century. Scientists have new skills and tasks linking different disciplines, applying different methodological procedures and technologies, and facing new challenges, from micro to macro-scale studies, and from land, atmosphere and oceans to planetary exploration. Scientists' duties go beyond scientific and technological knowledge and skills. Ethics (bioethics and geoethics) are part of their (our) professional responsibility ¹. At present, space agencies, through the well-established Planetary Protection requirements are committed to exploring space preventing all types of biological contamination, and preserving the planetary conditions, mainly considering biological and bioethical topics. Geoethics is, unfortunately, not very well known yet. However, it is not a new discipline. Despite the term being used with various meanings, Geoethics was born in 1991 in Příbram (Czech Republic) at the junction of Ethics and Geology. In accordance with the official definition of the International Association for Geoethics (IAGETH), it is an interdisciplinary field between Geosciences and Ethics which involves Earth and Planetary Sciences as well as applied ethics. In addition, studies on planetary geology (*sensu lato*) and astrobiology also require a geoethical approach. With the recent increase in the exploration and research of the planets and celestial bodies, planetary science and astrobiology are fast-growing scientific branches, and there is a great variety of scientific and social-cultural aspects which are interconnected. Many of them are related to: a) the concept of planetary habitability (including the Earth) and potential habitable environments, at different scales of space and time, and b) the multiple open issues and questions linking the abiotic and biotic worlds. Obviously, this also involves taking into account ethical approaches, which, giving the complexity and transdisciplinary nature of Astrobiology, could require a step forward towards the developing of astroethics, at least for considering and facing some special cases ². In this sense, a working group on astroethics has been recently established under the institutional umbrella of the International Association for Geoethics (IAGETH).

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Kelly Smith

Life as a Statistical Kind

The quest to define life has a long history, but the debate has recently received new attention as the search for life beyond Earth and developments in synthetic biology are forcing researchers to address whether the systems they study qualify as living. It is curious that nearly one hundred years after the emergence of the modern synthesis, biologists are still not able to describe their chosen object of study in clear terms. Some philosophers and biologists have even gone so far as to give up on the definitional enterprise altogether (Cleland and Chyba 2002, Cleland 2013, Smith 2016). In this paper, I argue that the problem lies largely with an implicit conception of "natural kinds" we have inherited from ancient times. Philosophers of science have long held that the business of science is the delineation of kinds or categories that exist in the world independent of subjective human interests (Dupré 1981, Hacking, 1983, Boyd 1991). Moreover, these kinds are traditionally portrayed as having neat demarcations determined by necessary and sufficient boundary conditions. This approach works reasonably well with the kinds we encounter in physics and chemistry, but it is not capable of handling the complexity that biology produces. Thus, attempts to define life in terms of necessary and sufficient conditions inevitably meet with devastating counterexamples. But since biological kinds are produced by evolutionary processes, which are themselves driven by variation, they will of necessity be blurry. The fault lies with our implicit expectations, however - we simply should not expect neat categories in biology. What is needed to bring the debate concerning the definition of life out of the doldrums is a new conception of scientific kinds that treats them as complex statistical entities evolving through state space.

Howard Smith

We are Probably Alone in the Universe - Some Ethical, Philosophical and Religious Issues

We are alone in the universe, at least for all practical purposes. This is the most probable conclusion to be drawn from a host of fundamental physical constraints and a host of new astrophysical observations, in particular the discovery of over 4,700 exoplanet candidates including some Earth-sized planets in their habitable zones. In this talk I will analyze recent observations in the broader context of extra-terrestrial intelligence (ETI), and review the reasons why recently improved estimates of Drake Equation parameters point to our solitude as being the most likely condition. The Anthropic Principle expresses the observation that the physical constants in the cosmos are remarkably finely tuned to make it perfect for hosting intelligent life. The Misanthropic Principle - my term - expresses the idea that the multiplicity of possible environments in this suitable cosmos is so varied and uncooperative (or hostile) either always or at some time during the roughly 3-4 billion years intelligent life needs

to emerge, that it is extremely unlikely for intelligent life to form and thrive. The implications of these discoveries and their modern context are radical. Since the discovery of first extrasolar planets in the last decade, philosophers have probed with renewed urgency the religious consequences of discovering intelligent species elsewhere in the cosmos and what their presence says about the human role in a cosmic plan (if any). The discussions about the religious implications of extraterrestrial intelligence have almost entirely fallen into two categories. The dominant group believes, like Epicurus, that humanity is the result of the natural evolution of systems of atoms. It assumes that the same processes of nature produced ETI elsewhere in a boundless cosmos, with the result that humanity is entirely reduced in stature and is not only ordinary by virtue of not being at the center of the universe, but also because it is in no way special. A smaller group of theologians accepts that ETI is common but asserts that the special redemptive quality Divinity is nevertheless present. Mystical Jewish theologians elevate humanity even further by adding a cosmic redemptive purpose to human activity. For all of these thinkers, whether ETI represents for them either chemistry or Divine potency, humanity is neither unique nor special, and the Earth is but one of many habitable planets. The evidence, however, currently indicates otherwise. Thus, the question raised above—What does the presence of ETI say about the human role in a cosmic plan?—is the wrong question. The more relevant question is what their absence, which appears to contradict Copernican assumptions, says about humanity and its purpose. The answers to this question, famously posed by Fermi but today greatly refined, are likely to be disconcerting to a public that is comfortable thinking of itself as cosmically irrelevant and free of any grand responsibilities. The message of modern research is not that we are ordinary, but the opposite: we appear to be quite extraordinary, even if we may not be unique. To be of flesh and blood is to be marvelous, and cosmically significant. We have responsibility. Important ethical issues are raised by this conclusion. For the research community, we need to be cautious about hyperbolic teases about ETI, and instead emphasize honestly that the intrinsic value of studying exoplanets is important enough by itself, even though the likelihood of ETI is slim. For the public, an awareness of our rare capabilities may hopefully generate a renewed appreciation of humanity, and deeper personal humility. Similarly the Earth, even if it is not unique, is for all intents and purposes a very special place. The implication of the Misanthropic Principle is that we will have to – and must – care for one another and for our beautiful planet by ourselves, without help from alien insights or technologies.

WEDNESDAY 14, Late morning session

Charley Lineweaver

The Galactic Habitable Zone and a Gaian Bottleneck: The physics, chemistry and biology of habitability

As we learn more about the Milky Way Galaxy, extrasolar planets, and the evolution of life on Earth, qualitative discussions of the prerequisites for life become more quantitative. Galactic prerequisites for complex life include: the presence of a host star, enough heavy elements to form terrestrial planets, sufficient time for biological evolution, and an environment free of complex-life-extinguishing supernovae. Rocky planets with the prerequisites and ingredients for life seem to be abundantly available in the universe. However, the universe does not seem to be teeming with life. The most common explanation for this is a low probability for the emergence of life (an emergence bottleneck), notionally due to the intricacies of the molecular recipe. I will present an alternative explanation: a Gaian bottleneck (Chopra & Lineweaver 2016). If life emerges on a planet, it only rarely evolves quickly enough to regulate temperature through albedo and atmospheric volatiles and maintain habitability. Such a Gaian bottleneck suggests that (i) extinction is the cosmic default for most life that has ever emerged on the surface of wet rocky planets in the universe and (ii) rocky planets need to be inhabited, to remain habitable.

Nikos Prantzos

On the Galactic habitable zone

The concept of Galactic Habitable Zone (GHZ) was introduced several years ago as an extension of the much older concept of Circumstellar Habitable Zone. However, the physical processes underlying the former concept are hard to identify and even harder to quantify. That difficulty does not allow us, at present, to draw any significant conclusions about the extent of the GHZ. I will review older and recent work on the subject and also some recent progress, showing that the entire Milky Way disk may be suitable for complex life.

Paul Mason

Habitability in the Local Universe

Complex life on the surface of planets is constrained by radiation and particles in the environment within which they reside. Habitability may be protected by the planets atmosphere and magnetic field, as well as the astrosphere provided by the stellar host winds. Indeed, the galactic magnetic field supported by supernovae provides protection from particles of extragalactic origin. As the Universe has evolved, it has expanded, star formation rates have declined, and threats to surface life generally have decreased. It is shown that conditions for habitability locally and in the Milky Way in particular are improved over many galaxies in the local Universe

THURSDAY 15, Early morning session

Carlos Briones

The systems perspective at the origins of life

Living systems must combine the ability to: i) keep their molecular components together and distinguish themselves from their environment; ii) stay away from thermodynamic equilibrium by capturing energy and material resources from such an environment; and iii) transmit heritable information to their progeny [1]. Therefore, in the transition from chemistry to biology membrane compartments, metabolic machineries and genetic mechanisms should have originated and combined in order for life to appear and evolve. Different scientific traditions in prebiotic chemistry and biochemistry have dealt with partial aspects of the complex problem of the origins of life, using diverse conceptual frameworks and experimental settings. However, the physicochemical mechanisms involved in the formation of the infra-biological subsystems often turned out to be incompatible [2]. Alternatively, the consideration of higher levels of molecular heterogeneity [3] and the use of systems chemistry-based approaches [4] provide a more realistic scenario for the origins of life, involving aqueous solutions of different monomers and oligomers, metal and mineral catalysts, or reactive interfaces with water-based media [5]. Following this systems approach, the traditional replication-first vs. metabolism-first controversy is being substituted by a scenario in which all the basic molecules co-evolved from the beginning, forming heterogeneous, pre-bio-chemical interaction networks [6]. This integrative approach could help explain the transition from complex (though still thermodynamically driven) chemical systems into proto-biological ones and, eventually, into full-fledged living organisms where kinetic and spatial control of reactions took over.

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Albert Fahrenbach

Radiolytic Synthesis of RNA Precursors

The RNA world hypothesis has long been challenged by the prebiotic synthesis of the canonical A/U/G/C monomers. Using the potentially prebiotic synthesis of the pyrimidine nucleotides C and U reported by Sutherland and coworkers in 2009 as a blueprint, I demonstrate how gamma-radiolysis of dilute solutions of hydrogen cyanide can lead to the production of many of the key intermediates in that pathway. An additional route for the production of imidazoles was also discovered – a class of compounds crucial for enabling efficient template-directed synthesis of RNA oligomers. Details of these radiolytically driven mechanisms will be discussed.

Kuhan Chandru

Broad Screen of Oligomerisable Molecules Reveals Unexpected Pathways to Prebiotically Accessing Large Dynamic Combinatorial Libraries

Screening a large set of potentially oligomerizable and prebiotically plausible molecules with respect to their ability to generate long oligomers under a wide variety of reaction conditions (pH, temperature, concentration, congeners) compatible with various geochemical settings on the primitive Earth and other primitive solar system environments, we found that α -hydroxy acids (α HA) are extraordinarily polymerizable. Although polymer chemistry has been extensively explored, desires to produce polymers with particular properties have largely driven research, and heterogeneity has not been among them, though this may offer certain advantages near the origin of life. α HAs which are among the most likely prebiotically abundant monomers, can generate vast libraries of oligomers, which are stable for significant amounts of time. Such libraries would likely significantly alter the catalytic landscape of their environment. They would remain accessible to the first replicating systems, both as provided by the environment and to those which could reliably make the monomers. These oligomers could have been, supplanted by others which were more stable during chemical or early biological evolution. This work places some constraints on the course of the earliest chemical and biological evolution, and suggests the origin of life may follow a similar arc wherever this chemistry is predisposed to occur.

THURSDAY 15, Late morning session

Dougal Ritson

Was the citric acid cycle a biotic or prebiotic invention?

The prevalence of the citric acid cycle and the central role it plays in biology today has led many to speculate that

it is amongst the oldest of metabolic pathways. Interest in the TCA cycle in the realms of origins of life research was fuelled by Wächtershäuser's hypothesis for the possible assimilation of reduced carbon compounds by running the citric acid cycle in reverse in an autocatalytic manner. Attractive as this idea was, after almost 30 years research it has not been demonstrated in the laboratory. Using a different approach, we believe that the components of the TCA cycle were prebiotically available but it is the ability of the cycle to propagate itself that must be questioned.

Satoshi Akanuma

Thermophilicity of early life inferred by the resurrection of ancient proteins

Evolutionary biologists have been discussing about the environmental temperature of the ancient life. We tackled this issue by computationally reconstructing ancestral amino acid sequences of a protein in combination with experimentally resurrecting the ancestral proteins. In some cases, ancestral amino acid sequences can be inferred using a multiple amino acid sequence alignment and a phylogenetic tree that can be constructed by comparing homologous amino acid sequences of a modern protein. In addition, the inferred protein sequence can be experimentally reconstructed by synthesizing and expressing the gene encoding the inferred sequence. We computed and experimentally reconstructed several ancestral amino acid sequences of nucleoside diphosphate kinases (NDKs) that might have been possessed by the last common ancestors of archaea and bacteria, and by the universal ancestor. Temperature-induced unfolding experiment showed that all of the reconstructed NDKs were extremely thermally stable. The observation was robust to the uncertainties associated with the predictions of the ancestral sequences, to the topologies of the phylogenetic trees, and to the amino acid substitution model used to infer the ancestral amino acid sequences (1,2). Thus, the ancient organisms were most likely thermophiles that thrived at very high temperatures.

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Kathryn Lanier

Reading the ribosome: The history of rRNA

We present a molecular-level model for the origin and evolution of the translation system, using a 3D comparative method. In this model, the ribosome evolved by accretion, recursively adding expansion segments, iteratively growing, subsuming, and freezing the rRNA. Functions of expansion segments in the ancestral ribosome are assigned by correspondence with their functions in the extant ribosome. The model explains the evolution of the large ribosomal subunit, the small ribosomal subunit, tRNA, and mRNA. Prokaryotic ribosomes evolved in six phases, sequentially acquiring capabilities for RNA folding, catalysis, subunit association, correlated evolution, decoding, energy-driven translocation, and surface proteinization. Two additional phases exclusive to eukaryotes led to tentacle-like rRNA expansions. In this model, ribosomal proteinization was a driving force for the broad adoption of proteins in other biological processes. The exit tunnel was clearly a central theme of all phases of ribosomal evolution and was continuously extended and rigidified. In the primitive noncoding ribosome, proto-mRNA and the small ribosomal subunit acted as cofactors, positioning the activated ends of tRNAs within the peptidyl transferase center. This association linked the evolution of the large and small ribosomal subunits, proto-mRNA, and tRNA.

Nicholas Kovacs

Frozen in Time: The History of Proteins

The ribosome is imprinted with a detailed chronology of the origins and early evolution of proteins. When arranged by phase of ribosomal evolution, ribosomal protein (rProtein) segments appear to expose the evolutionary history of protein folding. The data support a model in which aboriginal polypeptides evolved into globular proteins in a hierarchical step-wise process. The complexity of polypeptide assembly and folding increased over an evolutionary time scale. This protein evolution was chaperoned by ribosomal RNA (rRNA) at all stages. (i) Short random coil peptides bound to rRNA, and (ii) lengthened over time and coalesced into β - β secondary elements. Polypeptide secondary elements (iii) accreted and collapsed, primarily into β -domains. Domains (iv) accumulated and gained complex super-secondary structures composed of mixtures of α -helices and β -strands. Protein evolution was guided and accelerated throughout this process by interactions with rRNA. rRNA stabilized immature and intermediate polypeptide species, which converted stepwise to folding-competent domains, bypassing the immense random space of unproductive sequences. The broad diversity of proteins in nature descended from a limited number of prototypes created by the ribosome, on the ribosome and for the ribosome. Protein folding from random coil peptides to functional polymeric domains was an emergent property of rRNA-polypeptide interactions.

THURSDAY 15, Early afternoon session

Ana Lopez Sepulcre

Formamide (NH₂CHO) in space: a key precursor of pre-biotic chemistry

One of the major questions regarding the origin of life on Earth is whether the original mechanism that led from

simple molecules to life was connected to metabolism or to genetics, both intimately linked in living beings. Formamide (NH₂CHO) contains the four most important elements for biological systems, and it has recently been proposed as a precursor of both metabolic and genetic material, suggesting a common chemical origin for the two mechanisms. Moreover, recent experiments have shown that the four nucleic bases present in RNA might have naturally formed from formamide during the Late Heavy Bombardment, which further stresses its key role in the synthesis of biogenic molecules. Formamide was first detected in molecular clouds more than four decades ago. Despite this, dedicated observational studies have started only very recently, as its potential role as a precursor of prebiotic chemistry has become more evident. These studies report the presence of formamide in Solar System comets, as well as several star formation regions, including hot cores, hot corinos, and outflow shock spots. The presence of formamide in such a variety of environments opens the possibility of an exogenous delivery onto a very young Earth more than 4 billion years ago. In this contribution, we will present the different observational studies of formamide that have been carried out in the past years, with a particular emphasis on our new observational results from the IRAM large programmes ASAI and SOLIS. We will discuss the different chemical pathways that have been recently suggested to explain its formation in the interstellar medium, which include gas-phase as well as gas-grain reactions, and review the constraints brought by our most recent observations. Finally, we will stress the importance of joining efforts with experts on both theoretical and experimental chemistry in order to make progress

Ruth-Sophie Taubner (+ P. Pappenreiter, C. Pruckner, J. Zwicker, D. Smrzka, S. Bernacchi, C. Paulik, C. Schleper, M.G. Firneis, S. K.-M. R. Rittmann)

Testing the Habitability of Saturn's Moon Enceladus in an Interdisciplinary Attempt

The indirect proof of subsurface water oceans in icy moon like Jupiter's Europa or Saturn's Enceladus extended the number of potential habitats in the Solar System. The latter is one of the hot spots in the Solar System due to its erupting water plumes, which most likely origin in a (global) subsurface liquid water ocean. The detection of silicon-rich, nanometre-sized dust particles (1) and the abundance of various salt components in a certain population of E-ring grains (2) suggests that its subsurface aquifer is (or at least was) in direct contact with the underlying rocky core, which might imply water-rock interactions like low temperature serpentinization. Therefore, the most promising area on Enceladus where life may exist is at the seafloor of this subsurface water reservoir. If a subsurface ocean on Enceladus would host life, the organisms would have to be chemoautotroph, have to be independent of products directly or indirectly produced by photosynthesis, and have to be anaerobes. Organisms which fit this profile are for example methanogens. Regarding the plume composition (3,4), there may be a huge variety of potential substrates and even products of methanogens (5) on Enceladus, like CO₂, H₂, and CH₄. Therefore, methanogens are the most likely known terrestrial life form that could thrive under Enceladus-like conditions. We performed numerical experiments using the PHREEQC code (6) to test the possibility of low temperature serpentinization on Enceladus. For that, we assume the core composition to be similar to chondritic chondrites, i.e. to be composed of various combinations of olivine and pyroxenes. We show that the amount of produced H₂ during serpentinization is sufficient to serve as a potential substrate for methanogens. Among other methanogens we tested the hydrogenotrophic methanogenic strain *Methanothermococcus okinawensis* in respect to its tolerance towards potential inhibitors of biological methanogenesis detected in Enceladus' plume (3,4), e.g., high ammonia levels, formaldehyde (H₂CO), ethene (C₂H₄), and methanol (CH₃OH). Based on the results of these experiments, we performed high pressure closed batch experiments in the range of 10 to 90 bar, i.e. the pressure range expected in the subsurface ocean of Enceladus (1). The closed batch experiments were performed in a 0.7L stirred reactor at 64°C. Our experiments showed that biological methanogenesis could be feasible under Enceladus-like conditions, however abiotic methanogenesis is rather not likely to occur. Our study combines studies of various scientific fields and introduces novel aspects on potential habitats for microbial life in the Solar System, especially concerning icy moons.

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Lucy Norman

Compartmentalisation Strategies for Hydrocarbon-based Biota on Titan

The goal of this study was to determine the nature of compartmentalisation strategies for any organisms inhabiting the hydrocarbon lakes of Titan (the largest moon of Saturn). Since receiving huge amounts of data via the Cassini-Huygens mission astrobiologists have speculated that exotic biota might currently inhabit the

hydrocarbon liquid bodies on Titan. The biota has been theorized to consume acetylene and hydrogen whilst excreting methane leading to anomalous hydrogen depletions near the surface; and there has been evidence to suggest this depletion exists. Nevertheless, many questions still remain concerning the possible physiological traits of biota in these environments, including whether cell-like structures can form in low temperature, low molecular weight hydrocarbons. The backbone of terrestrial cell membranes are vesicular structures composed primarily of a phospholipid bilayer with the hydrophilic head groups arranged around the periphery and are thought to be akin to the first protocells that terrestrial life utilised. It may be that reverse vesicles, composed of a bilayer with the hydrophilic head groups arranged internally and a nonpolar core, may be ideal model cell membranes for alkane-based organisms inhabiting Titan's hydrocarbon lakes. A variety of different surfactants have been used to create reverse vesicles in nonpolar liquids to date including; non-ionic ethers and esters; cationic surfactant mixtures; zwitterionic gemini surfactants; block polymer surfactants; and zwitterionic phospholipid surfactants. In order to discover whether certain phospholipids can exhibit vesicular behaviour within hydrocarbon liquids, and to analyse their structure, we have carried out experimental studies using environmental conditions that are increasing comparable to those found on the surface of Titan. Experimental methods that have been used to determine the presence of vesicles include the use of microscopy, presence of the Tyndall scattering effect, transmission electron microscopy (TEM), dynamic light scattering (DLS), small-angle neutron scattering (SANS) and small-angle x-ray scattering (SAXS).

Daniel Boice

Phosphorous Chemistry in Comets and Astrobiology

Phosphorous is a key element in all known forms of life but its origins on Earth is unknown. P-bearing compounds have been observed in the ISM, photo-planetary disks, planetary atmospheres, and other regions of space. They are ubiquitous in meteorites, have been detected in the dust component of comets 1P/Halley and 81P/Wild 2, and in the gas phase (atomic P) of 67P/Churyumov-Gerasimenko by the Rosetta Mission. We present results from the first quantitative study of P-bearing molecules in comets to aid in future searches for this important element in comets, shedding light on issues of comet formation, delivery to Earth, and prebiotic to biotic evolution of life.

FRIDAY 16, Early morning session

Alain Lecavellier

Exoplanetary systems

Extrasolar planets, or "exoplanets", are discovered for the past twenty years. Today, we know more than 3500 extrasolar planets orbiting nearby stars in the Galaxy. Beyond the first step of counting the planets, astronomers are surprised by the astonishing diversity in these new worlds. Some of these planets have already been studied in great details, in particular through space telescopes like the Hubble Space Telescope or the Spitzer infrared observatory. In a specific configuration, planets that transit in front of their stars reveal the secrets of their atmospheres. The latest findings show many unexpected phenomena. Following the success of the last decade, astronomers are now looking for other Earths. They envision new types of planets: lava-planets emerging from the evaporation of the atmosphere of giant gaseous planets, or "ocean-planets". They develop the methods and build the instruments that, in the near future, will identify habitable worlds or look for the signatures of life

Hajime Yano

Astrobiology-driven Space Missions and Experiments: From the low Earth Orbit to the Ocean Worlds

Daniel Rouan

Exoplanet characterization with JWST

One of the main goal of the James Webb Space Telescope (JWST) will be to study the atmospheres of exoplanets, a first step to search for the building blocks of life elsewhere in the universe. JWST's unique combination of high sensitivity and broad wavelength coverage in the infrared (2-28 μ m) will enable a large program of exoplanet science that could cover a substantial fraction of the overall JWST mission. The program will be on a two-fold approach: a) direct imaging, especially with the two imagers MIRI (5-28 μ m) and NIRCAM (2-5 μ m) equipped with coronagraphs that will give the capability of imaging young giant-medium planets and detailed study of circumstellar disks; b) accurate measurement of transits with high signal-to-noise ratio. Spectroscopic capability (MIRI, NIRCAM, NIRISS and NIRSpec) will allow investigate planetary atmospheres through atmospheric absorption and thermal emission to determine atomic and molecular compositions, to probe radial and horizontal structure, and possibly to follow evolution, i.e., exoplanet weather. The NIRISS instrument will even possibly detect the signature of liquid water on rocky planets. JWST will sample the diversity of planets of varying masses, densities, orbital semi-major axes, and eccentricities around a variety of host star temperature, masses and metallicities.

Surangkha Rukdee

TARdYS an upcoming exoplanet hunter for the southern hemisphere

The relatively close habitable zone to the host stars of the very common cool-low mass stars makes M-dwarfs attractive for finding habitable planets. Up to date only a few of these stars can be observed by visible high resolution spectrographs, since their spectrum peaks in the infrared. We develop Tao Aiac high Resolution (d) Y band Spectrograph (TARdYS) for observing M-dwarfs in the southern hemisphere, where only a few high resolution near infrared spectrographs are available. TARdYS is a high resolution Echelle spectrograph ($R > 50,000$ at 0.843-1.117 μ m) to be installed at the Tokyo Atacama Observatory TAO 6.5 m telescope in Chile. We reduce aberration and noise through a white pupil design and placing the detector in a cryogenic environment cooled to 80K. Our optimization results in excellent resolution only limited by diffraction, even when taking realistic manufacturing and alignment tolerances into account. We will present design decisions leading up to our M-dwarf exoplanet detection strategy for the southern hemisphere, and opportunities for our upcoming exoplanet hunter.

FRIDAY 16, Late morning session

François Forget

Planetary climates, habitability and liquid water

While we develop the observation tools that will, someday, characterize habitable planets, the concept of habitability is regularly challenged. It not easy to define life and what is needed for it, so drawing a line between "habitable" and "not-habitable" is difficult. We usually postulate that "habitable = liquid water available" because liquid water seems required for life as we can imagine it. However, worlds with liquid water can be seen as more or less habitable, depending on 1) the available molecules and energy sources (notably light), 2) the time available for life to emerge and evolve. Different class of habitability can be defined, ranging, from worlds with liquid water only in the deep interior, to Earth-like cases with surface liquid water enabling photosynthetic life to modify the atmosphere in a detectable way. Within that context, we can agree to define the "Habitable zone" as the region outside which it is impossible for a rocky planet to maintain liquid water on its surface. More generally, a key issue in our investigation on life in the universe is to understand the climatic conditions that allow surface liquid water.

To first order, climate primarily depends on 1) The incident stellar flux; 2) The tidal evolution of the planetary spin which can notably lock a planet with a permanent night side, and, 3) last but not least, the atmospheric composition and the volatile inventory. What atmospheres can we expect? Which processes control their evolution? These are the key questions. Our solar system experience is too limited and observations are needed. Much can be learned even by characterizing atmospheres. I will discuss physical constraints which can help us to speculate on the possible type of atmosphere, depending on the planet size, its final distance for its star and the star type. Assuming that the atmosphere and the other parameter are known, the possible climates can be explored using Global Climate Models analogous to the ones developed to simulate the Earth as well as the other telluric atmospheres in the solar system. Our experience with Mars, Titan, Venus and Pluto suggests that realistic climate simulators can be developed by combining components like a “dynamical core”, a radiative transfer solver, a parametrisation of subgridscale turbulence and convection, a thermal ground model, and a volatile phase change code. On this basis, we can aspire to build reliable climate predictors for exoplanets. We have built such a 3D model and will present recent results relevant for the definition of the habitable zone around various kinds of stars. However, whatever the accuracy of the models, predicting the actual climate regime on a specific planet will remain challenging because climate systems are affected by strong positive feedbacks. They can drive planets with very similar forcing and volatile inventory to completely different states. For instance the coupling between temperature, volatile phase changes and radiative properties results in instabilities such as runaway glaciations and runaway greenhouse effect.

Amri Wandel (+J. Gale)

On the possibility of evolution and detectability of life on Proxima b

Recent detection of an Earth-sized planet within the Habitable Zone of Proxima Centauri emphasizes the question of habitability of planets orbiting Red Dwarf type stars. In particular Proxima b, being the closest potentially habitable exoplanet, would be the easiest to observe for biosignatures. We apply to the newly confirmed planet the analyses of potential threats to the evolution of life on Red Dwarf planets, reviewed in Gale and Wandel (2016), such as UV and X-ray flares, atmospheric runaway and tidal locking. We consider the possibility of oxygenic photosynthesis and the production and maintenance of an oxygen-rich atmosphere for Proxima b and test the feasibility of detecting biosignatures by future observations and facilities. We consider the detectability of the oxygen feature and suggest additional tests to increase its biotic credibility, once detected.

Ludmila Carone

The Trappist-1 planets: 3 worlds and even more possible climate states

We will show that the climate states of short-period tidally locked terrestrial planets around M dwarf stars are shaped by planetary waves. We will show that these results are highly relevant for the recently found Trappist-1 planets if they have an Earth-like atmosphere. Moreover, Trappist-1b and -1c are in a region of climate state bifurcation, where three different climate states are possible for each planet due to mixture of planetary waves. These different climate states show large differences in surface temperatures, circulation, wind systems and thus habitability prospect

Paul Mollière

The imprint of formation on planetary spectra

The spectrum of a planet may hold clues on its formation, potentially shedding light on where it formed within the protoplanetary disk and how it migrated. In order to enable such a study we connected state-of-the-art models of planet formation and evolution with a self-consistent, non-gray atmospheric model. We model the planet's formation via core accretion, including gas and planetesimal accretion processes and the planet's orbital migration within the disk. The disk structure is evolved including the disks viscous evolution and the mass accretion of the planet. We track where the planet accretes mass during its formation and by considering different disk chemistry models we obtain different planetary compositions. Thus, for every point in time after its formation we can calculate the planets self-consistent spectrum fully taking into account its evolutionary state and the composition it inherited from its formation. In a first study we applied our model to the formation of hot Jupiter's and investigated their possible range of compositions. We found that the enrichment of hot Jupiters should be dominated by planetesimal accretion and that hot Jupiters with C/O number ratios close to 1, resulting in a carbon-rich chemistry, should be rare. Thus hot Jupiter spectra are dominated by water, CO and CO₂. Further we found that to constrain the planet's formation location within the disk a better understanding of disk chemistry is imperative.

FRIDAY 16, Early afternoon session

Sean Raymond, by Ramon Brasser

Terrestrial planet formation at home and abroad

Our vision of planet formation — long tied to studies attempting to reproduce the orbital architecture of the Solar System — has been irrevocably changed by the discovery of thousands of extra-solar planets. The distribution of exoplanets shows a much broader diversity and includes categories of planets that are not represented in the Solar

System. The main goal of planet formation is to build a model that naturally encompasses and explains this diversity. The known extra-solar systems can be divided into just a few categories: i) Solar System-like systems with Jupiter-like planets on wide-separation, near-circular orbits; ii) systems with "angry" gas giant planets on eccentric or very short-period orbits; and iii) systems containing only low-mass planets, often referred to as "hot super-Earths". The systems in each category have a rich dynamical history that plays the central role in shaping the formation (and in some cases destruction) of rocky worlds. Although both terrestrial planets and gas giants form from the same building blocks — so-called "planetary embryos" — gas giants are constrained to grow very quickly and thus they influence the final assembly of terrestrial planets. In systems without giant planets, interactions with the protoplanetary disk causes embryos to migrate inward and become hot super-Earths. However, if an embryo grows large enough to capture gas from the disk and become a giant planet, it may act as a barrier to the inward migration of other super-Earths; this process can explain the lack of super-Earths in the Solar System. Systems with gas giants are shaped by two key processes: orbital migration and scattering. Orbital migration of gas giants is typically inward (a possible origin of hot Jupiters) but can in some configurations be directed outward (as in the Grand Tack model for the Solar System). In either case, migrating giants snowplow rocky material and drastically alter the growth and feeding zones of terrestrial planets. Finally, their eccentric orbits suggest that at least 75% of the known systems of giant exoplanets are thought to have undergone violent instabilities resulting gravitational scattering between gas giants and the destruction of one or more giant planets. These instabilities systematically destroy terrestrial planets (or their building blocks), typically by driving them into the central star. To conclude, there are specific branching points between different dynamical outcomes: for instance, the growth of a gas giant planet and an instability in a system of gas giants. We propose that these branching points are central in explaining the diversity of planetary systems and of terrestrial planets.

Martin Turbet

How could Early Mars have been habitable?

In the 1970s, there have been more and more evidences that liquid water flowed on ancient Mars : geomorphological clues (dry river beds and lakes), hydrated sedimentary minerals and high erosion rates. Yet, the stability of significant amount of surface liquid water, necessary to carve the 3.8 Gyrs old valley networks, remains unexplained. Climate models that consider only CO₂/H₂O as greenhouse gases have been unable to produce warm climates suitable for liquid water on Early Mars, given the lowered solar luminosity at that time. Recent studies suggest that temperatures above 0°C could have been caused by long-lived greenhouse warming produced for example by H₂ volcanic outgassing. Others proposed that the warm conditions required to explain the formation of valleys could have been transient and produced in response to meteoritic impacts. This scenario is appealing because : 1. The valley networks formation is contemporaneous with the Late Heavy Bombardment, responsible for high impact rates on ancient Mars. 2. It has been shown ('Icy Highlands' scenario) that, in a predominately cold climate, the ice preferentially accumulates exactly in the regions where the rivers were sculpted. This would be a very efficient mechanism of recharge of the valley network water sources between two impact-induced melting events. I will review the current status of the Early Mars climate enigma and I will take this opportunity to present the first 3D Global Climate Model simulations of meteoritic impacts on Early Mars

Ngoc Truong

Origin of Phobos and Deimos by Giant Impact: Lessons from Terrestrial Tektites

For both science and human exploration planning, determining the water content of Phobos and Deimos is important. The expected water content on the two martian moons depends on their origin and evolution through time, which still remain unknown. One intriguing hypothesis is that they are reaccreted debris resulting from one or more giant impacts on Mars. This hypothesis is commonly thought to imply that those moons would be depleted in volatiles, in particular water, as often assumed in the Giant Impact Origin hypothesis for Earth's Moon. But do giant impacts produce orbital debris that are necessarily devoid of water? Insights into the survival of target water in large impact events may be gained from studying the water content of terrestrial tektites, natural glasses derived from the hypervelocity impact melting, ejection, atmospheric transit, quenching, and fallback of upper crustal materials . Although tektites resemble volcanic glass in form, they are compositionally similar to sedimentary rocks minus most of the water. Among tektites, Australasian tektites have the higher water content, typically ~ 0.004 to 0.043 wt% (average ~ 0.02 wt%). If their source impact took place on emerged land, the impact target was likely a wet site, allowing those tektites to be buffered by water in the ejected cloud. Alternatively, the mole fraction of water in melting fluid is estimated to be at least 0.3 to explain the dissolved water content of Australasian tektites by using the model of water solubility in rhyolitic melts at low pressure , suggesting a submerged offshore impact site. Although the water content in Australasian tektites generally decreases as the distance increases away from Indochina, Australasian tektites recovered in Australia, which must have exited and reentered Earth's atmosphere, contain significant water (~0.01wt%). The survival of target water even in distal tektites suggests that large impacts do not necessarily produce water-depleted high-energy ejecta, if the original target materials were water-rich. This opens the possibility that for the hypothesis in which Phobos and/or Deimos are reaccreted Mars impact ejecta, not all target water was necessarily lost in the giant impact debris. This possibility is further supported by the recent realization that significant amounts of water are present in lunar crustal rocks. Our study suggests that Phobos and Deimos might have had an original water content of up to ~0.01 wt%, even in the Giant Impact hypothesis for their origin, if Mars crustal materials were water rich."

George Tan

High-throughput sequencing reveals diverse microbial communities in Icelandic Mars Analog Environments

Exploration missions to Mars rely on rovers to perform deep analyses over small sampling areas; however, landing site selection is done using large-scale but low-resolution remote sensing data. Using Earth analog environments to estimate the small-scale spatial and temporal distributions of key geochemical signatures and (for habitability studies) biomarkers helps ensure that the chosen sampling strategies meet mission science goals. Icelandic lava fields have a good heritage as Mars analog sites because of inhospitable conditions including low nutrient availability, temperature extremes, desiccation as well as their isolation from anthropogenic contamination. Our previous work in Icelandic Mars analog found statistically different ATP and DNA measurements of apparent homogeneous sample sites at four spatial scales (1 m, 10 m, 100 m, and >1km). However, ATP and DNA measurements do not reveal any information about the microbial diversity nor the microbial communities had been characterize in the Icelandic environments. We performed 16S sequencing on the collected samples in different spatial scales. The results reveal diverse ecosystems under apparent homogenous environments. These results are significant because they hint at the possibility that there could have been a diverse microbial population in apparent homogenous environment based on remote sensing. Future work will focus on correlating the metagenomic data with geochemical data to identify geochemical elements that affect microbial diversity to help guide future missions.

FRIDAY 16, Late afternoon session

Stephane Mazevet

Ab initio equation of states for planetary and exoplanetary modeling

Using ab initio molecular dynamics simulations, we calculate equation of states for five main constituents of planetary interiors: H, He, H₂O, SiO₂ and Fe. These equations of states are multi-phases, include liquid solid phases and for silica and iron a melting curve calculated using the two-phases approach up to 1000Mbar. Using a physically based parametrization of these results, we calculate consistent planetary models for the exoplanets detected so far and ranging from earth-like exoplanets, ice giants, to giants up to 10 times the mass of Jupiter.

Tetsuya Hara

On the Evolutionary History of the Water Ocean on Venus

We have estimated the habitable zone in a simplified model, including the parameters as albedo and/or cloudy effect. Under this model, it becomes clear the inner habitable zones include Venus. So we investigate the evolutionary history of the water ocean on Venus. It is discussed that water was abundant on Venus from the observation of excess deuterium concentration compared to that of the earth. It is indicated from the observations by the Venus Express that the planet's highland plateaus were ancient continents surrounded by water and made of substance similar to granite. It must be happened a runaway greenhouse on Venus. It is important to investigate the Venus history for the future of the earth.

POSTERS

Mijumo Bessho (Mizumo Bessho, Satoshi Akanuma, Shin-ichi Yokobori, Akihiko Yamagishi)

Reconstruction of ancestral proteins based on molecular phylogenetic analysis

To estimate the optimal growth temperature of the universal common ancestor "Commonote" and the surface temperature of early Earth, the amino acid sequences of ancient nucleoside diphosphate kinases (NDKs) were reconstructed by molecular phylogenetic analysis. We used two amino acid substitution models; (i) a homogeneous model that approximated invariable amino acid compositions over evolution, and (ii) a non-homogeneous model that allows changing the amino acid compositions through evolution. The inferred ancestral NDK sequences were reconstructed and characterized experimentally. Regardless of the amino acid substitution models, all ancestral NDKs showed high thermal stability. Using the denaturation temperatures of the reconstructed NDKs, we estimated that the common ancestors of Archaea and of Bacteria lived at 81-97°C and 80-94°C, respectively (1). Furthermore, we also estimated that the Commonote lived at a very high temperature too (2). The optimal growth temperatures of ancient organisms were sometimes estimated from the amino acid compositions of reconstructed proteins. We also calculated the optimal growth temperatures of the bacterial and archaeal common ancestors as well as that of the Commonote from the amino acid compositions of the reconstructed NDKs. The resulting optimal growth temperatures were quite lower than those estimated from the experimentally determined unfolding temperatures. Therefore, we concluded that prediction with amino acid compositions alone risks to underestimate the unfolding temperatures of ancient proteins and thus the optimal growth temperatures of the ancient organisms, and that experimentally reconstructing the ancient proteins and then determining their unfolding temperatures are important to estimate the optimal growth temperatures of the ancient organisms.

References : (1) Akanuma et al. PNAS 110, 11067-11072 (2013) (2) Akanuma et al. Evolution 69, 2954-2962 (2015)

Zachary Duca (+George Tan, Thomas Cantrell, Michelle Van Enige, Max Dorn, Michael Cato, Nicholas Speller, Aaron Pital, Richard Mathies, and Amanda Stockton)

Operation of pneumatically-actuated membrane-based microdevices designed for in situ analysis of extraterrestrial organic molecules after prolonged storage and at negative gravity

Programmable microfluidic architectures (PMAs) are powerful arrays of normally-closed, pneumatically-actuated monolithic membrane microvalves capable of conducting complex fluid manipulation on the microscale, including dilutions, mixing, transfer, reactions, etc.... With applications to all disciplines where field analysis is desirable, including point-of-care (POC) diagnostics, environmental science, space exploration, etc..., these microvalve systems have been integrated into multiple chemical analysis techniques, including microcapillary electrophoresis (μ CE) and ELISA assays. However, these systems have not seen wide-scale deployment in industry or spaceflight due in part to a misperception that the microvalves have a limited shelf-life due to irreversible bonding of the PDMS elastomer to the glass substrate. A further criticism for spaceflight applications has centered around a concern about operation at reduced or no gravity. Therefore, after 10 years of storage under ambient conditions, we tested a Mars Organic Analyzer microdevice fabricated in 2005 and demonstrated that it retained full functionality after 10 years of storage. All pneumatically-actuated valves opened after <5 hours of vacuum cycling at -950 mbar from STP. Using an automated LabView program to actuate multiple valves in series, the microdevice transferred fluid at a flow rate of $122 \pm 8 \mu\text{L}/\text{min}$. Fluid transfer was done at both +1 and -1 g, indicating successful future implementation in a zero g environment. This demonstration that microdevices retain full functionality after over 10 years of storage combined with successful operation in both +1 and -1 g environments validates the value of PMA-based microdevices for fluidic manipulation in outer planetary missions.

Birgit Loibnegger (+ R. Dvorak)

A dynamical study on exocomets and their importance in water transport to the habitable zone

The formation of our Solar System still yields many open questions beginning with the accurate composition and structure of the disk, migration during the disk phase and formation of the terrestrial planets (especially Mercury and Mars) up to the important question about the origin of Earth's water. The scenario and the efficiency of water transport by planetesimals, asteroids and comets is still part of discussions and one of the most important unresolved questions about the early Solar System. Nevertheless, when it comes to habitability and the search for life in extrasolar planetary systems, water transport is one of the key questions to be solved. The first extrasolar system named to harbour extrasolar cometary like bodies (so called falling evaporating bodies - FEBs) was β Pictoris (Beust et al., 1990). Since then at least 5 additional systems with features associated with comets have been found. The better understanding of cometary dynamics in extrasolar systems shall provide information about cometary reservoirs (analogue to the Oort Cloud and Kuiper belt in the Solar System), cometary families (analogue to the Jupiter family of comets), and give an insight in water transport especially to possible planets in the habitable zone. In our studies we did massive n-body integrations to investigate the influence of the build of the planetary systems on the formation of cometary reservoirs and created statistics of close encounters and collisions (important for the transport of water) in confirmed exoplanetary systems. We found that planetary systems need a massive perturber to scatter the comets and the transport of water via comets to the habitable zone is then possible.

Alicia Negron-Mendoza (E. Aguilar-Ovando, J. Cruz-Castañeda, T. Buhse, S. Ramos-Bernal and A. Negrón Mendoza)
Stability of glyceraldehyde in a high radiation field. Chemical evolution implications

The synthesis and preservation organic compounds of biological importance in prebiotic conditions are fundamental. A group of these molecules is sugars, because they play important metabolic roles in biological systems, as structural or energy molecules. This type of molecules could be present in icy bodies [1]. Glyceraldehyde is a molecule that contains both an aldehyde group and two-hydroxyl groups, and it is a highly reactive molecule [1, 2]. According to Weber and Pizzarello [2], glyceraldehyde was probably present on the prebiotic Earth, since it has been readily synthesized under prebiotic conditions [4]. Recently glyceraldehyde has been synthesized from icy analogs that simulated extraterrestrial bodies [1]. On the other hand, ionizing radiation may have had a major role as an energy source because of its high efficiency in inducing the synthesis of organic compounds, its penetration into matter, and its relative abundance. There are two contributors: ionizing radiation from the Earth's crust for the presence of radionuclides and radiation from extraterrestrial sources such as cosmic rays or solar wind [4]. The aim of this work is focused on studying the stability of organic molecules of biological and prebiological importance under ionizing radiation fields. To this end, we investigate the radiolysis of glyceraldehyde in aqueous solution, varying the adsorbed dose. Glyceraldehyde is considered the simplest triose. Its interaction with radiation may give rise to the formation of sugar-like products.

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Alicia Negron-Mendoza (D. Torres-Ricardez, M. Colín-García, I. Mejía-Luna, S Ramos-Bernal, A. Negrón-Mendoza and A. Heredia)

Adsorption of histidine after ultraviolet irradiation onto calcite in simulated calcite-rich Achaean environment.

Calcite promotes a variety of organic reactions, and its complex crystal planes make feasible to increase the diversity of chemical reactions. Monocrystals of calcite were used to get insight in the chemical adsorption and dimerization of histidine, an amino acid whose potential catalytic activity has been tested (Shen et al. 1990).

Adsorption experiments onto (104) crystalline plane and well-polished polycrystalline calcite were performed using solutions of UV-irradiated histidine. Samples were analyzed by UV-Vis and high-performance liquid chromatography-mass spectrometry. Molecular simulations on HyperChem were implemented to understand the calcite-histidine interactions. In our preliminary results, a condensation-dimerization reaction occurs onto the (104) crystalline plane, although with less histidine adsorption about the polycrystalline surface. We suggest that surfaces of calcite as a rock-forming mineral have various features, selecting and dimerizing histidine in specific crystalline planes. Thus, calcite mineral surfaces may have contributed the chemical evolution of histidine, possibly by organizing self-assemblies and promoting dimerization of this key biomolecule

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Lucy Norman

Evidence for four of the earliest primitive species of predatory animals in the Neoproterozoic Doushantuo Formation

We provide evidence for four pelagic chemoheterotrophic eukaryotes, either protists or basal pelagic metazoans, which dominate the phosphate deposits of the Doushantuo Fm (635-551 Myr). We have distinguished between these fossils and EPS aggregates by analysing structural, size and compositional variations among the phosphate spheroids of the Doushantuo Fm. EPS aggregates commonly contained illite and pyrite, with growth often limited by high quantities of clay particle accretion. The presence of sulfate reducing bacteria in the palaeoenvironment was inferred from the frequent presence of pyrite in the EPS aggregates and matrix, and, dolomite in the matrix. In contrast to a variety of microbiota contained in the EPS aggregates, the predatory eukaryotes preferentially consumed photosynthetic microbiota such as Myxococcoides. We suggest that the Doushantuo Fm phosphates were formed in a stratified oxic-anoxic marine basin with high biological productivity which was stable over an extensive period.

Sandra Ramos

Life and its definitions

Life researchers lack agreements on a common definition of life. The lack of clarity between concept and experience may be one of several reasons for the lack of a common definition of life. The life concept exist in the mind, and is not the object to which it points. The separate processes of conceptual thinking and direct

experiencing are deceptively quick, and are easily blended, making the perception of concept an object as the same entity.

Takahiro Sasamoto (Takahiro Sasamoto, Masami Shimada, Akihiko Yamagishi, Satoshi Akanuma)

How many amino acid alphabets were used for primitive proteins?—Elucidation of the smallest amino acid sets for stable and active proteins

The origin of life has been one of the fundamental themes for a long time. The nature of primitive proteins is also unclear. The most extant proteins are synthesized by using 20 amino acid alphabets that are encoded by the standard genetic code. It has been thought that the last universal common ancestor “Commonote” also synthesized the proteins composed of 20 amino acid alphabets. However, it is hard to believe that the same translation system was used for protein synthesis at the beginning. Therefore, in early evolution, a simpler system involving less amino acid alphabets might be used, and subsequently the extant system was developed through the evolution. In this study, we tried to infer the smallest amino acid sets to synthesize a stable and active protein by simplifying the amino acid composition of an experimentally resurrected ancestral protein. Previously, we resurrected the ancestral nucleoside diphosphate kinase Arc1 that might be possessed by the last common ancestor of archaea (1). Arc1 lacks cysteine and thus is composed of 19 amino acid alphabets. Arc1 shows high thermal stability (the unfold midpoint temperature is 114°C). We constructed 19 Arc1 variants in each of which an amino acid alphabet was completely eliminated by changing to other residues. By analyzing their stability and activity, we found 10 amino acid alphabets that could be easily lacked. Next, we systematically increased lacking amino acid alphabets. Finally, we obtained two simplified Arc1 derivatives that were composed of only 13 amino acid alphabets. Therefore, at least 13 amino acid alphabets are sufficient to synthesize a stable and active NDK. It has been thought that His, Asn, Tyr were hardly synthesized in an abiotic environment. However, His, Asn, Tyr appeared to be important for synthesizing active NDKs. Therefore, we think two possibilities; one is that His, Asn, Tyr were actually used for primitive protein synthesis. The other is that the primitive proteins provided only a scaffold for chemical reactions and other molecules such as RNA and metal might bind to the protein scaffold and play a central role in catalytic functions.

References : (1) Akanuma et al., PNAS 110, 11067–11072 (2013)

Ana Suzuki (+Tetsuya Hara, Takanori Sasaki)

Greenhouse effects on terrestrial planets with various atmospheres

Kasting et al. (1993) calculated the boundaries of the Habitable Zone (HZ) based on one-dimensional, cloud-free climate model. Kopparapu et al. (2013) updated this model and obtained new estimates for HZ widths around F, G, K, and M stars. In their models, the inner edge of the HZ was determined by loss of water, or the runaway greenhouse effect. According to Kopparapu et al. (2013), the water-loss limit is 0.99AU, and the runaway greenhouse limit is 0.97AU for a terrestrial planet the atmospheric composition of which is Earth-like. In this study, we focus on the greenhouse effects. Ingersoll (1969) found the existence of an upper limit of the outgoing infrared radiation. If the incident stellar flux is larger than the limit, the planet goes into the runaway greenhouse state. Nakajima et al. (1992) studied the limit precisely and showed the detailed atmospheric structures. Here we calculated the greenhouse effects for extraterrestrial planets with various atmospheres by using their model. Our results are preliminary yet, but we indicated that the greenhouse effects strongly depend on the atmospheric compositions. We conclude that it is necessary to consider the atmospheric composition of the planet in order to decide inner HZ.

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On-ground spectroscopic and photometric survey for the PLATO exoplanetary research space mission

There is a strong need of stellar variability and spectroscopic information that is necessary for developing the PLATO input catalogue. Current photometric catalogs and spectroscopic surveys are still not able to provide all the necessary information on variability and spectroscopic data that are required for a successful target selection. We are running a photometric and spectroscopic survey of the northern sky fields that will be targeted by the PLATO mission. We are accomplishing a long-duration stellar variability observations in PLATO fields of the northern sky and a full spectroscopic characterisation of brightest targets to contribute in developing the PLATO input catalogue. Our targets are the brightest stars that are important for PLATO. Our aim is to determine the main atmospheric parameters and chemical composition of up to 32 elements, variability information, main variability modes, photometric time-series data files. In this contribution we present the target selection criteria for the mission and the first results of the survey.

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Estimating the pH environment of the last universal common ancestor by reconstructing and characterizing ancestral proteins

All of the species existing today share basic parts of the genetic system. Therefore, all the species on Earth are thought to have originated from a common ancestor. By reconstructing and characterizing ancestral proteins that might be hosted by the common ancestor, we can infer its environment. We constructed three different phylogenetic trees by comparing the amino acid sequences of nucleoside diphosphate kinase (NDK) from existing species. Then, three amino acid sequences corresponding to NDK from the common ancestor were inferred by using the phylogenetic trees and the non-homogeneous PhyloBayes program. The ancestral amino acid sequences were reverse transcribed into the DNA sequences that were then synthesized. By expressing the ancestral genes individually in *Escherichia coli*, the ancestral NDKs were reconstructed. Then, we examined the thermal stability of these ancestral NDKs as the function of pH. The ancestral NDKs showed the highest stability at a neutral pH as similar to extant NDKs from organisms that live in neutral pH environments. Therefore, we conclude that the common ancestor, most likely, lived in a neutral pH environment.