ABSTRACTS

Monday, 25 *morning session*

Lalonde Stefan
CNRS / European Institute for Marine Studies

Oxygenic photosynthesis during the Archean: theory, evidence, and controversy

The origin of oxygenic photosynthesis is one of the most dramatic evolutionary events that the Earth has ever experienced. Most experts would agree that the ~2.3 Ga Great Oxidation Event provides a hard lower age limit on the evolution of oxygenic photosynthesis, however placing an upper age limit on its origin is much more difficult. In the last few years, significant geological evidence has begun accumulating that indicates that free oxygen was transiently present in the much deeper past, as far back as 3.2 Ga. Nevertheless, the geological evidence for an early origin of oxygenic photosynthesis remains mired in controversy. I will review this evidence and discuss mechanistic considerations for the earliest production of free oxygen that might guide the search for unequivocal evidence from the rock record. I will also present new geochemical data from Precambrian sedimentary rocks 3.2 to 2.8 Ga in age that represent recent and ongoing efforts in the search for the earliest traces of oxygenic photosynthesis.
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Heubeck Christoph
Department of Geosciences, Jena University

The ICDP Drilling Project: Barberton Archaean Surface Environments, South Africa (3.2 Ga)

The evolutionary development of oxygenic photosynthesis is a key question in early Earth research because it was and is responsible for the profound transformation of surface environments across our planet and allowed the rise of eukaryotic and complex multicellular life. Various geochemical clues suggest that there were at least temporary variations in the overall very low level of atmospheric oxygen by ~3 Ga. This is consistent with results of recent molecular clock analyses that suggest the onset of oxygenic photosynthesis prior to that time, probably via microbial consortia including highly productive benthic cyanobacteria that colonized early shorelines.

The oldest strata suitable to test the hypothesis of – perhaps local and/or temporary – oxygenation are the ca. 3.2 billion-year-old sedimentary (and minor volcanic) units of the Moodies Group in the Barberton Greenstone Belt, South Africa. These record surface processes in very well preserved and correlatable fluvial-to- prodeltaic siliciclastic rocks; in addition, the ~3.7 km thick strata provide an extremely high resolution (mean ~1 km/Ma) over a relatively short interval of 1-14 Ma. Despite tight regional folding, the metamorphic grade is only lower greenschist facies, and there is a nearly complete absence of penetrative strain due to widespread early-diagenetic silicification. This has preserved abundant primary micro- and macrotextures. Mapping has documented paleosols, terrestrial evaporites, potentially eolian strata, shoreline systems, tidal microbial mats, deltaic complexes, and marine ferruginous sediments / BIF. They provide a worldwide unique opportunity to robustly reconstruct early bio-geo-atmo-hydrosphere processes and conditions, particularly those related to diverse and well-documented microbial life, at an unrivalled level of regional and temporal resolution and during a critical period in Earth history.

In order to avoid the effects of oxidative weathering, a particular problem in fine-grained strata, and to obtain continuous sections suitable for geochemical and time-series analyses, we propose to drill five key sections. Nine inclined drillholes, each of 350-600 m length (MD), will provide maximum information across a range of terrestrial-marine facies transitions. We have resubmitted the full proposal and hope to begin drilling in the second half of 2020.

We will investigate (1) conformable terrestrial-marine transitions for environmental proxies; (2) diagnostic lithologies (such as various paleosols, nearshore BIFs, evaporites and basaltic lavas) for their environmental significance; (3) the compositional, facies and morphological variability of thick and laterally extensive microbial mats; and (4) sedimentary and mineralogical responses to surface variables, such as tides, climate, potential meteorite impacts, and radiation, in particular in deep-water strata.
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Daniel Isabelle
Université de Lyon

Role of clay minerals in the emergence of life

Polymerization of the building blocks of life from the dilute early ocean requires a concentration mechanism. A frequently proposed mechanism is the adsorption on minerals that have a high reactive surface. Therefore, we have carried out a comprehensive experimental and theoretical study of this phenomenon, guided by the quickly evolving understanding of the geochemistry of early Earth environments that could have witnessed the emergence of life. Adsorption experiments have been designed on the minerals that certainly exhibit the largest specific surface areas and that were the most abundant in the Hadean environments, i.e. phyllosilicates and clay minerals in particular. Our work aims at understanding how nucleotides, the building blocks of RNA and DNA, might have interacted with phyllosilicates under various physico-chemical conditions. We report the results of series of detailed batch adsorption experiments that explore important parameters such as temperature, pH, salinity, aqueous chemistry... This has allowed building a comprehensive, generalized model of the adsorption mechanisms of nucleotides onto phyllosilicates particles, mainly governed by phosphate reactivity. These results have been very recently complemented by high-resolution investigations that included, vibrational spectroscopy, low pressure gas adsorption, X-ray microscopy, and theoretical calculations in order to acquire data on the adsorption configurations and localization of nucleotides on mineral surfaces. The recent integrated results confirmed and complemented our model.

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Li Yiliang
The University of Hong Kong

Microorganisms might be able to deal with UVR before the emergence of a ozonosphere

The surficial environment of early Earth (~3.8-2.5 Ga) was characterized by deleterious short-wavelengthed ultraviolet radiations (UVRs), where 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 oceans and land. As an important part of early biosphere, primitive photosynthetic microorganisms had to cope with this harsh surficial environment for the sake of harvesting solar energy. At present, the life on Earth are protected from UVR by an ozonosphere shield. However, the ecological distribution of photosynthesis in Archean before the formation of an effective ozonosphere remains unclear. It is known that some cyanobacterial species have developed sheath pigments on the cell exterior, such as scytonemin, to filter UVR as a living strategy. In this study, ab initio calculations were carried out to investigate the properties of UVR absorbing by scytonemin and its structural derivatives, including two putative precursors and the oxidized/reduced transformations. The results indicate that that scytonemin and its derivatives have significant absorptions in the UVC region, which further suggest the oceanic and terrestrial surfaces of Earth could be habitable for Archean life with sheath pigments before the formation of an atmospheric UVR shield.

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Smith Eric
Earth-Life Science Institute

Moving beyond narrative for questions of chance and necessity

At a mechanistic level, life is not one phenomenon, but rather a collection of conceptually very diverse phenomena unified by their interdependency. Therefore the questions of where or when "it" (meaning Life) emerged probably beg for a kind of answer -- a narrative -- that is premature at this early stage of our understanding, and that leads away from better systematic science instead of toward it. We can identify several levels in the hierarchy of life that seem to have preserved especially rich information about how particular stages of emergence were accomplished. Perhaps we can re-frame traditional questions about "where", "when", "how", and "how likely" in concepts that are more natural for the data, so that they guide the formulation of narrative, rather than being limited by a presumed one. I will discuss two such levels as current exciting research frontiers. Many detailed dependencies and overlaps of chemotrophic metabolism with mantle-hydration redox flows have suggested to researchers that biochemistry follows "paths of least resistance" in metal-catalyzed organic redox chemistry, a point of view often abbreviated (too simply) as "metabolism-first". We are beginning to understand the crucial problem of selectivity that would create such paths of least resistance, from both the organic and the mineral sides of the process, in much more detail than existed even ten years ago, but it is still far from clear whether we see the outline of a continuous process from geochemistry to metabolism. Further up in the hierarchy of life, many links have been found among the ribosome, the translation system, and the bioenergetics of thioesters, seemingly from around the time when the genetic code was being established. To me, these suggest that discussions of the rise of coding in a "Miller-Urey" or even "Oparin-Haldane" primordial soup are conceptually completely wrong (in the way that a mixed metaphor is wrong), and that we must understand the origin of later-stage amino acid biosynthesis and genetic encoding in terms of focused, highly non-equilibrium microenvironments created in the few dynamical domains where robust RNA-peptide folding connected to the thioester bridge between redox and phosphate energy disequilibria. A common theme in both areas is a change in our focus away from emphasizing components, and toward the limits of available processes.

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Ranjan Sukrit
MIT

The Planetary Environment for Prebiotic Chemistry

A broad range of theories for the origin of life on Earth have been proposed. These theories lead to diverse predictions for the probability of abiogenesis on Earth and other worlds, and hence the distribution of life in the cosmos. I will review the current paradigm of origin-of-life studies. Through case studies of current leading origin-of-life scenarios, I will discuss why prebiotic chemistry is tightly coupled to the planetary environment, and how studies of early Earth can inform laboratory simulations of abiogenesis. Finally, I will discuss how the search for life beyond Earth (e.g., on M-dwarf planets) has the unique potential to directly constrain our understanding of the frequency and mechanisms for the emergence of life.

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Monday, 25 *afternoon session*

Guedel Manuel
University of Vienna

Setting the stage: Key constraints from star formation and stellar evolution on planetary habitable conditions

Whether a terrestrial planet becomes habitable - like Earth - or not - like Venus or perhaps Mars - depends on astrophysical conditions initiated already in the early stages of star formation and the early evolution of the host star; even the wider environment of the forming planetary system matters. Key points are, for example, the type of star formation environment or the presence of nearby massive stars. Later, a number of timescales in the early evolution of a protoplanetary disk and the growth of a planet determine the accretion of primordial gas envelopes. Subsequently, the activity and rotation evolution of the host star plays a crucial role in the evolution of planetary secondary atmospheres. I discuss several of these astrophysical factors and specifically outline some open issues and controversies.

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Bolmont Emeline
Observatory of Geneva

Habitability of rocky planets around low-mass stars

The most promising Habitable Zone (HZ) planets have been discovered around low-mass stars (Proxima-b around the ~0.12 Msun star Proxima and some of the TRAPPIST-1 planets around a ~0.09 Msun star).
These rocky planets represent the future of the atmospheric characterization of HZ planets (with JWST, the E-ELT...), but their past evolution and their environment are very different from that of the Earth. Thus, to prepare for these future observations, we have to understand the specificities of these planets and what makes them different from the Earth.

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Bonfils Xavier
Institut de Planétologie et d'Astrophysique de Grenoble

Habitable-zone planets orbiting M dwarfs. Status and prospects for detection and characterization

Targetting M dwarfs has been an observational advantage for many detection methods. Searching for planets around them did yield many landmark discoveries, including several Earth-class planets orbiting in so call habitable zones. I shall review current efforts to make the census of exo-earths amenable to atmospheric characterization and the prospects to probe the composition of their atmosphere with current and next-generation telescopes.

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Tuesday, 26 *morning session*

Ohishi Masatoshi
National Astronomical Observatory of Japan

Recent Findings on Prebiotic Organic Molecules in Space

It is generally accepted that origin of life was the result of chemical evolution of organic molecules on the primordial Earth. Thus, an im-portant issue in astrobiology is where prebiotic organic molecules are formed, terrestrial or extraterrestrial. After the famous Urey-Miller's experiment, many researchers believed that the primary formation site of prebiotic organic molecules was the surface of Earth under reducing atmosphere. Recent modelling of the Earth's early atmosphere suggests more neutral conditions which preclude the formation of significant amount of prebiotic organic molecules. The situation, in turn, lead people to consider another possibility: delivery of extraterrestrial prebiotic organic molecules through comets, aster-oids, meteorites, and interplanetary dust particles (the exogenous delivery hypothesis). One research suggested that extraterrestrial organ-ic compounds may be more abundant by three orders of magnitude than their terrestrial formation (Ehrenfreund et al. 2002). It is likely that a combination of these sources contributed to the building blocks of life on the early Earth. What is certain is that once life emerged on the primordial Earth, it was capable to adapt quickly to the surrounding environment for its survival through finding shelter from the UV photons and energy source. This continuing process led to complex metabolic life and even our own existence.
I will talk on recent progress regarding prebiotic organic molecules in space, which may be brought to the early Earth. If the exogenous delivery hypothesis works, similar process would occur even in other extrasolar Earth-like planets.

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Furukawa Yoshihiro
Tohoku University

Sugar formation on the prebiotic Earth and beyond

When we suppose that primordial RNA carried gene code and catalyzed biological reactions. The RNA sugar, ribose, is an essential molecule in the origin of life. Ribose forms in formose reaction in which formaldehyde condenses in alkaline solution. However, once ribose form in the formose reaction, it decays soon and yield is significantly low. Borate increases the yield of ribose in this reaction improving the stability of ribose. Alkaline borate-rich environments might have been present on the prebiotic Earth but the area was significantly limited. Minerals are natural catalysts in many chemical reactions. Thus, we have investigated the potential of minerals in the sugar formation reactions simulating prebiotic Earth and other planetary environments. Minerals might have significantly expanded the possibility of sugar formation on prebiotic environments.

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Shoji Mitsuo
University of Tsukuba

Glycine formation reactions via none-radical and radical processes in interstellar medium

Glycine (gly) is the simplest amino acid and the basic building block for all living things on Earth. Therefore, gly has been an intensive searching target in the interstellar medium (ISM), and it directly relates to reveal the origin of life. As some precursor molecules such as glycolaldehyde and amino acetonitrile have been detected, detection of more complex prebiotic molecules in the ISM is expected with the recent developments of astronomical technologies. In the present study, chemical formation reactions of glycine are theoretically investigated by using quantum chemical approaches [1,2]. According to the classification into the six patterns of all the possible formation reactions, the constituent carbon and nitrogen atoms in the glycine are traced back to the three common interstellar molecules, CH3OH, HCN and NH3 [2].

[1] M.Kayanuma et al., CPL 687(1), 178 (2017).
[2] A.Sato et al., Mol. Astrophys. 10, 11 (2018).

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Jheeta Sohan
NoR HGT & LUCA

Synthesis of the basic 'building blocks' of life

The necessary molecules for the basic 'building blocks' of life – ie molecules – can be made by the action of charged particles and UV light, especially at the boundaries of denser and less dense atmospheric layers; during electrical discharge (ie lightning strikes) in the primordial planetary atmosphere; at the hydrothermal vents after the formation of earth's crust; on the shores of primordial seas and oceans when the tides were huge and more frequent and in the small puddles of water at the foot hills of volcanoes due to gas from the magma being percolated through the water. However, these places are insignificant compared to the vastness of space where molecules were being formed via the processes of astrochemistry.
It is believed that some of the necessary organic molecules may have been formed in specific areas of space (namely dark molecular clouds, eg Horsehead nebula) and delivered on to the Earth during the heavy bombardment period of its history, approximately 4.3-4.0 billion years ago. These organic molecules may have played a pivotal role in the formation of life on Earth. In addition, it is believed that life on Earth was formed within a very short geological time frame of only 200-300 million years. So, it is not unreasonable to suppose that these molecules were initially made in space which in effect could be, metaphorically speaking, a huge chemical laboratory.
To date no less than 190 molecules have been discovered in dark molecular clouds; the formation of molecules under a variety of simulated space conditions (eg different temperatures, levels of radiation energies and different types of impinging radiations) compares well with what is found in these huge structures. Such molecules are then eventually delivered on the surface of a planet by impactors. Collectively, the molecules made in the vastness of space and those other places mentioned at the beginning of this abstract form the inventory of molecules from which life on Earth emerged.

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Tuesday, 26 *afternoon session*

Lagage Pierre-Olivier
CEA, Paris-Saclay University

***Prospects in Characterizing Exoplanetary Atmospheres in the Next Decade and Beyon*d**

The last twenty years have witnessed an exceptionally fast development in the field of the extra-solar planets. About 4000 exoplanets have been detected so far, showing how diverse the planets in our galaxy can be. While the detection of exoplanets is an important ongoing field of activity, the characterization of the atmosphere of known exoplanets has begun and is developing very rapidly. A lot can be learnt from spectroscopic observations of an exoplanet atmosphere; the molecular composition of giant exoplanet atmospheres can trace the planet's formation and evolution; the atmosphere of rocky exoplanets can host bio-signature gases...
In this , I will review the expected development of the field in the next decade and beyond. The James Webb Space Telescope, to be launched in 2021, will be a game changer in the study of exoplanet atmospheres, and will bring the potentiality to characterize the atmosphere of a few 'habitable' planets transiting dwarf stars, such as the Trappist1 star. At the end of the 2020s, Extremely Large Telescopes equipped with high spectral resolution instruments will be ready to track molecules present in the atmosphere of exoplanets, including 'habitable' exoplanets orbiting the nearest dwarf stars, such as Proxima b. In 2028, the ESA ARIEL space mission will start characterizing the atmosphere of exoplanets with a statistical approach; indeed about 1000 exoplanets from hot to warm and with masses ranging from Jupiter mass to Earth mass, will be studied. The characterization of the atmosphere of exoplanets in the 'habitable' zone of Sun-like stars is in view, but requires important technical developments.

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Triaud Amaury
University of Birmingham

Earth-like worlds orbiting non Solar-like stars

Two decades of exoplanetary investigations have revealed an impressive diversity, in physical properties, but also in the environments that planets orbit in. This diversity provides challenges, but it also offers unthought-of advantages.
Thanks to the ease of studying them, and their relatively high abundance, we will investigate how planets orbiting the smallest stars that exist are crucial in our understanding of planets formation, and in measuring how frequently biology arises in the Cosmos.

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Kokubo Eichiro
National Astronomical Observatory of Japan

Formation of Terrestrial Planets

In the standard formation scenario of planetary systems, planets form from a protoplanetary disk that consists of gas and dust. The scenario can be divided into three stages: (1) formation of planetesimals from dust, (2) formation of protoplanets from planetesimals, and (3) formation of planets from protoplanets. In stage (1), planetesimals form from dust through some instability of a dust layer or coagulation of dust grains. Planetesimals are small building blocks of solid planets. Planetesimals grow by mutual collisions to protoplanets or planetary embryos through runaway and oligarchic growth in stage (2). The final stage (3) depends on a type of planets. The final stage of terrestrial planet formation is giant impacts among protoplanets while sweeping residual planetesimals. In the present talk, I review the elementary processes of terrestrial planet formation and also discuss the origin of the diversity of terrestrial planets.

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Jacobson Seth
Northwestern University

What makes the Solar System unique?

From exoplanet studies, it is becoming increasingly clear that the Solar System is an outlier. In fact, we may not even contain the most common type of planet in the Solar System--the super-Earth in a short period orbit. Using our current understanding of pebble accretion and planetary migration, we can make some progress in understanding how this discrepancy arises. However, why our system is rare and others are common is still a mystery.

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Prantzos Nikos
Institut d'Astrophysique de Paris et Université Paris-Sorbonne

A reassessment of Drake's equation and Fermi's paradox

I discuss the physical meaning of the Drake equation and analyse it in a way revealing the implications of its last term, namely the lifetime of technologically evolved civilizations, the importance of which is often overlooked. The analysis allows us to define a region in the parameter space of the Drake equation, where the so-called "great silence" may be easily understood. The adopted framework is also applied to the analysis of the Fermi paradox, under the assumption of a simplified scheme for the colonization of the Galaxy. From the joint analysis of the Drake equation and the Fermi paradox, it appears that for sufficiently long-lived civilizations, colonization of the Galaxy appears to be the only reasonable option to gain knowledge about other life-forms. The analysis allows one to define a corresponding region in the parameter space of the Drake equation where the Fermi paradox holds.

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Jia Tony
Earth-Life Science Institute, Tokyo Institute of Technology

Membraneless Polyester Microdroplets as Primordial Compartments at the Origins of Life

Compartmentalization was essential to primitive chemical systems during the emergence of life, both by preventing leakage of important components, i.e., genetic materials, and by enhancing chemical reactions. Although life-as-we-know-it utilises a lipid bilayer membrane compartment, as prebiotic chemistry was significantly diverse, primitive living systems may have started from other types of boundary systems. Here, we demonstrate membraneless compartmentalization derived from prebiotically available non-biological compounds such as α-hydroxy acids (αHAs), a congener of alpha amino acids that is prebiotically ubiquitous. We characterised membraneless microdroplets generated from homo- and hetero-polyesters synthesized from drying αHA solutions with various side-chains. These microdroplets can preferentially and differentially segregate and compartmentalize fluorescent dyes and fluorescently-tagged RNA, providing readily-available compartments that could facilitate chemical evolution by protecting, exchanging, and encapsulating primitive components. Facile polymerization of αHAs provides a novel pathway for the assembly of combinatorially diverse primitive compartments on early Earth that could have been more accessible in a messy prebiotic environment, catering specifically to hosting a variety of possible prebiotic metabolic and replication processes that could be subjected to further chemical evolution before the amalgamation of the Last Universal Common Ancestor.

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Maurer Sarah
Central Connecticut State University

The ability of simple membranes to harvest light-energy: proton gradient generation and CO2 reduction

Ionizing radiation is one of the most abundant energy sources in the universe and has often been used by astrobiologists to generate interesting organic products. Photochemistry using UV or visible light has often been explored in the presence of membranes as a type of primitive photosynthetic mechanism that can lead to unique living properties such as cell growth and generation of electrochemical gradients. A summary of the research in this area will be presented followed by a presentation of my lab's more recent project involving photochemistry in a mixture of oily surfactants and polycyclic aromatic hydrocarbons (PAHs). When suspended in an aqueous phase, these molecules self-assemble into aggregates that resemble cell membranes, with an aqueous interior and hydrophobic boundary. Upon sun-like illumination, these suspensions have been shown to change pH rapidly. However, little is known about the products generated or the mechanism of this pH change. We evaluated the pH change under several different PAHs, and characterized the dependence on starting pH, electron donors present, concentration of bicarbonate, and concentration of salt. The samples were then analyzed for presence of formaldehyde and formic acid using GC-MS.

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Lancet Doron
Weizmann Institute of Science

Enceladus reported organic chemistry supports Origin of Life in a Lipid-World scenario

A recent breakthrough publication [1] has reported complex organic molecules in the plumes emanating from the subglacial water ocean of Saturn's moon Enceladus. Based on detailed chemical scrutiny, the authors invoke primordial or endogenously synthesized carbon-rich monomers (<200 u) and polymers (up to 8000 u). This appears to represent the first reported extraterrestrial organics-rich water body, a conceivable milieu for early steps in life's origin ("prebiotic soup"). One may ask which origin of life scenario appears more consistent with the reported molecular configurations on Enceladus. The observed monomeric organics are carbon-rich unsaturated molecules, vastly different from present day metabolites, amino acids and nucleotide bases, but quite chemically akin to simple lipids. The organic polymers are proposed to resemble terrestrial insoluble kerogens and humic substances, as well as refractory organic macromolecules found in carbonaceous chondritic meteorites. The authors posit that such polymers, upon long-term hydrous interactions, might break down to micelle-forming amphiphiles. In support of this, published detailed analyses of the Murchison Chondrite [2] are dominated by an immense diversity of likely amphiphilic monomers. Our specific quantitative model for compositionally reproducing lipid micelles [3] is amphiphile-based, and provides a simulatable path towards further molecular complexification [4]. It also benefits from a pronounced organic diversity [4], thus contrasting with other origin models that require the presence of very specific building blocks, and are expected to be hindered by excess of irrelevant compounds. Thus, the Enceladus finds optimally suit a Lipid-World scenario [5] for life's origin. The perspective provided by such a target origin model may also bring new insights regarding future planetary missions [6].

[1] Postberg, F., Khawaja, N., Abel, B., Choblet, G., Glein, C.R., Gudipati, M.S., Henderson, B.L., Hsu, H.-W., Kempf, S., Klenner, F., et al. 2018 Macromolecular organic compounds from the depths of Enceladus. Nature 558, 564-568. (doi:10.1038/s41586-018-0246-4).
[2] Schmitt-Kopplin, P., Gabelica, Z., Gougeon, R.D., Fekete, A., Kanawati, B., Harir, M., Gebefuegi, I., Eckel, G. & Hertkorn, N. 2010 High molecular diversity of extraterrestrial organic matter in Murchison meteorite revealed 40 years after its fall. Proceedings of the National Academy of Sciences 107, 2763-2768.
[3] Segré, D., Ben-Eli, D. & Lancet, D. 2000 Compositional genomes: prebiotic information transfer in mutually catalytic noncovalent assemblies. Proceedings of the National Academy of Sciences 97, 4112-4117.
[4] Lancet, D., Zidovetzki, R. & Markovitch, O. 2018 Systems protobiology: origin of life in lipid catalytic networks. Journal of The Royal Society Interface 15, 20180159.
[5] Segré, D., Ben-Eli, D., Deamer, D.W. & Lancet, D. 2001 The lipid world. Origins of Life and Evolution of the Biosphere 31, 119-145.
[6] Lancet, D. & Kahana, A. 2019 Enceladus: first observed primordial soup could arbitrate origin of life debate. Astrobiology Sumbitted.

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Biondi Elisa
Foundation for Applied Molecular Evolution

Alternative biopolymeres in early evolution

One of the more discussed hypotheses for the origin of life is the ""RNA first"" model. This model postulates that organic molecular systems first gained access to Darwinism through a spontaneous prebiotic formation of RNA molecules that were able to generate replicates, with imperfections, where the imperfections were themselves replicable.

If this model were true, one would think that the key product that it proposes (an RNA replicase) would be easily obtained by modern prebiotic chemists who, after all, can access directed and prospective evolution, including the ability to order reagents with controlled purity, to avoid conditions that are obviously destructive, and to guide with facility the same process that, on early Earth, allegedly produced the replicase without guidance of any kind. To date, only a highly derived RNA ligase, developed in the Holliger lab, has come close to being an RNA replicase.

The fact that it is so difficult to reproduce an RNA species central to the ""RNA first"" hypothesis suggests that we are missing something. Thus, many laboratories have sought alternative biopolymers that are both prebiotically accessible, and that also support Darwinism better than standard RNA, managing the rather low intrinsic catalytic ability of RNA as it is today found in terran biology, and the frequently reproduced experimental observation that it is easier to get nucleic acid molecules that catalyze the destruction of RNAs than nucleic acids that catalyze the synthesis of RNA.

This work reports on experimental results with such nucleic acid-like biopolymers made from six different building blocks (Artificially Expanded Genetic Alphabet, or AEGIS). These additional nucleotides carry functionality that chemical theory suggests might assist in binding and catalysis, perhaps even catalysis for the synthesis of RNA.

The presentation will briefly describe molecular biology for this artificial genetic system, including pipelines to synthesize its nucleoside triphosphates and phosphoramidites, procedures to synthesize a oligonucleotides, enzymes that copy the alien genetic system, and procedures that place the expanded, richer, genetic system under Darwinian selection pressure in the laboratory, with downstream sequencing and analysis to assess the sequelae of laboratory Darwinism.

These results have led to several discoveries. First, additional building blocks appeared to allow the system to adopt macro conformations different from, and additional to, those accessible with standard four letter nucleic acids. Further, it appears that the added information density by added letters provides options for the system to access specific binding confirmations. Further, although quantitative comparison is difficult, preliminary data suggests that the added functionality also allows the system to get tighter and more specific interactions between evolvable biopolymers and a target as it serves both genetic and phenotypic roles. Finally, recent results from parallel in-vitro selections of standard and AEGIS libraries indicate that added functionality might indeed allow for more efficient evolvability of shorter biopolymers.

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Kim Hyo-Joong
Firebird Biomolecular Sciences

Prebiotic Stereoselective Nucleotide Synthesis

RNA first model is widely considered for the Origin of Life on Earth because RNA can perform a role in both genetics and catalysis. To support RNA first model, it is required to synthesize RNA in prebiotic condition of early Earth. RNA is not simple molecule and it has quite complex structure. Many efforts have been devoted to show RNA can be synthesized in prebiotic condition for the last several decades and it is still ongoing activity in the community. One of the challenging problems is how to make nucleoside or its phosphorylated form, nucleotide. Many synthetic strategies have been proposed to tackle this problem.
In this presentation, the nucleotide synthesis from the coupling of nucleobases and phosphorylated ribose, ribose 1,2-cyclic phosphate will be discussed. In addition to ribonucleotides, other form of nucleotides which have threose (component of TNA which is another candidate for the prebiotic genetic molecule) or non-canonical nucleobases will be discussed.

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Hansma Helen Greenwood
University of California at Santa Barbara

Biotite is a better mica for the origins of life

Biotite is an iron-rich mica capable of redox reactions, which are needed for the origins of life. Like Muscovite mica, biotite's mineral sheets are held together by potassium ions, which are found at high concentrations in all living cells. There are few good ideas for the original source of life's high concentrations of intracellular potassium, so this is a significant advantage that mica brings to origins-of-life possibilities. The spaces between mica sheets may have provided confinement and protection for the earliest molecules of life, without the need for membranes [1]. Liquid-in-liquid 'membraneless organelles' form from RNA and peptides in all branches of life. RNA and peptides may have come together to form the earliest ribosomes, by this process of liquid-in-liquid phase separation [2]. Hydrogen bonds are ubiquitous in living systems and also form between mica surfaces and organic molecules [3]. Mechanical energy of moving mica sheets may have provided the energy for life's origins, before high-energy organic molecules were available [1].

1. Hansma, H. G. (2010). ""Possible origin of life between mica sheets."" Journal of theoretical biology 266(1): 175-188.
2. Hansma, H. G. (2017). ""Better than Membranes at the Origin of Life?"" Life 7(2): 28.
3. Yu, J., Y. Kan, M. Rapp, E. Danner, W. Wei, S. Das, D. R. Miller, Y. Chen, J. H. Waite and J. N. Israelachvili (2013). Proceedings of the National Academy of Sciences 110(39): 15680-15685.

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Hordijk Wim
Complexity Institute

Autocatalytic sets and the origin of life

Life is more than the sum of its constituent molecules. Living organisms depend on a particular chemical organization, i.e., the ways in which their constituent molecules interact and cooperate with each other. One way to study such a chemical organization is with autocatalytic sets. An autocatalytic set is a self-sustaining chemical reaction network in which all molecules mutually catalyze each other's formation from a basic food source.The concept of autocatalytic sets has been formalized and studied mathematically and computationally as RAF theory. This theory has shown that autocatalytic sets are highly likely to exist in simple polymer models of chemical reaction networks, and that such sets can, in principle, be evolvable due to their hierarchical structure of many autocatalytic subsets. Furthermore, the framework has been applied successfully to study real chemical and biological examples of autocatalytic sets. In this talk I will give a general (and gentle) introduction to RAF theory, present its main results, and how they could be relevant to the origin of life.

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Javaux Emmannuelle
University of Liege

The earliest traces of life: evidence and challenges

The search for life on the early Earth or beyond Earth requires the characterization of biosignatures, or "indices of life". These traditionally include fossil chemicals produced only by biological activity, isotopic composition indicative of biological cycling, biosedimentary structures induced by microbial activities such as stromatolites, and microstructures interpreted as morphological fossils. Advances in micro- and nanoscale technologies and experimental approaches to better constrain abiotic processes mimicking life can help to test their biogenicity, when combined with the geological context of preservation. This talk will review the challenges of studying the early record of life and will discuss some putative and some more convincing evidence of the early traces of life.

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BellElizabeth
UCLA

Identifying and assessing traces of early life in the zircon record

Several lines of evidence suggest that life on Earth may be as or more ancient than the early Archean. The chief difficulty in assessing various hypothesized scenarios for the early Earth's environment is the lack of a known rock record prior to 4.02 Ga. This earliest eon of Earth history (the Hadean) can be studied directly only by detrital minerals in later sediments. The most well-studied suite of Hadean minerals is the Jack Hills detrital zircons (Western Australia), ranging to nearly 4.4 Ga in age and containing a variety of geochemical and petrological information about the Hadean magmas in which they crystallized. While pointing to the composition of at least part of the Hadean crust, these zircons and their cargo of mineral inclusions also provide indirect evidence for conditions in the surface and near-surface environment of Hadean Earth through a variety of isotopic systems and trace elements. Carbonaceous mineral inclusions may provide evidence for Hadean carbon cycling: an isotopically light graphite inclusion in a 4.1 Ga zircon may provide evidence for life on Earth by 4.1 Ga. By more fully exploiting mineral inclusions and trace element chemistry, especially in Hadean-Archean zircons from sites other than Jack Hills, we can develop a better grasp on not only the igneous crustal composition but potentially also the surficial environment at the dawn of life.

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Michalski Joseph
University of Hong Kong

Mars as a Rosetta Stone for the Origin of Life

The next step in NASA's Mars exploration strategy is to search via rover and future sample return for biosignatures, textural or chemical clues that microbial life was once there. The decision of exactly where to search is a huge one that will shape Mars exploration for decades, and we must be mindful of how terrestrial biases can affect exploration strategy. Surface environments on Earth that favour biosignature preservation might not translate to Mars, where photosynthesis may have never evolved. Ancient hydrothermal environments akin to those where life seemingly formed on Earth might be more likely to preserve biosignatures on Mars.

Given that life likely originated in hydrothermal environments on Earth, given that they contain evidence for biosignatures in ancient and modern deposits, and given that we have identified vast and diverse hydrothermal systems on Mars, it makes sense to search for chemical clues to life's origins on Mars in hydrothermal deposits, or in lakes fuelled by hydrothermal fluids. Such deposits could contain not only direct biosignatures, but essential clues to prebiotic chemical processes that are simply not preserved anywhere on Earth. Mars is more than just an interesting planet – it is a time capsule, a Rosetta Stone for Earth's long lost early geologic record. Mars represents an opportunity to explore our origins through space and time, in a geologic history not preserved on planet Earth.

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Tue Hassenkam
University of Copenhagen

Elements of Eoarchean life trapped in mineral inclusions

Metasedimentary rocks from Isua, West Greenland (> 3,700 million years old) contain 13C depleted carbonaceous compounds, with isotopic ratios compatible with a biogenic origin. Metamorphic garnet crystals in these rocks contain trails of carbonaceous inclusions contiguous with carbon-rich sedimentary beds in the host rock, where carbon is fully graphitized. Previous studies4,5 have not been able to document other elements of life (mainly H, O, N and P) structurally bound to this carbonaceous material. Here we studied carbonaceous inclusions armoured within garnet porphyroblasts by in-situ Infrared absorption on ~10-21 m3 domains within these inclusions. The absorption spectra are consistent with carbon bonding to N and O and likely to phosphate. The levels of C-H or O-H bonds were found to be low. These results are consistent with biogenic organic material isolated for billions of years and thermally matured at temperatures around 500 oC. They therefore provide spatial characterization for potentially the oldest biogenic carbon relics in Earth's geologic record. The preservation of Eoarchean organic residues within sedimentary material corroborate earlier claims for biogenic origins of carbon in Isua metasediments.

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Friday, 29 *morning session*

Assis Fernandes Vera
School of Earth and Environmental Sciences, University of Manchester, UK

Earth-Moon impact bombardment history: how does it fit with that of the inner Solar System?

One of the major issues in planetary sciences that still needs better understanding and constraints is the flux and chronology of impacts onto planetary bodies extinct and extant. The lunar surface provides one of the best-preserved impact cratering records in the inner Solar System. Therefore, this record is vital in the understanding of the bombardment history of the complete inner Solar System, i.e., possible changes of the impact flux, the source of the impacting projectiles, as well as the possible related volatile delivery by asteroids and/or comets to the terrestrial planets. The initial work on samples brought by the Apollo and Luna missions showed a persuasive large number of samples showing ~3.9 Ga re-set age [1 & 2] and interpreted as the time interval (100-200 Ma) when several of the large basins (>300 km craters) formed (e.g., Imbrium, Serenitatis, Crisium) and termed as "the lunar cataclysm". However, it is yet not clear whether this age represents the end of a continuous decay of the impact flux or whether it represents a temporal increase (a spike) in the number of impact events at 3.9 Ga. Recently using high-resolution 40Ar-39Ar step heating technique [3] reported new impact ages obtained from Apollo 16 and Apollo 17 samples. The impact ages range from 4.293±0.044 to ≤3.298±0.052 Ga, with a greater incidence of samples with a ~4.2 Ga re-set age. Although the ~4.2 Ga age had been reported previously by (e.g., [4-6]), little attention was given to it until more recently [3, 7-15]. Similar ages have since also been reported by others [7-15]. Thus, suggesting that at least two heavy impact periods occurred, i.e. 4.2 and 3.9 Ga. With this in mind, [3&14] compiled 280 40Ar/39Ar ages of Apollo and Luna mission samples and lunar meteorites and of meteorites from other planetary bodies. This compilation reveals a complex and spiky impact bombardment onto the Earth-Moon system, and onto other parts of the Solar System during the initial 1 Ga. Considering the possibility of a "busy" and extended period of bombardment, [14] denominated it as the Heavy Bombardment Eon (HBE). It is characterized by separated periods of increase abundance in impact events of varying sizes, and quieter periods in the Earth-Moon system [3] and potentially in other parts of the inner Solar system [14]. It is probable that during the HBE, impacts influenced the initial attempts for life to develop since on Earth (e.g., prior to 4.2 Ga). As a consequence of an impact spike in the bombardment flux, it is conceivable that these life forms either became extinct or on a stand-by mode which could strive once a low in the impact flux occurred. Moreover, and as a result of influx of different material from distinctive parts of the Solar System, there was also the delivery of different volatiles and organic components throughout this HBE [14 and references therein] and which caused continuous changes in the terrestrial environment. This permitted different life forms to emerge and develop simultaneously permitting them to survive in different environmental conditions.
Acknowledgements: This work is in continuous progress in collaboration with Stephanie Werner, Benjamin Bultel and Tobias Rolf at the CEED, University of Oslo, Norway, and Jörg Fritz at the Zentrum für Rieskrater und Impaktforschung Nördlingen, Germany.
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Qin Liping
School of Earth and Space Science, University of Science and Technology of China

What can we learn about the origin of the Solar System from the study of extraterrestrial materials

Meteorites and other extraterrestrial materials provide excellent opportunities to examine the early history of the Solar System as they often stopped to evolve shortly after the formation of the Solar System. Many of them are the remnants of old planetesimals, from which the terrestrial planets are widely thought to have accreted from, so they also record early stages of planet formation. In the recent past, the employment of high-precision isotope analyses does provide one of the most robust constraints on the formation sequence of Solar System objects and on the building blocks of terrestrial materials. With these new results, our view on the Solar System formation has been changed. In this study, I will review the advancements that have been made in the past decade or so towards a better understanding of the origin of our Solar System.

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Yabuta Hikaru
Hiroshima University

Overview of the Carbonaceous Asteroid Ryugu and Summary for the First Half of Hayabusa2 Asteroid Sample Return Mission

Hayabusa2 is a Japanese C-type asteroid sample return mission. C-type asteroid is thought to contain relatively high amount of organic carbon and water as hydrated minerals, which would give us the opportunity to understand the origin and evolution of the life’s building blocks in the early Solar System.
On June 27, 2018, the Hayabusa2 spacecraft has arrived at the near Earth asteroid Ryugu. Ryugu is a top shape asteroid that has a very dark surface. The mean radius of the asteroid is about 450 m and the rotation period is 7.6 hours. Ryugu is likely a rubble pile, because of a number of large boulders everywhere and the low density of the asteroid.
Immediately after the arrival, remote-sensing observations were begun with the on-board instruments, Optical Navigation Camera (ONC), Near Infrared Spectrometer (NIRS3), Thermal Infrared Imager (TIR), and Laser Altimeter (LIDAR). Based on the remote sensing data, we have carried out the landing site selection (LSS) for the first touch down. In September and October, 2018, rovers (MINERVA II-1) and a lander (MASCOT) were successfully released, respectively. After solar conjunction during November-December, sample collection and an impact experiment using a small carry-on impactor (SCI) will be scheduled this year.

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Fournier Greg
Massachusetts Institute of Technology

LUCA: A complex end, and an ordinary beginning

The Last Universal Common Ancestor (LUCA) is a biological concept that can be defined both theoretically and observationally. Theoretically, in that it represents the necessary coalescent point that all extant lineages on Earth can be traced back to. Observationally, in that many gene families have broad taxonomic distributions and phylogenies supportive of their inheritance from a common ancestral group. In considering the complexity of LUCA with respect to cellular life as we know it, several points should be carefully considered. What complexity necessarily evolved pre-LUCA, as apparent in the history of ancient duplicated gene families, and the highly conserved core of molecular biology, such as the genetic code and ribosome? How much of what we observe about LUCA can be explained by applying uniformitarian principles? Is there any evidence that LUCA was "special" in any way, temporally or biologically? Do proposed scenarios of prebiotic evolution directly inform or predict the nature of LUCA? Was LUCA alone, or part of an ecosystem?

And finally, what are the observational biases that can influence our thinking? In considering these questions, I propose that LUCA was likely an "ordinary" population of cells in many ways, albeit simple in comparison to extant representatives of microbial groups, and that we should be careful not to overstate its biological or evolutionary significance. Perhaps the most important metric of LUCA's complexity is as an "end state" of the processes of prebiotic and biotic evolution that established the shared ancestral characters of life on Earth.

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Harris AJ and Aaron Goldman
Oberlin College and Conservatory, Oberlin, Ohio USA

Biological Complexity of the Last Universal Common Ancestor

We present the current evidence for the complexity of the last universal common ancestor, or LUCA, of the three domains of life on Earth and highlight the utility of this early organism as an emerging, computationally accessible model system for both earlier life forms and descendant biodiversity. The LUCA occurred on Earth 3-4 billion years ago and most likely exhibited complexity in its genetic machinery, metabolism, and structure based on computational and experimental studies. The genetic machinery of the LUCA included a well-developed translational system for assembling amino acids into proteins using RNA-encoded instructions. The translational system in the LUCA is evidenced, in part, by the large number of protein families involved in translation that occur universally within the three domains of life. According to our recent research, one of these protein families comprises RNA methyltransferases, which are important in modifying RNA for translational accuracy and occurred in at least two copies, or separate genes, in the LUCA. The LUCA also likely possessed a complex metabolic network. The metabolic capacities of the LUCA probably included the production and utilization of the energy molecule, ATP, and the synthesis of complex sugars, amino acids, nucleotides, and their respective polymers, based on evidence from gene phylogenies, structural homologies of proteins among extant species, and other methods. Structurally, the LUCA was almost certainly a cellular organism with mechanisms for constructing cellular membranes, undergoing cell division, and performing transmembrane transport. Cellularity in the LUCA is consistent with both informatics-based research and evolutionary theory. One aspect of the LUCA that remains poorly understood is organization of its genetic machinery upstream of translation, such as its chromosomal structure, mechanisms for regulating gene expression, and even the type of molecule comprising its genomic material. It is widely assumed that the LUCA had a DNA genome, although alternative opinions exist particularly because there are no universal DNA replication proteins, or polymerases, and few apparent universal proteins known to interact with DNA. We have recently identified several protein families within the LUCA that likely performed functions related to the conformation of DNA into chromosomes. We have studied these protein families using computational methods especially focusing on those that manipulate DNA conformation to up- and downregulate transcription in modern organisms. Our work suggests that the genomic material of the LUCA consisted of DNA and was organized and maintained within chromosomes. Our work also provides insights into how early life may have utilized transcriptional regulatory states, or epigenetics, which represents an important ecological and evolutionary mechanism for extant species. While not all studies of the LUCA agree on the details of its biology, the emerging consensus, in our view, is that this ancient organism was at least as complex as some modern, free-living bacteria. We expect that further characterization of the LUCA may result in a better understanding of the evolutionary and planetary processes that have shaped biodiversity throughout the history of life on Earth.

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Friday, 29 ***afternoon session***

Malaterre Christophe
Université du Québec à Montréal (UQAM)

Chance or necessity: What is at stake?

Researchers on the origins of life are often characterized as belonging to either one of two camps: the ‘almost a miracle' camp (Fry 2000) for which life is but the result of an extremely unlikely event (in the company of Crick, Mayr and Monod), and the ‘definitely not a miracle’ camp (alongside Bernal, Eigen, de Duve and many others). In this contribution, I will first explore the motivations for each one of the two camps (i.e. the reasons they offer for justifying their respective stances) as well as the epistemic consequences of adopting either view. I will then argue that the distinction between the two camps hinges upon two underlying—yet often overlooked—questions: (1) What is it that we assign probabilities to (i.e. what are the events at stake)? (2) How do we estimate these probabilities (i.e. the probability distribution over the events)? Whereas answers to (1) can be reasonably mapped and agreed upon, I will argue that answers to (2) require a second order probability: a probability over origins-of-life theories or ‘plausibility’ assessment, that is much more elusive. Any attempt to addressing the ‘chance or necessity’ dilemma requires answers to both questions.

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POSTER ABSTRACTS

Terada Yuka
University of Tokyo

Multi-color transit observations of the warm Jupiter WASP-80b

Transit depths of a true planet have a weak wavelength dependence caused by the nature of the planetary atmosphere. To measure the weak wavelength dependence in transit depths is useful to study the composition of a planetary atmosphere.

WASP-80b is a warm Jupiter in a 3-day orbit around a late-K/early-M dwarf. The number of giant planets around a late-K/early-M dwarf which have been discovered so far is small. As the planet has an equilibrium temperature of ~800 K or less, the existence of haze is theoretically suggested. Fukui et al. (2014) suggested the possibility of haze since the spectrum in the optical region is larger than in the near infrared region. On the other hand, Parviainen et al. (2017) reported the flat transmission spectrum, and the effect of Rayleigh scattering due to haze has not been observed.

However, in observations made so far, the uncertainty of the extinction ratio in the g band (400-550 nm) is large. If haze exists, the possibility that the spectrum in the g band becomes larger than other bands due to the effect of Rayleigh scattering. Therefore, we conducted multi-color transit observations including the g band using the Okayama 188 cm telescope / MuSCAT and the Canary Islands 1.5 m telescope / MuSCAT 2. As a result, we find a flat transmission spectrum with no evidence of Rayleigh scattering.

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Kawai Jun Toyama
Prefectural Institute for Pharmaceutical Research

Organic compounds in Titan tholins and chemical evolutions in the Titan liquidosphere

Titan is the largest moon of Saturn and possesses a dense atmosphere composed of nitrogen and methane. Various types of organic compounds (hydrocarbons, nitriles, etc.) have been found on Titan, which were generated by reactions taking place in its atmosphere. These reactions are considered to provide crucial evidence for chemical reactions which may have occurred in the atmosphere of primitive Earth. Cassini discovered several lakes of liquid methane and ethane on Titan's surface; in addition, the presence of ammonia water in its subsurface was implied. In order to simulate the chemical reactions in Titan's atmosphere, gas mixtures of nitrogen and methane have been exposed to plasma discharges to synthesize complex organic matters.

1. We focused on the formation of nucleic acid bases and related compounds recovered from synthesized Titan tholins. The five nucleic acid bases that terrestrial life uses (adenine, cytosine, thymine, guanine, and uracil) have already been reported to be present in synthesized Titan tholins. Purines and pyrimidines, including the five aforementioned nucleic acid bases, were extracted from synthesized Titan tholins and analyzed by HPLC and LC/ MS. As a result, the pyrimidine bases of isocytosine and 2, 4-diaminopyrimidine were detected together with the terrestrial nucleic acid bases of adenine, uracil, and cytosine. These results obtained in conjunction with those from previous studies show that some nucleic acid bases and related pyrimidine bases are found in synthesized Titan tholins, suggesting that chemical evolutions toward xenogenetic systems could occur in Titan's environment.

2. We examined the possibility of self-assembled of Titan tholins in Titan’s liquidosphere. As a substitute for the liquid ethane and methane that exist on its surface, hexane, a non-polar solvent, and chloroform, a slightly polar solvent, were used because they exist in the liquid phase at room temperature. Titan tholins were insoluble in non-polar solvents, such as liquid ethane and methane, but slightly soluble in chloroform. Infrared spectroscopy showed that tholins have amino groups and azide groups, such as the hydrophilic and alkyl groups. The results suggest that coacervates can self-assemble in Titan’s liquidosphere and have the potential to undergo further chemical evolution when interaction with liquid ethane and methane, a non-polar solvent, occurs on its surface or with ammonia water, a polar solvent, on its subsurface. In addition, we are trying to observe reverse micelles with TEM and analyze SAXS and SANS in low temperature.