BP 24: Synthetic life-like systems and Origins of Life

Time: Wednesday 15:00–18:00 Location: H 1028

Invited Talk BP 24.1 Wed 15:00 H 1028

Steps towards the de-novo synthesis of life — •Sijbren Otto — University of Groningen, Groningen, the Netherlands

How the immense complexity of living organisms has arisen is one of the most intriguing questions in contemporary science. We have started to explore experimentally how organization and function can emerge from complex molecular networks in aqueous solution. We focus on networks of molecules that can interconvert, to give mixtures that can change their composition in response to external or internal stimuli. Molecular recognition between molecules in such mixtures leads to their mutual stabilization, which drives the synthesis of more of the privileged structures, amounting to self-replication. We have witnessed spontaneous differentiation (a process akin to speciation as it occurs in biology) in a system made from a mixture of two building blocks. When such systems are operated under far-from-equilibrium flow conditions, adaptation of the replicators to a changing environment can occur. Replicators that are able to catalyse reactions other than their own formation have been obtained, representing a first step towards metabolism. Rudimentary Darwinian evolution of purely synthetic molecules has also been achieved and the prospect of synthesizing life de-novo is becoming increasingly realistic.

BP 24.2 Wed 15:30 H 1028

Sequence self-selection by cyclic phase separation — •Philipp Schwintek[1], Giacomo Bartolucci[2], Adriana Calaca Serrao[1], Dieter Braun[1], Christof Weber[2], Alexandra Kühnlein[1], Yasha Rana[2], Philipp Janto[1], Dorothea Hofer[1], and Christof Mast[1] — [1]Ludwigs-Maximilian-Universität München and Center for NanoScience, Munich 80799, Germany — [2]Division Biological Physics, Max Planck Institute for the Physics of Complex Systems, Dresden 01187, Germany

The emergence of functional oligonucleotides on early Earth required a molecular selection mechanism to screen for specific sequences with prebiotic functions. Cyclic processes such as daily temperature oscillations were ubiquitous in this environment and could trigger oligonucleotide phase separation. Here, we propose sequence selection based on phase separation cycles realized through sedimentation in a system subjected to the feeding of oligonucleotides. Using theory and experiments with DNA, we show sequence-specific enrichment in the sedimented dense phase, in particular of short 22-mer DNA sequences. The underlying mechanism selects for complementarity, as it enriches sequences that tightly interact in the dense phase through base-pairing. Our mechanism also enables initially weakly biased pools to enhance their sequence bias or to replace the previously most abundant sequences as the cycles progress. Our findings provide an example of a selection mechanism that may have eased screening for auto-catalytic self-replicating oligonucleotides.

BP 24.3 Wed 15:45 H 1028

Thermal gradients drive separation of ions, naturally creating local niches for the OoL — •Thomas Matreux, Paula Aikkila, Almuth Schmid, Mechthild Rappold, Dieter Braun, and Christof B. Mast — LMU München, Deutschland

Rocks and their constituent phases provided a feedstock for the emergence of life. However, leachate concentrations, diluted by the ocean or retained by chelation processes, were too low to kickstart life and were mostly present in incompatible compositions. We are interested how physical non-equilibria can overcome this problem and offer unique opportunities for molecular selection on all levels.

Ions leached from mineral samples are selectively accumulated by heat flows through water-filled fractures. In contrast to up-concentration by dehydration or freezing, this actively alters the Magnesium:Sodium ratio to an extent that permits key ribozyme activities. Phosphate is liberated and made accessible at neutral pH by thermally driven separation starting from acid-dissolved Apatite, presumably the most abundant phosphorous mineral that is close to insoluble at physiological pH.

Even single ion species such as Na and Cl are fractionated to form pH gradients. In multi-ion systems, thermal gradients can drive the precipitation of otherwise unfavorable species such as Magnesium phosphates.

Heat flows thereby naturally provide local niches with optimized pH and salt conditions for key steps of nascent life.

BP 24.4 Wed 16:00 H 1028

A Mechanical-Electrical Model to Describe the Negative Differential Resistance in Membranotronic Devices — •Max Huber[1,2,3], Jörg Schuster[1,2,3], Oliver G. Schmidt[1,4,5], Harald Kuhn[3], and Daniil Karnaushenko[1] — [1]Research Center for Materials, Architectures and Integration of Nanomembranes (MAIN), TU Chemnitz, Chemnitz, Germany — [2]Center for Microtechnologies, TU Chemnitz, Chemnitz, Germany — [3]Fraunhofer Institute for Electronic Nano Systems ENAS, Chemnitz, Germany — [4]Material Systems for Nanoelectronics, TU Chemnitz, Chemnitz, Germany — [5]Nanophysics, Faculty of Physics, TU Dresden, Dresden, Germany

Membranotronic devices are artificial neural membranes designed to mimic the functionality of biological neural networks [*Adv. Funct. Mater.*, **32**(24), 2200233 (2022)]. Negative differential resistance (NDR) is essential for their function. We present a physical model of a membranotronic device which generates NDR. It consists of a deformable membrane with holes allowing ion currents, which are modulated by a deformation resulting from an applied voltage. A mechanical model for micro-electro-mechanical systems describes the deformable membrane including holes. We perform a parameter variation study and show that our model can reproduce the NDR for a wide and physically reasonable range of parameter combinations. In essence, our work bridges the gap between artificial membranotronic devices and biological neural membrane by providing a robust physical model capable of emulating NDR, a key feature in the operation of such systems.

15 min. break

BP 24.5 Wed 16:30 H 1028

Protein Design for and with Synthetic Cells — •Béla P. Frohn and Petra Schwille — Max Planck Institute of Biochemistry, Martinsried, Germany

Bottom-Up Synthetic Biology creates cell-like systems from a minimal set of functional modules, such as purified proteins, membranes and DNA. This facilitates the study of biological systems under extremely well-defined conditions, where every parameter is known and can be controlled. Here we show that these systems provide an ideal screening platform to test designed proteins for complex biological functions, i.e., functions that only arise from interaction with the environment. On one hand, this can be used to build customisable minimal cells for medical and industrial applications. On the other hand, it allows to test fundamental principles of life under controlled conditions, via building systems from scratch that implement specific biophysical functions, enabling the field to move from post-hoc analysis of systems found in nature towards true hypothesis testing. As an example, we present a computational and experimental pipeline to design and screen proteins to test different theories of large-scale membrane deformation.

BP 24.6 Wed 16:45 H 1028

Networks of heat-flow chambers to trigger prebiotic reactions — Thomas Matreux, Paula Aikkila, and •Christof Mast — Systems Biophysics, Center for Nanoscience, LMU, Geschwister-Scholl-Platz 1, 80539 Munich, Germany

Prebiotic chemistry must achieve high yields to kickstart life, despite the complex conditions prevailing on the early Earth. While this is achieved in the laboratory through purification procedures and clearly timed process steps, the question arises as to how prebiotic chemistry can be successful in a homogeneous primordial pond. We investigate the influence of heat flows through networks of thin rock fractures numerically and experimentally. The physical non-equilibrium establishes a wide variety of compound compositions in the different pore sections, enabling different prebiotic chemistry. We test this hypothesis using the example of TMP-triggered glycine dimerization as well as nucleoside phosphorylation taking place in experimental pore systems and find a strong enhancement of yield. Our results show that even the simplest boundary conditions - ubiquitous heat flows and simple rock cracks - can create ideal conditions for prebiotic chemistry.

BP 24.7 Wed 17:00 H 1028

Persistent Motion of Liposomes Driven by a Mechanochem-

ical Feedback Loop — •Tom Burkart[1], Meifang Fu[2,3], Petra Schwille[3], and Erwin Frey[1] — [1]Arnold Sommerfeld Center for Theoretical Physics (ASC) and Center for NanoScience (CeNS), LMU München, Munich, Germany — [2]MPI of Biochemistry, Martinsried, Germany — [3]Shenzhen Institute of Advanced Technology (SIAT), Shenzhen, China

Can a living cell be synthesized de novo, and can we reconstruct features such as cell motility in their biomimetic analogues? Cell motion involves multiple chemical and mechanical processes that are coupled via feedbacks spanning a large range of time and length scales. Reconstitution of cell-like motion therefore is an extremely challenging yet rewarding way for us to better understand this basic property of life. We accomplish motion of liposomes by realizing a mechanochemical feedback loop between the E. coli MinDE protein system and the liposomes, controlled by protein reactions and membrane adhesion. Self-organized chemical gradients of membrane-binding Min proteins induce deformations of liposomes into asymmetric shapes. This asymmetry yields mechanical force gradients resulting in directional liposome movement, which in turn reorganizes the protein pattern. In-silico reconstitution of the protein reaction-diffusion dynamics and the dynamic liposome geometry show that a simple mechanochemical feedback loop - consisting of protein pattern formation sensitive to membrane geometries and membrane adhesion sensitive to protein concentrations - is sufficient to induce persistent liposome motion.

BP 24.8 Wed 17:15 H 1028

Speeding up chemical reactions - Precursor vs Wet dry cycle — •Pranay Jaiswal, Ivar Haugerud, and Christoph Weber — Institute of Physics, University of Augsburg, Augsburg, Germany

The coexistence of liquid and solid phases allows for localisation of key molecules and compounds. Solid surfaces can act as a catalyst and can adsorb and concentrate organic molecules, increasing their local concentrations and enhancing interaction and the likelihood of chemical reactions. This concentration effect is particularly significant in dilute environments, such as early Earth's oceans, where it would have been challenging for complex organic compounds to form without the aid of solid surfaces. Solid phases provide a protective shield for organic molecules against harsh environmental conditions. This protection is vital for the preservation and stability of early organic matter, enabling the development of more intricate and functional molecules. In this work we developed a theoretical model of liquid solid phase coexistence that provide diverse chemical landscapes. Different phases offer distinct chemical conditions and reactivity. Furthermore, we introduced non-equilibrium conditions of precursor cycles in contrast to wet-dry cycles. These cycles speed up chemical processes and leads to a resonance behaviour in the cycle frequency that maximises the chemical turnover, creating selective environments.

BP 24.9 Wed 17:30 H 1028

Polyplex formation process investigated by coarse-grained molecular dynamics simulations — •Jonas Lehnen[1], Friederike Schmid[1], and Giovanni Settanni[2] — [1]Institute of Physics, JGU Mainz, Germany — [2]Faculty of Physics and Astronomy, Ruhr University Bochum, Germany

Messenger RNA vaccines have proven invaluable in the fight against the COVID-19 pandemic. Among the vehicles for non-viral gene delivery Polyethylenimine (PEI) has attracted attention due to its high transfection efficiency. PEI binds to negatively charged mRNA forming polyplexes. The size and characteristics of these nanoparticles (NP) depend on the pH used for their assembly as well as salt, PEI and RNA concentration. Small NP have been shown to be critical for high transfection efficiency. We use coarse-grained molecular dynamics simulations with explicit ions to examine the effects of the various factors determining polyplex size and gain a better understanding of the processes involved in their formation. In agreement with available experimental data, our simulations show how small NP sizes are obtained when mixing RNA with an amount of PEI largely exceeding the requirement for RNA neutralization. Further, we present insight on the importance to focus not only on stoichiometric ratios of RNA and PEI but also on the overall concentration. Finally we present a kinetic and a thermodynamic mechanism which can explain the experimental results, and could be leveraged to reliably produce small NPs, minimizing the amount of necessary PEI, which, in large doses, can be toxic.

BP 24.10 Wed 17:45 H 1028

Coupling polymerization with droplet condensation simplifies forming protocells — •Xi Chen, Jens-Uwe Sommer, and Tyler Harmon — Leibniz-Institut für Polymerforschung Dresden, Institut Theory der Polymere 01069 Dsden

Macromolecules are essential building blocks of life, but how these long chains could be first synthesized in prebiotic conditions remains a mystery due to two major issues: the conditions are too dilute for robust chemical reactions and polymerization is expected to produce only short chains. Two independent solutions have been proposed for these two problems: droplet compartments could concentrate molecules for chemical reactions; autocatalytic templated assembly could produce polymers with medium lengths. We propose that coupling polymerization and liquid-liquid phase separation much more robustly solves both problems than either one individually. We use effective droplet model to investigate a minimal system with autocatalytic polymerization of a single monomer type. Small molecules form condensed droplets when polymerized into medium chains. These droplets further function as a reaction center that could significantly enhance the degree of polymerization to generate longer chains than templating alone. Additionally, the compartment is stable to much lower dilute concentrations.