The Israel Society for Astrobiology and the Origin of Life

35th Annual Meeting, May 30th 2022 - The Hebrew U. of Jerusalem

Abstracts

Session 1: Origin of Life 9:00-11:30

09:20-10:00 – Keynote: Loren Williams (Georgia Tech) - RNA and Protein: Molecules in Mutualism

The origins of life on earth is a solvable problem, in part because biology recorded historical benchmarks within the ribosome. The ribosome is a remarkable document, a rich vein of information on biological universality and history. In analogy with tree growth rings or geological strata, the ribosome grew and froze and grew and froze and grew, recording around 4 billion years of biological history. The irrepressible ribosome continues to record even today, preserving current history, which will be interpretable billions of years in the future. We are developing methods to allow us to read the ribosome over ever more expansive timeframes, in ever increasing detail. We detect records of the genesis and diversification of RNA folding, protein folding, and RNA-protein mutualism and on specialized features in the human lineage. In this talk we will explain how we read the ribosome and we will recount part of its narrative.

10:00-10:15 – Nir Ben-Tal (TAU) -Protein archaeology: How proteins emerged and evolve?

10:15-10:30 – Tanaya Bose (WIS) - Glimpse into origin of life: From RNA to proteins

High-resolution structures of ribosomes from various prokaryotic and eukaryotic organisms, determined by us and elsewhere, indicated that peptide bonds are created in the peptidyl transferase center (PTC), a semi-symmetrical RNA-made pocket, located in the core of the otherwise asymmetric ribosome. The three-dimensional structure and the nucleotide sequence of this region are highly conserved among all domains of life, hinting at its prebiotic origin and implying that it is a remnant of a prebiotic entity. In addition to the findings that RNA can self replicate and possess

catalytic activities, these characteristics led to our “protoribosome” hypothesis. As a result of extensive studies, we recently provided an experimental proof of this concept via the successful peptide bonds formed using our in vitro synthesized constructs of such RNA pockets between relevant minimal substrates, detected using MALDI and MS techniques. Hence, it is conceivable that this entity, which existed in the RNA-dominated world, represents the origin of the ribosome, thus also the origin of life. Accordingly, as we suggested, the protoribosome is the missing link between the RNA-dominated world and the contemporary protein/nucleic acids life.

10:30-10:45 – Avshalom C. Elitzur (chapmanU) The Ski-Lift Pathway to Complexity: Thermodynamically Unique, Biologically Ubiquitous

We study the thermodynamics of biological complexity, beginning with a brief review of the relations between complexity and the more familiar notions of order and information. We then address the energetic cost of precisely re-arranging one high-entropy state into another. Surprisingly, the only practical way to do that is to decrease the state's entropy to minimum before the rearrangement to the next high-entropy state. This conclusion has some non-trivial bearings. Complexity is partly akin to entropy. Hence, the same counterintuitive zigzag holds for the pathway by which complex organic states are generated, maintained and transformed: First a state of excess order is created, and then (with the aid of information) degraded into the specific desired complex state. We prove this argument first intuitively, with a simple Lego model, and then mathematically, by computing the energy cost of the rearrangement's precision. On these we base our claim for ubiquity across biological domains, illustrated with some intriguing examples. We offer an estimate of the orders of magnitude where the Ski-Lift Pathway is superior to the straight transition between states.

10:45-11:00 – Itay Fayerverker and Tal Mor (Technion) - Emergence of the code - a model of three amino acids

The origin of translation and the molecules involved in the relevant evolutionary steps is still a mystery. Relying on ideas by Trifonov, de Duve, and our recent paper by Agmon Fayerverker and Mor, we give statistical evidence that three amino acids might be much older than all others, in terms of extreme conservation in specific current-day tRNA molecules and relevance to initial steps in the origin of life. These amino acids are Alanine (Ala) Glycine (Gly) and Aspartic Acid (Asp). For each of those, we find specific 9 nucleotides (in 14-mer strings) that are highly conserved, and that are closely related to the current genetic code. By speculating the relevant prebiotic aminoacylation (charging) process connecting the relevant amino acid to its tRNA, while relying on work by Shimizu and by Yarus, as well as a 2015 paper by van der Gulik and Speijer, we suggest that aminoacylation (charging) of relevant proto-tRNA is possible if enhanced by three very short peptides, GlyGly, AlaAsp, and AspGlyAsp. We finally present a minimal model for the emergence of the genetic code, in which in addition to aminoacylation, also non-enzymatic template replication (Szostak) and a non-motoric proto ribosome (Agmon Bashan and Yonath) are involved, while still relying on just those three amino acids and three peptides. We make use of the

terminology of autocatalytic sets of molecules, and we suggest that non-coded AlaAsp GlyGly and AspGlyAsp are gradually replaced by coded ones, via the most basic pre-biotic translation process, leading to some type of pre-life that we name “coded life”. This presents a potential stage in the evolution of a peptide-RNA world.

11:00-11:15 – Ayala Lampel (TAU) - Biomolecular Condensates Formed by Designer Minimalistic Peptides

Inspired by the role of intracellular liquid-liquid phase separation (LLPS) in formation of membraneless organelles, there is great interest in developing dynamic compartments formed by LLPS of intrinsically disordered proteins (IDPs) or short peptides. However, the molecular mechanisms underlying the formation of such biomolecular condensates have not been fully elucidated, rendering on-demand design of synthetic condensates with tailored physico-chemical functionalities and responsiveness to specific stimuli a significant challenge. To address this need we have designed a library of LLPS-promoting peptide building blocks composed of various assembly domains. We show that the LLPS propensity, dynamics, and encapsulation efficiency of compartments can be tuned by specific changes to the peptide composition at the single amino acids level, with Raman and NMR spectroscopy proving instrumental in determining the molecular contribution of each side chain to droplet formation. The resulting sequence-structure-function correlation is mandatory for future development of compartments for a variety of applications.

Session 2: Biochemistry 13:00-15:00

13:00-13:40 – Keynote: Itamar Willner (HUJI) - A Protoribosome and Prebiotic Nanotechnology

13:40-13:55 – Sergey Semenov (WIS) - Probing out-of-equilibrium conditions in prebiotic chemistry

13:55-14:10 – Moran Frenkel-Pinter (HUJI) – Chemical Evolution Reimagined

Some of the most interesting open questions about the origins of life and molecular sciences center on chemical evolution and the spontaneous generation of new complex and functional chemical species. The spectacular polymers that underlay biology demonstrate an untapped, by modern science, creative potential. We hypothesized that prebiotic chemical evolutionary processes leading to biopolymers were not idiosyncratic one-off events. We have developed an experimental platform that accomplishes chemical evolution in the laboratory. We have observed empirical outcomes, some of which were not foreseen. We have constructed experimental chemical systems that: (i) undergo continuous recursive change with transitions to new chemical spaces while not converging, (ii) demonstrate stringent chemical selection, during which combinatorial explosion is avoided, (iii) maintain synchronicity of molecular sub-populations, and (iv) harvest environmental energy that is invested in

chemical reactions. These results suggest that chemical evolution can be adapted to produce a broad array of molecules with novel structures and functions.

14:10-14:25 – Meital Reches (HUJI) - The amino acid DOPA in Peptides, Materials & Origin of Life

3,4-dihydroxyphenylalanine (DOPA) is a natural non-coded amino acid formed by post-translation modification. DOPA is abundant in marine mussel foot proteins and provides it with its adhesive properties. It can form different types of bonds with a solid surface including aromatic interactions, coordination and hydrogen bonds. We designed short peptides that contain DOPA to form functional coatings and materials with adhesive properties. DOPA functions in the marine environment under harsh conditions of high salt concentration, UV radiation and extreme temperatures. We, therefore, postulated that it might serve a role as a molecule in the prebiotic world. This lecture will present the function of DOPA as an adhesive in different materials and applications and its ability to catalyze chemical reactions.

14:25-14:40 – Norman Metanis (HUJI) - Functional “Ambidexterity” in an Ancient Nucleic Acid-Binding Protein

14:40-14:55 – Hava Sadihov-Hanoch (BGU), Nucleic-Acid-Peptide chimeras in the origin of life

Considering that modern living organisms utilize both nucleic acids and proteins and complexes formed by co-assembly of the two molecules. These biological systems, in which weak non-covalent interactions of simple building blocks form functional complex machinery, inspire the design of new self-assembling materials, based for example on nucleic acids and peptides. In our system, two short complementary DNA segments are attached to an amphiphilic peptide sequence previously investigated by our lab. We demonstrate the self-assembly of our system into several different topologies, fibers, and multi-lamellar spherical structures, and we present the co-assembly pathway leading from one type of aggregates to another. In addition, we find that when forming the onion-like structure, the conjugates exhibit conformational changes of DNA hybridization. We found evidence for coacervates formation through liquid liquid phase separation (LLPS) process induced by non-covalent interaction between the peptide and the complementary conjugates. A better understanding of the LLPS will help understand the self-assembly mechanism and chemical reactions. We believe that studying the new nucleic-acid-peptide conjugates may help us understand some characteristics of the earliest stages in biomolecular evolution.

Session 3: Astrobiology 15:30-17:15

15:30-15:50 – Amri Wandel (HUJI) - Copernican solution to the Fermi Paradox

A new solution to the Fermi Paradox is presented, building on the Copernican Principle: Earth is an average planet, one of billions in the Galaxy. We identify two

criteria that may distinguish Earth motivating alien visits. The biotic criterion - being one of the few nearest planets to the alien civilization, showing biosignatures, and the "technosignature-criterion" - Earth's technosignature, in particular artificial radio emissions (the "radiosphere"). We show that the probability that an alien civilization would be close enough is very low for each of these two criteria, unless civilizations are highly abundant (>millions in the Galaxy). Due to the expansion of the radiosphere the probability of the techno-criterion increases with time and approaches unity hundreds to thousands of years after the onset of radio emissions. Surprising new implications and constraints to the Drake equation are derived.

15:50-16:10 – Uri Malamud (Technion) - Are there any pristine comets? Constraints from pebble structure

We combine theoretical and empirical methods to show that if comets (or any small Solar system icy planetesimals) are composed of pebble piles, their internal radiogenic as well as geochemical heating results in novel evolutionary outcomes, which are significantly different compared to existing literature. We utilize a 1D thermo-physical evolution code, modified to include state-of-the-art empirical measurements of pebble thermal conductivity and compression, the latter obtained through a new dedicated laboratory experiment. Results indicate that due to the low pebble thermal conductivity, the peak temperatures attained inside comets during evolution are much higher than in any previous study given the same formation time. Only extremely small, sub-kilometer comets have the potential to retain the primordial, uniform and thermally unprocessed composition from which they formed. Comets with radii in excess of about 20 km are swept by rapid aqueous hydration reactions. Other sizes across this range result in the processing and differentiation of various volatiles, the degree of which correlates with the exact size and formation time. We discuss the importance of our findings for the formation, present-day attributes and future research of comets.

16:10-16:30 – Volker Perdelwitz (Ariel U) - Chromospheric Activity of Planet Host Stars

Chromospheric emission constitutes a major fraction of the stellar emission in the blue and near-UV range, especially for cool dwarfs and young stellar objects. In my presentation, I will introduce current techniques to determine the magnitude and variability of this emission, which plays a key role in our understanding of the habitability of exoplanets.

16:30-16:50 – Alona Vazan (OpenU) - Habitability of water-rich planets

Although water is necessary for life as we know it, a large fraction of water in planetary interiors may lead to unique conditions, under which the interior structure differs from the simple layered structure of a water ocean on top of a rocky surface, that supports life. We combined thermal evolution model with experimental data of ice-rock interaction at high pressure, and find that ice and rock are miscible in each other in wet planetary interiors. We find that when water-ice is abundant in planetary interiors the interior tends to stay mixed for billions of years, and differs from the simple layered structure that is essential for life as we know it.

16:50-17:10 – Inwoo Han (KASI, South Korea) - Planets of evolved giant stars: detection and habitability