**Israel Society for Astrobiology and the Study of the Origin of Life (ILASOL) 27th meeting**

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1. **How frequent is extraterrestrial biotic life?**

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The recent results of the Kepler mission have by now demonstrated that planets in general and Earth-sized planets in particular are quite common. These data allow to estimate the probability of extra-solar planets with conditions appropriate for the evolution of biological life as we know it. On this basis we present a quantitative estimate of how many biotic worlds can be expected to exist among the stars around us.

1. **The formation of Uranus and Neptune and intermediate-mass planets**

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Uranus and Neptune serve as calibrators for the rapidly growing number of extrasolar planets in a similar mass regime and they also contain valuable information on the origin of the Solar System. However, in contrast to their importance, little is known about these planets. The formation mechanism for icy planets is not fully understood, and the compositions and internal structures of the planets are also not well-constrained. Despite Uranus' similarity to Neptune, the two planets differ in their physical properties such as thermal emission, obliquity, inferred atmospheric enrichment, and possibly, their internal structures. Some of these differences might be related to different formation scenarios, and/or different evolution histories. In this talk I will present possible formation mechanisms and internal structures of Uranus and Neptune, and how the two could be linked. Open questions, future investigations, the connection to astrobiology, and implications for characterization of extrasolar planets with similar masses will be discussed.

1. **Could planets orbiting red dwarf stars support oxygenic photosynthesis and hence complex life?**

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Within the last 15 years, telescopes on Earth and in space have confirmed the existence of numerous extra-Solar-system planets. Most of them orbit Red Dwarf (RD) stars. Conditions on them appear at first sight to be unfavorable for life. The radiation flux of RDs is lower than that of our Sun, which puts their “Habitable Zones” (in which surface temperatures on orbiting planets allow for liquid water) very close to the Star. This would produce tidal locking and possibly highly erratic and harsh climates. The surface temperatures of RDs (~2,000-4,000oK) are lower than that of our Sun (5,800oK) which results in their EM radiation being shifted to the Near Infra-Red (NIR) wavelengths, longer than the Photosynthetically Active, 400-700nm, Radiation (PAR) required for the oxygenic photosynthesis of Earth plants, an essential prerequisite of complex life. However, recent research indicates that the environment on RD planets could support life. Despite tidal locking, wind speeds and climate fluctuations are calculated to be mild. Although peak radiation is within the NIR, part of the waveband would still be within the PAR range. Moreover, oxygenic photosynthesis has recently been found at wavelengths up to 740nm, where the quantum-photon energy is 1.77eV; still well above the 1.23eV required for splitting water.  The possibly low EMR on the star facing side is offset by the continuous illumination. This could provide sufficient energy for photosynthesis and growth. In brief: the estimated chance for the existence of extra-Solar-system life (always with the caveat “Life as we know it”) has risen dramatically in the last decade.

1. **Planetary evolution and biochemical adaptations: between contingency and determinism?**

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Comparative genomics provides important insights into some very early stages of biological evolution of the gene content of the last common ancestor (LCA or LUCA) indicate the existence of a set of highly conserved genes related to RNA metabolism, which is consistent with the hypothesis that extant living systems were preceded by an RNA/protein world. The crystal structure of the ribosome has revealed that it is a RNA enzyme that catalyzes peptide bond formation supporting the possibility that protein biosynthesis is the evolutionary outcome of an earlier RNA World stage. However, a major unsolved issue is the nature of the evolutionary processes that led to the selection of the L α-amino acids found in proteins from the large pool of prebiotic compounds. The ease of their formation in laboratory simulations suggest they were present in the primitive Earth, a possibility strongly supported by the chemical characterization of approximately 80 different amino acids in carbon-rich meteorites. The inventory of extraterrestrial amino acids includes not only the genetically-encoded valine, but also of isovaline and norvaline. Reports that down-shifts of free oxygen lead to high levels of intracellular accumulation of norvaline, which can be incorporated in proteins due to the misainoacylation of tRNALeu, demonstrates the biochemical and metabolic consequences of the development of a highly oxidizing environment. Accordingly, biochemical evolution can be understood against an axis representing geological time in which three major epochs can be defined: (a) an early stage of cell evolution during RNA played a much more conspicuous metabolic role; (b) an enzyme-dependent phase during which anaerobic biosynthetic pathways diversified and became established; and (c) a third stage during which the accumulation of free oxygen of cyanobacterial origin in the Precambrian atmosphere and its hazardous effects on microbial evolution became a powerful selection pressure that led first to the appearance of polyphyletic protection and repair mechanisms and in many cases, to the exploitation the properties of oxygen and the replacement of anaerobic pathways RNA or ribonucleotide components and derivatives, by more effective O2-dependent pathways.

1. **The mechanistic and evolutionary aspects of the 2’- and 3’-OH paradigm in biosynthetic machinery**

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The translation machinery underlies a multitude of biological processes within the cell. The design and implementation of the modern translation apparatus on even the simplest course of action is extremely complex, and involves different RNA and protein factors. According to the “RNA world” idea, the critical link in the translation machinery may be assigned to an adaptor tRNA molecule. Its exceptional functional and structural characteristics are of primary importance in understanding the evolutionary relationships among all these macromolecular components. The 2’-3’ hydroxyls of the tRNA A76 constitute chemical groups of critical functional importance, as they are implicated in almost all phases of protein biosynthesis. They contribute to: a) each step of the tRNA aminoacylation reaction catalyzed by aminoacyl-tRNA synthetases (aaRSs); b) the isomerase activity of EF-Tu, involving a mixture of the 2´(3´)- aminoacyl tRNA isomers as substrates, thereby producing the required combination of amino acid and tRNA; and c) peptide bond formation at the peptidyl transferase center (PTC) of the ribosome. We hypothesize that specific functions assigned to the 2’-3’ hydroxyls during peptide bond formation co-evolved, together with two modes of attack on the aminoacyl-adenylate carbonyl typical for two classes of aaRSs, and alongside the isomerase activity of EF-Tu. Protein components of the translational apparatus are universally recognized as being of ancient origin, possibly replacing RNA-based enzymes that may have existed before the last universal common ancestor (LUCA). We believe that a remnant of these processes is still imprinted on the organization of modern-day translation. Earlier publications indicate that it is possible to select ribozymes capable of attaching the aa-AMP moiety to RNA molecules. The scenario described herein would gain general acceptance, if a ribozyme able to activate the amino acid and transfer it onto the terminal ribose of the tRNA, would be found in any life form, or generated in vitro. Interestingly, recent studies have demonstrated the plausibility of using metals, likely abandoned under primordial conditions, as biomimetic catalysts of the aminoacylation reaction.

1. **Origin of chirality in proteins**

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In previous work we proposed that chemical evolution started with in a process similar to movement of molecules through a chromatograph. This is opposed to the conventional “soup” model which has these molecules falling into a body of water where they subsequently are expected to react.   We demonstrated how the “chromatograph” approach could lead to the synthesis of RNA with its  known pentose  sugar component. Subsequently we showed that the reaction leading to RNA synthesis can branch off to form polypeptides, the backbone of proteins, thus solving the “chicken and egg” problem of RNA and protein formation. We now point out that as a result of adsorption to certain features of a solid polar surface the polypeptide thus formed could react  to form proteins with complete l (or d) chirality. This complete chirality can also be formed from glycine condensation in similar circumstances.

1. **From structure to function: possible implications of β-sheet peptides to the origin of life**

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Peptides or proteins convert under various conditions from their soluble forms into highly ordered amyloid-like aggregates. The self-assembly processes of peptides have been intensively investigated during the past few years with special focus on amphiphilic sequences. In another research line, much effort was invested in the study of non-enzymatic molecular replication systems. There, the design of replicating peptides centered mainly on α-helix-forming sequences that self-assemble into coiled-coil tertiary structures.[1] However, it has been postulated that shorter peptides with simpler sequences may serve as templates for self-replication, provided that they are able to arrange themselves into unique and well defined structures. We show here that rather simple peptides, close analogs of the synthetic amphiphilic -(Phe-Glu)n- peptides, can form a variety of soluble β-sheet structures in water, part of which serve to significantly accelerate peptide ligation and self-replication.[2-3,5] We have investigated the structural hierarchy obtained by dynamic self-assembly of the peptides [Figure 1], revealing fast formation of β-plates, followed by fibers and then rearrangement into hollow nano-tubes at the later stages. In presence of electrophilic and nucleophilic fragments, these structures showed different rates of replication.[4] This study enables the expansion of the repertoire of families of replicating molecules. Also significant is the fact that the β-sheet replication is achieved using short peptides, possessing only alternating aromatic and charged amino acids. These systems demonstrate a stepwise mechanism that may have played a role in the origin of life, by which short peptides undergo self-assembly to form defined templates, which in turn become efficient replicators.

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Figure 1 : Schematic presentation of the β-sheet peptides template replication and its mechanism: dynamic self-assembly processes (*top*) and autocatalytic reaction (*bottom*).

1. **Prebiotic evolution of molecular assemblies: from molecules to ecology**

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The graded autocatalysis replication domain (GARD) model simulates compositional species of lipid assemblies (composomes) that replicate and evolve. We used GARD to examine relationships between molecular parameters and population ecology. Using the logistic equation, we show that molecular diversity augments the growth rate and diminishes the carrying capacity of composomes populations.

1. **How fast can life evolve?**

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Prevalent estimates for the likelihood of extraterrestrial life seem to take it for granted that the time needed for its emergence and evolution is of the scale known from Earth, i.e. some billion years. We challenge this implicit assumption. From the thermodynamic viewpoint, a biosphere’s entropy exchanges with the environment are time-dependent on three basic quantities: matter, energy and space. Should one or more of these be more abundant, the time factor can be by far shorter. In other words, on a planet of greater surface and/or with larger amounts of available chemicals and/or free energy, evolution may proceed orders of magnitude faster than on Earth. We study this possibility together with a new set of physical limitations and explore their main consequences.

1. **The role of experiments, preconceived ideas, and scientific authorities in early controversies about the origin of life and the creation of artificial life in the laboratory**

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For centuries the question of the origin of life had focused on the question of the spontaneous generation of life, at least primitive forms of life, from inanimate matter, an idea that had been promoted most prominently by Aristotle. The widespread belief in spontaneous generation, which had been adopted by the Church, too, was finally abandoned at the beginning of the 20th century, when the question of the origin of life became related to that of the artificial generation of life in the laboratory. This paper examines the role of scientific authorities, researchers’ basic beliefs, crucial experiments, and scientific advance in the controversies about the doctrine of spontaneous generation from the 17th to the 19th centuries, and it analyzes the subsequent debates about the synthesis of artificial life in the changing scientific contexts of the 19th and early 20th centuries.

1. **Significance of a nonlinear pattern formation approach to cell morphology and functionality**

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In 1952, Turing suggested that developmental processes in biology could be addressed by means of biochemical activator-inhibitor dynamics and specifically the corresponding diffusion driven instabilities. In the same year, Hodgkin and Huxley showed that propagation of the action potential in a squid axon could be explained in the framework of excitable media that is via solitary waves. These two seminal works paved significant directions in biological and medical research, highlighting dynamical systems and pattern formation methods, examples of which include signal propagation in neurons, angiogenesis, morphogenesis, cancer, and cardiac arrhythmia. Consequently, ever increasing advances in mathematical and numerical methods allow new vistas to biological systems. One of the examples that would be highlighted here is the role of nonlinear patterns in cellular protrusions, i.e. the world of filopodia. Filopodia is paramount to cell functionalities, examples of which include cell migration, neurite outgrowth, and wound healing (sensing). Therefore, understanding the filopodia properties is not only an important task but also a highly challenging intellectually due to their diverse spatiotemporal behaviors. In my talk I’ll focus on two topics, both approached by the pattern formation theory: (1) reaction-diffusion-elasticity approach towards understanding the key ingredients of Filopodia initiation and (2) reaction-diffusion-advection approach to self-organization of propagating myosins inside the filopodia.

1. **Global asymmetry of space and time – are they interrelated?**

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Deviation from perfect symmetry by reflection, termed dissymmetry or asymmetry, has been reported in the literature, primarily in assemblies of chiral molecules. It corresponds to a small preference for one type of symmetry over the other, which could be accounted for as being generated by the "parity violation" of the nuclear weak force. Calculations have shown that the interaction of the asymmetric field of this force with the asymmetric field of the electron cloud of a chiral molecule creates a miniscule difference in the ground-state energy between its isomers. It was proposed that this basic difference can be amplified to a detectable macroscopic difference when combined with autocatalytic processes in addition to interaction with a selective spin isomer of H2O (reviewed by Deamer et al, 2007). However, for most cases of detectable physical differences between chiral isomers, in particular in chiral fluids, this putative mechanism is far from providing a reasonable explanation for such a distinct chiral discrimination. In this lecture a series of new observations will be presented which support the possibility that the global space may have deviated a priori from absolute symmetry, a possibility which complies with observations in atoms, molecules and may be even implicated in the asymmetrical configuration of spiral galaxies. It was recently proposed (Shinitzky, 2013) that space asymmetry is actually a global feature which emerged at the Big-Bang and thus generated the basic laws of statistical thermodynamics in our universe. It might be further speculated that this accidental space asymmetry was essential for elimination of self annihilation which presumably occurs in abortive "symmetrical Big-Bangs". Space asymmetry can be conceptually presented as a hybrid of spaces of opposite symmetry which are unequal in mass and in addition attain their isolated features by adopting a 4th dimension which is a prerequisite for preventing collapse by racemization. Such a 4 dimensional space can be extrapolated to our 3D space, where a universal definition of "right" versus "left", with respect to the traditional definition on Earth, prevails. It corresponds to an absolute difference between the relative statistical weights of the "right" versus the "left" directions, when presented in classical 3D Euclidian coordinates or, analogously, to a difference between the clockwise and anti clockwise orientations in polar coordinates. Experimental verification of this assertion can be approached by comparative determinations of physical factors like density, heat of dilution or optical activity of homogeneous chiral systems, like chiral fluids or chiral solutions. Based on published data of measurements in such model systems, a difference in the range of 0.1 to 1% of physical parameters between chiral systems of opposite handedness, is expected. The 4th dimension of space, proposed above, may be termed as "the dimension of space asymmetry" and is analogous to time as the 4th dimension and may even overlap with it. This possibility may lead us to a somewhat bold assertion of far reaching implications that in our 3D realm time is a feature of space asymmetry. The implied asymmetry of time, thus suggests, an expected difference in the range of 0.1-1%, between the time-coordinate in right-handed versus left-handed matrices of chiral milieus. Experiments in this avenue are now being carried out in chiral fluids. Preliminary results will be presented.

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1. **Compositional assemblies behave similarly to quasispecies model**

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The quasispecies model describes the dynamics of self-replicating entities which replicate with relatively high mutation rate, such as RNA viruses and RNA-world models for the origin of life, both of which assume sequential information storage. Here, we used the graded autocatalysis replication domain (GARD) model to show how compositional molecular assemblies also follow the quasispecies model. GARD's composomes occupy the compositional space at different distances from master composome-type (compotype), and mutate towards and away from the master compotype at different rates. When these mutation rates are considered as part of the Eigen quasispecies equation, the dynamics and steady-state of composomes distribution around the master compotype are similar to those obtained from population dynamics of the GARD model. Thus, compotypes can indeed be considered as quasispecies, as was previously suggested.

1. **Life and information**

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