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Lecture „The molecular origins of life” – Winter semester 2016/17

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The goal of this lecture is to provide students with broad prospective on the phenomenon of life, particularly the preconditions and important aspects of its formation process – both on the early Earth, as well as, hypothetically, elsewhere in the Universe.

The introductory part of the course will delimit the subject by defining life and locating it in the cosmological perspective. The possible range of habitable environments for the known forms of life in the Universe will be discussed along with basic aspects of xenobiochemistry, which is how likely life based on elements other than carbon, or molecules significantly different from known biomolecules, could have potentially appeared and survived.

The core of this course will be dedicated to analyse molecular processes that currently seem most plausible for the formation of life. We will analyse chemical reactions relevant for abiotic synthesis of nucleotides, sugars, aminoacids, and lipids, as well as the propensity of these building blocks to assemble into oligonucleotides, proteins, or membranes in the prebiotic era on Earth. We will emphasize the aspects of supramolecular self-assembly, autoreplication, and chirality amplification, as the crucial chemical and physical processes for life development. Then, we will consider interactions among the molecular and functional components of life required for the formation of first functional protocells. Finally we will highlight meaningful molecular aspects in the formation of multicellular organisms and the enormous variety of living creatures that we experience on the contemporary Earth.

The course will be continued in the next semester. Then we will learn about current progress on the issue of synthetic life. We will review the most recent efforts and achievements in developing artificial systems that exhibit characteristics of life or mimic its important features. We will discuss plausible perspectives for constructing artificial cells and exploring evolutionary processes at the molecular and organismal level.

Topic 1

What is life? Where could it occur?

This lecture will address the following questions that define the contemporary astrobiology:

- What are the physical properties that allow Universe to support life?
- What makes Earth the proper place to develop and evolve life?
- Where else in the Universe, and in which form, might life have arisen? How to find and recognize it?

We will discuss:

- Understanding life on Earth as the single known example of life in the broadest context of the Universe.
- How to define life to include all living systems imaginable in the Universe and to exclude all non-living systems?

- How the Universe came into being and evolved? What aspects make it capable of harbouring life? What could have gone wrong?
- How came that Earth is a living planet, while the neighbours are not? Conditions for a planet to become and remain habitable, and to give rise to life.

Topic 2

The primordial soup

How building blocks of life could have formed from elements and simple starting materials available on Earth?

- Theoretical considerations of Oparin and Haldane. Simulations of atmospheric conditions on the early Earth.
- Terrestrial vs. extraterrestrial sources of life's building blocks – the Murchison's meteorite.
- Spontaneous formation of aminoacids: the Miller-Urey's experiment and its contemporary versions; Strecker-type of reactivity.
- The prebiotic synthesis of sugars: the formose reaction (Butlerov) and its modifications towards ribose; aldol-type reactivity.
- The prebiotic synthesis of lipids.
- Spontaneous formation of nucleobases: J. Oro and acidic condensation of ammonium cyanide and HCN – adenine, cytosine, uracil, problematic synthesis of guanine.
- Early attempts on abiotic formation of nucleosides
- Spontaneous formation of activated nucleosides – Sutherland's combined synthesis of sugars and nucleobases
- Prebiotic polymerization – plausible conditions for activation of aminoacids and nucleotides
- The origin of homochirality and autocatalytic reactions

Topic 3

Systems chemistry

- Information storage on genetic polymers
- Templated reactions and chemical networks
- Inheritance of the information – replication of genetic polymers under abiotic conditions

Topic 4

The spark of life

- Early discussions on spontaneous generation of life – Panspermia, works of Pasteur, Oparin
- "Metabolism first" – spontaneous self-assembly of complete metabolic chemistry networks, lipid aggregates, "the Lipid world"
- "Genes first" – templated reactions, self-replication, molecular evolution,
- "The RNA world" – RNA as the fundamental and central biopolymer: its view in the 1950-1970 as the information transporter, discovery of its catalytic properties (ribozymes), investigation of ribosomes, multiple regulatory roles in cells and organisms (siRNA), "molecular fossils" from the "RNA world" era.
- "RNA second" – was RNA the primordial genetic polymer? Or was it already a product of evolutionary processes? XNAs: TNA, LNA, PNA.

Topic 5

From molecules to cells

- Meet LUCA – the Last Universal Common Ancestor cooked in the pot of primordial soup. How did he look like?
- Combining together the elements: ribozymes, RNA aptamers and RNA-based metabolism
- Translating information into polypeptides – the genetic code
- Why DNA become the archival storage? Did it precede proteins?
- Enzyme-driven metabolic networks and lipid membranes
- Formation of protocells

Topic 6

The history of life on Earth

- The geological life timescale
- The first complex ecosystems
- The appearance of LUCA
- Photosynthesis, the advent of aerobic metabolism
- Eucaryotes, multicellular life – explosions and extinctions
- Extremophilic organisms – the limits of adaptation and its most important mechanisms
- Habitable worlds “out there” ...; space exploration programs