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Searching for an Exo-life in the Solar System

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Abstract How to define life? This very brief paper tries to bring some elements of answer to the question—essential for exobiology—with some chemical considerations.

Keywords Definition of life · Exobiology · Prebiotic chemistry · Replicating macromolecules

From Exobiology to the Origin of Life on Earth and the Definition of Life

Exobiology, the study of life in the universe, in particular the study of its origin(s), evolution and distribution in the whole universe, as well as the study of processes and structures related to life, is a very interdisciplinary field centered around the different aspects of LIFE. One the fundamental question of exobiology is how to define life. Indeed the quest for another life, one of the main goal of exobiology, implies to have available a definition of what is looked for. Similarly, the study of the origin of life on Earth, which is also part of exobiology, requires to be able to differentiate a non-living system from a living system, and to identify the level of chemical evolution at which a system is leaving the world of inanimate matter and can be considered as "living".

The question of the definition of life usually seems so obvious, that we are always surprised by the difficulty of the exercise when we try to answer the question. Identifying a living being is not always easy, even at the macroscopic level. Look at the ivy on the wall of a house. It seems immobile, as an inanimate object, far from the living world. Of course, if we change the time scale of observation and look at it for days, we will see that it moves slowly, which may be considered, as its very complex and regular structure, as a sign—but not an evidence—of life. And if we move from the macroscopic to the microscopic scale, then we see cells which move and duplicate: a strong indication of the presence of a living system.

Adapted from Raulin (2007).

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A Chemical Definition?

Much has already been said on how defining life and how difficult it is to answer the question. In fact, the definition of life given by a scientist is often directly linked to his own field. Life can be defined as the cell, for a cell biologist, as nucleic acid for a molecular biologist, as a system kept far from equilibrium by an energy flux for a thermodynamician. The prebiotic chemist Leslie Orgel (1975) called living systems CITROENS, not the name of the French car company, but as "Complex Information Transforming Reproducing Objects that Evolve by Natural Selection". Note that the scientists who are supposed to know the best the living systems, the biologists, usually do not try to give a definition of life: the 800 pages book "Le traité du vivant" by Jacques Ruffié (1982) does not include any.

The main difficulty of defining life lies in the absence of several elements in the set "Life". Indeed, so far we have only one example, one unit: the terrestrial life. Of course, there is an apparent wide diversity of life on Earth, and many differences between terrestrial living systems: at the macroscopic scale, in structure, morphology, appearance, but also in the processes involved: heterotrophic life, autotrophic life, oxygen producers, methanogens, etc… However, all living systems on Earth have common properties, at the macroscopic level and, first of all, at the molecular one. They are made of the same carbonaceous materials, built on the same molecular models, and use the same fundamental macromolecules, carriers of the genetic information (nucleic acids) and chemical and structural information (proteins).

Thus one approach which is often followed for defining life, is to list the common properties of all terrestrial living systems particularly those which seem more specific of the living world. I personally select three main properties from such an approach. The first is the level of complexity and the large quantity of information which is stored in a living system. The second is the property of replication, which can be done with changes, allowing the system to adapt to the constraints of its environment. And the third is this possibility of evolution, by natural selection, allowing the species to stay alive and to evolve, eventually with an increase of its complexity and level of stored information.

On the Earth, the set of these properties is specific of very complex chemical systems based on carbon chemistry and liquid water. They are the result of a long chemical evolution which preceded the biological one on Earth, about four billion years ago. A subtle chemical cooking, using carbon compounds, liquid water and energy, all present in the primitive environment of the Earth, yielding the first replicating macromolecules, and then the first living cell. All living forms present on Earth today have a common ancestor: "LUCA" the Last Common Universal Ancestor. But there was probably a pre-LUCA world, an RNA world, where RNA was playing simultaneously the roles of DNA and proteins. And before there was probably a pre-RNA world, with replicating macromolecules similar to present nucleic acids, but using simpler and more robust nucleotides. The later were the first living systems, a link between prebiotic chemistry and life. This chemical origin of life, could justify a chemical definition of life: life is a complex chemical system able to replicate and to evolve through a natural selection.

The Search for Life Elsewhere

The terrestrial scenario of the emergence of life and the resulting chemical definition of life can be used as a reference to search for life elsewhere. We may be too much limiting when looking for extraterrestrial life based on carbon chemistry and liquid water, but—at least—we know that life does exist with these ingredients, and we understand some of the processes which allowed life to emerge from chemical evolution and the associated planetary environmental conditions. We thus look for planetary bodies where liquid water and carbonaceous matter are or have been simultaneously present.

This is very likely the case of Venus and Mars, which were quite similar to the Earth more than three billion years ago. Since that time Venus has experienced a dramatic warming, due to a diverging greenhouse effect. The planet lost most of its water, and its surface is today too hot for living organisms and even for most organic compounds. If life arose on Venus, it has disappeared today, as well as its hypothetical traces. Mars also experienced paramount changes: it lost most of its atmosphere, and the surface liquid water bodies. However, a large fraction of Mars surface or close subsurface has not been renewed, and could still include traces of passed life. Moreover the present surface conditions are hostile but the subsurface may be habitable and may still house life. Life may also be present in the internal ocean of Europa, or even the deeper one of Titan, or in the internal liquid water reservoir of Enceladus. These hypothetical extraterrestrial lives are supposed to be based on carbon chemistry but may use organic replicative polymeric molecules different from those of present terrestrial life. Indeed, if life on Earth evolved from a pre-RNA world to an RNA world and the current DNA world, we may envisaged a similar prebiotic/primitive life evolution in these extraterrestrial environments, starting from an "Exo-pre-RNA world" which could even imply nucleotides different from the (still unknown) nucleotides of the Earth pre-RNA world. If life did not evolve as far as it did on Earth, and the extraterrestrial biological evolution did not passed this first level, we have to search for molecular traces of this Exo-pre-RNA chemical life on the potential extraterrestrial habitats.

Conversely, finding such traces, for instance on Mars, should provide essential information on the origin of life on Earth, by a comparative molecular biology approach. It should also help understanding the initial steps of biological evolution. And, with a second element in the set "Life", it should help us to define what is life.

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