Autopoiesis Concepts for Chemical Origins of Life and Synthetic Biology

Stenogram of the popular lecture on the foreign bibliographic seminar

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Abstract

The monograph (*Luisi P.L. "The Emergence of Life: From Chemical Origins to Synthetic Biology", 2010, Cambridge University Press, Cambridge, New York etc., 315 p.*) is a well-written, informative book providing a novel view on the interrelation between the abiogenesis as the natural origin of life and synthetic biology as the artificial synthesis of life. This concept is specially known as autopoiesis. As its name implies, it is a correlate of self-organization, but this word has quite a broad meaning in the literature. Consequently, some further restriction is required for this term in abiogenetic, as well as in "biogenetic" applications. There is, in fact, one basic reason for considering the abiogenetic problem in terms of self-organization theory. It follows from the extremely boundless complexity of biological systems.

Keywords: autopoiesis, autopoesis, chemical physics, synthetic biology, emergence of life, chemical origins of life.

1. Introduction

The monograph (*Luisi P.L. "The Emergence of Life: From Chemical Origins to Synthetic Biology", 2010, Cambridge University Press, Cambridge, New York etc., 315 p.*) is a well-written, informative book providing a novel view on the interrelation between the abiogenesis as the natural origin of life and synthetic biology as the artificial synthesis of life. This concept is specially known as autopoiesis. As its name implies, it is a correlate of self-organization, but this word has quite a broad meaning in the literature. Consequently, some further restriction is required for this term in abiogenetic, as well as in "biogenetic" applications. There is, in fact, one basic reason for considering the abiogenetic problem in terms of self-organization theory. It follows from the extremely boundless complexity of biological systems. The behavior of elementary biopolymers in cells is not less complicated, but it is well-known that, statistically, physicochemical steps leading to cooperative molecular network state are very complicated and stochastically improbable processes, requiring dozen billions years to achieve an appropriate adaptive coordination of molecular conformations and spatiotemporal synchronization of reaction pathways. Meanwhile, it is worth mentioning that the Earth age is 4.54 billion years (only!) on the 20-billion-year timeline of the Universe at best such. All this seems to convenience that life is almost impossible and,

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consequently, one may conclude that we do not exist at all. This is quite amusing, because the aforementioned strict result of positivistic scientific calculations, based on the rigorous statistical logic, leads us to absolutely undisguised solipsistic, subjective-idealistic and even immaterialistic conclusions! "This gives a contradiction, and the proof is complete" in terms of the predicate logic. It is hopeless to try to find a correct solution of the incorrect problem using an incomplete variance set. Another method uses various unverifiable and hardly relevant factors including hyperphysical and supernatural agents, such as eternal life transfer in multiple interconnected Universes and "directed panspermia" as a doctrine about the Earth life having been seeded by other civilizations. The above concept is almost identical with theological constructions about the intelligent design of life, based on dogmatic creationism, because this speculation way is also a satisfactory modus for the subjective overcoming of the time constraint problem in the ontology of life and its unexamined complexity.

The following simple reasoning may give us some insights into this question: there is a vitally important distinction between catalyzed and uncatalyzed processes. If we introduce a necessarily existing catalyst or an accelerant into the natural medium (e.g. the oxidation/reduction processes via an intermediary compound, known as energy carrier, or a physical factor by which the reaction rate constant may be shifted), we can avoid the inevitability of the statistically supernatural agents for "apologetics" of self-sustaining high organized life existence. There is enough experimental evidence for the fact that model "abiogenetic" processes take place in laboratory only under high-energy conditions or on the active surfaces of some mineral catalysts. That is plausible because abiogenesis is not the pre-Pasteurian "spontaneous generation" and, obviously, requires a special inducer for initiation and "energizing" of the following metabolic processes.

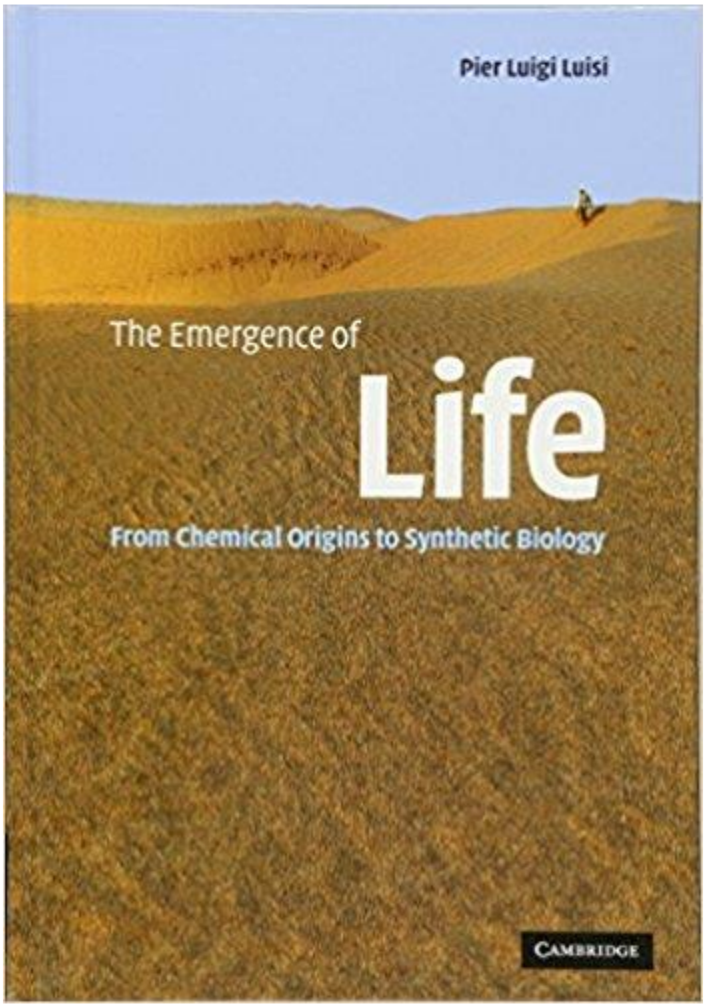

Fig. 1. 1-st edition (Luisi, 2010): Luisi P.L. "The Emergence of Life: From Chemical Origins to Synthetic Biology", 2010, Cambridge University Press, Cambridge, New York etc., 315 p. [ISBN-10: 0521821177 ISBN-13: 978-0521821179]

Most of our positions about abiogenesis come from experiments and, positively, unless there are experimental reasons for the contrary, it should be assumed that such processes simply do not occur without indispensable physical conditions. It seems reasonable to assume that those physical conditions may be interpreted as general inducers of abiogenesis. All such factors could produce unexpected effects on the abiogenetic process and they were also likely to take place within the ancient Earth or in cosmic conditions. The medium response to the effect depends on its sensitivity to the physical spectrum range used (that is known as spectral selectivity) or/and on selective recognition based on supramolecular chemistry principles, par excellence, complementary interactions as a form of early chemical specificity or selectivity of prebiological sensitive matter. Formally, the variety of such systems is endless, but we can see that most of laboratory abiogenesis simulations rely on and are based on the Earth conditions and the Earth organic life reconstruction. This limitation is of particular significance for synthetic biology and molecular biomimetics, because one is tempted to surmise that the Earth life is similar to all forms of life in the Universe and, consequently, search and simulation of the Earth life is based on the principles of the Earth life identification ("identical life of identical twins"). In fact, practically we do not really need any information about other possible forms of life, but it is not equivalent to its isomorphism to the organic life and to the statement, that other forms simply do not exist. In the before-mentioned widespread approaches to the abiogenesis modeling we shall meet another generalization of the same basic idea, because anyone can see, that this approach involves copying of substrate-dependent outward phenomena, but not the identification and imitation of the functional principles of biological processes. Indeed, it may not even be possible to imitate general life principles without general life function inducers! This is very strange, because the statements about impossibility of physical dynamics without an impulse and energy should look familiar to anyone who has studied physics in a high school, but the equivalent statement about biophysical dynamics initiation and, consequently, the need for an inducer of model dynamics in "artificial life" modeling and creation is not quite evident and generally accepted.

It is of great historical interest to trace the origins of this ridiculous situation. On the one hand, we can state that many authors make no difference between conservative and non-conservative self-organization mechanisms, but on the other hand, we can see that it is widely believed that forced induction of life processes is similar to "vis vitalis" or "entelechy" in archaic natural philosophy. This practice leads to a serious philosophical confusion, because similar scientists make the anti-idealistic, antivitalistic assumptions to avoid some undue associations, but these assumptions lead to mechanistic-idealistic conclusions, because they neglect a number of objective forces and factors without which any mechanism of abiogenesis becomes even more statistically incredible than it really is in practice. But this is not the way how it naturally happened, because specified inducers or "energizers" of the biological processes were not supernatural factors. Thus, it is unreasonable to expect any process to start without the objective inducers, but we also have no a priori reasons to expect that those processes were unearthly ones. Furthermore, it is therefore important to consider and understand the processes involved in geochemical and geophysical, astrochemical and astrophysical evolution before the general activation mechanism of the abiogenesis will completely emerge in our mind. But how can we understand this result without direct experiments on "environmental" (e.g. early Earth and cosmic conditions) reconstruction? And how good will be the simulation of the abiogenetic process without a full variance of this processes at the model scale that is incommensurable with the natural conditions? How should we then interpret the different scaling of the processes with unequal sets of probability samplings between the inducer-accelerated abiogenetic process and the inducer-free one? In order to keep our readers from misunderstanding, the following paragraphs outline the main methodological difficulties arising from modeling of the abiogenetic processes on our planet, but the arguments provided below can be equally applied to extraterrestrial forms of life, if any exist.

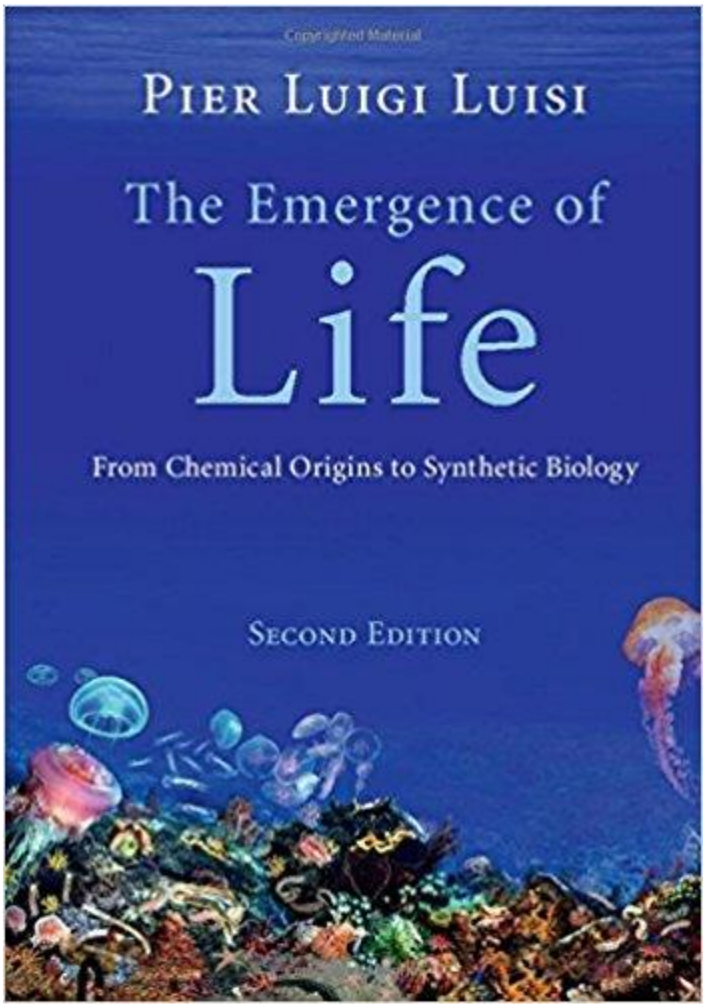

Fig. 2. 2-nd edition (Luisi, 2016) Luisi P.L. "The Emergence of Life: From Chemical Origins to Synthetic Biology", 2016, Cambridge University Press, Cambridge, New York etc., 478 p. [ISBN-10: 1107092396; ISBN-13: 978-1107092396]

The first methodological difficulty emerges as soon as we attempt to create artificial life as a model of the native product which is a result of a multimillion-year chemical evolutionary process, because there is no experimental foundation for extrapolation of "expressly-accelerated" abiogenetic principles on the natural evolution. The converse, though less trivial, is also true, as well as the fact that the forced aging of the photographic or polymeric material is not similar to the native aging of this material.

Nevertheless, the difference between the process rates does not exclude the equivalence of the process phenomenology at the atomic and molecular scale. This equivalence is based on the equivalence of physical mechanisms and laws for process accelerating in physicochemical kinetics. The scheme we will use is identical to that used for model reactor optimization: either we raise the temperature, or increase the particle collision rate, or even catalyze the process using chemical agents, the total result in the form of the reaction rate acceleration is expected to be the same. Yet it is not quite true to argue that those manipulations are fully equivalent - conversely, it is clear that the reaction pathways for different cases can be dissimilar. But that is exactly a qualitative difference between biological and non-biological process acceleration and, hence, a general discrepancy between biological and non-biological self-organization. In other words, the real difficulty lies in our insufficient knowledge about physical conditions of the early Earth or planetary reaction conditions, which determine a decision point for alternative selection of the accelerating way; and the main experimental imperfection arises from the statistical scale inconsistency of any artificial simulation tools with respect to the large-scale natural mechanisms of abiogenesis. This is the fundamental physical feature of any kind of geophysical, astrophysical and other similar trends of local laboratory modeling, because geophysical method applies thermobarogeochemical (or seismochemical) approach to the process acceleration and astrophysical simulation method is substantially based on particle swarms and Monte-Carlo statistical approaches - i.e. physical tools for acceleration of chemical evolutionary processes, including those ones at the protobiological state. Probably, the most known technique is that involving plasma physics, e.g. Urey-Miller experiment, but it is only a method for plasma-chemical synthesis of organic compounds with high molecular weights. However, this method presupposes a detailed knowledge of the early Earth atmosphere chemistry and the search of sugars, amino acids and other abundant bioorganic chemical constituents of life. However, this selective methodology neglects a number of concomitant chemical processes resulting in the synthesis of alternative compounds which are not characteristic of modern bioorganic chemistry. A serious disadvantage of this method is the impossibility to accidentally synthesize and analyze a series of alternative compounds and to define them irrespectively as new life indicators, based on the strictly experimental "abiogenetic" conditions. In other words, the above way of interpreting possesses no predictive value! Strictly speaking, however, such a decision is meaningless because there are several ways of providing the interpretation of accelerated life emergence, but all of them are not falsifiable (or refutable) and all of them do not satisfy the scientific objectivity status. This avoids the problem of the need to decide whether abiogenesis is possible or not in this particular model case. To date, a full comprehensive and self-consistent theory of abiogenesis does not exist due to the lack of completely satisfactory models of life; but the absence of such a completely satisfactory theoretical model of life results from the ignoring of the basic mechanisms of abiogenesis. In other world, "vicious circle is virtuous circle".

Fig. 3. Prof. Dr. Pier Luigi Luisi

A pedantic experimentalist might wonder whether the only method available to us so far is a total impact on the experimental medium leading to numerous substances with the subsequent digging there in search of single minor compounds, whereas much research has been concentrated on the search of specific marker biochemical molecules in a set of artifacts and various molecular-chemical noise. Serious complications in many laboratory measurements usually arise from the choice of the marker compound. It is obviously impossible to gain a comprehensive knowledge about the abiogenetic marker compound nature without a fundamental knowledge of the natural conditions during abiogenesis, since the bifurcation tree of molecular evolution can certainly follow a different path. This is not as simple as it may seem, since we can conclude, that the life chemistry character is a direct result of the geochemistry (or the "planetochemistry") of its abiogenetic conditions. Let us suppose, for example, that the Earth atmosphere was less reduced than one would expect at first, and thus the catalyzing clay mineralogenesis was distorted and shifted, the atmosphere chemistry was not good enough for the effective lighting propagation and the streamers of stratospheric discharges did not reach the near-earth area. In this case large-scale chemical processes of molecular evolution in this area would not resemble our life genesis background preconditions and precursors. And now let us consider a hypothetical experiment in which we can reconstruct the prehistoric world parameters mentioned here. We will then need a special argument to show that "another world is another life". The second experiment differs from the first one in several important ways. The first thing we can do is to change the composition of the atmosphere, and secondly we can substitute the material template for molecular precipitation and concentration including porous mineral intrusion for affine separation of the synthesized molecules based on the natural pseudo-chromatographic principles that are known to occur frequently under geochemical conditions. By a suitable choice of the solid phase of the mineral templates and the gas phase of the early atmosphere substituent it is possible to change the final "prebiotic" products (as it is known for industrial reactor design and optimization). Possibly, there is an important difference between "life as it is" and "life as it could be" and, consequently, between the abiogenesis modeling and the "strong Artificial Life" trend in "wet artificial life" modeling. In order to prove this result using combinatorial chemistry principles we should first calculate the probabilistic parameter for the desired product prevalence and also the statistical distribution of the other molecular structures. In many cases this will become obvious from physicochemical, e.g. spectral, investigation of our experimental result material. We turn our attention next to proving that spatiotemporal physicochemical kinetics and structural supramolecular properties of some active compounds similar to their biochemical prototypes also give evidence for replication and molecular evolutionary selection, but no prior knowledge of the chemical perquisites and the initial parameters is required. This experiment may seem artificial, but it clearly illustrates that the basic interpretation of the Urey-Miller experiments is opened to some criticism and the various results of this experiments can be appropriately interpreted in other hands. We would like to look at this result here from a slightly different point of view and, clearly, we aim to search for the better experimental principles and interpretation approaches to this controversial issue.

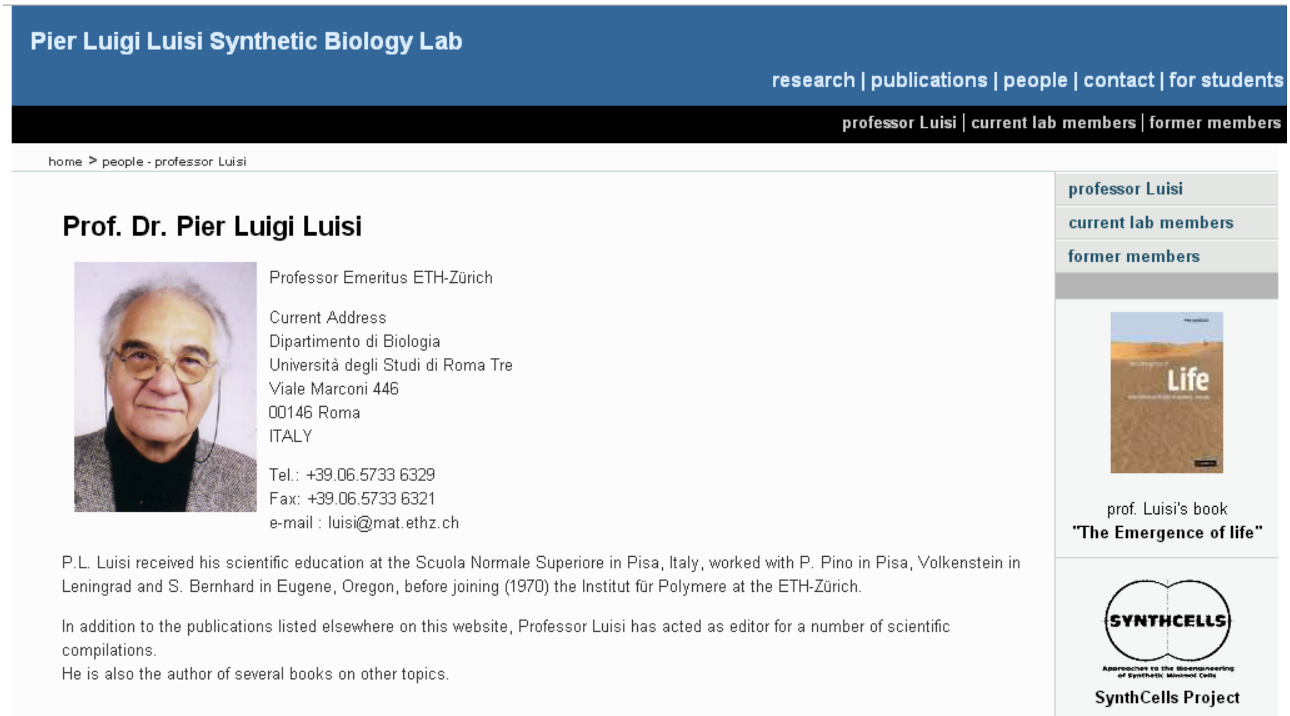

Fig. 4. Web-page of the Pier Luigi Luisi Synthetic Biology Lab (http://www.plluisi.org/luisi.html)

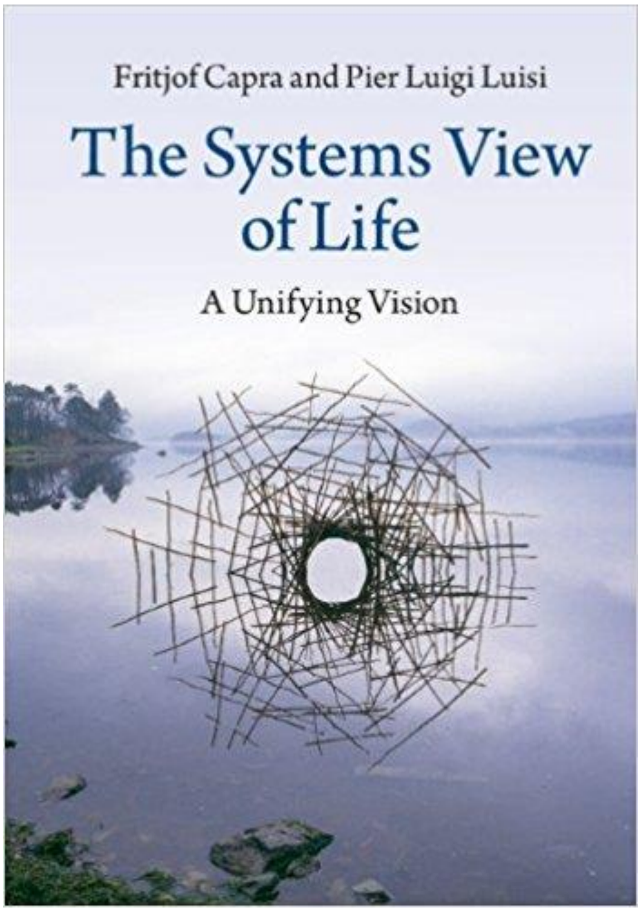

Fig. 5. "The Systems View of Life". Novel book in frame of the autopietic concepts

The question under consideration is also extremely fundamental for the emergence of biological organization principles if we consider the mechanisms more carefully. The classical Urey-Miller experiment discussed above is a special case of the generalized principle of the molecular life elements generation. This is why we were also able to obtain other "elements", but all such components can effect the origin of life only if they are sterically compatible, i.e. capable of providing chemical protocell organization. Nevertheless, the problem of prebiological supramolecular system complexation (which is directly interdeducible from the first "bichemical networking" problem) has not yet been solved satisfactorily. Here we present a necessary and sufficient condition for spatiotemporal complexation origin of biochemical structure dynamics and system reaction pathways. This will provide us the required characterization of cellular life unit formation principle which has not yet been discussed in the well-known standard variations of the abiogenetic experiments, since classical scholars considered only the proposed possible pathways, but did not examine the possibility of existing of the spatiotemporal reaction pathways which make them systematic. This is in fact a more complicated problem than the usual determination of molecular indicators of life in the "primordial soup" models, but the remarkable fact is that these necessary conditions are also sufficient for life! If we consider the real cellular life as a structural-heterogeneous multiphase dynamic system, we can see that the model life is impossible without compartmentalization and also without a "mover" of interfacial dynamics that should be synchronized in space and time. For this case, the only way is to synchronize its spatiotemporal dynamics in cooperative activity on the first stage of its mutual coexistence. From this analysis we should expect that the abiogenesis inducer should be the iducer not only of the simple chemical synthesis, but also of the metabolism initiation, interfacial compartmentalization and energy supply for these endergonic processes, for its coupled self-sustaining spatiotemporal dynamics. This follows at once from our physical considerations.

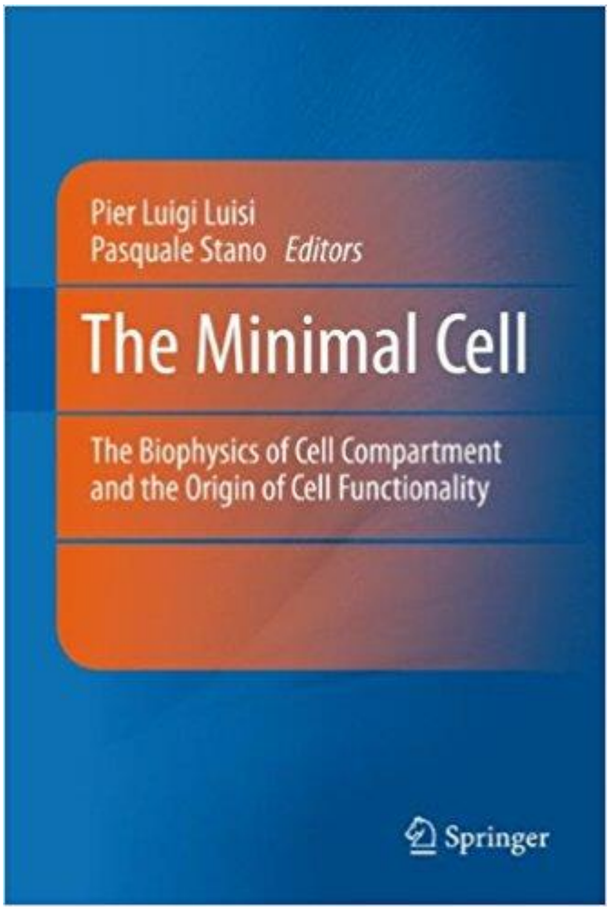

Fig. 6. The Minimal Cell: The Biophysics of Cell Compartment and the Origin of Cell Functionality, 2010 (Ed. by P.L. Luisi, P. Stano). One more book in frame autopoietic concept of abiogenesis, synthetic cell modeling and cellular morphogenesis (compartmentalization)

The "if" part is rather easy (no one objects if we say about the possibility, but not about the principal law), but the "only if" part is more difficult, because at the obsolete state of our knowledge, it is inevitable that in more complicated systems (than single atoms in classical quantum mechanics), it is necessary to take into account the existence of unexpected medium effects. Until the early 2000-s it was a common belief that we can synthesize protocell models using only structural (e.g. emulsification, inverse liposomal units, ultrasound processing) or only chemical (e.g. mineral templating or molecular imprinting, abiosynthesis or Urey-Miller experiments etc.) factors without their combining and complexation via energy sources. As a result, most of the workers in this field were about to consider abiogenesis as an equilibrium process and believed that metabolic reactions in protocell models could be initiated without any nonlinear dynamic mechanisms, i.e. only based on equilibrium chemical exchange principles. Well! But this practice leads to serious confusions, because the model system in this case tends to return to its thermodynamically stationary form; and it becomes tempting to assume that the abiogenetic process is actually an unrepeated, unknowable and wonderful (hyperphysical) phenomenon. However, it seemed inconceivable to the 19th-20th century biologists that such an evolutionary agnosticism is not quite good. The simplest way to overcome this difficulty is to conclude, that life is infinite in the Universe and might have had an extraterrestrial nature. The ideas involved in this speculations are so simple that seem not to require any proofs. This unfalsifiable idea is both self-contained and attractive, but its self-sufficiency is equal to the internal logic of the myth, because it is not thermodynamically deducible (since it appeals to transphysical infinity, that is not better, than spiritual eternity or immortality of life) as the statement about the possibility of the abiogenesis without an external inducer, which is also thermodynamically groundless (rejected by this methodological contrivance).

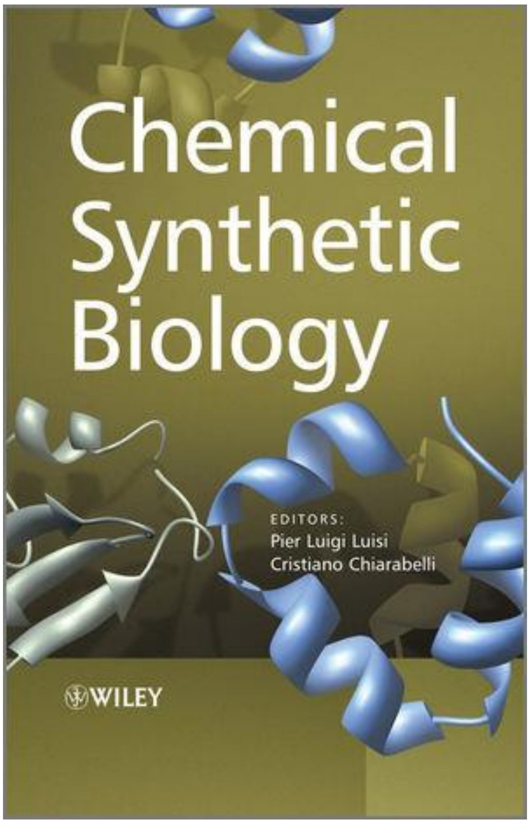

Fig. 7. "Chemical Synthetic Biology" (Ed. by P.L. Luisi, C. Chiarbeli). From the Back Cover (Chemical Synthetic Biology): "... chemical synthetic biology is concerned with the synthesis of new biological macromolecular structures (proteins and nucleic acids) and minimal life forms (semi-synthetic minimal cells) not found in nature, and - in contrast to other aspects of synthetic biology - without the use of genetic manipulation". (Chemical Synthetic Biology, 2011)

This becomes plausible from P.L. Luisi cosiderations, because his book, particularly, takes the reader through the transition from inanimate matter to life, i.e. from prebiotic chemistry to synthetic biology making the reader to believe into the concept named "autopoesis", which leads to the idea of compartments, discussed with an emphasis on vesicles and other highly orderly aggregates. Reading of his monograph suggests the difference between "models for cells" and "model of cells", because a true abiogenetic model should demonstrate the spontaneous increase in complexity from inanimate matter to the first cellular life forms, that makes possible the generation of the minimal cellular life within the laboratory.

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