Abiogenesis as a theoretical challenge: chance and directionality through the lens of scientific realism

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Abstract

In this paper I intend to reflect on the intellectual rationale underlying the origin of life scientific research field by reconsidering some of its conceptual premises and difficulties.

Keywords:
Origin of life, scientific realism, chance, prebiotic evolution.

1. Introduction

Life is one (between many other) way in which the matter of the universe is organized. The scientific study of the origin of life (henceforth OoL) assumes that life emerged through a combination of deterministic laws and particular boundary conditions of the Earth. Addressing the OoL question means to uncover the historical evolutionary processes, the chemical pathway that goes from simple elements to more and more complex molecular structure and chemical nectworks up up to the common ancestor. Despite a century of speculation and a half-century of active experimentation, there is no consensus on a coherent sequence of events and some sub-topics, paradoxes and enigmas (about chirality, self-replication, cellularity, genetic code and so forth) are a perennial source of debate. Many good reviews have been written on this subject and I invite the interested reader to refer to them [1, 2, 3, 4, 5, 6, 7, 8]. The aim of this brief paper is to critically reconsider some theoretical assumptions. If we assume that life originated *de novo* on the Earth, it is the result of a series of geo-physical-chemical process. I argue

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that a rational framework for OoL field should be located in the philosopical reflection of the status of *earth sciences*. Further, here I contend that reframing the OoL field in the ligh of a *scientific realist* stance will help to clarify some recurring issues and enduring misunderstanding of the research field.

2. Setting the problem

I will start my discussion with a definition:

Definition 1. *the term abiogenesis refers to the sequence of steps that started from monomeric building blocks to more and more complex molecular structure and chemical networks that eventually aggregated into Earth's first cells.*

It has been stated many times and in different forms that for prebiotic evolution to be accepted as a scientific endeavor must adhere to the following *continuity* assumption [9, 10, 11]:

Assumption 1. *Abiogenesis has been a continuous process.*

Of course this is not the only position, others are also present in the literature [9]. On the other extreme we see the "fantastic luck" hypothesis i.e. life appeared abruptly by chance. Here I will consider assumption 1 as a starting point for the following discussion. What differentiates the living from the nonliving is a perennial source of debate. Szostak recently affirmed that discussions about if and how we can draw a line that separates life from non-life are useless [12]. He motivates this using an *assumption 1* argument i.e the existence of a continuum between inanimate and living state of matter. For Iris Fry continuity it is equivalent to say that there is no unbridgeable gap between inorganic matter and living systems, plus the corollary that the emergence of life is *considered a highly probable event* [13]. This is related to the problem of how the minimal complexity required for a chemical system to start on the path of Darwinian evolution has been achieved. The continuity thesis from one side, and a trend towards an increasing complexity on the other, seems to require the existence of a constant driving force behind abiogenesis for two distinct reasons: a) to counterbalance destructive tendencies like hydrolysis in the evolving chemical structures and b) reduce the role played by chance to a minimum acceptable for a scientific discourse.

But is this search of a "driving force of life" meaningful? Old and new attempts to locate a prebiotic driving force in different mechanisms have been proposed, in what follows a brief description of them:

- extending Darwinian arguments to the molecular level. Recently it has been advocated in [14] but is an idea that, in different forms, more or less explicitly, commonly pops up in OoL literature (see also [14]). It has been advocated that the rise of Darwinian evolution represents the very property able to discern between life and non-life [15].

- Invoking far-from-equilibrium thermodynamics principles behind the self-organization of life. Recently, for example, variations of the theme about *maximum entropy production principle* (MEPP) has been suggested [16, 17, 18, 19]. According to the MEPP approach, thermodynamic processes far from thermodynamic equilibrium evolve to steady states at which they dissipate energy and produce entropy at the maximum possible rate. Life is a very efficient *entropy producer*, so, according to this line of reasoning, it is not at all true that laws of thermodynamics play against the evolution of life complexity but quite the opposite, they favor it! The use MEPP in explanations raised a lot of controversies and failed to convince the scientific community so far (For a critical revision of alleged maximum entropy principles in chemistry see [20]).

- Some authors try to locate the origin of life as just one step in the wider historical path of cosmic evolution. For example Eric Chaisson elaborated a general theoretical rationale where the appearance of life responds to a more general logic about the increasing complexity of the whole universe [21]. Some authors include also cultural and social complexity into the big picture [22].

This line of reasoning is in my opinion flawed. The historical path that goes from the end of the late bombardment to first prokaryotes covers around 300 million years and went through a plethora of paradoxes and enigmas about chirality, self-replication, cellularity, genetic code and so forth. Recently a "global reactor theory" of abiogenesis has been proposed [23]. Summarizing a large amount of empirical evidences, the authors stress how environmental complexity was a necessary requirement in abiogenesis. A wide range of environmental conditions (seas, alkaline streams, volcanoes, meteors, and so on) must have been involved in the origin of life, each favouring the production of a specific relevant compounds. Circulation processes at different scales allowed important building blocks like amino acids, nucleotides,

lipids and carbohydrates, to mix each other. Matter and energy fluxes assume the form of cycles (*Morowitz theorem* [24]) that can evolve to self-sustaining auto-catalytic systems. These can be characterized as autopoietic dissipative structure with different stability. Thus the way the Hadean Earth gave birth to life has to be understood as the result of complex geophysical and geochemical phenomena at a variety of local and global scale. Different causal mechanism operated at different time and in different location and this makes any attempts of *reductio ad unum* (where one single overarching causal mechanism plays a role of driving force that led to life) unsustainable. I summarize my arguments in the following:

Proposition 2. *Abiogenesis is the product of the interaction of multiple environments where at different times different causal mechanism operated in concert. Further, some sudden "catastrophic" events introduced irreversibility and channeled the evolutionary path that led to life in a fundamental way.*

3. The importance of a solid philosophical foundation

As it has been stressed, life (at least for its early stages) was the product of the geology and geochemistry of the Hadean and the problem of its origin it has to be addressed with the same conceptual tool that we use to give a sense to geological and environmental facts. The most common accepted intellectual and philosophical rationale for the the geo-sciences is *scientific realism* [25]. A realist stance put emphases on: (a) a search for underlying *causal mechanisms*: the underlying cause of observed events to explain their emergence. (b) the role of emergence in complex open systems; and (c) emphasis on the role played by contingent features of the settings in which natural process occur. Realism asserts that cause and effect are contingent on conditions of the local context. In other words, in one situation, "A" may lead to "B" but in another situation, "A" may lead to "C". A classic example is gunpowder: it has the (necessary) causal power to detonate due to its chemical structure, yet whether it does so depend on contingent circumstances: the presence of oxygen, the amount of powder, ambient temperature and so on. Although objects possess causal powers (like the property to detonate) necessarily by virtue of their internal constitution, it is contingent to the local context whether they are activated or not. Their effects depend on the presence of certain contingently related conditions ([26], p. 124; see also [27]).

As an example, I will picture here Darwinian evolution arguments through the lens of realism. The complexity of life forms that we observe in nature (empirical) can be explained through the understanding of a mechanism something situated at a deeper level: natural selection (plus some others). Those mechanism acted on specific environmental context to give rise to specific configurations of structures and patterns. A probabilistic component (in the sense of genetic random mutations that are irrespective of organism needs) enters in the Darwinian evolution pictures as a key ingredient since it is connected to the ability of life to generate genetic variability on which selection will operate through a non-random process [1]. With abuse of language we can say that the success of life in resisting on this planet for billions of years is also relate to its ability of internalize, manage and even turn to its advantage unavoidable random factors. But there is no predetermined path. For example it has been recognized that the existence of an "arrow of complexity" in biological evolution has to be understood in a "passive" sense: natural selection is not an a priori pressure to complexity but it will push in that direction to the extent that it provides selective advantages [28]. Complexity here looks like a global by-product of the evolutionary mechanism (for different opinions on this matter, see [29]).

Abiogenesis may be modeled as a sequence of so-called "emergent" properties, each of which represent a new stratum of complexity with its own set of causal mechanisms. Thermodynamic imperatives played an important role throughout abiogenesis in limiting and directing flows, transduction and storing of energy. When self-replicating entities entered the scene, a primordial principle of chemical selection boosted and constrained the evolutionary path in a dramatic way. The evolutionary step followed by the compartmentalization through lipidic membranes represent another "catastrophic" event in the film of evolution with its own causal powers. Many other example can be made. So we can expect that different causal mechanism operated at different time and in different location and this makes any attempts of *reduction ad unum* (where one single causal mechanism plays a role of driving force that led to life) unsustainable. I will introduce a provocative image (albeit obviously forced) to clarify my position. To ask "what is the origin of life" can be compared to ask "what is the origin of rivers". In this latter case the endeavor is to understand which and how some geological processes from inside and outside the Earth, operating at different scales and times (cycles of water and rock, tectonics, erosion, climate, landslides, meteoric impacts and so on) eventually get coupled to produce the *natural entity* that we now

call a river. Does it make sens to talk about a *driving force* of rivers? It is interesting to stress that a boundary between the system of interest (the river) and an external environment through this historical evolution is to some extent arbitrary and a matter on convention. *At the beginning there were only environment*. I think that exploring an ontology that embrace this *no-bounday hypothesis* or *radical openess* (the idea that there are no natural systems except in the eyes of an observer who needs to draw artificial boundaries around phenomena to generate feasible models [30, 31]) at least for the initial steps of abiogenesis can be rewarding for the OoL field. Before the probiotic entities acquired the ability to adapt "Darwinianly", they where inevitably at the mercy of the local surrounding for their stability, survival and eventually evolution. During this stage a clear separation betweeen entities and environment loses its sense.

Summarizing the discussion above, based on theoretical speculation and empirical facts (as far as we know), I think is not reasonable to imagine the presence of a singular dominant driving force guiding the OoL process. About the continuity assumption, I agree with Popa [32] that is more correct to talk about a *punctuated gradualism*. Catastrophic events (of small as well as large magnitude) are part of Earth's geologic history and it's likely to expect that they affected the path to life.

4. Some final remarks

In a totally deterministic universe everything has been decided at the instant $t = 0$. On the other hand if we accept that chance plays an irreducible role (as it seems to happen in the realm of quantum mechanics), this leaves open the possibility of the *unexpected*: different paths of evolution are possible and "miracles" too. If the fate of the universe is predetermined or not is a metaphysical, not a scientific endeavor. Saying that life started "by chance" is, in a scientific mind-frame, meaningless. When we say that the coin has 0.5 probability to land on Head this does not mean that we cannot know the causes of this outcome or that there are no causes that generated it but that *we are not interested in exactly dermine them*. As explained before in the discussion about realism, any event is a combination of (usually many) causal mechanisms and particular local conditions. OoL research aims in understanding both: the (many different) causal mechanisms involved coupled with the (many different) historical boundary conditions. One critical difficulty is related to the poor knowledge about the actual conditions of the

primitive environment and lack of paleontological and molecular relics [33]. The main challenge and limitation of computer simulation and laboratory experiments lies exactly here: the setting of initial parameters run the risk of being regarded arbitrary or highly speculative [34]. How special were the condition of the Hadean Earth is hard to say but the "global reactor" picture of abiogenesis, where many location got intermixed in the production of life, gives the impression that the one we inhabit looks really a singular place in the universe.

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