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La vida en Marte: ¿Qué puede decirnos el uso de biofirmas sobre nuestra comprensión del proceso de la vida?

Sávio Torres de Farias[1,2]
[1]Laboratório de Genética Evolutiva Paulo Leminski, Centro de Ciências Exatas e da Natureza, Universidade Federal da Paraíba. João Pessoa, Paraíba, Brazil.
[2]Network of Researchers on the Chemical Evolution of Life (NoRCEL), Leeds LS7 3RB, UK.
Email: stfarias@yahoo.com.br
https://orcid.org/0000-0002-2997-3629

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Resumen

La astrobiología es uno de los campos científicos de más rápida expansión en la actualidad. Entre los diversos problemas a los que se enfrenta esta área del conocimiento, la búsqueda de vida fuera de nuestro planeta resulta especialmente desafiante. Cuando se trata de identificar vida más allá de nuestro planeta, uno de los desafíos más difíciles es el uso de firmas biológicas. Las biofirmas pueden verse como cualquier molécula o proceso, que proviene de la actividad biológica y puede indicar la existencia de vida en algún momento, en el presente o en el pasado, en cada ambiente. La identificación de biofirmas que puedan distinguir claramente entre evidencia de vida o simplemente un artefacto producido por otros procesos naturales representa un desafío práctico y teórico para la astrobiología. Dada la complejidad de esta discusión, es necesario abordar varios puntos, las posibles reacciones químicas dadas las condiciones locales del medio a estudiar, la universalidad del fenómeno de la vida tal como la conocemos en nuestro planeta, lo que entendemos como esencia del fenómeno de la vida, entre otros. La elección de biofirmas que puedan revelar señales de vida debe cumplir con varios criterios que buscan eliminar o minimizar la posibilidad de falsos positivos. Aquí espero discutir las implicaciones del uso de biofirmas considerando los avances recientes en la química prebiótica, así como nuevos marcos conceptuales para el fenómeno de la vida y sus implicaciones para el desarrollo de biofirmas de una manera no tipológica, lo que podría abrir un nuevo camino. para descubrir vida estructuralmente distinta de la que conocemos, y también permitirá una mejor comprensión de la vida tal como la conocemos en nuestro planeta.

Palabras clave: Biofirmas, concepto de vida, química prebiótica.

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SCIENCE OUTREACH ARTICLE

Life on Mars: What can the use of biosignatures tell us about our comprehension of life process?

Sávio Torres de Farias[1,2]
[1]Laboratório de Genética Evolutiva Paulo Leminski, Centro de Ciências Exatas e da Natureza, Universidade Federal da Paraíba. João Pessoa, Paraíba, Brazil.
[2]Network of Researchers on the Chemical Evolution of Life (NoRCEL), Leeds LS7 3RB, UK.
Email: stfarias@yahoo.com.br
https://orcid.org/0000-0002-2997-3629

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Abstract

Astrobiology is one of the fastest expanding scientific fields today. Among the various issues that this area of knowledge faces, the search for life outside our planet proves to be especially challenging. When it comes to identifying life beyond our planet, one of the most difficult challenges is the use of biosignatures. Biosignatures can be seen as any molecule or process, that comes from biological activity and can indicate the existence of life at some point, in the present or past, in each environment. The identification of biosignatures that can clearly distinguish between evidence of life or just an artifact produced by other natural processes represents a practical and theoretical challenge for astrobiology. Given the complexity of this discussion, several points must be addressed, the possible chemical reactions given the local conditions of the environment to be studied, the universality of the phenomenon of life as we know it on our planet, what we understand as the essence of the phenomenon of life, among others. The choice of biosignatures that may reveal signs of life must comply with several criteria that seek to eliminate or minimize the possibility of false positives. Here, I hope to discuss the implications of using biosignatures considering recent advances in prebiotic chemistry, as well as new conceptual frameworks for the phenomenon of life and its implications for the development of biosignatures in a non-typological way, which could open a new way to discover life structurally distinct from what we know, as well as will enable a better understanding of life as we know it on our planet.

Keywords: Biosignatures, Life concept, prebiotic chemistry

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Introduction

In 1971, two years after the first man stepped foot on the moon, English singer David Bowie released his fourth album, Hunky Dory, which included the song ”Life on Mars?” According to Bowie, the lyrics of this song were ”a sensitive reaction of a young girl to the media”. The question expressed in the song’s title accurately represents society’s perception of advances in space research at the time. This song recently celebrated its 50th anniversary, and the iconic question has remained in society’s imagination while also becoming a fertile field of scientific investigation. Astrobiology is a large scientific field whose scope includes the search for life beyond our planet as well as the relationship of life with the universe. Astrobiology is one of the fastest-growing scientific fields today. One of the primary reasons for this rapid expansion is the multidisciplinary nature of this area, which brings together physics, chemistry, biology, philosophy, and other fields of knowledge in a collaborative effort. Reflections on the diversity of astrobiology-related areas reveal an infinite number of issues that have been addressed from the most diverse perspectives to better understand what characterizes and supports life on our planet, and based on this understanding, we seek evidence or elements that can support life in other environments outside our planet (Blumberg, 2011). One of the major topics of debate in astrobiology is the search for biosignatures that can be used to indicate the possibility of extraterrestrial life (Westall and Cockell, 2016, Walker et al., 2018, Catling et al., 2018, Schwieterman et al., 2018, Marshall et al., 2021, Green et al., 2021). Biosignatures can be seen as any molecule or process, that comes from biological activity and can indicate the existence of life at some point, in the present or past, in each environment. Advances in space observation and exploration technologies have allowed open new horizons in the search for life outside our planet.

The possibility of carrying out studies that reveal the composition of a given planet has been heating up theoretical discussions about how we can differentiate, on these planets, compounds originating from purely chemical processes from those that can be generated by biological activity. At the heart of this discussion is the search for biosignatures that are universally produced by biological activity. Clearly this is not a simple activity, since compounds produced on our planet by biological activity can often be produced on other planets, under other conditions, as part of permitted or possible chemical reactions (Fujii et al. 2018, Schwieterman et al., 2018, Catling et al., 2018, Meadows et al., 2018, Martins 2020) Clearly, the search for good biosignatures has a background in life as we know it on Earth, and we cannot escape the constraints involved in solving this problem. In this regard, many of the biosignatures that are discussed and used today are the result of metabolic pathways found in specific groups of organisms. I must emphasize that the observations I punctuated are not only in the sense that we may not be observing life forms based on different organizations and structures using terrestrial biosignatures, but also the implications of finding signs of life using the biosignatures observed in organisms as we know them.

In this sense, we cannot leave aside the discussion of how we understand the phenomenon of life, and in this discussion, we cannot focus on groups of molecules or processes, but on what really distinguishes the phenomenon of life from other natural phenomena. It is undeniable that life is the result of a differentiated organization of matter, so we must ask ourselves, what new and exclusive property emerged from this new organization of matter that we can call life? The discovery of biosignatures as well as life beyond our planet should spark important debates about how we understand life as a phenomenon in the universe. In this essay, I will seek to explore new findings from pre-biotic chemistry, as well as new views on the nature of the phenomenon of life and how these points can be incorporated into the discussion on biosignatures, as well as, I will also discuss the consequences of the possibility of the existence of life outside our planet and how can change our view of life as we know it.

Biosignatures, origin of life and prebiotic chemistry

The search for understanding the conditions and phenomena that led to the organization of matter to the formation of life has been a field of intense debate. The identification of the transition point between the living and the non-living is essential for the development of models and concepts that better describe the phenomenon of life. In this sense, different points of view regarding the moment in which life emerged lead to different understandings of what characterizes this phenomenon. These questions have a profound impact on the formulation of experiments that seek to identify the possibility of life outside our planet, as they can lead to the search for processes that do not reveal the possibility of life, but only which necessary elements would be present in certain environments, however without describing the other conditions for these elements to organize and interact to structure life. Thus, we must look at what the phenomenon of life is from a broader perspective, moving away from the typological characteristics of living beings that we know and focusing on the processes that distinguish the phenomenon of life from the non-living organization of matter. Many of the methods for detecting biological activity outside our planet are based on determining the composition of the atmosphere of the planet under analysis, as well as studies on our planet that show that such compounds are produced exclusively by biological activity. Furthermore, recent missions to the planet Mars have collected and analyzed the composition of this planet and assessed whether there is any evidence of past or present life. However, all of these approaches are anchored in characteristics observed in organisms on our planet, which has evidently limited our detection power.

The astrobiology community is increasingly concerned with how to improve the accuracy of biosignature detection. These efforts have recently been seen in the work of Green et al. (2021) and the report of the NASA workshop on life detection (2021). Green et al. (2021) raises several current issues, both in detecting signs of life beyond our planet and in how these results are presented to the scientific community and society, which can lead to misunderstandings about the true scientific value of such results. As a result, it proposes a progressive scale that can aid identify the signs until a positive result is confirmed. Green et al. (2021) highlights the environmental relevance of such signals, the discrimination of abiotic false positives, the identification of other biosignatures together, the elimination of alternative hypotheses that could explain the detected signal, and contamination with materials from our planet as important points. In a complementary sense, the report of the NASA workshop on life detection (2021) starts off one broad discussion about the possible origins of biosignatures, raising critical questions in the most diverse directions and prompting us to think more carefully about the possible outcomes and their implications for detecting life beyond our planet. One of the points raised, which I believe is critical to emphasize, is the importance of taking a closer look at the results of prebiotic chemistry studies when deciding and interpreting positive results on biological signals. At this point, I would like to suggest a thought experiment. Assume we discover signs of life on Mars using biosignatures derived from terrestrial organisms. The first question is whether this reaction can occur in the absence of life. Although it may appear to be a trivial question for researchers, new prebiotic chemistry elements can lead to new ways of interpreting this type of data. Several studies have shown that many basal metabolic pathways, such as glycolysis (Keller et al., 2014), pentose pathway (Keller et al., 2016), citric acid cycle (Muchowska et al., 2019), and others (Barge et al., 2020) can occur with chemical catalysts under prebiotic conditions. These findings raise new questions about how life might have evolved on our planet, as we can imagine that some of the most fundamental metabolic pathways could have existed in a prebiotic environment and that life co-opted these reactions for its survival. Take, for example, pyruvate, the product of the glycolytic pathway, but we can think of any other product of the basal metabolic pathways. Currently, practically all pyruvates found on our planet are products of biological activity, so we can infer that if we find pyruvate on another planet, we have a strong indication of biological activity on that planet. However, studies have shown that under prebiotic conditions, it is possible that practically all glycolysis reactions occur with chemical catalysts (Keller et al., 2014, 2016).

Considering these new data, some authors have proposed that several metabolic pathways considered exclusively biological may have emerged from the chemistry possible in the atmospheric conditions of primitive Earth and were incorporated by organisms during the maturation process of biological systems (Prosdocimi and Farias 2022). Thus, these new data pose new challenges, because, if we find a biosignature, we must know whether under the conditions of that planet this biosignature can be produced by non-biological processes. So, how are we to interpret the identification of biosignatures on another planet? Were they real signs of life? Or could they indicate signs of the possibility of life development? We can think that what we now know as the products of living organisms may have been products of prebiotic chemistry on early Earth. These points were raised at the NASA workshop on life detection and should be debated and evaluated more thoroughly, including incorporation into biosignature detection protocols like the one proposed by Green et al (2021). In this regard, another point to consider in this discussion is the possibility of testing the synthesis of biotic compounds on Mars under prebiotic conditions. We currently have a lot of knowledge about the current atmosphere (Changela et al. 2021), as well as good evidence of Mars' primitive atmosphere (Kobayashi et al. 1997), which allows for experiments to be carried out to see if the synthesis of compounds that can support the organization and maintenance of a biological system is possible in such conditions (Kobayashi et al. 1999).

Concepts of life and biosignatures

The search for and the identification of biosignatures that can really distinguish abiotic events from biotic events requires a deep understanding of what the phenomenon of life is in a universal context, in addition to a prior understanding of the biology of known organisms. In this context, the formulation of more precise concepts or those that point to universal characteristics is necessary for broader biosignature formulations. Despite having more than 100 conceptual formulations about the phenomenon of life, we still have difficulties obtaining a widely accepted concept that does not present exceptions within our knowledge of life on Earth. Farias et al. (2021) divide conceptual formulations about life into three major groups: those based on physical characteristics, those based on cellular structure, and those based on molecular structure. Cellular and molecular approaches to conceptualizing life are currently the most accepted and used, even if indirectly, in the choice of biosignatures, since the metabolic processes of organisms that fit these concepts are preferred. Evidently, we cannot claim that such choices are wrong, as they are within the known spectrum of biological activity. However, both concepts based on cellular structures and on molecular structures use the typological organization of living beings as an argument, which at first may not represent a problem if life is organized on other planets with a typology like the one that we know for the planet Earth. However, this type of approach restricts our observational power, not allowing us to identify the phenomenon of life if it is organized under another typological structure. In the present context, we must understand typological characteristics as the physical characteristics presented by living beings. In this sense, the physical approach is broader in terms of the possibility of identifying phenomena that we could infer as alive. However, the physical approach, due to its amplitude power, cannot make a clear conceptual distinction, even on our planet, between merely physical events and biological events. Several authors have proposed a change to the conceptual paradigm in order to solve this impasse, shifting the conceptual analysis of biological entities to the processes performed by these entities (Dupré and Nicholson, 2018, Simons 2018, Farias et al. 2021).This type of approach seeks to evade typological characterization, thus concentrating its efforts on general processes that may occur under another typological framework, but which we can identify as processes carried out by living organisms. Dupré and Nicholson (2018) argue that even entities can be understood as specific temporal stages of stable processes. The spatial-temporal organization processes, together with their causal and temporal relationships with other processes, will determine the stability and persistence of those entities. Simons (2018) suggested that material entities should be understood as some sort of precipitation of the processes that maintain and stabilize them. Farias et al. (2021) analyzed the structures or processes that are unique and exclusive to living beings and propose that the processing of encoded information is a characteristic that is present in all living beings and is exclusive to this type of organization, making it impossible to identify encoded information outside the biological sphere.

A similar approach had already been suggested by Claus Emmeche (1998), who proposed that the concept of life should be based on the code-structural nature of biological systems. For this author, "life is the functional interpretation of signs in self-organizing material 'code-systems' that construct their own 'umwelts'" (Emmeche, 1998). In a similar sense, Sebeok (1988) proposes that semiosis is what distinguishes all that is animate from the lifeless. Their studies have established important characteristics identified in biological codes, such as: (i) the code must connect two words, one defined as the signal and the other described as the biological sense; (ii) a code must have an adapter that establishes the rules of correlation and makes contact between the signal and its meaning; and, (iii) the code must be a natural convention; even if the information is changed experimentally, it must still act as a code (Barbieri, 2014; Hofmeyr, 2018). Thus, we suggest that such observations about biological systems be considered in the process of identifying and selecting biosignatures, as approaches such as those indicated can expand the search field and identify the phenomenon of life regardless of the typological structure in which such a phenomenon is structured on another planet. Evidently, we must not abandon typological approaches in the study of biosignatures, but rather incorporate concepts that can increase our exploratory power. The development of markers that can identify coded information processing structures could represent a new milestone in the exploration of environments outside our planet.

What if we find life on mars?

Another situation that we should investigate is whether we confirm the existence of organisms outside our planet. How can this discovery change the way we understand the phenomenon of life on our planet? Currently, we have extensive knowledge of how life may have emerged and evolved on our planet. Our data indicate that life as we know it had a unique origin and diversified through processes such as mutation, natural selection, gene drift, migration, among others. The use of biosignatures based on the organisms we know has as a background the idea that the processes that led to the formation of living beings on planet Earth can be universal and that the processes carried out by living beings, given the appropriate conditions, would occur in a similar way off our planet. This idea, in a way, has principles contrary to knowledge about current evolutionary biology. In this way, the discovery of life outside our planet can drastically change the fundamentals that support the understanding of life on our own planet. Let us imagine the following situation: We found life on Mars, and when we analyze these Martian organisms, we identify that they have DNA as an informational molecule, have certain metabolic pathways in common with terrestrial organisms, as well as a similar structural organization. How can we eliminate the possibility of terrestrial contamination on Mars? At first, the general organization of these bodies would be similar. Could we think that life originated elsewhere in space and dispersed to Earth and Mars independently? Or is life a deterministic process in the universe and thus, given the proper circumstances, life could appear similarly at different points in the universe? If we have an affirmative answer to the last question, could we say that the evolutionary process that guides life on our planet would be a universal process? Is life a cosmic imperative? and thus always organizing under the same rules and operation?

In addition to the possible consequences in our scientific understanding of biological processes, we cannot forget the profound changes that such data can generate in human social bases. The perception that life is not an organization exclusive to planet Earth can affect several fields of human understanding, among them, we can mention discussions involving religious aspects, our relationship with our planet and the changes it has been going through in last years, among others. These questions may appear trivial, but by delving deeply into them and considering the implications of each possible answer, we can start a broad discussion about the true nature of life on our planet, which will undoubtedly improve the resolution of our search tools for life on other planets. In this way, we can also believe that by focusing on the issues presented, new ways of thinking about space exploration can be evidenced.

Last considerations

For decades, artists and scientists have been inspired by the search for life beyond our planet. Advances in knowledge about living beings, as well as advances in technology, have made it increasingly possible to explore environments beyond our planet. In this sense, astrobiology has solidified itself as the science of the future, bringing together disparate fields to both understand more and more life on our planet and increase the likelihood of finding similar phenomenon in other parts of the universe. The correct use of biosignatures proves difficult not only for correctly identifying a true vital signal, but also to interpret this phenomenon as universal.

Astrobiology philosophy must anticipate facts and devise ways to interpret future discoveries that have the potential to profoundly impact our understanding of how we understand life on our own planet. In this context, to improve the potential for detecting life outside our planet, we cannot leave aside new data on the chemical possibilities in atmospheres with conditions different from ours, as well as new discussions about what and how we understand the phenomenon of life. These two new approaches can add to the existing ones and help us to put together this picture of how life may have emerged and whether this process that led to the emergence of life is exclusive to an extremely particular condition that existed on primitive Earth, or if it is a cosmic imperative and has been repeating itself in different parts of the universe. So, I end this brief essay with the following question: if we find life on Mars, what would that mean?

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