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LIFE ESTIMATES IN THE UNIVERSE: OUTSTANDING THE IMPORTANCE OF ASTROCHEMICAL AND ASTROBIOLOGICAL PARAMETERS

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RESUMEN

El origen de la vida, su evolución inicial y presencia fuera de la Tierra han sido importantes interrogantes de la ciencia. Una de las primeras aproximaciones que estudió estos aspectos fue la ecuación de Drake (1961). Sin embargo, estudios posteriores no han considerado factores clave derivados del conocimiento moderno de la química y la biología. Así, este trabajo realizó un análisis documental de las diversas estimaciones de la vida en el universo, los parámetros empleados y sus aportes. En consecuencia, proponemos tres enfoques (astroquímico, química prebiótica y astrobiológico evolutivo) basados en el principio de contingencia evolutiva molecular y biológica en el universo, los cuales podrían ser incluidos en futuras modificaciones de la ecuación de Drake.

ABSTRACT

The origin of life, its initial evolution and presence outside the Earth have been important questions of science. One of the first approaches to study these aspects was the Drake equation (1961). However, subsequent studies have not considered key factors derived from modern knowledge of chemistry and biology. Thus, this work performed a documentary analysis of the diverse estimates of life in the universe, their parameters and their contributions. Consequently, we propose three approaches (astrochemical, prebiotic chemistry and evolutionary astrobiology) based on the principle of molecular and biological evolutionary contingency in the universe, which could be included in future modifications of the Drake equation.

Key Words: exobiology — chemical evolution

1. INTRODUCTION

Among the most relevant unknowns in the science is understanding how life originated on Earth, its evolution and possible presence outside it. This question has managed to promote the consolidation of two emerging fields since the middle of the 20th century; Astrochemistry and Astrobiology, which pinpoint towards the investigation of these topics considering planetary, stellar and galactic contexts. Thus, both scientific disciplines offer the possibility to understand the evolution of matter in the history of the universe and how it can evolve towards living systems (Smith et al. 2013). In this sense, the Drake equation (Sagan 1963) was the first approach to make estimates of intelligent life in the universe. Initially, the parameters mentioned in that mathematical equation (seven factors) have been a key reference at a theoretical level for the different subsequent research works.

During the last 60 years, the epistemological proximity of astronomy with physical sciences has generated a limited focus to the origin of life in the universe, many times circumscribed to a predominantly astrophysical approach. Although, it is important to mention that some modifications in the Drake equation have incorporated innovative elements that highlight chemical and biological aspects. Among the most relevant studies outstanding as follow: for the first time, Freeman & Lampton (1975) took into account nucleosynthesis concept, life evolution time and analysis derived from the diversity of families with intelligent species, with Earth planet as a reference. Walter et al. (1980) considered the presence of an oxidizing atmosphere; Russell (1983) proposed the degree of encephalization as a measure of biological complexity; Chela-Flores (2000) suggested a parameter associated with eukaryogenesis; Frank (2001) incorporated the concept of Gaia; Forgan (2009) and Ramirez (2017) applied a statistical treatment in three scenarios for the emergence and development of life; Konesky (2010) alluded to the importance of atmospheric biomarkers in exoplanets; Seager (2017) contributed with a notable modification of the equation considering gaseous biomark-

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ers detectable in exoplanets; Sanberg (2018) delved into prebiotic chemical and genetic aspects; Molina (2019) included carbon-based biospheres or biosystems and anthropic intelligence; Tsumura (2020) integrated mass extinctions and time of biological evolution; Totani (2020) addressed the possibilities of origin of RNA in the universe, and recently Platt (2021) introduced exomoons as potential places of habitability and origin of life.

Herein, we developed a retrospective documentary review considering diverse estimates of life outside the Earth derived from the Drake equation. Furthermore, we focused on three analysis frames (astrochemical, prebiotic chemical, and evolutionary astrobiology) which allowed postulate some factors for more plausible and complex approximations taking as reference a historical temporal analysis of chemical and biological evolution of life on Earth (the only one life form that we know in the universe). In this sense, this research takes into account aspects derived from modern knowledge of chemistry and biology. Finally, this work raises a transdisciplinary vision to address the most compelling question: are we alone in the universe?

2. METHODOLOGY

We carried out a systematic review considering all scientific papers published during the last 60 years related to Drake equation. Those articles were located using the Google Scholar, Scopus and Web of Science databases, using "Drake Equation" as keyword. Thus, as inclusion criteria, we considered papers in both languages: English and Spanish. According to the information in each article, we classified its contribution taking as reference the number and types of parameters proposed by the authors in the different mathematical approaches. These parameters or factors were categorized as astrophysical, astrochemical, astrogeological, astrobiological and historical-technological.

3. RESULTS AND DISCUSSION

After analyzing more than 50 scientific papers, the findings evidenced that representativeness of studies along the first four decades (60-90's) were close to 26%, compared with 74% in the last 20 years, which is consistent with a major advance in Astrochemistry and Astrobiology. Of the articles reviewed, 32 proposed some modification of the equation. In general, all the investigations assessed an average between 8 and 9 parameters with an interval that ranges from a maximum value of 20 (Molina 2019) to 4 as minimum value (i.e. (Konesky 2010)). The most investigations proposed between 6 and 8 parameters (20 studies). Moreover, the findings obtained from the classification for the factors in the 5 categories of analysis showed that the percentage of level of importance for astrophysical aspects represented 37.4%, astrochemical 9.7%, astrogeological 5.1%, astrobiological 26.9% and finally, historical-technological with 20.9%. These results indicate the low importance of chemical and geological aspects as factors in the equation. Historically these kinds of parameters have been absent in several estimates of life in the universe. Also, our outcomes showed a prominent importance that many studies have given to the communicative and technological capacity of a civilization, based on predominantly astrophysical aspects. This result is broadly consistent with research field of most authors and an outstanding determinism in the physical sciences. Consequently, it is necessary to generate a transdisciplinary focus for more complete estimations of life possibilities in the universe.

Therefore, this research work proposes to integration of 3 approaches to contribute in more verisimilitude approximations of the estimates of life outside the Earth. They are supported by an historical axis related with molecular and biological evolutionary contingency in the universe. Also, the detail in these approaches are based on recent knowledge derived from areas such as: organic chemistry, synthetic chemistry, biochemistry, molecular biology, evolutionary biology and paleontology. The three approaches will be described as follow:

Astrochemical: Molecular evolution in the universe begins with interstellar clouds, these are diffuse and molecular ones. The second are important because have regions of star birth and constitute the next stage in molecular evolution (Vallance 2017; Yamamoto 2017). Later, when the star is formed, a protoplanetary disk is produced around, in which planets could formed. Thus, it is important to advance in the knowledge of the abundance of chemical substances in different degrees of structural complexity: from the bioelements C, H, O, N, P, S, following by simple molecules (H_2O, CO_2, CH_4, NH_3, CO), to more complex compounds such as: CH_3OH or HCHO that potentially would be produce prebiotic monomers such as aminoacids and monosaccharides (Sanford et al. 2020). It is important to mention that particularities of the planetary composition have been analyzed by Seager (2017) providing a frame of reference for the search for biosignals in exoplanets.

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Prebiotic Chemistry: This approach allows us to understand what kind of mechanisms made possible the transition processes from chemical to biological systems, this aspect is an essential stage in possible estimates of life in the universe. Thus, the chemistry of prebiotic systems, defined as the study of chemical complex systems and interactions networks of molecules, which can allow understanding the emergence of molecular machines that might promote the development of functional entities at biochemical and metabolic level (Lopez & Fiore 2019). Recently, advances in this field are shedding more light to abiotically generation of molecules with biological importance. Finally, prebiotic chemistry has allowed the study of the first biomolecules and potential reactions that made possible the origin of the first chemical system capable of self-organizing, exchanging energy and matter with their environment with the aim to self-maintaining, reproduce and evolve (Ruiz-Mirazo et al. 2014).

Evolutionary-Astrobiology: Evolution by natural selection is the process inherent to life that allowed the historical development of biodiversity along near 4000 M.y.a. However, the study of macroevolutionary patterns on Earth show the importance of diverse physical and climatically processes framed with sufficient time (near 3000 M.y.a since life origin) for the consolidation of life with high level of complexity as we evidence in animals, plants or fungi (Gould 1990). In this way, taking history of life as a reference, we propose some contingent factors that must have arisen in the unlikely appearance of an intelligent species like us. These factors were stablished according to evolutionary and paleobiological recent knowledge as follow: the macromolecular origin of a cellular entity delimited by a membrane, with metabolism and information system, multicellularity development as potential for eventual further complexity, the development of a system that integrates efficiently process and centralize information such as the nervous system in animals, morphological evolution that allowed an objects fine-manipulation system with finally the development of self-consciousness and language, all these aspects have not recently been treated in the light of current knowledge (Mayr 1985; Russell 1995).

4. CONCLUSION

According to our documentary analysis, we concluded that in the last 60 years, the estimates of Drake equation have had an outstanding astrophysical and historical-technological component. This is consistent with the outstanding determinism in several physical sciences with respect to the origin of life, its evolution and the origin of an intelligent specie. Finally, taking as reference advances derived from various fields of modern chemistry and biology, we propose three approaches (astrochemical, prebiotic chemistry and evolutionary astrobiology) based on the historical principle of *molecular and biological evolutionary contingency* in the universe, which could be included in subsequent modifications of the Drake equation.

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