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REVIEW ARTICLE

# Brief review about history of astrobiology

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**Abstract**
The main idea of this work is to develop a chronological and descriptive historical review in a summarized form about content on astrobiology, which is a research area considered as an emerging science. This is exploratory research that was developed from document review from scientific articles and books, that related to the themes of astrobiology, exobiology and the search for life outside the Earth were used. Based on the research developed, it was possible to collect data related to the vision of other worlds beyond Earth from the ancient Greeks to the present day. Finally, it was possible to conclude that although astrobiology is a recent area of scientific research, the concept and search for life outside the Earth already existed long before the development of modern science.

## Contents



## Introduction

Historically speaking, astrobiology was considered by many science practitioners as the research that was concerned only with the study of extraterrestrial life. Thus, it was notoriously criticized by a lot of researchers, such as biologist George Gaylord Simpson (1964), who used to refer to the area as 'a "science" that has not yet demonstrated whether its object of study exists!' If astrobiology were understood to mean solely the study of extraterrestrial life – which it is not – Simpson's criticism would remain strictly true.

Nonetheless, astrobiology seeks to study life as a planetary phenomenon, and aims to understand the fundamental nature of life on Earth and the possibility of life elsewhere (Mix *et al*., 2006). In seeking to understand the full story of life in the Universe in a holistic way, astrobiology asks questions that transcend all these individual scientific subjects (Domagal-Goldman *et al*., 2016). The fundamental questions of what 'life' means and how it arose have brought in broad philosophical concerns (Mix *et al*., 2006).

Astrobiological research potentially has much broader consequences than simply scientific discovery, as it includes questions that have been of great interest to humans for millennia. According to Briot (2012), the possibility that life exists elsewhere in the Universe is related to the question of plurality of worlds and probably dates back to Greek philosophers.

In fact, according to Morrison, these questions – 'How did life begin?', 'Are there other planets like Earth?', 'What is our future as terrestrial life expands beyond the home planet?' are age-old (Morrison, 2001). However, this is the first time in human history that advances in science with technology help make it possible for us to provide some answers about these themes.

## Astrobiology from 341 B.C. to 1100 A.D.

Although the term 'astrobiology' only appeared during the 20th century, according to Noack *et al.* (2015), research on life outside the Earth began more than 2000 years ago. This is a fact that is not surprising, since the simple possibility of life in other parts of the Universe, according to Briot (2012), would be linked to the issue of the multiplicity of worlds historically debated, initially between singularists and pluralists from Greece and ancient Rome.

The term 'singularists' indicates practitioners of science who advocate the human uniqueness in the Universe, that is, the unique manifestation of technological intelligent life existing in the entire Milky Way. The 'pluralists', on the contrary, defend the multiplicity of worlds inhabited by intelligent living beings, that is, the plurality of worlds (Barcelos, 1999).

The ancients of Greece and Rome were deeply divided over the existence of other worlds, especially the possibility of life outside Earth. Pluralists generally have their origins in ideas developed by Epicurus (341 B.C.–270 B.C.), Democritus (460 B.C.–370 B.C.) and Leucippus (born in the 5th century B.C.). This group promulgated arguments that, nowadays, are modern theories of the scientific field, such as:

(1) matter is composed of atoms;
(2) the current state of nature is the result of a long evolutionary process;
(3) there is life elsewhere in the Universe.

It is important to point out that, however modern these ideas may seem, they all indisputably date from antiquity, where they can be seen in Epicurus' 'Letter to Herodotus', in a passage in which the philosopher's atheism is implicit:

> 'There are infinite worlds the same and different from ours. For atoms being infinite in number… are carried away into space. For these atoms … were not used either in one world or in a limited number of worlds, nor in all the worlds which are similar, or in those which are different from these. So that nowhere is there an obstacle to the infinite number of worlds (Crowe, 1986)'.

Elsewhere in the letter, Epicurus adds another comment extremely pertinent to this discussion: 'We must believe that in all worlds there are living creatures, and plants and other things that we see here in this world…' (Crowe, 1986). According to Crowe (1986), Metrodorus of Chios (4th century), leading disciple of Epicurus among his contemporaries, endorses Epicurean thinking by saying: 'It would be strange if a single ear of corn grew on a great plain or if there were only one world present in infinity'.

It is worth mentioning here the great Epicurean influence also for the poet Lucretius (99 B.C.–55 A.D.), in *De rerum natura* he mixed elegant verse with the illusion of optics, the sweetness of wines to the evolution and structure of the Universe, expressed in this topic:

> 'Empty space stretches out without limits in all directions and innumerable are the seeds that rush down countless courses in an unfathomable universe…, it is in the highest degree different that this earth and sky are the only ones that were created and that all these particles are doing nothing. This stems from the fact that our world was made by the spontaneous, haphazard, accidental and random collision of the purposeless coalescence of atoms whose suddenly formed combinations could serve [to produce] … land, sky, sea and living creatures (Crowe, 1986)'.

However, these questions about the plurality of worlds were not widely accepted by people for several centuries (Corrêa *et al.*, 2010). It is possible to list some of these cases as that of Hippolytus in the

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3rd century, the bishop of Caesarea Eusebius in the 4th century in Israel and the bishop of Cyprus Theodoret in the 5th century, according to Crowe (1986), being these the best known. Thus, it was only between the 12th and 13th centuries that the possibility of a plurality of worlds was discussed more widely, in which one of the most important disseminators was Albertus Magnus (1193–1280), a Christian scholar in the West, who wove the following comment: 'Since one of Nature's most wonderful and noble questions is whether there is one world or many … it seems desirable to ask questions about it'.

## Astrobiology from 1200 to 1900

In 1277 an ironic event occurred which Pierre Duhem and others claim to be one of the main causes of this modern science. The Bishop of Paris Étienne Tempier raised the following question: 'would it be possible for many worlds to be produced from the First Cause' – according Chela-Flores *et al*. (2000), we define as a first cause the origin of life in the Universe. This paradigm made science practitioners change their views, causing many authors to come to formulate analyses that showed that God could create multiple worlds. Although few have insisted that God actually do so, this process has led to a valuable reexamination and critique of Aristotle's anti-pluralist arguments, mentioning such names as William de Ockham (1280–1340) and University of Paris rector Jean Buridan (1295–1358).

As can be seen, the interest in possibly having many other planets with life is not exclusive to the present time. With the return of interest in the plurality of worlds in 1440, German Cardinal Nikolas Kreb (1401–1464) commonly known as Nicolas of Cusa published an extremely controversial masterpiece – at least for that time in the Middle Ages – *De docta ignorantia* (I.P.E., 2021).

In that work, Nikolas de Cusa categorically suggests, in the 15th century, the existence of other Earth-like planets revolving around other stars also similar to the Sun.

> 'Life as it exists on earth, in the form of men, animals and plants, can be found, let us suppose, in a higher form in the solar and stellar regions. Instead of thinking that so many stars and parts of the sky are uninhabited and that only this earth of ours is populated – and that with beings, perhaps of an inferior type – we need to appreciate the idea that in each region there are inhabitants, differing in nature by position and all due to its origin in God, who is the center of all star regions (IPE, 2021)'.

He also adds:

> 'The Sun is a star like other stars, just as the Earth is not the center of the universe, it is not at rest and its poles are not fixed. The celestial bodies are not strictly spherical, nor are their orbits circular (I.P.E., 2021)'.

Later, the 16th-century Italian Dominican friar Giordano Bruno argued that the stars were distant suns surrounded by their own planets, as well as asserting that the Universe is infinite and could not have a centre (Gustafson, 2020). In 1685, the French author Bernard le Bovier de Fontenelle published Conversations on the Plurality of Worlds, writing not in Latin, which was common for scholars at the time, but in French, as his aim was to make ideas accessible to popular culture (Fontenelle, 2003).

It is important to highlight that since Antiquity, according to D'Ischia *et al*. (2019), the astronomical questions of the time and the methods used to formulate and answer them were clearly within the realm of philosophy. However, according to D'Ischia *et al*. (2019), this changed mainly in the 16th century, when Tycho Brahe and Johannes Kepler transformed astronomy into a modern empirical science, formulating – in principle – testable hypotheses from systematic observations of the sky. It is worth mentioning Johannes Kepler's pluralist vision in the midst of a letter sent to Galileo:

> 'I rejoice that I have been, to some extent, restored to life by your work. If you had discovered planets revolving around one of the fixed stars, there would now be waiting for chains and a prison among Bruno's innumerables. I should rather say, exile in its infinite space. Therefore, by

> reporting that these four planets revolve, not around one of the fixed stars, but around the planet Jupiter, you have, for the time being, freed me from the great fear that seized me as soon as I heard about your book (Crowe, 1986)'.

Another example, according to Schwartzman (2001), of a paradigm shift in vision was given by Sir Isaac Newton's (1643–1727) harmonious understanding of the Universe from empirical observation and mathematical structuring, later exposed in his work Philosophiae Naturalis Principia Mathematica (5 July 1687) – two other editions were published in 1713 and 1726.

Although it is possible to observe the whole big scenario of development of thought about the plurality of worlds, consequently, the search for questions about environments like the Earth. Until recently, the development of related research covering this theme, despite having stimulated the curiosity of many science practitioners, it still conveyed the general impression, according to D'Ischia *et al.* (2019), of not being a scientific field, as it was based on speculative theoretical analysis rather than solid experimental evidence.

## Astrobiology after 1900

Following the evolutionary historical timeline of astrobiology from the last century, the first material in a scientific journal, it seems, was written by renowned mathematician and engineer of Polish origin and Soviet nationalized Ari Abramóvich Shtérnfeld, published on 1 July 1935 (*La vie dans l'Univers*) in the popular French science journal, *La Nature*, since 1873. The article in question begins with a historical description of Greek philosophy and covers a range of beliefs and hypotheses about life in the Universe, being at the time cover story.

The second part of Sternfeld's article describes the general aspects of the 'Origin of Life', using arguments related to natural and astronomical sciences that led to the birth of a new science whose main objective would be to assess the habitability of other worlds. The description is called astrobiology (Briot, 2012). It should be noted here that this is, it seems, the oldest and perhaps the first definition of the word astrobiology with its contemporary meaning.

Another interesting point about this scientific work is the sentence written in the next chapter of the article 'There is no comprehensive definition of life, as far as we know, so we leave it to the reader's intuition'. Sternfeld then reviews several theories about the origin of life and discusses the transfer of life between planets, or today known as panspermia. It also describes life under extreme conditions.

Sternfeld's article is quite rich in details; it brings other concepts besides being innovative, extremely visionary, such as the suggestion of properties of the atmosphere present in Saturn's natural satellite, the moon Titan. It can be said that this, among many others, was one of the greatest achievements described in that article, as this detection took place only almost 70 years later, through the Huygens probe that, taken by means of Cassini, landed on Titan and obtained information on environmental conditions and confirmed Sternfeld's theory related to the existence of an atmosphere on this moon, in addition to having collected important topographic data and searching for hypothetical traces of life.

Sternfeld, at the end of his article, wrote in the concluding chapter: 'Our main conclusion is that all possibilities remain open and that nothing has been proved. Despite considerable efforts by famous astronomers and advances in astronomical instrumentation, the question of whether life exists on other planets remains unanswered. Can we hope to reach some conclusions?' (Sternfeld, 1935).

Shortly thereafter, Sternfeld's work motivated the French philosopher and historian René Berthelot (1872–1960) to write a monograph entitled *La pensée de l'Asie et l'astrobiologie* (1938). In that work on anthropology, astrobiology had a concept that related the stage of human development that human societies subscribe to as animistic or vitalist interpretations of natural phenomena. Although the work brought a certain degree of astronomical knowledge, there was an intrinsic belief in it that astronomical phenomena – astrology – shaped terrestrial and human life phenomena (Berthelot, 1938; Lemarchand, 2010). Although Berthelot's conception of astrobiology had completely fallen out of favour in the 21st century, it was employed in *hoc sensu* by French intellectuals until the late 20th century (Christie, 2019, p. 4).

Later, Lafleur (1941) defined astrobiology a few years later as 'the consideration of life elsewhere than on Earth'. Lafleur's article is often considered the first use of the word astrobiology, but Sternfeld's 1935 article predates Lafleur's essay. In 1945, Gavriil Adrianovich Tikhov, a Russian astronomer, coined the word astrobotany to describe the search for vegetation on Mars (Tikhov, 1953). In 1947, Tikhov inaugurated the 'Astrobotany Section of the Academy of Sciences of the Republic of Kazakhstan' of the former Soviet Union.

At a conference of the British Interplanetary Society in 1952, the Irish physicist and philosopher of science, John D. Bernal (1901–1971) expanded his speculations on the origin of life in the Universe, stating that 'the biology of the future would not be limited to the Earth, and it would encompass a much broader spectrum, transforming itself into a true cosmobiology'. This has been perhaps one of the first terms used at a kind of international conference, by a renowned scientist, to describe a field that would study the possibilities of biological activities and life beyond our planet. Curiously, in 1953, Gavriil Tikhov began to use in his publications also the term astrobiology and cosmobiology as a generalization from the study of terrestrial biology to that of living systems on other worlds (Briot, 2012).

In 1955, American astronomer Otto Struve (1987–1963) independently coined the word astrobiology to describe the broad study of life beyond Earth. Struve also served as the first director of the US National Radio Astronomy Observatory (NRAO). At this point, the term astrobiology was beginning to gain notoriety and academic popularity. Flavio A. Pereira created, in 1956, the Brazilian Interplanetary Society (a kind of sister organization of the traditional British Interplanetary Society) and published in Brazil a book in Portuguese – native language in Brazil – on astrobiology, possibly the first dedicated to the modern meaning of the subject.

The following year, in June 1957, Albert G. Wilson, director of the Lowell Observatory, organized the first 'American Astrobiology Symposium' (Wilson, 1958), but at that time the meaning of the word astrobiology was not as restricted as its current meaning. The articles presented dealt not only with life in other celestial bodies, but also with problems common to astronomy and biology, for example, physiological problems with astronomical observations.

At this time there were two large groups of leading scientists in the USA who were responsible for coordinating research in the field of 'extraterrestrial life'. The first of them was on Extraterrestrial Life of the National Bioastronautics Committee belonging to the Board of the Armed Forces, was chaired by Melvin Calvin (1911–1997) and had the participation of Carl Sagan (1934–1996). The second group made up the Panel on Extraterrestrial Life of the National Academy of Sciences, which was chaired by the prominent biologist and geneticist Joshua Lederberg (1925–2008). During those days, the topics were dominated by the search for life on Mars and the development of on-board devices, intended for the first planetary probes. This scientific activity was – at that time – generically called bioastronautics.

In 1960, Frank D. Drake performed the first experiment, using NRAO facilities. Since then, projects have been developed with the interest in detecting artificial signals from nearby stars, using radio telescopes available all over the world. According to Frank Drake, the discovery of a signal that could not be associated with a source of natural origin would indicate the existence of intelligent life beyond Earth (Lemarchand, 2000). In November 1961, Otto Struve was responsible for organizing the Green Bank Conference, aimed at determining the possibility of detecting evidence of intelligent life in the Universe and where the so-called Drake equation was presented for the first time, aimed at determining the possible number of technological civilizations in the Galaxy.

It is important to note that from this time onwards, several scientific works, books and academic meetings emerged, aimed at developing the most appropriate detection methodologies, which were then categorized under the banner of 'Interstellar Communication' (Hoerner, 1961; Cameron, 1963; Drake, 2013; Dick, 2020). In February 1963, the first International Symposium on Exobiology was organized within NASA's Jet Propulsion Laboratory, Mamikunian attributed to Joshua Lederberg (1960) the creation of the word exobiology (Manikunian and Briggs, 1965). In fact, Lederberg published a seminal paper in which he coined the term exobiology to describe what he called 'the biology of extraterrestrial origin'. According to Lederberg: 'The primary goal of exobiological research is to compare the various models of chemical evolution of the planets, emphasizing those dominant features that are present in each of them' (Lederberg, 1963).

Professor Rudolf Pesek, in 1965, was responsible for organizing an international meeting on the problem of extraterrestrial civilizations, more specifically, to address issues related to programmes of Communication with Extraterrestrial Intelligence (coining the acronym CETI), which according to Lemarchand (2000), the choice was also connected with the well-known fact that Ceti in Latin is the genitive of Cetus (family to with the Dolphins – a species that humans were try to communicate with over the some decades, precisely since 1950). In addition, on the other hand, one of the stars that Frank Drake observed in his OZMA project was precisely Tau Ceti.

After a series of workshops organized by NASA, in the mid-1970s, some experts feared that a hypothetical extraterrestrial message from an advanced society could make people lose faith in the ability of the human race and eventually deprive them of the initiative to make new discoveries or have negative consequences for humanity (Morrison *et al*., 1977; Lemarchand, 2000). Despite the fact that if a message was received there would be no obligation to respond, the organizers of these workshops decided to change the acronym for communication with extraterrestrial intelligence (CETI) to search for extraterrestrial intelligence (SETI) (Billingham and Pešek, 1979). Since then, this term has been widely used (Pešek, 1973; Lemarchand, 2000).

In the late 1970s (1976–1977), according to Dick (2012), numerous scientists gathered for the first time to contemplate this programme and try to gain some institutional support from NASA authorities and the US Congress. Among the discussions promoted at the time, the possibilities of cultural evolution beyond the Earth can be listed, which was led by none other than the young Nobelist Joshua Lederberg, whose 2-day 'Workshop on Cultural Evolution' sought to focus more specifically on the 'evolution of intelligent species and technological civilizations'.

All this scientific movement aroused the interest of the International Astronomical Union (IAU), which developed from the sponsorship of the joint meeting of several commissions and a meeting with more than 1000 astronomers on the search for extraterrestrial life during the XVII General Assembly in Montreal in 1979. According to Papagiannis 1980, about 3 years later, the commission 51 was created to dedicate itself to this subject called bioastronomy, during the XVIII General Assembly of the International Astronomical Union (IAU), held in Patras, Greece.

In the early 1990, shortly before the inauguration of NASA's SETI operations, the American institution convened a series of workshops on the cultural aspects of SETI (CASETI) (Lemarchand, 2000). It is essential to note how the first SETI practitioners were already sensitive to the concerns of society, developing during these meetings an interdisciplinary brainstorming model, with astronomers, anthropologists, religious, historians, as well as various representatives of the media and some diplomats. In 1993, the US Congress cancelled any NASA involvement in a SETI programme (Garber, 2014). According to Harrison *et al*. (2000), this fact generated a delay of almost a decade of the results of the SETI programme.

The premature end of NASA's SETI programme did not end discussions of astrobiology and society. However, this fact had a substantial impact on the integration between the areas of social sciences and humanities with space exploration, in which the relationship between the fields became increasingly dispersed and sporadic.

Regarding the most recent events, probably the detection of the first planet around a twin solar star (called 51 *Pegasi*), in 1995, can be seen as one of the crucial points that influenced the practice of scientific research in astrobiology. This discovery was made by astronomers Michel Mayor and Didier Queloz (1995), after centuries of conjecture about the plurality of worlds.

Since the first discovery of a planet orbiting a star other than the Sun, more than 5000 exoplanets have been detected (Christiansen, 2022). The question here is, on what kind of planets have they been detected? To explain this, it is first necessary to understand the planets that make up the Solar System.

Fundamentally, planets with average densities between 4 and 6 g $m^{-3}$ are considered rocky, that is, they have a solid surface or crust. This category includes Mercury, Venus, Earth and Mars. On the other hand, planets that have densities between 1.7 and 0.5 g $m^{-3}$ are called gaseous, such as Jupiter, Saturn, Uranus and Neptune that do not have a rigid surface.

All this information is essential, as the detected planets are generally classified as rocky or gaseous, with an analogy associated with planets in the Solar System (Howard, 2013). However, this simplification is not entirely adequate due to the diversity of exoplanets that exist. The classification of rocky planets, for example, can be divided into 'Earth' or 'super Earth' type and gaseous ones can have their subclasses of 'Neptune type', 'Jupiter type' and 'super Jupiter' (Petigura *et al*., 2013). In general, according to Foreman-Mackey *et al*. (2014), planets of the Earth type 5.65%, super Earth 23.96%, Neptune 55.07%, Jupiter 13.72% and super Jupiter 1.60% were detected by the Hubble telescope.

Another point of extreme relevance for changing the conception of the feasibility of developing research in the field of astrobiology, according to Rothschild and Mancinelli (2001), was the discovery of organisms capable of surviving in extreme environments (Table 1) in the middle to 1990. It is important to emphasize that, in 1974, the term extremophile and the possibility of existing beings with this ability had already been mentioned by MacElroy, in his scientific work 'Some comments on the evolution of extremophiles' (MacElroy, 1974; Dick, 2020).

The word 'extreme', even, according to Rothschild and Mancinelli (2001), was coined by the Romans and in the 15th century it came to French and English. Today, it is known that there are beings, previously unimaginable to the 'ancients', living on Earth (Fig. 1) that can be a plausible form of life to exist on Mars, Europa, Enceladus, Titan, in some other part of the Solar System or even in some exoplanet.

Thus, this second discovery related to microorganisms capable of living in extreme environments broadened perspectives on life outside Earth, as it no longer needed to meet anthropocentric standards and made the search for life outside Earth more plausible. Furthermore, another valid point to be highlighted is that this discovery also opened the way for the possibility of life being uprooted and transported from one planetary body to another (Fig. 2).

Thus, at the end of 1990, a large number of science practitioners from different areas (astrophysics, geosciences, chemistry, physics and even people from biology) became interested in this new scientific scenario. The world that before followed the Aristotelian thought 'everything in moderation', after both discoveries began to admit the possibility of extraterrestrial life, with characteristics similar to these extremophiles.

Based on this, the attention of a significant portion of the scientific community became interested in ancient problems of plurality of worlds, which were 'reborn' with great force from the possibility of finding other planets identical to Earth and extraterrestrial lives that no longer needed only follow anthropocentric patterns. Thus, with this abrupt change in the scientific community, paradigms, scientific criteria, research practices and vision of the plurality of worlds, such as astrobiology as a scientific field, were quickly changed.

In 1998, surprisingly, the NASA Astrobiology Institute was founded and the first of several astrobiology roadmaps was built, which served as a research focus for the last two decades (Des Marais *et al*., 2008). At the same time, in Spain, the Center of Astrobiology of Madrid (CAB) was created, with the aim of revising a proposal submitted to NASA by a group of Spanish and North American scientists led by Juan Pérez-Mercader to join the newly created Instituto of Astrobiology at NASA (NAI) (Lemarchand, 2000). After a thorough review and evaluation of the proposal and following an exchange of letters at the government level, the CAB joined the NAI in April 2000, thus becoming the first associate member of the NAI outside the USA. The other NAI associate member centre has been, since 2003, the Australian Center for Astrobiology.

In 1999, NASA's Ames Research Center organized a workshop on the social implications of astrobiology (Harrison and Connell, 2001). This time around 50 academics, from futurists like Alvin Toffler to anthropologists, scientists and journalists gathered to discuss the matter. Not surprisingly, the group stressed the importance of their task: to encourage public understanding of this new scientific field,

***Table 1.*** *Classification and examples of extremophiles (Rothschild and Mancinelli, 2001)*

| Environmental parameter | Type | Definition | Examples |
| --- | --- | --- | --- |
| Temperature | Hyperthermophile | Growth >80°C | *Pyrolobus fumarii*, 113°C |
| | Thermophile | Growth 60–80°C | *Synechococcus lividus* |
| | Mesophile | 15–60°C | *Homo sapiens* |
| | Psychrophile | <15°C | *Psychrobacter*, some insects |
| Radiation | | | *Deinococcus radiodurans* |
| Pressure | Barophile | Weight-loving | Unknown |
| | Piezophile | Pressure-loving | For microbe, 130 MPa |
| Gravity | Hypergravity | >1*g* | Not known |
| | Hypogravity | <1*g* | Not known |
| Vacuum | | Tolerates vacuum (space devoid of matter) | Tardigrades, insects, microbes, seeds |
| Desiccation | Xerophiles | Anhydrobiotic | *Artemia salina*: nematodes, microbes, fungi, lichens |
| Salinity | Halophile | Salt-loving (2–5 M NaCl) | Halobacteriaceae, *Dunaliella salina* |
| pH | Alkaliphile | pH >9 | *Natronobacterium*, *Bacillus firmus* OF4, *Spirulina* spp. (all pH 10.5) |
| | Acidophile | Low pH-loving | *Cyanidium caldarium*, *Ferroplasma* sp. (both pH 0) |
| Oxygen tension | Anaerobe | Cannot tolerate $O_2$ | *Methanococcus jannaschii* |
| | Microaerophile | Tolerates some $O_2$ | *Clostridium* |
| | Aerobe | Requires $O_2$ | *H. sapiens* |
| Chemical extremes | Gases | | *C. caldarium* (pure $CO_2$) |
| | Metals | Can tolerate high concentrations of metal (metalotolerant) | *Ferroplasma acidarmanus* (Cu, As, Cd, Zn)<br>*Ralstonia* sp. CH34 (Zn, Co, Cd, Hg, Pb) |

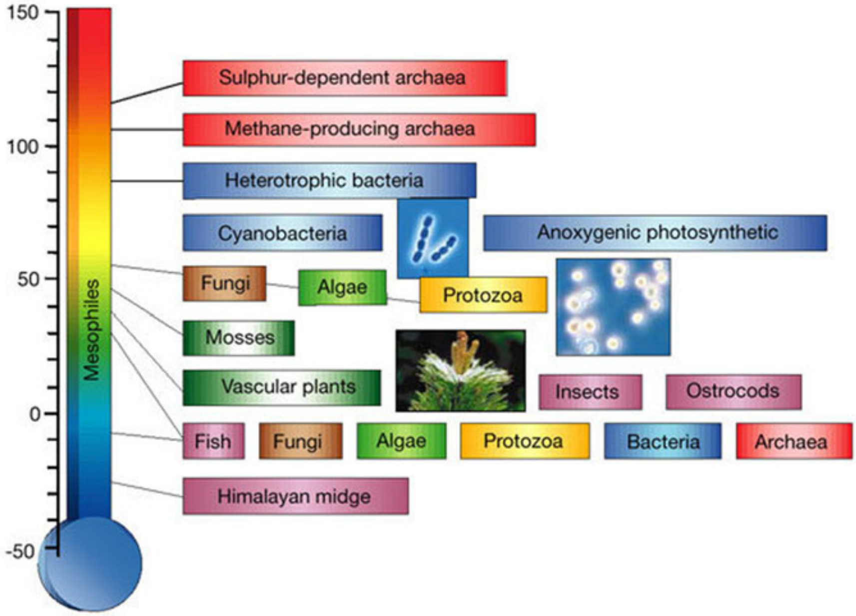


***Fig. 1.*** *Temperature limits for life. The highest and lowest temperature for each major taxon is given. Archaea are in red, bacteria in blue, algae in light green, fungi in brown, protozoa in yellow, plants in dark green and animals in purple (Rothschild and Mancinelli, 2001).*

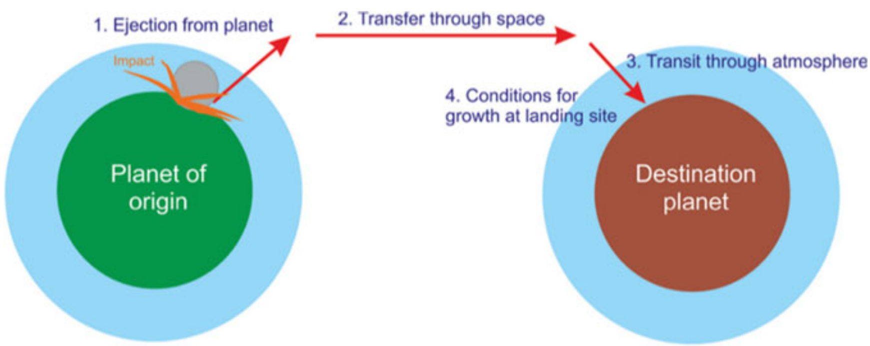


***Fig. 2.*** *Schematic system showing the scatter filters that life must survive to be transferred from one planet to another. The thickness of the atmosphere is exaggerated (Cockell, 2020).*

gauge public reaction to astrobiological discoveries and prepare for the future through policy decisions in the face of 'a possible sea of living worlds' (Dick, 2012).

They strongly advocated carrying out serious levels of research and outreach before the fact of discovery, arguing that such research should be integrated into major scientific initiatives (as would soon be done with the Human Genome Project). 'Science and society are deeply and irrevocably intertwined', they wrote, 'and a mutual appreciation of the close relationship is vital to the integrity of both fields' (Dick, 2012).

The planetary scientist, Constance Bertka, in conjunction with NASA and the Templeton Foundation, in 2003 and 2004, headed the Dialogue on Science, Ethics and Religion programme at the American Association for the Advancement of Science (AAAS), that included ethical and theological perspectives on the origins, extent and future of life in the Earth and Universe (Bertka,

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2009). In 2009, held under the auspices of the NASA Astrobiology Institute, some 43 invited scholars gathered at the SETI Institute to develop an 'Astrobiology and Society' roadmap. However, the societal impact roadmap (Race *et al*., 2012) was not officially adopted by NASA, unlike the science roadmap. Unfortunately, due to the 'Astrobiology and Society roadmap' yet has not become policy backed up by sustained funding.

According to Dick (2012), when the Royal Society of London sponsored a meeting on the detection of extraterrestrial life and the consequences for science and society in 2010 and a satellite meeting seeking a scientific and societal agenda on extraterrestrial life, the organizers wrote:

> 'While scientists are obliged to assess benefits and risks that relate to their research, the political responsibility for decisions arising following the detection of extraterrestrial life cannot and should not rest with them. Any such decision will require a broad societal dialogue and a proper political mandate. If extraterrestrial life happens to be detected, a coordinated response that takes into account all the related sensitivities should already be in place (Dominik and Zarnecki, 2011, p. 503)'.

At that time, specifically in 2011, it was developed by NASA's Baruch S. Blumberg NASA/Library of Congress Chair in Astrobiology to address the humanistic and social aspects of astrobiology in recognition of the importance of these issues. In contrast to the NASA astrobiology roadmap, in 2017–2018 astrobiology and society became a foundational theme for the proposed European Astrobiology Institute (EAI) (Horneck *et al*., 2016; Dick, 2020). Although not yet fully established as of this writing, the EAI systematically laid out the societal issues in a roadmap that bids fair to become an integral part of astrobiology in Europe (Capova *et al*., 2018).

## Conclusion

Based on the perspectives of the history of philosophy of science on the development of thinking about the possibility of life outside Earth, whether in the long or short term, it can be said that the efforts produced so far have not yet been sufficient to generate results. However, the lack of evidence to date should not be taken as evidence of the absence of life beyond Earth. Although there are risks in maintaining a position, in which a perspective is adopted under the Copernican and Darwinian assumptions that the Earth should not be considered as the only one to have an environment conducive for life to evolve by natural selection. According to Fry (2015), it is prudent to think – still without having detected signs of extraterrestrial life, or knowing if there is intelligent life or not – what would be the consequences of finding living organisms, whether in microbial, complex or intelligent form.

In fact, a report by the World Economic Forum (2013) declared as one of the five X factors, the discovery of life beyond Earth, as one of the emerging concerns for planet Earth, having possible future importance, but with consequences still unknown. Paying attention to X factors, the report suggested, would lead to a more proactive approach if and when these events actually occur, resulting in more 'cognitive resilience' and perhaps preventing at least some undesirable social consequences. Such consequences, according to Dick (2020), could occur even if simple alien life were discovered.

The discovery of even simple life would fuel speculation about the existence of other intelligent beings and challenge many assumptions that underpin human philosophy and religion (Ben-David and Freudenthal, 1991). The study of these assumptions and implications is therefore far from being a 'merely' scientific matter. It is a worthy effort, in which there must be a combination between the *fields* of human, social and scientific sciences, motivated and motivating its *agents* (Bourdieu, 2003). In conclusion, even if life outside Earth is never discovered, this mobilization between the different *agents* and their *fields* significantly contributes to a cosmic social perspective necessary in the face of current turbulent times and to our future.

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