FROM PANSPERMIA TO BIOASTRONOMY, THE EVOLUTION OF THE HYPOTHESIS OF UNIVERSAL LIFE

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(Received 3 November, 1996)

Abstract. During the 19th and early 20th centuries, ideas related to the possible origin in space of bioorganic molecules, or seeds, or even germs and organisms (and how they reached the Earth) included the Panspermia theory. Based on the idea of the eternity of life proposed by eminent physicists – such as Arrhenius and Kelvin – 'Panspermia' is mainly divided into two branches: lithopanspermia (transport of germs inside stones traveling in space) and radiopanspermia (transport of spores by radiative pressure of stellar light). We point out some arguments to help to understand whether 'Panspermia' could exist nowadays as the same theory defined one century ago. And we wonder about the kind of evolution 'Panspermia' could have undergone during only a few decades. This possible evolution of the 'Panspermia' concept takes place in the framework of the emergence of a new field, Bioastronomy. We present how this discipline has emerged during a few decades and how it has evolved. We consider its relationship with the progression of other scientific fields, and finally we examine how it is now included in different projects of space agencies. Bioastronomy researches having become more and more robust during the last few years, we emphasize several questions about new ideas and their consequences for the current hypothesis of 'Panspermia' and of universal life.

1. Introduction

About 2300 yr ago, philosopher Epicurus (341–270 B.C.), and later the Epicureans, considered the possibility of universal life, giving the roots of the idea of the existence of other worlds, an idea that had originated with Democritus (460–370 B.C.) and Leucippus (460–370 B.C.) two centuries earlier (Crowe, 1986). Lucretius (98–55 B.C.), and later Bruno (1548–1600), Huygens (1629–1695), Fontenelle (1657–1757), Kant (1724–1804), Goethe (1749–1832) and Flammarion (1842–1925) (among others...) raised this question many times (Crowe, 1986), but it seems that Huygens (1698) was the first one to ask: 'How in practice can we observe other planetary systems?'.

Charles Darwin (1809–1882) himself accepted pluralism of life in the cosmos, and in fact this cosmic perspective may have facilitated his attempt to explain by naturalistic means the origin of various terrestrial forms of life (Crowe, 1986).

After many decades of scientific investigations (and more than 2000 yr of continual questioning) about extraterrestrial life, the search for life in the universe

Origins of Life and Evolution of the Biosphere **28:** 597–612, 1998.

and the questions about the eventuality of a universal life, covered today by the term ‘Bioastronomy’ (or ‘Exobiology’), has developed considerably.

On the other hand, ‘Panspermia’ theories, born during the XIXth century, enabled some thinking about the transport of life in space and the sowing of planets by germs. Starting from the concept that life would have been as eternal as the universe, ‘Panspermia’ supported the idea of the eternity of processes leading to the emergence of life.

Have the discoveries made in this new field of scientific researches about extraterrestrial life (Bioastronomy) influenced the ‘modern’ view about ‘Panspermia’? Has the meaning of ‘Panspermia’ changed since its emergence in the middle of the last century?

In this paper we aim to investigate how the scientific developments and the intellectual evolution of our century have altered the terms in which ‘Panspermia’ can be formulated today.

2. Birth of ‘Panspermia’

It seems that the rigid interpretation of the results of the French biologist L. Pasteur (1822–1895) as a refutation of spontaneous generation bolstered the belief that life was necessarily antecedent to life (Kamminga, 1982). However, this left the question of how the first living things arose (Dick, 1996). From that point of view, the concept of eternity of life (suggested during Antiquity) was curiously revived by experimental arguments. The question of ‘how did life appear?’ had no meaning in this context, and the problem of the origin of life on Earth became a problem of physics: ‘what could be the possible mechanisms for the interplanetary transfer of organisms?’ (Kamminga, 1982).

The ‘modern’ theory, with the inclusion of the possible development of life first in an extraterrestrial place followed by subsequent migration to the Earth, had been proposed in 1865 by the German physician Hermann E. Richter, a defender of Darwin who advocated the meteoric origin of life on Earth (lithopanspermia). In 1871, William Thomson (1824–1907) (Lord Kelvin), supported (during the Naturalists Congress of Edinburgh) the same thesis of a sowing by germs carried by meteorites falling on the Earth. The German physicist Hermann von Helmholtz (1821–1894) revealed in 1875 that he had arrived at the same hypothesis slightly before Sir William Thomson (Crowe, 1986). A few years later (in 1884), Ph. Van Tieghem (1839–1914), a well known French botanist, defended the same idea in his *Traité de botanique* (Crowe, 1986). At last, the Swedish chemist Svante Arrhenius (1859–1927) suggested in 1907 another version of Panspermia: germs would have been ejected from planets outside the solar system and would have been scattered in the galaxy where, carried by the radiative pressure of stars (radiopanspermia), they would finally have encountered and sown our planet (Arrhenius, 1908). Every hypothesis supported the idea that life was eternal and the sowing of planets a continuous process.

French agronomist Paul Becquerel (nephew of the physicist Henri Becquerel) undertook experiments to test the Arrhenius's hypothesis. He studied the U.V. interactions with spores (such as *Aspergillus niger*) and bacteria at very low temperatures and high vacuum. The results were negative: the spores did not resist the U.V. conditions he used, and he concluded that they would have a killing action on living material. And Becquerel then deduced that spores should be destroyed during their travel between the stars and that the interplanetary medium would be completely sterilizing. His conclusion was clear: life must have a terrestrial origin (Becquerel, 1910a). Nevertheless, he thought that the biological processes which had occurred on the early Earth could happen on other worlds. He proposed a 'universal cosmic hypothesis', in which there is an eternal evolution of matter and energy (Becquerel, 1910b).

At that time, none of the scientific hypotheses related to the origins of life on Earth was yet born, even if the experiments undertaken by L. Pasteur in 1860 showed that life was not a spontaneous process (Maurel, 1995). The Russian biochemist A. I. Oparin (1894–1980), one of the pioneers of biochemistry in the Soviet Union, was the first in 1924 to propose a well-argued scientific scenario leading to bioorganic molecules on primitive Earth (Oparin, 1938). Oparin did not reject Panspermia, but he agreed with others that such a theory only pushed the question of origins to some other planet (Dick, 1996). Oparin was particularly interested in the basic question of whether there is a fundamental difference between living and dead things, and he felt that to discover the conditions under which the properties of life were conjoined, would be to explain the origin of life (Dick, 1996). Another pioneer, British chemist J. B. S. Haldane, independently suggested a terrestrial scenario with a gradual process of evolution (Haldane, 1929) just before Oparin's model of chemical evolution (English edition, 1938). The most important influence of the Oparin-Haldane hypothesis was the experimental work it inspired: it became possible to investigate a kind of 'spontaneous generation', namely the generation of complex organic molecules by chemical synthesis (Dick, 1996). The biochemist M. Calvin undertook in 1951 the first experiments designed to synthesize organics compounds under conditions consistent with the primitive Earth's environment (Garrison *et al.*, 1951), but very different from Oparin's proposal (i.e. mainly composed of CO_2). The subsequent experimental work by the American chemist S. Miller (Miller, 1953) was the first to put the hypothesis of the reducing atmosphere suggested by Oparin into practice, and this led the way to a new experimental field of organic chemistry, namely prebiotic chemistry (Maurel, 1994).

3. Would ‘Panspermia’ Be Still Alive?

In the 1950s, an astrophysicist of Russian origin, Otto Struve (1897–1963), proposed a variation of Arrhenius’s theory, suggesting that life may be carried from planet to planet by intelligent, though not necessarily intentional, intervention (a sort of prelude to the Crick’s hypothesis proposed a few decades later).

The discovery of extraterrestrial structures interpreted first as ‘germs’ in carbonaceous meteorites strengthened the hypothesis of the occurrence and travel of life in universe, and seemed to bring new modes of construction to the ‘Panspermia’ theory. In 1961, G. Claus and B. Nagy thought they had found microbiological organisms in the Orgueil meteorite that had fallen near Montauban (France) in 1864 (Claus and Nagy, 1961). But, further examinations of the structures demonstrated that they were made by terrestrial microbiological contaminations. ‘Panspermia’ thus moved back one pace. It happened that at the same time, the first identification of amino acids in carbonaceous meteorites had been made by Kaplan *et al.* in 1963 (Kaplan *et al.*, 1963). Amino acids are not life, but the presence of some of the building blocks of life in extraterrestrial materials was a way open to the universality of bioorganic chemistry. Meteorites and comets were supposed to be the best means of transport of living organisms or at least basic organics for life.

Seventy years after the hypothesis of Nobel Laureate Arrhenius, another Nobel prizewinner, British biologist Francis Crick, boldly suggested that life arose on Earth because some extraterrestrial organisms were deliberately transmitted to the Earth by intelligent beings on another (extra-solar) planet in order to develop life on Earth: this was called ‘directed Panspermia’ (Crick and Orgel, 1973). This theory was supported mainly with the argument that life would have had enough time to emerge twice during the evolution of the universe (Crick, 1981). At the same time, astrophysicists Fred Hoyle and Chandra Wickramasinghe proposed the idea of a sowing of the Earth by bacteria coming from space via comets (Hoyle and Wickramasinghe, 1979). It was yet another version of Panspermia. In his famous book *The Black Cloud*, Fred Hoyle described the emergence of a form of (‘bioelectromagnetic’) complexity built out of plasma, magnetic fields, hot gas, and dust (Morrison, 1963).

In fact, these Panspermia theories have been proposed since theories about life’s emergence on Earth have narrowed the time between the formation of the Earth and the first microfossils; moreover, the ‘primitive soup’ hypothesis has been much debated by these scientists because they estimated that the ‘soup’ was much too ‘light’ to lead to living organisms. Scenarios that supported extraterrestrial organics coming from comets and meteorites could offer some comfortable explanations to thicken the ‘soup’. It seems today that the problems with the ‘short’ time-scale between the Earth’s formation and the first living organisms are not absolutely solved. Cyanobacteria living 3.5 billion years ago (Awramik, 1983) would have been rather evolved if one takes into account their biological acquisitions: this remark (if it owns a real scientific validity) seems to show that life could have so existed maybe hundreds of millions of years before terrestrial cyanobacteria or even before the Earth's formation. From that last point of view, Panspermia seems to be reviving: bacterial life could have come from elsewhere in the universe, removing the problem of short time-scale on our planet.

The 'Panspermia' hypothesis was also resurrected by the discovery in 1973 of a low-temperature quantum limit of a chemical reaction rate, in studies of radiation-induced polymerisation of formaldehyde (Goldanskii, 1973): that quantum tunneling permits chemical reactivity and finite reaction rates, even at very low temperature (close to absolute zero). Caused by quantum tunnelling, this type of reaction can lead to the exothermic formation of quite complex molecules (Goldanskii, 1993). N. C. Wickramasinghe and F. Hoyle examined the possibility of building complex molecules under combination of deep cosmic cold and various radiations of cosmic origin (Wickramasinghe, 1974; Hoyle and Wickramasinghe, 1977). Thus quantum tunnelling would suggest the possibility of a cold pre-history of life and it would be possible to consider interstellar grains as possible cold seeds of life (Goldanskii, 1977). The contribution of J. M. Greenberg to the understanding of the reactions between mantles of grains and the formation of complex molecules (Greenberg, 1974) strengthened the hypothesis of prebiotic evolution in interstellar clouds.

4. Early Stages of Answers to Huygens's Questioning

The fundamental question raised by Ch. Huygens three centuries ago about the possibility of observing other planetary systems began to be addressed after 1930. Since the first flyby of the Moon in 1959, planetary exploration has developed and the origin of the solar system has been characterized by more robust hypotheses. The proposed solutions suggest that the process of formation of planets around the sun was not necessarily an exception in the universe, and the question clearly arises: is our solar system a rarity or do many stars have their own?

The Dutch astronomer P. Van de Kamp is the first scientist (in 1938, at Sproul Observatory, U.S.A.) who started to look for planets around other stars (Van de Kamp, 1945); he used methods involving perturbations of the central star position. He detected 'something' (the presence of two planets of Jupiter size?) around Barnard's star (Van de Kamp, 1969) and this remained for many years the first and only hope for extrasolar planets. But, unfortunately, it appeared that only artefacts were responsible, not planets, resulting from the limitations of instrumentation (Davoust, 1991) (systematic errors in the telescope and measuring system had probably led to the apparent wobbles of Barnard's star).

Following this disappointment, several years of doubts hampered the scientific community, when planetary systems were considered to be extremely rare in the universe.

5. Searching for Interstellar Communications

Around the 1960s, it appeared that, although there is apparently little chance of discovering ‘intelligent’ extraterrestrial life via direct contact, we can attempt to overhear transmissions that have either leaked from an extrasolar planet or have been deliberately beamed into space in order to be detected. This new approach became feasible only after the detection of microwaves by means of radiotelescopes had considerably developed.

The first modern scientific strategy related to the search for a hypothetical ‘intelligent’ extraterrestrial life came in 1959 from Giuseppe Cocconi and Philip Morrison (Cocconi and Morrison, 1959). In their paper ‘Searching for Interstellar Communications’, they proposed that a search should be made at the radio wavelengths of the electromagnetic spectrum for signals originated by extraterrestrial intelligence, since photons are the ideal particles for transmitting information over very long distances in space, and since the microwave region is the only one that is fairly quiet in our galaxy. They indicated that decimetric wavelengths were the best ones for propagation in space, and they suggested that the characteristic wavelength of 21 cm from hydrogen (the most abundant element in the universe) would be a universal wavelength. This should be the wavelength at which astronomers should listen.

In 1960, astronomer Frank Drake was the first to search for extraterrestrial intelligent signals by listening at this wavelength. He looked at two sunlike nearby stars (Tau Ceti and Epsilon Eridani) at this wavelength with the help of the giant radiotelescope Green Bank (West Virginia, U.S.A.). This was the project Ozma (Drake, 1961), followed in November 1961 by the Green Bank Conference on Extraterrestrial Intelligent Life. The same year, a mathematical formula was built by F. Drake, the famous Drake equation (also called the Green Bank equation), which attempted to simplify the difficulties of estimating (by means of probability products) how many technological civilizations available for communication could exist in our galaxy (N) (Pearman, 1963)

$$N = N_* x N_{\mathrm{pl}} x N_H x N_L x N_{Evol} x N_{Comm} x L$$

N_* = rate of star formation;

N_{pl} = fraction of stars which have planetary systems;

N_H = average number of planets per planetary system which fall in a ‘habitable’ zone;

N_L = fraction of habitable planets on which life arises;

N_{Evol} = fraction of planets with life on which intelligence arises;

N_{Comm} = fraction of intelligent species that evolve to a technological stage that enables technological civilizations;

L = lifetime of such technological civilizations.

Drake’s formula is of course a framework of thoughts rather than a rigid equation with a single solution. The first term of this formula is the only one well known, and the other ones are very uncertain or even fully unknown. Furthermore, the formula was based on a terrestrial life model. And it seems difficult to generalize from just one very well known planetary system, the solar system. Other forms of life, other types of biochemistry, could be imagined ... and lead to many questions. This formula underlines our ignorance of the many parameters.

6. Birth of SETI

Some radioastronomers and astrophysicists have joined together in a search for extraterrestrial intelligence to try to pick up interstellar messages: from this collaboration, the committee CETI (Communication with ExtraTerrestrial Intelligence) was born in 1965: the concept and the word were introduced into the International Academy of Astronautics (founded in 1960) by the Soviet astronomer R. Pesek (Almar, 1988). The term CETI changed to SETI (Search for ExtraTerrestrial Intelligence) in 1986 in order to express its growing interest in every possible kind of search for extraterrestrial civilizations (Almar, 1988).The main aim was to look for artificial signals among millions of wavelengths from stars with the help of a radio-receiver containing several millions of channels.

The French radiotelescope of Nançay (France) has been used since the 1980s for SETI searches, and many SETI observations of stars have been carried out. Some astronomers such as Jill Tarter and François Biraud have analyzed data obtained with the help of the Nançay radiotelescope, the Arecibo radiotelescope or the antenna at the Goldstone Deep Space Network site (U.S.A.). About 4O instruments in total have been used by SETI’s teams to search for extraterrestrial life. Astronomer Jean Heidmann, whose primary work dealt with observations of galaxies and the expansion of the universe, entered into the ‘SETI club’ through radio observations of these galaxies with the neutral hydrogen 21 cm line (Heidmann, 1995).

In 1972, the first message engraved on an aluminium plate (showing a man, a woman, the solar system, a hydrogen atom and the positions and periods of 14 pulsars) was sent in space on board the Pioneer 10 and Pioneer 11 spacecrafts. After flybying Jupiter, Pioneer 10 has travelled beyond the solar system and now seems to be heading towards the constellation Orion, while Pioneer 11 has left the solar system in another direction.

Another way to communicate was used in 1974 with the Arecibo radiotelescope (Puerto Rico): a message was sent towards M13 (globular cluster) at the wavelength of 13 cm, written in a binary system language and representing atomic weights of some elements, a few molecules of DNA, a human being (with its height and its weight on the Earth), the position of the Earth in the solar system, and finally the radiotelescope with its dimensions.

A different type of process is to consider the physical and biochemical aspects of organisms in order to search for extraterrestrial eukaryotes (SETE). According to J. Chela-Flores, one possibility seems to be feasible: searching for cellular division and the related delay in replication of heterochromatic chromosome segments. A SETE program could distinguish between a primitive eukaryote and a prokaryote, and finally help to understand whether an organism in an extraterrestrial planet, or satellite, has taken the first steps towards eukaryogenesis (Chela-Flores, 1996).

In the case of extraterrestrial civilizations, attempts to communicate seem nowadays to have been replaced by more specific projects, such as a better understanding of planetary formation, the emergence of life, and the identification of planetary environments suitable for life. Finally, it is possible that the more we suspect the presence of extraterrestrial life in universe, the more we want to try to prove it by rational means.

From a (terrestrial) biological point of view, it seems that we have more and more partial answers to the question ‘What is life?’. But some fundamental problems remain. For instance, the failure of quantum mechanics to make classical systems such as measurement apparatuses emergent beyond the limit of quantum systems opens the possibility that ‘life’ is a genuine level on its own, not a construction of complex systems. From an exobiological point of view, these problems give rise to deeper reflections about ‘Could life be universal?’.

7. Martian Life and Panspermia

Italian astronomer Giovanni Schiaparelli (1835–1910) observed the Martian surface at the end of the 19th century and described many giant channels whose regularity was for him too strong to be natural. He advanced a hypothesis for the existence of a Martian life, sufficiently ‘intelligent’ to build such structures. American astronomer Percival Lowell (1855–1916) spent money to have an observatory built (in Flagstaff, Arizona) in order to examine in detail the channels (Raulin *et al.*, 1997). But we have to wait until the 1940’s to get a confident answer to this enigma: high-quality views of Martian surface obtained from Pic du Midi Observatory (France) showed faults instead of channels.

With the help of planetary exploration, a better understanding of environments required for the emergence and development of life has been possible. Astrophysicist Carl Sagan had an especially important role in the consolidation of researches on extraterrestrial life (Cooper, 1976). In 1976, at Sagan’s instigation, the first exobiological experiments on board of Viking landed on the surface of the planet Mars. They searched for evidence of microbiological life or bioorganic chemistry in the Martian soil. But no biological signatures (nor even organic molecules) were found either in the atmosphere or on the surface. Voyager probes, whose encounters with the giant planets occurred in 1980/89, gave a good crop of information related to organic compounds, indeed even to prebiotic molecules, in planetary environments such as Titan's.

The existence of life on Mars has long been debated. While it is highly unlikely that any advanced form of life currently exists on Mars, many scientists feel that microbial forms of life might exist below the surface. The detection of organic compounds would provide much evidence for the possible existence of life (past, if not present) on Mars.

Quite recently (August 1996), a paper entitled 'Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001' (McKay *et al.*, 1996) clearly suggested that life has been present on Mars. The analysis of one of the Martian meteorites found in Alan Hill (Antarctica), the 4.5 billion-year-old orthopyroxenite Allan Hills (ALH) 84001, showed the existence of carbonate globules 3.6 billion years old, purported to be the result of biogenic processes, and abundant polycyclic aromatic hydrocarbons (PAHs). One of the interpretations proposed in this work would be that these observations correlate with the past presence of Martian bacteria. In fact, this paper was not the first one to clearly consider the existence of Martian microfossils: in 1989, Colin T. Pillinger and his colleagues described 'evidence' of microfossils embedded into the Martian meteorite EETA79001 (Wright *et al.*, 1989). And today, it seems that 'counter-evidences' presently follow 'evidences'. These hesitations show that discoveries of highest importance as these ones must be treated with the greatest caution: this case represents an interesting example of the significance of scientific criticism and doubt, in the context of the history of scientific concepts.

This hypothesis of Martian past life raises a question: if past life could come to Earth by means of meteorites (we could call it 'past-lithopanspermia'), why couldn't extraterrestrial living bacteria arrive in good health on the terrestrial surface?

8. Birth of Bioastronomy

In 1982, the International Astronomical Union (IAU) created a special committee (commission 51) with M. D. Papagiannis as first President, entitled 'Bioastronomy, search for extraterrestrial life', a new field embracing the following principal topics (Papagiannis, 1984):

- search for extrasolar planets;
- planetary evolution and possibility of life;
- detection of extraterrestrial radio messages;
- search for organic molecules in the universe;
- detection of primitive biological activity;
- collaboration with other international organizations.

Subsequently, hopes increased for discovering planets around other stars.

In 1983, IRAS (InfraRed Astronomical Satellite) demonstrated with significant infrared signatures that many young stars are surrounded by compact dust clouds, interpreted as protoplanetary and debris disks (such as Beta Pictoris's disk). This has been recently confirmed by Hubble Space Telescope observations. The discovery of several stars surrounded by gas and dust disks stressed the fact that the formation of planets might not be a singular process in the universe. Since the observations of P. Van de Kamp, much effort has been spent to detect extrasolar planets, particularly with the development of ground-based techniques such as radial velocity and astrometric methods. Brown dwarfs (very massive planets with a mass between 13 and 80 times Jupiter's mass) have been identified by means of central star perturbations methods.

Reflection by various authors on the presence of life around other stars has resulted in the concept of a 'habitable zone'. It is the distance at which (according to the formula:

$$T_{\text{planet}} = (1 - A)^{1/4} T_{\text{star}} (R_{\text{star}}/2a)^{1/2} \ ,$$

with T_{star} temperature, R_{star} radius, A albedo of the planet, and a orbital distance of the planet to the star), a planet can sustain liquid water. The underlying prejudice is that life represents a complex chemical phenomenon requiring a liquid/solid interface, with water as the most favourable liquid. For a solar-type star, the consequent star-planet distance is near the Earth-Sun distance (1 UA).

The first detections of extrasolar planets were made possible by the improvement of spectroscopic techniques. They currently achieve a precision of 3 m s^{-1}, sufficient to detect the variations of radial velocity of a star under the gravitational influence of a planet like Jupiter (which causes a modulation with an amplitude of 13 m s^{-1}). But, even with a much higher (by a factor of 3) radial velocity, it seems that it will not be possible to detect Earth-like planets in the habitable zone by this method (Schneider, 1996a).

Since the 1970s, the idea that planets could be searched by timing of pulsars has been discussed. In 1976, Demianski and Proszynski suggested that there might be a large mass planet around the binary pulsar PSR B1620-26 (Demianski and Proszynski, 1976). In 1993, Wolszczan and Frail found 3 planets around PSR 1257+12 at Arecibo radiotelescope; finally it appears that this pulsar has a 4th planet (Wolszczan, 1997). In the meantime, the planet around the binary pulsar PSR B1620-26 was confirmed (Arzoumian *et al.*, 1996). These last years produced more results about extrasolar planets than the six previous decades since Van de Kamp, even if these results are not absolutely confirmed. Swiss astronomers Michel Mayor and Didier Queloz discovered in 1995 (Observatoire de Haute-Provence, France) a Jupiter mid-mass planet around the star 51 Peg (although this discovery is now disputed: Gray, 1997; Pan *et al.*, 1997). About ten Jupiter-like planets have now been found around other stars (Mayor and Queloz, 1995; Marcy and Butler, 1996; Butler and Marcy, 1996; Cochran *et al.*, 1997; Butler *et al.*, 1997; Noyes *et al.*, 1997) (see Table I). None of them falls within the habitable zone of its star, except

70 Vir b. This planet, having at least 6.6 Jupiter masses, is very probably gaseous and there would be no possible biochemical activity at a liquid/solid interface. However, it is quite likely that this planet has an Earth-like satellite (similarly to our Jupiter and Saturn) on which water and solid rocks could co-exist, with the subsequent development of complex organochemical phenomena.

A new perspective called the ‘Darwin project’ has arisen very recently. The search for biochemical activity in planets around stars has now become a reality. After J. Lovelock’s suggestion (Lovelock, 1975) to search for out-of-equilibrium molecules, mainly O_2, T. Owen has suggested that these molecules could be found in spectroscopic observations of planets. This idea is very difficult to implement for two reasons: first, because the star-to-planet brightness ratio is very small (typically 10^{-9} in visible light), and second because, seen from the Earth, a planet is very close to its parent star, so that it falls inside the diffraction halo made by the star in an image taken by a telescope, and thus, it is presently impossible to separate the star and the planet. The current adaptative optics projects do not attenuate sufficiently the star’s light to make this observation possible.

A few solutions have been proposed to circumvent these problems: instead of separating spatially the planet and the star, it is possible to sound, under favourable circumstances, the planetary atmosphere during a transit in front of the star: it is then possible to measure its composition by absorption lines obtained in the spectrum of the parent star (which is then partially seen through the planet’s atmosphere) (Schneider, 1994). This method requires a very large telescope, and is possible only if the planet’s orbit is oriented so that the planet passes periodically in front of the star. It is thus a justification for searching for planets by the observation of their transits. It is also possible to occult the parent star by an occulting screen on an orbit with a telescope sitting on the same orbit, but in counter-rotation with respect to the occulting screen (Schneider, 1996b). Lastly, instead of searching for oxygen, the search for ozone at 9.6 microns is easier, since the planet to star brightness ratio is then 10^{-6}. The spatial star/planet separation can be made by a ‘nulling’ interferometer as proposed by Bracewell (Bracewell, 1984). This project was submitted to the European Space Agency in 1993 (Leger *et al.*, 1996) and is now under consideration; a similar project has subsequently also been submitted to NASA (Angel and Woolf, 1997). Due to budgetary limitations, these space projects will not be launched (if approved) before 2010–2015.

9. A New Place for Panspermia?

Analyses of carbonaceous chondrites such as Murchison and Orgueil provided a lot of information related to organic (indeed even prebiotic or biogenic) compounds of extraterrestrial origin. With the development of microtechniques of analysis, it was also apparent that micrometeorites carry a large quantity of carbonaceous compounds. Among more than 70 amino-acids identified in carbonaceous chondrites,

Table I

Catalog of confirmed extrasolar planets (regularly updated on Internet at the URL http://www.obspm.fr/planets)

Star	Planet			
Distance (light years)	M (sin i) Mass Jup. (J) Mass Earth (E)	Orbit (AU)	Period years (y) days (d)	Eccentricity
PSR 1257+12	A 0.015 (E)	0.19	25.34 (d)	0.0
∼1000	B 3.4 (E)	0.36	66.54 (d)	0.0182
	C 2.8 (E)	0.47	98.22 (d)	0.0264
	D 100 (E)	40 (?)	170 (?) (y)	
51 Peg (?)	0.47 (J)	0.05	4.2293 (d)	0.0
45				
Ups And	0.68 (J)	0.057	4.611 (d)	0.109
47				
55 Cnc	A 0.84 (J)	0.11	14.648 (d)	0.051
45	B >5 (J)	>4	>8 (y)	–
16 Cyg B	1.5 (J)	1.7	804 (d)	0.67
72				
47 Uma	2.8 (J)	2.11	2.98 (y)	0.03
45				
Tau Boo	3.87 (J)	0.0462	3.3128 (d)	0.018
49				
70 Vir	6.6 (J)	0.43	116.6 (d)	0.4
80				
PSR B1620-26	<10 (J)	∼20	∼100 (y)	–
∼4000				
Rho CrB	1.1 (J)	0.23	39.645 (d)	0.028
50				

eight are biogenic molecules (they are part of the building blocks of proteins). Five biogenic molecules, building blocks of DNA, have also been detected in carbonaceous chondrites.

The detection of many organics in carbonaceous chondrites and micrometeorites has strengthened the hypothesis of a sowing of the Earth 4 billion years ago by organic materials leading to the first biogenic ones. According to this argument, this was a sort of 'Panspermia' theory, but this one assumes that what was traveling 4 billion years ago from space to Earth was not life, but only its building blocks, chemical ingredients which could yield life.

Since the 1970s, work on the survival of bacterial spores in space showed that 'Panspermia' could be supported by experiments undertaken on board spacecrafts and artificial satellites (Horneck *et al.*, 1974). It seems that space has been generally viewed as extremely hostile to all forms of life, due to high vacuum, the complex radiation field and extreme temperatures (Horneck *et al.*, 1994). Parameters such as vacuum, solar electromagnetic radiation up to the highly energetic vacuum-U.V. range and cosmic radiations were considered. German biologist G. Horneck tested the resistance and analyzed the responses after retrieval of some bacterial spores (mainly *Bacillus subtilis*) exposed to the space environment. For example, the study has been carried out for nearly six years on board of the NASA Long Duration Exposure Facility (LDEF) and for 11 months on the European Retrievable Carrier (EURECA). After 6 yr spent in space vacuum on the free-flyer satellite LDEF, there was a significant percentage of viable spores even with no protection against dehydration. On the other hand, it seems that solar U.V. radiation would be the most deleterious parameter reducing survival spores if exposed without any shielding (Horneck, 1993; Horneck *et al.*, 1994).

Bacterial spores can survive over several years in space, provided they are protected against the high influx of solar U.V. radiation, by means of dust or soil particles, or by shadowing, or else by thick layers as they occur in bacterial colonies (Horneck, 1993; Horneck *et al.*, 1994). Whatever the limiting parameters, the concrete results with spore viability obtained on LDEF or other spacecrafts gave some additional support for the possibility of interplanetary transfer of life, in some protective conditions. Nevertheless, experiments on board of EURECA I using spores embedded in clay or in simulated Martian soil ('artificial meteorites') have been analyzed and some difficulties emerged: in the vacuum-exposed samples, no viable spore was found. This result, if confirmed, would limit the chances of interplanetary transport of spores embedded in rock material (Horneck *et al.*, 1995).

These 'modern' experiments are somewhat reminiscent of the experiments mentioned at the beginning of this paper undertaken by P. Becquerel: 80 yr later, even if the experiments have considerably evolved and the results are more specific, it is clear that the idea of testing bacterial resistance to space, and then 'Panspermia', is still alive.

10. Conclusions: What Does 'Universal Life' Mean Today?

Fantastic progress in several scientific fields has led to another view of the hypothesis of a 'Universal Life', and has demonstrated that this concept was only understandable considering pluridisciplinary researches, namely:

- planet, small bodies and meteorites observation and exploration;
- space organic chemistry;
- molecular biology and biochemistry related to origins of life, and biological evolution;
- Precambrian paleontology and isotopic analysis;
- organic chemistry in laboratory and simulation experiments;
- search for extrasolar planets;
- search for extraterrestrial intelligence.

At the beginning of this century, the arguments about extraterrestrial life seemed to have had no experimental basis. The XXth century has seen the explosion of the fields mentioned above, and in this way, has brought to light some questions and consolidated some hypotheses. But some basic points are still unsolved, such as one of the oldest: ‘what is life?’, in the sense ‘is life a continuum of complex organic evolution?’, that is, one of the forms of a universal evolution? Or ‘is there a break in the type of evolution (chemical to biological)?’, such that life would be a fortuitous, unlikely event, and so ‘what would then be the chances, the probabilities of the emergence of life elsewere?’

We don’t know yet if many Earth-like planets exist in our Galaxy, but it is possible that planetary systems would not be rarities in the universe. If no extraterrestrial messages have yet been detected with radio-wavelengths, the technological development of receivers has considerably increased the possibilities for listening to stars. The discovery of many organic molecules in interstellar space, in planetary environments, in comets, meteorites and micrometeorites would be some proof of, at least (if life is unique to the Earth), a universal organic chemistry. In this context, and considering the results from fields related to ‘Bioastronomy’, it seems that nowadays ‘Panspermia’ could focus much more on the sowing of planets by complex organic compounds. But the debate is not closed. Though still unconfirmed and much debated, the existence of past Martian bacteria is tentatively accepted in the scientific community. The same story happens for the detection of extrasolar planets, which is still much debated. But the two stories show that these scientific results, which consist in switching from a terrestrial and unique notion of life and environment for life to a universal notion, need time and very robust consolidations. Moreover, it would be the first time that experimental works would lead the scientific concepts to evolve towards a universal view of life and Earth-like planets.

Experiments and observations have shown that space would not be so hostile as we thought a few decades ago. From that point of view, ‘Panspermia’ would be stronger than at the beginning of this century, when mainly only speculations on that topic were possible. We can conclude that there is a partial renewal of the idea that life could come from space even if ‘Panspermia’ is nowadays more limited than a few decades ago: life is no more considered to be eternal.

Nevertheless, it seems that ‘Panspermia’ as a myth has been supplanted by ‘Bioastronomy’: scientific facts replace the ‘archetypes’ which, one century ago, tried to represent the duality of Earth/Heavens. Furthermore, the notion of timescale and eternity has considerably changed during the 20th century. Eternity of life and universe was supported by the ‘Panspermia’ theory. Nowadays, the term ‘eternity’ owns a different meaning built on scientific parameters, and the notion of ‘origins’ (of life and universe), which has appeared during this century, has been considerably clarified and must be discussed within the debate about the concept of ‘Time’ (Derrida, 1976; Schneider, 1995).

Acknowledgements

We thank Dr. William J. Hagan for his suggestions and his constructive criticism of our manuscript.

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