Series

What history tells us X. Fifty years ago: the beginnings of exobiology

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1. Introduction

In a few weeks the fiftieth anniversary of the October 4th, 1957 launch by the Soviet Union of the first artificial Earth satellite, Sputnik-1 will be celebrated. This event had dramatic consequences for the relations between the United States and the Soviet Union, and more generally remodelled global geopolitics. This entry of mankind into the space age also deeply affected our day-to-day life, with the rapid use of artificial satellites in communications and observations of Earth.

It might seem out of place to celebrate this event in a journal devoted to the biosciences, but there is a good reason: the launch very rapidly led to the development of exobiology, i.e. the active scientific search for extraterrestrial life. Two biologists, John Haldane and Joshua Lederberg, and the discussions they had in Calcutta in November 1957, had a major role in this rise. The highly publicized recent development of astrobiology at the end of the 1990s was only a "renaissance" of exobiology (Dick and Strick 2005).

My aim is neither to retrace the complete history of exobiology and astrobiology – this would take too long, and has already been excellently done (Dick and Strick 2005) – nor to focus on questions of science policy, the action of NASA as a scientific entrepreneur or how the politic context, the Cold War, impacted on space research in general, and exobiology in particular (Wolfe 2002). Instead, I intend to describe the contrasting attitude of biologists towards the rise of exobiology, and the search for life on planets other than Earth, from the enthusiasm of Lederberg, Alexander Rich and Norman Horowitz to the harsh criticisms of George Simpson, Ernst Mayr, and most evolutionary biologists. The debate which was initiated then is still active today, and knowledge of this historical episode can help us avoid repeating the same arguments as those exchanged at this period. More interestingly, a careful description of this past debate reveals different opinions about what life is and how it evolved that are still prevalent among biologists.

2. The early involvement of Lederberg in exobiology

The active involvement of Lederberg in exobiology preceded the award of the Nobel Prize in 1958, although the latter gave him the means to advance his ideas. Lederberg famously demonstrated in 1946, at the age of 21, the existence of genetic exchange among bacteria. This discovery represented the birth of bacterial (and bacteriophage) genetics, the importance of which was considerable in the development of molecular biology (Morange 1998).

In October 1957, Lederberg was in Australia, visiting the laboratory of MacFarlane Burnet, and discussing the mechanisms of antibody synthesis (Lederberg 1987). These discussions gave rise, two years later, to another famous paper by Lederberg, in which he linked Burnet's clonal selection theory to recent results on protein synthesis obtained by molecular biologists, and definitely rejected the instructive model hitherto dominant that the antibody moulds itself on the antigen it recognizes (Lederberg 1959). Lederberg left Australia to visit Haldane, who had recently settled in Calcutta. They spent nights discussing the launch of Sputnik-1 and its consequences, and imagined that the communist leaders might decide to send a vessel carrying an atomic bomb to the Moon and provoke an explosion visible from Earth to celebrate the fortieth anniversary of the October Revolution.

Lederberg found this prospect, which happily did not materialise, frightening because such an explosion would contaminate the surface of the moon and prevent further studies of life forms existing elsewhere than on Earth

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(Lederberg and Cowie 1958). Lederberg introduced the term exobiology for the first time during a conference held in Nice (France) in 1960, and popularized it in an article published in *Science* the same year (Lederberg 1960). He pressed the American authorities, and later the leaders of the newly created spatial agency, NASA, to develop a programme designed to search for extraterrestrial forms of life, and simultaneously to protect them from contamination by terrestrial organisms (Sagan *et al* 1968), as well as to protect Earth against possible contamination by these exo-organisms. For the latter reason, Lederberg favoured the development of automatic vessels for the search for life on Mars. He took an active part in the development of the NASA exobiology programme (Dick and Strick 2005), and in the design of the experiments conducted on board the Viking vessels that landed on Mars in the summer of 1976 (Klein *et al* 1976a). Although the ambiguous (Klein *et al* 1976b), but rapidly considered negative, results obtained – absence of any organic compounds on the surface of Mars (Biemann *et al* 1976) – stopped the development of similar missions for a while, the biological module of the Viking vessels was an unequivocal technological success and constituted a huge leap forward in the design of experiments aimed at uncovering evidence of exo-forms of life.

3. A favourable context

How is it possible to explain the rapid interest of Lederberg in the existence of extraterrestrial organisms, and the swift rise of exobiology? As we have seen, his first motivation apparently was the fear of contamination. Such a fear was widely shared at this period of Cold War, when both the United States and the Soviet Union tested more and more powerful nuclear weapons in the atmosphere, contaminating the whole surface of the Earth.

But two other reasons explain this sudden interest in exobiology. The first is the impact that Stanley Miller's 1953 experiment on the abiotic synthesis of amino acids had (Miller 1953). Miller was not the first to attempt such experiments (Garrison *et al* 1951), but the abundance and diversity of the molecules synthesized, and the experimental conditions that he chose according to the recommendations of Harold Urey (Urey 1952), conditions identical to those supposed to reign on the primitive Earth (Oparin 1924; Haldane 1929), gave his results a high visibility and credibility. These experiments were quickly reproduced (Abelson 1956), and extended to the production of polymers – the so-called proteinoids (Fox and Harada 1958) – of nucleic acid bases (Oro 1960, 1961; Fox and Harada 1961) and nucleotides (Ponnamperuma *et al* 1963) (for a general review *see* Ponnamperuma and Gabel 1968). The Miller experiment led to a revival of studies on the origin of life, with the organization of a first congress in Moscow in August 1957, attended by most people active in the field (Pirie 1957).

But the impact of this experiment cannot be considered independently of the rise of molecular biology, whose influence was not exerted directly through its results, the characterization of the structure of DNA and proteins, and the existence of a genetic code. Paradoxically, the importance of two different types of macromolecules and of a highly complex relation between them represented an unexpected and huge challenge for researchers working on the origin of life. But molecular biology – and biochemistry before it – had amply demonstrated that there was no secret of life, no hidden force, and that all the wonderful properties of organisms were the simple results of chemistry. Since the bricks of life could be easily obtained in the conditions supposed to be those of the primitive Earth, the study of the path towards life was wide open, as was the search for extraterrestrial forms of life.

Some other "discoveries" were made in the same years, supporting the idea that life was common in the Universe, and present on other planets of the solar system: evidence for vegetation on Mars (Sinton 1959), discovery of exo-organisms on meteorites (Claus and Nagy 1961), resistance of terrestrial microorganisms to the Martian environment (Hawrylewicz *et al* 1962), arguments in favour of the very rapid appearance of life on Earth (Barghoorn and Tyler 1965), and so on. Nevertheless, the possibility of any planet of the solar system harbouring life was cast into doubt (Abelson 1961). The reality of some of the previous discoveries was also soon questioned (Anders and Fitch 1962). This did not prevent them, however, from contributing to a general belief that life was present everywhere in the Universe.

3. The strong opposition to exobiology of George Gaylord Simpson and other evolutionists

In this euphoric context, it is quite remarkable that the strongest opposition came from evolutionists. In an astounding 1964 paper, Simpson criticized all the exobiological projects, from the search for life on Mars to the attempts to communicate with intelligent extraterrestrial civilizations (Simpson 1964). He converted the name exobiologists into ex-biologists, suggesting that the leaders in exobiology were incompetent in biology.

The reasons behind the attitude of George Simpson are multiple. The first came from the rapid rise of molecular biology as a new discipline, and the justified fear that more and more money would be allocated to it, at the expense of evolutionary biology. The large amount of money earmarked for the exobiological projects, which was huge in comparison with the cost of research in biology, but not in comparison with the amount of money allocated to NASA, strengthened this fear. In addition, Lederberg and his colleagues were accused of providing an illusory scientific justification for the space programmes, whose main motivation was the re-establishment of American prestige, which was threatened by the successes of Soviet Union, and of fostering the confusion between science and science fiction. Simpson also expressed regrets that the experts in biology consulted for the new exobiological programmes were biochemists and molecular biologists, such as Matthew Meselson, Paul Doty, Alexander Rich, Norman Horowitz, not *true* biologists like evolutionary biologists. In 1961, in "Cause and effect in biology", Mayr had already expressed the same point of view (Mayr 1961): molecular and physicochemical explanations in biology are only part of the story. Evolutionary explanations are equally important, even more so in fact because they are the only fully biological explanations. Therefore, evolutionary biologists are obviously the most competent to say what life is.

The second reason for rejecting exobiology is related to the conception of what science is. For Lederberg, biology was not yet fully scientific, because its subject matter, life, is unique – all the organisms on Earth have a common ancestor (Lederberg 1960). Only the discovery of other forms of life would allow the observations made on Earth to be generalized, and biology to reach a theoretical level comparable to that of physics. This argument was not directly addressed by Simpson. Comparison with physics was obviously not for him a good criterion in specifying the scientific nature of biology. In other writings, Simpson argued that the biological sciences were a model for other sciences, by their inclusion of time and history in their explanatory models (Simpson 1963). It was the scientific character of exobiology that was questionable, with its abundance of bold hypotheses unconstrained by hard facts. Exobiology is a science that lacks subject matter, with no hope of improvement in this situation in the near future. If extraterrestrials do exist, according to Simpson, there are only two contrasting possibilities: either they will be similar to terrestrial organisms, and their study will be without value, or they will be very different, and will not even be recognized as living.

Another reason Simpson rejected exobiology was the large role its programmes accorded to the search for intelligent extraterrestrial civilizations, what later came to be known as the SETI programmes. For Simpson and Mayr, such programmes presupposed the existence of trends in evolution, inexorably leading to the formation of intelligent organisms, humanoids, similar to human beings in their cognitive abilities. Such a conviction stemmed from a blind belief in determinism, a misunderstanding of the Darwinian theory of evolution, and an ignorance of evolutionary facts: cephalization is not a major trend in evolution, and is far less visible, for instance, than the repeated acquisition of eyes. What is selected in organisms is not "higher qualities", but adaptation to a specific environment, *i.e.* a higher rate of reproduction therein. There is no possible repeatability in the evolution of organisms for two additive reasons: the environment to which organisms adapt is permanently changing in a random way, and evolution builds on pre-existing organisms, *i.e.* on the results of an historical process.

Another disagreement between Lederberg and Simpson related to the nature of a biological explanation. For Simpson, it is the explanation of the way natural selection gave organisms their properties. For Lederberg, an explanation of life must also include an explanation of the way organisms progressively emerged. The rules of the game of life are known, and they provide an explanation of biological facts for Simpson. Understanding the way these rules were made possible is also an essential part of biological explanations for Lederberg.

Mayr expressed the same doubts about the interest of exobiological projects some years later: "If life, in the form of some bacteria-like organisms, actually were found unexpectedly, this would tell us very little. Yes, living molecular assemblages might originate occasionally. So what? Is it worth hundreds of million dollars, like the ill-fated recent Mars probe? I doubt it" (Mayr 2004).

Among evolutionary biologists, only Gould expressed a different opinion (Gould 1980). He was a strong supporter of the exobiology programme, and even of its SETI component. Gould was accustomed to expressing unorthodox ideas among evolutionary biologists. His predisposition against gradualism in evolution found nice support in the apparent rapid formation of organisms on Earth, and plausibly on other planets. There were leaps in the formation of the first living systems, as there were leaps in the evolution of organisms. This does not, however, mean that the problem of extraterrestrial life was a major one for him, and there is no allusion to exobiology in the more than one thousand pages of his last book (Gould 2002).

4. Conclusion

The discussions are far from over between the physicists, chemists, biochemists and molecular biologists who support the exobiology programmes and the evolutionary biologists who oppose them. With the partial cessation of the SETI programme, the core of the debate is now the probability that life exists on other planets. This probability is seen as high by the supporters and low by the opponents. Both see the formation of amino acids in prebiotic conditions as easy; the formation of nucleic acids remains more problematic. But there is a vast gap between these elementary building blocks and a fully functioning cell, which reproduces and selectively exchanges molecules and energy with its environment. Two mechanisms are presently being explored to bridge this gap and were, in fact, already being studied in the 1960s. The first is the action of natural selection in the prebiotic world, whatever its precise nature – facilitating, for instance, the accumulation of RNA molecules which self-replicate more rapidly and faithfully than the others. The second is the existence of principles of self-organization driving the first macromolecular assemblages towards the formation of reproducing cells (Fox 1968; Kauffman 1993). Opponents find both solutions difficult to accept. The first, because it attributes to natural selection a wide, but also less precise meaning; the second, because it proposes the existence in evolution of a force acting in parallel to, and independently of, natural selection.

Numerous observations have been made since the 1960s: the catalytic power of RNAs has been demonstrated, arguments in favour of a primitive RNA world have accumulated, the presence of amino acids in interstellar space is well documented, organisms in hydrothermal vents of deep-sea floors have been characterized and are actively studied because they might provide information on primitive forms of life, firm evidence for the presence in the past of water on the surface of Mars, and so forth (Fry 2000; Hazen 2005). Despite these transformations, debates on the probability of discovering organisms elsewhere in the Universe, and the value of the exobiological programmes show no signs of dying down.

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