EVOLUTION OF INTELLIGENT BEHAVIOR: DOES COMPLEX CHEMISTRY OFFER EVIDENCE OF PURPOSE?

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ABSTRACT. The question that brings us together is whether in science (cosmology, astrophysics or biology especially biochemistry) there may be laws, general mechanisms (for instance, natural selection), and special values of some physical constants that could be interpreted in natural theology as indications of purpose. The example of 'fine-tuning' in astrophysics has led to a weaker and a stronger version of the Anthropic Principle. Firstly, there are some remarkable numerical coincidences in the fundamental constants of physics that seem to conspire in favor of the appearance of intelligent life in the universe (an early remark attributed to Hoyle). These arguments have inspired discussions in the cultural frontier with the humanities. Is there an analogy in biochemistry? We will argue that the appearance of intelligent life may be interpreted, not only as the conspiracy of the values of the physical constants of microscopic physics, but intelligent life also seems to be the end product of a 'conspiracy' of evolution; indeed, natural selection and convergence are relevant at various levels, starting at the level of biochemistry and ending at the cosmic level. We will illustrate general aspects of this 'second interpretation' for the appearance of intelligent behavior in the universe.

What is the position of our tree of life in the universe?

In order to decide what is the position of our tree of life in the universe, we must appeal to science. First of all, we should put aside some philosophical objections that have been deeply rooted in the literature. Evolutionary convergence is an aspect of evolution that restricts its intrinsic randomness and suggests the following possibility:

In Monod's book *Chance and Necessity* the author overemphasized the role of 'pure chance' in evolution. He excluded the role that evolutionary convergence may have had in the evolution of life on Earth. On this basis Monod concluded that trends in biological evolution must be rejected. This question is not merely philosophical, although its philosophical implications are important. The question of evolutionary trends is relevant to the subject of astrobiology. For there has been an enormous technological revolution in the capability of scanning the celestial sphere for traces of ongoing communication amongst civilizations that are the product of evolution of intelligent behavior elsewhere. We further underline the fact that chance at the molecular level (mutations in the genome), does not exclude organisms from exhibiting trends at a higher level of organization.

Another aspect of the existence of trends in evolution is also relevant to natural theology, as it has been discussed extensively (Peacocke, 1988). This seems to be an appropriate place to leave the subject of deeper implications of the search for extraterrestrial life at this particular crossroad of bioastronomy, philosophy and theology. However, we would like to underline the importance of the trends in evolution for both science and theology. The rationale for the SETI project is the assumption that trends in evolution that have been observed on Earth may serve as a basis for understanding the eventual "contact" between different forms of civilizations that do not belong to the same tree of life.

Natural theology, on the other hand, is the body of knowledge about religion that can be obtained by human reason alone without appealing to revelation. Within this context, the trends towards larger brains that have been observed in evolution on Earth may serve for the intrinsic and necessary problem in natural theology, namely, rationalizing the concept of Divine Action, without the fear of failing to establish a reasonable constructive dialogue with science. The realization that randomness in evolution does not rule out the existence of evolutionary convergence, opens the door for real progress in the integrated approach to all forms of culture. Such an approach will not fall in the trap that dates back to the publication of Darwin's seminal work, when possibly, because of the difficulty of communication between science and religion, a confrontation between faith and reason emerged. Unfortunately, such a confrontation has not disappeared altogether.

The Weak Anthropic Principles in Cosmology and in Biology (including biochemistry)

There is no difficulty in accepting the 'weak' anthropic principle: change the laws (and constants of nature) and the universe that would emerge most likely would not be compatible with life. In biochemistry there is clearly an analogous statement, namely, omit the observed cosmic abundance of the biogenic elements that are favorable to life; further omit the environments (earthlike planets or Europalike satellites) that favor evolution and radiative adaptation; the consequence is that life would not arise.

However, difficulties would arise both in cosmology and in biology if we were to formulate the anthropic principles in the following 'strong' terms:

> (a) *The laws of nature and the physical constants were established so that human beings would arise in the universe.*
>
> *(b) The distribution of earthlike environments and Europalike satellites were laid out so that human beings would arise in the universe.*

One evident difficulty which we have considered in some detail in our recent book (2001). The laws of nature, according to the evidence that we can infer from the Earth biota, which by now is about 3 billion-year-old, only imply that the evolution of intelligent behavior seems inevitable. What is not evident is the inevitability of the emergence of human beings.

Is there an analogy of fine-tuning in biochemistry?

Two issues have been discussed in the past regarding the universal nature of biology in general, and biochemistry in particular: (1) Life may be a cosmic imperative (De Duve, 1995). (2) Multicellular life may be a rare phenomenon in the cosmos, although the existence of microbial life may still be widespread (the 'Rare-Earth' hypothesis, Ward and Brownlee, 2000). We shall discuss a third issue: (3) evolution of intelligent behavior may be just a question of time (and preservation of steady planetary conditions), and hence ubiquitous in the universe. Darwin's theory of evolution is assumed to be the only theory that can adequately account for the phenomena that we associate with life anywhere in the universe (Dawkins, 1983). We argue in favor of the inevitability of the origin and evolution of life. We assume that Darwinian evolution is a universal process and that the role of contingency has to be seen in the restricted context of parallelism and evolutionary convergence (Akindahunsi and Chela-Flores, 2004). Convergence is not restricted to biology, but also in other realms of science. The question "What would be conserved if the tape of evolution were played twice?", is relevant for astrobiology. It has been raised repeatedly in the past (Fontana and Buss, 1994). Besides it underlies one of the basic questions in astrobiology. Since all forms of life known to us are terrestrial organisms, it is relevant to the question of whether the science of biology is of universal validity (Dawkins, 1983; Chela-Flores, 2003a).

The sharp distinction between chance (contingency) and necessity (natural selection as the main driving force in evolution) is relevant for astrobiology. Independent of historical contingency, natural selection is powerful enough for organisms living in similar environments to be shaped to similar ends. For this reason, it is important to document the phenomenon of evolutionary convergence at all levels (cf., next section) in the ascent from stardust to brain evolution. In particular, documenting evolutionary convergence at the molecular level is the first step in this direction. Our examples militate in favor of assuming that, to a certain extent and in certain conditions, natural selection may be stronger than chance (Conway-Morris, 1998). We raise the question of the possible universality of biochemistry, one of the sciences supporting chemical evolution.

Convergence at the cosmic level and its tests within the solar system

In a way, the key question of the convergence in biochemistry arises first of all due to the nature of the formation of solar systems. For we have learnt that the key elements for life are intrinsically bound to the small bodies that seem to be characteristic of solar systems in general. Hydrogen and helium make up almost the totality of the chemical species of the Universe. Only 2% of matter is of a different nature, of which approximately one half is made by the five additional biogenic elements (C, N, O, S, P). From organic chemistry we know that nuclear synthesis is relevant for the generation of the elements of the Periodic Table beyond hydrogen and helium and, eventually, for the first appearance of life in solar systems. The elements synthesized in stellar interiors are needed for making the organic compounds that have been observed in the circumstellar, as well as in interstellar medium, in comets, and other small bodies. The same biogenic elements are also needed for the synthesis of biomolecules of life. Besides, the spontaneous generation of amino acids in the interstellar medium is suggested by general arguments based on biochemistry. The detection of amino acids in the room-temperature residue of an interstellar ice analogue that was ultraviolet-irradiated in a high vacuum has yielded 16 amino acids, some of which are also found in meteorites (Muñoz Caro *et al.,* 2002; cf., also Bernstein *et al.,* 2002). There are factors, which contribute to the formation of habitable planets. The Murchison meteorite may even play a role in the origin of life: According to chemical analyses, some amino acids have been found in several meteorites: in Murchison we find basic molecules for the origin of life such as lipids, nucleotides, and over 70 amino acids (Cronin and Chang, 1993). Most of the amino acids are not relevant to life on Earth and may be unique to meteorites. This remark demonstrates that those amino acids present in the meteorite, which also plays the role of protein monomers, are indeed of extraterrestrial origin.) If the presence of biomolecules on the early Earth is due in part to the bombardment of interplanetary dust particles, or comets and meteorites, then the same phenomenon could have taken place in any of other solar systems.

Diverse types of convergence in biochemistry

Mechanistic convergence occurs when the sequence and structure of molecules are very different but the mechanisms by which they act are similar. Serine proteases have evolved independently in bacteria (e.g. subtilisin) and vertebrates (e.g. trypsin). Despite their very different sequences and three-dimensional structures, they are such that the same set of three amino acids form the active site. The catalytic triads are His 57, Asp 102, and Ser 195 (trypsin) and Asp 32, His 64 and Ser 221 (subtilisin) (Doolittle, 1994, Tramontano, 2002). Another popular example often cited are the antifreeze glycoproteins in Antarctic notothenioid fish and Arctic cod, but as we have reviewed it recently, we shall omit the details (Akindahunsi and Chela-Flores, 2004)

The red- and green-like visual pigments in fish, Astyanax fasciatus, and human is another case of convergence at the molecular level. The blind cavefish *Astyanax fasciatus* is sensitive to two long wavelength visual pigments. In humans, the long wavelength green and red visual pigments diverged about 30 Myr BP. The mammalian lineage diverged from fishes about 400 Myr BP, but a recent episode in evolution has granted fish multiple wavelength-sensitive green and red pigments. Genetic analysis demonstrates that the red pigment in humans and fish evolved independently from the green pigment by a few identical amino acid substitutions (Yokoyama and Yokoyama, 1990), a clear case of evolutionary convergence at the molecular level.

The emergence of intelligent life in the universe, another case of fine-tuning?

We have assumed that natural selection seems to be powerful enough to shape terrestrial organisms to similar ends, independent of historical contingency. Besides, it can be said in stronger terms that essentially, evolutionary convergence can be viewed as a 're-run of the tape of evolution', with end results that are broadly predictable.

The assumed universality of biochemistry suggests that in solar system missions, biomarkers should be selected from standard biochemistry. Given the importance of deciding whether the evolution of intelligent behavior has followed a convergent evolutionary pathway, and given the intrinsic difficulty of testing directly (the 50 year-old SETI project), within the realm of science we can begin testing the lowest sages of the evolutionary pathway within the solar system. Indeed, we are in a position to search directly evolutionary biomarkers on Europa. We have considered that if extant microorganisms are to be encountered, the most urgent set of evolutionary biomarkers are ion channels (Chela-Flores, 2003b). Given the length of time before we can test them directly, a full discussion at the present time of the feasibility of carrying out a proper test is timely. Within the restrictions of an *in-situ* laboratory, tests on the ice surface for microorganisms present some challenges that seem within the possibilities of molecular biology techniques. However, the most interesting case concerns the next orbital mission. It is expected to determine specific locations where the icy surface is thin enough for a submersible (hydrobot) penetration, or for testing directly the surface for the presence of microorganisms. We already know from the dynamics of iced surfaces in Antarctica, for instance over Lake Vostok, that microorganisms are found in the ice overlying the lake. We have discussed these possibilities separately (Gatta and Chela-Flores, 2004) and conclude that commercial interest has already pushed some of the experimental equipment required in future tests in solar system exploration in the right direction (miniaturization, so that the space mission can be fitted adequately and realistically). We consider that the techniques of microscopic fluorescence could be adapted to a future mission that included the possibility of landing (or even penetrating) on the icy surface. Thus, we may conclude that within the realm of scientific research in the foreseeable future we can address the question of 'fine-tuning' in the following sense: Evolution of the cosmos, and especially biological evolution right from the biochemical level, may be 'fine-tuned' for the inevitable emergence of intelligent behavior throughout the cosmos, provided there is preservation of steady planetary conditions over geologic time.

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