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The search for extraterrestrial intelligences and the Fermi Paradox

Nikos Prantzos

Institut d'Astrophysique de Paris

Abstract. Of all the questions that Man asks himself about the Universe, the one concerning the possibility of the existence of an extra-terrestrial life form, and even more of an extra-terrestrial civilization, is probably the most fascinating. We cannot answer it today, but we can imagine the implications for the human species and its future in the Universe.

1. The debate on the "Plurality of Worlds": chance or necessity?

Advances in 18th century astronomy and the understanding that stars are suns like ours reinforced the idea that countless Inhabited Earths exist in the Universe. However, at the beginning of the 20th century, the debate on the Plurality of worlds was enriched by arguments inspired by biology. Alfred Russel Wallace, the co-founder with Charles Darwin of the theory of evolution, was the first to use this kind of argument against the notion of another intelligent life form in the Universe. In the 1905 edition of his book *Man's Place in Nature*, Wallace noted that Man is the result of a series of unique and unpredictable events in the long chain of evolution. The likelihood of this same series of events happening elsewhere, even in Earth-like environments, is remote. This argument also applies to intelligent life.

Adopted by many biologists, Wallace's argument introduced into the debate on the Plurality of worlds the "sense of history": a series of individually unimportant events, the effects of which are amplified over time to the point that the end result becomes completely unpredictable. Indeed, the traditional presentation of Darwinian evolution emphasizes the progressive complexification of matter, as if it were an inevitable process. The passage from bacteria to multicellular organisms, from fish to reptiles, and from mammals to humans is considered a one-way street. Along this path, natural selection rewards those who adapt best to their environment with the survival of their lineage. However, as the American biologist Stephen Jay Gould points out, this conception of evolution can be totally wrong. Natural selection is not the only factor determining the evolution of species, and it does not always take small steps. Catastrophic phenomena have wiped out species that seemed well equipped to survive by natural selection.

The most famous example is undoubtedly that of the dinosaurs: after a reign of 130 million years, these "terrible lizards" disappeared 65 million years ago, due to the collision of the Earth with a large asteroid. The survivors of such disasters in Earth's history did not always display greater complexity than those who disappeared, and their comparative advantage was not, a priori, obvious. From this point of view, mammals owe their survival only to their good fortune and not to any "superiority" over dinosaurs. Is then the emergence of man and of intelligence, during these last millions of years, a matter of pure chance? These considerations have extremely important implications for the existence of other intelligent life forms in the Universe.

2. The number of extra-terrestrial civilizations is... N

The scientific study of the subject "Extra-terrestrial Intelligences" has a short history; it dates back only about sixty years. In an article published in 1959 by the British journal *Nature*, American physicists Giuseppe Cocconi and Philip Morrison suggested that the microwaves (radio waves of high frequencies) are the best means for interstellar communication. Micro waves penetrate not only the Earth's atmosphere but also the clouds of gas and dust pervading the Galaxy. In contrast, visible photons, our traditional "window" to the Universe, are absorbed by these clouds; thus, optical telescopes see much less far into the Milky Way's disk than radio-telescopes. Moreover, microwaves have another advantage: they carry little energy, which means that sending a message by this type of wave is preferable from an energy point of view.

These considerations inaugurated the modern era of the debate on the Plurality of worlds by opening the perspective of a scientific study of the problem. It was from this period that the acronym ETI (Extra-Terrestrial Intelligence) was born. The first to put these ideas into practice was American astronomer Frank Drake, who started in 1960 the first programme of radio-signal research with the radiotelescope of Green Bank, USA. In 1961 Drake organized the first conference on radio communication with extra-terrestrials at Green Bank. Preparing the agenda of the conference, he tried to assess the likelihood of success of that research, by attempting an estimate of the number of technological civilizations today present in our Galaxy. His formula, the famous "Drake Equation", has generated a phenomenal amount of work and analysis over the past half century.

Drake's equation describes a steady state, where the number of communicating civilizations remains approximately constant (those that disappear are replaced by an equal number of new ones). This number N is given by:

$$N = R_\star f_{\rm PLA} n_{\rm e} f_{\rm LIFE} f_{\rm INT} f_{\rm TEC} L \tag{1}$$

where $R_\star$ is the star formation rate in the Milky Way (number of new stars formed per year), $f_{\rm PLA}$ gives the fraction of stars with planets, $n_{\rm e}$ is the number of telluric planets in the continuously habitable zones of these stars (at distances where the heat of the star allows temperatures favoring the presence of liquid water) for billions of years (so that complex life has time to appear), $f_{\rm LIFE}$ is the fraction of habitable planets on which life actually appeared, $f_{\rm INT}$ provides the fraction of these planets where evolution has produced intelligent beings, $f_{\rm TEC}$ is the fraction of planets whose beings are capable of communicating by radio signals, and L represents the average lifespan of these technological civilizations.

It is clear that Drake's formula has no predictive power: only the first three factors are more or less known today, which is a definite progress compared to the XXth century, where only the first one was known. The value of $R_\star$ is estimate at around 10 stars per year and has not changed much over the last billion years. For $f_{\rm PLA}$ and $n_{\rm e}$, the latest statistics on the number of terrestrial planets detected around nearby stars, through the observations of the NASA's space telescope *Kepler* in the last decade suggests that such planets occur around 10% of solar type stars, which make up one tenth of the total number of stars. Thus, the product of these three factors in an astrophysical term $R_{\rm ASTRO} = R_\star f_{\rm PLA} n_{\rm e}$ roughly gives 0.1 telluric planets formed each year in the Galaxy.

By grouping the following three into a biotechnological factor $f_{\rm BIOTEC} = f_{\rm LIFE} f_{\rm INT} f_{\rm TEC}$, the Drake equation is written: $N = R_{\rm ASTRO} f_{\rm BIOTEC} L$ (see **?**). The advantage of this writing is to allow the visualization of the impact of factors $f_{\rm BIOTEC}$ and L, after having fixed the value of $R_{\rm ASTRO}$ by observations. By assigning $f_{\rm BIOTEC}$ its maximum value ($= 1$, being the product of three fractions), Drake's formula is simplified

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to $N = 0.1L$: the *maximum* number of civilizations in the Galaxy is one tenth of their lifespan, expressed in years. But it is expected to be much lower, because $f_{\rm BIOTEC}$ can only be (much) smaller than 1.

Contrary to what is often claimed, the value $N < 1$ (N less than 1) is allowed, but it has only a statistical significance. It means that the emergence of a civilization is a rare event in the Galaxy, with two successive civilizations being separated in time by a period longer than their lifespan. Thus, "alone in space" does not necessarily mean "alone in time" nor "to be the first", nor "to be unique". Thousands of technological civilizations appeared, perhaps, in the Galaxy, lived a long time – thousands or millions of years – and even colonized their neighborhood, being "alone" in the Galaxy during that time; and they disappeared, unable to communicate with others, unaware that others have preceded them and unknown to their successors. Our own civilisation may just be such a "lonely heart" in the Milky Way.

So far, ETI research has yielded two results, one likely definite, the other perhaps provisional. The probes sent to explore our Solar System did not signal any form of life in our close vicinity; however, it is not yet ruled out that microscopic life forms have appeared in the past on Mars or that they exist today in the icy oceans of certain satellites of giant planets, such as Europe or Enceladus. In addition, listening to the sky in radio frequencies did not result in any detection of an extra-terrestrial signal; taking into account the difficulty of the task (where to look? in what frequency? how long? with what sensitivity? etc), this result is not surprising. However, even if we manage to listen to the hundred billion stars of our Galaxy over ten billion radio channels for several centuries, what conclusion could we draw from the absence of an artificial signal? Quite simply, that none of these hypothetical civilizations is currently broadcasting in our direction, which does not really settle the debate on the existence of ETI.

3. The Fermi Paradox

There is another fact of observation, the importance of which is difficult to measure: the absence of the slightest trace of an ETI on our planet or in the Solar System. The late 1940s saw the first wave of reports of flying saucers and other unidentified flying objects (UFOs), especially in the United States. During a visit to the Los Alamos military laboratory in 1950, the Italian physicist Enrico Fermi –Nobel Prize winner in Physics– engaged in a discussion on this subject with his colleagues. Discussion shifted to the more general topic of extra-terrestrial civilizations and interstellar travel. "But where are they?" Fermi suddenly asked his interlocutors, meaning that if "they" exist, "they" should have visited us several times already in the past. According to Fermi, the absence of traces of such a visit did not necessarily imply the non-existence of extra-terrestrials; it could result either from the impossibility of interstellar travel, or from the too short lifespan of a technological civilization, probably self-destroyed after the discovery of the secrets of the atom (the period of "the equilibrium of terror" between the United States and the Soviet Union had just begun at the time).

This discussion remained virtually unknown for a long time. In 1975, astronomers Michael Hart and David Viewing rediscovered independently Fermi's arguments. Hart radically concluded that the absence of extra-terrestrials on Earth meant that we are the only technological civilization in the Galaxy and therefore the search for radio signals would only be a waste of time and money. It was after this provocative article that the subject was baptized "the Fermi paradox". Hart's pessimistic conclusions opened a period of passionate debate around ETI, particularly in the United States, a controversy that continues to this day.

4. Cosmic loneliness?

Any paradox rests on the invalidity of one (at least) of its underlying hypotheses, but it is impossible to present here all the arguments of the supporters and opponents of ETI on the Fermi paradox. The arguments most often discussed do not concern the "physical" aspect of the problem (feasibility of interstellar travel, construction of self-reproducing robots, etc.) but its "sociological" aspects. Some think that extra-terrestrials are not interested in space travel or expansion in the Galaxy: their civilization would quickly turn to spiritual values (contemplation, meditation, etc.), or it would have adopted the "zero growth" dear to certain common e environmentalists, which would have prevented them from space colonization. Others, like Fermi, fear that the longevity of a technological civilization is too short for any significant colonization of its vicinity.

Another class of sociological arguments, generally known as the "zoo –or quarantine– cosmic hypothesis" was formulated in the early twentieth century by the father of astronautics Konstantin Tsiolkovsky, and independently rediscovered in 1984 by American astronomer John Ball: the aliens would have arrived in our solar system, in the recent or distant past, but would limit themselves to observing us from afar for various reasons: they would consider us too "primitive" and would wait for our "maturation" to include us in their "galactic community" (according to Tsiolkovsky), or they would not want to interfere with our development (principle often invoked in the famous television series Star Trek under the name of "prime directive"). According to a variant of this argument, extra-terrestrials would have even contributed to the development of intelligence in our ancestors (the most famous version being undoubtedly that proposed by the science fiction writer Arthur Clarke and his famous "black monolith", appearing in Stanley Kubryk's movie *2001, A Space Odyssey*).

There is a common weak point in all sociological arguments. It is hard to accept that they apply to *all* extraterrestrial civilizations, without any exception. If hypothetical civilizations are numerous, at least one should have escaped annihilation, mastered space travel, and embarked on a galactic colonization program. The behavior of animal species on Earth shows us that they always go through a phase of expansion, favored by natural selection, because it maximizes their chances of survival. Moreover, at least one of these civilizations should have transgressed the "taboo" of avoiding all contact with our own. If none of them did, we would be "atypical", because we would be the only ones wanting to communicate with other civilizations. But it may be that the typical lifespan of civilizations, even as great as several million years, is too short to allow them to explore a large enough fraction of the Milky Way and find us.

The Plurality of Worlds is more controversial today than ever. The arguments on both sides ("We are unlikely to be alone in this vast Universe" and "Where are they?") are of statistical nature. Therefore, their value is extremely low, since one cannot make statistics on the basis of a single known case, life on Earth. The detection of an inhabited planet – and even more of an extraterrestrial civilization – would constitute one of the major events in the history of the human species. The non-detection of ETI signals, even after several centuries of research, would not prove the non-existence of extra-terrestrial civilizations. It should, however, prepare us for a life of cosmic solitude ...

Reference

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