

ADAPTATIONISM FAILS TO RESOLVE FERMI'S PARADOX

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SUMMARY: One of the most interesting problems in the nascent discipline of astrobiology is more than half-century old Fermi's paradox: why, considering extraordinary young age of Earth and the Solar System in the Galactic context, don't we perceive much older intelligent communities or signposts of their activity? In spite of a vigorous research activity in recent years, especially bolstered by successes of astrobiology in finding extrasolar planets and extremophiles, this problem (also known as the "Great Silence" or "astrosociological" paradox) remains as open as ever. In a previous paper, we have discussed a particular evolutionary solution suggested by Karl Schroeder based on the currently dominant evolutionary doctrine of adaptationism. Here, we extend that discussion with emphasis on the problems such a solution is bound to face, and conclude that it is ultimately quite unlikely.

Key words. Astrobiology – Extraterrestrial intelligence

1. INTRODUCTION: FERMI'S PARADOX AND ASTROBIOLOGY

*When the stars were right, They could
plunge from world to world through the
sky; but when stars were wrong, They
could not live.*

Howard P. Lovecraft (1928)

*How can one hide from that which never
sets?*

Heraclitus of Ephesus (cca. 550 BC)

In a previous paper (Ćirković 2005), we have described an interesting solution of Fermi's paradox¹, proposed in a qualitative form by the Canadian novelist Karl Schroeder in his recent novel *Permanence* (Schroeder 2002), based among other things upon previous speculations of Raup (1992), Lipunov (1997), and others. Urban legend (corroborated by historical research; see Jones 1985) has it that the great Italian physicist Enrico Fermi at dinner with Emil Konopinski, Edward Teller, and Herbert York, about 1950, asked "Where are they?" in reference

¹It would be most appropriate to call it Tsiolkovsky-Fermi-Viewing-Hart-Tipler's paradox (for much of the history, see Webb 2002; see also Lipunov 1997). We shall use the locution "Fermi's paradox" for the sake of brevity, but with full respect for contributions of the other important authors. Also known as the "Great Silence" (Brin 1983) or "astrosociological" paradox (Gindilis and Rudnitskii 1993).

to extraterrestrial visitors. The question belies a profound understanding of the spatial and temporal scales of our universe. Even going at a fraction of the speed of light, the time it would take to cross galactic distances is small compared to the age of the Galaxy. Thus, the presumed fact that there are no extraterrestrials in the Solar System—neither now nor in our past light cone—requires an explanation. To this, we can today add the absence of extraterrestrial intelligent **manifestations** detectable by modern astronomical instruments, like Dyson shells² or traces of burning antimatter fuel (Jugaku and Nishimura 2003, Harris 2002). Hereby, we consider the adaptationist solution in some more detail and attempt to elaborate its weaknesses.

Before we briefly review the adaptationist solution to Fermi's paradox, a word about the conceptual importance of this topic for biological science may be in order. In an interesting debate, the philosopher of biology Eliot Sober has argued that the deployment of multiple radical/controversial hypotheses is in itself an **adaptive strategy in the scientific domain** (Sober 1994). He makes the convincing case that early commitment to the reality of theoretical constructs allows science to flourish. This is particularly interesting in the context of the relative primacy of physics among the sciences in the last century: giants of the XX century physics were people who were bold to put forward ideas not suffering, to paraphrase Niels Bohr's famous rebuttal, from "insufficient craziness". With exactly this *leit-motif* in mind, we approach the present topic and problems in astrobiology in general. Astrobiology is, admittedly, still in its infancy as a scientific discipline. However, it seems natural to try to investigate extrapolations of our best biological theories to encompass larger and larger, as well as more diverse habitats. Astrobiology is, as several authors have recently emphasized (e.g. Des Marais and Walter 1999, Knoll and Bambach 2000), our best chance of overcoming the "provincial" (Munson 1975) or "unfalsifiable" (Popper 2002) nature of biology in general, and evolutionary theory in particular. Great minds have been aware of this for a long time; for instance, Henderson wrote in his classic 1913 monograph *The Fitness of the Environment*:

The properties of matter and the course of cosmic evolution are now seen to be intimately related to the structure of the living being and to its activities; they become, therefore, far more important in biology than has previously been suspected. For the whole evolutionary process, both cosmic and organic, is one, and the biologist may now rightly regard the Universe in its very essence as biocentric.

2. THE ADAPTATIONIST SOLUTION

Let us now briefly review the adaptationist solution to Fermi's paradox. Schroeder starts by criticising what he call *providential* view of life and intelligence in the universe, which he links to Teilhard de Chardin, but which applies with equal force to an array of very diverse secular thinkers, from Herbert Spencer to Carl Sagan: view of special properties of life intelligence which make them in a very tangible sense the "pinnacle of creation" (either designed or naturalistic), and whose emergence demarkates a new epoch in the overall history of matter in the universe. In a simplified rendering, it is easy to search for life and intelligence because they are so different from all other phenomena in nature, and that applies even more forcefully to the tool-making consciousness, since it can intentionally influence its physical environment. Tool-making consciousness is, according to this view, the basic property of complex information-processing entities. This is the view behind the SETI projects of today, and much has been written in its favor. But it is far from being limited to astrobiology: this is also the default attitude of AI researchers, popular science writers, and most of the public perception of the world science unveils in its progress is framed in its terms.

What should we contrast this providential view of intelligence? Schroeder offers a clever alternative, which he does not dub, but which we can, for reasons to be shortly described, call **adaptationist**:

What we found instead was that even though a species might remain starfaring for millions of years, consciousness does not seem to be required for toolmaking. In fact, consciousness appears to be a phase. No species we have studied has retained what we could call self-awareness for its entire history. Certainly none has evolved into some state *above* consciousness. (p. 108)

This is the crux of the problem (for the astrobiologist protagonists of Schroeder's novel; solution for us, wishing to resolve Fermi's paradox!): our estimates and expectations of the phenomenon of intelligence—which is, above all, a biological phenomenon—are wrong. Intelligence is significant only insofar as it offers an evolutionary advantage, a meaningful response to the selective pressure of the fluctuating environment. Only so far, and no further is the "selfish gene" willing to carry that piece of luggage.

This approach to explanation in evolutionary biology is known as **adaptationism**; its major proponents being distinguished biologists such as Richard Dawkins and John Maynard-Smith, as well as contemporary philosophers such as Daniel Den-

²In a prescient 1960 study, Freeman Dyson suggested that the natural course of increase in the power consumption of a technological civilization will lead to its utilizing most of the energy output of its parent star. To that effect, he suggested that very advanced societies will build an array of devices surrounding most of its parent star, thus from the outside looking like an (infrared emitting) shell. This idea is in accordance with Kardashev's concept of the Type II society (Kardashev 1964) and has received many subsequent elaborations (e.g. Badescu 1995).

nett or Eliot Sobber.³ Adaptation is a trait that has been selected for by natural selection. Adaptationist hypothesis can be conventionally defined as a statement that asserts that a given trait in a population is an adaptation. In other words, natural selection is the major (if not the sole) cause of presence and persistence of traits in a given population. The definition of Sober (1993) in his influential book goes as follows:

Adaptationism: Most phenotypic traits in most populations can be explained by a model in which selection is described and nonselective processes are ignored. (p. 122)

Examples of adaptationist explanations abound. Camouflage colors of birds and insects, Eskimo faces, two-component spray of the bombardier beetle, horns of *Ontophagus acuminatus*, and myriads of other observed properties of living beings are interpreted as giving their carriers an advantage in the endless mill of natural selection. Their genes are more likely to propagate along the thousands of generations of natural history. The most extreme version of adaptationism is sometimes called gene-centrism and is expounded by Richard Dawkins, and neatly encapsulated in the title of his best-selling book *The Selfish Gene* (Dawkins 1989): genes are using (in a sufficiently impersonal sense of the word, see Ref. 16) organisms to propagate their own copies as efficiently as possible in time. It may be of historical interest that adaptationism is usually traced back to Alfred R. Wallace, one of the two great biological revolutionaries, who was also one of the forefathers of modern astrobiology with his intriguing and remarkably prescient book *Man's Place in the Universe* (Wallace 1903).

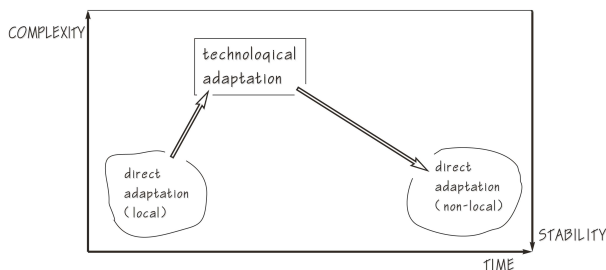


Fig. 1. Adaptationist solution to Fermi's paradox schematized. Switching to technological adaptation is necessarily followed by reverting to simpler, but more stable direct ("post-technological") adaptation now in various locales. Just as technological adaptation can be thought of as intentional development of characters mimicking and improving certain adaptive traits found in nature, the direct adaptation during the reversion phase can be described as appearance of traits mimicking some features of technology.

The adaptationist view is the scientific foundation of Schroeder's solution to Fermi's paradox. Intelligence is an adaptive trait, like any other. Adaptive traits are bound to disappear once the environment changes sufficiently for any selective advantage which existed previously to disappear.⁴ However, tool-making (technological) capacities of advanced intelligent communities actively influence their environment, and decrease selective pressure ("flattening" the fitness landscape, to use the popular evolutionary picture). In the long run, the intelligence is bound to disappear, as its selective advantage is temporally limited by ever-changing physical and ecological conditions. In Schroeder's words:

Look at crocodiles. Humans might move into their environment—underwater in swamps. We might devise all kinds of sophisticated devices to help us live there, or artificially keep the swamp drained. But do you really think that, over thousands or millions of years, there won't be political uprisings? System failures? Religious wars? Mad bombers? The instant something perturbs the social systems that's needed to support the technology, the crocodiles will take over again, because all they have to do to survive is swim and eat... It's the same with consciousness. We know now that it evolves to enable a species to deal with unforeseen situations. By definition, anything we've mastered becomes instinctive. Walking is not something we have to consciously think about, right? Well, what about physics, chemistry, social engineering? If we have to think about them, we haven't mastered them—they are still troublesome to us. A species that succeeds in really mastering something like physics has no more need to be conscious of it. Quantum mechanics becomes an instinct, the way ballistics already is for us. Originally, we must have had to put a lot of thought into throwing things like rocks or spears. We eventually evolved to be able to throw without thinking—and that is a sign of things to come. Some day, we'll become... able to maintain a technological infrastructure without needing to *think* about it. Without need to think, at all...

This chain of events is schematically shown in Fig. 1. An intelligent species can last long in the state of direct adaptation to their environment on the home planet (local)—several hundred thousand years in the case of *homo sapiens sapiens*. A rather fast transition from direct to technological adaptation corresponds to building of a technical civilization, this crucial ingredient of all SETI studies. But the stage of technological adaptation, distributed all over the various planets, is inherently less stable. In a long run, it will tend to pass into a state of fragmented habitats reverting to direct biological adap-

³For some of the many contemporary reviews, see Larson (2004), Tucić (2004), Gould (2002), Wallace (2004).

⁴The may get *exapted* (Gould and Vrba 1982, Gould 2002), i.e. get to be used for a purpose different from the original one. However, this does not seem relevant for the present purpose, since it is hard to imagine intelligence or tool-making capacity becoming exaptations on the biological (and not cultural) level.

tation ("crocodiles returning"). The second transition is much slower and might be occasionally interrupted or arrested; yet, the general trend toward return to direct adaptation is inescapable. This bifurcation is, in this view, tantamount to extinction of the original intelligent species, and its remains are gradually submerged into the general astrobiological "noise" of the Galaxy. The transient nature of the phase of technological adaptation constitutes the bulk of the "Great Filter" explaining the *silentium universi*. A colorful metaphor of the rise and fall of such advanced technological communities can be found, for instance, in a piece of the 1967-68 woodcut *Metamorphosis III* by great M. K. Escher (Fig. 2).



Fig. 2. A metaphor of the adaptationist solution to Fermi's paradox: emergence of complexity crowned by society (of social insects!) from the simple pattern, followed by reverting to simpler, but more stable forms (imagine the time flowing along the added horizontal axis). This is a section from the three-color woodcut *Metamorphosis III* which Escher finished (after considerable delays and even reluctance, as described in his diaries) in 1968. The metaphor is limited by the fact that the final state of the direct adaptation is not the mirror-image of the original pre-intelligence state ("evolution doesn't repeat itself").

Ironically enough, the application of adaptationism to Fermi's paradox has some similarities with the old biological heresy of **orthogenesis**, historically the major rival to Darwinism on the opposite side of the functionalism/formalism divide (Gould 2002, Tucić 2004, Larson 2004). It was championed during roughly 1870-1950 by distinguished naturalists like Hyatt, Haacke, Cope, Eimer, Whitman, and Schindewolf. Darwin himself called it rather dismissively (but very aptly from the present point of view!) "Descent-theory" in the beginning, and Schindewolf called it *typostrophism* in its last blossom, but it amounts to the same idea: a global morphological type of a species (or a higher taxon in some versions) contains big, but ultimately finite, potential for variation. This pool of possibilities will be manifested through one or more internal channels which direct evolution of a species from its beginning to inevitable end. *Contra* Darwin and subsequent adap-

tationists, orthogeneticists believed that variation is not isotropic and although they did allow for natural selection shaping some of the traits of species, the highest relative frequency must be ascribed to the directional change along the preset channels of a given, discrete morphological form. Famous examples of orthogenesis included those cases where evolution clearly led organisms toward extinction by mechanical continuation of unadaptive traits: ever-increasing teeth of saber-tooth cats which, after passing through some optimum size, clearly impeded efficiency of their feeding. The choice and nature of these orthogenetic channels differed from author to author, but most XX century orthogeneticists found them in the laws of embryological development, notably the (in)famous biogenetic law of Ernst Haeckel. Another aspect of orthogenesis, however, is interesting from the present point of view. In one of the historically last serious analysis of orthogenesis, Grene (1958) writes on Schindewolf's *typostrophism*:

Furthermore, Schindewolf agrees with the older paleontologists that within each type, once it had appeared, there is a progressive, orthogenetic development. In fact, there is a rhythm analogous to that of birth, maturation, and senescence: the sudden appearance of a new type, its orthogenetic advance, and finally a stage of the breaking up of types which usually leads to extinction. (p. 112)

This presents a strong analogy with the adaptationist view of the generic history of tool-making civilizations. How comes, we need to ask, that the application of the most rigorous functionalist programme, such as adaptationism, leads to a picture so similar to the one portrayed by eminent formalist view such as orthogenesis? The answer, one is tempted to conclude, is that the function/form distinction becomes blurred when it comes to the evolution of cultural concepts, notably technology. We may find a clue in the functionalism itself; as Grene cogently notes, there we perceive

...the ruling passion of Darwinism: [in] the determination not to look at structure. Structure must be explained *away*; it must be reduced to the conditions out of which it arose rather than acknowledged *as* structure in itself. (p. 126)

What exactly plays the role of structure (or form) in the case of technological civilization? It seems that at least part of that role has to lie with the **technology itself**; and, indeed, this is what has already been either neglected or downplayed by the ultra-Darwinian adaptationism applied—rather roughly—to the evolution of humanity (e.g. Wright 2000). Thus, treating technology as something malleable mainly by external factors and accommodating purely functional needs, leads to something very similar to the orthogenetic *fatum* to which many of the historically raised criticisms apply. We shall return to this topic in the subsection dealing with post-biological evolution below.

3. DIFFICULTIES WITH THE ADAPTATIONIST APPROACH

Here we briefly consider some of the objections to the application of adaptationism for solving Fermi's paradox. Although some of them appeared in the literature in other contexts, none were applied in this manner, and most of them are new. None of these arguments are decisive, but in the young field plagued with uncertainties this is not to be expected either. Taken together, they strongly indicate that, while undoubtedly adaptationism plays some role in the overall astrobiological evolution of the Galaxy, it cannot pretend to *bona fide* resolve Fermi's puzzling question.

3.1. Cultural and postbiological evolution

In an important recent paper, the distinguished historian of science Stephen J. Dick argued that there is a tension between SETI, as conventionally understood, and prospects following exponential growth of technology as perceived in recent times on Earth (Dick 2003):

But if there is a flaw in the logic of the Fermi paradox and extraterrestrials *are* a natural outcome of cosmic evolution, then cultural evolution may have resulted in a postbiological universe in which machines are the predominant intelligence. This is more than mere conjecture; it is a recognition of the fact that cultural evolution – the final frontier of the Drake Equation – needs to be taken into account no less than the astronomical and biological components of cosmic evolution. [emphasis in the original]

It is easy to understand the necessity of redefining astrobiological studies in general and our view of Fermi's paradox in particular in this context: for example, postbiological evolution makes those behavioral and social traits like territoriality or expansion drive (to fill the available ecological niche) which are—more or less successfully—”derived from nature” lose their relevance.

One approach we find promising is the concept of *megatrajectory*, introduced by Knoll and Bambach (2000), who cogently argue that astrobiology is the ultimate field for confirmation or rejection of our biological concepts. In relation to the old problem of progress (or its absence) in the evolution of life on Earth, Knoll and Bambach offer a middle road encompassing both contingent and convergent features of biological evolution through the idea of a megatrajectory:

We believe that six broad megatrajectories capture the essence of vectorial change in the history of life. The megatrajectories for a logical sequence dictated by the necessity for complexity level N to exist before N+1 can evolve... In the view offered here, each megatrajectory adds new and qualitatively distinct dimensions to the way life utilizes ecospace.

The six megatrajectories outlined by the biological evolution on Earth so far are, from the origin of life to the "Last Common Ancestor" prokaryote diversification, unicellular eukaryote diversification, multicellularity, invasion of the land, and appearance of intelligence and technology. *Postbiological evolution may present the seventh megatrajectory*, triggered by the emergence of artificial intelligence at least equivalent to the biologically-evolved one, as well as the invention of several key technologies of the similar level of complexity and environmental impact, like molecular nanoassembling or stellar uplifting.

In other words, it seems necessary to reject a particular form of inductivist fallacy. As in earlier times, inductivists argued (when criticized, for instance, by Karl R. Popper and others) that it is natural to assume a "meta-rule" of inference along the lines of "future will resemble the past", thus there is a creeping prejudice that the present and future modes of evolution need to be the same as those leading us to the present epoch. This is a consequence of the (today typical) idolatry of adaptation: almost reflex and non-thinking assumption that any evolution has to be adaptationist (e.g. Dennett 1995). *Contra* such fashionable views like evolutionary psychology/behavioral ecology/sociobiology, there is no reason to believe that **all** complex living systems evolve according to the rules of functionalist natural selection, and not, for instance, in a Lamarckian, orthogenetic or saltationist manner. Without entering this excessively complex topic here, we may note that however we assess our experience with intelligence, culture, tool-making and technology, everything points that it is non-Darwinian evolution, if for nothing, then because the vector of change is not isotropic. The inductivist meta-rule has been successfully relegated to the history of epistemology, but the prejudice in biology is still very strong, and that exactly in the time when first serious quantitative models of complex cultural evolution begin to appear in the literature (e.g. F ath and Sarvary 2005).

Herein lies one of the weaknesses of adaptationist solution: there is no proof—or indeed a clear counterargument—that a chain of **intentional** strategies for preventing adaptationist devolution could not extend over an arbitrarily long time in the history of an advanced civilization. In other words, things certainly can and **will** go wrong at many locations over a sufficient period of time, but one could easily imagine planning and building of "concentric rings" of safety mechanisms, each projected to be activated after all previous have failed. Intentionality brings an entirely new **qualitative** angle in the picture. Each mechanism individually can and **will** eventually fail in deep time (geological or astrophysical), but there seems to be no reason why the entire system could not be simply vast enough and continuously assembled over time in order to counter the diverging trends of isolation and devolution.

3.2. Right wall of complexity?

Adaptationist solution assumes that the realm of knowledge and phenomenal experiences of advanced intelligent beings is necessarily finite, no mat-

ter how huge it is. While this may sound innocent enough (all meaningful physical quantities, in contrast to mathematical ones, are usually held to be finite), and even in accordance with the currently fashionable tendencies—at least within physical science—of searching for the “theory of everything”, this assumption is in no way incontrovertible. In other words, and to use another oft-discussed biological metaphor (e.g. Shanahan 1999, Radick 2000, Gould 1996, 2002), adaptationist solution requires that besides the left wall of minimal complexity (in the vicinity of which reside members of the realms of *Bacteria* and *Archea*), biological world is necessarily limited by the **fixed** right wall of maximal complexity (and we may assume that members of the transient state of advanced, space-faring technological species reside just left of this unscaleable barrier).

This concept is suspicious on several grounds. Apart from the possibility of postbiological evolution considered above, and concerns of Knoll and Bambach (2000) about repeated scaling of the maximal complexity within different macroevolutionary regimes, this form of finitism is under fire in both mathematical and cosmological domains. Gödel’s theorem and subsequent results in the flourishing research field of incompleteness and randomness in pure mathematics (e.g. Chaitin 1987), show that even the most abstract world of mathematical truth is inexhaustible in a very specific and quantitative way. On the opposite end of the cognitive spectrum, modern cosmology strongly indicates the existence of some form of the **multiverse** – the infinite set of cosmological domains, of which our entire visible universe is just an infinitesimal part (e.g. Linde 1990, Ellis et al. 2004). All this suggests that the domain of knowledge is indeed infinite (while, of course, the actual amount of knowledge at any particular epoch is bound to be finite), which would remove a plank from the foundations of the adaptationist approach.⁵

3.3. Mass extinctions – the Galactic variety

What adaptationism fails to explain on Earth, it will fail to explain in the Milky Way. Perhaps the foremost problem with the adaptationist doctrine as currently presented by the evolutionary orthodoxy, is its failure to be useful in cases of brief and sudden episodes in the history of life known as the mass extinctions. In the words of Raup’s (1991) colorful subtitle, in such difficult times “luck” is more important than “genes”. In our (highly incomplete) fossil record, “Big Five” mass extinction episodes stand as the most remarkable features, after the Cambrian Explosion, of the history of life (e.g. Jablonski 1986, Raup 1994, Courtillot 1999, Ward and Brownlee 2000).

For the present purposes, it is important to understand that the fact of mass extinction under-

mines the doctrine of extrapolationism, usually serving to “fill in the gaps” of the evolutionary record. In famous words of Gould (2002), mass extinctions are found to be “more frequent, more rapid, more intense, and more different in their effects” than naturalists have suspected prior to 1980. Broadening of the stage of biological research, characteristic for astrobiology, brings new agents of destruction in addition to the “classical” terrestrial ones (for a preliminary list, see Dragićević and Ćirković 2002). Notable (but far from unique!) examples are intermittent bursts of high-energy cosmic rays and electromagnetic radiation of cosmic origin. For instance, in a recent study, Smith et al. (2004) write:

In any case, Mars should have been subjected to brief optically thin exposures to sterilizing γ -rays and hard X-rays from solar flares, supernovae, and γ -ray bursts many times during the last Gyr. Similarly, if Mars began with a thick atmosphere, then its early evolution would have been punctuated with bursts of UV representing redistributed X-rays from the same astronomical sources.

If, as we may have some independent indications from planetology, Martian conditions are in fact very frequent and even more life-conducting than early Earth’s, the conclusion that such radiation-driven extinction events are even more prominent in the overall history of life in the Milky Way than judged by the terrestrial record alone seems inescapable. In other words, astrobiological evolution of the Milky Way also possesses its “third tier”, the overarching global level of change (Gould 1985).

The important paper of Annis (1999) opens a new vista in studying Fermi’s paradox by introducing—though not quite explicitly—the notion of the **global regulation mechanism: a dynamical process** preventing or impeding uniform emergence and development of life all over the Galaxy. In Annis’ model, which he dubbed the phase-transition model for reasons to be explained shortly, the role of such global Galactic regulation is played by gamma-ray bursts (henceforth GRBs), colossal explosions caused either by terminal collapse of supermassive objects (“hypernovae”) or mergers of binary neutron stars. GRBs observed since 1950s have been known for almost a decade already to be of cosmological origin, arising in galaxies often billions of parsecs away, and it has been calculated that these are the most energetic events in the universe since the Big Bang itself. Astrobiological and ecological consequences of GRBs and related phenomena have been investigated recently in several studies (Thorsett 1995, Scalo and Wheeler 2002, Smith et al. 2004). To offer just a flavor of the results, let us mention that Dar (1997) has calculated that the terminal collapse of the famous supermassive object Eta Carinae could deposit in the upper atmosphere of Earth the en-

⁵Adaptationist might retort that the amount of **useful** knowledge will still be finite, and that useless information (like positions and momenta of molecules in a chunk of gas, or 10^{100} th digit in the decimal expansion of π) does not count. However, the criterion of usefulness is obviously culture- and circumstance-dependent! While the issue certainly deserves further scrutiny, we feel that the onus of the proof here lies with the finitist.

ergy equivalent to the simultaneous explosions of 1 kiloton nuclear bomb per square kilometer all over the hemisphere facing the hypernova! Annis suggested that GRBs could cause mass extinctions of life all over the Galaxy (or at least a big part of it), preventing or arresting the emergence of complex life forms. Thus, there is only a very small probability that a particular planetary biosphere could evolve intelligent beings in our past. However, since the regulation mechanism exhibits **secular evolution**, with the rate of catastrophic events decreasing with time, at some point the astrobiological evolution of the Galaxy will experience a change of regime. When the rate of catastrophic events is high, there is a sort of quasi-equilibrium state between the natural tendency of life to spread, diversify, and complexify, and the rate of destruction and extinctions. When the rate becomes lower than some threshold value, intelligent and space-faring species can arise in the interval between the two extinctions and make themselves immune (presumably through technological means) to further extinctions, and spread among the stars. Thus the Galaxy experiences a **phase transition**: from an essentially dead place, with pockets of low-complexity life restricted to planetary surfaces, it will, on a very short timescale (essentially Fermi's colonization scale), become filled with high-complexity life. Consequences of such a scenario for SETI projects have been studied by Ćirković (2004), where it has been shown that the difference in the outcome of our estimates based on the Drake equation can indeed be very different, depending on the degree of gradualism assumed. All this lies firmly beyond the scope of the adaptationist approach.

Modern comprehension of origin of life on Earth contributes to viability of Annis' model. Fossil records indicate that unicellular, prokaryotic form of life was originated more than once during early evolution of planet Earth and that their extermination was consequence of events in their astronomical environment (sudden and frequent collisions with meteorites, radiation originated from near supernovae explosion, gravitational perturbations, etc.). Complex form of life could evolve only when the frequency of that kind of events were reduced above some threshold. Nevertheless, mass extinction has played significant regulating role in development of life forms that have led to intelligence. The most famous (and often cited) example is sudden adaptive radiation of mammals which after the dinosaur extinction, took their place in empty ecological niches. Most specialized forms of life suffered greatest damage while mammals were much more primitive (*vis-à-vis* unspecialized teeth, nutriment, extremities, etc.) and they simply have had more adaptive space to adjust to new environment conditions.

Astronomical events, such as supernovae explosions could be source of high energy radiation that could have destroying effect on living beings. Although, radiation can cause hyperploidy, an increase of DNA content in cells, and can induce DNA rearrangements, so it is probable that evolution of life can be affected by its radiation environment (e.g. Yang et al. 1994). Primary radiation damage does not di-

rectly lead to mutations, but requires modification, i.e. it has to be fixed so that it could be inherited. Big deletions are not the sole type of mutations that densely ionizing particles cause, but also point mutations that could be less lethal (Kiefer et al. 1994).

3.4. The problem of scales

In order to deploy the adaptationist solution, the relevant timescales for rise and devolution of tool-making intelligent species need to have particular range of values. They, in turn, need to be accommodated within the know temporal framework of the Galactic chemical and dynamical evolution, as well as the known stellar lifetimes. Although the detailed quantitative understanding of the age distribution of the potential life-bearing sites is still elusive, this is the astrobiological field in which great strides have been made recently. And the results obtained so far indicate that the required concordance of timescales may not be so easy to achieve as it may seem.

The seminal work of Lineweaver and his collaborators (Lineweaver 2001, Lineweaver et al. 2004) shows that the Earth-like planets began forming in the Milky Way about 9.3 Gyr ago, while their average age is 6.4 ± 0.9 Gyr. This is significantly larger than the age of Earth (measured to be 4.56 ± 0.01 Gyr; see Allègre et al 1995), indicating that the difference between evolutionary ages of other biospheres in the Galaxy and ours should—on the Copernican assumption of our average location and properties—be almost two billion years. This is exactly what makes Fermi's paradox more serious than it was at times of Fermi or even Hart-Tipler: considering rapid emergence of early life on Earth almost as soon as our planet became inhabitable (Oberbeck and Fogleman 1989, Lineweaver and Davis 2002) the fact that the difference is so much larger than the Fermi's timescale for crossing the Galaxy or creating astro-engineering projects detectable at huge distances is quite disturbing.

In principle, Fermi's paradox in the original (or at least Hart's [1975] form) can be written as the relationship between timescales which should be satisfied at any life-bearing planet in the Milky Way:

$$t_{\text{planet}} + t_{\text{bio}} + t_{\nearrow} \geq t_0 \quad (1)$$

where t_{planet} is the time of the planet formation (in other words, the age of the Galaxy at the time of each individual planet formation); t_{bio} is the timescale of biological evolution (cf. Carter 1993) best understood as the (mean) time required for reaching biological complexity necessary for intelligence/tool-making; with t_{\nearrow} we denote the rise of the advanced technological civilization, until its "zenith" or, in terms of the adaptationism, the timescale for flattening of the fitness landscape; t_{Fermi} is the timescale for large-scale Galactic colonization and/or creating detectable astroengineering markers; and t_0 is the present epoch in the Galactic history (we can choose to reckon it from the Galaxy formation, about 12

Gyr ago). It should be kept in mind that all these timescales are indexed throughout the set of habitable planets (past and present). For the case of Earth, t_{planet} is given by the value of about 4.5 Gyr, t_{bio} is about 3.8 Gyr, and t_{\nearrow} is **at least** about 0.001 Gyr (i.e. since the appearance of the first intelligent species of our hominid ancestors; the exact value is unimportant, as will be clearly seen). Finally, Fermi's point was exactly that t_{Fermi} is likely to be of the order to magnitude of 0.01 Gyr, way smaller from either t_{planet} or t_0 . (In fact, a non-trivial component of the paradox is the conjecture that for any location \vec{x} in the Milky Way, the timescale for reaching the vicinity of the Sun by moving with average velocity $\langle v \rangle$, $|\vec{x} - \vec{x}_{\odot}| / \langle v \rangle$, can be effectively maximized by the timescale t_{Fermi} which is orders of magnitude smaller than the present age of the Galaxy.)

Now, the adaptationist solution can be reformulated as adding a term corresponding to the effective timescale for the "decline" of the species, i.e. reversion to the direct adaptation in the post-cultural stage:

$$t_{\text{planet}} + t_{\text{bio}} + t_{\nearrow} + t_{\searrow} \geq t_0 - t_{\searrow} \quad (2)$$

where t_{\searrow} now stands for this reversion timescale. Obviously, it is easier to satisfy (2) than (1), which was the goal of the solution in the first place, but is it even formally sufficient? To see this, we can plug some values from the distribution of the planetary ages, and consider some further simplifications. For the earlier planets, and neglecting Fermi's timescale (since it is at least an order of magnitude smaller than others), we obtain that all plausible values of biological and cultural timescales need to satisfy

$$t_{\text{bio}} + t_{\nearrow} + t_{\searrow} \geq 3.7 \text{ Gyr}, \quad (3)$$

again, for any particular location in space.

Potentially, the plausible values of the timescales t_{\nearrow} and t_{\searrow} could be established using stochastic simulations constrained with some of the methodology currently used, for instance, to infer the speed limits on evolution from the fossil record (e.g. Kirchner 2002). Unfortunately, at our present level of ignorance, this is likely to give just a very broad distribution of timescales; this remains an important constraint for any particular model of astrobiological dynamics.

3.5. Detectability or existence?

In a beautiful passage in Book V of his famous poem *De Rerum Natura*, Roman poet and late-Epicurean philosopher Lucretius wrote the following intriguing verses:

If there had been no origin-in-birth
Of lands and sky, and they had ever been
The everlasting, why, ere Theban war
And obsequies of Troy, have other bards
Not also chanted other high affairs?
Whither have sunk so oft so many deeds
Of heroes? Why do those deeds live no more,
Ingrafted in eternal monuments
Of glory? Verily, I guess, because
The Sun is new, and of a recent date
The nature of our universe, and had
Not long ago its own exordium.⁶

Neglecting here its cosmological context of arguing for a finite past age of the universe, this passage indicates an oft-neglected aspect of Fermi's paradox—it is not enough to somehow remove all advanced technological civilizations from our past light cone, but we need to erase their more durable and potentially detectable achievements as well. The very existence of the fascinating discipline of archaeology tells us that cultures (and even individual memes) produce records significantly more durable than themselves. It is only to be expected that such trend will continue to hold even more forcefully for higher levels of complexity and more advanced cultures. There are even some factors related to the properties of our cosmic environment that enhance this trend; notably, it has already been repeatedly suggested that the traces of any hypothetical extraterrestrial visitations in the past of Earth and the Solar System would be easier to locate on the Moon than on Earth, due to the vastly suppressed erosion there.

For further example, let us, for the sake of discussion, allow that a significant fraction of advanced technological civilizations evolves toward the Kardashev Type II (i.e. a community completely managing the energy output of its parent star); for the information-processing need of advanced communities, see Ćirković and Radujkov (2001). The straightforward way of achieving this is the construction of a Dyson shell (Dyson 1960). Once constructed, such an example of astroengineering, will be quite durable due to the properties of the interplanetary and interstellar space itself; like the Pyramids of Egypt, a Dyson shell is likely to outlive its creators for a vast period of time, thus being an advanced analogue of Lucretius' "eternal monuments". The preliminary searches (e.g. Jugaku and Nishimura 2003) show the absence of such artefacts in the Galactic vicinity of the Sun.

Those who wish to argue for adaptationism as the solution of Fermi's paradox should make a pause before discarding this complication. Even on the adaptationist scenario, the duration of the technological apex of a technological community can be very long, likely expressed in millions of years. There is plenty of time to build not only Dyson shells, but perform many other durable and detectable astroengineering feats. Their absence (to the best of our current knowledge) testifies that the boundary between conscious tool-making and the state of di-

⁶In translation of William E. Leonard, available via WWW Project Gutenberg (Lucretius 1997).

rect adaptation to environment is much sharper than adaptationism would allow.

3.6. Contingency argument and adaptationism

The historical fact that some of distinguished evolutionary biologists like George G. Simpson (1964) or Ernest Mayr (1993) have been sceptical about extraterrestrial life, intelligence and SETI projects have been flaunted around every now and then (e.g. Barrow and Tipler 1986, Tipler 1980). Neglecting extrascientific part of their arguments,⁷ this scepticism has ostensibly been based on the **contingency argument**: since the compartment of the biological morphospace occupied by intelligent, tool-making beings is infinitesimally small, probability that the evolutionary random walk will reach that compartment twice—even if the number of sites for evolution is measured in billions—is practically zero. While we cannot enter this very complex topic here, we notice that this is tightly related to the perceived role of contingency in terrestrial evolution, as highlighted particularly vividly in the case study of the Cambrian fauna of Burgess Shale (Gould 1989); if we "rewind the tape" of evolution and let the Burgess Shale fauna evolve again over the half a billion years that had elapsed since the end of Cambrium, chances that human beings would appear are nil!⁸

It is a bit ironic that adherents to strict adaptationism in terrestrial evolution, who were the target of Gould's persistent criticism not only in *The Wonderful Life*, but over the last three decades, and those extending the strict adaptationism into realms of sociobiology, behavioral ecology, or evolutionary psychology, like Edward O. Wilson, Robert Wright or William D. Hamilton, have argued that the evolution of high intelligence was **likely from the start** (e.g. Wright 2000). A particularly forceful form of such biological determinism has been recently put forward by the distinguished British paleontologist Simon Conway Morris (one of the heroes of *The Wonderful Life*!) in his book on *Life's Solution: Inevitable Humans in a Lonely Universe* (Conway Morris 2003). Conway Morris emphasizes the role of **convergence** which increases the effective size of the morphospace compartment containing intelligent beings. We do not need to take his claim as strongly as the subtitle indicates: even if humans are not "inevitable", some other form of intelligent life may as well be, due **exactly to the selective advantages** offered, in short and medium term, by intelligence and tool-making.

There is a clear message here, which tends to be overheard, due to the often extrascientific noise (of which Conway Morris, with his worries about ethics and the contemporary loss of values, is not innocent). Those biologists wishing to uphold both

contingency argument and adaptationist solution to Fermi's paradox are operating a double standard: **either** a tool-making compartment is small everywhere, convergence is unimportant, contingency all-important, and we are alone in the Galaxy (if not in the entire Hubble volume), **or** convergence suppresses contingency at some level of complexity and selective advantages of tool-making are indeed more-or-less quickly found by Mother Nature; but not both. To insist on both depending on the aspect of the problem (convergence dominant on Earth, but contingency elsewhere) is a poor scientific attitude smelling badly of anthropocentrism.⁹

4. DISCUSSION

We have hereby argued that adaptationist solution of Fermi's paradox is insufficient in purely explanatory sense. Stressful physical and biotic environments resulting in adaptation and speciation are crucial for evolution of life, especially high complexity forms of life with intelligence and consciousness.

Of course, one should keep in mind that in evolutionary biology term "adaptation" is used in more than one meaning. In contrast to adaptation, i.e. traits of specimens or populations, intelligence could be appointed as "adaptability", i.e. the ability of specimen and population to remain or become phenotypically (specimen) or genetically (population) adaptive to variable conditions of environment (Tucić 2003). According to that wider view, intelligence, and consciousness as her following phenomenon, could not be considered on a par with any other trait of living beings.

Adaptationist solution to Fermi's paradox is, in a sense, the counterpoint of the classical "mandatory self-destruction" solution, often repeated in the Cold-War days by such SETI dissidents like von Hoerner or Shklovskii (in his later writings). While self-destruction solution emphasized catastrophic frustration of being prevented by internal reasons of fulfilling the creative potential of our (and, by analogy, other) civilization, the adaptationist solution emphasizes (in a gradualist manner) exactly the ultimate futility of such fulfillment. We have tried to show here that, however, in spite of its wider pretensions, adaptationism is as limited in astrobiology as is the Cold War politics a form of relations in the human history as a whole.

This conclusion is not entirely unexpected. Through dramatic increase of the very physical scope of ecosystems considered, astrobiology offers strong incentive to explanatory pluralism. On the most abstract epistemological level, small systems are more likely to have a satisfactory monist explanation than the large ones; to explain the topography of a village

⁷E.g. the worry about the magnitude of the U.S. federal debt in Mayr (1993).

⁸But see Dennett (1995) and Conway Morris (1998) for a critical assessment of the Burgess Shale argumentation.

⁹To add another ironic twist, Gould himself was one of the small number of evolutionists actively supporting SETI projects through signing petition and public defense of its budget (Gould 1987).

usually does not require any knowledge on the plate tectonics. Similarly, even if the adaptationist "shiny happy consensus" is sufficient to account for the topography of the terrestrial design space, its chances of being a universal explanatory strategy are reduced even prior to any further inquiry into a particular astrobio-logical problem.

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АДАПТАЦИОНИЗАМ НИЈЕ РЕШЕЊЕ ФЕРМИЈЕВОГ ПАРАДОКСА

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Један од најинтересантнијих проблема у младој области астробиологије јесте више од пола века стари Фермијев парадокс: зашто, кад узмемо у обзир малу старост Земље и Сунчевог система у галактичком контексту, не запажамо далеко старије интелигентне заједнице или трагове њихове активности? Упркос снажној истраживачкој активности у последњим годинама, посебно подстакнутим успесима астробиологије у проналажењу екстрасоларних планета и екстремофила, овај проб-

лем (такође познат као проблем "Велике тишине" или "астросоциолошки" парадокс) остаје отворен као и увек. У претходном чланку, разматрали смо једно конкретно еволуционо решење које је предложио Карл Шредер на бази данас доминантне еволуционе доктрине адаптационизма. Овде ми проширујемо ту студију са нагласком на проблеме са којима се такво решење суочава, и закључујемо да је оно у крајњем исходу мало вероватно.