NEOCATASTROPHISM AND THE MILKY WAY ASTROBIOLOGICAL LANDSCAPE

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SUMMARY: The number and distribution of habitable planets in the Milky Way is one of the foremost problems of contemporary astrobiological research. We investigate the effects of applying general neocatastrophic paradigm to the evolution of the Galactic Habitable Zone. In this paper, we investigate the limits of simple, 1-dimensional astrobiological models, and consider the role of regulation mechanisms in shapening the "astrobiological landscape". We show that the transition from predominantly gradualist to predominantly (neo)catastrophist history of our Galaxy leads to the build-up of large-scale correlations between habitable sites, offering possible keys to such important problems as Carter's "anthropic" argument and Fermi's paradox. In addition, we consider the possibilities for extending the present class of models into spatially realistic 3-dimensional case via probabilistic cellular automata.

Key words. Astrobiology – methods: numerical – Galaxy: evolution – extraterrestrial intelligence

How many kingdoms know us not!

Blaise Pascal, *Thoughts*, 207

1. INTRODUCTION

The concept of the Galactic Habitable Zone (henceforth GHZ) emerged as one of the crucial terms of the contemporary astrobiological research (often dubbed, with much justification, "the astrobiological revolution"). Starting with the pioneering paper by Gonzalez et al. (2001), the concept experienced significant elaboration and generalization (e.g. Lineweaver et al. 2004, Gonzalez 2005,

Ćirković 2004a, Blair et al. 2008), as well as occasional criticism (Prantzos 2007). On the balance, it seems that it has offered a useful framework for formulation of some of the most general, far-reaching ideas about the emergence of life (biogenesis) and intelligence (noogenesis) on the Galactic scale. In the present paper, we study the class of simplest, 1-dimensional astrobiological models of GHZ, examine their limits of application and discuss a particular hypothesis about the general astrobiological evolution in the Milky Way, namely the neocatastrophic view.

The present approach seeks to join the older tradition of more specialized SETI-oriented models, as exemplified by the studies of Newman and Sagan (1981), Fogg (1987) or Landis (1998) with the recent

astrobiological developments, notably GHZ elaborations and the re-emergence of (neo)catastrophic view of the large-scale biospheric evolution. Some results of this kind of modeling have been presented by Vukotić and Ćirković (2007, henceforth Paper I) and Vukotić (2008, henceforth Paper II). The application of these results to resolving the famous Carter's argument against extraterrestrial intelligence has been presented in Ćirković et al. (2008). Finally, the resolution of Fermi's paradox through the phase transition scenario encapsulated by these models is presented in Ćirković and Vukotić (2008). Here, we would like to elaborate upon the applicability conditions of such stochastic models, properties of the relevant regulation mechanisms, as well as their embedding into a more general and realistic 2-D and 3-D astrobiological modeling framework.

2. MOTIVATION FOR 1-D NEOCATASTROPHIC MODELS

We know very little about the details of what could be dubbed "astrobiological dynamics", namely the laws governing biogenesis and noogenesis, the dependence of the speed of evolution and size of the morphological space on the environmental conditions in general case, etc. Even in such situations, as for instance the history of many-body physics shows us, one can learn a great deal about the large-scale, collective behavior of the system through Monte Carlo simulations, which neglects local details and gives information only on the most general trends. Along the line of the same idea, we have constructed a series of 1-dimensional models, where we are only interested in the number of inhabited planets in any given epoch, while the local biological timescales are chosen at random from a sufficiently broad temporal interval. Specifically, we have been motivated by the idea of "simulating" the important Carter's anthropic argument against extraterrestrial intelligence (Carter 1983). Carter's argument is one of the three "classical" (in the sense of being discussed in most of the SETI-era starting from early 1960s) anti-SETI arguments. These are (in somewhat simplified terms):

1. *Fermi's paradox* (Brin 1983, Jones 1985, Webb 2003): Any early spacefaring civilization should have colonized the entire Galaxy, including the Solar System and Earth by this late time in Galactic history. This is not what we observe ("Great Silence").

2. *Carter's anthropic argument* (Carter 1983, 1993, Livio 1999): If biological and astrophysical timescales determining the evolution of life and intelligence are independent, we have a posteriori Bayesian reasons to believe that the biological timescale is much larger than the astrophysical one, thus making the evolution of life and intelligence elsewhere correspondingly improbable.

3. *The argument from biological contingency* (Simpson 1964, Mayr 1993): the part of biological morphospace containing intelligent beings capable of SETI-like communication is so minuscule in volume, that even if all habitable planets in the Galaxy are indeed inhabited by life of some kind, SETI will still be condemned to failure.

The "Big Three" arguments against SETI have played a large role not only in academic discussions about these topics, but also in its wider cultural and societal perspectives (i.e. Mayr 1993), including the US government budget cuts for SETI. They have been influential in formulating the controversial, but very popular in the astrobiological circles, "rare Earth" hypothesis (Ward and Brownlee 2000, Conway Morris 2003). As has been argued elsewhere (Ćirković 2004ab, Ćirković et al. 2008), these arguments are inconclusive, but very instructive and should present a strong motivation for the development of theoretical SETI.

The present approach can be regarded as a way of direct simulation testing of the famous Drake equation, developed by Frank Drake for the first SETI symposium in 1961. In a sense, it is one of the very rare theoretical SETI results. Although there is no canonical form of the Drake equation, and the expression quoted by various authors is often dependent on the desired result of the analysis, we use the following form (e.g. Shklovskii and Sagan 1966, Walters et al. 1980):

$$N = R_* f_g f_p n_e f_l f_i f_c L, \qquad (1)$$

while keeping in mind that other equivalent forms exist. In this expression, the symbols have the following meanings:

N = the number of Galactic civilizations with which communication is possible.

R_* = mean rate of star formation in the Galaxy,

f_g = fraction of stars suitable for supporting life,

f_p = fraction of stars with planetary systems,

n_e = number of planets per planetary system with conditions ecologically suitable for the origin and evolution of life,

f_l = fraction of suitable planets where life originates and evolves into more complex forms,

f_i = fraction of planets bearing life with intelligence,

f_c = fraction of planets with intelligence that develops a technological phase during which there is the capability for an interest in interstellar communication,

L = mean lifetime of a technological civilization.

Drake's equation is usually used as a rule-of-thumb estimate in order to assess feasibility of SETI projects covering fixed number of targets. It has many weaknesses, repeatedly elaborated by both contact-pessimists and optimists (e.g. Lem 1977, Brin 1983, Gould 1987, Fogg 1988, Ćirković 2004b). However, in order to assess validity of its estimates, we need to compare them with a more detailed numerical model and, since the only value we are interested in is the total number of targets N, the 1-D models like the one we propose are satisfactory candidates. Various f-parameters in Drake's equation are, essentially, filters for habitability; a large part of them can be thought of as **regulation mechanisms** influencing the local evolution on habitable planets in GHZ. Astronomical factors in Eq. (1) are nowadays reasonably well-understood due to the immense progress in astrobiological research in recent years; notably, this applies to R, f_g, f_p and, in significantly lesser degree, n_e. As a result of such development, main uncertainties left lie with biological and "sociological" factors, namely f_l, f_i, f_c and – in particular – L.

3. A SURVEY OF NEOCATASTROPHIC REGULATION MECHANISMS

While the detailed discussion of astrobiological regulation is beyond the scope of the present paper, it is important, at least, to consider some background information underlying any neocatastrophic model. We envisage (quasi)equilibrium GHZ where astrobiological "clocks" tick at various rates on different planets, but are subject to temporally and spatially correlated "resetting events". "Resetting events" could, in principle be uncorrelated as well, but we are more interested in a subset which can be correlated over large spatial volume. Those are the **global** regulation mechanisms, because they influence a large part or the whole GHZ. It is important to understand that only global mechanisms can ensure stability of equilibrium states. This is related to what is in classical SETI studies called "non-exclusivity" of explanations for the "Great Silence", i.e. the absence of visible manifestations of very advanced extraterrestrial civilizations (Brin 1983).

Thus, the desiderata for viable mechanisms of global regulation are: (i) sufficient lethality, (ii) a large volume of effect (comparable to GHZ volume), and (iii) secular evolution, i.e. the decrease of average risk with time. The requirement (ii) is the rationale for using the term "global", while bearing in mind that this does not necessarily imply that the **entire** GHZ is affected, just a substantial part of it. The last property enables phase transition to occur, obviating the "anthropic" question why have we emerged at precisely this point in Milky Way's history? (More on the phase transition itself in the forthcoming study Ćirković and Vukotić 2008.)

Annis (1999a) noticed that gamma-ray bursts (GRBs) seem to satisfy all three desiderata. These strongest explosions in the universe have several ways of adversely influencing biospheres over a large range of distances within their host galaxies (Thorsett 1995, Scalo and Wheeler 2002, Melott et al. 2004). The decrease of their frequency in time, roughly following an exponential trend, recoverable from cosmological observations, makes the astrobiological clocks in GHZ running longer and longer without reset. This, in turn, virtually guarantees that at some point there will be a sudden "phase transition" between mostly dead Galaxy and the Galaxy teeming with life (and, presumably, viable SETI targets). It is this aspect of Annis' conjecture rather than the specific regulation mechanism he advocated that renders his theoretical approach genuinely novel.

Obviously, the increase in level of technological sophistication which, in accordance with our assumptions, is just the extension of the increase in biospherical complexity will—if unimpeded for quite a brief period beyond the present human level—lead to the security of intelligent community (and, indeed, most of the domicile biosphere) against the GRB threat. There are two aspects of such development. The first, astronomical, will enable accurate surveillance on all potential Galactic GRBs (that is, relativistic binaries and hypernovae-progenitors), thus enabling accurate prediction of the event with a large temporal margin. The second, mitigating, will enable adequate planetary and structural protection, including macroengineering projects; cf. Badescu et al. (2006). This is probably only of the order of decades in the future from the point of view of the present human civilization.

Among other regulation mechanisms occasionally proposed in the literature, one may mention:

1. Galactic tides. The claimed periodicities in biological mass extinctions (Raup and Sepkoski 1986, Raup 1999) has provoked a lot of discussion, and the one of less controversial explanations has been the hypothesis of Galactic tides perturbing local Oort clouds (e.g. Delsemme 1987, Matese and Whitmire 1996). The case for periodicities has recently come under severe criticism (Stigler and Wagner 1987, Jetsu 1997, Jetsu and Pelt 2000), to which we shall return below.

2. Spiral-arm crossings (Shaviv 2002ab, Gies and Helsel 2005), which could influence climate, and consequently, cause global catastrophes on Earth-like planets everywhere in GHZ; this is one more form in which the notion of "coherent catastrophism" (Asher et al. 1994) can be effectively generalized.

3. Neutrino bombs. Collar (1996) has proposed that even "normal" stellar-collapse neutrinos might play an important biological role and potentially cause mass extinctions.

4. Magnetars (e.g. Komissarov and Barkov 2007) were suggested as origin of high-energy cosmic rays in a manner similar to supernovae and GRBs.

5. Nuclear outbursts. Clarke (1981) has suggested in an early version of the phase-transition model that the large-scale environment is decisive in emergence or not of a viable SETI target. Clarke based his view on the idea, somewhat fashionable in late 1970s, that the nucleus of the Milky Way can undergo Seyfert-like recurrent bursts of activity (e.g. Sanders and Prendergast 1974, van Bueren 1978, Clube 1978, Giler 1983). A variation on this theme is the theory of LaViolette (1987) postulating "volleys" of cosmic rays from the Galactic center.

These (and other conceivable) mechanisms are not, of course, of equal credibility and importance. It is certain, for instance, that the possible lethal influence of neutrinos has been vastly overestimated by Collar (1996), or that even the relatively close events like the terminal explosion of Eta Carinae are likely to have much smaller influence on the terrestrial biosphere than it was envisaged earlier (cf. Thomas et al. 2008). Nuclear outbursts are much harder to quantify, but it seems that they do not present a significant threat in the GHZ either. We make the list here just in order to emphasize how these have been discussed (and critically assessed) in the literature thus far, while the mainstream astrobiological discourse remained rather gradualist in its outlook.

The issue of periodicity of certain of the regulation mechanisms has repeatedly surfaced in the literature, after the seminal paper of Raup and Sepkoski (1984), claiming a statistically significant periodicity in the data on marine extinction of terrestrial species. The underlying idea has been that the asteroidal/cometary impacts, to which most of the mass extinction episodes have been ascribed, are in turn triggered by an astronomical "clock" with period variously claimed to be about 30 Myr. Recently, Rohde and Muller (2005) have reworked the periodicity hypothesis with much more comprehensive data, detecting a significant period of longer duration, ~ 140 Myr. In recent years, it seems that the hypothesis of periodicity has been repeatedly criticized (e.g. Jetsu and Pelt 2000).

In fact, the weakening of the case for "strong" periodicity is convenient from the point of view of the present model. Some periodicities are expected to be generated by periodical secondary regulating mechanisms which do possess intrinsic regularity (like the Galactic tides and/or spiral-arm-crossing climatic effects), but the main signal is expected to originate in intrinsically aperiodic events, that is, both types of GRBs.

Thus, we can partially reject the criticisms of Abbas and Abbas (1998) directed at Collar's hypothesis (see "Neutrino bombs" subsection above). We do not need to explain periodicity of extinction events, since we do not believe that the case for periodicity in the strong sense has been convincingly made. What we do need to explain is the average spacing between the extinction events sampled over a sufficiently long period of terrestrial history, coupled with possible weak periodic signal. In addition, we need to explain the long delay between the epoch of biogenesis and the Cambrian explosion of multicellular life which, at least on Earth, was a precondition for noogenesis. We feel that (as elaborated above) GRBs offer a plausible explanation for such a temporal pattern.

Apart from global, there certainly exist local regulating mechanisms, like the impacts of comets and asteroids, for quite some time the prime "suspects" for causes of the palaeontological mass extinctions (e.g. Raup 1991, 1994, 1999), if we do *not* ascribe them to the Galactic effects. Galactic effects of this type are also uncorrelated, so they can be regarded as playing the role of random "noise" in the astrobiological clocks resetting. This complex behavior should not be surprising at all. In fact, it is reasonable to assume that galactic ecology is, like the terrestrial one, made of complex nested systems simple in an overview, but incredibly complex in detail.

Symbolically, we can write:

Regulation mechanisms = GRBs + Galactic tides + ...

Building of complete "risk function" for all various kinds of risks is undoubtedly a hard task, but its completion could open quite new vistas for astrobiological modeling in the future.

We could add any "sociological" explanation in Brin's (1983) catalog to this category of local regulating mechanisms. All suggested variations on the theme of self-destruction of technological civilizations, through nuclear (/chemical/biological/nanotechnogical/...) warfare or through ecological devastation of its environment (including the ultimative—and highly speculative—ecological catastrophes like the vacuum phase transition or creation of destructive strangelets), belong to this category. Probabilities and rates for these local mechanisms are much harder to classify (as admitted by Newman and Sagan, among the SETI optimists), but in the present model it is not really necessary. These local influences play only a role of small perturbations in the overall picture, at least until the technological civilization capable of making itself immune to the kind of global catastrophes considered emerges.

The overall regulatory complex (global + local influences) is capable of explaining why we do not observe extragalactic ETI signals or traces of advanced astroengineering activities. Since the volume of space sampled by extragalactic observations is much larger than that of Galactic studies, it would seem natural at first glance to expect even more rare events, like the emergence of Kardashev's Type III civilizations, observable from afar (e.g. Annis 1999b). However, there is a catch here; the true volume is 4-volume of spacetime, and it is severely limited by the finite velocity of light. We assume that the same regulatory mechanisms are acting in other spiral galaxies in the same manner as in the Milky Way.

Finally, a local non-destructive regulation mechanism which can be of importance is hypothetical interstellar panspermia (for a historical overview, see Raulin-Cerceau et al. 1998). The most radical version of the idea is the hypothesis by Hoyle and Wickramasinghe, developed in the monograph of Hoyle et al. (1986), that some terrestrial epidemics are caused by microorganisms delivered to Earth via comets' tails. However, even the more modest versions of panspermia, developed recently, for instance by Wallis and Wickramasinghe (2004) or Napier (2004), have significant capacity for influencing and directly shaping the astrobiological landscape. Since the probability of occurrence of panspermia is strongly dependent on the spatial scales, our 1-D model cannot take it into account, but more sophisticated models will undoubtedly need to incorporate the possibility of such (constructive) local interaction.

Various regulation mechanisms are not mutually exclusive. On the contrary, they are additive and mutually reinforcing. This is a sort of situation quite usual in terrestrial ecology. For instance, a major parameter of terrestrial biosphere is the rate of release of carbon. It is influenced by several quite distinct processes; e.g. higher temperatures increase soil respiration rates, releasing organic carbon stored in soils, creating a positive feedback loop. In the same time, an increase in frequency of forest fires leads to net replacement of older, larger trees by the younger, smaller ones, resulting in the net release of carbon from forest biomass, also creating a positive feedback (Woodward, Lomas, and Betts 1998).

4. ASTROBIOLOGICAL LANDSCAPE

A representative prediction of our simplified model is shown in Fig. 1 (for technical details, see Papers I and II). Resetting events are taken to be GRBs, randomly occurring with exponentially decreasing frequency and the fixed characteristic decay timescale of $\tau = 3$ Gyr, in accordance with the cosmological observations of distant bursts (e.g. Bromm and Loeb 2002). The biological timescales for noogenesis are randomly sampled from a log-uniform distribution between 10^8 yrs (the minimum suggested by McKay 1996) and 10^{16} yrs (the total lifetime of the Galaxy as a well defined entity; Adams and Laughlin 1997). We limit our model to the stellar population of the Milky Way thin disk, the age of which is set, for simplicity, to $t_{tdisk} = 10$ Gyr. We use the age distribution of terrestrial planets calculated on the basis of chemical evolution by Lineweaver (2001) as our input data. Probability Q measuring conveniently averaged severity of the resetting events can be regarded as both (1) a geometrical probability of an average habitable planet being in the "lethal zone" of a GRB, and (2) probability describing more complex effects dealing with the physics and ecology of the extinction mechanism. It is important to keep in mind that both these effects can be subsumed into a single quantity in simple models, but more sophisticated future work to be discussed in the next section will include multiple probability parameters. Output is the number of habitable sites achieving noogenesis at least once (in this way we avoid overly speculative issue whether multiple noogenesis events are possible concurrently or successively at the same planet).

All physical mechanisms of resetting the astrobiological clock on an average habitable planet are subsumed into a single value of the probability Q. We notice that for small values of Q we recover the naive SETI optimism of the "Galactic Club" era of 1960s and 1970s, where a sort of monolithic assent toward Galaxy full of intelligent species and, consequently, viable SETI targets can be perceived. In the other limiting case, when $Q \to 1$, we obtain the most interesting case of truly temporally correlated ages for biogenesis and noogenesis. Thus, the toy model counts only planets achieving noogenesis (emergence of intelligent observers) at least once and it does not take into account any subsequent destructive processes, either natural or intelligence-caused (like nuclear, biotech or nanotech self-destruction). As $Q \to 1$ the overall number of planets with achieved noogenesis is decreasing, reaching maxima around 5 Gyr (Fig. 1, lower panel). Although the absolute values of N are certainly too high for a realistic model (main simplification being log-uniform timescale distribution), the overall picture still reflects the basic trends and sets the stage for further detailed work.

We notice that the correlated ("rugged") landscape for high Q values (Fig. 1., upper panel) means that there will be a higher "tier" of development at each local site (neglecting, for the moment, interaction of sites, especially if we are interested in advanced technological civilizations, which cannot be modeled by this approach); this is analogous of the "third tier" of terrestrial macroevolution (Gould 1985) comprised of mass extinction episodes and their effects on the phylogeny of life. Also, the maxima at the lower panel of Fig. 1. indicate that Earth's noogenesis timescale is fairly typical, at least for adopted values of relevant Galactic parameters. This results in spite of the fact that no specifically "Copernican" assumption has been built in the model. As discussed above, this is good news for practical SETI, since it means that there is a significant number of potential search targets within the same tier Earth's biosphere and human civilization belong. Of course, the real landscape is much more complex and irregular (even the assumption of unique value of Q for any particular history is gross simplification); hopefully, these results will provoke further work on theoretical grounding of SETI projects.
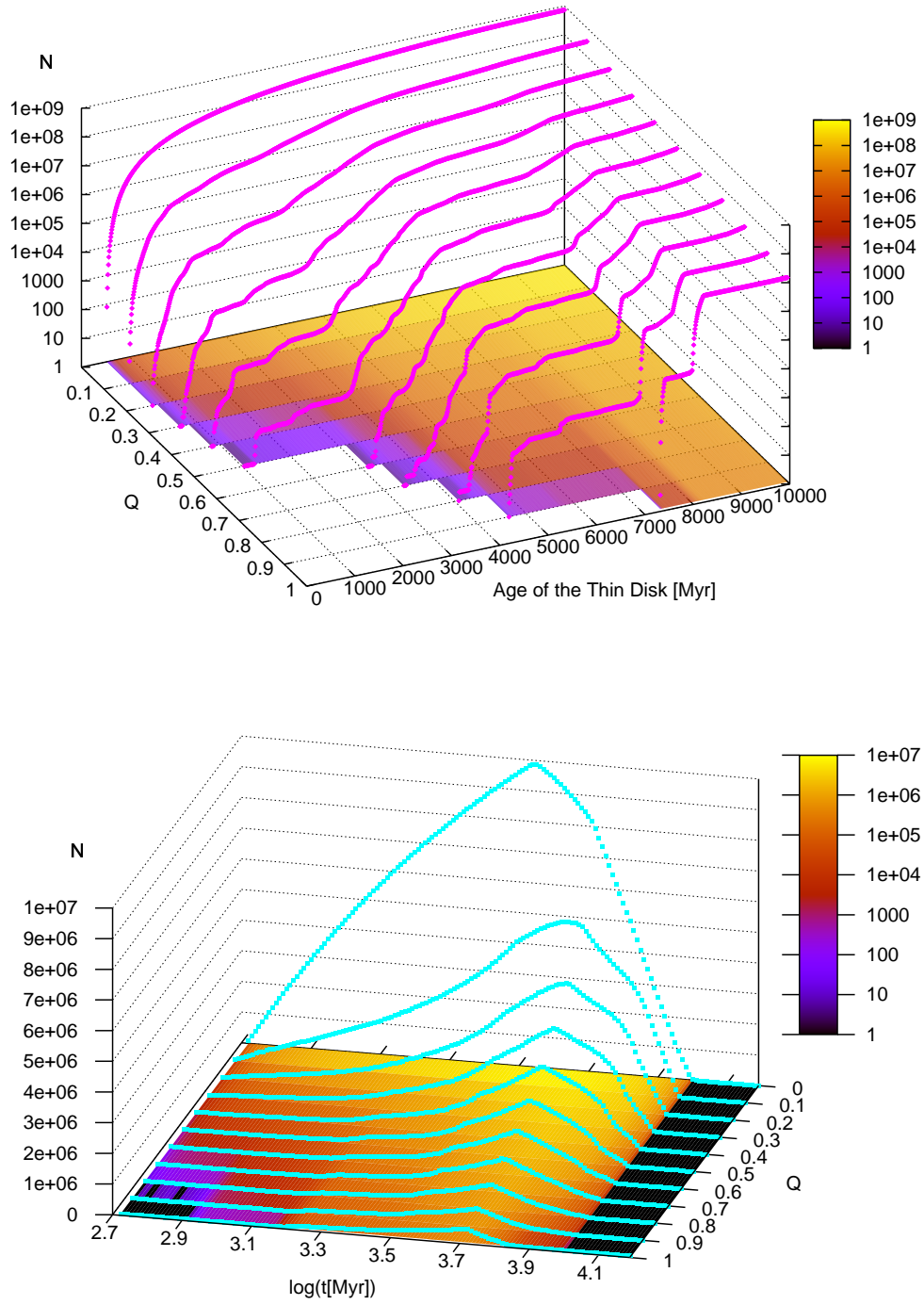
Fig. 1. *Astrobiological landscape in 1-D simplified models with GHZ comprising 10^9 habitable sites. Upper panel: number of planets that have achieved noogenesis at least once (cumulative plot); lower panel: number of planets with elapsed time t between planet formation and completion of noogenesis.*

5. DISCUSSION AND FUTURE PLANS

One might argue here that we should not consider "indiscriminative" SETI, but apply some other constraints in order to assess its meaningfulness. Here, one may again use some of the ammunition of contact pessimists against them. In contrast to naive contact optimism, we are certainly not entitled to invest money and effort into attempts at communication with intelligent societies of any age. The lower limit of age (the development of radio and/or similar devices for long-range communication) is taken explicitly into account in the Drake equation, but the anthropic reasoning indicates that we are mistaken into not taking into account the upper limit as well. In the opinion of the present authors (elaborated in Ćirković and Vukotić 2008), it is preposterous to assume that SETI can be meaningfully aimed at hypothetical societies 1 Gyr (say) older than ours. 1 Gyr ago, there were no multicellular organisms on Earth. There are no more reasons to expect beings 1 Gyr older than us to communicate with us using radio (or anything even remotely similar) than there is reason to try to establish dialogue with procaryotes.

However, if the ages of inhabited planets are to a large degree correlated, this obstacle dissolves. We have clustering of ages of biospheres around particular values and, possibly, clustering of ages of technological civilizations (and, thus, viable SETI targets) as well. This immediately undermines Carter's argument for the uniqueness of humans (as shown in more detail in Ćirković et al. 2008), but it also opens wide space for ingenuity in the field of practical SETI efforts. In this manner, advances in theoretical understanding of rather new context can pave the way for prolonged technical and experimental work, as happened many times in the history of science.

In the course of the future work, we intend to apply a different strategy, namely the probabilistic cellular automata models, which could in contrast to the present model give us more realistic 2-D and 3-D pictures of the GHZ evolution. Cellular automata are spatially extended nonlinear dynamical systems with a huge variety of dynamical behaviors, especially convenient for modeling systems containing a large number of locally interacting similar components; this immediately brings in mind stellar systems in general, and Milky Way and its GHZ in particular. Although a vague precursor of such an approach exists in the work of Landis (1998) on application of the percolation theory to solving Fermi's paradox, no systematic investigation of this class of astrobiological models have been performed thus far. It is clear that this would be complementary to the 1-D models presented here. In the cellular automata models it would be quite easy to implement the interstellar interactions between the sites, either in forms of naturally-occurring panspermia, or – from the point of view of Fermi's paradox especially interesting – interstellar colonization. This would be in accordance with the general physical usage of the cellular automata models for simulating those complex dynamical systems where local interactions are simple while the whole system is both too large and too sensitive to the initial conditions for the direct approach to be worthwhile. (In astrobiology we need to add another layer of difficulty to this, since we are in fact lacking knowledge on the details of "local dynamics", namely biogenesis and noogenesis on terrestrial planets in GHZ.) As an example of the effect which would be natural to model within the 3-D framework is the "substructure" within GHZ formed by, for instance, nonlinear proportionality between the local metallicity at any given epoch and the probability of a star having planets (of any kind).[1]

In a sense, there is a deeper logic in the successive application of these classes of models for resolving the long-standing arguments of SETI sceptics. While Carter's anthropic argument was essentially a 1-D problem (only the number of inhabited planets at given epoch mattered), Fermi's paradox is essentially 3-D problem (spatial extent of civilizations at given epoch). Thus, the toy 1-D model can serve to undermine Carter's argument (as shown in Ćirković et al. 2008), but a stronger class of models is necessary in order to do the same with Fermi's paradox. We shall investigate whether 3-D cellular automata models are up to the task in a subsequent work. In particular, *phase transitions* are common phenomena in nonlinear systems studied thus far with help of probabilistic cellular automata (e.g. Kaneko and Akutsu 1986). Finally, in order to face the hardest of all skeptical arguments, the argument from biological contingency, one needs additional complexity stemming from the parameters determining the size of the relevant parts of evolutionary morphospace. It is unclear at present how one could quantify such a situation, but it is to be hoped that the rapid development of astrobiological modeling will be up to the task.

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[1] We acknowledge an anonymous referee for bringing our attention to this important effect.

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НЕОКАТАСТРОФИЗАМ И АСТРОБИОЛОШКИ ПЕЈЗАЖ МЛЕЧНОГ ПУТА

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Број и расподела настањивих планета у Млечном путу један је од најзначајнијих проблема савремених астробиолошких истраживања. Овде истражујемо ефекте промене опште неокатастрофичке парадигме на еволуцију Галактичке настањиве зоне. У овом раду, испитујемо границе једноставних, 1-димензионалних астробиолошких модела и разматрамо улогу регулационих механизама у обликовању "астробиолошког пејзажа". Показујемо како транзиција са преовладавајуће градуалистичке на преовладавајуће (нео)катастрофичку историју наше Галаксије води до настанка корелација између настањивих локација на великој скали, чиме се отварају могућности решавања тако важних проблема какви су Картеров "антропички" аргумент и Фермијев парадокс. Уз то, разматрамо могућности проширења садашње класе модела на просторно реалистични 3-димензионални случај коришћењем пробабилистичких целуларних аутомата.