

ASTROBIOLOGICAL LANDSCAPE AND NEOCATASTROPHISM

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Abstract. We review results of the simple 1-D models of the Galactic Habitable Zone constructed within neocatastrophic paradigm. The emerging astrobiological landscape demonstrates the capability of this theoretical framework to resolve the classical puzzles of Fermi's paradox and Carter's anthropic argument against extraterrestrial intelligence. Preliminary results show that astrobiology offers a clear rationale for the "Copernican" assumption of typicality of the age of the terrestrial biosphere.

1. INTRODUCTION

The introduction of the Galactic Habitable Zone (GHZ) concept by Gonzalez, Brownlee and Ward (2001) made possible addressing some of the quantitative issues of Galaxy's astrobiological history. The pioneering studies (Lineweaver, Fenner and Gibson 2004, Ćirković 2005, Prantzos 2008) have not made a clear standard in defining GHZ boundaries, but rather offered a framework for building up more profound quantitative models than ever before. Now, there is ample room to make one step ahead towards the resolution of Fermi's paradox and testing the Carter's anthropic argument. We briefly review the results of Vukotić and Ćirković (2007, 2008), Ćirković and Vukotić (2008), Vukotić (2008), Ćirković et al. (2008) and Forgan (2009), investigating the GHZ with Monte Carlo models. Here, we present an outline of our recent work and suggestions for forthcoming studies.

1. 1. RE-EMERGING NEOCATASTROPHISM

A growing belief that simple life is widespread within GHZ boundaries adds more weight to neocatastrophic explanation of Fermi's paradox and undermining of Carter's argument. A role of interrupts in the slowly grinding mill of astrobiological evolution is played by global regulation mechanisms (henceforth GRMs): not very-well understood processes capable of arresting or postponing the advent of complex beings and intelligent observers in a large part of GHZ. In general, they will tend to hinder simple life from advancing to more complex lifeforms (although indirectly they may provide for a needed "evolution pump", by changing the rules of the evolutionary game and opening ecological niches for new taxa). A prototype GRM should be: (1) lethal enough – total or partial sterilization of habitable sites; (2) global – active all over a large fraction of the GHZ and (3) secularly evolving. If the secular evolution leads to the decreasing frequency, as it becomes very plausible when we consider specific

astrophysical processes, such GRMs are able of shaping the Galactic astrobiological "landscape" (cf. Fig. 1) in a way capable of resolving the difficulties. As time passes, because of 3), the GRMs will create larger temporal windows within simple life can freely evolve into more complex forms, such as humans or other hypothetical intelligent beings in the Milky Way. This behavior will at some point create a phase shift: from an essentially dead place with pockets of simple life scattered around the Galactic disk, our Galaxy could be crowded with various complex life forms. We intend to test the potential of this paradigm starting with simple Monte Carlo simulations of GHZ.

Gamma-ray bursts (GRBs) fit best to the three conditions above (for details see our papers cited in the previous section and references therein). In the next section, we shall briefly present an array of our simple 1-D GHZ models in which we have implemented a Global Risk Function (GRF) with the properties of GRBs acting on a set of habitable planets. Also, different biological timescales were implemented. All our models give results that are tentative support for astrobiological phase transition (APT) in the neocatastrophic paradigm. Validity of our results is constrained by the uncertainties in input parameters. Future astrobiological missions and projects, as well as further theoretical insight, should help with better constraining of input parameters.

2. A SHORT OUTLINE OF 1-D MODELS

In the first and simplest model, GRF is represented by a series of 200 random events with the exponentially decreasing frequency (for details see Ćirković, Vukotić and Dragićević 2008). The model considers 10^6 possible habitats with biological noogenesis timescales randomly chosen on a logarithmic timescale in the 10^8 to 10^{16} yrs interval. All habitats are of the same age (starting at $t = 0$) and the simulation timescale is taken to be 12 Gyr. So simple it can be described in a few sentences and with very rough estimates of input parameters, this model clearly showed a large potential in undermining the Carter's argument. This follows from the obviously strong temporal correlations built-up during the Galactic history in the catastrophic limit ($Q \rightarrow 1$). Although more sophisticated our later models essentially gave no new qualitative results because we made no changes in basic concept. The refinements were made in input functions and parameters.

The improvement for the next model was implementing the age distribution of terrestrial planets according to Lineweaver (2001) – for details see Vukotić and Ćirković (2007). The essence of Lineweaver's results is that metallicity determines the formation rates of terrestrial planets, while being rather well-understood through both observational and theoretical work on the Galactic chemical evolution. Making it more realistic, the number of habitats was raised to 10^9 and biological timescales (this particular input is very hard to constrain and this is not likely to change in the near future) were randomly sampled from 10^2 to 10^{10} Myr on a linear timescale.

Finally, the last model is taking into account the Main Sequence lifetime of the host star that creates a dead-end for the life forms that are unable to achieve sufficient complexity to avoid it. The biological timescales are randomly sampled from a log-uniform distribution of the Main Sequence lifetimes for Sun-like stars (this model is presented in Vukotić 2008, Ćirković and Vukotić 2008).

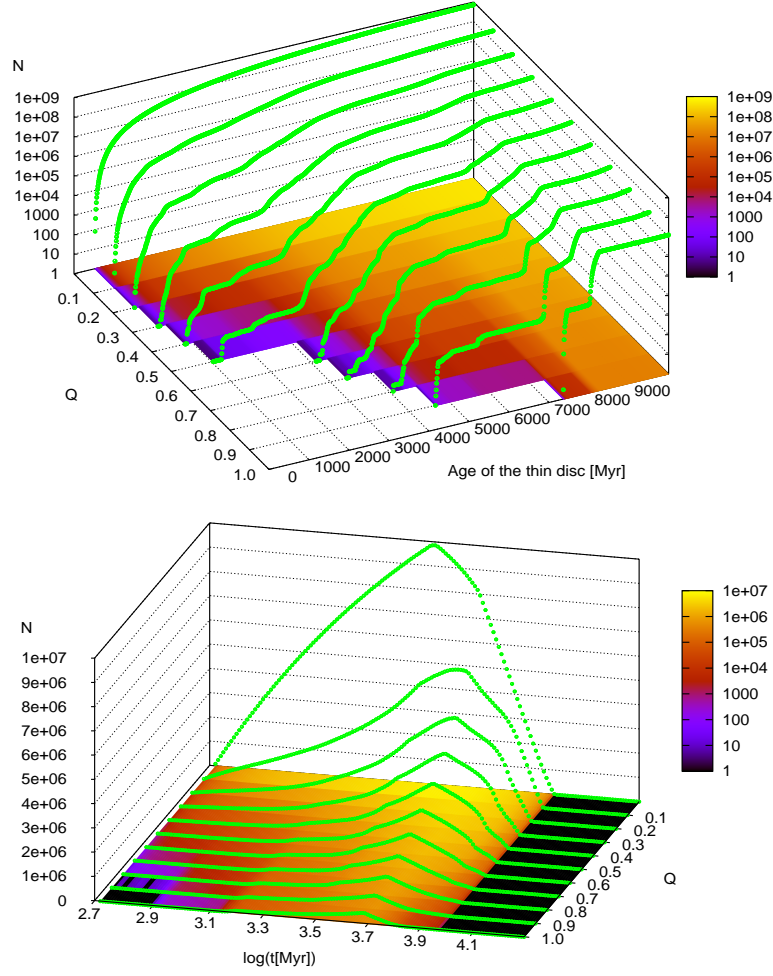


Figure 1: The simple 1-D model results from Ćirković, Vukotić (2008): upper panel – The number of planets that have achieved noogenesis at least once (cumulative plot), as a function of the age of the Milky Way thin disc stellar population and the mean extinction probability Q per global catastrophe; lower panel – The resulting age distribution of timescales for noogenesis.

3. RESULTS AND FUTURE PROSPECTS

Our results are indicative of the astrobiological phase transition in a catastrophes-driven evolution (as in upper panel of Fig. 1). The step-like transition signature is clearly seen throughout the model series for GRF with large reset probabilities Q . In the future the discovery of extraterrestrial life and possible neighboring Galactizens is likely to be far more probable – Fermi’s paradox might not be a paradox after all. The scenario exposed by Ćirković and Vukotić (2008) predicts that the age-difference between intelligent observers will not be astronomically large, as expected on the basis of (over)simplistic estimates (e.g. Duric and Field 2003).

An interesting point can be made from lower panel of Fig. 1. It presents the number of modelled planets that have completed noogenesis in a given time interval. With adopted input parameters and the Earth being a typical GHZ planet results show that the line of maxima is shifted towards larger time values in respect to $\log t = 3.66$ Myr for the terrestrial case. This sustainability comes from the GRF resetting the planets astrobiological clocks. This means that Earth is amongst first planets to have achieved noogenesis and that within ~ 1 Gyr from now there will be a sudden increase in the number of planets with intelligent life.

However, quantitative predictions still remain a major drawback. Earth-like planet surveys in the near future will provide large exoplanet databases that are of crucial importance for estimating the total number of possible life cradles within the GHZ. More realistic models, especially better parameterization of GRF, will follow from spatial modelling of GHZ and including more phenomena in the analysis. Thorough studies of Earth's and Solar system fossil records will help in better constraining of biological timescales. In the ongoing work, we shall generalize the present APT model with more phenomenological details, notably (i) the realistic luminosity function of gamma-ray bursts, (ii) finite disk scale-height and other inhomogeneities of GHZ, (iii) better accounting for the distribution of the absorbing interstellar medium, (iv) local limitations on the habitability of planets, like the probability of creating "ocean-worlds" or destruction of habitable worlds by migrating giant planets, (v) geophysical and biotic feedback effects on the duration of geological uninhabitability, and (vi) non-zero probability of interstellar panspermia. In addition, the biological ("local") side of the tale needs to be elaborated in more detail, especially in order to elucidate all concurrent physical and ecological processes determining reset probabilities Q . New quantitative approaches will be needed for these more complicated issues, one of them being probabilistic cellular automata. Quantifying the GHZ is a promising multidisciplinary challenge for forthcoming studies.

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