Publ. Astron. Obs. Belgrade No. 91 (2012), 217 - 219 *Contributed paper*

GALACTIC HABITABLE ZONE AND ASTROBIOLOGICAL COMPLEXITY

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Abstract. This is a short thesis description and for the sake of brevity most things are left out. For more details, those interested are further directed to the thesis related papers in this article reference list. Thesis itself is available at the University of Belgrade library "Svetozar Markovic" (Serbian version only). In this thesis we study the astrobiological history of the Galactic habitable zone through the means of numerical modeling. First group of simulations are unidimensional (time-axis) toy models examine the influence of global regulation mechanisms (gamma-ray bursts and supernovae) on temporal evolution of Galactic astrobiological complexity. It is shown that under the assumption of global regulation classical anti SETI arguments can be undermined. Second group of simulations are more complex bidimensional probabilistic cellular automata models of the Galactic thin disk. They confirm the findings of the toy models and give some insights into the spatial clustering of astrobiological complexity. As a new emerging multidisciplinary science the basic concepts of astrobiology are poorly understood and although all the simulations present here do not include some basic physics (such as Galactic kinematics and dynamics), the input parameters are somewhat arbitrary and could use a future refinement (such as the boundaries of the Galactic habitable zone). This is the cause for low weight and high uncertainty in the output results of the simulations. However, the probabilistic cellular automata has shown as a highly adaptable modeling platform that can simulate various class of astrobiological models with great ease.

1. INTRODUCTION

Discovery of the first extrasolar planets in the last decade of the past millennium (Wolszczan and Frail 1992) have boosted the astrobiological studies and further emancipated the microbiology as a new and exciting multidisciplinary research field (Horneck and Rettberg 2007). More robust research was applied and recently lunched space missions have a major part of their agenda devoted to traditional astrobiology questions. As rocky planets (and solid cores of giant planets) require a certain amount of metalicity to form (Lineweaver 2001), the Galactic chemical evolution is the basic condition for considering the boundaries of Galactic Habitable Zone (GHZ) – a few kpc wide galactocentric annular ring where life friendly conditions are more likely to occur than in other parts of the Galaxy (Gonzalez et al. 2001, Lineweaver et al. 2004, Gonzalez 2005). The GHZ should also be subjected to moderate supernova and gamma-ray burst rates, which can significantly constrain the life harboring abilities of Earth-like hosts and also dynamical stability should be considered. The life complexity is quantified with the discrete parameter called astrobiological complexity – based on the Earth historical record. The goal of the thesis (Vukotić 2010b) was to get insight in the evolution of the astrobiological complexity within GHZ and to resolve classic skeptic anti-SETI arguments (i.e. Barrow and Tipler 1986, Carter 1983). The research was performed using Monte Carlo numerical technics (Press et al. 1992, Forgan 2009, Forgan and Rice 2010).

2. UNIDIMENSIONAL MODELS

The habitable sites are assigned a random amount of time to achieve sufficient astrobiological complexity indicative of technological civilization. The assigned temporal intervals are evolved under forced regime. With a certain probability the reset events (that occur with decreasing frequency) are allowed to reset the astrobiological clocks of simulated habitable sites (Annis 1999, Bostrom and Ćirković 2008). If the site's clock undergoes the reset it is further evolved from the beginning. This is repeated until the noogenesis interval expires before the next reset or the end of the simulation timescale is reached. At each simulation timestep the cumulative number of completed noogenesis intervals is plotted.

The plots strongly suggest that forced evolutionary regimes lead to an astrobiological phase transition. With the large part of the Galactic history deprived of noogenesis the secularly decreasing frequency of reset events creates a temporal window at some point in Galactic history resulting in fast increase of the number of habitable sites that have achieved noogenesis. This demonstrated that astrobiological phase transition paradigm has the potential to resolve classic SETI issues such as Fermi paradox. (For details see Ćirković et al. (2009), Vukotić and Ćirković (2007), Ćirković and Vukotić (2008), Vukotić and Ćirković (2008), Ćirković and Vukotić (2009) Vukotić and Ćirković (2010) and Vukotić (2010a)).

3. BIDIMENSIONAL MODELS

Temporal mechanics of unidimensional models is extended spatially using the Probabilistic Cellular Automata modeling platform (Ilachinski 2001). Each cell of a 4 state PCA lattice resembles a habitable site within the GHZ. The sites are evolved under probabilistic rules set by input probabilities. Input probabilities are calculated from evolutionary timescales (genesis of life, evolution from simple to complex life and further to technological civilization). Timescales are classified as **intrinsic**, **neighborhood driven** and **globally driven**. Intrinsic timescales are indicative of site changing its state as if it were evolving in an isolation. Neighborhood timescales are primarily intended to model the interstellar colonization (site changes its state because it is colonized by the adjacent cells) and globally driven should implement time forcing evolution as in unidimensional models, according to star formation history (Rocha-Pinto et al. 2000ab).

Qualitative findings from unidimensional modeling were confirmed. The spatial extension required the development of cluster analysis tools in order to quantify the colonization and global regulation driven GHZ emerging cluster patterns. At present, it is not possible to determine input astrobiological timescales with sufficient accuracy which makes the quantitative results rather of no practical importance. The

PCA mechanics has shown as quite convenient for testing various hypothesis. Each hypothesis can be characterized with a certain set of input timescales without changing the underlying PCA mechanics. For more details see Vukotić (2010b).

Acknowledgements

This research has been supported by the Ministry of Education and Science of the Republic of Serbia through the project ON176021: "Visible and invisible matter in nearby galaxies: theory and observations".

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