Supernovae rate constraints on the galactic habitable zone

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Introduction

Conditions for evolution of complex life are not homogenous throughout the Galaxy. The so-called Galactic habitable zone is a ring-shaped region in the disk, whose outer limit is determined by low metallicity, whereas the inner limit is defined by transient threats – frequent supernovae explosions, gamma ray bursts, and gravitational perturbations. The goal of the research was to find the possibility of nearby supernovae events during the last 500 Myr, and evaluate the possible impact of core-collapse supernovae to Earth's biosphere. Differential Galactic disk rotation, distribution functions of supernovae in the disk, spiral arms' crossing frequency and uncertainties in Galactic parameters were taken into account.

Motivation

The evolution of life on Earth was not constant - a steady increase of diversity during the last 500 Myr is punctured with dramatic mass extinctions.

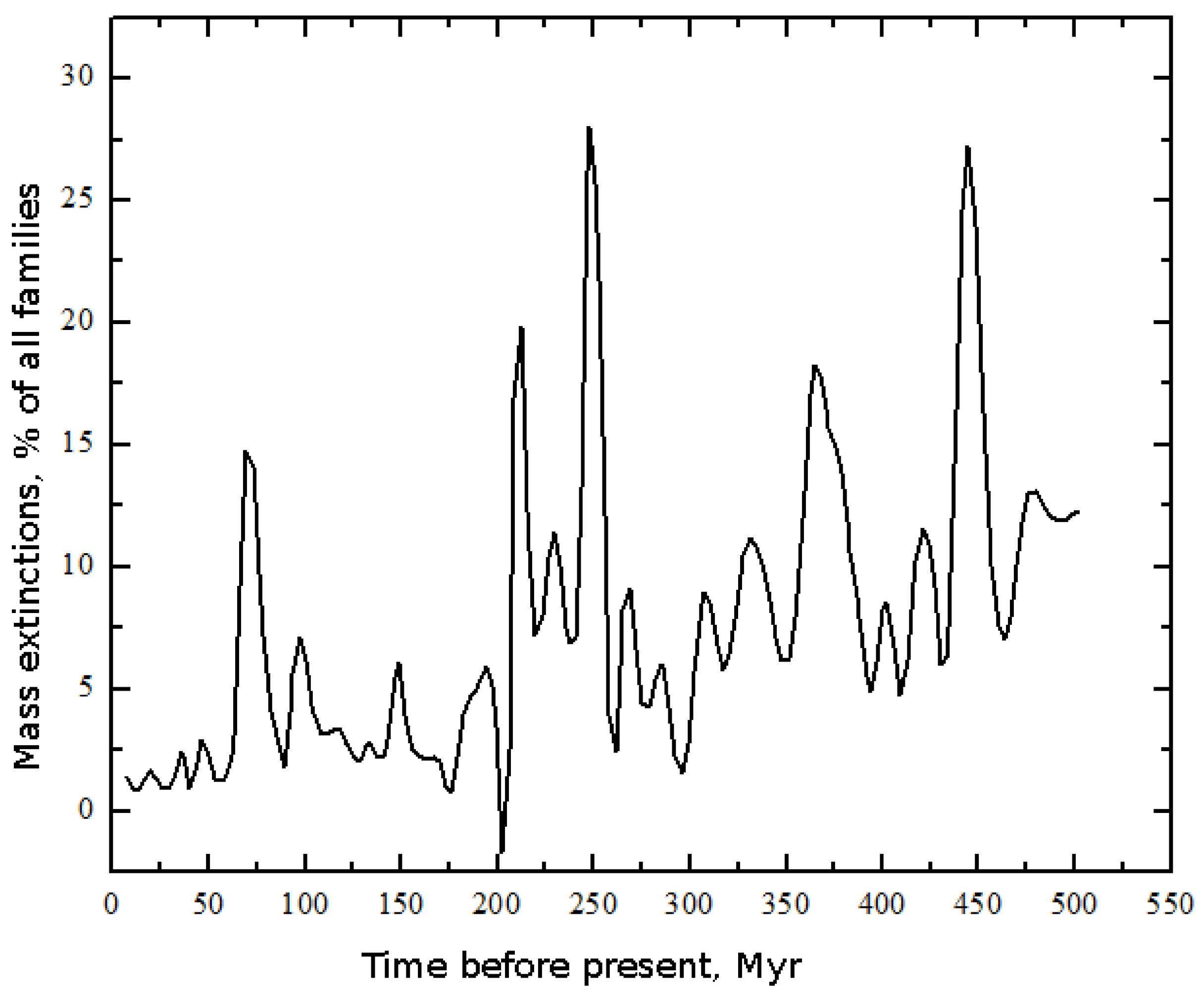

Figure 1: Mass extinctions according to M. Benton's *The Fossil Record 2* [1] diversity database.

An explosion of a nearby supernova might seriously impact the terrestrial biosphere. The ozone layer would be severely damaged by UV/optical radiation, cosmic and X-rays. Increased solar UV radiation might reduce the photosynthesis, cause severe burns and skin cancers in multicellular organisms. In our work we considered 10 pc as the maximal "dangerous" distance of a core-collapse supernova explosion.

Supernovae in our Galaxy

The core collapse supernovae are not homogenously distributed throughout the Milky Way. The radial and vertical distributions of SN can be aproximated as a double exponent:

$$\Re_{SN}(R,z) = \Re_C \cdot e^{(-R/h_r)} \cdot e^{(-|z|/h_z)},$$

here h_r is the disc scale length, h_z - disc scale height, z - vertical distance to the Galactic plane, R - galactocentric distance.

We obtained the galactic rate of core collapse supernovae events using the PEGASE code package. It was equal to $\Re_{SN} = 2.4 \cdot 10^4 \cdot \mathrm{Myr}^{-1}$. Having done this, we now could find the distribution of SN in the region which interests us - namely, 6 R 10 kpc. We calculated the distribution of core collapse SN in 10 pc width rings in this region and found the mean time which stars spend in the spiral arms – it was then possible to find the spacial distribution of the possibilities of nearby SN explosions.

Our model of the Galaxy

We modelled the four spiral arms of the Galaxy as logarithmic spirals and assumed that their width is constant (1 Kpc) and the supernovae are distributed evenly inside the arms.

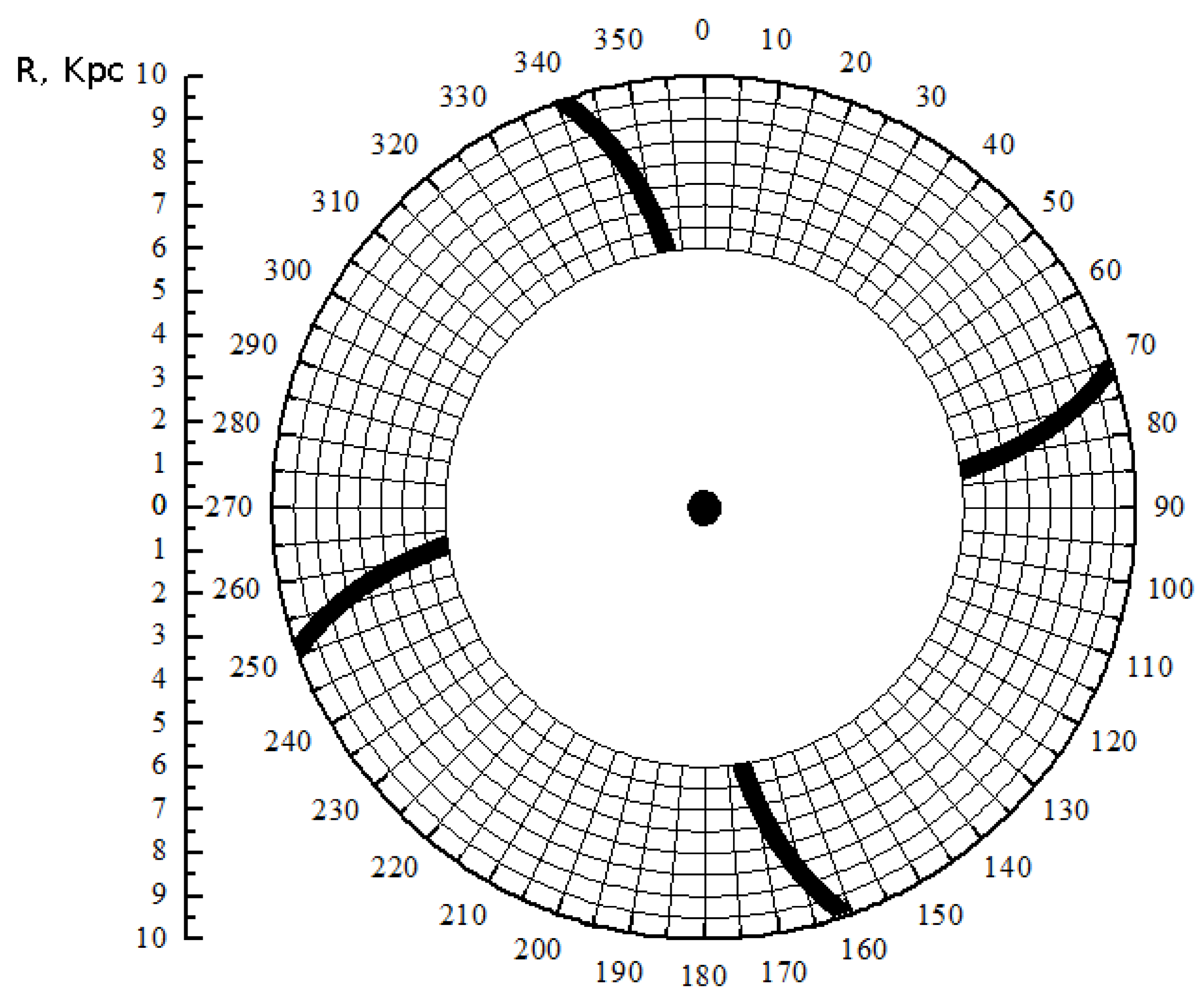

Figure 2: Our model of the Galaxy, the spiral arms are modelled according to J. Valee's meta-analysis of the Galactic structure [2].

Possibility of a nearby supernova as a function of galactocentric distance and the star's position

The rotation of the Galaxy's stars and gas is differential, while the spiral arms rotate as a rigid body. Moreover, the differential velocity of stellar matter is not constant – it is defined by the Galaxy's rotation curve. These two velocities are only equal at the co-rotation radius R_{corot}.

The number of spiral arms crossed in the last 500 Myr depends on both the relative star's movement and it's position between the spiral arms. The end result is a quite complex distribution of dangerous regions in the Galaxy.

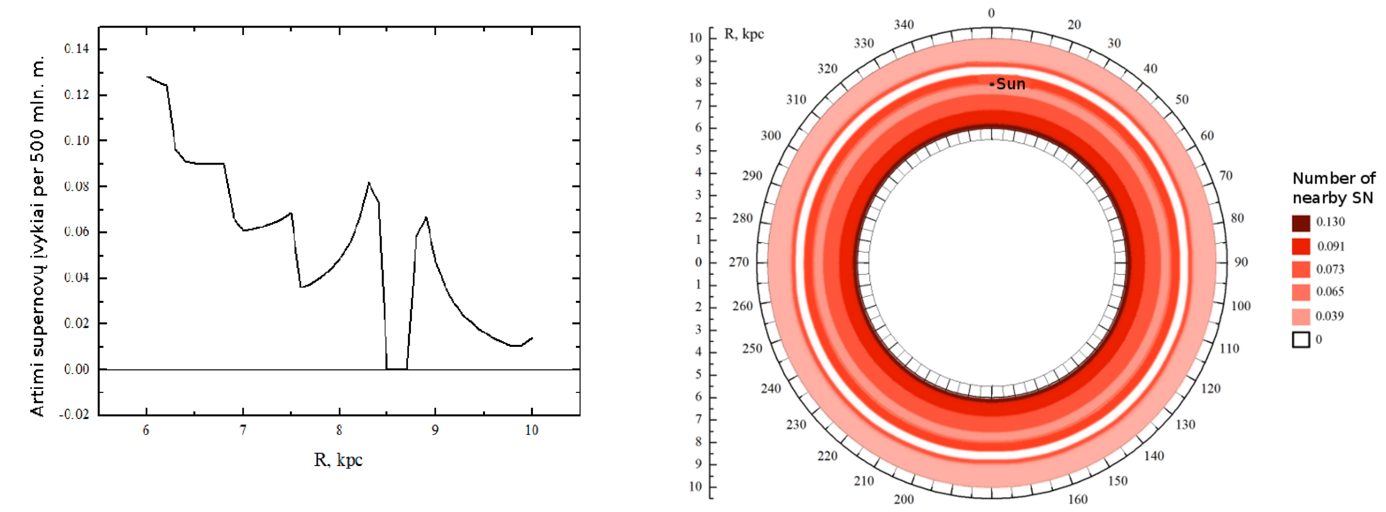

Figure 3: Probability of a nearby supernova explosion for a star, whose position with respect to the spiral arms is the same, as the Sun's.

The Galactic habitable zone

It is evident that the Galactic habitable zone is not simply an annulus-like region of the Galactic disk. After taking the relative star motion between the spiral arms and effects of a star's position between the arms into consideration, we see that the Galactic habitable zone is not homogenous. Habitability of a star system has to be evaluated on an individual basis, since it depends on the star's orbit, velocity, galactocentric radius R and position between the arms. If we assume that the Sun is based at R = 8.0 Kpc from the GC and the spiral pattern velocity $\Omega_p = 25$ km s^{-1}, then the possibility of a nearby supernova during the last 500 Myr is only 0.048 - more than 8 times less than some cited[3] values. The reason of this difference is our better understanding of the location of R_{corot}.

Main References

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