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Assessing the influence of astronomical phenomena on the Earth's biosphere

F. Feng, C. A. L. Bailer-Jones
Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany (ffeng@mpia.de, calj@mpia.de)

Abstract

The fossil record suggests that biodiversity has varied considerably over Phanerozoic eon (past 550 Myr). Some claim the presence of a periodic component in this variation [8,9], which could be caused by some astronomical mechanism related to Sun's orbit through the Galaxy [3–5]. The periodic component supposedly arises from the (quasi)-periodic motion of the Sun about the Galactic plane and/or through the spiral arms. However, many researchers have pointed out that methods used to analyze the data and even the data themselves are problematic [1, 6, 10]. In order to assess the plausibility of the Sun's orbit modulating biodiversity, we have first studied the stability of its periodic motion. Second, assuming that the extinction rate is proportional to the local stellar density (implying some non-specific extinction mechanism), we assess how well different dynamical models of the solar orbit can explain the fossil record.

For the first task, we test the sensitivity of the periodicity of the solar orbit to initial conditions and parameters of the Galactic potential model, in order to test claims that the solar orbit could produce periodic extinctions at all. We adopt the Galactic potential model of [4] and the logarithmic spiral arm model of [11] with a pattern speed given in [7] (Figure 1). We then produce a large sample of orbits by perturbing the initial conditions. We find that a strict periodic orbit arises only when there is an exact circular orbit, or at specific values of the initial conditions which give rise to a resonance between the perpendicular and azimuthal motions. The periods of these two kinds of orbits are determined primarily by the initial radius, $R(t = 0)$, and initial angular velocity. $\dot{\phi}(t = 0)$, if we fix the other model parameters. However, we do find that about 90% of orbits have plane-crossing aperiodicities less than 10% (Figure 2). So while a strict periodicity is unlikely, a quasi-periodicity is likely.

Second, to assess the influence of the time-varying local stellar environment on the extinction rate, we calculate the likelihood of the extinction record (Figure 3) for each of these dynamical models, over the past 550 Myr (see [2] for the general model). We compare these likelihoods to that of alternative hypotheses, such as a uniform extinction rate. The results in Table 1 show that the evidence (likelihood averaged over other model parameters) of the various dynamical models are no higher than that of the uniform model, i.e. the data are no better explained by a dynamical model. This suggests that the local stellar density has a limited overall impact on the long-term variation of the terrestrial extinction rate. This work continues.

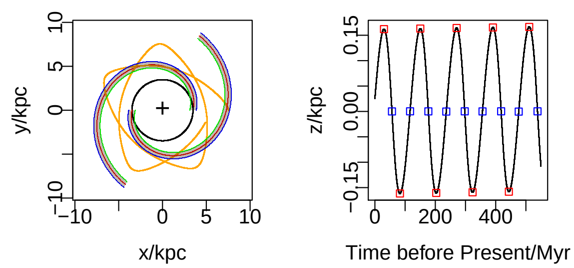

Figure 1: Left: the spiral arm model (grey) and one particular solar orbit (orange) in the Galactic plane. Right: the motion of the Sun perpendicular to the plan in one particular orbit showing the plane crossing points (blue squares) and peaks (red squares).

Table 1: The evidence of the uniform model and of dynamical models with different parameters perturbed.

Dynamical Model	Evidence
R(t=0)	1.86×10^{-3}
$\dot{\phi}(t = 0)$	1.86×10^{-3}
R(t=0),$\dot{\phi}(t = 0)$	1.86×10^{-3}
R(t=0), $V_R(t = 0)$, $\dot{\phi}(t = 0)$, $V_z(t = 0)$	1.86×10^{-3}
Uniform Model	1.85×10^{-3}

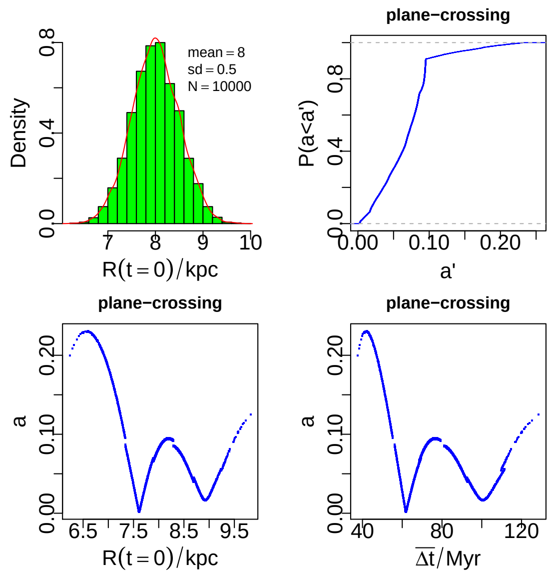

Figure 2: The dynamical model. Top left: histogram of R(t=0). Top right: cumulative probability of the aperiodicity of orbits with different R(t=0). Aperiodicity is defined as the standard deviation of the intervals (Δt_i) between two neighbouring plane crossings (blue squares in Figure 1) relative to the average interval ($\overline{\Delta t}$), i.e. $a \equiv \sigma(\Delta t)/\overline{\Delta t}$. Bottom left: Aperiodicity as a function of R(t=0). Bottom right: Aperiodicity as a function of the average interval ($\overline{\Delta t}$).

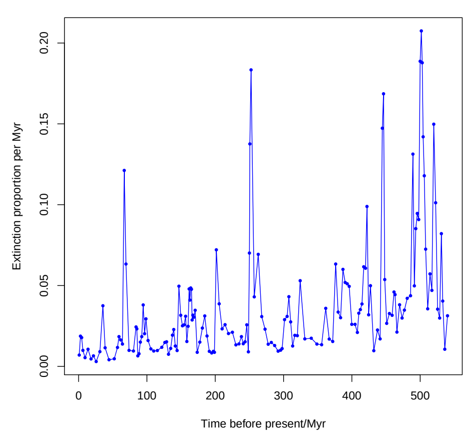

Figure 3: Extinction proportion per Myr from [9] (online supplementary material).

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