Comment on “Does the rapid appearance of life on Earth suggest that life is common in the Universe”

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In a recent paper astro-ph/0205014 Lineweaver and Davis performed a statistical analysis to claim that the rapidity of biogenesis on Earth indicates high probability of biogenesis on terrestrial-type planets. We argue that the rapid appearance of life on Earth hardly tells us anything about the probability of life to appear on other planet. The conclusion should be different. The rapid initial biogenesis is consistent with a large number \( N \) of the order of 10 of crucial steps in evolution from simplest life forms to humans.

I. DISCRETE EVOLUTION MODEL

Let us consider a model of “discrete evolution”. It is known that the evolution from the simplest life form to humans may be expressed in terms of qualitative steps, for example, first live cell,..., cell with a nucleus,..., multicell organism, ... , mollusk, fish, amphibian, reptile, mammal, human. Let us denote the total number of “crucial steps”, or “classes” by \( N \), and probability of a new class \( \lambda_n \) to appear from a previous class \( \lambda_{n-1} \) per unit time as \( \lambda_n \). The corresponding probability for a class \( n \) to appear during a small time \( t_n \) is

\[
P_n = \lambda_n t_n.
\]

The total probability for a human to appear during time \( t = \sum t_n \) can be presented as the product of the probabilities

\[
P(t) = \prod \lambda_n t_n = \prod \lambda_n \cdot t_n.
\]

The maximum of this expression is achieved for all \( t_n = t/N \).

By comparing this with the time life has existed on Earth

\[
t \simeq 4 \text{Gyr}.
\]

we conclude that the number of crucial steps in evolution from the simplest life form to humans is \( N \sim 10 \).

II. THE CASCADE MODEL

To make this conclusion more reliable we present another toy-model that somehow takes into account a continuous character of the evolution. Let us consider a direct chain of classes (steps) which leads from the first life to humans.

The time dependence of the populations \( W_k(t) \) in these classes can be determined from the following equations:

\[
\frac{dW_1}{dt} = \Gamma_1 W_0 \quad \cdots \cdots \cdots
\]

\[
\frac{dW_k}{dt} = \Gamma_k W_{k-1} \quad \cdots \cdots \cdots
\]

The term \( \Gamma_k W_{k-1} \) in the right-hand-side of (6) is responsible for the flux from the previous class. In what follows we assume that the initial conditions are \( W_0(0) = 1 \) (no life) and \( W_k(0) = 0 \) for \( k > 0 \).

Equations (6) have the simple solution,

\[
W_n = \left( \prod \Gamma_n \right) \frac{t^n}{n!}.
\]

The probability for life to appear and the probability of humans to appear (class \( N > 1 \)) in this model is determined by arbitrary parameters \( \Gamma_n \). However, for any \( \Gamma_n \) class \( N \) is populated long after class 1. Indeed, to reach the same probability \( W_N(t_N) = W_1(t_1) \) the time should be

\[
t_N \simeq \frac{N(\Gamma_1 t_1)^{1/N}}{\Gamma}.
\]

Here \( \Gamma = (\prod \Gamma_n)^{1/N} \) is the geometrical average value.

We can slightly modify this model by writing an equation describing the probability of the system to reach a certain class during its evolution. For simplicity we assume that all \( \Gamma_n = \Gamma \). For this case the probabilities for
different classes can be determined by the “probability conservation equations”,

\[
\begin{align*}
\frac{dW_0}{dt} &= -\Gamma W_0 \\
\frac{dW_1}{dt} &= \Gamma W_0 - \Gamma W_1 \\
\vdots \\
\frac{dW_k}{dt} &= \Gamma W_{k-1} - \Gamma W_k
\end{align*}
\]

The first term \( \Gamma W_{k-1} \) in the right-hand-side of (9) is responsible for the flux from the previous class, and the second term \( \Gamma W_k \) describes the transition from the class \( k \), into the next class \( k+1 \).

Equations (9) have the simple solution,

\[
W_0 = \exp(-\Gamma t) \\
W_n = \frac{(\Gamma t)^n}{n!} \exp(-\Gamma t) = \frac{(\Gamma t)^n}{n!} W_0.
\]

(10)

For an infinite chain one can easily check the normalization condition for the probabilities,

\[
\sum_{n=0}^{\infty} W_n = \exp(-\Gamma t) \sum_{n=0}^{\infty} \frac{(\Gamma t)^n}{n!} = 1.
\]

(11)

The maximal probability \( W_n = \frac{n^n}{n!} \exp(-n) \approx 1/\sqrt{2\pi n} \) to be in the class \( n \) determined by the condition \( dW_n/dt = 0 \), occurs for \( t = n/\Gamma \), therefore, this solution can be considered as a cascade in the population of different classes. Indeed, at small times \( t \ll \tau \equiv 1/\Gamma \) the system is practically in the initial state (no life), at times \( t \approx \tau \) the flow spreads into the first class, for \( t = n\tau \) it spreads into the \( n \)-th class, etc.

The probability for life to appear and the probability of humans to appear (class \( N >> 1 \)) in this model is determined by a single parameter \( \Gamma \). However, again class \( N \) is populated long after class 1. For \( t << 1/\Gamma \) this model gives the same result as a model considered above.

III. CONCLUSIONS

The probabilities of the first life to appear are determined by the arbitrary parameters \( \lambda_1 \) in the first model and \( \Gamma \) in the second model. For any values of these parameters the first life should appear on a much shorter time scale than “humans” (if the number of steps \( N >> 1 \)).

Thus, the rapid appearance of life on Earth hardly tells us anything about the probability of life to appear on another planet. It only tells us that there was a large number of crucial intermediate steps between the first live organisms and humans.

IV. ACKNOWLEDGMENTS

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[1] C.H. Lineweaver, T.M. Davis. astro-ph/0205014 accepted to Astrobiology.