Statistics of One: What Earth can and can't tell us about life in the universe.

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Abstract

Recent studies have attempted to extrapolate the abundance of life in the universe and the properties of such life from the history of life on Earth. A common "reasonable" assumption in such studies is that the history of life on earth is typical of life in the universe. In this poster we examine the question of whether life on Earth is likely to be typical of life in the universe. In determining this we must consider that, as observers, we are biased by having only one example of life: the example that led to our evolution on a 4.5 billion year old earth. This "anthropic principle," is more accurately described as an anthropic bias, which alters the relationship between measured quanities such as evolutionary timescales and the distribution of values these quantities may have in reality. In some instances this bias can be quantified. We apply a statistical approach to quantifying this bias in the case of the timescales involved in abiogenesis and evolution of intelligent species.

Methodology

For simplicity, we model the evolution of intelligent life as two Poissonian processes, abiogenesis, and evolution of intelligence with typical timescales of τ_{bio} and τ_{evo}. In practice, this method works for arbitrary numbers of variables and non-Poissonian processes. We also t_{bio} and t_{evo} as the actual time required for abiogenesis and evolution on a specific world. Our task is, given a single measurement of t_{bio} and t_{evo}, what is the distribution of likely values of τ_{bio} and τ_{evo}.

For a given τ_{bio}, the probability of life existing on a planet identical to earth at some time t_0 is:

$$P_L(t_0) = \frac{1}{\tau_{bio}} \int_0^{t_0} \exp\left(\frac{-t}{\tau_{bio}}\right) dt$$

and the expectation value of t_{bio} on worlds where life has arisen prior to time t_0 is

$$\langle t_{bio} \rangle = \frac{\tau_{bio} + (-t_0 - \tau_{bio}) \exp\left(\frac{-t_0}{\tau_{bio}}\right)}{1 - \exp\left(\frac{-t_0}{\tau_{bio}}\right)}$$

The probability of an intelligent species evolving prior to t_0 is then

$$P_i(t_0) = \frac{P_L(t_0)}{\tau_{evo}} \int_0^{t_0 - \langle t_{bio} \rangle} \exp\left(\frac{-t}{\tau_{evo}}\right) dt$$

and the expectation value of t_{evo} on worlds where intelligence has evolved is

$$\langle t_{evo} \rangle = \frac{\tau_{evo} + (\langle t_{bio} \rangle - t_0 - \tau_{evo}) \exp\left(\frac{-t_0 + \langle t_{bio} \rangle}{\tau_{evo}}\right)}{1 - \exp\left(\frac{-t_0 + \langle t_{bio} \rangle}{\tau_{evo}}\right)}$$

For given values of τ_{bio} and τ_{evo} such values are easily computed. However, in the real world, τ_{bio} and τ_{evo} are the unknowns and $\langle t_{bio} \rangle$ and $\langle t_{bio} \rangle$ can only be determined from a large number of measurements. In the case of Earth, we have only a single measurement. The process is also complicated by the fact that the question cannot be asked until after the point $t_0 > (t_{bio} + t_{evo})$. (Given the relative time scales of evolution and social change, one might easily assume the contraint $t_0 = (t_{bio} + t_{evo})$. We will not, however, make this assumption in our further calculations.)

In order to condsider how measurements of t_{bio} and t_{evo} constrain τ_{bio} and τ_{evo} we need to consider the distribution of possible values of t_{bio} and t_{evo} for a prior distribution of τ_{bio} and τ_{evo}.

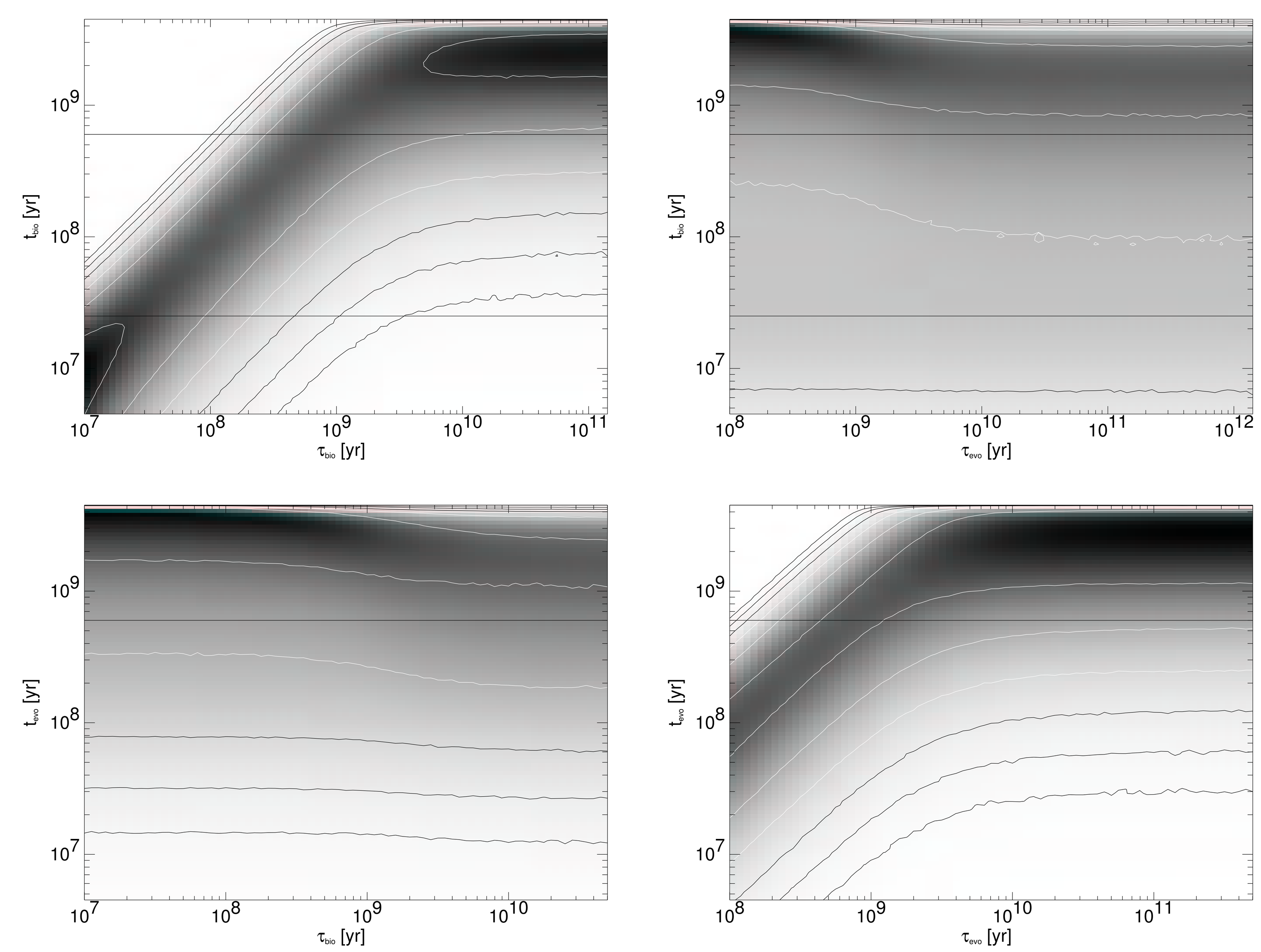

Figure 1. Likelyhood distribution for measured values of t_{bio} and t_{evo} vs τ_{bio} and τ_{bio}. Horizontal lines show limits to measurements of t_{bio} and t_{evo} on Earth.

Likelyhood Distributions

For an unknown timescale, the appropriate unitless prior distribution representing a total lack of knowledge is:

$$P_0(\tau) = \frac{d\tau}{\tau} = d \log(\tau)$$

In other words, the probable values of a timescale are equally distributed in logarithmic space. At each possible value of τ we can determine the normalized distribution of values of measured values of $D_\tau(t)$. The relative likelyhood of a measurement t corresponding to a value of τ is then $L_\tau(t, \tau) = D_\tau(t) P_0(\tau)$. Using our two parameter model, we have computed the likelyhood distributions $L_{\tau_{bio}}(t_b io, \tau_{bio}, \tau_{evo})$ and $L_{\tau_{evo}}(t_e vo, \tau_{bio}, \tau_{evo})$ for $t_0 = 4.5$Gyr.

Figure 1 shows the likelyhood distributions. The contours represent a change of a factor of two. As would be expected, there is a significant dependence of t values on their corresponding τ values, with the expectation values of t roughly equal to τ at $\tau \ll t_0$ and increasing to $\sim t_0/2$ at $\tau \gg t_0$. There is also some cross dependence of t_{bio} on τ_{evo} and t_{evo} on τ_{bio} due to the constraint $(t_{bio} + t_{evo}) < t_0$. Horizontal lines show limits to measurements of 25Myr $< t_{bio} <$ 600Myr and 600Myr $< t_{evo} <$ 4.5Gyr.

By integrating the distributions between these limits, we can generate a probability distribution for values of τ_{bio} and τ_{evo}. This distribution is shown in Figure 2.

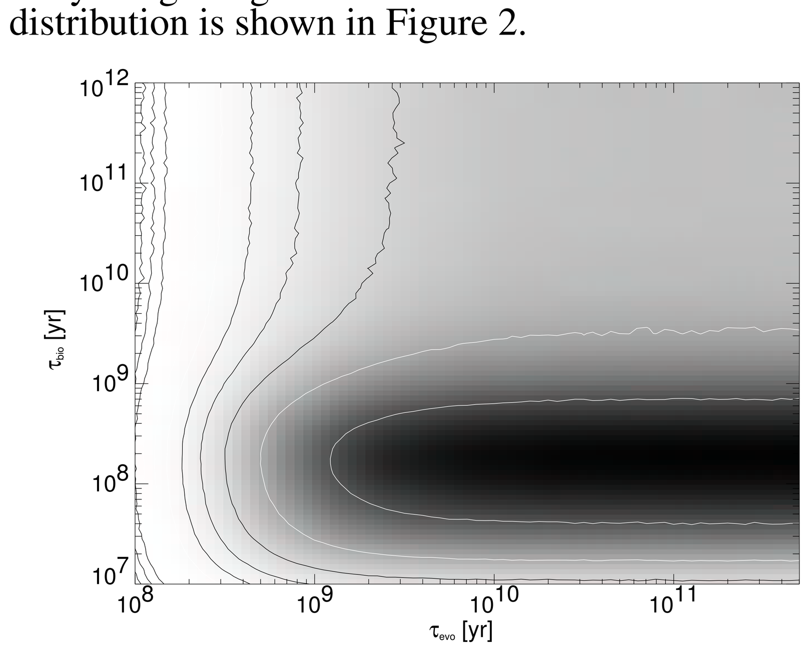

Figure 2. Likelyhood distribution of τ_{bio} and τ_{evo}.

Note that neither τ_{bio} nor τ_{evo} are well constrained by the timescales found on the earth. While τ_{bio} has a well defined peak-likelyhood value, the distribution does not go to zero at large values of τ_{bio}, but tends toward a constant value. The distribution of τ_{evo} on the other hand, does not have a well defined maximum likelyhood value, but trends toward a constant value. This distribution can be used as the prior for subsequent observations, should any arise. The relative likelyhood distributions for each parameter are shown in Figure 3.

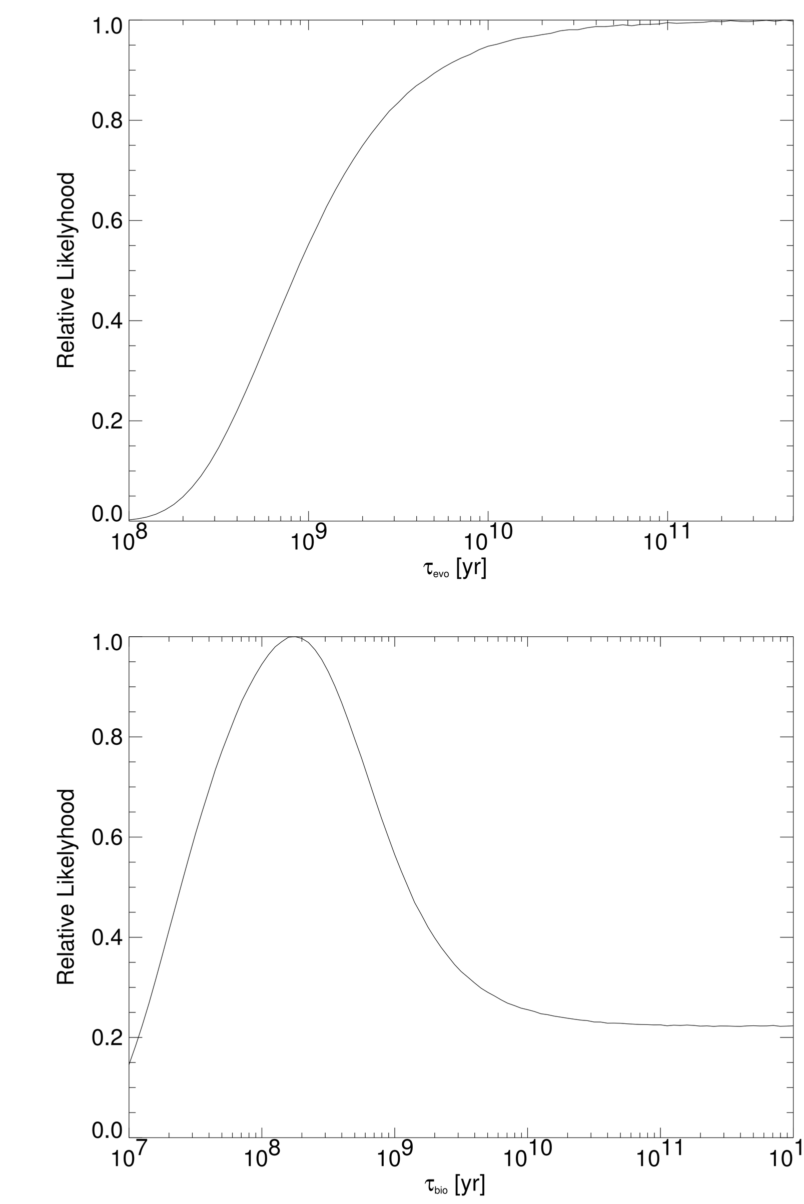

Figure 3. Likelyhood distributions for τ_{bio} and τ_{evo}.

Conclusions

- When only a single example of a class is available, an observer must consider whether the observed properties are indicative of a general property of a class. This can be done using relatively straightforward statistical methods.
- In specific, we have examined the question of whether the observed timescales of abiogenesis and evolution of intelligence on Earth can be used to constrain the corresponding timescales on Earthlike planets in general.
- It is likely that the measured timescale of evolution on intelligence on earth greatly underestimates the typical timescale required.
- The early origin of life on earth results in the a well defined peak in the distribution of potential values of the general timescale. However, the distribution tends toward a constant value for large timescales. That indicates a very significant probability that the time required for abiogenesis on earth was atypically short.
- Without further examples, other derivations, or analytical reasons restrict long duration timescales, no upper limit can be placed on the timescales required for abiogenesis and evolution of intelligence.

Table 1:

Fig. 1.—

Fig. 2.—

Fig. 3.—