

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

Presented at Bioastronomy 2004: Habitable Worlds, Reykjavik, Iceland July 12-16, 2004

*abstract: Astrobiology 4, 266 (2004)*

Eric J. Korpela

*Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450*

korpela@ssl.berkeley.edu

## 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.(1) 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 quantities 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  $\tau_{\text{bio}}$  and  $\tau_{\text{evo}}$ . In practice, this method works for arbitrary numbers of variables and non-Poissonian processes. We also  $t_{\text{bio}}$  and  $t_{\text{evo}}$  as the actual time required for abiogenesis and evolution on a specific world. Our task is, given a single measurement of  $t_{\text{bio}}$  and  $t_{\text{evo}}$ , what is the distribution of likely values of  $\tau_{\text{bio}}$  and  $\tau_{\text{evo}}$ .

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

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

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

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

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

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

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

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

For given values of  $\tau_{\text{bio}}$  and  $\tau_{\text{evo}}$  such values are easily computed. However, in the real world,  $\tau_{\text{bio}}$  and  $\tau_{\text{evo}}$  are the unknowns and  $\langle t_{\text{bio}} \rangle$  and  $\langle t_{\text{evo}} \rangle$  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  $t_0 > (t_{\text{bio}} + t_{\text{evo}})$ . (Given the relative time scales of evolution and social change, one might easily assume the constraint  $t_0 = (t_{\text{bio}} + t_{\text{evo}})$ . We will not, however, make this assumption in our further calculations.)

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

### Likelihood 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  $\tau$  we can determine the normalized distribution of values of measured values of  $D_\tau(t)$ . The relative likelihood of a measurement  $t$  corresponding to a value of  $\tau$  is then  $L_\tau(t, \tau) = D_\tau(t) P_0(\tau)$ . Using our two parameter model, we have computed the likelihood distributions  $L_{\tau_{\text{bio}}}(t_{\text{bio}}, \tau_{\text{bio}}, \tau_{\text{evo}})$  and  $L_{\tau_{\text{evo}}}(t_{\text{evo}}, \tau_{\text{bio}}, \tau_{\text{evo}})$  for  $t_0 = 4.5\text{Gyr}$ .

Figure 1 shows the likelihood 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

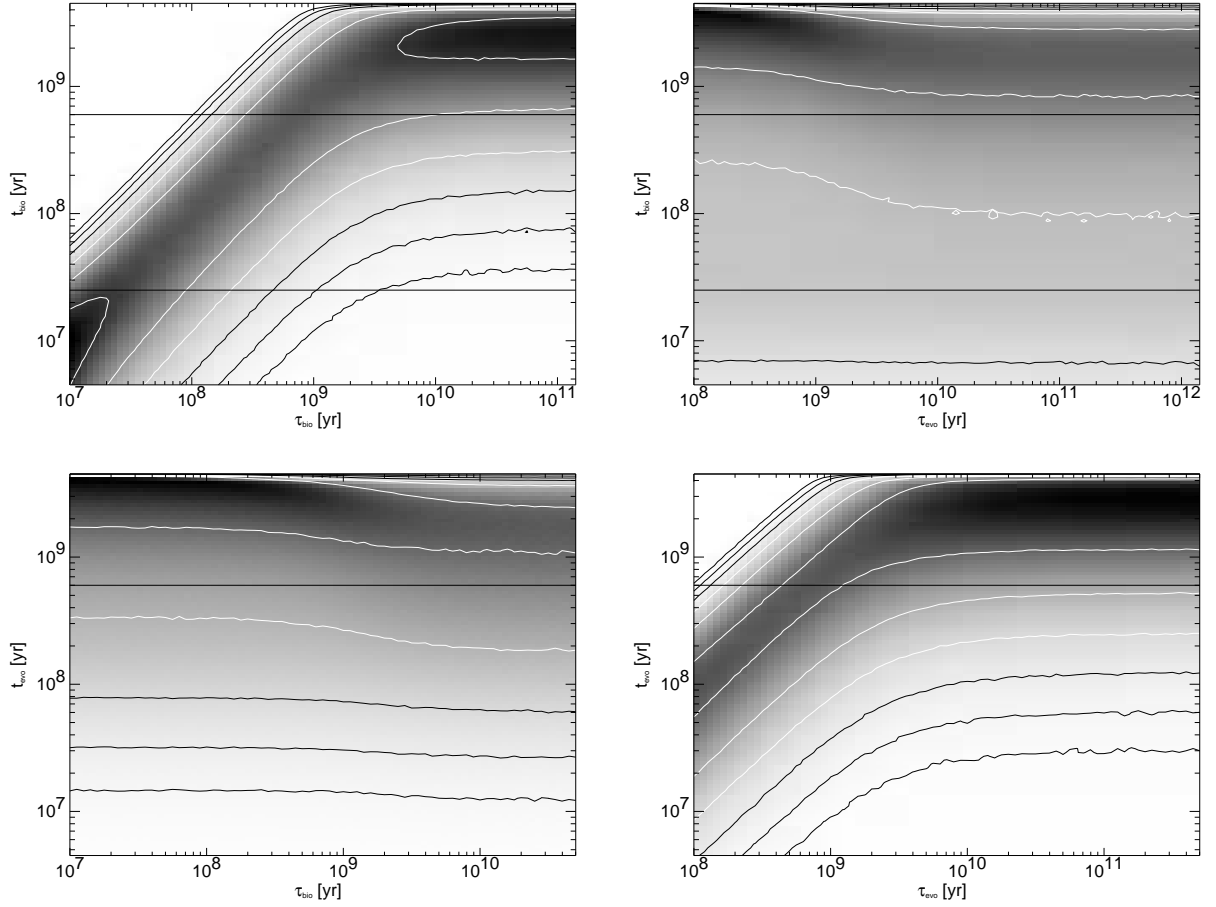


Fig. 1.— Likelihood distribution for measured values of  $t_{\text{bio}}$  and  $t_{\text{evo}}$  vs  $\tau_{\text{bio}}$  and  $\tau_{\text{evo}}$ . Horizontal lines show limits to measurements of  $t_{\text{bio}}$  and  $t_{\text{evo}}$  on Earth.

$\tau$  values, with the expectation values of  $t$  roughly equal to  $\tau$  at  $\tau \ll t_0$  and increasing to  $\sim t_0/2$  at  $\tau \gg t_0$ . There is also some cross dependence of  $t_{\text{bio}}$  on  $\tau_{\text{evo}}$  and  $t_{\text{evo}}$  on  $\tau_{\text{bio}}$  due to the constraint  $(t_{\text{bio}} + t_{\text{evo}}) < t_0$ . Horizontal lines show limits to measurements of  $25\text{Myr} < t_{\text{bio}} < 600\text{Myr}$  and  $600\text{Myr} < t_{\text{evo}} < 4.5\text{Gyr}$ .

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

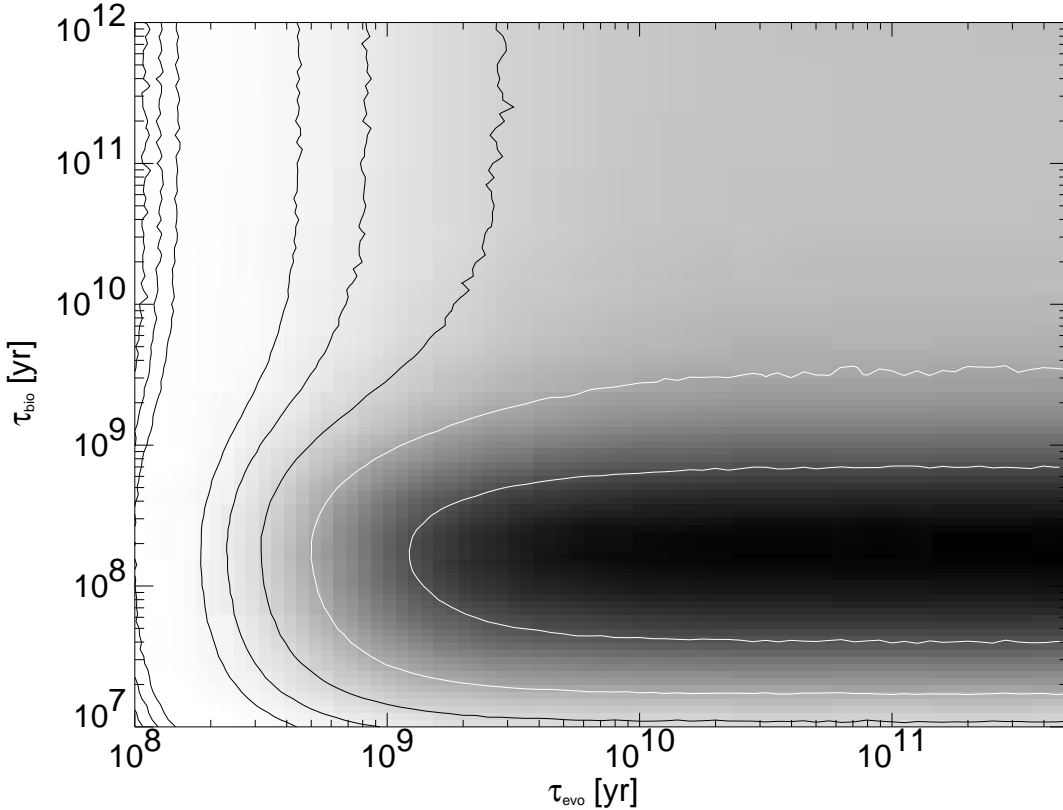


Fig. 2.— Likelihood distribution of  $\tau_{\text{bio}}$  and  $\tau_{\text{evo}}$ .

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

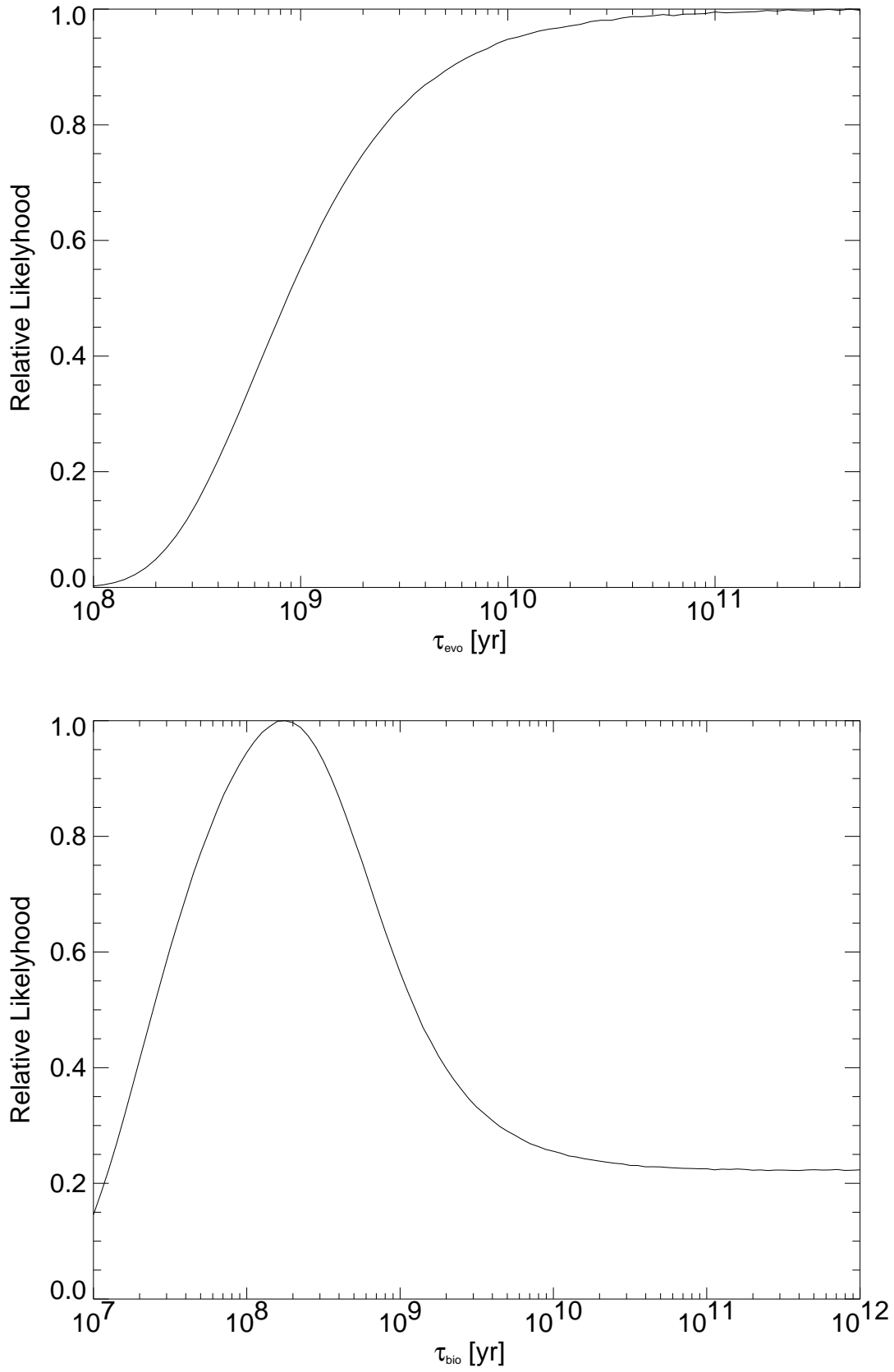


Fig. 3.— Likelihood distributions for  $\tau_{\text{bio}}$  and  $\tau_{\text{evo}}$ .

## 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.

## REFERENCES

Lineweaver, C. H. and Davis, T. M., “Does the Rapid Appearance of Life on Earth Suggest that Life Is Common in the Universe?,” *Astrobiology* **2**, 293–304 (Aug. 2002).