Are we alone in the Universe? The emergence of life

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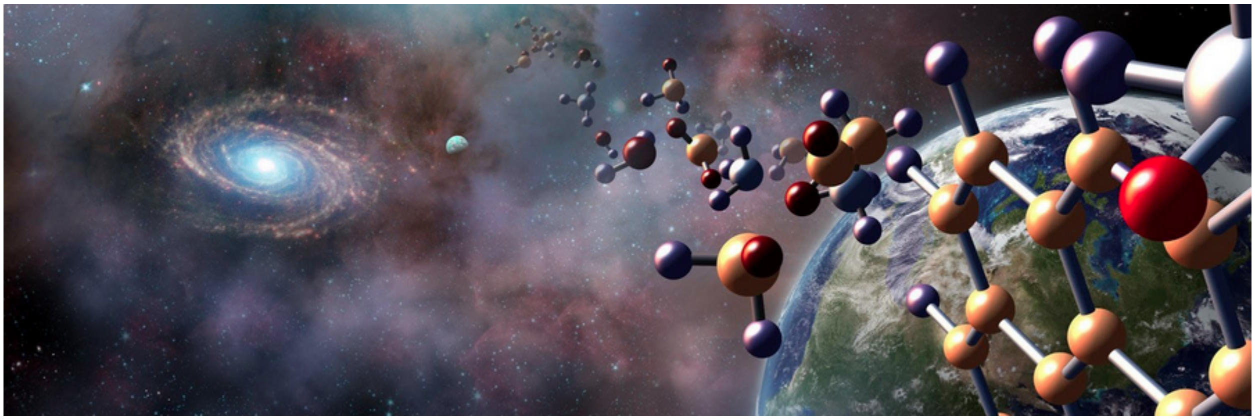

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We are thinking creatures living on a planet orbiting a pretty common star in a pretty common galaxy. Our home planet has been around for about 4.5 billion years, while the Universe is about 13.7 billion years old. We just learned that there are about 1 000 000 000 000 000 000 000 = 10^{21} planets potentially similar to the Earth in the cosmos, a number larger than the amount of grains of sand found on every beach and every desert on Earth. **Are we alone?** To answer this question in 1961 scientist Frank Drake formulated his famous equation, which I discussed in the previous post of this series. The Drake equation calculates the number N of communicative civilizations in our Galaxy. In its 2015 form it reads:

> $N \approx 2\, f_l\, f_i\, f_c\, L$

One of the most important factors in the equation is f_l, the fraction of Earth-like planets in the habitable zone that develop life. It is a measure of the likelihood of **life emergence**. I won't get into the interesting but complex debate about the definition of "life". Instead I will use an operative, somewhat restrictive definition: "life as we know it". Loosely meaning anything similar to what we've seen on Earth. One has to start somewhere.

How can we estimate the likelihood of life emergence? If life was impossible, nobody would know about it. Similarly, the fact that we see life on Earth can not be used to draw conclusions on how widespread life is in the Universe; if Earth were the only life-hosting planet in the cosmos, we would necessarily be living there. However, finding just another place outside Earth where life can be supported changes everything. Evidence of life (even fossil) on Mars or on a moon of Saturn or Jupiter would demonstrate that the emergence of life (biogenesis) does not require a very narrow, unlikely set of conditions.

I strongly believe we'll see proof of the existence of life in other regions of the solar system very soon. Until that moment, an interesting argument used to constrain f_l is the rapidity of biogenesis on Earth. It is the following: imagine a lottery with life as first prize. If the emergence of life is a **very unlikely** outcome (requiring very specific conditions), then to win **one has to play many times** to get the winning ticket. If on the other hand winning the lottery is relatively easy (many winning tickets, meaning that many different combinations of environmental conditions lead to life) one needs to play just a few times before winning.

It turns out that biogenesis on Earth was fairly rapid compared to geologic timescales. Using a conservative upper limit of 600 million years for conditions to be "stable enough" for life to emerge, the probability of biogenesis on terrestrial (Earth-like) planets is constrained to those older than 1 billion years, greater than 13% Lineweaver and Davis (2002). That is, about 1 in 10 Earth-like planets in the habitable zone should develop life. | $f_l \geq 0.13$ I am pretty confident life as we know it is widespread in the Universe: Microbial life is likely present in several places in our solar system as well as in a large fraction of the billions of planets in the cosmos.

The next factor in the Drake equation measures the **probability of life evolving into "intelligent life"**. Intelligence gives a clear evolutionary advantage and therefore may represent a common pathway of life. Broadly speaking, on Earth intelligent life has appeared at least a couple of times (cetacean intelligence). However we need to consider that the transition from simple microbial life to complex animals was a very long process. On Earth it took more than 3 billion years for life to evolve from single-celled bacteria to Homo sapiens. Therefore the same reasoning used for estimating f_l might argue for a small value of f_i, though it is very hard to come up with a precise number. It seems plausible that $f_i << 1$, meaning that even if life is widespread, intelligent life might be very rare. Note that this perspective is quite different from the very optimistic view of Frank Drake, who argued that life is very likely to evolve into intelligent life, or that $f_i \sim 1$.

To communicate with other intelligent life, a civilization has to develop some sort of technology. If again we consider Earth's case, this happened for humans but not, for example, for dolphins. The factor f_c **measures the fraction of civilizations that develop communicative technology**. As intelligence and curiosity seem to go hand-in-hand, it seems conceivable that a large fraction of intelligent lifeforms might eventually evolve towards a technological, communicative form. | $f_c \sim 1$
Putting these factors into the Drake equation above we get | $N \approx \frac{1}{4} f_i L$.
This states that the number of communicative civilizations in our Galaxy is just the product of the chance of emergence of intelligent life times the average lifetime of a civilization's communicative phase. It is hard to put strong theoretical constraints on both these factors. However, one can turn the problem around, and in the final post of this series I will show how the current search for radio signals from extraterrestrial intelligence (SETI) can be used to put some important constraints on the two factors f_i and L, and how this information can be used to make bold predictions about the future of humankind.

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References

Lineweaver, C. H., & Davis, T. M. (2002, Aug). Does the Rapid Appearance of Life on Earth Suggest that Life Is Common in the Universe? *Astrobiology*, *2*(3), 293-304. Retrieved from http://dx.doi.org/10.1089/153110702762027871 doi: 10.1089/153110702762027871