

Astro2020 Science White Paper

A Technosignature Carrying a Message Will Likely Inform us of Crucial Biological Details of Life Outside our Solar System

Thematic Areas:

- Planetary Systems
- Star and Planet Formation
- Formation and Evolution of Compact Objects
- Cosmology and Fundamental Physics
- Stars and Stellar Evolution
- Resolved Stellar Populations and their Environments
- Galaxy Evolution
- Multi-Messenger Astronomy and Astrophysics

Principal Author:

Name: Larry Lesyna

Institution: LXL Technology

Email: lesyna@lxltech.com

Phone: +1 702 518 4131

Abstract: A detection of a technosignature carrying a message has long been considered proof that life exists outside our solar system. I reason that the content of any such message will likely contain a plethora of biological information, including the self-replicating molecular system of the transmitting intelligence, and that the details of this biological information may be unattainable by any other means. Communication rates over interstellar distances can be high enough to convey this information with present technology, but the search for these special technosignatures will benefit from increases in receiver aperture and advances in signal processing technologies. Radio searches for interstellar messages will augment plans to search for extraterrestrial life as described in a recent NAS document “An Astrobiology Strategy for the Search for Life in the Universe”.

What can searches for biosignatures tell us about life on exoplanets?

The recent National Academy of Sciences (NAS) pre-publication book [1] “An Astrobiology Strategy for the Search for Life in the Universe” describes in detail science questions, technology challenges, and makes recommendations for obtaining measurements related to the goal of searching for life in the universe. Robotic spacecraft and landers are recommended for the search for life within our solar system; ground or space-based telescopes searching for biosignatures are recommended for the search for life on exoplanets. A biosignature has the characteristic of being a measurable feature that has a high probability of being caused by the presence of life, and a low probability of being caused by the absence of life. The steps needed to determining exoplanetary biosignatures can be a challenging process as noted in [1]. If life similar to that on Earth exists on an exoplanet, then matching its biosignature to either the Earth’s (or a reasonable variation of Earth’s) biosignature, for example by transmission spectroscopy of the atmosphere of an exoplanet, can be successful. Agnostic biosignatures for life as we don’t know it, will be more challenging to predict, and successfully identifying presently unknown forms of life on exoplanets will be more difficult. A biosignature detection might provide strong, if not compelling evidence that life exists, and also explain photosynthesis and respiration processes. The details about how this life self-sustains a chemical system capable of Darwinian evolution, and other important biological details will be difficult, if not impossible to obtain. Due to sensitivity limits imposed by current technology and facilities, the first searches for biosignatures on habitable zone terrestrial exoplanets will be around M dwarfs. In contrast to G dwarf stars like our Sun, it is an open question as to whether M dwarf habitable zone planets are indeed habitable. For example, the super-luminous pre-main sequence phase of M dwarfs could strip planetary atmospheres and evaporating oceans [1].

What additional information can interstellar messages tell us about life on exoplanets?

I am now going to assume that an interstellar message exists. It is beyond the scope of this paper to assess the probability that this message *actually* exists, or to try to solve the “Fermi Paradox”, and so on. I just posit an interstellar message exists and we have decoded it.

In order to estimate what the probable content of an interstellar message is, I try to make as few assumptions as possible in order to reach a consistent, as well as probable conclusion. A few fundamental assumptions are:

- 1) The Extraterrestrial Intelligence (ETI) is transmitting a message deliberately with the hope that it will be detected by another form of intelligence. There is a limit on how much power the ETI can transmit.
- 2) The ETI are sending a message which suggests some form of action on the receiver’s part, or to take no action. For example, I believe that the ETI would tell us why they are transmitting and whether they wanted us to respond or not. The SETI community has

long considered the possibility of replying to an interstellar message, and internationally agreed post-detection protocols are in place and should be followed.

- 3) The ETI are conveying information that would be difficult or impossible for a receiver with even more advanced technology than the ETI's to obtain on their own. My rationale for this assumption is that the ETI may not be able assess the receiver's technological level and it could be equal or greater than the ETI's. Transmitted power limits the information rate for a communication channel, and the ETI would prioritize what it sends to convey new information, and avoid sending information that the receiver may already have.

Transmitted information that falls under these assumptions would include details of the ETI itself, its evolutionary history, other forms of life, its exact location, and the past and present state of the abode of the ETI. This is because even a highly advanced technology might be limited to remote sensing techniques if it wanted to probe the neighborhood of the ETI. These methods would be inconclusive or incapable of discerning the details of the emergence of life and the planetary and stellar evolution within a particular stellar system, during its entire history.

Ref. [1] describes the general criteria for the fundamental characteristics of life:

- A means to sustain thermodynamic disequilibrium;
- An environment capable of maintaining covalent bonds, especially between carbon, hydrogen, and other atoms;
- A liquid environment; and
- A self-replicating molecular system that can support Darwinian evolution.

I believe that the interstellar message would contain these details and much more biological information.

Can an interstellar message actually deliver this information to us?

I estimate that describing the minimal general criteria for Earth-based life would require about 15 pages of text, or about 10^5 bits of information. We do not know the number of bits for the ETI's lifeform, but can guess that it is within an order of magnitude. The question then becomes: Can the ETI's technosignature communicate this data reliably over interstellar distances?

Messerschmitt [2] has extensively examined the information rate achievable over interstellar distances using radio waves. One conclusion is that, even after accounting for possible degradations imposed by the interstellar medium, it is practical to achieve communication rates very close to the theoretical maximum imposed by the Shannon-Hartley theorem in the power

limited regime. Messerschmitt gives as one example an interstellar communication system between two Arecibo sized (305 m) radio telescopes pointed at each other, separated by a distance of 10^3 light years. For a transmitting power of 18 kW, an information rate of 1 bit s^{-1} is achieved. About a day of time is needed to receive the 10^5 bits of information that describe the general criteria for the biology of the ETI.

We can consider the possibility that messages with higher communication rates than 1 bit s^{-1} are being sent and contain richer biological information. The information rate is proportional to received power, and also transmitted power. We can construct phased arrays of radio telescopes with a larger collecting area, or we can hope that the ETI is transmitting more power towards us (a typical nuclear power plant generates $1 \text{ GW} \gg 18 \text{ kW}$). The human genome contains about 6×10^9 bits of information, and a communication channel of 200 bit s^{-1} could receive this amount of information in a year.

What types of Technosignatures should we search for?

A recent NASA sponsored workshop [3] surveyed and considered many types of technosignatures. Some of these included searching for signs of astro-engineering structures, waste heat from civilizations, artificial sources of lighting or molecules, as well as the more traditional SETI in the electromagnetic spectrum, where it is assumed that a transmitter is in operation emitting an artificial signal. It is conceivable that some of the non-SETI technosignatures could be modulated in some way to deliver a message so I do not rule them out. However, it has been established that traditional SETI offers acceptable communication rates for a message. Furthermore, upon detection of a message using traditional SETI, if humanity decides to respond, we are likely technologically ready to do so at the received portion of the electromagnetic spectrum. This may not be the case for the other types of technosignatures. The workshop also concluded that null results for radio signal searches to date span only a tiny fraction of the search space and these null results do not warrant abandonment of radio searches for the future.

Radio searches continue to be an excellent choice amongst all types of searches for interstellar messages.

What advances would improve the likelihood of success?

In contrast to technosignature searches that provide mostly just a yes/no answer to whether ETIs exist, this method to extract biological information about the ETI depends upon us being able to decode an interstellar message. We have no previous experience in this area. I can guess that the message is being sent with the intent to be easy to decode, and thus will contain redundancies, references to mathematics and physical theory and other common reference points for the purpose of defining a comprehensible expressive language. Advice from linguistic experts would be beneficial. After the undecoded message is independently verified as genuine, there will probably be no shortage of interest by people with appropriate and complementary

areas of expertise eager to decode it. In addition, the undecoded message could be posted on the internet, as suggested in ref. [4], and machine learning techniques could be applied.

Detecting the presence of a signal that is designed to use the transmitted power most efficiently may necessitate new and more flexible digital computing platforms. Messerschmitt [2] gives examples of message-carrying signals that have much larger bandwidths than those for traditional SETI searches of narrow band signals. They can convey information by coordination of the time and transmitted frequency of energy pulses. Present signal processing techniques may miss these types of signals.

Other beneficial advances share much in common with traditional radio astronomy. These include methods to increase total aperture size and increase the number of directions on the sky that can be observed simultaneously. Advances in efficient antenna element design, phased array feeds, and beamforming techniques fall into this category.

Conclusions:

The successful detection of a technosignature with a message will probably answer the most important questions about the biology of the life that generates the message. It may also provide an evolutionary history of that life and its stellar system. Sensitive technosignature searches can be done now for life on exoplanets that orbit a star similar to our Sun. Larger apertures enable more sensitive searches and enhance the communication rate.

References

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