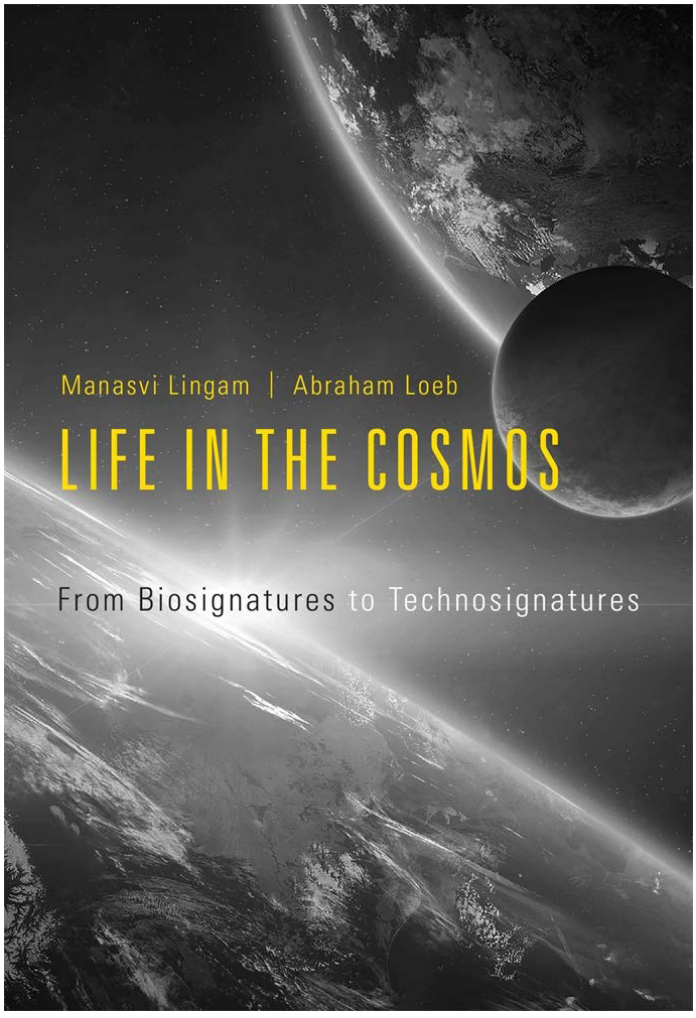
Book Review: Life in the Cosmos

From Biosignatures to Technosignatures

Andreas Hein

Our lead feature this time is a review by Dr Andreas Hein, Associate Professor - Space Systems Engineering, Université du Luxembourg, and Technical Director, i4is, of the book, *Life in the Cosmos - From Biosignatures to Technosignatures*, Manasvi Lingam and Avi Loeb, 1088 pages, Harvard University Press 2021. (www.hup.harvard.edu/catalog.php?isbn=9780674987579).



Introduction

How can I write a review of a friend's book? Manasvi Lingam, who is the main author of the book "Life in the Cosmos" is a close collaborator and a friend of mine. This obviously makes my review not independent, which is the first point I want to disclose right at the beginning. The second point, which outweighs the first in my view, is that I have limited knowledge of astrobiology. Hence, consider this review written by an educated amateur.

Life in the Cosmos – From Biosignatures to Technosignatures, written by Manasvi Lingam and Avi Loeb, was published by Harvard University Press in 2021. Avi Loeb is a professor at Harvard University and a well-known figure in astrophysics and cosmology. While he has built his scientific reputation in these fields, he has made headlines in recent years for publications within the area of SETI (Search for Extraterrestrial Intelligence) and astrobiology. Today, he is known to a wider audience via his conjecture that the interstellar object 'Oumuamua could be artificial. Most recently, he has launched the Galileo project to investigate potential signs of extraterrestrial technological civilization. It is therefore safe to say that he is not afraid of controversy and to enter fields where he has limited experience.

Manasvi Lingam is a professor of astrobiology at the Florida Institute of Technology. While he is still a relatively junior researcher, he has already an impressive track record of publications in astrobiology but also other fields such as plasma physics. From my personal collaboration with him, I know about his exceptional breadth of knowledge in a variety of fields. Manasvi was a postdoc of Avi Loeb several years ago and they share a history of collaboration, which resulted in a number of journal papers but also this book.

While I do not have insights into the repartition of the work between the two authors, I suspect that Manasvi has probably done most of the writing, as his distinct writing style was recognizable throughout the book. I will come back to this point later. But let's get to the book itself.

When this book arrived at my place, I was immediately impressed by its size and weight. It has roughly the size and feel of a brick but its layout is delicate, starting from the font used on the cover and its main body, as is the thin paper on which it is printed, hinting at the enormous quantity of material on the over 1000 pages. I usually do not pay much attention to these aspects, but this book already stands out in that respect.

Now, let's get to the actual content of the book. The title of the book "Life in the Cosmos – From Biosignatures to Technosignatures" already indicates that we are not dealing with a book that focuses on a narrow sub-domain of astrobiology but a book that covers the whole spectrum from simple life to intelligent civilizations. Manasvi is known for a number of audacious papers on a variety of topics related to astrobiology. Avi Loeb, the second author, and much more senior colleague is similarly known for having published a number of audacious, sometimes contested, papers in this field. The general population might know him mostly from his publications related to 'Oumuamua. Both authors rather have a background in theoretical physics/astrobiology, meaning that their research is less on the experimental side of astrobiology.

The structure of the book follows a clear logic, coherent with the title, starting from the basic properties of life, which we know from Earth in terms of its origins and evolution, extraterrestrial biospheres, and extraterrestrial technospheres.

The Content

Chapter 1 provides an overview of definitions of life and its requirements. Readers familiar with astrobiology will know that defining life is notoriously difficult and no convincing all-encompassing definition has been provided yet. Lingam and Loeb are of course aware of this and they lay out some important definitions (NASA's astrobiology division's definition, Boltzmann and Schrödinger's definitions) and their limitations using examples. In about six pages, the authors provide a lucid summary of the current state of the scientific debate. Due to its nature, this chapter is the by far most philosophical one of the book. In 1.2, they continue with the requirements of life, such as carbon and water, potential alternatives. 1.3 introduces, in an almost poetic turn the Anna Karenina Principle ("Happy families are all alike; every unhappy family is unhappy in its own way."), which basically points at the multi-factor nature of life, where each condition needs to be satisfied. Only those who satisfy all criteria (the happy families) exist for this very reason (all alike in that aspect), all others (unhappy families) do not for a variety of reasons (failed in their own way). For life to exist, a set of necessary criteria need to be satisfied and one key research question is what these criteria are.

Chapter 2 describes how life might have emerged on Earth. The origin of life (abiogenesis) on Earth from inorganic matter is one of the big questions in science and the authors provide an overview of current hypotheses and theories. They go on in length regarding the specific conditions under which life emerged on Earth, ranging from atmospheric conditions, radioactivity, impacts,

[1] *What are the characteristics of life?* https://astrobiology.nasa.gov/education/alp/characteristics-of-life/
[2] en.wikipedia.org/wiki/What_Is_Life

hydrothermal conditions etc. DNA/RNA as basic building blocks of life are introduced. Section 2.8 provides an overview of mathematical models of the origin of life, introducing, for example, Jeremy England's non-equilibrium statistical mechanics model.

Chapter 3 provides an overview of the evolution of life on Earth with its different stages, ranging from single-cell organisms, sexual reproduction, multi-cellular organisms, and intelligence. While the main focus is on Earth, sub-sections are sprinkled in where the implications for extraterrestrial life are made, for example, regarding extraterrestrial technological intelligence.

Chapter 4 focuses on stellar habitability factors. This includes a discussion of the well-known habitable zone (traditional one for CO2-H2O as greenhouse gases and extensions CO2-CH4, and CO2-H2 atmospheres), stellar winds, stellar electromagnetic radiation, stellar flares and space weather.

Coming from the stellar habitability factors, **Chapter 5** now focuses on the habitability regulators of planets, covering multiple factors: temperature, plate tectonics, tidal locking, atmospheric composition, landmass vs ocean ratio. Temperature plays an important role in determining the metabolic rate of organisms, which has a significant impact on factors such as population growth, turnover of biomass in an ecosystem, and biodiversity. However, a sudden increase in temperature, for example, due to extremely large solar flares, may lead to a significant loss of biodiversity.

Chapter 6 deals with biosignatures, in other words, signs that hint at biological life. The focus is on biosignatures at the molecular level, which can be potentially detected by observing the spectrum of a planet. The presence of a certain molecule would appear as an absorption line. Different methods for detecting biosignatures are introduced such as during the transit of a planet in front of a star, which provides an opportunity for various types of spectroscopy. Subsequently, indirect methods for detecting signs of habitability are introduced such as the presence of a magnetic field, the architecture of the planetary system and its composition, atmospheric and ocean losses, and stellar parameters. The presence of certain gases in the atmosphere might also be biosignatures. The recent alleged discovery of phosphine in the Venusian atmosphere would fall into this category. The chapter continues with surface and temporal biosignatures and ends with how to assess the plausibility of life detection, using a Bayesian approach. The question is essentially, how different evidence can be combined to arrive at conclusions on the likelihood of life detection.

Chapter 7 treats life in subsurface oceans. Most readers have probably heard about potential life in the subsurface oceans of Europa or Enceladus in our solar system. However, much more potential worlds are considered such as Titan, Ganymede, Callisto, who also have oceans. Subsequently, specific environmental conditions in such oceans and their implications for life are discussed, including the existence of ecosystems and their evolution.

Part 3 of the book deals with technosignatures. **Chapter 8** introduces the famous Drake equation and Fermi's Paradox. Readers familiar with the discussions on extraterrestrial intelligence will likely be familiar with both concepts. The Drake equation in its original form was used to estimate the abundance of intelligent life in our galaxy. Some of its values can be empirically determined today such as the number of planets around stars. Others, such as the fraction of life-bearing planets is still unknown. The Drake equation, its implications and critique is discussed in detail and one gets an overview of the scientific discussion around this topic. Next comes Fermi's Paradox, another key concept concerning extraterrestrial intelligence. The famous question, allegedly asked by Fermi: "Where is everybody?" points at the apparent contradiction between the theoretical abundance of extraterrestrial intelligence and its observational absence. Various "solutions" to the Fermi Paradox are presented such as the Zoo hypothesis, underpinned by the respective equations and a discussion.

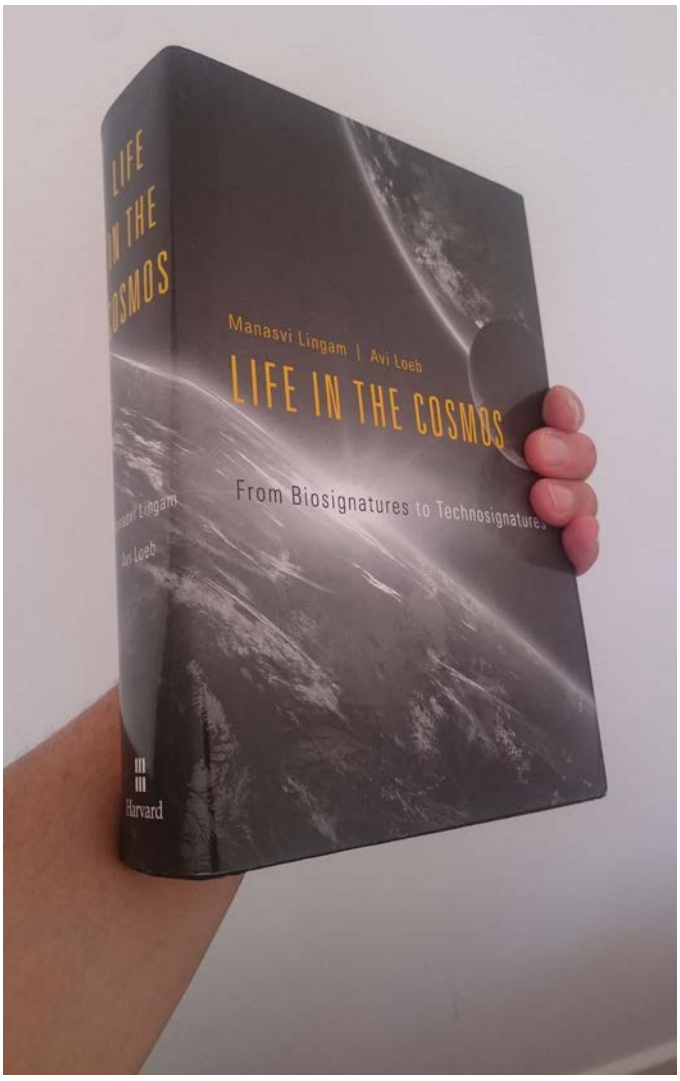
Chapter 9 deals with the search for technosignatures. This is a field which has recently received a lot of attention. The chapter aggregates the search for signals, which is part of "traditional" SETI and physical artifacts such as inscribed artifacts for transmitting messages to megastructures such as Dyson Spheres (called Stapledon-Dyson Spheres in the honour of Stapledon, who also proposed them in this novel "Last and First Men" and "Star Maker"). The Kardashev scale is introduced, which is equally well-known and classifies the level of energy consumption of a civilization (planetary, stellar, to galactic level). The artifacts treated in this chapter range from pollution in the atmosphere, energy

leakage from propulsion systems such as light sails, antimatter, etc to global warming and its mitigation. Also, satellites and space debris are considered as potentially detectable. Finally, the implications of these technosignatures on the search strategy are discussed. The authors conclude that a minimum budget of $1 million per year would be merited, given the likelihood of detection and the potential impact of detecting ETI.

Chapter 10 deals with the propagation of life in the universe in the widest sense. Interstellar travel enthusiasts will find all relevant interstellar propulsion methods described in this chapter such as fusion, laser, interstellar ramjet, and light sail propulsion. Magnetic and electric sails are also treated. However, the authors begin the chapter with the rather controversial topic of panspermia. This is interesting, as panspermia is an essentially non-technological way of how life may propagate throughout the universe. The discovery of 'Oumuamua and (comet) Borisov has shown that panspermia might indeed be able to travel between the stars. A dedicated section deals with interstellar panspermia and its propagation mechanisms, which lead to its ejection out of a star system.

The book ends with an epilogue with recommendations on future research directions. Poetry is abundantly sprinkled in this book and it is no surprise that it concludes with a phrase from Virgil's Aeneid: "Blessings on your fresh courage, child; thus one journeys to the stars." What more could be said?

Target audience



In terms of accessibility, I would recommend the book to readers who have at least a basic foundation in the natural sciences, eg chemistry and mathematics, although high school level would be sufficient. To fully appreciate the book, I would rather recommend it to undergraduate students and upwards in natural sciences/engineering, although some of the chapters, for example, chapter 1 are accessible to a layperson as well. Nevertheless, this is definitely not a popular science book and it doesn't try to be one. The language used is sophisticated, similar to the one found in scientific publications. For my personal taste, it was sometimes a bit too much (e.g. the use of Latin expressions such as "sensu latu"), where I thought that non-native English (or non-Latin) speakers might need to check a dictionary ("variegated", "well-nigh", p.374). Fortunately, the use of such sophisticated vocabulary does not significantly alter the reading experience. It also becomes clear that the authors have done their share of reading the Classics ("we must navigate the waters carefully, between the Scylla of labyrinthine, tangled reality and the Charybdis of reductive oversimplification," p.375). Whether the reader appreciates such references is a matter of taste.

Hence, students and researchers who intend to work on an astrobiology-related topic will find this book fantastic as a starting point for further research, as it provides an up-to-date overview of the literature. The more generally interested reader will find a fantastic place for brief exposés on astrobiology topics that are rather self-contained and can be read independently of other chapters. A huge amount of references invites to dig deeper into each subtopic. I would say that this book is going to be the one-stop-shop for astrobiology for years to come. A must-have for those interested in astrobiology and bold enough to work through over 1000 pages of intellectual condensate.