strangers in a strange land

A BLACK-BOX APPROACH TO IDENTIFYING BIOSIGNATURES

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0 ABSTRACT

Searching for life on other planets and planetary bodies poses a number of challenges, especially given that there is currently no clear evidence that lifeforms can only conform to characteristics observed on Earth. While current astrobiology missions operate under the assumption that any astrobiological entities of interest will have similar properties to organisms on Earth ('canonical' lifeforms), the current convention of searching for direct evidence of such lifeforms (e.g. organic compounds, genetic material, etc.) is largely exclusionary to any biologically valid lifeforms which are not currently a part of the canonical model of life that is used to drive exploratory efforts.

It is proposed that the definition of life be broadened to include any entities capable of maintaining homeostasis relative to an entropic environment. Thus, instead of the traditional strategy of searching for direct evidence of life conforming to Earth-based standards, i.e., looking for specific organic compounds, a new strategy could be used to indirectly identify lifeforms through their utilization of environmental resources (e.g. as energy sources).

1 INTRODUCTION

Standard approaches to identifying potential evidence of past or extant life on other planets typically rely on the assumption that any astrobiological entities of interest will be within parameters consistent with 'canonical' lifeforms observed on Earth. However, apart from a lack of data to the contrary, there is little justification for the assumption that astrobiological life must have the same characteristics as lifeforms observed on Earth. Indeed, given that life on other planets could have developed significantly earlier or later than life on Earth, it is possible that astrobiological lifeforms will be vastly different from Earth-based lifeforms. Accounting for the impact of evolution in driving biological development towards unique characteristics better suited to the environment on the planetary body of interest, it is even more likely that astrobiological entities are likely to have considerably diverged from the known characteristics of canonical lifeforms to better suit their native environments. This issue is further complicated by the fact that there are multiple competing definitions of what can be considered a 'canonical lifeform' even on Earth. Most astrobiological missions use a mechanistic definition of life based on chemical compositions; however, it is debatable whether entities such as viruses and prions are, in fact, living. Thus, taking a direct approach of searching for lifeforms that are recognizable as meeting the Earth-based definition of life – when said definition is already murky at best, and is further complicated by uncertainty as to whether or not such lifeforms exist or what characteristics they might have due to the different environments of other planetary bodies - is likely to be a limiting approach.

It is currently impractical to generate search parameters which are likely to yield positive direct identification of non-canonical lifeforms, should they exist. Rather than attempting to constrain the solution space of potential lifeforms solely with Earth-based data, and searching for direct evidence of life (e.g. component molecules) based on that assumed solution space, the author proposes an alternative black-box system. This system, by virtue of taking an implicit approach to identifying signs of life reduces the number of assumptions which need to be made about the lifeforms being searched for (the proverbial 'black box') and which instead relies on searching for anomalous environmental fluxes which might be evidence of what biotic entities, if any, could be in the black box. Subsequently, if a positive indicator of life is found, the biosignatures themselves can be used to inform a later direct identification.

2 OBJECTIVES

Current approaches to finding life largely rely on a Bayesian approach to identifying whether biotic entities (B) are likely present in a specific abiotic environment of interest (A):

$$P(B|A) = [P(A|B)*P(A)]/P(B)$$

This work seeks to identify an alternate method which does not require estimation of $P(A|B)$, to eliminate dependence on an Earth-based diffuse prior.

stochasticity

- Environmental processes seeded with a random element (e.g. weather), driven by abiotic factors
- 'Background noise' against which biosignatures must be detected

abiotic factors

- Includes physical parameters and driving forces that shape the base environment of the planetary body of interest: geological forces, surface chemical composition, etc.
- Documented (at least in part) for many planetary bodies
- Data can be acquired through remote (satellite) measurement & localized sampling

Standard methodology:

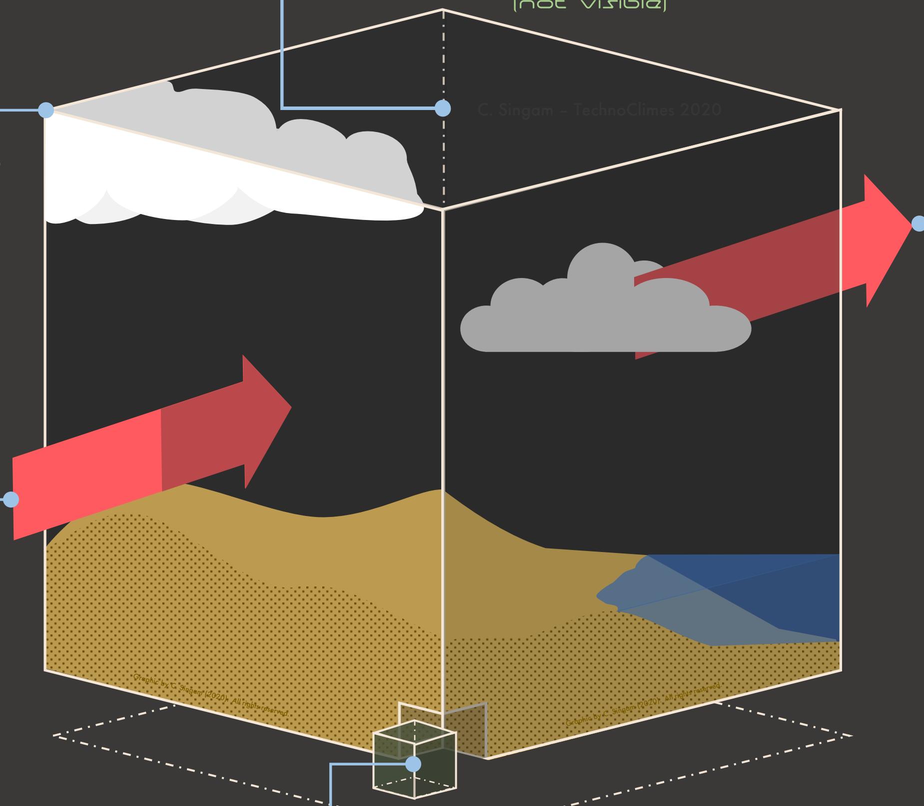
- Evaluated for general impact on perceived habitability (e.g. whether observed temperature fluctuations are survivable by any Earth-based lifeforms)
- Data on abiotic factors usually considered incidental to astrobiological mission objectives

Black box approach:

- Abiotic factors act as inputs to 'black box' model
- Provide baseline from which implicit biosignatures can be observed

biosignature-producing agents

(not visible)



biosignatures

- Readable output produced by 'black box' biotic entities; i.e. observable metrics which are strongly indicative of past or extant life

Standard methodology:

- Search for explicit indicators of life (e.g. genetic material, amino acids, other potential organismal components)
- Operates best on small scale due to testing limitations (typically requires direct access to physical samples)

Black box approach:

- Longitudinal observation of abiotic phenomena and fluctuations in abiotic factors via remote measurement (e.g. fluctuations in levels of certain inorganic compounds due to consumption by chemolithotrophs) to identify presence of biotic entity; follow-up localized studies to identify and characterize source of biosignatures
- Relies on identifying variations from expected environmental baseline not attributable to stochastic noise; can use cutting-edge analytic techniques for extracting signal from noise

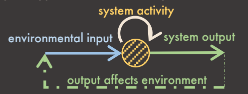
canonical biotic entities

Biotic entities which are visible to current identification methods comprise a segment of the larger set of biosignature-producing agents (inclusive of non-canonical biotic agents). Biotic entities, by virtue of being real (non-isolated) systems which exhibit organization relative to their disordered surroundings, should be expected to have a dynamic influence on the baseline state of their environment that can be observed over some time interval. These dynamic changes thus permit the detection of these 'black box' entities without direct observation of the biological entities in question: i.e., via implicit biosignatures.

3 PROPOSED PARADIGM

4 METHODOLOGY

Biological entities are, fundamentally, inherently ordered systems in an otherwise disordered context. As non-isolated systems, the environment exerts an effect on the system (tending towards increased entropy) resulting in a push-pull dynamic with the entity's surroundings (with the environmental input being modulated by system activity in order to maintain homeostasis, and the system output reflecting the byproducts of that activity on the environment).



Given the delay between input and output caused by intervening system activity, a biologically active system thus should generate a cyclic signature reflective of that push-pull dynamic, best observed via a time-ordered metric that is affected by both at least one input and one output (e.g. the environmental concentration of a metabolite over time). Such signatures are consistent with existing knowledge of biological function and the reliance of biological systems on feedback loops to maintain system stability; a classic example of such a signature is seen in the archetypal predator-prey relationships modeled by Lotka-Volterra equations. The prey component, representing a renewable environmental consumable x (e.g. a metabolite) consumed by a predatory system y, is modeled as:

$$dx/dt = \alpha x - \beta xy$$

This basic model is assumes that external factors affecting the consumable (other than the system of interest) are negligible; however, abiotic variables may exhibit patterns caused by geologic and environmental phenomena (e.g. the day/night cycle, which also induces cyclical fluctuations in abiotic factors), resulting in a fluctuating environmental baseline from which the biotic signal must be discerned, and which is further convoluted by stochasticity and any measurement artifact. However, abiotic phenomena (such as geological cycles and day/night cycles) can be readily modeled based on the laws of physics and existing knowledge of physical phenomena; unlike biotic processes, which are highly variable even within a single biome and which can rapidly evolve, abiotic processes are relatively well-documented and have a fair degree of consistency across various planetary bodies. Thus, a rudimentary model of the predicted environmental base signature can be developed, and subtracted from the main dataset in order to identify whether or not an implicit biosignature is present. The resulting time-series data can subsequently be run through a filtration algorithm in order to smooth the data and mitigate the effect of stochasticity on observed patterns, and subsequently deconvolved in order to identify composite cyclical patterns (a la Fourier transform) from which potential implicit biosignatures can be distinguished (based on being either significantly out of phase with abiotic patterns, operating on a different temporal scale, or otherwise being statistically anomalous).

5 CONCLUSIONS

Technology is currently at a stage where data can be collected with sufficient fidelity to implement this methodology; with advances in digital data processing for pattern-recognition and denoising, it is also possible that data of sub-optimal quality can potentially be used as well. The main advantage of the proposed black-box methodology is that it is independent on Earth-centric notions of what chemical or biological forms life might take, instead relying on a basic entropy-based definition of life and physical laws in order to identify implicit biosignatures. It also holds promise for providing lower-risk means of searching for signs of life with fewer planetary protection implications than traditional lander-centric missions.

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