Fractal Sparse-Origin Hypothesis of Cosmic Life Distribution

A Theoretical Framework for Singular Emergence of Life in Large-Scale Astrophysical Domains

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Abstract

Conventional astrobiology assumes that life emerges probabilistically in any environment exhibiting appropriate biochemical and thermodynamic conditions. This assumption implicitly treats abiogenesis as a repeatable phenomenon across multiple independent sites. This paper introduces the *Fractal Sparse-Origin Hypothesis*, proposing that within any large-scale astrophysical region—such as a multi-galaxy cluster—life emerges only once, at a statistically unique site, regardless of how many environments appear suitable.

We argue that abiogenesis depends on ultra-low–probability fractal boundary intersections among chemical symmetry-breaking processes, environmental anisotropies, and transient temporal windows. The result is a sparse, non-recursive distribution of life wherein suitability is necessary but not sufficient; the probability density collapses toward a delta-like singularity, explaining the Fermi Paradox without invoking extinction, great filters, or behavioral assumptions.

A formal model is developed based on a fractal-intersection function and boundary-state probability collapse. Implications for astrobiology, cosmic evolution, and the statistical structure of life-bearing regions are discussed.

1 Introduction

The dominant framework in astrobiology assumes that life emerges whenever environmental conditions (e.g., liquid water, suitable chemistry, stable energy gradients) fall within recognized habitability ranges. Under this model, life is expected to arise multiple times within a galaxy or across cosmologically similar regions.

However, empirical observation contradicts this expectation. Despite billions of potentially habitable exoplanets, no independently arisen biosphere has been detected. The Fermi Paradox remains unresolved under frequent-emergence assumptions.

We propose that the assumption itself is flawed. This work introduces a new hypothesis: life does not repeatedly arise even in large regions where conditions appear favorable. Instead, life emerges at only one singular point within an entire high-scale region (e.g., thousands of star systems or multiple galaxies).

This paper formalizes the hypothesis, constructs a mathematical model, and outlines its implications.

2 Theoretical Background

2.1 Abiogenesis as a boundary phenomenon

Existing abiogenesis models assume high-dimensional chemical state spaces where life appears once certain conditions are met. We instead view abiogenesis as a *fractal boundary-intersection event*, meaning:

- it is not continuous,
- not smooth,
- not guaranteed to recur,
- dependent on rare intersection sets with extremely small measure.

2.2 Sparse occurrence in large-scale spaces

Unlike classical probability models, fractal phenomena often produce singleton outcomes even under large input spaces, including:

- unique fixed points,
- non-repeating attractor intersections,
- singularities in chaotic systems.

This motivates applying fractal sparsity to abiogenesis.

3 Model and Mathematical Framework

We now formalize the Fractal Sparse-Origin Hypothesis.

3.1 Region definition

Let a cosmic region R contain N environments:

$$R = \{E_1, E_2, \ldots, E_N\}, \tag{1}$$

where each E_i satisfies known habitability criteria.

3.2 Fractal intersection requirement

Let $B_i(t)$ denote the boundary-state vector of environment E_i at time t, integrating:

- thermodynamic gradients,
- chemical asymmetries,
- radiation flux,
- environmental anisotropy,
- stochastic fluctuations.

Define the abiogenesis intersection set

$$\mathcal{I} \subset \mathbb{R}^k, \tag{2}$$

where $|\mathcal{I}|$ is extremely small (measure approaching zero).

Life emerges in R if and only if

$$\exists!\, E_k \in R \quad \text{such that} \quad B_k(t) \in \mathcal{I}, \tag{3}$$

where "$\exists!$" indicates existence of a unique such environment.

3.3 Probability collapse

For large-scale regions,

$$P\big(B_i(t) \in \mathcal{I}\big) \to 0 \tag{4}$$

for any given environment E_i.

Thus, the probability of multiple independent abiogenesis events within R satisfies

$$P(\text{multiple abiogenesis events in } R) \approx 0, \tag{5}$$

while the probability of exactly one emergence in R satisfies

$$P(\text{exactly one emergence in } R) \approx 1. \tag{6}$$

This yields a delta-like spike in the probability distribution:

$$P(x) = \delta(x - x_0), \tag{7}$$

where x_0 is the unique fractal point corresponding to the emergent life-bearing environment.

3.4 Binary emergence function

Define the binary emergence function:

$$F(R) = \begin{cases} 1, & \text{life emerges at one unique site in } R, \\ 0, & \text{otherwise.} \end{cases} \tag{8}$$

This replaces the traditional additive model in which probabilities of emergence are summed over environments. Here, suitability no longer implies recurrence.

4 Implications

4.1 Reinterpretation of habitability

Under this framework, habitability becomes necessary but not predictive. Most habitable planets will never experience abiogenesis, despite satisfying conventional conditions for life.

4.2 Fermi Paradox resolution

The Fermi Paradox is alleviated without invoking civilizational behavior or catastrophic filters. If life emerges only once per large-scale region, an absence of detectable extraterrestrial civilizations in our galactic neighborhood is expected rather than paradoxical. Earth is simply the unique fractal anchor within our domain.

4.3 Cosmic life structure

Life-bearing regions resemble a sparse, island-like structure in state space:

- fractal islands,
- sparse fixed points,
- non-overlapping attractor solutions.

They are not continuous ecosystems across galaxies but isolated emergent solutions.

4.4 Multiple emergences across domains

Independent life elsewhere may exist but is separated by:

- cosmological distances,
- non-overlapping fractal regions,
- asymmetric boundary histories.

This produces effective isolation between life-bearing domains.

5 Discussion

The model challenges conventional SETI expectations by limiting life to one origin per large-scale domain. Earth is not an exceptionally "lucky" case; rather, it is the unique solution to an ultra-constrained boundary-intersection problem within our region.

Key predictions include:

- no second genesis will be found within the Milky Way;
- exoplanet biosignatures will be rare or absent despite apparent habitability;
- civilizational dynamics are secondary to abiogenesis constraints;
- life tends to cluster in isolated zones separated by vast sterile regions;
- abiogenesis is not scalable based on environmental similarity alone.

This model is compatible with:

- chaotic boundary dynamics,

- anthropic reasoning,
- cosmological inflation and domain partitioning,
- multi-region fractal partitioning of parameter space.

6 Conclusion

The Fractal Sparse-Origin Hypothesis reframes life's emergence as a singleton fractal-boundary event rather than a repetitive chemical outcome. Abiogenesis depends on rare boundary intersections with vanishing measure, yielding at most one life-bearing site per large cosmic region.

This provides a mathematically grounded explanation for the Fermi Paradox and predicts that Earth-like life will not be duplicated within our galactic domain. Future work should formalize the fractal-space parameters $\mathcal{I}$, incorporate stochastic astrophysical modeling, and simulate the emergence distribution across multi-galactic clusters.

These results highlight the value of treating abiogenesis as a singular boundary-intersection event, suggesting that future research should explore whether additional fractal constraints arise naturally from astrophysical or chemical processes.

Acknowledgments

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References

1. Ward, P. D., & Brownlee, D. (2000). *Rare Earth: Why Complex Life Is Uncommon in the Universe*. Copernicus Books.
2. Sylos Labini, F., Pietronero, L., & Gabrielli, A. (1998). The fractal structure of the universe: a new field theory approach. *Physics Letters B*, 293(1-2), 155–158.
3. Carter, B. (1983). *The Anthropic Principle and its Implications for Cosmology*. Philosophical Transactions of the Royal Society A.
4. Lineweaver, C. H., & Davis, T. (2002). *Does the Rapid Appearance of Life on Earth Suggest that Life Is Common in the Universe?* Astrobiology.

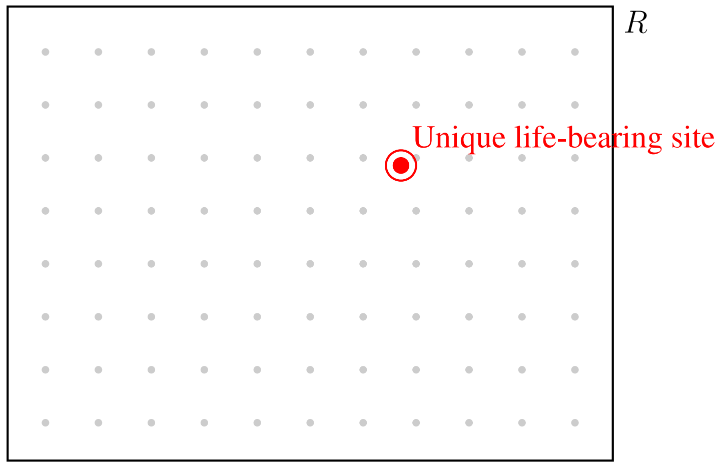
5. Kauffman, S. A. (1993). *The Origins of Order: Self-Organization and Selection in Evolution*. Oxford University Press.

6. Davies, P. C. W. (2019). *The Demon in the Machine: How Hidden Webs of Information Are Solving the Mystery of Life*. Penguin.

7. Smolin, L. (1997). *The Life of the Cosmos*. Oxford University Press.

Appendix A: Conceptual Figures

Figure 1: Fractal Sparse Distribution of Life-Bearing Sites



Many suitable environments in R, but only one yields abiogenesis

Figure 1: Illustration of the sparse fractal origin.

Figure 2: Delta-like Probability Distribution

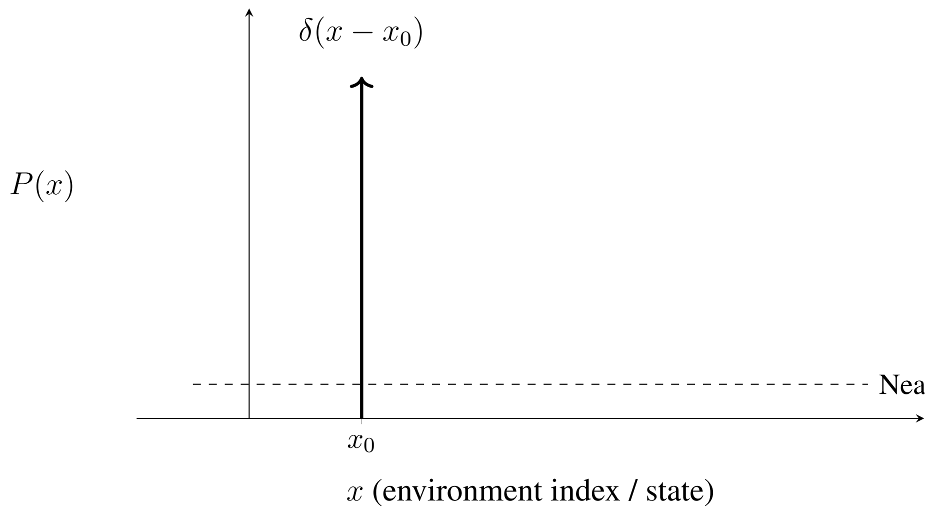


Figure 2: Probability collapse into a delta-like emergence spike.