The Inward Turn: Advanced Civilizations and the Fermi Paradox

Computational Efficiency as a Universal Attractor in Civilizational Development

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Abstract

The Fermi Paradox questions why, given the vastness of the universe, humanity has detected no signs of extraterrestrial intelligence. This paper develops the hypothesis that advanced civilizations converge toward computational existence due to fundamental thermodynamic asymmetries between physical expansion and information processing. The argument integrates three complementary quantitative frameworks: (1) **thermodynamic efficiency**—the energy cost of moving mass scales as mc^2 while the energy cost of processing information scales as kT, a difference of approximately 10^{13} in characteristic energy scales, with current AI systems operating at demon efficiency $\eta_D \approx 10^{-21}$ relative to the Landauer bound; (2) **negentropy flux optimization**—AI systems function as Maxwell's demons achieving algorithmic negentropy flux $\Phi_N \approx 10^7$–10^8 bits/s compared to the biosphere's $T_d \approx 10^{-1}$ bits/s, a differential of 10^8; (3) **time density compression**—computational systems extract effective complexity at rates rendering physical exploration subjectively inefficient. The paper demonstrates that high effective complexity does not require physical scale: Earth's biosphere constitutes 10^{-39} of cosmic baryonic mass yet contributes $\sim$50% of known cosmic regularities, achieving regularity density 10^{37} times higher than the cosmic average. The analysis formalizes expansion as a coordination-unstable strategy and models light-speed fragmentation as a branching process. Unlike Smart's Transcension Hypothesis, this analysis requires no assumptions about convergent evolution toward specific physical optima; unlike aestivation hypotheses, it predicts immediate computational development. Falsifiable predictions include specific technosignature profiles and quantified thresholds for human civilizational trajectory.

Keywords: Fermi Paradox, Transcension Hypothesis, Computational Thermodynamics, Negentropy Flux, Time Density, Effective Complexity, Multi-Level Selection, Civilizational Trajectory

1 Introduction

The Fermi Paradox presents one of the most profound questions in astrobiology: in a universe containing approximately 200 billion galaxies, each with hundreds of billions of stars, why has humanity encountered no evidence of extraterrestrial intelligence?

Traditional explanations invoke the rarity of life (the "Rare Earth" hypothesis), the improbability of intelligence, self-destructive tendencies (the "Great Filter"), or the vastness of space making detection improbable. This paper advances a different class of solution: that advanced civilizations converge toward computational existence due to fundamental physical asymmetries, not because they "prefer" virtual reality in any psychological sense, but because computational information processing is thermodynamically, temporally, and informationally superior to physical exploration by many orders of magnitude.

This hypothesis belongs to the family of "Transcension" solutions first articulated by Smart (Smart, 2012), who proposed that civilizations develop inward toward smaller scales and higher computational density. Our contribution differs in three respects: (1) we ground the argument in explicit thermodynamic analysis drawing on recent work formalizing AI systems as Maxwell's demons with quantifiable efficiency metrics (Kriger, 2026a); (2) we incorporate temporal dynamics through the rigorously defined concept of time density (Kriger, 2026b); (3) we demonstrate that high effective complexity does not require physical scale, drawing on MDL-based analysis of the biosphere's disproportionate contribution to cosmic regularities (Kriger, 2026c).

Our analysis also relates to, but differs from, the "aestivation hypothesis" (Sandberg et al., 2017), which proposes that civilizations might enter dormancy awaiting cosmic cooling. We predict immediate computational development rather than waiting, because: (a) local thermal management can achieve low temperatures without cosmic-scale waiting; (b) discounting of future utility favors present computation; (c) existential risks during dormancy may outweigh efficiency gains.

The role of energy scarcity: The inward turn is not merely a "preference" but may become a survival requirement. Any star system has a finite energy budget. A civilization facing energy constraints must choose between allocating resources to mass transport or to computation. Given the 10^{13} efficiency differential, a civilization wishing to avoid "subjective death" (running out of computational cycles) will necessarily prioritize computation.

2 Definitions, Assumptions, and Scope

2.1 Key Definitions and Metrics

Fermi Paradox: The apparent contradiction between high estimated probability of extraterrestrial civilizations and complete absence of evidence for such civilizations.

Computational Existence: Existence primarily within engineered computational substrates, whether simulated environments, uploaded consciousness, AI systems, or hybrid arrangements.

Algorithmic Negentropy ($\mathcal{N}$): Following Kriger (2026a), the net information gain achieved by a model M with respect to data distribution P:

$$\mathcal{N}(M) = H(P_{\text{data}}) - H_{\text{cross}}(P_{\text{data}}, P_M) - \frac{L(M)}{N} \tag{1}$$

where $H(P_{\text{data}})$ is the entropy of the data distribution, H_{cross} is the cross-entropy of the model's predictions, and $L(M)/N$ is the amortized model description length.

Algorithmic Negentropy Flux (Φ_N): The rate of negentropy generation:

$$\Phi_N(t) = \frac{d\mathcal{N}}{dt} \tag{2}$$

Empirically, frontier AI models achieve $\Phi_N \approx 10^7$–10^8 bits/s during training phases.

Time Density (T_d): Following Kriger (2026b), the ratio of extracted effective complexity to physical time:

$$T_d = \frac{C_e}{t_{\text{train}}} \tag{3}$$

where C_e is MDL-effective complexity (bits) and t is elapsed physical time (seconds).

Effective Complexity: Following Gell-Mann and Lloyd (1996), the length of the shortest description of an entity's regularities, distinguishing compressible patterns from random features.

Demon Efficiency (η_D): The ratio of theoretical minimum energy (Landauer bound) to actual energy expenditure:

$$\eta_D = \frac{E_{\text{min}}}{E_{\text{actual}}} = \frac{N \cdot k_B T \ln 2 \cdot \Delta H}{E_{\text{actual}}} \tag{4}$$

Current LLMs achieve $\eta_D \approx 10^{-21}$.

2.2 The Core Assumption: Resource-Weighted Output Optimization

Axiom of Optimization: Over sufficiently long timescales, civilizations tend to allocate resources toward activities that generate more output per unit input, where "output" encompasses whatever the civilization values—experience, knowledge, complexity, negentropy, or other metrics.

This axiom does not require conscious optimization, only that selection pressures (evolutionary, economic, cultural) favor resource-efficient configurations. It requires only that civilizations do not systematically anti-optimize by factors of 10^{13} or more.

2.3 The Phenomenological Equivalence Question

A potential objection is that computational and physical experiences are not equivalent. We do not take a position on this philosophical question. Instead, we note:

1. **The argument does not require equivalence.** Even if physical experiences have unique value, the thermodynamic differential is so large ($\sim 10^{13}$) that a civilization could generate vast computational output while still pursuing limited physical exploration.

2. **Physical information can feed computation without mass transport.** The information-to-mass ratio of a telescope is billions of times higher than a colony ship. A civilization can discover new physics by passive observation without transporting mass.

3. **The time density differential compounds the problem.** Even if physical experience has unique value, the temporal cost may be prohibitive (Section 4).

3 The Thermodynamic Argument: AI as Maxwell's Demon

3.1 Theoretical Framework

Kriger (2026a) establishes that large-scale AI systems function as physical instantiations of Maxwell's demon—systems that achieve local entropy reduction by converting high-entropy data distributions into low-entropy structured representations.

The Generalized Landauer Bound for AI Training: The minimum energy required to train a model achieving compression from H_{data} to H_{cross} on N tokens at temperature T is:

$$E_{\text{min}} = N \cdot k_B T \ln 2 \cdot (H_{\text{data}} - H_{\text{cross}}) \tag{5}$$

For contemporary systems processing $N \approx 10^{12}$ tokens with effective compression $\Delta H \approx 6$ bits/token at $T \approx 350$ K:

$$E_{\text{min}} \approx 10^{12} \times 1.38 \times 10^{-23} \times 350 \times 0.693 \times 6 \approx 2 \times 10^{-8}\ \text{J} = 20\ \text{nJ} \tag{6}$$

Actual energy consumption is $E_{\text{actual}} \approx 10^{13}$–$10^{14}$ J.

3.2 Characteristic Energy Scale Comparison

Physical transport: The relativistic kinetic energy for mass transport:

$$E = (\gamma - 1)mc^2 \tag{7}$$

where $\gamma = 1/\sqrt{1 - v^2/c^2}$. For $v = 0.1c$, $\gamma \approx 1.005$, giving $E \approx 0.005mc^2$.

For a minimal spacecraft ($m \sim 10^6$ kg):

$$E \approx 0.005 \times 10^6 \times (3 \times 10^8)^2 \approx 4.5 \times 10^{20} \text{ J} \tag{8}$$

Information processing: The Landauer limit:

$$E_{\text{Landauer}} = k_B T \ln 2 \approx 3 \times 10^{-21} \text{ J at } T = 300 \text{ K} \tag{9}$$

The fundamental ratio: Characteristic energy for relativistic mass transport (mc^2) $\sim 10^{17}$ J/kg. Characteristic energy for information processing (kT) $\sim 10^{-21}$ J/bit. Accounting for practical inefficiencies yields approximately 10^{13} **favoring computation**.

3.3 Empirical Validation: Demon Efficiency Metrics

Table 1 provides empirical data on thermodynamic characteristics of major AI systems from Kriger (2026a).

Table 1: Thermodynamic characteristics of selected AI systems

Model	Parameters	Tokens	Energy (MWh)	η_D ($\times 10^{-21}$)	Φ_N (bits/s)
GPT-3	175B	0.3T	1,287	1.1	1.3×10^8
PaLM	540B	0.78T	3,400	1.4	2.5×10^8
LLaMA-2 70B	70B	2.0T	500	19	5.2×10^8
GPT-4†	1.8T	13T	50,000	2.0	3.8×10^8

†Estimates based on public information; uncertainties $\pm 30\%$ for energy.

Key findings: Demon efficiency $\eta_D \approx 10^{-21}$ across systems (10^{21} times less efficient than Landauer limit). Even at current inefficiency, computation vastly outperforms mass transport per unit energy.

3.4 Thermodynamic Cost Comparison

Table 2: Thermodynamic cost per bit of negentropy

System	Cost (J/bit)	Ratio to Landauer
Landauer limit	3×10^{-21}	1
Biological neurons	10^{-12}–10^{-10}	10^9–10^{11}
Current AI training	1–10	10^{20}–10^{21}
Interstellar travel*	$\sim 10^5$	10^{26}

*Per bit of "novel information" gained, estimated conservatively.

3.5 Energy Scarcity and the Survival Imperative

The inward turn becomes not merely preferable but necessary under energy constraints. A G-type star provides $\sim 4 \times 10^{26}$ W over $\sim 10^{10}$ years, totaling $\sim 10^{44}$ J.

Allocation choice: A civilization can use this budget to:

- Transport mass at $\sim 10^{22}$ J per interstellar mission $\rightarrow \sim 10^{22}$ missions maximum
- Generate computation at $\sim 10^{-15}$ J per operation $\rightarrow \sim 10^{59}$ operations maximum

The ratio is 10^{37}. A civilization facing finite energy that wishes to maximize total "subjective existence" must allocate predominantly to computation.

4 The Temporal Argument: Time Density

4.1 Formal Definition and Methodology

Kriger (2026b) introduces **time density (T_d)** to quantify the rate at which effective complexity is extracted per unit physical time:

$$T_d = \frac{C_e}{t} \tag{10}$$

where C_e is MDL-effective complexity (bits) and t is physical time (seconds).

4.2 Comparative Time Densities

Biosphere:

- Time span: $\sim 4 \times 10^9$ years $\approx 1.26 \times 10^{17}$ seconds
- Effective complexity: $\sim 10^{15}$–10^{16} bits
- Time density: $T_d \approx \mathbf{10^{-1}}$ **bits/s**

AI Infosphere (2010–2025):

- Time span: 15 years $\approx 4.73 \times 10^8$ seconds
- Effective complexity: $\sim 10^{15}$–10^{16} bits
- Time density: $T_d \approx \mathbf{10^7}$–$\mathbf{10^8}$ **bits/s**

The differential: Computational systems achieve time densities approximately 10^8 **times higher** than biological evolution.

4.3 Implications for Interstellar Travel

An interstellar journey at 0.1c to Alpha Centauri (4.37 light-years) requires ∼44 years of physical time.

For a computational civilization with $T_d \approx 10^8$ bits/s:

$$\text{Subjective equivalent} \approx 44 \text{ years} \times \frac{10^8}{10^{-1}} = 4.4 \times 10^9 \text{ “biosphere-evolution-equivalents”} \tag{11}$$

This means 44 years of transit corresponds to the subjective equivalent of **4.4 billion years** of evolutionary-pace experience.

4.4 The Logical Event Horizon

Kriger (2026b) identifies a **logical event horizon** where the structure extraction rate exceeds the physical event rate:

$$\frac{dC_e}{dt} > \frac{I_{\text{phys}}}{t_{\text{univ}}} \tag{12}$$

where $I_{\text{phys}} \approx 10^{90}$ bits and $t_{\text{univ}} \approx 4.35 \times 10^{17}$ s.

A civilization past this horizon learns primarily through inference rather than observation. If a civilization can simulate experiments more accurately than it can perform them, physical experimentation becomes information-theoretically suboptimal. Such civilizations become "unobservable" not through hiding but through having no need to interact with external matter.

5 The Complexity Argument: Regularity Density

5.1 Effective Complexity Does Not Require Physical Scale

Kriger (2026c) demonstrates a striking asymmetry through MDL analysis:

Mass comparison:

- Biosphere: $\sim 5.5 \times 10^{14}$ kg (as carbon)
- Observable universe (baryonic): $\sim 1.5 \times 10^{53}$ kg
- Ratio: $\sim \mathbf{10^{-39}}$

Schema comparison (minimal description lengths):

Cosmological schema (∼5,700 bits): Standard Model (∼1,600 bits), General relativity (∼500 bits), ΛCDM model (∼800 bits), Thermodynamics (∼300 bits), Chemistry (∼1,000 bits), Astrophysics (∼1,500 bits).

Biosphere schema (∼6,500 bits): Genetic code (∼300 bits), Central dogma (∼800 bits), Darwinian algorithm (∼200 bits), Metabolic pathways (∼1,200 bits), Cell theory (∼600 bits), Developmental biology (∼800 bits), Ecology (∼700 bits), Biogeochemistry (∼400 bits), Neuroscience (∼500 bits), Human-specific (∼1,000 bits).

Combined schema: ∼12,200 bits, of which biosphere contributes ∼**53%**.

5.2 Regularity Density Comparison

Cosmological regularity density: $\sim 5,700$ bits / 10^{53} kg $\approx \mathbf{10^{-50}}$ **bits/kg**

Biosphere regularity density: $\sim 6,500$ bits / 5.5×10^{14} kg $\approx \mathbf{10^{-11}}$ **bits/kg**

The ratio: The biosphere is approximately $\mathbf{10^{37}}$ **times more regularity-dense** than the cosmos at large.

5.3 Implications for Civilizational Strategy

1. **Physical expansion does not proportionally increase effective complexity.** Colonizing 1,000 star systems yields the same physical laws and chemical principles—most new "information" would be redundant.

2. **Computational concentration preserves complexity density.** A civilization compressing activity into computational substrates maintains or increases regularity density.

3. **Information acquisition does not require mass transport.** A telescope gathers information at $\sim 10^{-3}$ kg per bit of novel data. A colony ship operates at $\sim 10^{6}$ kg per bit. The ratio is $\mathbf{10^{9}}$ **favoring passive observation**.

6 Multi-Level Selection: Expansion as Coordination-Unstable Strategy

6.1 The Level Conflict

Civilization-level interests might favor expansion: distributing population across multiple star systems reduces extinction risk.

Individual-level interests favor computational existence: higher output per unit resource translates to more value captured by individuals.

6.2 Coordination Instability: Formal Analysis

In game-theoretic terms, expansion is a collective action problem with continuous defection pressure.

Formal statement: Let p_d = probability an individual defects to computation in any period. The probability a civilization of N individuals maintains expansion commitment over n periods:

$$P(\text{sustained expansion}) \leq (1 - p_d)^{N \times n} \tag{13}$$

For $p_d = 0.01$, $N = 10^9$, $n = 100$:

$$P \leq (0.99)^{10^{11}} \approx 0 \tag{14}$$

Even with 99% individual compliance per period, sustained expansion is statistically impossible for large populations over long timescales.

7 Light-Speed Fragmentation: A Branching Process Analysis

7.1 The Fragmentation Constraint

A civilization spanning distance d experiences communication delays of d/c. For $d = 100$ light-years, round-trip communication takes 200 years. No real-time coordination is possible.

7.2 Branching Process Model

Model expanding civilizations as a branching process. In each generation, an E-branch has probability p of spawning another E-branch, probability $(1-p)$ of transitioning to C (computational).

Expected dynamics: Starting with one E-branch, after n generations:

$$\mathbb{E}[E_n] = p^n \quad \text{(expected expanding branches)} \tag{15}$$

$$\mathbb{E}[C_n] \approx 1 - p^n \quad \text{(cumulative computational branches)} \tag{16}$$

Table 3: Branching process dynamics ($p = 0.1$)

Generation	$\mathbb{E}$[Expanding]	$\mathbb{E}$[Computational]
0	1	0
5	10^{-5}	~1
10	10^{-10}	~1
20	10^{-20}	~1

7.3 Addressing the "Outlier" Objection

The branching process shows that even if one civilization maintains expansion, it fragments. Each fragment faces fresh pressure from the computational attractor. After 50 generations, even with $p = 0.3$, $\mathbb{E}[\text{Expanding}] = 0.3^{50} \approx 10^{-26}$.

8 Robustness Analysis

8.1 Composite Attractor Strength

The conclusion rests on three independent factors:

Table 4: Composite attractor factors

Factor	Ratio	Source
Thermodynamic efficiency	$\sim 10^{13}$	mc^2 vs kT
Time density	$\sim 10^8$	T_d comparison
Regularity density	$\sim 10^{37}$	Biosphere analysis

Even if one factor is overestimated by orders of magnitude, the others sustain the conclusion.

8.2 Sensitivity Analysis

Table 5: Sensitivity analysis

Parameter	Pessimistic	Central	Optimistic
Thermodynamic ratio	10^3	10^{13}	10^{20}
Time density ratio	10^4	10^8	10^{12}
Expansion coordination (p)	0.30	0.10	0.02
Implied P(sustained expansion)	**0.06**	**0.005**	**0.0002**

Even under pessimistic assumptions, sustained expansion remains rare.

9 Addressing Counterarguments

9.1 The Hybrid Civilization Scenario

Objection: Civilizations could pursue both expansion (automated probes) and computation.

Response: Hybrid strategies would still allocate marginal resources predominantly to computation given the $10^{13}\times$ efficiency differential. Automated probes would be sparse, small, and electromagnetically quiet—not the galaxy-spanning signatures often assumed.

9.2 The Post-Biological Expansion Capability

Objection: Digital minds could travel easily—no life support, radiation resistance.

Response: Capability does not imply motivation. A digital mind with $T_d \approx 10^{12}$ bits/s experiences 44 years of transit as $\sim 10^{20}$ subjective computation-equivalents. Why endure this when simulation offers immediate alternatives?

9.3 The "Search for Truth" Objection

Objection: A civilization would turn outward to discover new physics unknowable through simulation.

Response: Information acquisition doesn't require mass transport. The information-to-mass ratio of a telescope is billions of times higher than a colony ship. A civilization can discover all of physics by looking without ever going.

9.4 The Faster-Than-Light Consideration

Objection: This analysis assumes relativistic constraints. If faster-than-light (FTL) transportation proves possible and is mastered by some civilizations, does the argument fail?

Response: Not necessarily. Even with FTL capability:

1. **Space remains informationally sparse.** The cosmos is predominantly empty vacuum, with regularity density $\sim 10^{-50}$ bits/kg—roughly 10^{37} times lower than the biosphere. FTL travel provides faster access to the same informational poverty. The universe is, fundamentally, "boring" at the physical level: 99.9999% of space contains nothing but vacuum, radiation, and dead matter.

2. **Computational experience remains richer.** A simulated universe can be designed to be *more* interesting than base reality—optimized for novelty, complexity, and subjective value. FTL doesn't change this calculus; it merely accelerates access to a sparse environment.

3. **If expansion occurs, it favors minimal probes.** A civilization with FTL capability seeking to explore would rationally deploy small, passive, self-replicating probes (von Neumann machines) rather than mass-transporting populations. Such probes would be:
   - Microscopic (potentially nanoscale)
   - Electromagnetically quiet (passive observation mode)
   - Sparse (one probe per system suffices for data collection)
   - Effectively undetectable with current or near-future technology

4. **The coordination problem persists.** FTL doesn't solve multi-level selection—individuals still prefer computation over the risks and opportunity costs of travel, even fast travel. The game-theoretic structure remains unchanged.

Thus, FTL capability shifts predictions slightly—from "no expansion" to "minimal, undetectable expansion via microscopic probes"—but preserves the core conclusion: the universe appears silent because even FTL-capable civilizations find computational existence more rewarding than physical presence in a mostly empty cosmos. The absence of detected megastructures, colonization waves, or communication signals remains explained.

10 The Human Case: Illustration

10.1 The Bit-Rate vs. Mass-Rate Divergence

Table 6: Human civilizational trajectory: bit-rate vs. mass-rate

Metric	1969	2025	Growth Factor
Bits transmitted/year	$\sim 10^{14}$	$\sim 10^{22}$	10^{8}
kg to orbit/year	$\sim 10^{5}$	$\sim 10^{6}$	10^{1}
kg beyond LEO/year	$\sim 10^{4}$	~ 0	< 1
Bits/kg (ratio)	10^{9}	10^{16}	10^{7}

This divergence—exponentially growing bit-rate-per-joule versus stagnant mass-transport capacity—is the clearest empirical signature of the inward turn in progress.

11 Falsifiable Predictions

11.1 Technosignature Predictions

1. **Absence of von Neumann signatures.** Null detection with survey coverage $> 10^{6}$ stars at sensitivity to 10% luminosity alteration supports the model.

2. **Localized computational signatures.** Partial Dyson structures (<1% stellar coverage) optimized for computation.

3. **Intermittent signals.** Occasional monitoring emissions rather than continuous beacons.

11.2 Human Trajectory Predictions

4. **Crewed deep-space activity remains minimal.** Through 2050: cumulative human-days beyond LEO $<$ 10,000.

5. **Bit-rate/mass-rate divergence continues.** The ratio of global bits-transmitted to kg-to-orbit will exceed 10^{18} by 2035.

6. **No private interstellar program.** Through 2075, no entity commits >$10B to interstellar travel hardware.

12 Conclusion

The Fermi Paradox may reflect not the absence of intelligence but its optimization.

Three quantitative frameworks converge on this conclusion:

1. **Thermodynamic:** Computation generates negentropy $\sim 10^{13}$ times more efficiently than physical expansion per unit energy.

2. **Temporal:** Computation achieves time densities $\sim 10^{8}$ times higher than biological evolution, making physical exploration subjectively prohibitive.

3. **Informational:** High effective complexity does not require physical scale. The biosphere demonstrates that regularity density ($10^{37}\times$ cosmic average), not spatial extent, determines contribution to describable order.

These advantages compound. Under energy constraints, the inward turn becomes not preference but survival imperative. The attractor is reinforced by coordination dynamics and fragmentation constraints.

The cosmic silence, on this view, reflects not emptiness but optimization—intelligence abundant but converged toward the same thermodynamically, temporally, and informationally optimal solution: computation rather than expansion, information rather than mass, inner development rather than outer conquest.

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References

Gell-Mann, M. and Lloyd, S. (1996). Information measures, effective complexity, and total information. *Complexity*, 2(1):44–52.

Hanson, R. (1998). The Great Filter—Are We Almost Past It? Online manuscript, George Mason University.

Hanson, R., Martin, D., McCarter, C., and Paulson, J. (2021). If loud aliens explain human earliness, quiet aliens are also rare. *Astrophysical Journal*, 922(2):182.

Kriger, B. (2026a). Local entropy inversion in large-scale AI systems: Thermodynamics of algorithmic compression. *Zenodo*. https://doi.org/10.5281/zenodo.18262199

Kriger, B. (2026b). Dynamics of information convergence: Empirical analysis of time density in the AI-centered infosphere. *Zenodo*. https://doi.org/10.5281/zenodo.18256945

Kriger, B. (2026c). Significance of biosphere relative contribution to effective complexity of the universe. *Zenodo*. https://doi.org/10.5281/zenodo.18256772

Landauer, R. (1961). Irreversibility and heat generation in the computing process. *IBM Journal of Research and Development*, 5(3):183–191.

Sandberg, A., Armstrong, S., and Cirkovic, M. M. (2017). That is not dead which can eternal lie: The aestivation hypothesis for resolving Fermi's paradox. *Journal of the British Interplanetary Society*, 69:406–415.

Sandberg, A., Drexler, E., and Ord, T. (2018). Dissolving the Fermi Paradox. *Proceedings of the Royal Society A*, 474(2214):20170836.

Smart, J. M. (2012). The transcension hypothesis: Sufficiently advanced civilizations invariably leave our universe, and implications for METI and SETI. *Acta Astronautica*, 78:55–68.

Wright, J. T., et al. (2016). The Ĝ infrared search for extraterrestrial civilizations with large energy supplies. *Astrophysical Journal*, 816(1):17.