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Article

Thermodynamic Coherence and Virial Inversion in Black Hole Evolution

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Abstract

This paper introduces a conceptual framework for black hole thermodynamic coherence, reframing evaporation and mass absorption as inverse virial dynamics. Coherence is defined as the inverse of the entropy–temperature product and shown to scale inversely with mass-energy. Two Python-based simulations were implemented to explore this model. The first simulation tracks black hole evaporation as a coherence ascent, modeling mass loss and contradiction energy absorption using a simplified virial imbalance condition [3]. The second simulation extends this by incorporating Hawking temperature and entropy, and introduces an entropic penalty mechanism for absorbing highly contradictory matter [4]. This penalty scales with both virial imbalance and coherence, demonstrating reduced tolerance for disorder as structural selectivity increases. Together, these simulations offer a diagnostic lens for horizon dynamics, contradiction resolution, and phase alignment, positioning black holes not as entropy sinks but as coherence-processing regimes.

Keywords: black hole thermodynamics; virial theorem; coherence; contradiction energy; evaporation; phase alignment; horizon dynamics

1. Introduction

Black holes are traditionally modeled as entropy-maximizing systems governed by Hawking radiation and Bekenstein entropy. This paper reframes black hole evolution through the lens of thermodynamic coherence, defining a new metric $C_t = 1/(S \cdot T)$ that scales inversely with mass. We interpret evaporation as a coherence ascent and infalling matter as contradiction energy resolved at the horizon. This model inverts the classical virial theorem and introduces a diagnostic framework for horizon dynamics.

To explore these dynamics, we implemented two Python-based simulations using Google Colab. The first simulation models black hole evaporation as a monotonic increase in coherence, tracking mass loss and contradiction energy over time. It defines coherence as the inverse of mass-energy and simulates infall events using a simplified virial imbalance condition.

The second simulation extends this framework by incorporating Hawking temperature and entropy, and introduces an entropic penalty mechanism for absorbing highly contradictory matter. This penalty scales with the virial imbalance and the black hole’s current coherence, demonstrating how structural selectivity increases as mass decreases. Together, these simulations provide a numerical foundation for interpreting black holes as coherence-processing regimes.

2. Results

We implemented a numerical simulation of black hole evaporation and contradiction absorption using a conceptual model where physical constants are normalized ($G = c = \hbar = k_B = 1$). The simulation begins with a black hole of mass $M = 10.0$ and evolves over 20 time steps with an evaporation rate of 10% per step. At each step, the mass decreases, and the thermodynamic coherence $C_t = 2/(Mc^2)$ increases monotonically. This models the black hole becoming more structurally selective as it evaporates.

After the evaporation sequence, we simulate an infalling contradiction—an object with kinetic energy $K = 5.0$ and potential energy $U = -9.0$, yielding a virial imbalance of $2K + U = 1.0$ J. This contradiction energy is absorbed by the black hole, increasing its mass and reducing its coherence accordingly.

Table 1. Normalized Black Hole Evolution During Evaporation and Contradiction Absorption [3]. The first five rows show the black hole’s mass, coherence, and contradiction energy over selected time steps during evaporation. Coherence C_t is normalized to a maximum value of 1. The final row (–) represents a contradiction absorption event, where an infalling virial imbalance of 1.0 J is absorbed and converted into additional mass. This increases the black hole’s mass from 1.218 kg to 2.218 kg and reduces its coherence from 1.000 to 0.549. The drop in coherence reflects the inverse relationship between mass and structural selectivity: absorbing contradiction increases energy content while reducing phase alignment. This confirms the model’s interpretation of black holes as coherence-processing systems.

Step	Mass (kg)	Normalized Coherence C_t	Contradiction Energy E_c (J)
0	10.000	0.122	10.000
5	5.904	0.206	5.904
10	3.487	0.350	3.487
15	2.060	0.591	2.060
20	1.218	1.000	1.218
–	2.218	0.549	2.218

The final row shows the effect of the contradiction absorption event. The black hole gains 1.0 kg of mass from the infalling virial imbalance, reducing its coherence from 1.000 to 0.549. This confirms the model’s behavior: contradiction energy is absorbed as mass, and coherence adjusts accordingly, preserving the inverse energy relationship.

These results support the interpretation of black holes as coherence-processing systems that absorb structural imbalance and evolve toward higher selectivity through evaporation.

We implemented a second simulation of black hole coherence evolution using a conceptual model where mass, energy, and thermodynamic quantities are scaled for clarity [4]. The simulation begins with a black hole of mass $M = 100.0$ and tracks its evolution through evaporation and two infall events: one coherent and one contradictory.

During evaporation, the mass decreases over 10 time steps, following a rate proportional to $1/M^2$. As mass falls, thermodynamic coherence $C_t = 2/(Mc^2)$ increases, Hawking temperature rises, and entropy decreases. This models the black hole becoming more structurally selective as it shrinks.

In the first infall event, the black hole absorbs coherent matter with near-perfect virial balance ($2K + U = 0$). The mass increases with minimal penalty, and coherence adjusts accordingly.

In the second infall event, the black hole absorbs contradictory matter with a large virial imbalance ($2K + U = 1990$). This triggers a conceptual entropic penalty, reducing the net mass gain and sharply lowering coherence. The penalty scales with the contradiction magnitude and the black hole’s current coherence, reflecting its reduced tolerance for disorder as it becomes more selective.

Table 2. Normalized Coherence Evolution During Evaporation and Infall Events [4].

Step	Mass (M)	Coherence C_t	Temperature T_H	Entropy (S)
Initial	100.000	0.020	0.010	10000.000
Evap 10	99.950	0.020	0.010	9990.002
Coherent Infall	99.950 → 100.000	0.020 → 0.020	0.010	10000.000
Contradictory Infall	100.000 → 80.100	0.020 → 0.025	0.012	6416.010

The final row shows the impact of absorbing contradictory matter. Despite a large incoming energy, the entropic penalty reduces the net mass gain, resulting in a coherence increase and entropy

drop. This confirms the model's logic: contradiction absorption under high coherence leads to structural refinement and energy loss.

3. Discussion

This Thermodynamic Coherence model inverts the classical virial theorem. In standard self-gravitating systems, equilibrium is achieved when $2K + U = 0$. Here, the black hole enforces coherence by absorbing imbalance. Evaporation is not decay—it is refinement. The horizon acts as a semantic filter, suppressing misaligned structure and favoring phase-aligned inputs.

3.1. Physical Interpretation of Coherence C_t

We define thermodynamic coherence C_t as the inverse of the entropy–temperature product, $C_t = 1/(S \cdot T)$, which scales inversely with mass-energy. In condensed matter physics, coherence describes the phase alignment of quantum states, such as in Bose-Einstein condensates or superconductors. We extend this concept to black holes, where C_t represents the degree of phase alignment among the black hole's microstates. As C_t increases, the system transitions toward a more ordered configuration, analogous to a quantum condensate. This reframing suggests that black holes evolve not toward maximal entropy, but toward maximal structural selectivity.

3.2. Comparison to Bekenstein-Hawking Entropy

Bekenstein [1] and Hawking [2] defined black hole entropy as proportional to horizon area, $S \propto A$, interpreting black holes as entropy-maximizing systems. Our model introduces coherence $C_t \propto 1/S$ as a measure of order. This inversion implies that black holes do not merely accumulate disorder but actively refine their internal structure. As mass decreases through evaporation, coherence increases, suggesting a transition from disordered to coherent states.

3.3. Relation to ER=EPR and Holography

The ER=EPR conjecture proposed by Maldacena and Susskind [5] equates entangled black holes (EPR pairs) with wormhole connections (ER bridges), offering a resolution to the information paradox. Our coherence framework complements this by providing a thermodynamic mechanism for information preservation. While ER=EPR encodes information in entangled microstates, our model shows how these microstates can phase-lock into a coherent state, ensuring that information is not lost but structurally refined through horizon dynamics.

3.4. Connection to Loop Quantum Gravity

In Loop Quantum Gravity, spacetime is composed of discrete spin networks that can condense into geometric states [6]. Our coherence phase transition resembles this condensation process. As black holes evaporate and C_t increases, the system may undergo a transition analogous to spin foam condensation, where quantum entanglement gives rise to emergent geometry. This suggests a deep link between thermodynamic coherence and quantum spacetime structure.

3.5. Holographic Phase Transitions in AdS/CFT

The Hawking-Page transition [7] in AdS/CFT describes a phase shift between thermal AdS space and a black hole in the dual conformal field theory. Our model's coherence ascent may correspond to a similar holographic phase transition. As the black hole evaporates and C_t increases, the dual CFT could shift from a disordered to a coherent regime, offering a new interpretation of holographic thermodynamics grounded in structural refinement.

3.6. Inversion of Quantum Darwinism

Quantum Darwinism [8] explains how quantum systems decohere into classical states by redundantly encoding information in the environment. Our model suggests the inverse: black holes transition from classical disorder (Shannon entropy) to quantum coherence (C_t). This inversion im-

plies that black holes may act as quantum Darwinism in reverse—refining rather than dissipating information, and evolving toward phase-aligned microstates.

3.7. Simulation Support

Two Python-based simulations support this framework. The first [3] models evaporation as a monotonic coherence increase, tracking mass loss and contradiction energy over time. It demonstrates that infalling systems with non-zero virial imbalance are absorbed as contradiction energy, reinforcing the black hole's structural selectivity.

The second simulation [4] extends this logic by incorporating Hawking temperature and entropy, and introducing an entropic penalty for absorbing highly contradictory matter. This penalty scales with both the virial imbalance and the black hole's current coherence, showing that smaller, more selective black holes are less tolerant of disorder. The simulation confirms that contradiction absorption under high coherence leads to reduced net mass gain and sharper coherence shifts.

Together, these models position black holes not as entropy endpoints, but as coherence-processing regimes—absorbing contradiction, resolving imbalance, and enforcing phase alignment at the horizon.

4. Conclusions

We present a coherence-based framework for black hole evolution, grounded in inverse energy logic and virial contradiction absorption. Two simulations demonstrate how evaporation increases structural selectivity and how contradiction absorption depends on coherence state. This model offers a diagnostic tool for interpreting horizon dynamics, thermodynamic refinement, and structural alignment. Future work may extend this to quantum coherence regimes, semantic field modeling, and multi-body gravitational systems. **Conflicts of Interest:** The author declares no conflicts of interest.

Data Availability Statement: The simulation code supporting the findings of this study is publicly available via Google Colab:

- Black Hole Coherence Simulation: [VirialSim2025](#)
- Entropic Penalty and Virial Resolution Model: [Barton2025b](#)

Institutional Review Board Statement: Not applicable. This study does not involve human or animal subjects.

Informed Consent Statement: Not applicable. No human participants were involved in this study.

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