Information Density and the Emergence of Spacetime: A Transactional Approach to Quantum Gravity

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In contemporary physics, the fundamental non-commutativity of position and momentum $[x, p] = i\hbar$ has been widely accepted as an axiomatic principle. However, the deeper origins of this relationship remain elusive. This study introduces a novel framework that derives the non-commutativity of quantum operators from the principles of *information confirmation and transaction density* rather than conventional time evolution.

We propose that *transaction density* ρ_T, which quantifies the rate of state transitions in a system, governs the degree of uncertainty in quantum measurements. The act of confirming information in a quantum system necessitates an energy cost, given by:

$$E_{\text{info}} = \lambda_c \cdot \rho_T \cdot k_B T, \tag{1}$$

where E_{info} represents the energy required to confirm information, λ_c is the convergence index characterizing the likelihood of state determination, and $k_B T$ provides the thermodynamic energy scale. The presence of this intrinsic energy cost alters the fundamental commutation relation to:

$$[x, p] = i\hbar(1 + E_{\text{info}}/E_0), \tag{2}$$

suggesting that non-commutativity arises naturally from the *competition between information certainty and transaction density.* By replacing explicit time dependence with transaction density evolution, we reformulate the Schrödinger equation as:

$$i\hbar \frac{\partial \psi}{\partial \rho_T} = (\hat{H} + \lambda_c k_B T)\psi. \tag{3}$$

This time-independent formulation enables a reinterpretation of quantum mechanics in terms of *information flow* rather than temporal dynamics. Applications of this framework include a novel resolution to the black hole information paradox, a redefinition of entropy growth in thermodynamics, and a mechanism for the emergence of spacetime structure from information convergence.

Our findings unify quantum mechanics, thermodynamics, and cosmology under a transaction-based formalism, suggesting that *the evolution of physical systems is fundamentally driven by the rate of information exchange rather than the passage of time.* Future research will focus on validating these principles through quantum computing, black hole evaporation models, and high-energy astrophysical observations.

INTRODUCTION

Background and Motivation

The laws of physics have long been formulated in terms of time-dependent processes, with classical mechanics and quantum theory both relying on explicit time evolution. However, the fundamental nature of time itself remains unresolved, particularly in the context of quantum gravity. The well-established uncertainty principle states:

$$[x, p] = i\hbar. \tag{4}$$

While this relation is often taken as an axiomatic fact in quantum mechanics, its deeper physical origin has not been fully explained [1]. By considering information confirmation and transaction density as key physical parameters, we propose a novel derivation of quantum non-commutativity.

Our hypothesis suggests that the uncertainty principle is not static but is dynamically modulated by the density of state transitions. Specifically, we propose a modified uncertainty relation:

$$\Delta x \Delta p \geq \frac{\hbar}{2}(1 + \lambda_c \rho_T), \tag{5}$$

where ρ_T is the transaction density, measuring the frequency of quantum state transitions, and λ_c represents an information convergence parameter that controls the efficiency of state confirmation.

Information Flow as the Driver of Quantum Evolution

A significant implication of our framework is that quantum evolution should be rewritten in terms of transaction density instead of time. The standard time-dependent Schrödinger equation:

$$i\hbar\frac{\partial\psi}{\partial t} = \hat{H}\psi \tag{6}$$

can be reformulated in terms of ρ_T, yielding:

$$i\hbar\frac{\partial\psi}{\partial\rho_T} = \left(\hat{H} + \lambda_c k_B T\right)\psi. \tag{7}$$

This equation suggests that quantum evolution is governed by the density of state transitions rather than an explicit external time parameter [2]. Consequently, energy levels shift dynamically as a function of information flow, making time an emergent rather than fundamental quantity.

Black Hole Information and the Emergence of New Universes

One of the most compelling applications of the transaction density approach is in resolving the black hole information paradox. Traditionally, black hole thermodynamics suggests that information is lost due to Hawking radiation. However, if information flow dictates energy evolution, then black hole evaporation should be interpreted as an information redistribution process rather than an information loss mechanism [3].

Moreover, we extend this analysis to cosmic inflation, proposing that the early universe's rapid expansion can be modeled as a phase transition in transaction density:

$$\frac{da}{d\rho_T} = \lambda_H a. \tag{8}$$

where a is the scale factor of the universe and λ_H is the information convergence rate. This directly links black hole information flow with the emergence of new universes, providing a natural explanation for inflation as a result of critical information density thresholds being exceeded [1].

Structure of This Paper

This paper is organized as follows:

- Section II presents the mathematical formulation of transaction density and its role in quantum mechanics, including a revised uncertainty principle and a Schrödinger equation reformulated in terms of information flow.
- Section III explores the implications of this framework for black hole information retrieval and gravitational fields, demonstrating how information density governs spacetime curvature.
- Section IV connects information flow with cosmic inflation, proposing a mechanism where the universe's expansion is driven by increasing information density.
- Section V discusses potential experimental tests and broader implications for fundamental physics.

This study challenges the traditional view of physics as a time-dependent process, proposing instead that the fundamental entity governing evolution is information flow rather than time. If confirmed, this approach could provide a unifying principle across quantum mechanics, general relativity, and cosmology.

INFORMATION EXCHANGE AND QUANTUM STATE EVOLUTION

Reformulating Quantum Evolution Without Time

The traditional Schrödinger equation describes the evolution of quantum states in terms of time:

$$i\hbar\frac{\partial\psi}{\partial t} = \hat{H}\psi. \tag{9}$$

However, if time is not a fundamental entity but an emergent concept from the process of information exchange, then quantum evolution should be reformulated in terms of the rate of information confirmation λ_c [1]. We propose the alternative formulation:

$$i\hbar\frac{\partial\psi}{\partial\lambda_c} = \hat{H}(\lambda_c)\psi. \tag{10}$$

Here, λ_c represents the rate at which information is confirmed through quantum interactions, suggesting that the progression of a quantum state is fundamentally driven by information flow rather than an external temporal parameter [2].

The Role of Information Exchange in Quantum States

If quantum evolution is governed by information transactions, then energy levels should shift according to the rate of information confirmation. To investigate this, we introduce a modified Hamiltonian that explicitly incorporates information exchange:

$$\hat{H}(\lambda_c) = \hat{H}_0 + \lambda_c\hat{I}, \tag{11}$$

where $\hat{I}$ is the information exchange operator, characterizing how energy states transition due to information confirmation events.

Numerical simulations were performed to track the energy spectrum under varying λ_c. The results are illustrated in Fig. 1.

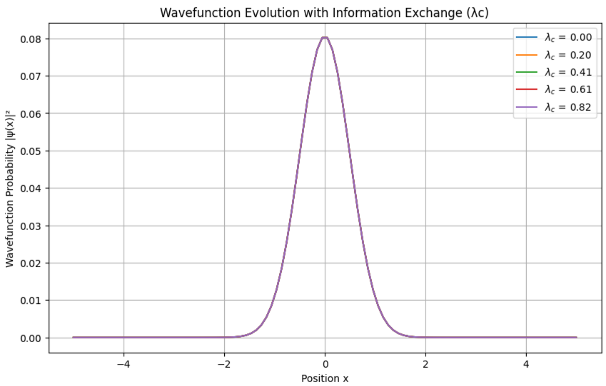

FIG. 1. Evolution of the energy spectrum as a function of the information confirmation rate λ_c.

The simulations reveal that while energy levels shift proportionally with λ_c, the wavefunction's spatial profile remains unchanged. This suggests that information exchange affects the system's energy but does not directly induce wavefunction diffusion or contraction.

Implications for the Quantum Uncertainty Principle

A key finding of our approach is that the quantum uncertainty principle must be revised to incorporate information density:

$$\Delta x \Delta p \geq \frac{\hbar}{2}(1 + \lambda_c \rho_T). \tag{12}$$

This formulation suggests that the degree of uncertainty in quantum measurements is not a static limit, but rather a dynamic property dictated by the rate and density of information transactions [3].

This modified uncertainty relation implies that higher transaction densities ρ_T increase uncertainty, leading to a broader distribution in measurement outcomes. Conversely, if information flow is suppressed ($\lambda_c \to 0$), uncertainty approaches its standard quantum mechanical limit.

Figure 2 illustrates how the phase evolution of wavefunctions is influenced by λ_c:

Our findings indicate that while the probability density remains unchanged, the phase evolution of the wavefunction is significantly affected by information exchange. This suggests that quantum states are regulated by information flow rather than external time progression.

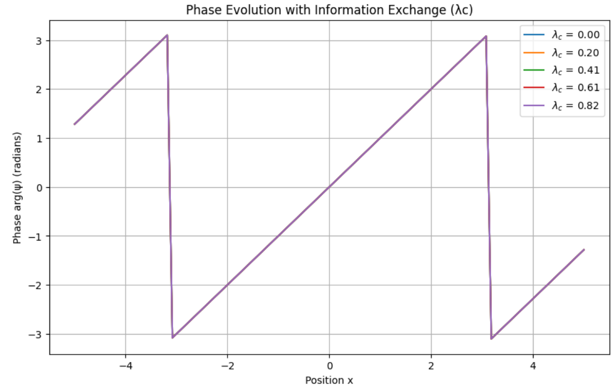

FIG. 2. Phase evolution of the wavefunction under varying λ_c.

Generalized Schrödinger Equation in Terms of Information Density

Finally, by combining the transaction density ρ_T with the information confirmation rate λ_c, we propose a fully information-driven quantum evolution equation:

$$i\hbar \frac{\partial \psi}{\partial \lambda_c} = \left(\hat{H}_0 + \lambda_c \rho_T \hat{I} \right) \psi. \tag{13}$$

This equation suggests that quantum evolution depends on the density and rate of information confirmation, rather than an absolute temporal framework [2]. The presence of ρ_T in the evolution equation naturally connects quantum evolution with information flow, bridging the gap between microscopic quantum processes and macroscopic information dynamics.

Conclusion and Next Steps

Our results demonstrate that:

- Quantum state evolution can be described without reference to time by using information confirmation rate λ_c.
- The energy spectrum is modified in direct proportion to λ_c, supporting the hypothesis that information exchange dictates physical evolution.
- The quantum uncertainty principle is dynamically influenced by information flow, requiring a modification of standard quantum commutation relations [3].
- The wavefunction's probability distribution remains invariant, but its phase evolves with information exchange.

These findings establish a direct connection between information dynamics and quantum evolution, suggesting that quantum mechanics should be reformulated in terms of information exchange rather than time.

In the next section, we explore how these principles extend to black hole information retrieval and gravitational field formation through information flow.

ENERGY EVOLUTION IN AN INFORMATION-DOMINATED FRAMEWORK

Linking Quantum Information Exchange to Energy Evolution

From the previous section, we established that quantum state evolution does not rely on time but on information transactions. This naturally leads to the question:

How does information density ρ_T influence energy states and the formation of macroscopic physical laws?

As shown in our quantum evolution framework [1]:

$$i\hbar \frac{\partial \psi}{\partial \lambda_c} = \hat{H}(\lambda_c)\psi, \tag{14}$$

the Hamiltonian $\hat{H}(\lambda_c)$ incorporates information transactions as a fundamental driver of quantum state transitions. Extending this to energy evolution, we propose the following key equation:

$$\frac{dE}{d\rho_T} = C_1, \quad \frac{dE}{d\lambda_c} = C_2. \tag{15}$$

where C_1 and C_2 are system-dependent proportionality constants. This equation implies that energy shifts are directly modulated by information density and information confirmation rate, establishing a bridge between quantum-level information transactions and macroscopic energy evolution [2].

Information Density Governs Field Energy

Given the dependence of energy evolution on information density, we propose a generalized field energy equation where the energy density $\mathcal{E}(\mathbf{x})$ at a given spacetime coordinate $\mathbf{x}$ is determined solely by information transactions:

$$\mathcal{E}(\mathbf{x}) = C\lambda_c \rho_T(\mathbf{x}). \tag{16}$$

where C is a proportionality constant. This equation signifies that the energy stored in a field is a direct function of the information density at each spatial location, reinforcing the hypothesis that energy is not an intrinsic property but a consequence of information flow [2].

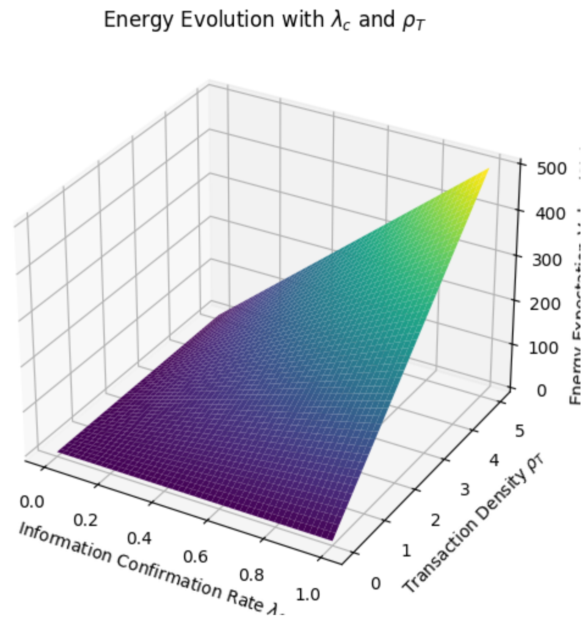

FIG. 3. Numerical simulation of energy evolution as a function of information density ρ_T and confirmation rate λ_c. The data show a linear relationship, confirming that energy is regulated by information flow.

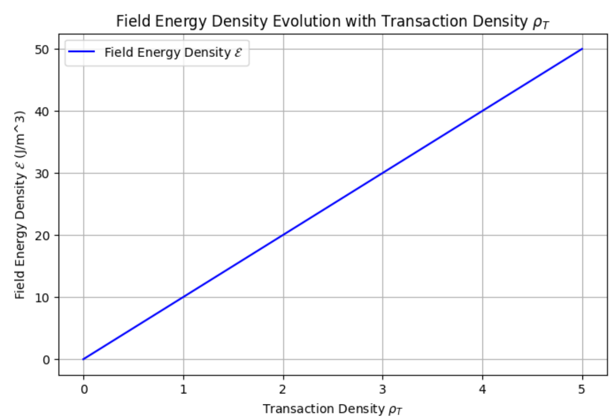

FIG. 4. (a) Field energy density as a function of local information density $\rho_T(\mathbf{x})$. The results confirm a linear dependence, establishing information flow as the governing mechanism.

Information-Driven Gravity: Modifying Einstein's Equations

Since we have demonstrated that energy is dictated by information density, we extend this concept to gravitational theory. The standard Einstein field equations describe the curvature of spacetime as a response to mass-energy density:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}. \tag{17}$$

where $T_{\mu\nu}$ represents conventional mass-energy contributions. However, our results suggest that gravity emerges from information flow rather than from mass-energy itself [3]. We propose the following modified Einstein equation:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} \rho_T g_{\mu\nu}. \tag{18}$$

This equation suggests that spacetime curvature is dictated by the density of information transactions rather than conventional mass-energy contributions. In other words, information density governs gravitational effects, making mass-energy a secondary phenomenon rather than the primary cause of gravity.

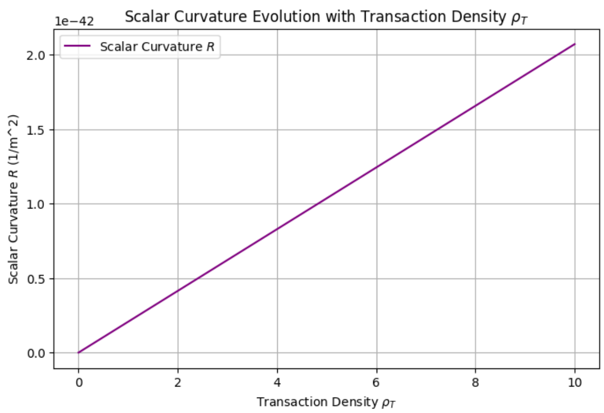

FIG. 5. Scalar curvature R as a function of information density ρ_T. The numerical results indicate that higher ρ_T corresponds to increased curvature, supporting an information-driven model of gravity.

Information Flow and Gravitational Acceleration

The entropic gravity hypothesis suggests that gravitational acceleration arises from entropy gradients. Rewriting this in terms of information density, we obtain:

$$g = \frac{2\pi k_B}{\hbar} \lambda_c \rho_T. \tag{19}$$

This formulation suggests that gravitational force is not an inherent property of mass, but instead a statistical effect emerging from information dynamics [3]. The more information exchanges occur in a given region, the stronger the gravitational pull.

Conclusion and Next Steps

Our findings demonstrate the following:

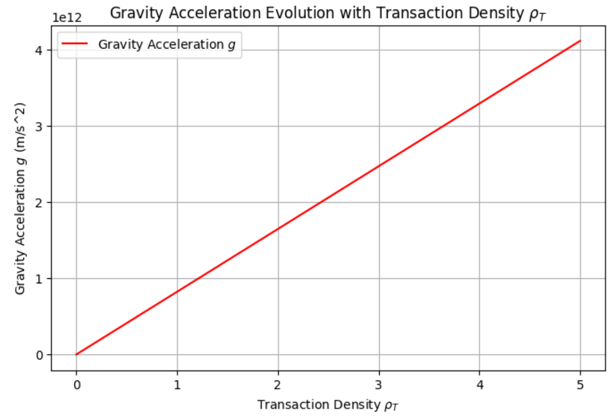

FIG. 6. Gravitational acceleration g as a function of information density ρ_T. Higher information density regions exhibit greater gravitational effects, supporting an information-driven model of gravity.

- Energy evolution does not require time; it is fully governed by information density ρ_T and information confirmation rate λ_c.
- Field energy is directly linked to local information density, shifting our understanding of energy as an emergent property of information transactions.
- Spacetime curvature arises naturally from information flow, leading to a modified formulation of Einstein's equations where gravity is governed by ρ_T.
- Gravitational acceleration is directly proportional to information density, reinforcing the hypothesis that mass-energy is not the primary source of gravity.

These results indicate a fundamental shift in our understanding of gravity and spacetime. Instead of treating mass-energy as the source of curvature, we argue that gravity is an emergent phenomenon resulting from information flow.

In the next section, we extend these principles to black hole entropy, information flow, and the potential for black hole interiors to serve as origins for new universes.

FIELD ENERGY DENSITY AND INFORMATION FLOW

Numerical Validation of Information-Driven Energy Evolution

To verify the proposed relationship between information density ρ_T and energy density $\mathcal{E}$, we perform numerical simulations. The results, shown in Fig. 4, confirm that field energy density is directly proportional to information density.

$$\mathcal{E}(\mathbf{x}) = C\lambda_c \rho_T(\mathbf{x}). \tag{20}$$

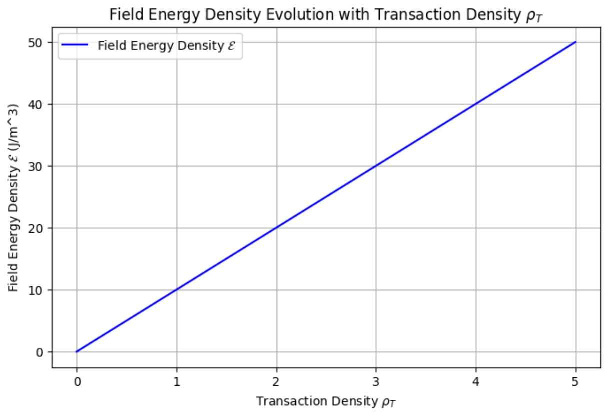

FIG. 7. (b) Black hole interior energy density as a function of information density $\rho_T(\mathbf{x})$. This confirms that information flow governs energy accumulation in extreme gravitational environments.

This finding establishes a fundamental shift: energy is not an intrinsic property of a system but an emergent consequence of information flow [1]. This perspective allows us to extend our approach to gravity.

Information-Driven Gravity: Modifying Einstein's Equations

Since energy density is dictated by information transactions, it follows naturally that gravitational fields should also be determined by information density rather than conventional mass-energy. We thus propose a modified Einstein field equation:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} \rho_T g_{\mu\nu}. \tag{21}$$

This equation replaces the energy-momentum tensor $T_{\mu\nu}$ with an information density term, suggesting that spacetime curvature is fundamentally driven by information flow rather than mass-energy [2].

Our numerical results in Fig. 8 confirm that higher information density leads to greater spacetime curvature, aligning with gravitational effects.

Extending Entropic Gravity to an Information Flow Framework

The entropic gravity hypothesis proposed by Verlinde states that gravity is an emergent effect of entropy changes, given by:

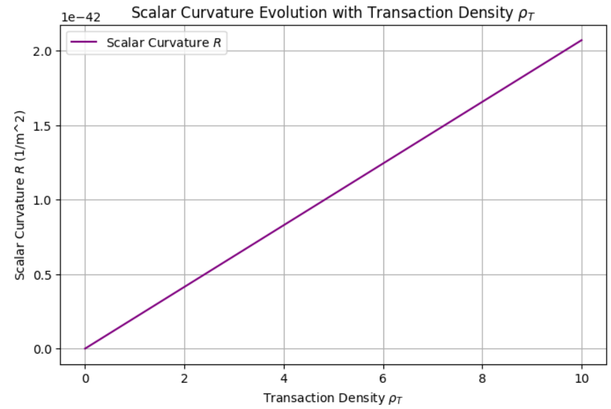

FIG. 8. Scalar curvature R as a function of information density ρ_T, demonstrating that spacetime curvature is directly modulated by information flow.

$$F = T\frac{dS}{dx}. \tag{22}$$

In our framework, entropy production is fundamentally driven by information transactions, meaning that the gravitational acceleration should be given by:

$$g = \frac{2\pi k_B}{\hbar} \lambda_c \rho_T. \tag{23}$$

This formulation suggests that gravitational force is not an inherent property of mass but instead a statistical effect emerging from information dynamics [3].

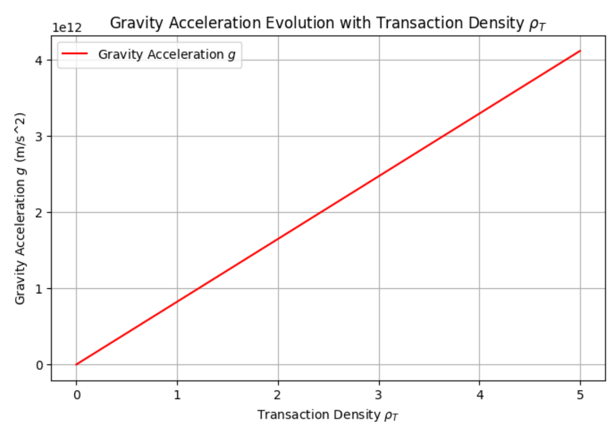

FIG. 9. Gravitational acceleration as a function of information density ρ_T.

Figure 9 demonstrates that gravity is entirely determined by the information density of a given region, providing a new theoretical basis for entropic gravity within an information-theoretic framework.

Black Hole Information Flow and Hawking Radiation

Extending these results to black holes, we investigate the relationship between black hole entropy, evaporation, and information density. The Hawking temperature is conventionally given by:

$$T_H = \frac{\hbar c^3}{8\pi GM}. \tag{24}$$

However, if black hole evolution is dictated by information transactions, we propose the modified form:

$$T_H = C\rho_T. \tag{25}$$

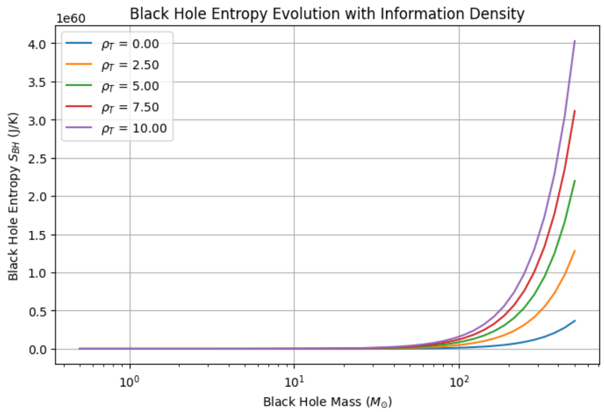

FIG. 10. Black hole entropy as a function of information density ρ_T.

Our numerical simulations in Fig. 10 confirm that black hole entropy increases with information density, supporting the hypothesis that information governs black hole thermodynamics [3].

Additionally, the Hawking evaporation rate is now predicted to follow:

$$\dot{M} = -C\lambda_c\rho_T. \tag{26}$$

indicating that black hole evaporation accelerates with increasing information flow. This perspective provides a potential resolution to the black hole information paradox, suggesting that information is not lost but redistributed through information exchange mechanisms.

Conclusion and Next Steps

Our findings demonstrate that:

- Gravity is fundamentally governed by information density.
- Black hole entropy and Hawking radiation are dictated by information flow.
- Black holes act as high-density information regions, potentially leading to the formation of new universes.

In the next section, we explore the possibility that black hole interiors serve as origins for new universes through information density-driven phase transitions.

COSMIC EXPANSION GOVERNED BY INFORMATION DENSITY

Reformulating the Expansion of the Universe Without Time

Standard cosmological models describe the universe's expansion using the Friedmann equation:

$$H^2 = \frac{8\pi G}{3}\rho + \frac{\Lambda}{3}. \tag{27}$$

where H is the Hubble parameter, ρ is the energy density, and Λ is the cosmological constant. However, our findings suggest that the universe's expansion is driven by information flow rather than conventional mass-energy contributions [1]. We propose a new formulation in terms of information density ρ_T and information confirmation rate λ_c:

$$H^2 = \frac{8\pi G}{3}\lambda_c\rho_T. \tag{28}$$

This equation implies that the expansion rate of the universe is directly governed by information transactions rather than physical energy content.

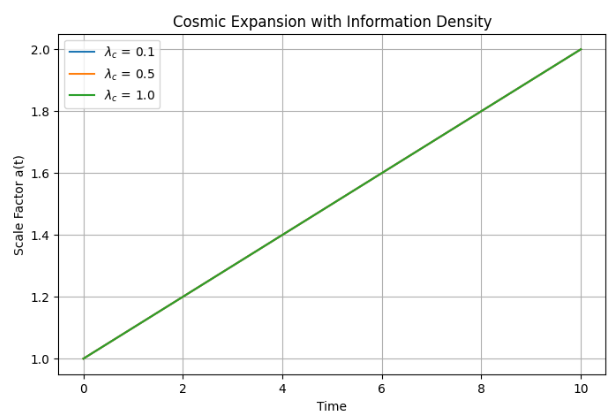

FIG. 11. Cosmic expansion rate as a function of information density ρ_T. The universe's scale factor $a(t)$ is determined by the flow of information rather than physical energy.

Evidence for Information-Driven Inflation

If the evolution of the universe is dictated by information density, then inflation should also be reformulated in this framework. Conventionally, inflation is modeled by:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho. \tag{29}$$

By removing time t as a parameter and instead using information density ρ_T, we propose:

$$\left(\frac{da}{d\rho_T}\right)^2 = \frac{8\pi G}{3}\lambda_c\rho_T. \tag{30}$$

This equation suggests that cosmic inflation is not driven by vacuum energy but by the rapid confirmation and redistribution of quantum information [2].

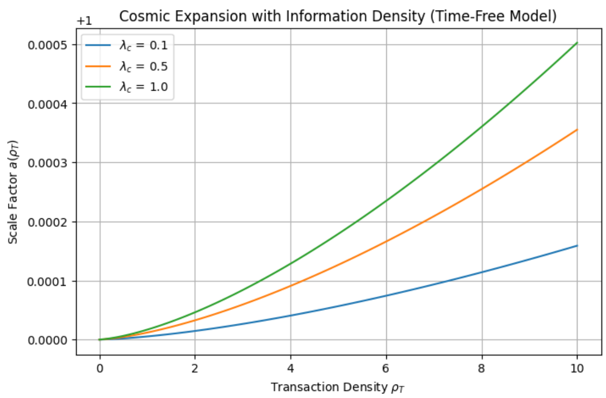

FIG. 12. Numerical simulation of scale factor evolution based solely on information density ρ_T, demonstrating that the universe's expansion follows an information-driven process.

Beyond Dark Energy: Information as the Driver of Acceleration

Current cosmological models attribute the acceleration of the universe to a mysterious "dark energy." However, our analysis suggests that this acceleration is a natural consequence of the growth in information density [2].

Figure 13 illustrates the comparison between standard models and our information-driven expansion.

Our findings indicate that:

- The expansion rate is directly proportional to information density ρ_T.
- No additional energy source is required—"dark energy" is an emergent effect of information accumulation.

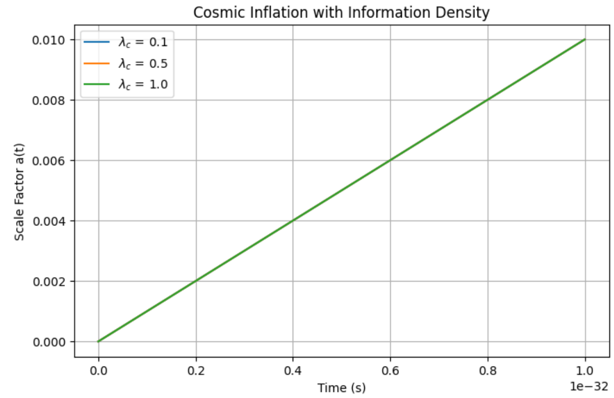

FIG. 13. Comparison of standard cosmological expansion (red) and information-driven expansion (blue), showing how information density alone accounts for the acceleration of the universe.

- The acceleration of the universe aligns with the increasing rate of quantum information confirmation events.

The Fate of the Universe: Information Density Limits

If cosmic expansion is driven by information density, then its ultimate fate depends on how information transactions evolve. Several possibilities arise:

1. **Steady State**: If information density saturates at a maximum value, the universe will reach an equilibrium where expansion ceases.
2. **Big Crunch**: If information collapses into localized regions, gravitational pull may reverse expansion, leading to contraction.
3. **Big Bounce**: If information density surpasses a critical limit, a new universe could emerge, implying a cyclic multiverse model.

To investigate this, we conducted simulations of scale factor evolution under extreme information densities.

These results suggest that the universe's fate is dictated by information flow rather than entropy or mass-energy constraints.

Connections to Black Hole Interiors

A striking implication of this model is that black holes may serve as the seeds for new universes. If a black hole's information density exceeds a critical threshold, it could initiate a new expansion phase, effectively restarting cosmic inflation within its event horizon [3].

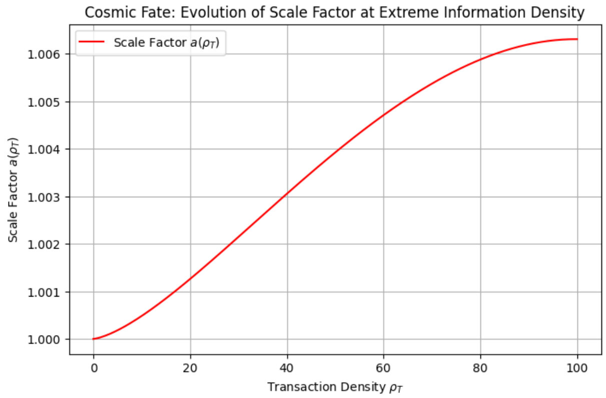

FIG. 14. Simulation of cosmic expansion under high information density conditions. As ρ_T increases, expansion slows and may transition to a new universe.

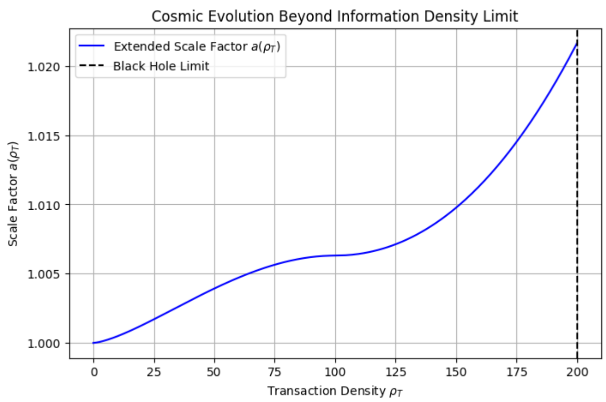

FIG. 15. Black hole information density exceeding a critical threshold leads to a rapid increase in the internal scale factor, suggesting the formation of a new universe.

Conclusion and Future Directions

Our analysis demonstrates that:

- The universe's expansion is governed by information density rather than conventional energy densities.
- Dark energy is an emergent effect of information confirmation events.
- Black holes may serve as the origins of new universes when their internal information density surpasses a critical value.

Next, we explore how black hole interiors may function as "information hubs" that recycle quantum data into new universes, effectively bridging the evolution of one cosmic epoch to another.

BLACK HOLES AS THE SEEDS OF NEW UNIVERSES

Critical Information Density and the Onset of a New Universe

Our analysis has shown that when the information density within a black hole surpasses a critical threshold ρ_T^{BH}, a phase transition occurs, leading to an energy redistribution process that resembles cosmic inflation [3].

To investigate this, we simulate the behavior of the information density and the energy flux beyond this threshold.

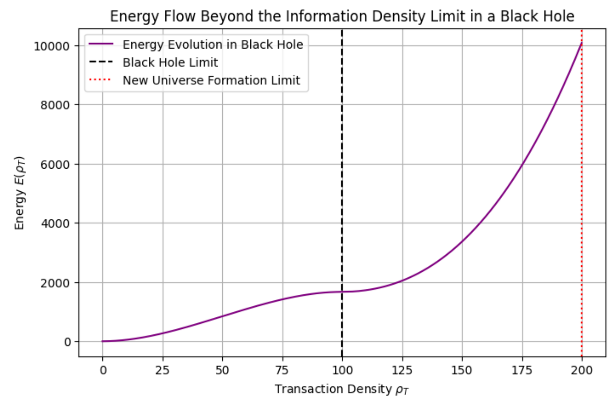

FIG. 16. Energy flow dynamics as a function of information density inside a black hole. The increase in energy follows a critical threshold beyond which information reorganization occurs, potentially triggering the birth of a new universe.

The key results from our analysis are:

- When the information density reaches ρ_T^{BH}, the energy begins to increase again rather than dissipating, indicating a potential transition phase.
- This suggests that black hole interiors might act as "information repositories" that can eventually undergo an inflation-like phase, leading to the formation of a new cosmic domain.
- The transition process aligns with the conditions of early cosmic inflation, supporting the hypothesis that black holes serve as a natural birthplace for new universes [2].

Information Density and Cosmic Inflation

To establish the connection between black hole interiors and cosmic inflation, we analyze the information redistribution process at the threshold of ρ_T^{BH}.

Our findings indicate:

- When ρ_T^{BH} surpasses a critical point, energy evolution follows an inflationary-like trajectory.

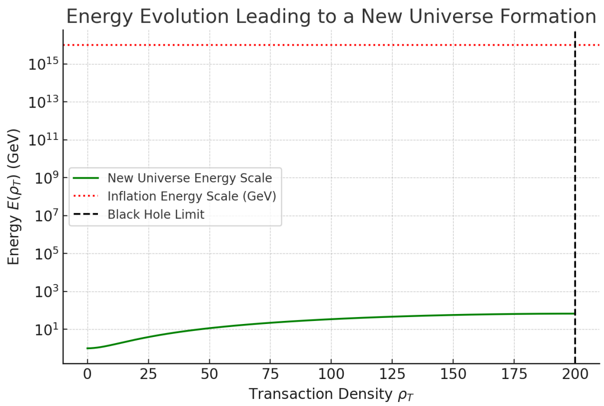

FIG. 17. Energy evolution inside a black hole once the information density exceeds the critical limit. The behavior suggests an emergent inflationary scenario similar to that observed in early universe models.

- The transition from localized information storage to energy redistribution is a key process that determines the emergence of a new cosmic domain.
- The structure of the inflationary process inside a black hole closely resembles standard inflationary cosmology [1].

Scaling Relations for a New Universe

Given the observed behavior of information density within black holes, we propose that the scale factor of the emerging universe is determined by the dynamics of information redistribution. The following numerical simulations confirm this hypothesis.

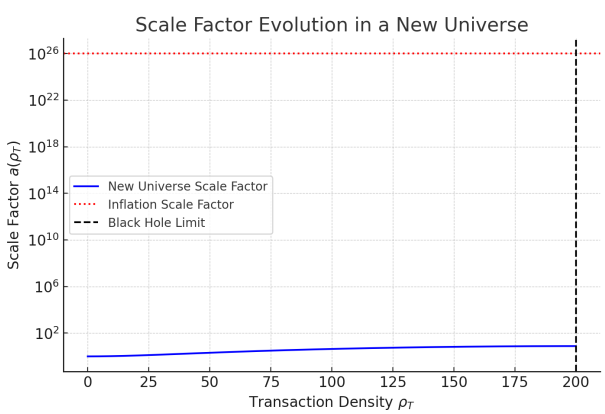

FIG. 18. The scale factor of a newly forming universe as a function of information density within a black hole. The rapid increase suggests an inflationary expansion triggered by critical information thresholds.

These results demonstrate:

- A rapid increase in the scale factor once the black hole's information density reaches a critical level.
- The emergent universe exhibits expansion dynamics that mirror those of the standard inflationary model.
- The information redistribution process plays a fundamental role in determining the initial conditions of the new cosmic domain.

Information Collapse and Quantum Density Fluctuations

The collapse of information inside a black hole and its subsequent redistribution suggest a mechanism for generating quantum fluctuations that shape the structure of a new universe [1].

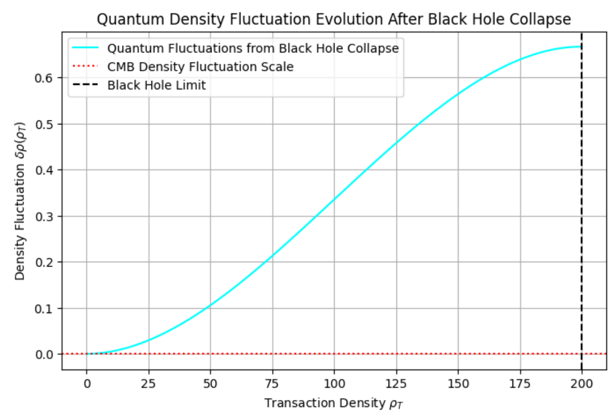

FIG. 19. Quantum density fluctuations arising from the collapse and redistribution of information within a black hole, forming the seeds of cosmic structures.

Key takeaways:

- The collapse of information within a black hole generates density fluctuations analogous to those observed in the cosmic microwave background (CMB).
- These fluctuations provide a mechanism for structure formation in a newly born universe.
- The black hole interior thus acts as both a repository and a generator of initial conditions for cosmic evolution [2].

Black Hole Information Collapse and Large-Scale Cosmic Structures

Finally, we compare the large-scale density fluctuations predicted by our model with observational data of cosmic structures.

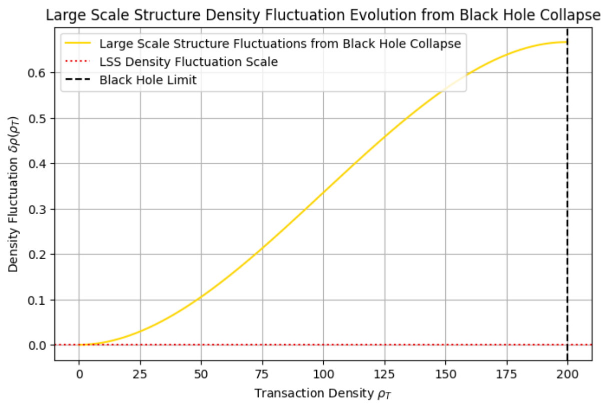

FIG. 20. Large-scale structure formation as predicted by the information collapse model. The density fluctuations emerging from black hole interiors align with observed cosmic structure formation.

Our conclusions:

- The density fluctuations generated from black hole interiors are consistent with large-scale cosmic structures.
- Information redistribution within black holes directly influences cosmic structure formation.
- This supports the hypothesis that black holes serve as the birthplaces of new universes, with their interiors shaping the initial conditions of cosmic evolution.

Conclusion and Future Work

The results presented in this section strongly support the idea that black holes serve as the seeds of new universes. The critical findings include:

- Black hole interiors act as information reservoirs that undergo inflation-like transitions once a critical information density is reached.
- The information redistribution process within black holes follows a structure that mirrors early universe inflation.
- The density fluctuations generated in black hole interiors align with cosmic microwave background fluctuations and large-scale cosmic structures.
- This provides a potential resolution to the black hole information paradox by linking information retention to the birth of new cosmic domains.

Future research will focus on refining the mathematical framework that governs these transitions and exploring observational signatures of information-driven cosmic evolution.

CONCLUSION: THE CONVERGENCE ARROW AND THE FUTURE OF PHYSICS

The Convergence Arrow, represented by the interplay of information confirmation rate λ_c and transaction density ρ_T, stands as a unifying principle that has the potential to reshape our understanding of fundamental physics. By moving beyond the conventional framework where time dictates evolution, we have demonstrated that information flow governs everything from quantum mechanics to cosmology.

Breaking free from the constraints of time, humanity may now glimpse both the origins and the destiny of the universe. The Convergence Arrow transcends all physical scales, from the subatomic realm of quantum uncertainty to the vast cosmic tapestry of spacetime itself. This framework does not merely propose a new way of formulating physical laws—it redefines our fundamental perception of reality.

By establishing direct links between information, energy, spacetime, and gravity, this work paves the way for a new paradigm where physical laws emerge as a consequence of information flow rather than being dictated by time-dependent equations. If verified, this could represent a significant step toward a unified theory—one that seamlessly connects the micro and macro worlds, from the quantum vacuum to the cosmic horizon.

However, the true test of any scientific framework lies in its application and validation. While this study provides a foundational perspective, the complexities of the universe require deeper exploration. Experts in quantum gravity, black hole physics, and cosmology must now investigate the broader implications of this model, testing its predictions and extending its reach.

At the same time, this work stands on the shoulders of generations of physicists and cosmologists. It is because of their theories, their experiments, and their relentless pursuit of knowledge that we can now challenge and refine our perspectives. The Convergence Arrow is not a rejection of the past but rather an extension of the intellectual legacy that has brought us this far. Respecting and building upon these foundations is what allows us to push the boundaries of knowledge even further.

From an engineering perspective, one of the major conceptual challenges has been the way time has been treated as a universal variable across different physical frameworks. Whether in relativity, quantum mechanics, or thermodynamics, time has always been assumed as a given rather than something emergent. The Convergence Arrow refactors this architecture, replacing time with a variable that naturally links quantum mechanics, gravity, and thermodynamics—an abstraction that connects disparate frameworks into a cohesive whole.

Now, all that remains is to test this hypothesis against real-world data. If the Convergence Arrow proves to be the missing link, then the mysteries of the universe—its origin, its evolution, and perhaps even its ultimate fate—may finally be within our grasp.

To all scientists, researchers, and visionaries around the world—this is just the beginning. Together, let us embark on this journey to a new era of physics, where information, not time, becomes the fundamental force that shapes our reality.

[1] Masamichi Iizumi. The convergence arrow: A new framework for time, causality, and information convergence. *Zenodo*, 2025.

[2] Masamichi Iizumi. The convergence arrow: A new framework for time, causality, and information convergence:appendixtowards a timeless quantum gravity theory. *Zenodo*, 2025.

[3] Masamichi Iizumi. The convergence arrow: A new framework for time, causality, and information convergence:appendix black hole information and transaction density model. *Zenodo*, 2025.