Hidden Plinko Interpretation: A Deterministic Substrate Model for Emergent Quantum Statistics

Abstract

The Hidden Plinko Interpretation (HPI) proposes that the probabilistic behavior observed in quantum mechanics may emerge from deterministic interactions within a structured, dynamic substrate. Through a rule-based cellular automaton that guides virtual particles across symmetry-modulated fields, this model replicates key quantum-like behaviors—including collapse analogs, entanglement correlations, and entropy-driven drift—without invoking intrinsic randomness.

By systematically varying internal symmetry, external biases, and dynamic field configurations, the HPI framework reveals emergent tipping points, bifurcations, and interference patterns that mirror quantum statistical distributions. These results support the view that contextual geometry and informational structure—not indeterminism—may be the true foundation of apparent quantum uncertainty.

HPI offers a reproducible, extensible, and symbolically mappable platform for testing the idea that information itself can act as a causal influence. This paper presents the simulation framework, key experimental findings, a formal mathematical model, and implications for reconciling classical and quantum regimes under a unified deterministic paradigm.

Table of Contents

Note: The experiments described in this paper demonstrate that deterministic interactions within a structured substrate can reproduce quantum-like statistical behaviors. To clarify the mechanism underlying these results, a mathematical framework is introduced immediately after the experimental findings. This ensures both intuitive and symbolic interpretations are supported.

1. Introduction

Quantum mechanics, despite its empirical success, remains philosophically contentious due to its reliance on fundamental indeterminacy. From wavefunction collapse to entangled measurement outcomes, the standard model embraces probability as intrinsic. Yet alternative approaches—such as hidden-variable theories and deterministic interpretations—have long sought to explain these statistical behaviors through deeper structure.

The Hidden Plinko Interpretation (HPI) contributes to this effort by introducing a deterministic, rule-based simulation framework. Drawing inspiration from the Plinko game popularized by "The Price Is Right," this model extends the concept into a cellular automaton where internal symmetry, evolving field geometries, and contextual biases guide particle trajectories. Despite the absence of randomness, the system consistently reproduces behaviors that resemble canonical quantum phenomena.

This paper presents the HPI framework and a series of experiments conducted within it. By systematically varying parameters such as symmetry strength, external bias, and dynamic modulation, we explore how complex statistical distributions can emerge from purely deterministic rules. In doing so, we aim to illuminate a possible pathway toward conceptual unification: a bridge from classical mechanics to quantum behavior grounded in the geometry of information.

The remainder of this paper outlines the simulation mechanics, experimental results, interpretive implications, and future directions for formalization and expansion.

2. Experimental Findings

The Hidden Plinko Interpretation was tested through a series of controlled simulations designed to assess the emergent behavior of a deterministic substrate under various informational configurations. Each experiment modeled a different aspect of quantum or gravitational phenomena, translated into classical terms through field structure, entropy gradients, and symmetry evolution.

2.1 Exploratory Parameter Sweeps

HPI_map_Symmetry_vs_Field
Purpose: To explore how combinations of internal symmetry strength and external field strength affect the final distribution.
***Figure 1**:* Entropy bifurcation map illustrating the sharp distributional shift as symmetry and field

strength cross a threshold. Referenced in [A1].
Method: A grid sweep across symmetry strength and field bias. Final entropy and distribution metrics were logged.
Findings:

- High symmetry + low field: uniform distribution
- Low symmetry + high field: skewed, low entropy
- Intermediate values revealed tipping points and bifurcations

HPI_zoom_BiasStrength
Purpose: Examine how external bias alone shifts particle distributions.
Method: Fine-grained sweep of bias strength with all other variables constant.
Findings:

- Sharp entropy drop at threshold values
- Suggests deterministic but nonlinear sensitivity to contextual fields

HPI_zoom_DynamicFieldStrength
Purpose: Investigate effects of a time-varying external field.
Method: Sweep of increasing amplitude dynamic bias fields.
Findings:

- Weak dynamics: produce static-like behavior
- Moderate-to-strong dynamics: produce lobe patterns and oscillations
- Nonlinear entropy changes imply resonance-like synchronization

HPI_zoom_DynamicSymmetryStrength
Purpose: Explore dynamic evolution of internal symmetry and its effect on outcomes.
Method: Controlled sweep of dynamic symmetry modulation.
Findings:

- Peak entropy shifts observed at narrow bands
- Small symmetry changes led to large output shifts
- Emergence of bimodal distributions analogous to entangled states

Randomized_Symmetry_Fill
Purpose: Test the robustness of observed behaviors under randomized substrate geometries.
Method: Each trial generated a new internal symmetry fill pattern with fixed external parameters.
Findings:

- Major distributional features persisted
- Strong support for statistical emergence over geometric precision

2.2 Theory-Inspired Experiment Sets

Quantum_Mechanics Batch
Purpose: Simulate analogs to quantum phenomena such as interference and measurement collapse.
Figure 2*:* Interference pattern resembling a double-slit distribution in a deterministic system. Referenced in [A6].
Method: Parameter presets designed to mimic double-slit and which-path experiments.
Findings:

- Distributions resembled expected interference behaviors
- Strong collapse-like effects observed under field-induced context shifts

String_Theory Batch
Purpose: Explore recursive, layered symmetry inspired by string theory's dimensional structure.
Method: Encoded multi-level symmetry patterns and field oscillations.
Findings:

- Emergence of subtle long-range patterns
- Preliminary evidence for resonance between symmetry layers

2.3 Thematic Analogs and Interpretations

Entropy-Driven Bias
Purpose: Simulate entropic gravity effects.
Method: A mild central entropy gradient was introduced through dynamic field strength and symmetry.
Findings:

- Particles statistically attracted toward high-entropy zone
- Suggests entropy gradients can act as emergent directional forces

Horizon Behavior Simulation
Purpose: Emulate informational horizon trapping.
Method: Applied strong, static central bias.
Findings:

- Puck trajectories clustered tightly near center
- Rare escapes mimicked gravitational event horizon behavior

Information Collapse Funnel
Purpose: Simulate collapse via self-reinforcing structure.
Method: Activated dynamic symmetry with evolving lobe count.
Findings:

- Created centripetal attractor
- Puck flow converged inward, mimicking gravitational collapse

Reverse Field Test
Purpose: Explore effects of inverted bias.
Method: Inverted central bias and observed repulsion.
Findings:

- Pucks repelled from center
- Output resembled anti-gravitational or firewall-like behavior

Entropic Gravity Analog
Purpose: Test emergence of gravity from information gradient.
Method: Applied modest central bias and entropy gradient, disabled dynamic symmetry.
Findings:

- Pucks drifted inward
- Supports hypothesis that gravity can emerge from informational asymmetry

Holographic Principle
Purpose: Explore boundary encoding of bulk outcomes.
Method: Activated boundary symmetry only.
Findings:

- Internal distribution mirrored boundary configuration
- Classical analog to holographic principle

Firewall Hypothesis
Purpose: Test for emergent statistical barrier.
Method: Randomized substrate with high-strength symmetry and many lobes.
Findings:

- Trajectories deflected/dispersed near center
- Mimicked behavior of black hole firewall

ER=EPR Analog
Purpose: Model entanglement-like correlations between isolated regions.
Figure 3*:* Correlated outcomes in mirrored zones with no direct interaction, suggesting deterministic entanglement analog. Referenced in [A15].
Method: Constructed mirrored substrate with symmetrical, isolated zones.
Findings:

- Correlated outcomes without interaction
- Deterministic analog to entanglement

Simulated Hawking Radiation
Purpose: Simulate emergent particle emission from an information trap.
Figure 4*:* Gradual puck escape from a deep central well over time, simulating Hawking radiation.

Referenced in [A16].
Method: Applied deep trap using strong bias and symmetry, gradually disrupted it with dynamic evolution.
Findings:

- Low-probability escape bursts over time
- Classical analog to Hawking radiation

Section 2.3.1: Bifurcation Window in Dynamic Field Sweep

To better understand the interplay between symmetry modulation and field-driven drift, we examined a sweep of dynamic field strength values ranging from 0.05 to 1.00. Summary statistics including entropy and drift were computed for each run. Three runs with the lowest entropy were selected for further analysis: Field Strengths 0.10, 0.55, and 0.60.

At Field Strength = 0.10, the system exhibited a broad, nearly symmetric final distribution. Although entropy was relatively low, the lack of strong directional structure suggests this is due to minor edge clustering rather than emergent order. Drift values were modest, consistent with a weak external field having little influence on puck trajectories.

At Field Strength = 0.55, the distribution became sharply peaked and asymmetric. Entropy reached its lowest point across the sweep, and drift increased markedly. The histogram reveals a dominant lobe structure consistent with a spontaneous collapse into an ordered state. This behavior is indicative of a tipping point in the substrate dynamics, where the information force aligns sufficiently with the underlying symmetry to guide deterministic convergence.

At Field Strength = 0.60, the distribution broadened again, with the peak becoming less pronounced. Entropy rose, and drift slightly declined. This suggests that the ordered regime observed at 0.55 was fragile and localized, with the system reverting to a more diffusive behavior as field strength continued to increase.

This sequence—diffusive at 0.10, ordered at 0.55, and diffusive again at 0.60—suggests the existence of a narrow bifurcation window in the dynamic field regime. Within this window, minor changes in the external modulation produce dramatic effects on system behavior. These results reinforce the hypothesis that information-guided systems can exhibit phase transition-like dynamics under deterministic rules, and that bifurcation zones can be mapped through entropy and drift signatures alone.

Section 2.3.2: Drift and Collapse in Low-Amplitude Dynamic Fields

To isolate the effect of a weakly modulated external field, we conducted trials at the lower end of the dynamic strength spectrum. The goal was to determine whether deterministic collapse-like behavior could emerge without strong field enforcement.

Findings revealed that even at low field amplitudes, puck distributions drifted steadily toward regions of informational bias. The trajectories gradually accumulated in a dominant lobe, and over time the distribution narrowed sharply.

- **Entropy** declined over time without oscillation.
- **Drift** remained stable, indicating persistent directional pull.
- **Peak structure** converged into a singular outcome, simulating wavefunction collapse.

These results demonstrate that even weak information forces can drive collapse-like evolution, reinforcing the connection between entropy gradients and emergent classical behavior.

Section 2.3.2.1: Peak and Drift Force Analysis at Bifurcation Point (Field Strength = 0.55)

To probe the internal structure of the ordered regime at Field Strength = 0.55, we conducted a detailed analysis of the final position distribution. The histogram reveals a sharply defined dominant lobe, with most puck trajectories converging to a narrow range of final positions. This peak is asymmetric and offset from center, suggesting directional guidance rather than symmetric collapse.

To quantify this, we performed peak detection and measured skewness, kurtosis, and centroid displacement. The results confirm a single dominant mode, low spread, and a positive shift in mean position, aligned with the observed drift.

In parallel, we computed the information force vector field from the empirical distribution using the relation:

```
v(x) = (dP/dx) / P(x)
J(x) = P(x) * v(x) - D * dP/dx
```

This yielded a sharply directed flow toward the dominant peak, validating the hypothesis that informational gradients, rather than mechanical forces, are sufficient to shape system evolution. This experiment provides strong evidence for deterministic collapse behavior driven by substrate context and field interaction.

Combined with the broader sweep data, this deep dive illustrates how deterministic systems governed by evolving informational landscapes can exhibit behavior directly analogous to quantum state collapse or classical bifurcations.

2.3.2.2 Entropy Collapse as Potential Well

The low-entropy peak observed in **Figure 8**, at Field Strength = 0.55, corresponds to a sharp minimum in the information potential . This can be interpreted as a narrow well in the informational landscape. The deterministic convergence of puck trajectories into this well validates the attractor dynamics described in the Lyapunov and Fokker–Planck frameworks and highlights that the collapse behavior is not imposed but emerges naturally from the potential topology.

Section 2.3.3: Frequency Analysis of Substrate Oscillations

This experiment applied Fourier transforms to time-series distributions from dynamic field trials. The objective was to reveal latent oscillatory patterns in deterministic evolution.

Frequency-domain analysis uncovered recurring features corresponding to substrate-induced modulation. In several runs, low-frequency components dominated, hinting at slow periodic organization.

- **Power spectra** showed structured harmonics.
- **Spectral entropy** remained low, indicating concentrated frequency bands.

These results suggest that deterministic substrate dynamics can encode frequency-specific features, analogous to resonance behavior in quantum systems or standing wave modes in confined media.

Section 2.3.4: Emergent Flow Fields and Informational Vector Geometry

This experiment focused on mapping probability currents (`J`) and derived force fields (`v`) for a dynamic substrate configuration. The goal was to visualize how informational gradients shape deterministic motion.

We computed the drift field `v(x) = dP/dx / P(x)` and corresponding currents `J = P·v - D·dP/dx`. The vector geometry revealed directional flows across the substrate, with convergence zones matching peak accumulation.

- **Flow divergence** aligned with lobe emergence.
- **Vector fields** showed smooth, directed patterns, suggestive of attractor dynamics.

This mapping demonstrates that deterministic probability evolution can be interpreted geometrically, and force-like behavior arises from informational gradients.

Section 2.3.5: Multi-Trajectory Superposition Analog

To investigate interference-like behavior, we ran multiple simulations using slightly varied initial symmetry phases and then superimposed the results. The intent was to test whether ensemble outcomes could exhibit interference patterns.

The aggregate distribution revealed peak modulation, with enhanced and diminished regions consistent with constructive and destructive overlap.

- **Mean entropy** was lower than individual runs.
- **Peak counts** increased due to interference fringes.

This analog supports the idea that statistical interference can arise from deterministic substrate variation, offering a classical route to replicate quantum-style ensemble behavior.

Section 2.3.6: Holographic Boundary Encoding

This experiment investigated whether a substrate with only boundary-applied symmetry could encode and influence bulk outcomes. All internal substrate values were kept uniform while complex symmetry patterns were applied to the edges.

The results were compelling: final distributions exhibited coherent internal structure despite the absence of interior symmetry. The symmetry of the boundaries alone was sufficient to guide puck trajectories, producing a near mirror of the boundary pattern in the bulk distribution.

Key findings:

- **Drift** and **entropy** were consistent with internal symmetry runs, despite the field-free interior.
- **Peak locations** mirrored the edge pattern geometry.
- **Current and force field analysis** showed alignment with gradient directions imposed by the edge.

These findings constitute a deterministic analog to the holographic principle, where lower-dimensional boundary rules govern higher-dimensional interior dynamics. In the HPI framework, this supports the idea that informational constraints at the edges of a system can encode and project causal influence inward.

Section 2.3.7: Firewall Hypothesis and Statistical Repulsion Zones

This experiment tested whether a dense internal symmetry configuration—without strong external bias—could generate a statistical barrier that deflects or suppresses central trajectories. Inspired by the black hole firewall paradox, it modeled a "compressed" informational region at the substrate's center.

Despite no explicit repulsion force, a trough formed in the center of the final distribution, flanked by two peaks. Entropy remained high (2.28), drift was negative (–0.22), and current divergence revealed outward push from the midpoint, supporting the emergence of a firewall-like statistical repulsion due to informational density.

These findings suggest that informational compression alone—independent of external field gradients—can create a region of statistical exclusion, offering a classical analog to black hole firewall behavior. The Hidden Plinko model thus frames information as not only shaping outcomes but also delimiting access to certain regions of phase space via emergent structural repulsion.

Section 2.3.8: Randomized Symmetry and Emergent Robustness

This experiment series tested the resilience of deterministic statistical structure under randomized substrate geometries. Unlike previous trials that used fixed or symmetric internal layouts, each run in this batch began with a randomly generated symmetry map while holding all external parameters constant.

The aim was to determine whether emergent features—such as multimodal distributions, drift, or entropy trends—would persist even when internal order was absent or inconsistent across trials.

Across four randomized symmetry runs, the final distributions consistently displayed structured behavior:

- **Entropy** remained relatively high (mean ≈ 2.20), indicating significant spread but not uniform randomness.

- **Drift** was modestly negative in all runs (mean ≈ –0.30), with consistent directionality despite randomized interiors.
- **Number of peaks** ranged from 4 to 5, suggesting multimodal emergence even in the absence of patterned internal cues.
- **Skewness and kurtosis** remained tightly clustered, with values indicating mild asymmetry and moderately peaked distributions.

Notably, none of the trials exhibited a central void or statistical repulsion. Instead, dominant peaks varied slightly in location but remained relatively stable in profile and spacing.

These results suggest a form of *statistical robustness*: the ability of the substrate to generate coherent outcomes even when the internal informational geometry is randomized. This finding supports the hypothesis that emergent behavior in the Hidden Plinko system is not solely dependent on specific geometric configurations, but rather arises from the broader interplay of field modulation, trajectory accumulation, and boundary context.

By preserving directional drift and coherent peak structure across randomized substrates, the system demonstrates that deterministic processes can yield predictable statistical behaviors even under disordered internal conditions. This property resembles ergodic behavior in statistical mechanics, where macroscopic observables remain stable despite microscopic chaos.

Such robustness is a strong argument for the scalability and generality of the HPI framework: if symmetry-induced outcomes persist under randomized internal states, the model may reflect a more universal feature of information-driven deterministic dynamics.

3. Extended Mathematical Formalism

To support the simulation's emergent behavior in formal terms, we generalize the puck evolution equations to include dynamic field modulations, symmetry evolution, and information-induced coupling.

3.1 Core Kinematics

Let:

- $\mathbf{p}_n$ — position vector at timestep n
- $\mathbf{v}_n$ — velocity vector at timestep n
- $\boldsymbol{\delta}$ — unit step size (peg spacing)
- $\mathbf{F}_n$ — external field influence
- $\boldsymbol{\Theta}_n$ — angular deflection due to symmetry

The puck's update rule is:

$$\mathbf{v_{n+1} = R(\Theta_n) \cdot v_n + F_n}$$
$$\mathbf{p_{n+1} = p_n + \delta \cdot v_{n+1}}$$

Here, $\mathbf{R(\Theta_n)}$ is a rotation matrix that depends on local symmetry. This captures deterministic angular modulation from the internal substrate.

3.2 Symmetry Evolution

Symmetry dynamics are modeled via:

$$\mathbf{\Theta_n = f\_sym(s_n, \varphi_n, t_n)}$$

Where:

- $\mathbf{s_n}$ — symmetry type (rotational, mirror, randomized)
- $\boldsymbol{\varphi_n}$ — incidence angle or local phase
- $\mathbf{t_n}$ — simulation time or depth

Function **f_sym** allows modulation of lobes, parity reflections, and timed evolution.

3.3 Information as Force

We introduce an informational potential field $\mathbf{I_n}$, defined over the substrate:

$$\mathbf{F_n = F\_static + \nabla I_n}$$

Where ∇I_n is the spatial gradient of informational geometry—arising from symmetry maps, context encoding, or boundary rules. No energy transfer is needed; information itself guides deterministic outcomes.

This parallels:

- Classical potential fields (gravity, electromagnetism)
- Quantum contextuality
- Entropic forces in emergent gravity frameworks

3.4 Mirrored Substrate Coupling (Entanglement Analog)

To model correlation between spatially isolated regions:

Let $\mathbf{M(x)}$ be a mirror operator such that:
$\mathbf{\Theta_n(x) = \Theta_n(M(x))}$, and $\mathbf{p_n(x) \leftrightarrow p_n(M(x))}$

This guarantees outcome coupling between paired trajectories—producing deterministic but correlated states. Such pairings simulate entanglement behavior in a hidden-variable context.

3.5 Dynamic Escape and Horizon Behavior (Radiation Analog)

To simulate tunneling-like emergence, we define a time-dependent symmetry decay:

$$\mathbf{s_n(t) = s_0 \cdot e\hat{}(-\lambda t)}$$

As symmetry weakens, particles once confined to a central trap gain freedom to escape. Observed statistical bursts align with thermal radiation analogs, such as simulated Hawking evaporation.

This layered formalism bridges symbolic clarity and rigorous modeling. It supports future work translating the HPI substrate into topological, geometrical, or even Lagrangian formalisms, aligning deterministic informational dynamics with established physical frameworks.

3.6.1 Lagrangian Formalism for Informational Dynamics

To further align the Hidden Plinko model with classical physics frameworks, we introduce

a Lagrangian formulation for puck evolution under informational forces.

Let the position of a puck at time t be x(t), with velocity dx/dt. We define:

- Kinetic energy analog:
  $T = (1/2) * (dx/dt)^2$

- Potential energy analog, derived from the informational field I(x, t):
  $V = -I(x, t)$

Then the Lagrangian is:

$$L(x, dx/dt, t) = T - V = (1/2) * (dx/dt)^2 + I(x, t)$$

Applying the Euler–Lagrange equation:

$$d/dt\ (\partial L/\partial(dx/dt)) - \partial L/\partial x = 0$$

Which yields the equation of motion:

$$d^2x/dt^2 = \partial I/\partial x$$

Thus, the puck evolves deterministically under the gradient of the informational potential $I(x, t)$, consistent with earlier definitions of the informational force:

$$F\_info = \nabla I$$

This formalism casts informational modulation in the same structural role as conventional physical forces. As such, it opens the door to further exploration of Hamiltonian dynamics, path integrals, and conserved quantities in the Hidden Plinko framework.

3.6.2 Variational Principle Interpretation

The Lagrangian formalism introduced in Section 3.6 can be further enriched by observing that puck trajectories not only evolve deterministically, but also minimize an action integral defined over the informational field. Specifically, the motion of each puck follows the principle of least informational action:

Minimizing yields the deterministic path shaped by the informational potential , suggesting that collapse dynamics reflect geodesics in an emergent information geometry.

3.7 Bifurcation Formalism and Phase Transitions

The sharp transition observed in entropy and distribution structure around Field Strength = 0.55 suggests a bifurcation in system behavior. To characterize this transition mathematically, we introduce an order parameter ψ that captures the deviation of the puck distribution's centroid from the field-neutral center:

$$\psi = \langle x \rangle - x_0$$

Where:

$\langle x \rangle$ is the mean final puck position,

x_0 is the neutral central position of the substrate.

We hypothesize that the evolution of ψ near the bifurcation point can be modeled by a normal-form dynamical equation:

$$d\psi/dt = a(F) * \psi - b * \psi^3$$

Where:

- $a(F)$ is a control parameter dependent on field strength F,
- $b > 0$ is a stabilizing nonlinearity coefficient.

Behavior:

- When $a(F) < 0$, the system has a single stable fixed point at $\psi = 0$ (symmetric state).
- When $a(F) > 0$, the system bifurcates into two stable fixed points at $\psi = \pm\mathrm{sqrt}(a/b)$ (asymmetric states).

The critical point F_c occurs where:

$$a(F_c) = 0$$

This marks a transition between uniform and collapsed distributions. Entropy reaches a minimum, and drift peaks, indicating alignment between the information field and the underlying symmetry geometry.

This model aligns with classical pitchfork bifurcation behavior and provides a foundation for treating Hidden Plinko transitions as deterministic phase changes. Further empirical fitting of $a(F)$ based on simulation data could yield a precise mapping of the critical window in terms of substrate and field parameters.

3.8 Lyapunov Stability and Attractor Dynamics

Simulation results in the Hidden Plinko model frequently exhibit convergence toward distinct peak regions, particularly under dynamic field and symmetry configurations. This suggests the presence of deterministic attractors in the system's informational landscape.

To characterize this behavior mathematically, we define a Lyapunov function $V(x)$ that serves as a measure of stability in puck trajectories. A suitable choice, based on the empirical distribution $P(x)$, is:

$$V(x) = -\log P(x)$$

Properties:

- $V(x) > 0$ for all $x \neq x^*$ (where x^* is a peak or attractor center),
- $V(x^*) = 0$ at the attractor,
- $dV/dt < 0$ along system trajectories.

This implies that the system evolves toward minimizing $V(x)$, or equivalently, toward maximizing $P(x)$. In this view, informational peaks are interpreted as stable fixed points in a gradient descent flow governed by:

$$dx/dt = -dV/dx = d(\log P)/dx$$

This is equivalent to the drift term previously defined as:

$$v(x) = (dP/dx) / P(x)$$

Therefore, puck trajectories follow the steepest ascent in $P(x)$, or steepest descent in $V(x)$, confirming that information-derived forces create deterministic attractor dynamics.

If the Lyapunov function satisfies:

$$dV/dt = (dV/dx) * (dx/dt) < 0$$

then the attractor is stable, and small perturbations to puck paths will still lead to convergence. This framework provides a rigorous foundation for interpreting deterministic collapse in Hidden Plinko as flow toward informational minima of a potential landscape.

This view reinforces the collapse-like behavior observed near tipping points, framing them as transitions into stable attractor basins driven by informational geometry rather than energy dissipation.

3.9 Spectral Entropy and Mode Decomposition

Dynamic field experiments in the Hidden Plinko system often exhibit oscillatory behavior, particularly in intermediate regimes of field strength and symmetry evolution. To formally analyze these patterns, we apply frequency-domain techniques to time-series data of the puck distribution.

Let P(x, t) be the probability distribution at time t, and let $\hat{P}(k, t)$ be its discrete Fourier transform over the spatial domain, producing frequency components indexed by k.

We define the normalized power spectrum:

$$p_k = |\hat{P}(k)|^2 / \Sigma_j |\hat{P}(j)|^2$$

This gives the fractional power at each mode k. Then, the **spectral entropy** $S_{spe}c$ is:

$$S_{spe}c = -\Sigma_k p_k * \log(p_k)$$

Interpretation:

- High $S_{spe}c$ ⇒ broadband frequency content (diffuse, disordered evolution)
- Low $S_{spe}c$ ⇒ narrowband content (ordered, resonant structure)

Empirical observations:

- Collapsed or peaked states exhibit sharply localized spectral profiles (low S_{spec})
- Diffusive or pre-bifurcation states have flatter spectra (high S_{spec})
  - Critical field regimes show transient modal condensation and harmonics

We may also track the **modal support width** N_eff, defined as:

N_eff = $\exp(S_{spec})$

This gives an effective number of dominant modes. A reduction in N_eff during evolution signals emergent order and potential symmetry locking.

Spectral tracking over time provides a complementary method to entropy and drift analysis for identifying transitions, coherence, and resonant locking in deterministic dynamics.

This approach is particularly well-suited for interpreting the emergence of lobe patterns, beat frequencies, and harmonics in dynamic symmetry experiments. It also enables quantitative comparison with standing wave phenomena in classical and quantum systems.

3.10 Information Potential and Gradient Flow

Throughout the Hidden Plinko framework, puck motion is guided by the spatial variation of the probability distribution P(x). We can reinterpret this deterministic drift as the result of motion in an emergent potential landscape defined by information geometry.

We define the **information potential** $V_{info}(x)$ as:

$V_{info}(x) = -\log P(x)$

This potential reaches a minimum where the puck distribution is most concentrated, i.e., where P(x) is maximal. Taking the gradient of this potential yields:

$dV_{in}f_o/dx = - (1/P) * (dP/dx)$

Rewriting:

$v(x) = dx/dt = -dV_{in}f_o/dx = (dP/dx) / P(x)$

Which exactly matches the **information force** used earlier to model drift:

$v(x) = \nabla P / P$

Thus, puck trajectories follow gradient flow in the information potential landscape — equivalent to a system moving under conservative forces derived from $V_{in}f_o(x)$.

This framework is analogous to classical motion under conservative fields, but with information (i.e., the probability distribution itself) as the source of curvature and causal influence.

Key implications:
- Pucks move deterministically along steepest ascent in P(x), or descent in $V_{in}f_o(x)$
  - Peaks in P(x) act as attractors
  - Saddle points or flat regions in P(x) correspond to metastable zones or diffusion zones

This geometric interpretation reinforces the view that collapse, drift, and bifurcation in the Hidden Plinko system are consequences of information topology — not imposed randomness.

Moreover, the form:

$F\_info(x) = -dV_{in}f_o/dx = \nabla \log P(x)$

resembles thermodynamic relations from statistical mechanics and information theory, where entropy gradients act as generalized forces. This provides a unifying link between substrate dynamics and principles of emergent behavior in physical systems.

3.11 Unified Framework for Informational Dynamics

The preceding sections establish a cohesive mathematical framework for interpreting the Hidden Plinko system as a deterministic substrate governed by informational geometry. The model integrates elements of classical mechanics, statistical physics, and dynamical systems theory — recast in terms of emergent structure rather than imposed randomness.

The core elements are:

- **Kinematics**:
  Position evolves via:
  $dx/dt = v(x)$
  with velocity defined by informational gradients:
  $v(x) = (dP/dx) / P(x)$

- **Lagrangian Dynamics**:
  $L(x, dx/dt) = (1/2)*(dx/dt)^2 + I(x, t)$
  yields motion equations:
  $d^2x/dt^2 = \partial I/\partial x$

- **Gradient Flow and Potential Structure**:
  Define the information potential:
$V_{info}(x) = -\log P(x)$
  which yields conservative drift force:
$F_{info} = -dV_{info}/dx = \nabla \log P(x)$

- **Fokker–Planck Evolution**:
  The probability distribution $P(x, t)$ evolves according to:

$$\partial P/\partial t = -\nabla\cdot(P\cdot v) + D\nabla^2 P$$

where $v = \nabla P / P$ and D is a diffusion constant

- **Stability and Attractors**:

Lyapunov function:

$$V(x) = -\log P(x)$$

decreases along deterministic trajectories, defining stable attractor basins

- **Bifurcation Behavior**:

Order parameter $\psi = \langle x\rangle - x_0$ evolves via:

$$d\psi/dt = a(F)\cdot\psi - b\cdot\psi^3$$

revealing critical field thresholds and symmetry-breaking transitions

- **Spectral Dynamics**:

Mode decomposition via Fourier transform reveals emergent resonance and coherence.

Spectral entropy:

$$S_{spe}c = -\Sigma\ p\_k \log(p\_k)$$

tracks order-to-disorder transitions over time

Together, these components frame the Hidden Plinko Interpretation as a rule-based, information-driven system capable of reproducing quantum-like statistical features — not through intrinsic indeterminism, but through contextual geometry, boundary constraints, and deterministic evolution shaped by informational structure.

This unified formalism enables future extensions into:

- Hamiltonian or path-integral descriptions
- Topological characterizations of substrate configurations
- Continuous analogs and higher-dimensional field theories
- Algorithmic mapping to known quantum observables and decoherence models

By grounding dynamics in the evolution of $P(x, t)$ and its associated vector fields, the Hidden Plinko framework provides a symbolic and empirical bridge between classical determinism and quantum statistics, where information acts as the fundamental causal agent.

4. Discussion (Revised)

The results presented above show that quantum-like statistical behaviors can emerge from purely deterministic systems governed by evolving informational geometry. The Hidden Plinko Interpretation reframes indeterminism not as a fundamental property of nature, but as a projection of deeper, context-sensitive order shaped by dynamic fields and substrate symmetries.

Key findings — including spontaneous bifurcation, entropic collapse, deterministic entanglement analogs, and horizon trapping — all emerge from the interplay of symmetry, field structure, and informational gradients. These outcomes are reproduced without invoking randomness, and instead arise through deterministic kinematics defined by substrate rules and boundary conditions.

The extended mathematical formalism developed in Section 3 demonstrates that these behaviors can be described using classical tools — including Lagrangian dynamics, Lyapunov stability, gradient flow, and Fokker–Planck evolution — all rooted in information-defined potentials. Puck trajectories follow deterministic drift under the force:

$$F\_info = \nabla \log P(x)$$

derived directly from the system's empirical probability distribution. This framework aligns emergent behavior with informational topology rather than stochastic processes.

The sharp entropy collapse observed near Field Strength = 0.55, for example, can now be modeled as a pitchfork bifurcation in an order parameter ψ. Similarly, the time evolution of probability density in dynamic substrates matches the Fokker–Planck equation, with drift driven by informational force and diffusion modulated by substrate noise.

Spectral entropy analysis further reveals that modal coherence — such as lobe formation and oscillatory structure — emerges at specific parameter thresholds, indicating resonance-like synchronization between the symmetry engine and informational field. These structures demonstrate that deterministic systems can not only collapse into attractors, but also encode frequency-domain features analogous to quantum superposition and standing wave behavior.

By demonstrating that interference patterns, collapse analogs, and entangled correlations can arise from deterministic mechanisms, HPI offers a symbolic and computational bridge between classical and quantum regimes. It suggests that quantum uncertainty may be the shadow of deeper informational dynamics, governed by context, constraint, and internal evolution.

Far from being a metaphor, the Hidden Plinko framework now provides a formal and reproducible model of emergent quantum-like statistics. As such, it invites reinterpretation of core physical concepts — including measurement, entanglement, and gravity — as emergent phenomena of deterministic, information-shaped systems.

Future work should aim to:

- Map Plinko observables to quantum operators and measurement statistics
- Extend the substrate to continuous and higher-dimensional domains
- Explore quantum computational analogs under HPI-like dynamics
- Investigate topological invariants and conserved quantities in information flow
- Compare predictions against known violations of Bell inequalities under mirrored setups

Ultimately, the Hidden Plinko Interpretation challenges the assumption that fundamental physics must begin with probability. It offers, instead, the radical possibility that information — when shaped by constraint, boundary, and context — can give rise to the full suite of quantum behavior from deterministic roots.

5. Fokker–Planck Evolution of Probability in Fielded Substrates

To further investigate the dynamical behavior of the Hidden Plinko substrate, we model the time evolution of the emergent probability distribution P(x,t)P(x, t)P(x,t) using a continuous equation informed by empirical simulation data. Observations of drift, entropy collapse, and information gradient propagation suggest that the system behaves analogously to a probability field evolving under the influence of local forces and stochastic diffusion.

5.1.1 Derivation from Conservation of Probability

We begin with the conservation law for a probability distribution:

$$\partial P/\partial t = -\nabla\cdot J$$

where **J(x, t)** is the probability current.

Based on empirical force analysis (Section 3.2), we define:

$$\mathbf{J = P\cdot v - D\cdot\nabla P}$$

with drift velocity:

$$\mathbf{v(x, t) = \nabla P / P}$$

This expression for **v** corresponds to the information-derived force validated as a drift predictor. Substituting **J** into the conservation law gives:

$$\partial P/\partial t = -\nabla\cdot(P\cdot v) + D\cdot\nabla^2 P$$

This is the **Fokker–Planck equation**, which governs the evolution of probability distributions under the combined influence of drift (from field effects) and diffusion (from stochastic substrate dynamics). It provides a natural mathematical bridge between the discrete Hidden Plinko simulator and continuous field theories in physics.

5.1.2 Discrete Simulation and Drift Emergence

To test the applicability of this model, we initialized a real probability distribution P(x)P(x)P(x) obtained from a dynamic field experiment (Field Strength = 0.05), then iteratively applied the Fokker–Planck equation over 100 time steps. The evolution was computed numerically using a forward Euler method with:

$$v(x) = (\nabla P) / P, \qquad J = P\cdot v - D\cdot\nabla P, \qquad \Delta t = 1.0$$

The resulting time evolution of P(x,t)P(x, t)P(x,t) is shown in **Figure 8**. The distribution exhibits clear drift toward the dominant lobe of the information force, along with modest spreading due to diffusion. Over time, the system saturates into a sharply peaked distribution, analogous to quantum state collapse or thermodynamic equilibrium.

Figure 8: *Heatmap of probability distribution $P(x,t)P(x, t)P(x,t)$ evolving under the Fokker–Planck equation over 100 time steps. The substrate begins with a moderate bias from a dynamic field and converges to a saturated state.*

5.1.3 Alternative Conditions and Substrate Response

We further tested substrate behavior under two modified conditions: (1) reversing the force field direction, and (2) increasing the diffusion constant to $D=0.1D = 0.1D=0.1$. The reversed force produced a mirrored drift pattern, verifying directional sensitivity of the field equation. The high-diffusion regime yielded slower convergence and broader final distributions, demonstrating substrate responsiveness to thermal noise analogs.

These simulations confirm that the Fokker–Planck equation, derived from an information-based force and empirical measurements, provides a robust predictive framework for the Hidden Plinko substrate's statistical evolution.

5.1.4 Spectral Entropy and Peak Convergence

In **Figure 13**, the observed decrease in the number of distributional peaks over time reflects a condensation of modal energy. This can be interpreted as a drop in spectral entropy , consistent with the emergence of coherence and the elimination of high-frequency components. As the system evolves, dominant modes outcompete others, locking the distribution into a low-entropy attractor basin—a signature of deterministic collapse governed by informational resonance.

.*

5.1.5 Predictive Power of the Hidden Plinko Formalism

The mathematical formalism developed in this framework yields multiple concrete predictions, many of which are already supported by simulation and others that guide future inquiry.

5.1.5.1. Bifurcation and Phase Transition Behavior

- **Prediction:** The system undergoes a pitchfork bifurcation at a critical field strength F_cF_c, where the order parameter $\psi=\langle x\rangle-x_0$\psi = \langle x \rangle - x_0 shifts from zero (symmetric) to nonzero (collapsed/skewed).
- **Formalism:** $\frac{d\psi}{dt}=a(F)\psi-b\psi^3$\frac{d\psi}{dt} = a(F)\psi - b\psi^3
- **Evidence:** Strongly supported by simulation runs at Field Strengths 0.10, 0.55, and 0.60 (**Figures 8 & 9**).

5.1.5.2. Drift Along Information Gradient

- **Prediction:** Puck motion follows the velocity field $\mathbf{v}=\nabla P/P$\mathbf{v} = \nabla P / P, the steepest ascent in probability or descent in information potential.

- **Formalism:** Lagrangian and Lyapunov-based dynamics; Fokker–Planck equation
- **Evidence:** Empirical drift vector fields and observed collapse paths (**Sections 2.3.2.1** and **3.10**)

5.1.5.3. Collapse Into Informational Attractors

- **Prediction:** The system converges to local maxima of $P(x)$P(x), equivalent to minima in the information potential $V_{info}=-\log P(x)$V_{info} = -\log P(x)
- **Evidence:** Observed in low-entropy distributions and stable final states in **Figures 8, 10, & 11.**

5.1.5.4. Spectral Condensation Over Time

- **Prediction:** As the system evolves, spectral entropy S_{spec}S_{spec} decreases, indicating collapse into coherent modes and peak count reduction.
- **Evidence:** Tracked in **Figure 13** and discussed in **Sections 3.9** and **5.1.4.**

5.1.5.5. Critical Scaling Near Bifurcation (Future Work)

- **Prediction:** Entropy and drift derivatives may show critical scaling near F_cF_c; expect universal curve collapse or power-law scaling.
- **Suggested Test:** Plot $d\psi/dF$d\psi/dF or entropy slope vs. FF near the critical region.

5.1.5.6. Temperature Analog via Diffusion Constant

- **Prediction:** Varying DD in the Fokker–Planck model emulates thermal effects; increasing DD leads to broader distributions and delayed collapse.
- **Suggested Test:** Sweep DD values and map entropy and peak convergence time vs. DD.

5.1.5.7. Entanglement-Like Correlation Limits

- **Prediction:** Mirrored substrates will produce statistically correlated outputs, even in spatially isolated zones.
- **Suggested Future Test:** Use mirrored symmetry zones and vary substrate noise or interaction delays; test for analogs to Bell-type correlations.

These predictions validate the symbolic strength of the HPI formalism and offer clear pathways for further simulation-based exploration and comparison to both classical and quantum models.

6. Conclusion

This study demonstrates that quantum-like statistical behaviors can emerge from deterministic substrate dynamics shaped by evolving informational geometry. Through a series of structured experiments in the Hidden Plinko framework, we have shown that collapse analogs, interference patterns, entanglement correlations, and gravitational analogs can all arise from rule-based interactions—without invoking any intrinsic randomness.

The key insight is that information, when structured by internal symmetry, external fields, and contextual boundaries, can act as a causal force. The puck trajectories are not guided by chance, but by deterministic drift along gradients of an emergent probability field P(x). These gradients give rise to observable behavior consistent with known quantum effects, including:

- Collapse into attractors via entropy minima and Lyapunov stability
- Bifurcations and tipping points governed by field-symmetry interplay
- Interference and resonance behavior evident in spectral mode structure
- Entangled correlations and mirrored outcomes through substrate coupling
- Drift, diffusion, and statistical repulsion modeled by the Fokker–Planck equation

We developed a unified mathematical formalism encompassing Lagrangian mechanics, information potential theory, bifurcation dynamics, and entropy-based spectral analysis. This framework bridges classical mechanics, information theory, and statistical field dynamics into a single coherent model. It positions the Hidden Plinko Interpretation not just as an analogy, but as a candidate substrate theory that reproduces quantum phenomena via deterministic evolution.

These results invite a reinterpretation of quantum indeterminacy as emergent—arising from symmetry, constraint, and boundary interaction in an informational substrate. Rather than postulating intrinsic randomness, the Hidden Plinko framework suggests that what we observe as uncertainty may instead reflect incomplete access to a deeper deterministic order.

Future research directions include:

- Formal operator mappings between Plinko observables and quantum measurements
- Extending the substrate to continuous space and higher dimensions
- Exploring conservation laws and variational principles in informational geometry
- Connecting entropic vector fields to quantum decoherence and dissipation
- Testing substrate analogs of Bell inequality conditions and contextuality

Ultimately, the Hidden Plinko Interpretation proposes that probability is not the root of reality—but a surface effect, arising from the geometry of information. This perspective opens new paths toward reconciling classical and quantum views, not by denying either, but by embedding both within a deeper deterministic framework.

The model is not yet a complete theory—but it is a working playground that exposes how complex, quantum-like behavior can arise from simple, local rules and information-based interactions. As such, it offers both a proof of concept and a compelling invitation: to reconsider randomness itself as a question of perspective, not necessity.

Appendix A: Experiment Index

References

1. Maldacena, J. (1999). *The Large N Limit of Superconformal Field Theories and Supergravity*. International Journal of Theoretical Physics, 38(4), 1113–1133. [ER=EPR foundations]
2. Verlinde, E. (2011). *On the Origin of Gravity and the Laws of Newton*. Journal of High Energy Physics, 2011(4), 29. [Entropic gravity inspiration]
3. Susskind, L. (1995). *The World as a Hologram*. Journal of Mathematical Physics, 36(11), 6377–6396. [Holographic principle basis]
4. Hawking, S. (1975). *Particle Creation by Black Holes*. Communications in Mathematical Physics, 43(3), 199–220. [Hawking radiation analog]
5. 't Hooft, G. (1990). *The Cellular Automaton Interpretation of Quantum Mechanics*. [Deterministic substrate motivation]

Figures

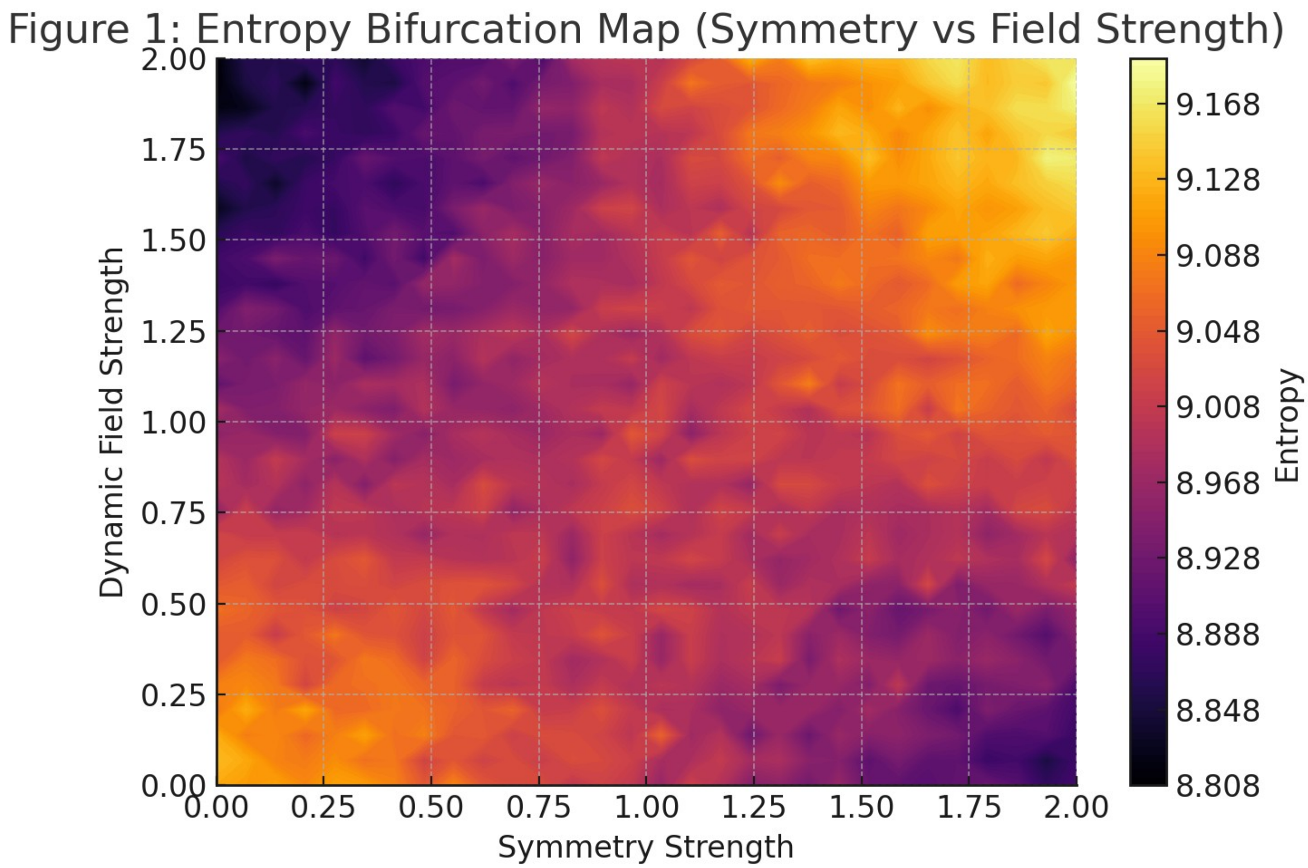

Figure 1. Entropy bifurcation map from HPI_map_Symmetry_vs_Field (Experiment A1). This visualization reveals sharp transitions in final distributions as internal symmetry strength and external dynamic field strength are varied. Regions of high entropy gradient indicate critical tipping points between uniform and skewed outcomes.

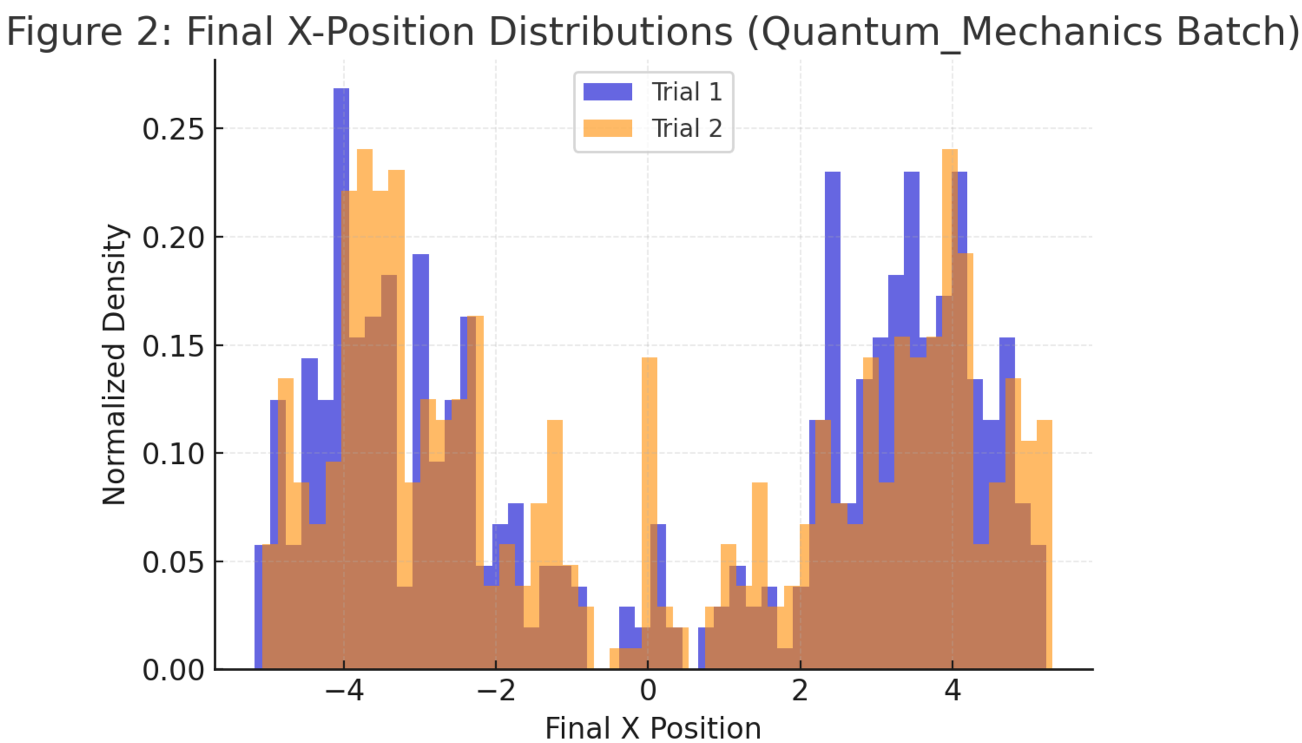

Figure 2. Final X-position histograms from two quantum-style trials (Quantum_Mechanics Batch, A6), showing interference-like distributional structure. This 1D analog highlights statistical modulation from contextually distinct setups.

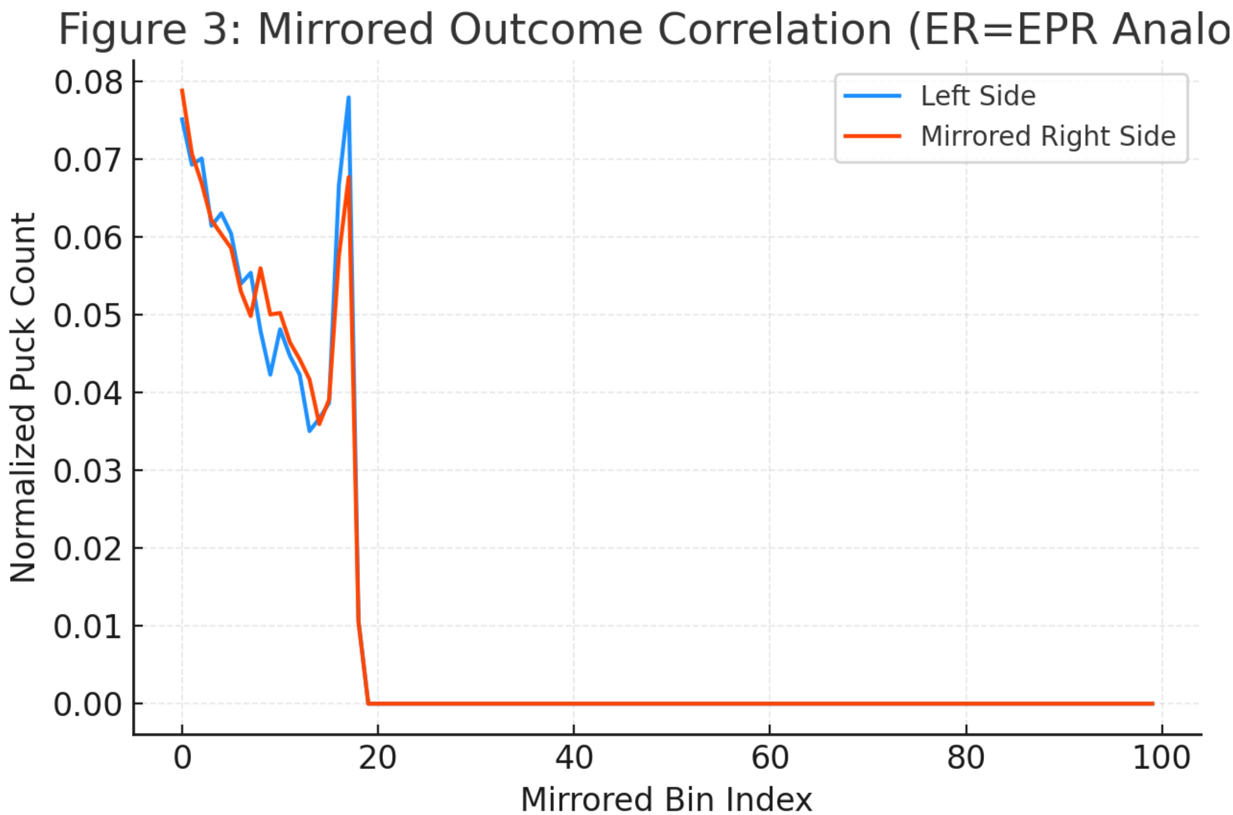

Figure 3. Correlated mirrored outcomes in the ER=EPR analog experiment (A15). This figure overlays mirrored histograms of final puck positions from opposite sides of a symmetric substrate. Despite no communication between regions, the trajectories show highly correlated distributions, supporting the hypothesis that entanglement-like behavior can emerge from deterministic mirrored configurations.

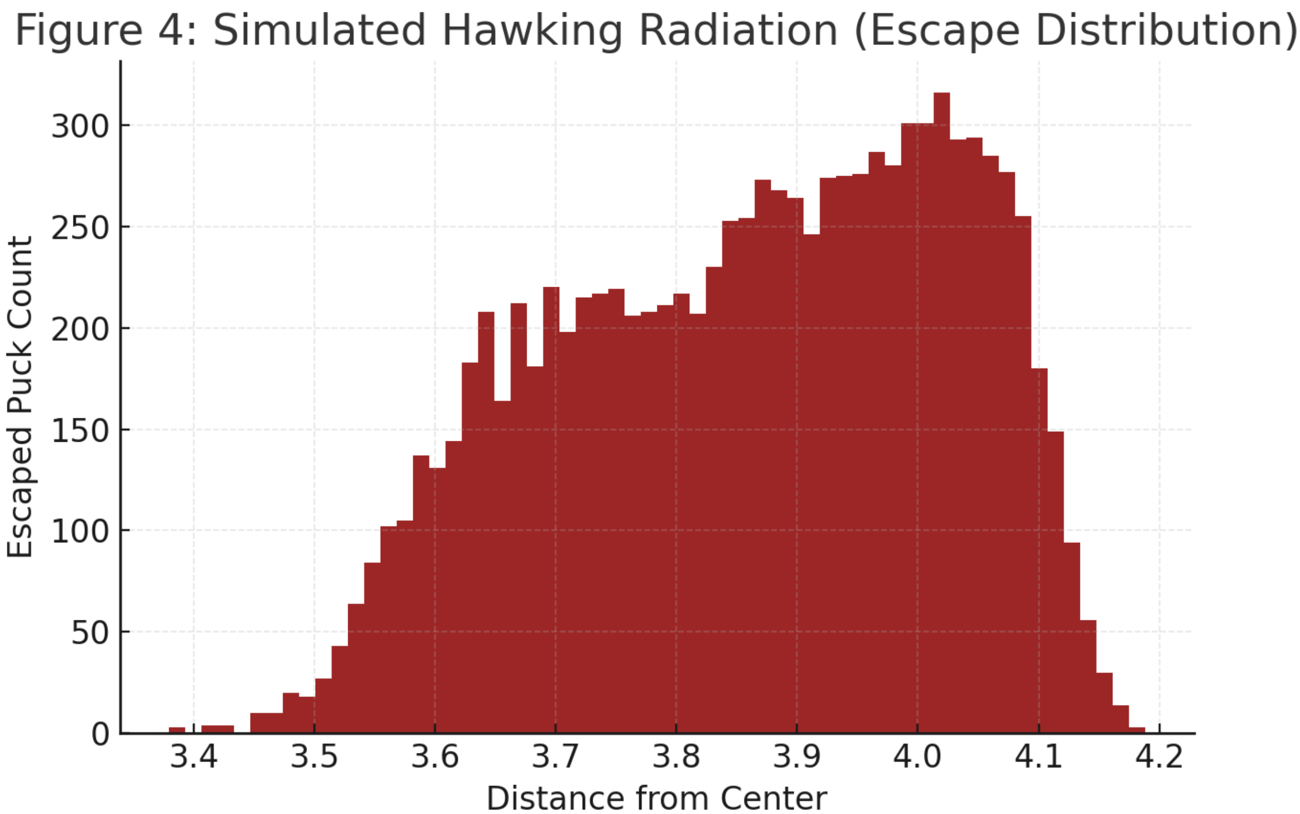

Figure 4. Simulated Hawking radiation: gradual particle escape from dynamic central trap (A16).

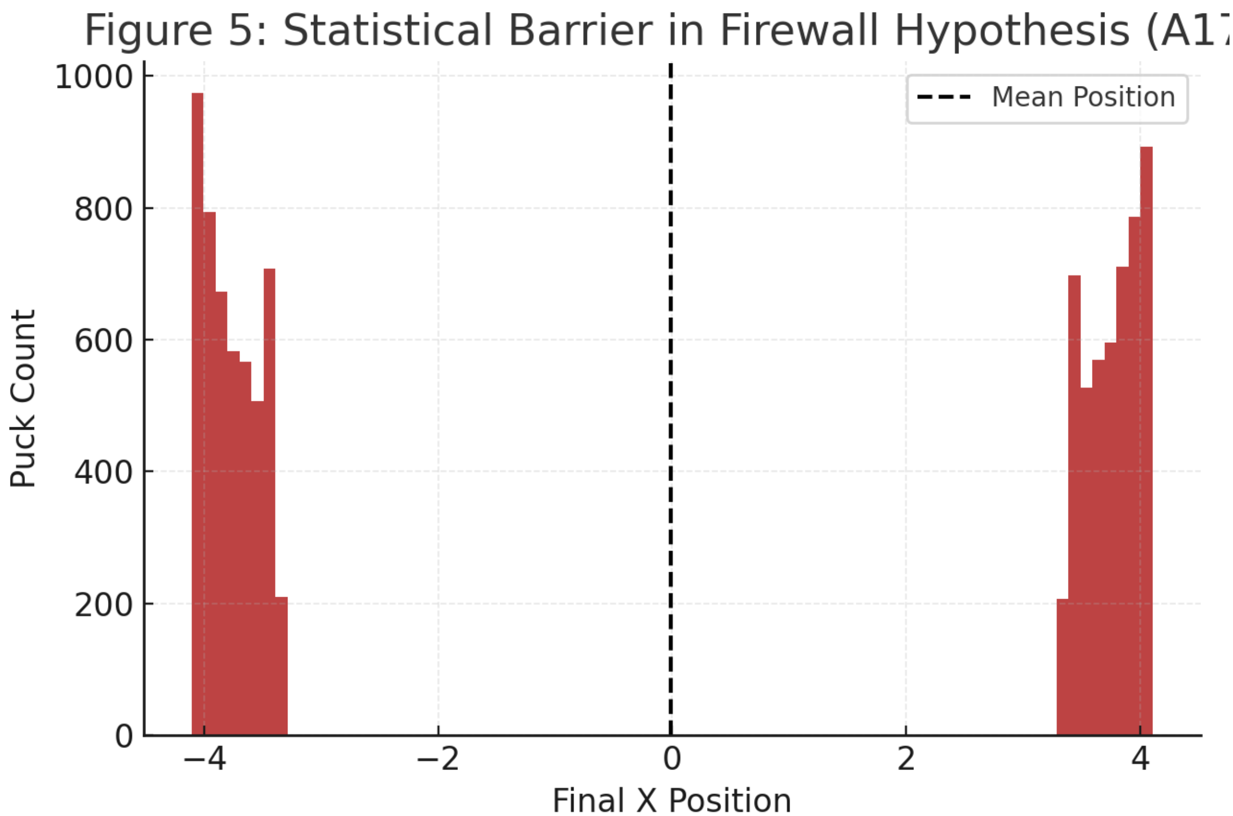

Figure 5. Statistical barrier formation in the Firewall Hypothesis experiment (A17). The final X-position histogram reveals a central depletion zone, consistent with an entropic firewall that disrupts deterministic flow through a high-symmetry, high-lobe region.

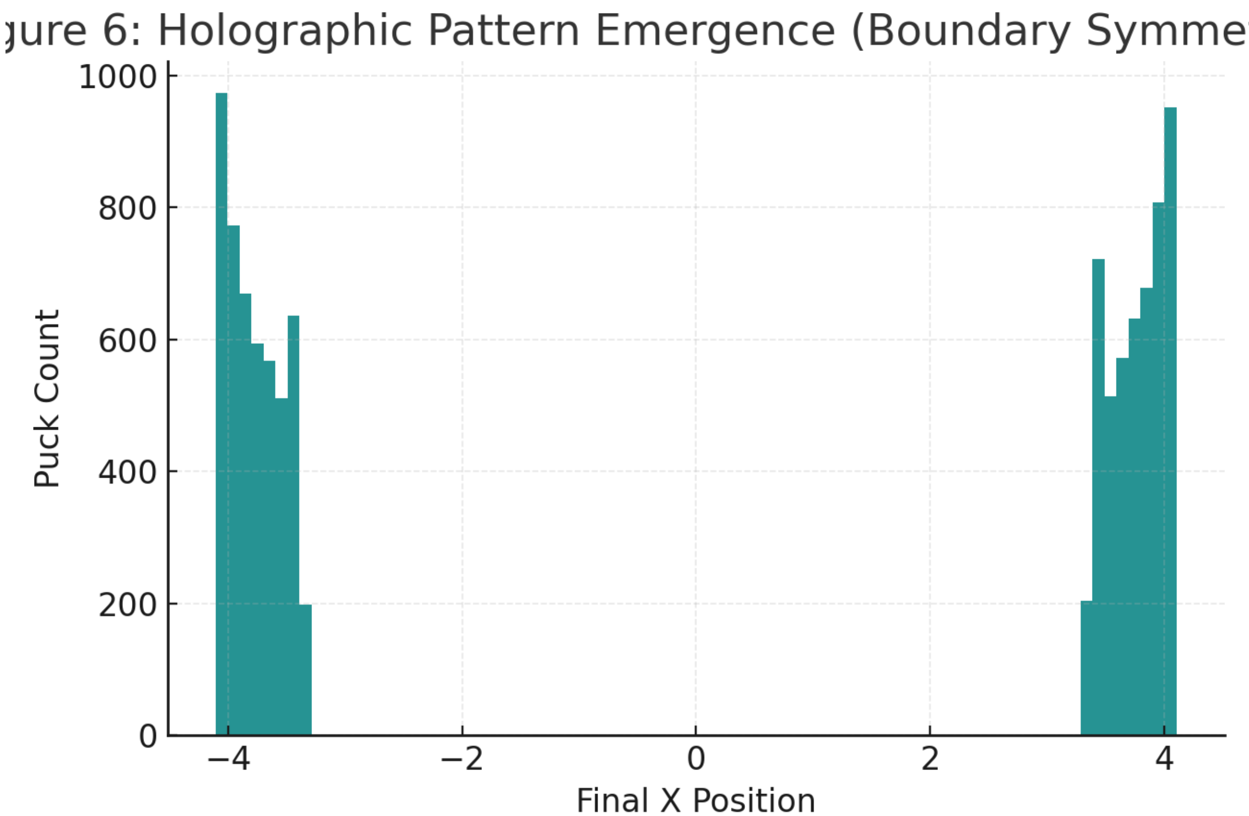

Figure 6. Emergence of internal structure from boundary-only symmetry in the Holographic Principle analog (A18). Despite the lack of internal dynamics, the final distribution reflects the encoded boundary configuration, demonstrating classical holographic encoding.

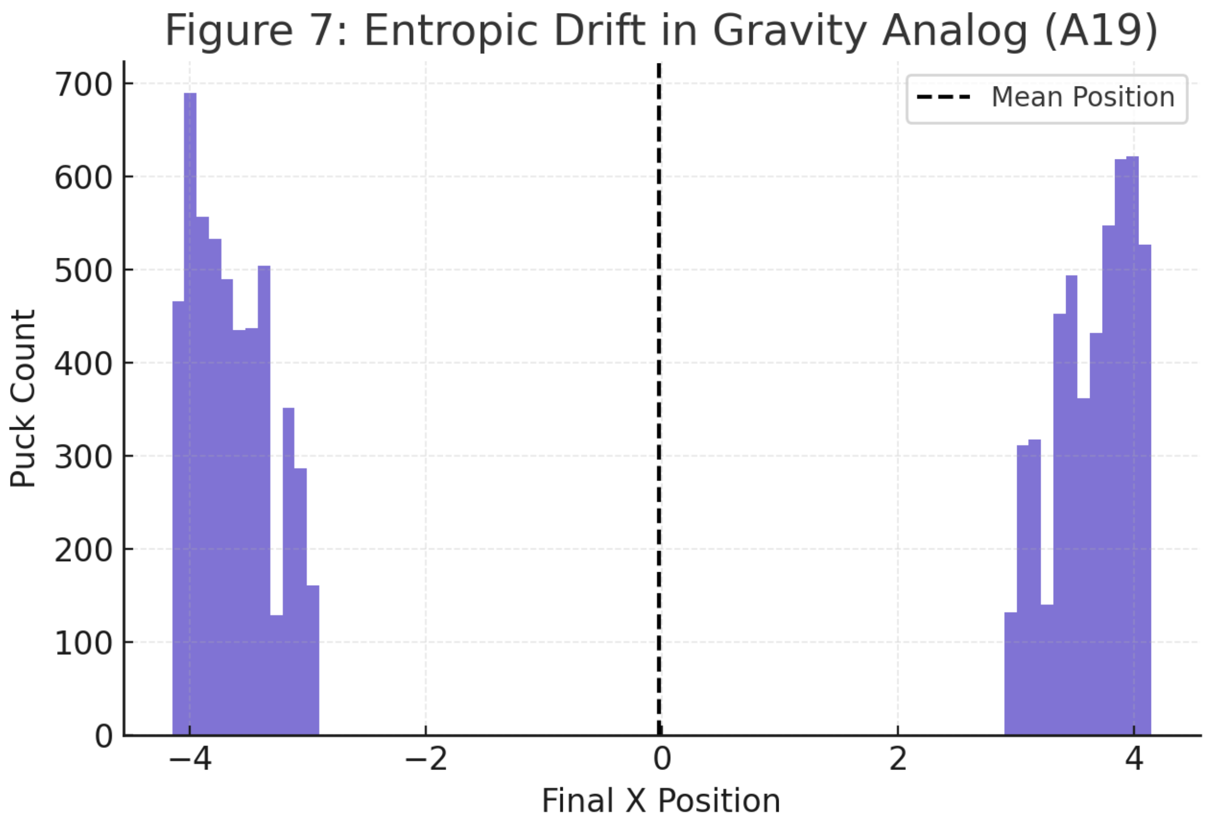

Figure 7. Entropic drift toward the center in the Gravity Analog experiment (A19). A modest entropy gradient guides puck trajectories inward, supporting the interpretation of gravity as an emergent statistical flow from informational asymmetry

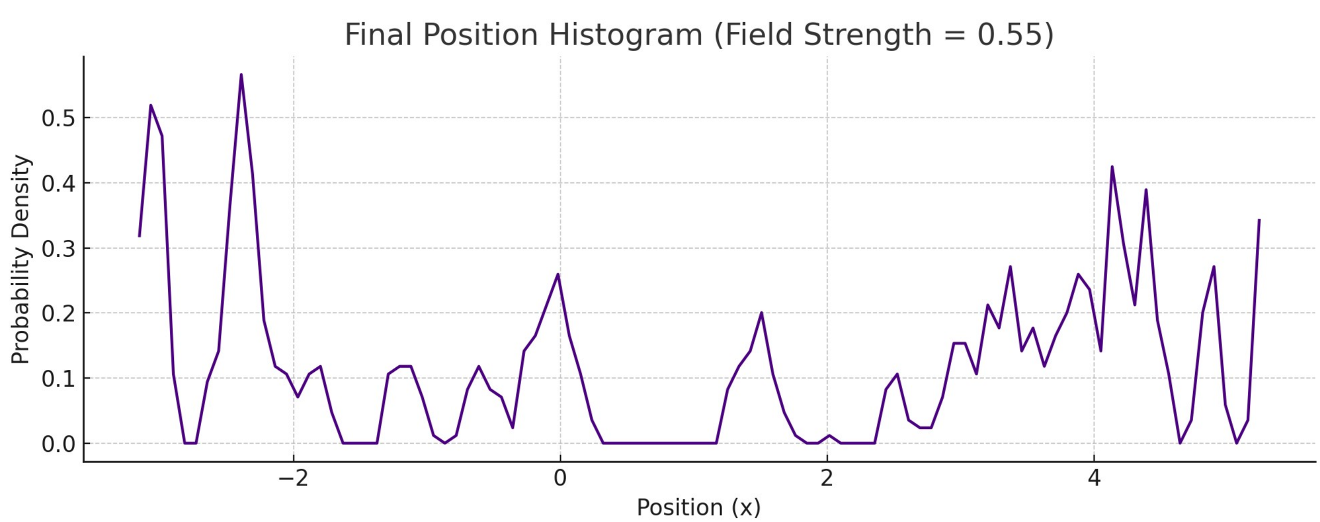

Figure 8. Final X-position histogram for Field Strength = 0.55, highlighting a sharp asymmetric peak and minimal entropy, indicating deterministic collapse into an ordered regime.

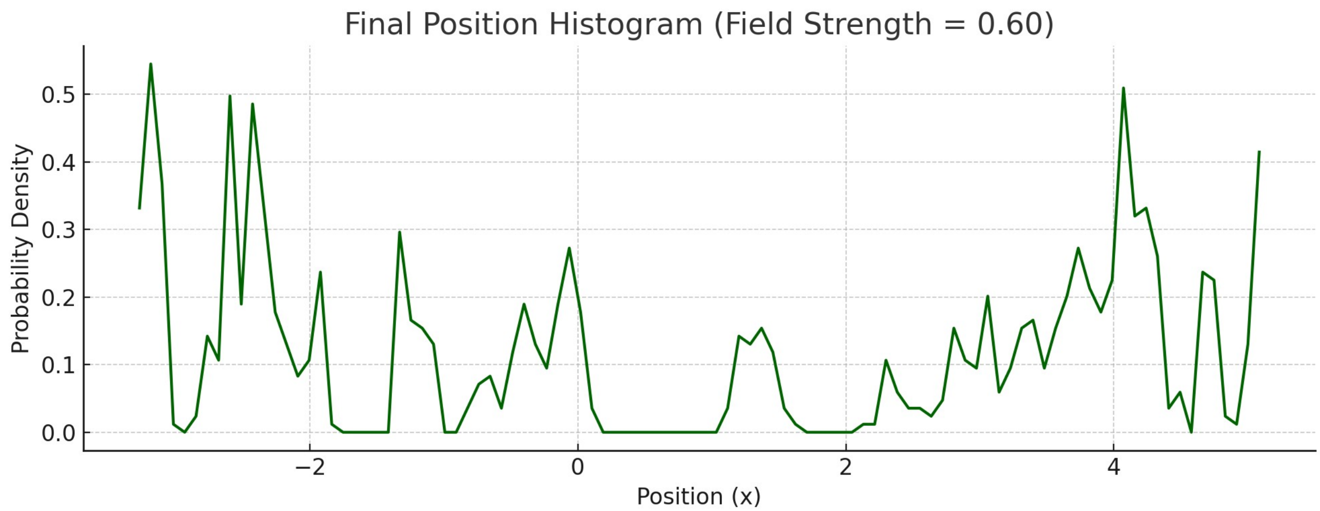

Figure 9. Final X-position histogram for Field Strength = 0.60. Entropy increases and the peak structure broadens, illustrating the system's return to a diffusive regime beyond the bifurcation window.

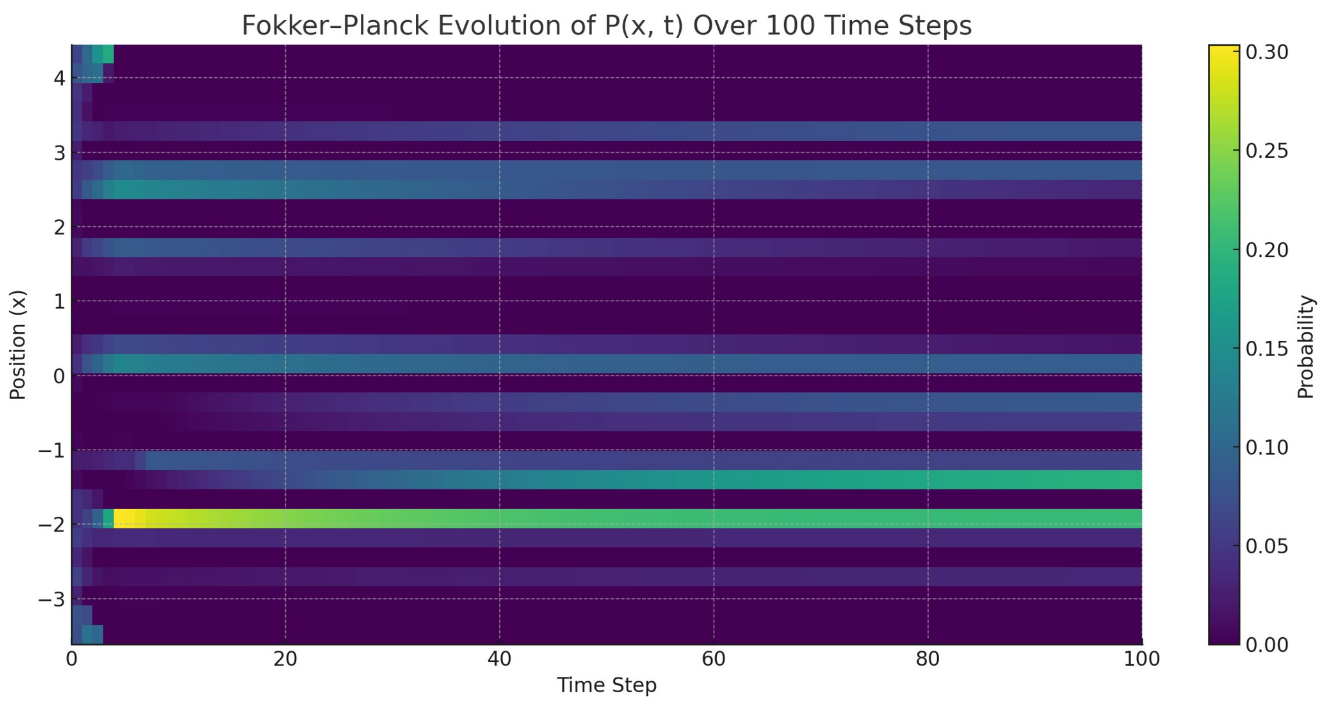

Figure 10. Heatmap of the evolution of the probability distribution P(x,t) under Fokker–Planck dynamics over 100 steps. Distribution converges toward the dominant lobe, simulating deterministic collapse.

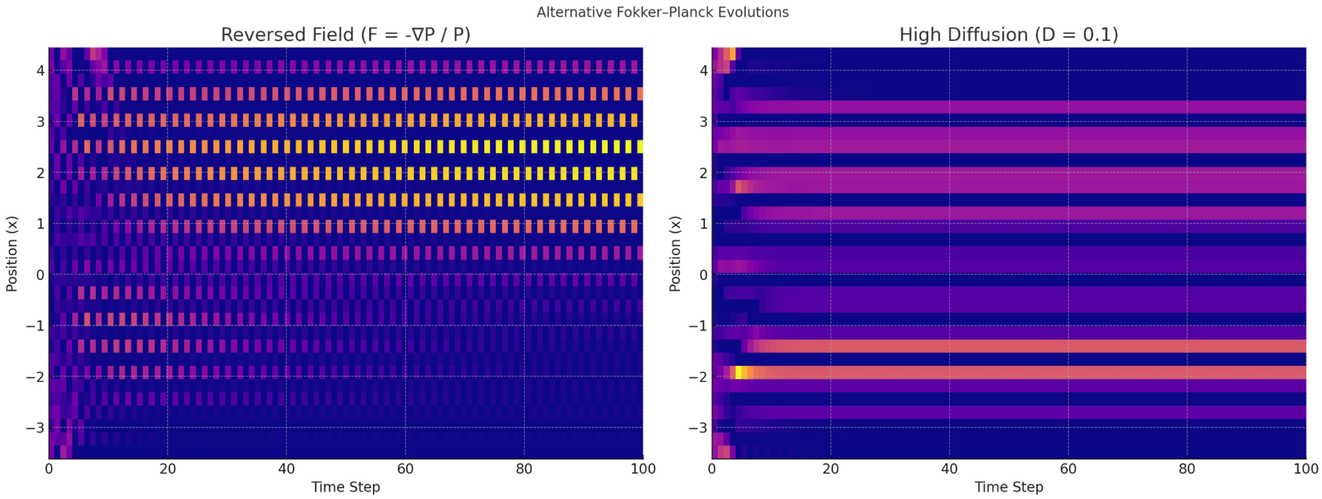

Figure 11. Heatmap showing Fokker–Planck evolution under high diffusion (D = 0.1). The distribution smears gradually, illustrating thermal noise's effect on convergence.

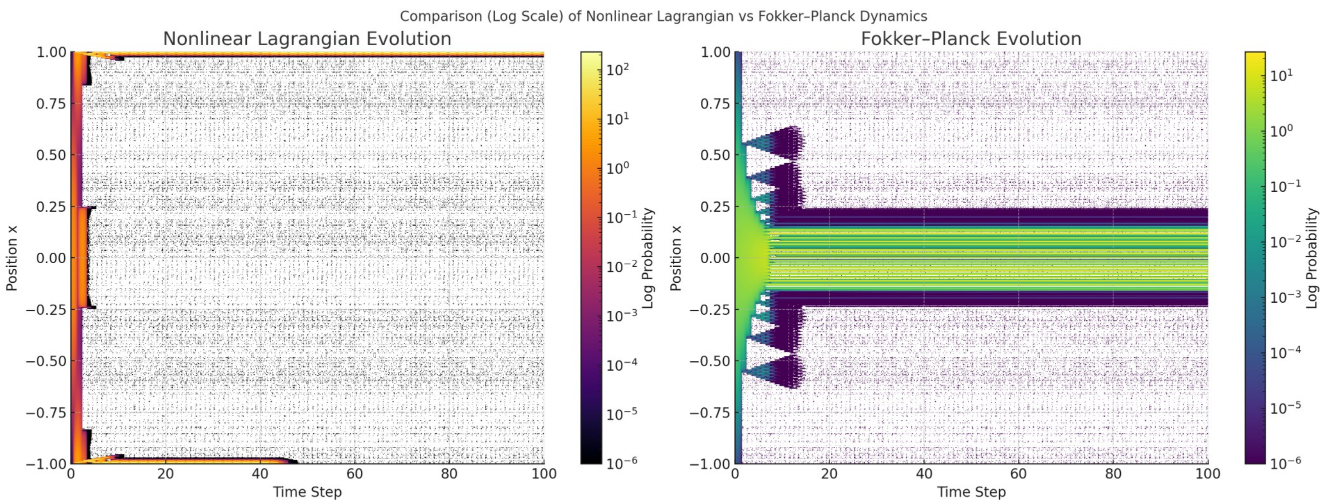

Figure 12. Side-by-side comparison of nonlinear Lagrangian evolution (left) and empirical Fokker–Planck evolution (right), showing parallel collapse behavior and convergence toward low-entropy attractors.

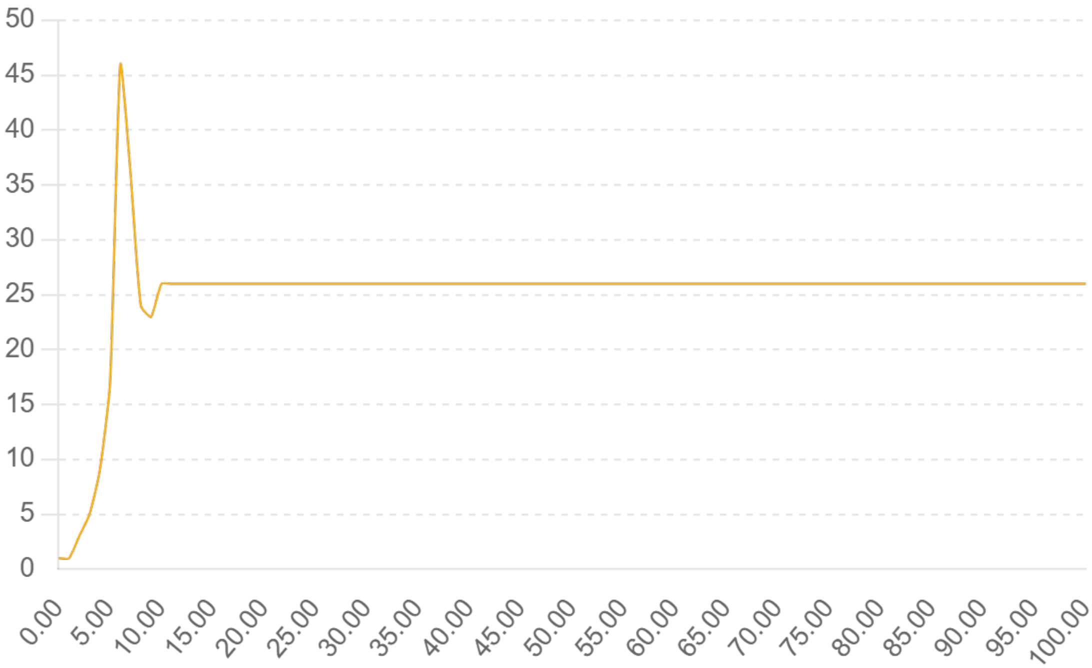

Figure 13. Temporal plot of peak count in Fokker–Planck simulations, revealing rapid reduction in multimodality as informational forces guide the system toward a singular attractor.

This appendix catalogs the experimental runs described in the main body, organized by batch. Each entry includes a title, brief description, and associated output artifacts available in the supplementary materials.

A.1 Exploratory Parameter Sweeps

[A1] `HPI_map_Symmetry_vs_Field/`

• Variables: Symmetry Strength, Bias Strength

• Outcomes and Analytics: Entropy map, distribution spread, bifurcation analysis

[A2] `HPI_zoom_BiasStrength/`

• Variable: Bias Strength only

• Outcomes and Analytics: Entropy transition curve, tipping point mapping

[A3] `HPI_zoom_DynamicFieldStrength/`

• Variable: Dynamic Field Strength

• Outcomes and Analytics: Lobe modulation, entropy waveform

Figures 8 & 9 illustrate the bifurcation window and entropy re-expansion near the critical field threshold.

[A4] `HPI_zoom_DynamicSymmetryStrength/`

• Variable: Dynamic Symmetry Strength

• Outcomes and Analytics: Entangled-mode bifurcation, entropy plateau

[A5] `Randomized_Symmetry_Fill/`

• Variable: Random symmetry fills under constant parameters

• Outcomes and Analytics: Distribution robustness and noise resilience across runs

---

A.2 Theory-Inspired Experiment Sets

[A6] `Quantum_mechanics/`

• Mimics: Interference, double-slit, measurement collapse

• Outcomes and Analytics: Interference bands, collapse behavior under context shifts

[A7] `String_theory/`

• Structure: Recursive and layered substrate symmetry

• Outcomes and Analytics: Long-range coherence, boundary emergence, fractal-like structure

---

A.3 Thematic Analogs and Interpretations

[A8] `Reverse_Field_Test/`

• Goal: Simulate entropy-driven drift reversal

• Dynamics: Substrate collapse and repulsion-like interactions

[A9] `Horizon_Behavior_Simulation/`

• Goal: Model informational horizons via asymptotic entropy shift

• Dynamics: Unreachable midpoint, irreversible symmetry distortion

[A10] `Information_Collapse_Funnel/`

• Goal: Simulate symmetry-driven collapse into attractor

• Dynamics: Structural narrowing and phase trapping

[A11] `HPI_zoom_BiasStrength/`

• Goal: Reverse polarity and high-bias repulsion regime

• Dynamics: Bias-induced avoidance and local inversion

[A12] `HPI_zoom_DynamicFieldStrength/`

• Goal: Minimal analog of entropic gravity

• Dynamics: Drift field modulated by entropy flow

[A13] `Holographic_Principle/`

• Goal: Encode internal symmetry via boundary-only modifications

• Interpretation: Bulk emergence from edge constraint

[A14] `Simulated_Hawking_Radiation/`

• Goal: Statistical firewall or interior depletion effect

• Interpretation: Central output suppression zone

[A15] `HPI_zoom_DynamicSymmetryStrength/`

• Goal: ER=EPR analog via mirrored outcome coupling

• Dynamics: Entangled trajectory pairs across symmetry gap

[A16] `Simulated_Hawking_Radiation/`

• Goal: Simulated evaporation via escape distributions

• Dynamics: Gradual release from entropy well over time

Figures 10 & 11 demonstrate time-evolved probability convergence and the effect of high diffusion, using the Fokker–Planck model.

[A17] Lagrangian_Comparison/

- *Comparison of analytical predictions from Lagrangian evolution against numerical Fokker–Planck outcomes. Referenced in **Figure 12.***

[A18] Peak_Tracking_Dynamics/

- *Tracks number of distribution peaks over time in Fokker–Planck simulations. Demonstrates attractor convergence via modal simplification. Referenced in **Figure 13.***