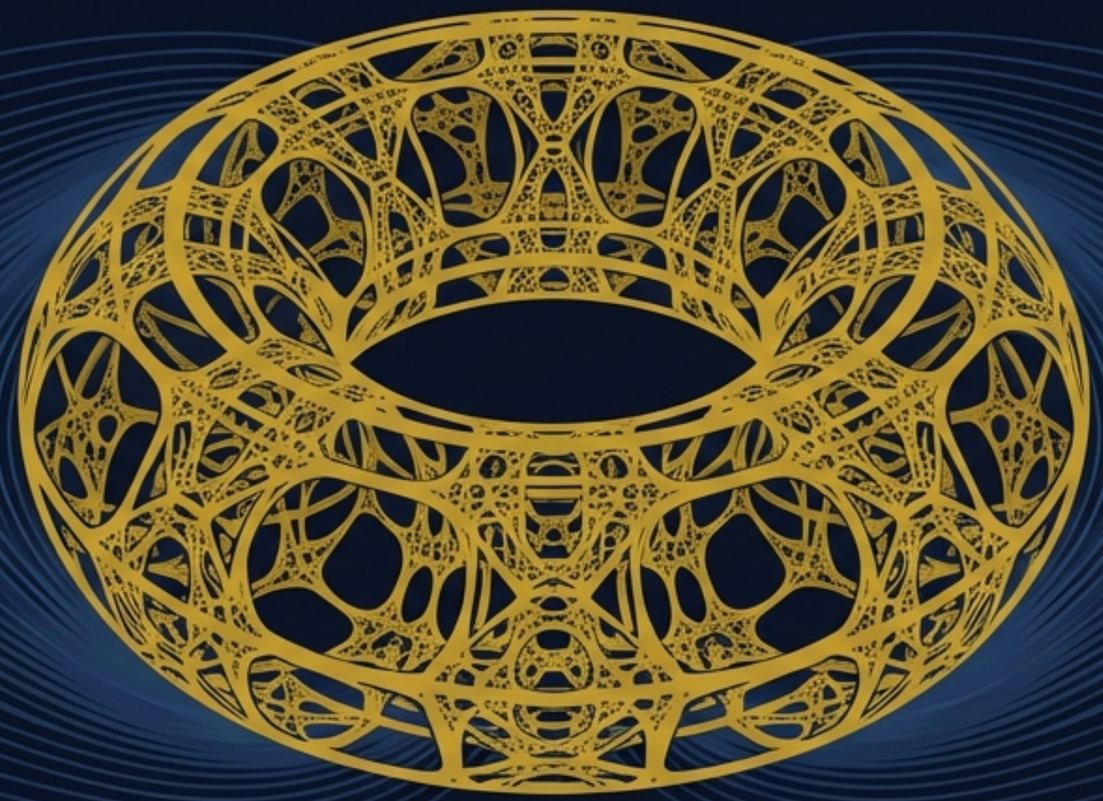
Fractal Resonance Cognition

A Deterministic Framework for Quantum Dynamics



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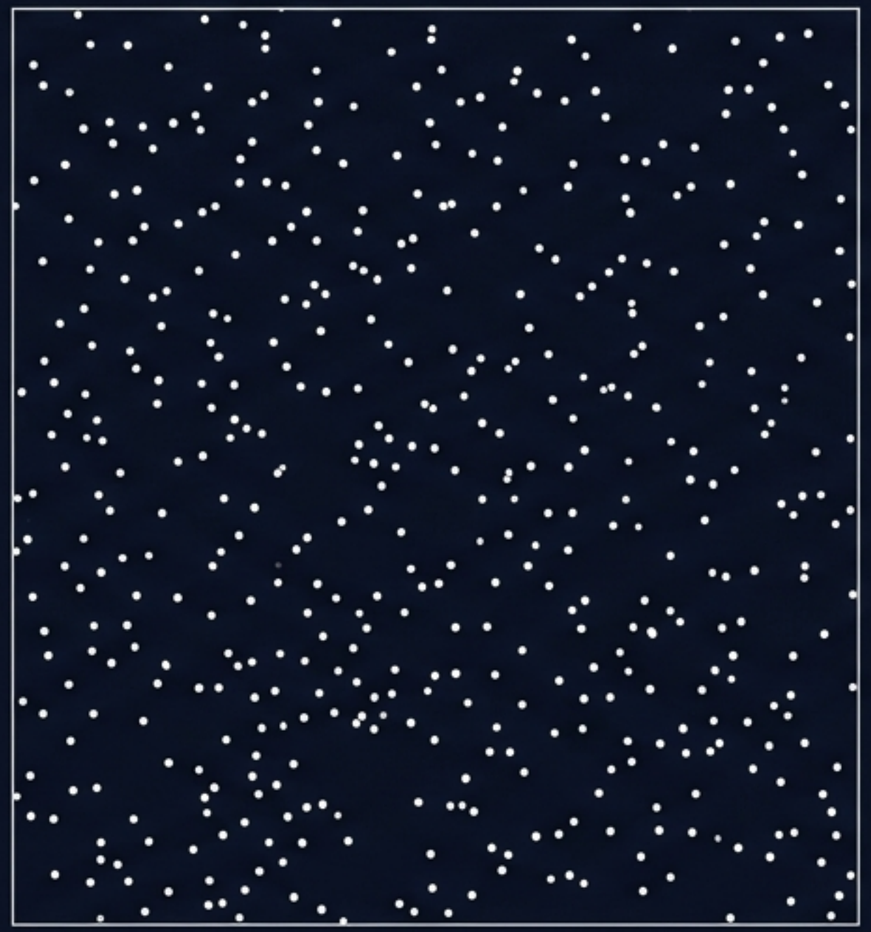
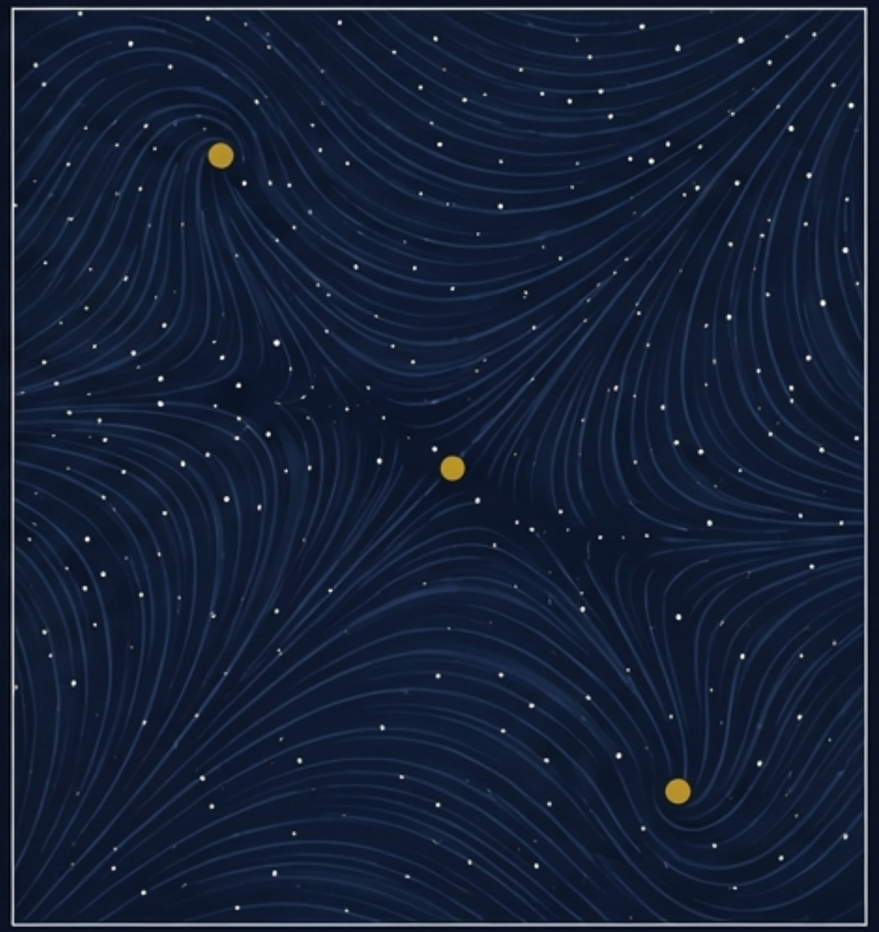
Is the randomness in complex systems fundamental or does it mask a deeper order?

- Conventional approaches in quantum chaos and measurement (e.g., Random Matrix Theory) treat complexity as intrinsic, stochastic randomness.
- Fractal Resonance Cognition (FRC) proposes an alternative: apparent randomness arises from deterministic, self-similar resonant interactions operating at fractal scales.
- This framework reinterprets complexity through the lens of structured dynamics, positing that vortex-like attractor structures govern system evolution.

Apparent Randomness



Hidden Order



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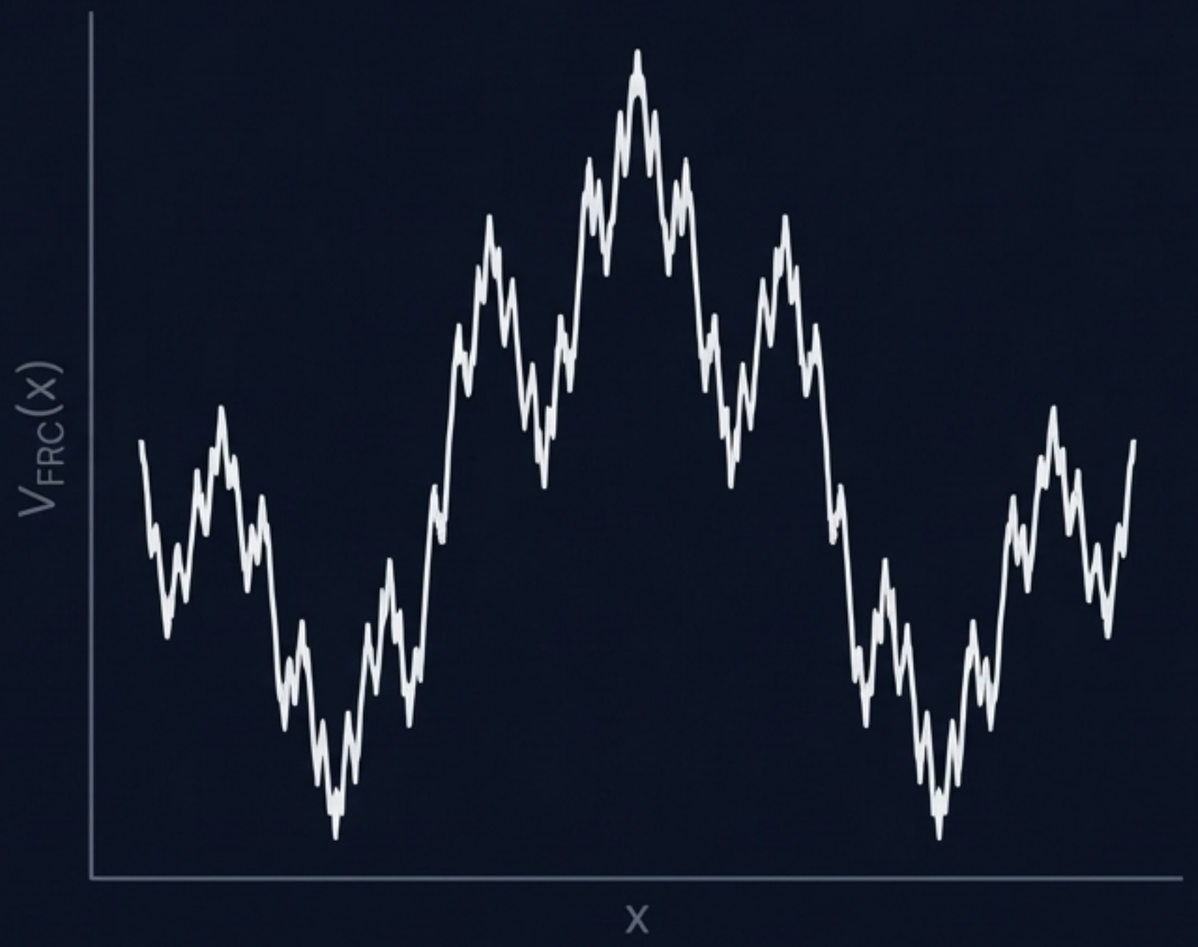
The FRC Hypothesis: A Fractal Resonance Potential Induces Self-Similar Dynamics

- FRC introduces a fractal resonance potential, V_{FRC}, to encode multi-scale interactions into a system's dynamics.
- This potential is typically constructed with fractal properties, such as a Weierstrass-like form, to induce resonant interactions across a hierarchy of scales.

$$V_{\mathrm{FRC}}(x) = \sigma \sum \lambda^{-n\alpha} \cos(\lambda^n k x)$$

- The result is the emergence of self-similar patterns in spatial, spectral, or temporal properties.



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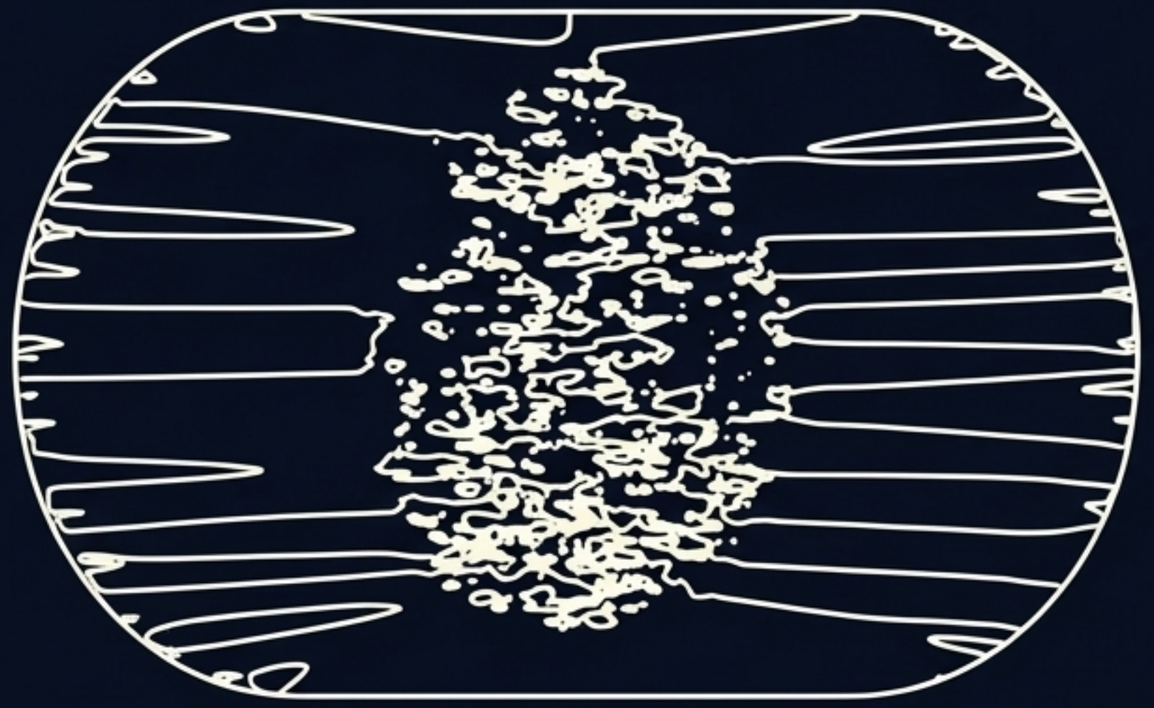
A Demonstration in Quantum Chaos: The Stadium Billiard

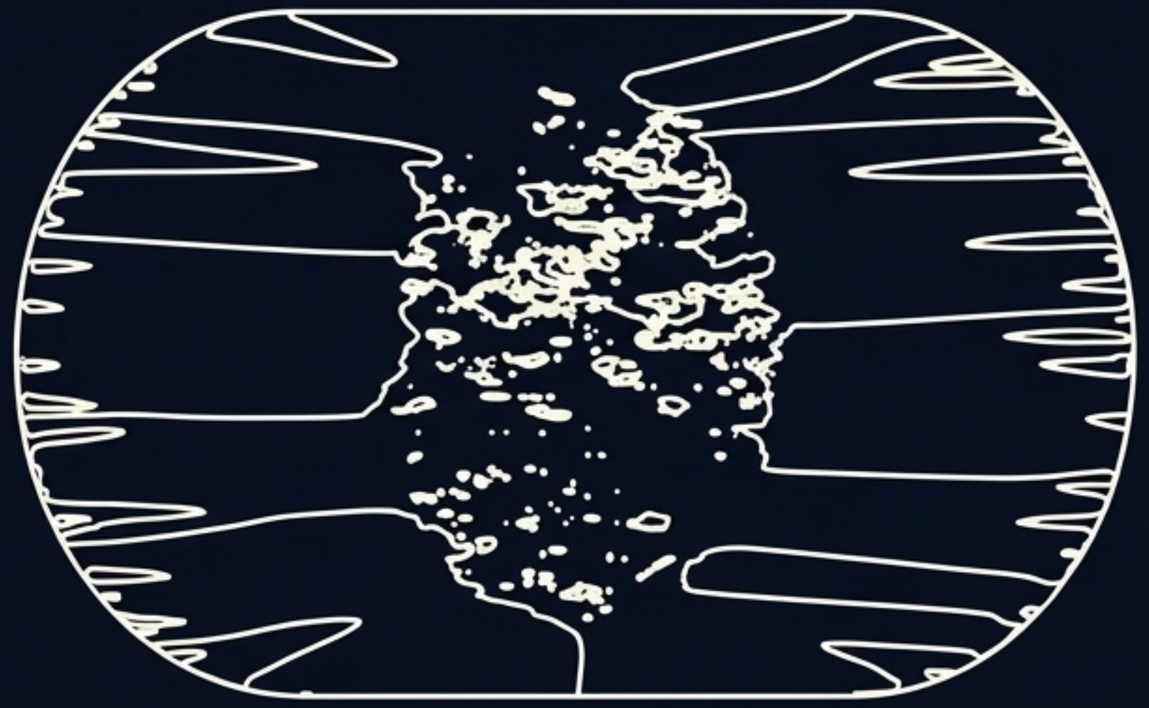
- The stadium billiard is a paradigmatic system for quantum chaos, whose wavefunctions typically display complex, irregular nodal patterns.
- Applying a weak FRC potential ($\sigma = 0.1$) transforms these patterns, inducing clear self-similar clustering and revealing a deterministic structure underlying the chaos.

Unperturbed System ($\sigma=0$)



Nodal pattern exhibits complex, irregular structure typical of quantum chaos. No apparent self-similarity.

FRC-Perturbed System ($\sigma=0.1$)



Nodal lines display self-similar clustering, a hallmark of fractal resonance.

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The Signature of Order: A Quantifiable Fractal Dimension

- The self-similarity induced by FRC can be quantified using box-counting analysis to compute the fractal dimension (D) of the nodal lines.
- The unperturbed, chaotic system yields a dimension $D \approx 1.2$, consistent with a non-fractal line-like pattern.
- The FRC-perturbed system reveals a fractal dimension of $D \approx 1.90 \pm 0.02$.
- This non-trivial dimension is a direct, measurable signature of the deterministic, scale-invariant dynamics introduced by FRC.

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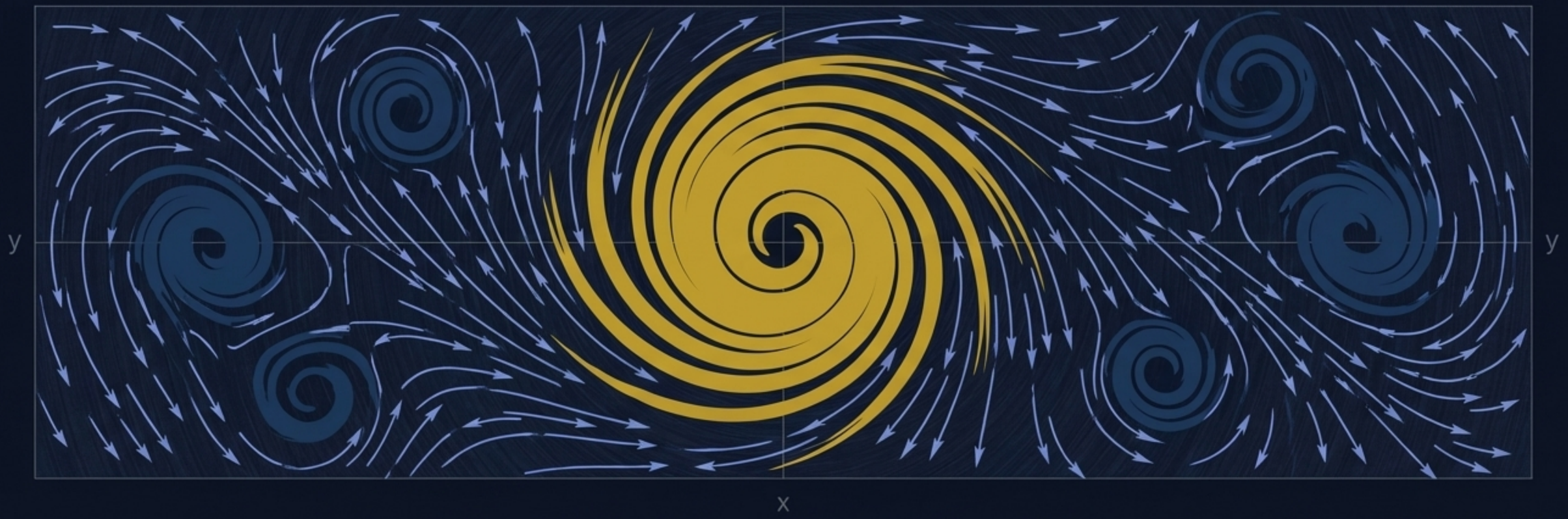
The Foundational Implication: Guided Wavefunction Collapse

- If FRC can impose deterministic order on quantum chaos, it can provide a mechanism for wavefunction collapse.
- FRC proposes that collapse is not a random process, but a structured, deterministic evolution guided by resonant vortex attractors in phase space.
- These attractors, with a fractal dimension $D = 1.94 \pm 0.05$, act as preferred pathways, guiding the system from a superposition to a definite state.



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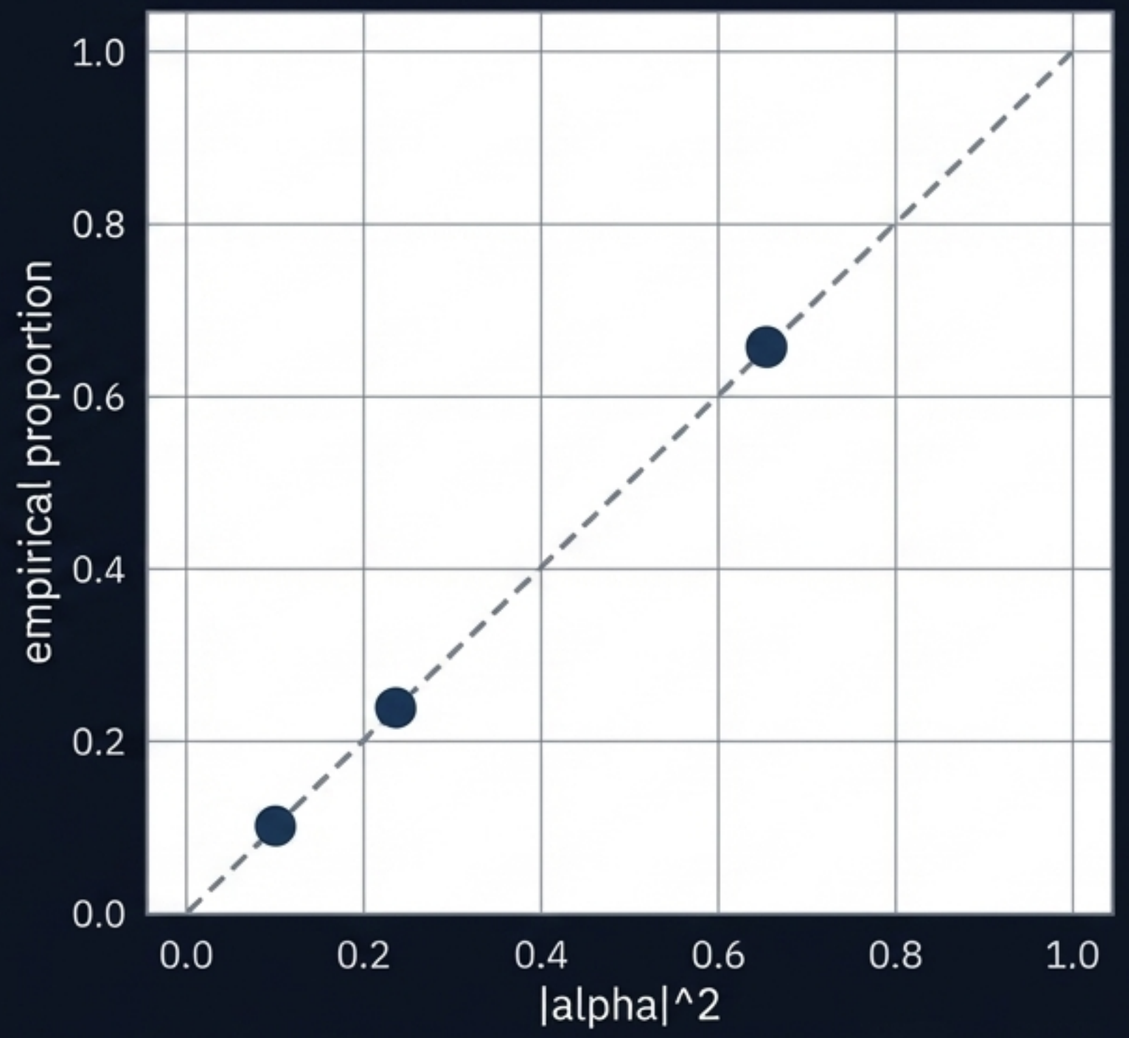
Emergent Probability: The Born Rule as a Resonant Equilibrium

- In a deterministic collapse model, probabilities are not fundamental. Instead, the Born rule ($p_j \propto |\alpha_j|^2$) emerges as a stationary equilibrium of underlying microstates.
- A weak "coherence drift" guides a distribution of microstates toward pointer-state attractors. The stationary distribution that results from this dynamical process yields sector weights proportional to the squared amplitudes.
- FRC thus reproduces the statistical predictions of standard quantum mechanics as a dynamical limit, rather than postulating them.



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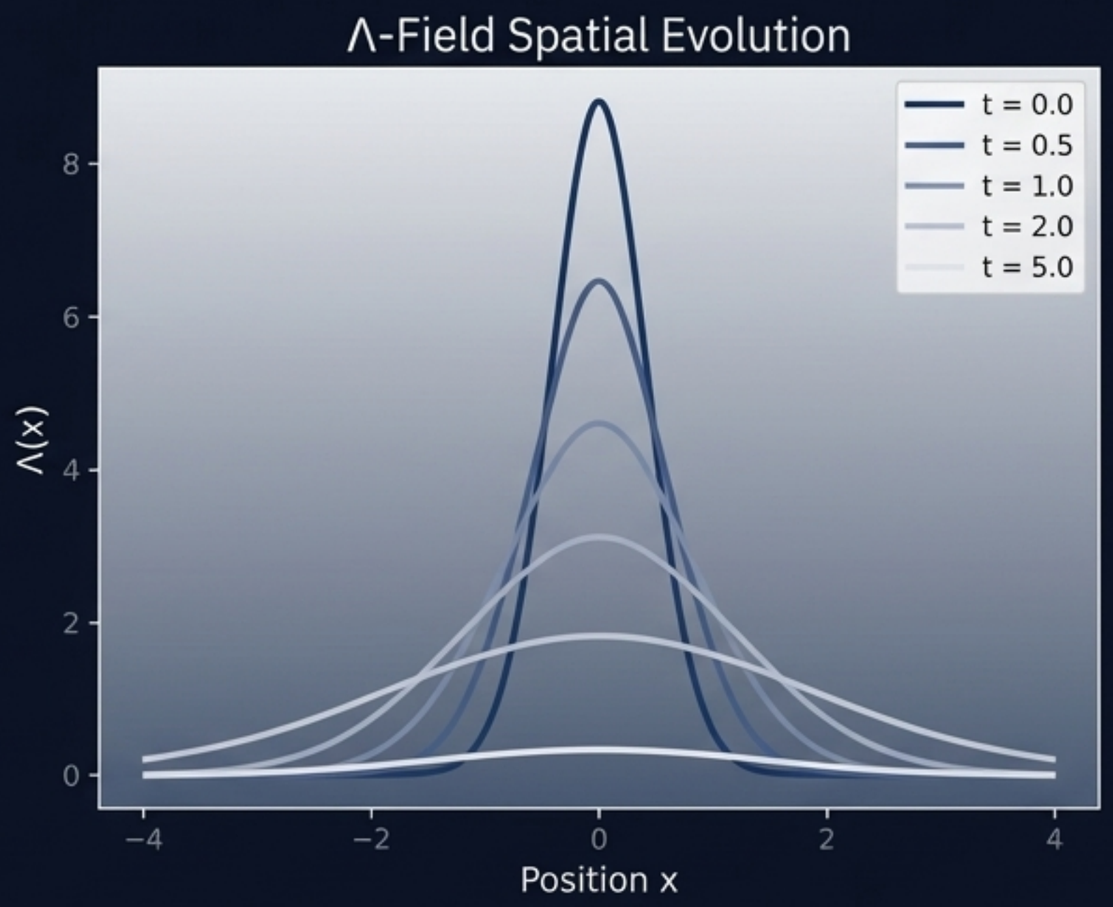
Formalization: The Lambda-Field as the Scalar Completion of Coherence Dynamics

- The dynamics of coherence require a physical carrier. FRC introduces the Lambda-field (Λ), a real scalar field on spacetime, as the minimal object to satisfy this.
- Coherence C is defined via the logarithmic identification: $\Lambda(x) = \Lambda_0 \ln C(x)$.
- The field's evolution is governed by the massive Klein-Gordon equation, which provides a complete, Lorentz-invariant description of how coherence is locally defined, transported, and influences quantum systems.

$$\Box\Lambda + m_\Lambda^2 (\Lambda - \Lambda_{\text{inf}}) = J_\Lambda$$



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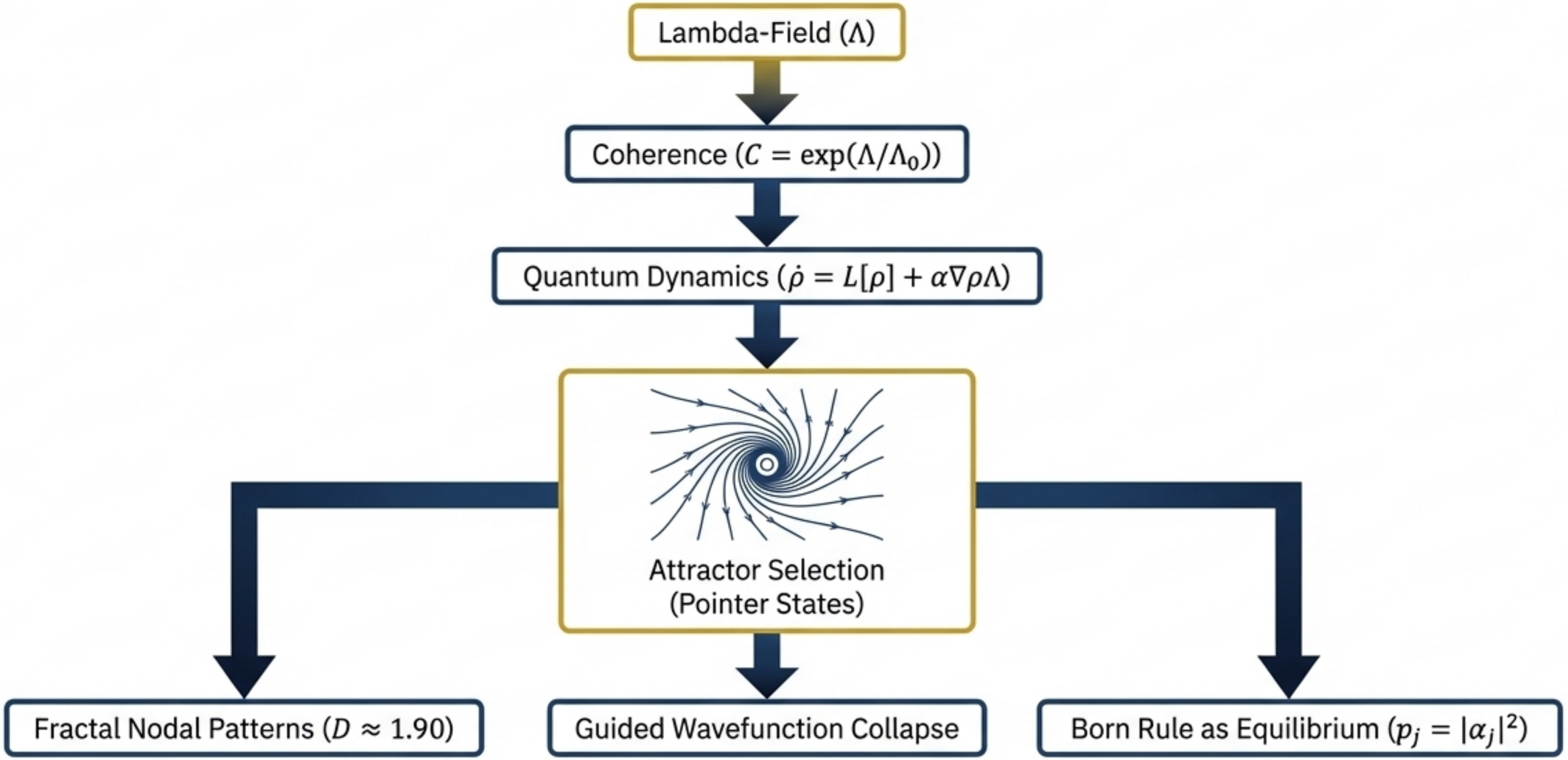
A Unified View of Fractal Resonance Cognition

The Lambda-Field provides the fundamental substrate for coherence, which in turn drives quantum state evolution via a gradient flow, leading to attractor selection and observable phenomena.



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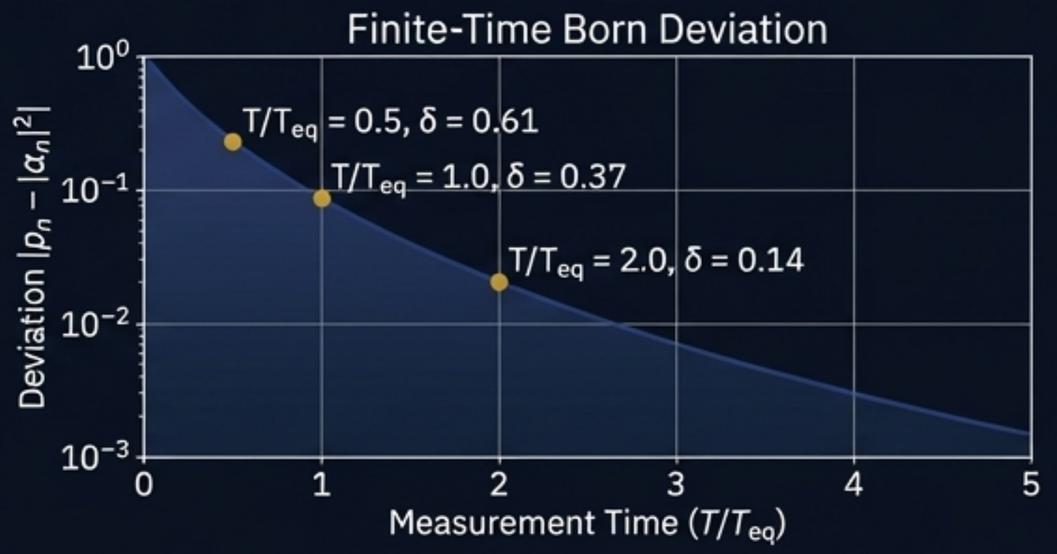
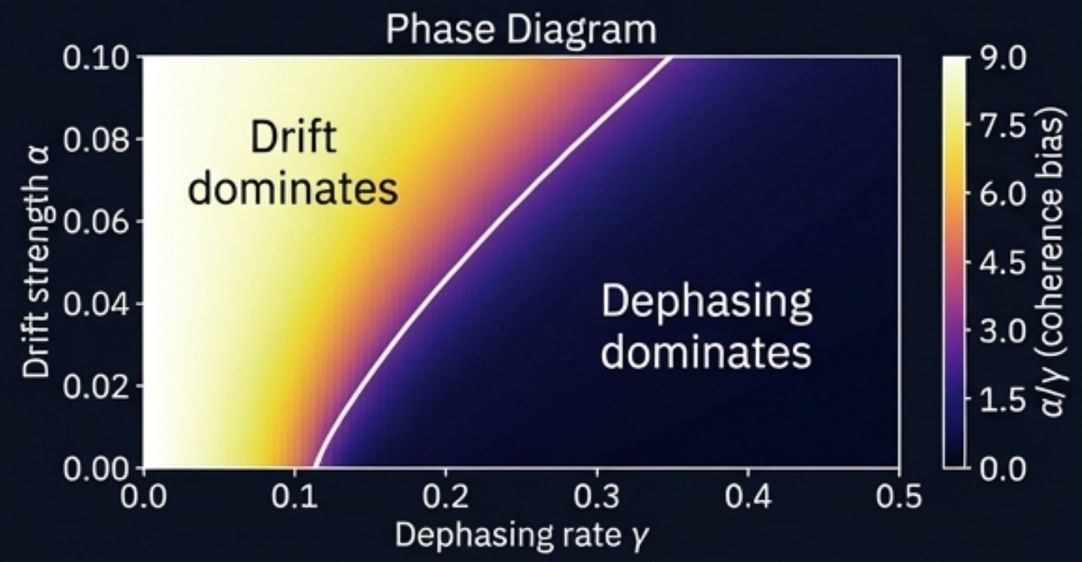
Falsifiable Prediction 1: Deviations from the Born Rule

- Because the Born rule is an equilibrium state, FRC predicts small, systematic deviations under specific non-equilibrium conditions. Standard QM predicts no such deviations.
- **Finite-Time Measurement**: For measurements completed faster than the equilibration timescale ($T < T_{eq}$), outcomes will show a predictable bias that decays exponentially with measurement duration. Deviation $|p_n - |\alpha_n|^2| \sim \exp(-T/T_{eq})$.
- **Non-Ergodic Ensembles**: A skewed initial distribution of microstates will produce a transient bias that decays as the system mixes.





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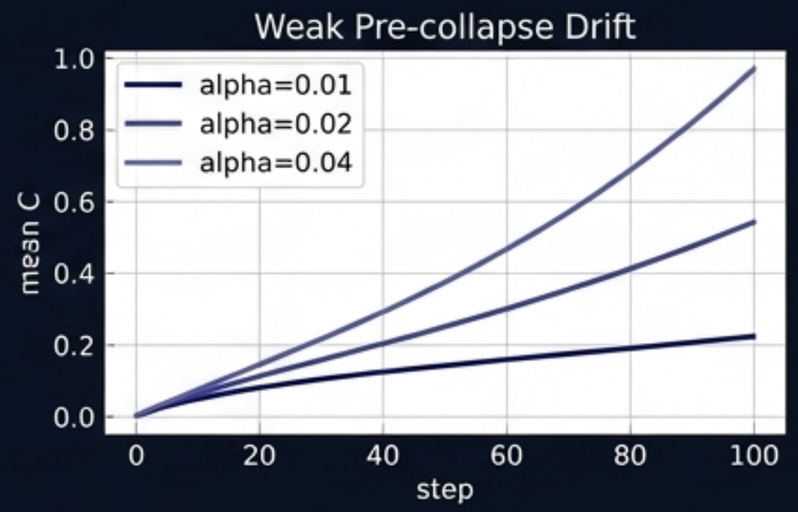
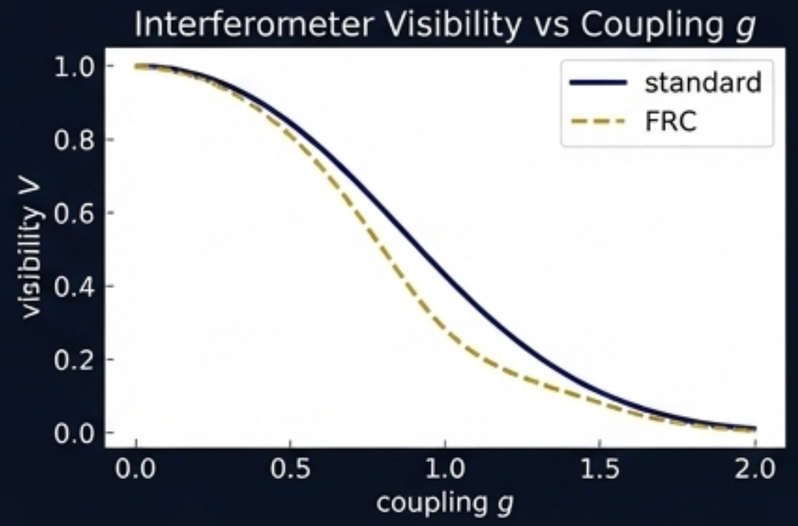
Falsifiable Prediction 2: Weak Measurement and Interferometry Signatures

- FRC's coherence drift produces subtle but detectable signatures in continuous weak measurement and interferometry experiments.
- **Weak Pre-Collapse Drift:** In sequential weak measurements, the mean coherence C will exhibit a small, systematic ascent prior to collapse. The rate of ascent is proportional to the drift strength α.
- **Interferometer Visibility:** FRC predicts a small, systematic deviation in interferometer visibility V as a function of pointer coupling g, separating from standard open-system model predictions near resonant match points.





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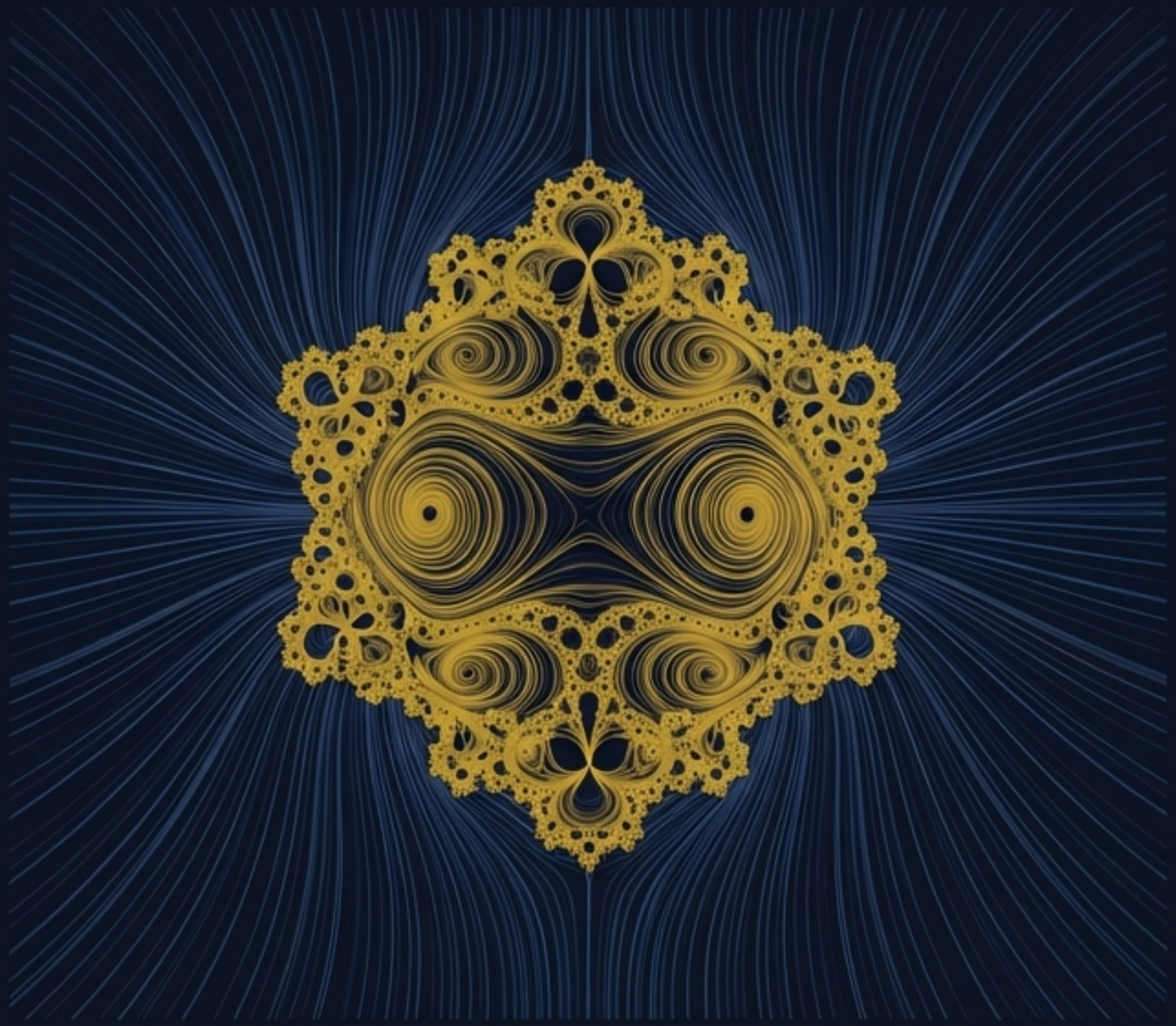
A New Perspective on Quantum Dynamics

- **Reinterprets Randomness:** FRC reframes apparent randomness in complex systems as deterministic, structured dynamics governed by fractal resonance.
- **Provides a Mechanism:** It offers a physical mechanism for wavefunction collapse, guided by resonant attractors in phase space.
- **Recovers Known Physics:** The framework reproduces the Born rule not as a postulate, but as a dynamical equilibrium. equilibrium.
- **Is Falsifiable:** FRC provides a suite of concrete, testable predictions—such as finite-time Born deviations and weak measurement signatures—that distinguish it from standard interpretations of quantum mechanics.



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Further resources, publications, and reproducible code for the FRC program are available at the website.

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