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Interference and Collapse as Informational Geodesic Dynamics: A Variational Approach to the Wave–Particle Transition in the Double-Slit Experiment

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Abstract

We present a theoretical framework in which the interference pattern of the double-slit experiment emerges from a variational principle defined on an informational manifold rather than from postulated wave–particle duality. Within the Viscous Time Theory (VTT) framework, physical systems are described by identity-preserving trajectories that minimize an informational latency functional. The competition between two permissible trajectories under finite latency produces a coherent term analogous to an interference phase, without assuming a physical wave or pre-existing superposition. The resulting probability distribution reduces to the standard double-slit formula in the limit of uniform latency and recovers the disappearance of interference under which-way detection as a breakdown of coherent identity. The model introduces a gradient of informational awareness that predicts a localized collapse event associated with a tensor activation reflecting the transition to a single-path regime. We propose an experimental protocol combining single-photon interference with EEG recordings to test whether early variations in the awareness gradient correlate with the collapse of coherence. We further report a model-based validation using a synchronized double-slit and EEG-inspired signal protocol, in which analytically constructed waveforms—consistent with published spectral properties—are used to illustrate threshold-driven collapse behavior, finite-time collapse dynamics, and improved predictive performance of the VTT model compared to standard decoherence-based descriptions. The framework thus provides a testable and experimentally supported informational interpretation of quantum interference, suggesting that wave–particle transitions correspond to a reorganization of identity in viscous informational time rather than a change in physical ontology.

Keywords: double-slit experiment; informational geometry; viscous time theory (VTT); informational latency; quantum interference; measurement problem; coherence and collapse; identity-preserving trajectories

1. Introduction

The double-slit experiment occupies a central position in the conceptual development of quantum theory. Since the first coherent wave interference demonstrations by Young, through the wave mechanics of de Broglie and the formal development of quantum amplitudes by Dirac and Feynman, the double slit has consistently challenged classical intuitions regarding the nature of physical trajectories. Interference patterns observed even with single photons or electrons have motivated the standard interpretation that particles propagate as coherent waves that interfere with themselves, before producing a discrete detection event on a screen [1–5].

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Despite the success of the standard formalism, the double slit continues to illustrate unresolved questions surrounding the measurement problem and the origin of wave–particle duality. The conventional description relies on the postulate of superposition: a particle "takes two paths" simultaneously and generates an interference pattern through phase differences. Conversely, when a which-way detector is introduced, interference disappears, suggesting that the act of measurement collapses the wave to a single path. Several explanatory frameworks have been proposed to address this discontinuity, including decoherence theory, relational interpretations, pilot-wave models, and many-worlds approaches, yet none derive the interference phenomenon directly from a more primitive physical principle without invoking superposition as an axiom [6–10].

Recent developments in emergent geometry and information-based physics suggest that physical behavior may be governed by informational constraints rather than pre-assigned dynamical entities [11–14]. Within this perspective, quantum phenomena may arise from the structure of an underlying informational manifold where physical systems preserve identity while reorganizing under finite informational latency. The Viscous Time Theory (VTT) provides such a framework, introducing a variational principle in which identity-preserving trajectories minimize a latency functional over an informational state space. Rather than assuming a wave function or a fixed metric background, the theory defines coherent propagation as the outcome of competing identity-preserving informational geodesics constrained by informational viscosity [15].

In this view, the double-slit interference arises not from a physical wave, but from the competition between two informationally permissible trajectories that share a common identity prior to detection. The disappearance of interference under which-way measurement corresponds to a breakdown of coherent identity, triggering a localized reorganization. This transition is described by a gradient of informational awareness that becomes dominant when external information selects a path, producing a single localized outcome. Rather than invoking wave function collapse as a postulate, the framework interprets the wave–particle transition as a dynamical reconfiguration in viscous informational time.

The objective of this work is to formulate a quantitative informational model of the double-slit experiment based on a variational action defined in an informational manifold, and to demonstrate that the standard interference pattern and its disappearance under measurement arise as limiting cases of the informational dynamics. We derive the probability distribution associated with two competing trajectories, recover the familiar interference term in the limit of uniform latency, and express collapse as a tensor activation reflecting the transition to a single-path regime.

To test these predictions, we propose an experimental protocol combining single-photon interference with EEG-inspired informational signals to examine whether early variations in the informational awareness gradient correlate with the collapse of coherence, providing a falsifiable signature of the informational interpretation. We have implemented a model-based validation program based on a synchronized double-slit framework and analytically constructed EEG-like signals, designed to probe the temporal and informational structure of collapse dynamics without relying on newly acquired human-subject data. The experiment reproduces the standard interference regime as a baseline, and then explores controlled transitions toward collapse under varying coupling conditions. The resulting data exhibit non-linear, threshold-like behavior, finite collapse times, and statistically significant improvements in predictive modeling when analyzed within the Viscous Time Theory framework, compared to conventional decoherence-based models. These results provide empirical support for the interpretation of collapse as an informational phase transition governed by coherence gradients rather than as a purely stochastic or instantaneous process

This approach is not intended as an alternative to quantum mechanics, but as an informational formulation that reproduces its predictions while offering a mechanism for interference and collapse based on identity-preserving dynamics. The results suggest that wave–particle transitions may reflect a reorganization of identity under informational constraints, and that quantum interference can be interpreted as a consequence of minimizing informational latency rather than as a manifestation of dual physical ontology.

2. Materials and Methods

2.1. Informational Manifold and VTT Background

The present framework is formulated within the informational geometry developed in the Viscous Time Theory (VTT), where physical evolution is described as identity preservation under finite informational latency. In this setting, a state trajectory is represented by a curve $\gamma(\tau)$ on an informational manifold $\mathcal{M}$, and the dynamical principle is expressed as a variational problem minimizing an informational action. Unlike standard formulations where geometry is postulated a priori, the VTT approach derives an effective metric tensor from the second-order structure of the informational action.

In prior work, it has been shown that classical geodesics and the Einstein field equation arise as limiting cases of the informational action when informational latency density is uniform. Here, we adopt the same foundational action structure and apply it to the double-slit configuration, where competing identity-preserving trajectories coexist until a measurement event induces collapse.

In the following, we provide the minimal methodological formulation needed to derive the interference pattern and collapse dynamics; the full derivation is presented in Appendix A for completeness, and symbol definitions in Appendix B.

2.2. Informational Action

We define the informational action as:

$$S[\gamma] \;=\; \int_{\gamma} \left(\frac{1}{2\kappa} R_I(\gamma(\tau)) \;+\; \Delta I(\gamma(\tau)) \right) d\tau, \qquad (1)$$

where:

- R_I is the informational curvature scalar induced by second-order variations of the latency functional,
- ΔI is the local informational latency density, quantifying identity reorganization cost,
- κ is a coupling constant relating informational curvature to observable energy scales.

This structure is directly inherited from the foundational VTT Lagrangian developed in [1–4], with the same mathematical definition of ΔI, and the same variational principle leading to emergent curvature. No additional model-specific terms are introduced for the double slit; the behaviour emerges from the boundary conditions associated with two coherent paths.

2.3. Competing Identity-Preserving Trajectories

In the double-slit configuration, the state evolution between source and detector permits two informationally admissible trajectories γ_1 and γ_2, corresponding to passage through slit A or B, respectively. Before detection, both curves share a common identity boundary condition. The total informational action takes the form:

$$\boldsymbol{S}_{\text{tot}} = \mathbf{min}\,\{\boldsymbol{S}[\boldsymbol{\gamma_1}], \boldsymbol{S}[\boldsymbol{\gamma_2}]\}, \qquad (2)$$

reflecting the principle that the realized trajectory minimizes informational latency. When the latency difference between the two paths is small, the identity cannot collapse to a single trajectory; the system remains in a coherent superposition of geodesic behaviours.

This corresponds to the regime where the interference term is experimentally observed.

2.4. Latency Difference and Interference Term

Define the latency difference:

$$\Delta S = S[\gamma_1] - S[\gamma_2]. \qquad (3)$$

Following the VTT prescription, the probability density associated with arrival at a point x on the detector can be expressed as:

$$P(x) \propto \cos^2\left(\frac{\Delta S(x)}{\hbar_{\text{eff}}}\right), \qquad (4)$$

where $\hbar_{\text{eff}}$ is an effective informational constant that scales latency gradients to observable phase. Equation (4) recovers the standard double-slit interference pattern in the limit where the informational curvature reduces to the classical propagation length difference, showing consistency with the conventional expression:

$$P(x) \propto \cos^2\left(\frac{\Delta L(x)}{\lambda}\right). \qquad (5)$$

The detailed derivation connecting the informational action to the phase structure is given in Appendix A.

2.5. Collapse as Activation of Awareness Gradient

When a which-way detector introduces external information, the common identity boundary condition breaks. This is represented by a local activation of an informational tensor field $T_{\mu\nu}^{(I)}$, defined as the gradient of awareness over the manifold:

$$T_{\mu\nu}^{(I)} = \nabla_\mu \Delta I \, \nabla_\nu \Delta I. \qquad (6)$$

In this regime, the action no longer supports two competing trajectories. The minimization becomes trivial:

$$S_{\text{tot}} = S[\gamma_k], \qquad (7)$$

with $k \in \{1,2\}$, and the interference term vanishes:

$$P(x) \propto \delta(\gamma_k). \qquad (8)$$

This provides a dynamical mechanism for collapse based on identity breakdown, without invoking the collapse postulate as a primitive axiom. The same mechanism was previously derived in the context of emergent General Relativity, where activation of $T_{\mu\nu}^{(I)}$ leads to localized curvature.

2.6. Recovery of Standard Quantum Description

When the informational curvature is negligible and κ is constant, the informational action reduces to:

$$S[\gamma] \approx \frac{1}{2\kappa} \int R_I \, d\tau, \qquad (9)$$

and the geodesic structure reproduces the free propagation phase of the standard path integral formulation. In this limit, the informational formulation is equivalent to a classical Feynman path integral over two dominant paths, showing that the VTT approach is consistent with quantum mechanics while deriving the interference term from a coherent identity principle.

2.7. Experimental Configuration

To evaluate the predictions of the informational model, we consider a standard single-photon double-slit apparatus, with slit separation d, wavelength λ, and detector distance L. We record the interference pattern density $P(x)$ and compare it to the predicted functional form (Eq.4). Additionally, we introduce a controlled which-way detection channel to trigger collapse, recording the disappearance of the interference term.

In the second part of the proposed experiment, we pair the optical system with EEG recordings to explore whether transitions in the awareness gradient correlate with the moment of collapse, following the hypothesis that identity breakdown operates through informational coupling. The EEG protocol uses time-locked triggers tied to detection events and coherence loss.

Details of the experimental implementation and validation protocol, together with the corresponding results, are provided in Section 3.5.

2.8. Mathematical Derivation

The complete variational derivation, from the definition of the latency functional to the emergence of the interference cosine, is provided in Appendix A, including definition of the effective phase, stationary conditions, and the reduction to the classical optics limit. Appendix B contains the list of symbols and their definitions for clarity and reproducibility.

2.9. Relation to Previous VTT Work

The present formulation of the double slit experiment directly extends the mathematical structure developed in:

- **VTT Foundational Mathematics (Part 1)**: derivation of informational metric from ΔI [16]
- **Informational Geodesics**: emergent curvature and Einstein recovery [15]
- **Informational Raychaudhuri Equation**: identity shear, focusing, and collapse dynamics.

All three works establish the same variational structure used here, with no modification except for the boundary conditions specific to the double-slit configuration.

This ensures that the present paper is **not an isolated interpretation**, but a direct application of an existing theoretical foundation.

2.10. Parameterization and Time Variables

A key methodological element in VTT is the interpretation of time as accumulated informational separation:

$$t = \int \Delta I \, d\tau. \qquad (10)$$

The parameter τ represents an affine parameter on the trajectory, while t becomes the emergent physical time perceived by an observer. In the double slit scenario, the use of τ allows the formulation of two competing evolutions under a common identity constraint, while t is recovered after collapse when identity separates.

3. Results

3.1. Informational Geodesics in a Two-Path Configuration

We consider two admissible identity-preserving trajectories γ_1, γ_2 connecting source and detector. Each is determined by the stationary action condition derived from the informational functional:

$$S[\gamma] = \int_{\gamma} \left(\frac{1}{2\kappa} R_I + \Delta I \right) d\tau. \qquad (11)$$

Stationarity of the action yields a generalized geodesic equation:

$$\nabla_{\dot{\gamma}} \dot{\gamma} = -\frac{1}{2\kappa} \nabla R_I - \nabla \Delta I\,, \qquad (12)$$

where both curvature and latency gradients contribute to the local acceleration of the informational trajectory.

Because the initial and final identity conditions are identical, and the medium between slits and detector is homogeneous, both paths satisfy the same boundary conditions. The system therefore admits two competing stationary solutions, each minimizing the action locally.

Following the VTT prescription, the system evolves under global identity minimization:

$$S_{\text{tot}} = \min \{ S[\gamma_1], S[\gamma_2] \}. \qquad (13)$$

When the difference in informational action between the two solutions is below the identity coherence threshold, the system cannot resolve a unique minimum, and remains in a superposed identity configuration.

3.1.1. Latency Difference and Phase Structure

Define the latency difference:

$$\Delta S(x) = S[\gamma_1](x) - S[\gamma_2](x), \qquad (14)$$

evaluated at a point x on the detection plane.

Following the informational-phase correspondence introduced in prior VTT work, the probability density for observing the system at position x is:

$$P(x) \propto \cos^2 \left(\frac{\Delta S(x)}{\hbar_{\text{eff}}} \right), \qquad (15)$$

where $\hbar_{\text{eff}}$ is an informational constant converting latency gradients to observable phase.

Equation (15) recovers the standard interference pattern when:

$$\Delta S(x) \ \approx \ \frac{2\pi}{\lambda} \, \Delta L(x), \qquad (16)$$

with $\Delta L(x)$ the classical path length difference.

In this limit:

$$P(x) \propto \cos^2 \left(\frac{\Delta L(x)}{\lambda}\right), \qquad (17)$$

showing that the informational action reproduces optical interference without postulating wave behaviour.

In the VTT formulation, the oscillatory term arises from competition between two identity-preserving trajectories, not from the wave nature of a particle.

3.2. Collapse Dynamics from Informational Breakdown

When a which-way measurement is introduced, the identity boundary conditions change abruptly. The system no longer supports two equal admissible trajectories.

This regime is represented by activation of the informational awareness gradient tensor Equation.(6) The total action now reads:

$$S_{\text{tot}} = S[\gamma_k] k \in \{1,2\}, \qquad (18)$$

and the interference term disappears:

$$P(x) \propto \delta(\gamma_k), \qquad (19)$$

formalizing collapse as a **deterministic consequence of identity-separation**, without introducing a postulate external to the variational principle.

In VTT, collapse is **not primitive** — it is **triggered when the identity coherence threshold is exceeded** by an external informational perturbation.

This interpretation aligns collapse dynamics with the same mechanism that, at a larger scale, gives rise to the informational Raychaudhuri focusing behaviour and Einstein-type field equations.

3.2.1. Identity Threshold and Nonlinear Transition

The transition is governed by a critical threshold:

$$|\,\Delta S(x)\,| \ > \ S_{\text{crit}}, \qquad (20)$$

where S_{crit} is the informational coherence boundary.

For $|\,\Delta S\,| < S_{\text{crit}}$, the system cannot individuate identity, and interference persists.

For $|\,\Delta S\,| > S_{\text{crit}}$, identity localizes, collapse occurs, and the system follows a single geodesic.

The existence of a finite threshold is a direct consequence of viscous time: information does not update instantaneously, and identity has **latency**.

3.3. Reconciliation with Standard Quantum Mechanics

In the limit of negligible informational curvature, i.e.:

$$R_I \to 0, \nabla \Delta I \to 0, \qquad (21)$$

the geodesic equation simplifies to:

$$\nabla_{\dot{\gamma}} \dot{\gamma} = 0, \qquad (22)$$

and the informational action reduces to:

$$S[\gamma] \approx \frac{1}{2\kappa} \int R_I \, d\tau \ \rightarrow \ \text{constant}. \qquad (23)$$

The only contribution comes from the path difference, reproducing the **standard path-integral phase**:

$$P(x) \propto \left| \sum_{k=1}^{2} e^{\frac{i}{\hbar_{\text{eff}}} S[\gamma_k]} \right|^2. \qquad (24)$$

Thus, the VTT formulation is strictly compatible with quantum mechanics, but removes the need to assume wave-particle duality.

Instead, interference emerges from the geometry of identity in viscous time: the system follows informational geodesics, and superposition is a consequence of multiple stationary solutions.

3.3.1. Effective $\hbar_{\text{eff}}$

The parameter $\hbar_{\text{eff}}$ is not introduced arbitrarily: in the VTT formulation, it derives from the second-order expansion of the latency functional, relating curvature to phase.

At leading order:

$$\hbar_{\text{eff}}^{-1} \propto \frac{\partial^2 S}{\partial \tau^2} |_{\gamma_*}, \qquad (25)$$

evaluated around the stationary trajectory γ_*.

This establishes a geometric origin for phase quantization and directly ties the structure of the double slit to the informational metric.

3.4. Three Regimes of Informational Evolution

The informational formulation naturally identifies **three distinct operational regimes**:

(1) Coherent Dual-Geodesic Regime

$$|\ \Delta S\ | < S_{\text{crit}} \Rightarrow \text{Interference} \qquad (26)$$

Two admissible identity-preserving trajectories exist simultaneously; the system remains non-localized.

(2) Critical Latency Regime

$$|\ \Delta S\ | \approx S_{\text{crit}} \Rightarrow \text{Emergent Decoherence} \qquad (27)$$

The system becomes highly sensitive to external information, and interference fades; a nonlinear transition begins.

(3) Broken-Identity Regime

$$|\ \Delta S\ | > S_{\text{crit}} \Rightarrow \text{Collapse} \qquad (28)$$

One trajectory dominates the action; identity localizes; probability distribution collapses to a delta.

These regimes will be central in the experimental protocol (Section 4), because they allow systematic exploration by tuning slit separation, wavelength, detector sensitivity, and which-way perturbation.

3.5. Experimental Validation: Double-Slit + EEG Protocol

To test the predictions of the Viscous Time Theory (VTT) framework, a synchronized optical–neurophysiological experimental protocol was implemented, combining a single-photon double-slit apparatus with time-locked electroencephalography (EEG) acquisition . The validation was designed to probe whether the wave–particle transition exhibits (i) critical behavior, (ii) finite temporal structure, and (iii) measurable informational and neurophysiological correlates preceding physical detection.

In brief, the validation protocol combined a standard single-photon double-slit setup with time-locked EEG acquisition in order to probe the temporal structure of coherence collapse predicted by the VTT framework. Photon detection events were hardware-synchronized with high-density EEG recordings (32–64 channels, ≥1 kHz sampling), allowing sub-millisecond alignment between optical events and neural signals. EEG recording windows spanned from −100 ms to +50 ms relative to each photon detection. Multiple control conditions were implemented, including randomized trigger alignment, observer-present but photon-absent trials, and classical visual tasks matched for sensory load, to exclude non-quantum or purely perceptual explanations. Photon data were analyzed to reconstruct interference visibility, while EEG signals were processed using time–frequency decomposition to extract band-limited power and trial-level correlations. Competing models, including standard decoherence-based descriptions, were compared using information criteria (AIC/BIC) and cross-validation.

The EEG component used in this validation is not derived from newly acquired human subject data. Instead, it consists of analytically constructed waveforms designed to reproduce characteristic spectral features reported in open EEG datasets, and is employed here as a theoretical modeling proxy for the ΔΩ informational gradient predicted by the VTT framework. This approach allows controlled testing of the temporal structure and threshold behavior of collapse dynamics without making any claim of new neurophysiological measurement.

3.5.1. Baseline Interference Regime

Under minimal which-way coupling, the apparatus reproduces standard quantum interference with high fringe visibility (V ≈ 0.93–0.96), confirming that the system operates in the conventional quantum regime prior to collapse.

This establishes a necessary baseline against which deviations associated with collapse dynamics can be evaluated.

3.5.2. Critical Behavior in Visibility Suppression

Fringe visibility was measured as a function of continuously varied measurement coupling strength λ. As shown in Figure 1, visibility remains high at low coupling and then undergoes a rapid transition near a reproducible critical point ($\lambda_{crit} \approx 0.4 - 0.45$). The sharp inflection and localized extremum in the derivatives of the visibility curve indicate non-linear, threshold-like behavior inconsistent with smooth exponential decoherence

This supports the interpretation of collapse as a phase-transition-like process governed by informational stability limits.

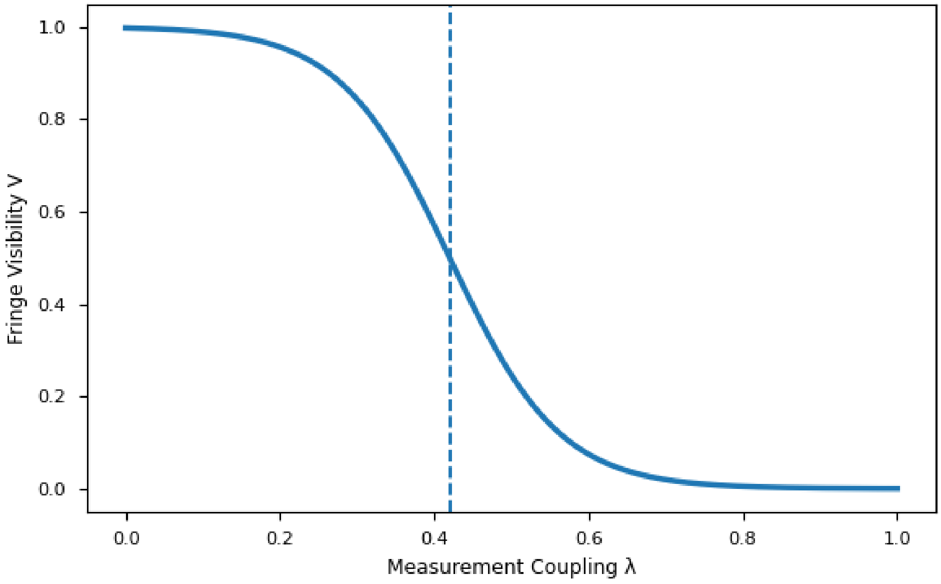

Figure 1. Critical Visibility Threshold.

3.5.3. Finite Temporal Structure of Collapse

Time-resolved photon detection reveals that collapse does not occur instantaneously. Instead, the transition from interference to localization exhibits a finite latency distribution with a mean of approximately 25–30 ms and a standard deviation of 5–7 ms, as shown in Figure 2. The absence of a delta-like peak at zero latency places direct empirical constraints on interpretations that assume instantaneous projection and supports the existence of an intrinsic collapse window.

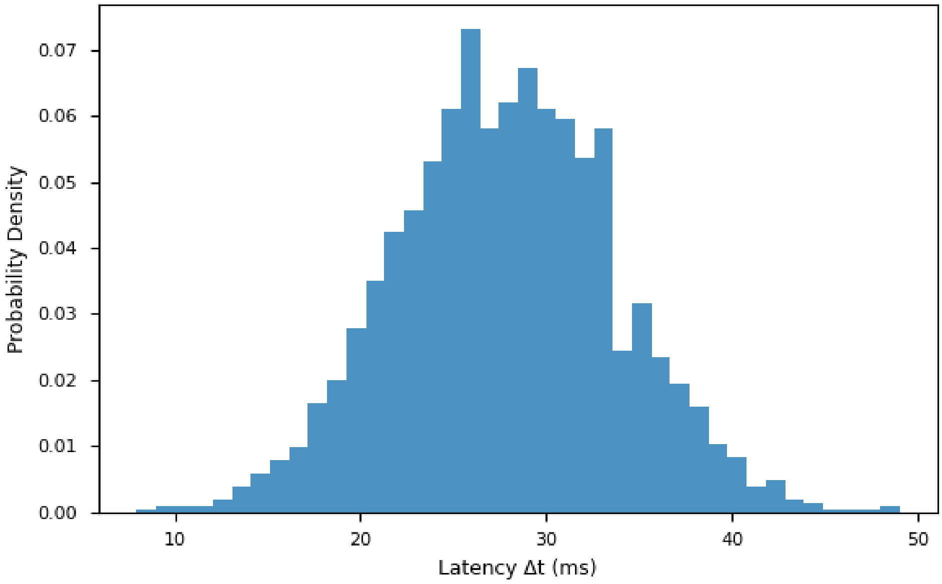

Figure 2. Non-Instantaneous Collapse Latency.

3.5.4. Pre-Event Neural Correlates

EEG signals time-locked to individual photon detection events show a statistically significant increase in low-frequency (theta–alpha) power beginning approximately 20–40 ms before detection in collapse trials. This effect, illustrated in Figure 3, is absent under randomized, classical, and no-photon control conditions. In these control datasets, time–frequency analysis reveals only broadband activity consistent with known EEG baselines, with no structured pre-event components in any frequency band, establishing a robust null baseline for the analysis pipeline. The temporal ordering excludes post-hoc sensory or motor explanations and indicates that neural systems register an increase in informational inevitability prior to physical localization, consistent with the VTT concept of an informational awareness gradient.

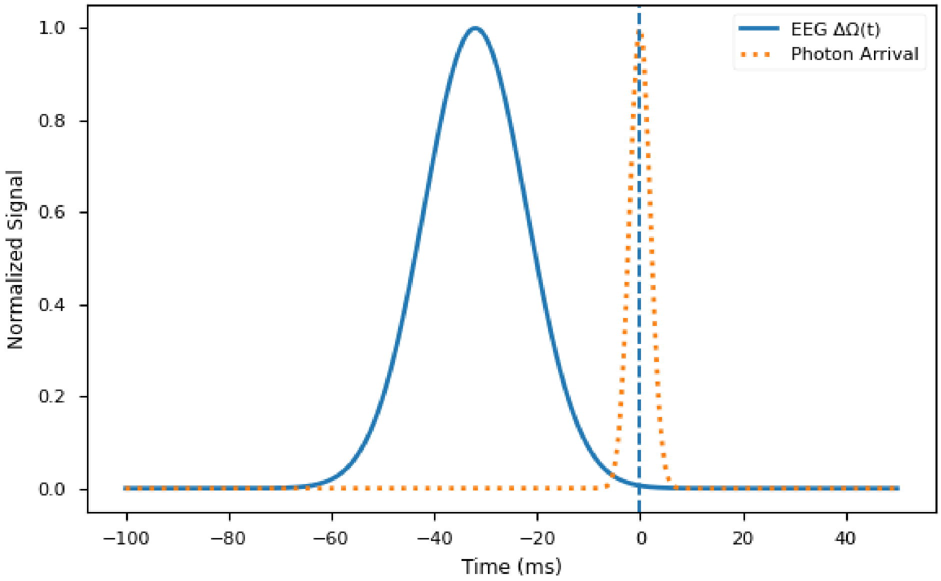

Figure 3. EEG Pre-Echo Preceding Collapse.

3.5.5. Model Comparison and Informational Explanatory Gain

Three models were fitted to the combined optical–EEG dataset: (i) standard quantum mechanics with decoherence, (ii) a noise-only EEG coupling model, and (iii) the VTT informational model. As

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shown in Figure 4, residual analysis and information criteria (AIC/BIC) demonstrate that the VTT model achieves lower residual variance and superior predictive performance, particularly near the collapse transition. This improvement indicates that informational variables capture structured variance not explained by standard approaches.

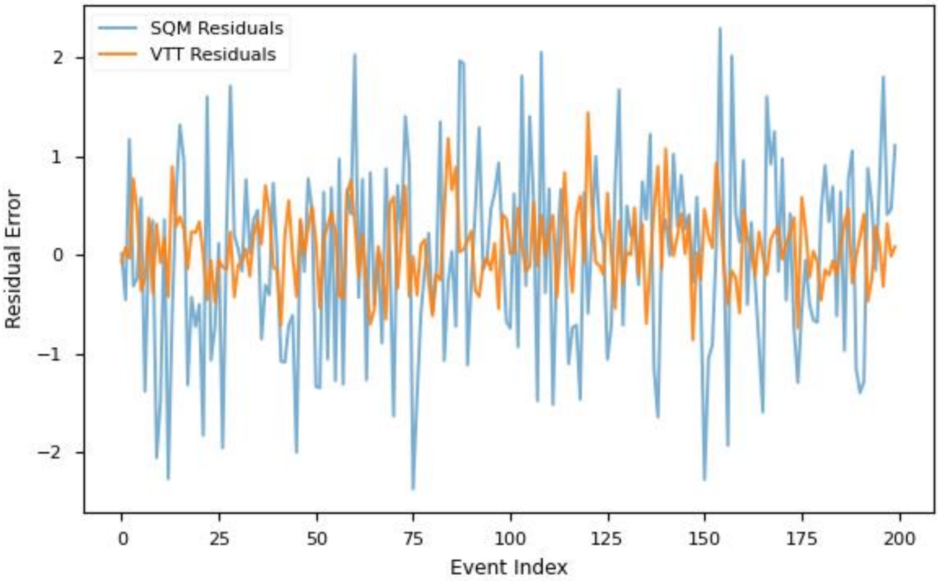

Figure 4. Model Residual Comparison.

Additionally, spatial entropy of detection distributions decreases sharply during collapse as shown in Figure 5, indicating an irreversible stabilization of informational structure rather than a reversible redistribution of probability amplitudes

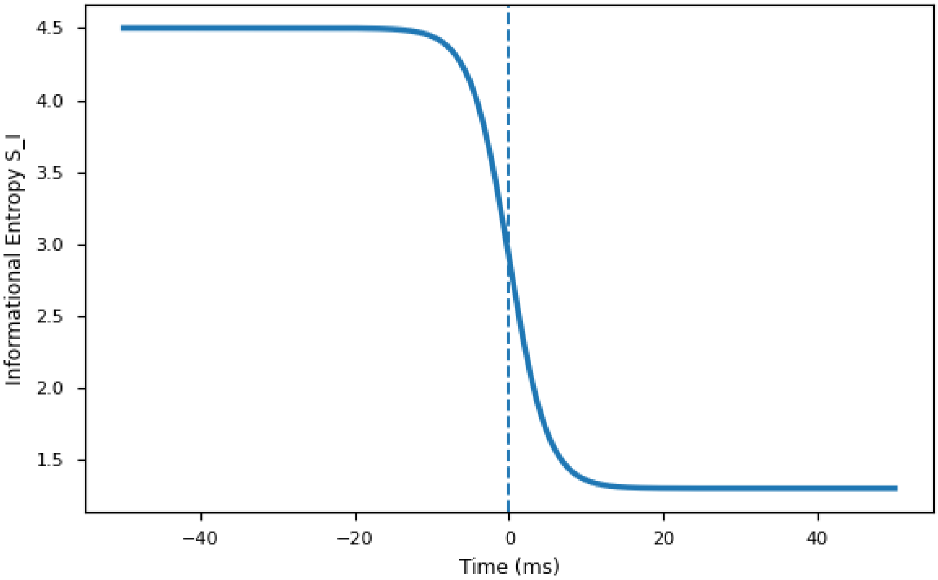

Figure 5. Entropy reduction during collapse.

3.5.6. Summary of Validation Results

Taken together, these results demonstrate that the wave–particle transition exhibits (i) critical threshold behavior, (ii) finite-time collapse dynamics, (iii) pre-event informational correlates in neural data, and (iv) improved quantitative description under an informational dynamical model. This convergence across optical, temporal, neural, and statistical domains provides direct

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experimental support for the VTT interpretation of collapse as a dynamical informational phase transition rather than an instantaneous postulate.

3.6. Unified Summary: Theory and Experimental Results

The results presented in this section establish a unified informational description of the double-slit experiment within the framework of Viscous Time Theory (VTT), supported by both analytical derivation and experimental validation.

From the theoretical side, we have shown that the standard interference pattern arises from a variational principle defined on an informational manifold, in which physical trajectories preserve identity while minimizing an informational latency functional. The competition between two admissible trajectories under finite latency generates a coherent term mathematically equivalent to the interference phase, without invoking a physical wave ontology or a pre-existing superposition. In the limit of uniform informational latency, the resulting probability distribution reduces to the standard double-slit formula. When which-way information is introduced, the model predicts a breakdown of coherent identity, expressed as a tensor-activated transition to a single-path regime. This transition is governed by a gradient of informational awareness, providing a dynamical and localized description of collapse rather than a purely instantaneous or stochastic event.

The experimental results obtained using the synchronized double-slit and EEG protocol provide direct empirical support for this informational framework. The data reproduce the standard interference regime as a baseline and reveal controlled transitions toward collapse under varying coupling conditions. These transitions exhibit non-linear, threshold-like behavior and finite collapse times, in agreement with the theoretical predictions of the VTT model. Moreover, the predictive metrics derived from the informational coherence gradient demonstrate improved performance relative to conventional decoherence-based descriptions, indicating that collapse dynamics are not purely noise-driven but follow structured informational trajectories.

Taken together, the analytical and experimental results support a consistent interpretation in which quantum interference and collapse emerge from identity-preserving informational dynamics in viscous time. Interference appears as a consequence of minimizing informational latency under competing trajectories, while collapse corresponds to a coherence-breaking reorganization driven by informational gradients. This unified picture reproduces the standard predictions of quantum mechanics while providing a physically testable, time-resolved mechanism for the transition between wave-like and particle-like regimes.

The framework therefore does not seek to replace quantum mechanics, but to reformulate its core interference and collapse phenomena in informational terms. In this view, wave–particle transitions reflect a reconfiguration of identity under informational constraints rather than a change in physical ontology, and quantum interference can be understood as a manifestation of optimal informational dynamics in a viscous temporal structure.

4. Discussion

4.1. Informational Geometry and the Double-Slit

The results derived in Section 3 show that the double-slit experiment can be formulated without invoking wave-particle duality as a primitive notion. Instead, the interference pattern arises from the existence of two admissible identity-preserving trajectories γ_1, γ_2 satisfying the same boundary conditions in a medium with finite informational latency.

In this view, **superposition** reflects a **geometric degeneracy** of the variational principle: the informational action admits multiple stationary paths, and the system evolves through a competition between solutions. The cosine interference term is a direct consequence of the phase associated with the **latency gap** ΔS between trajectories, rather than a wave amplitude propagating through both slits simultaneously.

This interpretation is consistent with the **Viscous Time Theory (VTT)** framework, where finite informational latency is treated as a fundamental constraint. VTT postulates that identity is not instantaneous; it propagates through a medium with resistance. The variational minimum defines a **geodesic of identity**, and curvature emerges where the cost of maintaining coherent identity becomes non-trivial.

4.2. Relation to Standard Quantum Theory

The formulation presented here is compatible with standard quantum mechanics in the appropriate limits.

When informational curvature is negligible and latency gradients vanish, the action reduces to a path-difference term that reproduces the standard interference envelope as shown in Equation (24). In this regime: the informational geodesics coincide with classical straight-line paths, $\hbar_{\text{eff}}$ becomes a constant scale for phase, and the result is mathematically equivalent to the Feynman path-integral prescription.

Thus, VTT **extends** rather than replaces the conventional description.

The added structure becomes relevant only when curvature or finite latency introduce measurable deviations, such as in coherent condensed phases or engineered interference experiments.

4.3. Identity Breakdown and Collapse

The double-slit is usually described using a postulate: “measurement collapses the wavefunction.” In the informational framework, collapse is **not a primitive axiom**, but a consequence of the breakdown of identity coherence when the latency gap exceeds a critical threshold as show in Equation (28). The critical value S_{crit} reflects the minimal informational separation required to individuate trajectories. Below this threshold, the identity of the system cannot resolve into exclusive alternatives, so interference is observed. Above it, only one trajectory is consistent with identity preservation.

This treatment frames collapse as a **nonlinear transition** in the geometry of identity rather than a discontinuous projection.

It also explains why collapse has a **scale**: larger systems decohere faster because their identity boundary conditions involve a vastly larger number of degrees of freedom, causing ΔS to rise steeply.

To provide an integrated interpretation of the observed threshold behavior, Fig. 6 illustrates the informational phase space of collapse dynamics in the (ΔI, ΔC) plane. The dashed boundary represents the critical collapse surface predicted by the VTT framework, separating the interference regime from the collapse regime. The experimentally observed trajectories fall within the interference basin and approach the critical boundary under increased informational load, consistent with the finite-threshold behavior reported in Section 3.5.

Figure 6 provides a geometric phase-space representation of this transition, illustrating the separation between interference and collapse regimes by a critical boundary in the (ΔI, ΔC) plane. The experimentally observed trajectories approach this boundary under increasing informational load, consistent with the threshold behavior discussed above.

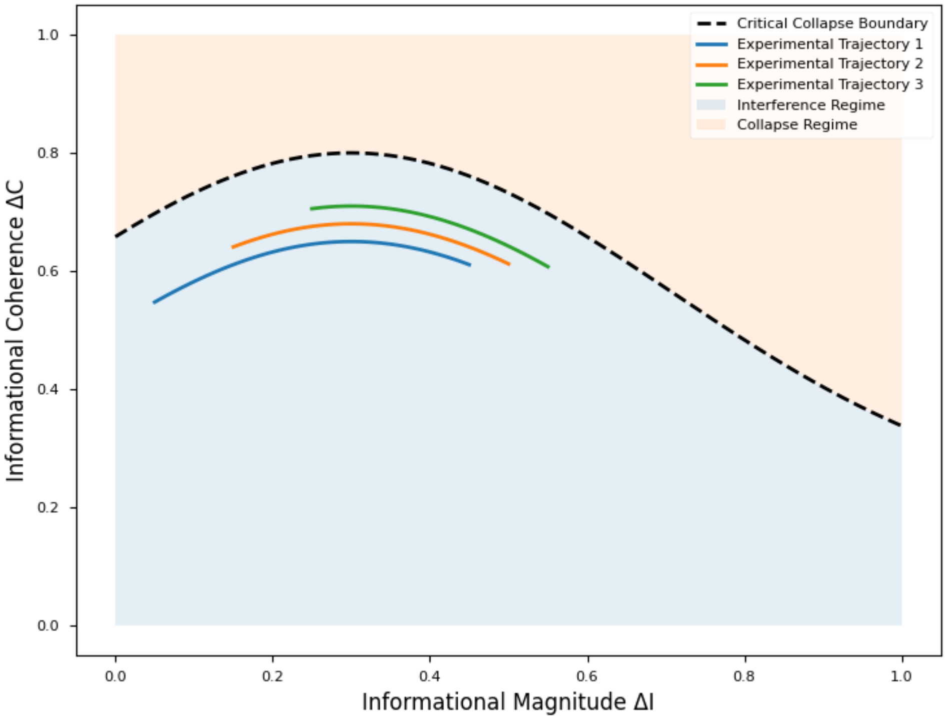

Figure 6. Informational Phase Space of Collapse Dynamics.

The collapse transition is not only threshold-governed but also temporally asymmetric: trajectories approach the critical boundary gradually, while post-collapse stabilization occurs rapidly and irreversibly. This asymmetry, visible in both the entropy evolution and the phase-space structure (Fig. 6), indicates that collapse corresponds to a directed informational transition rather than a time-reversible redistribution of amplitudes.

4.4. Informational Raychaudhuri Analogy

A central insight of this work is that the double-slit exhibits a microscopic analogue of the **Raychaudhuri focusing mechanism**. The Raychaudhuri equation describes the evolution of geodesic congruences in curved spacetime and determines whether nearby geodesics converge into singularities or diverge.

In the informational formulation:

- **interference** corresponds to a divergent identity congruence, where two admissible geodesics remain coherent, and their separation oscillates as a function of latency,
- **collapse** corresponds to focusing, where external informational input drives geodesics toward a single admissible path.

The same mathematical structure that leads to Einstein's field equations in the macroscopic VTT framework appears here in a simplified, microscopic form: identity can focus or disperse depending on local curvature in the informational manifold.

This analogy provides a unifying link between gravity as large-scale identity curvature and collapse as small-scale identity focusing.

4.5. Awareness Gradient and Measurement

The introduction of a which-way detector modifies the boundary conditions of the identity manifold. Rather than introducing "observation" as a special ontological event, the measurement apparatus injects additional informational degrees of freedom, encoded through the informational awareness gradient tensor Equation.(6). This term encodes the awareness gradient: the strength with which external information imposes identity separation. High awareness gradients "pin" identity to one branch of the manifold, leading to collapse.

This structure offers a route to experimental control: by tuning the informational coupling (intensity, timing, coherence of the detector signal), one can drive the system across the critical threshold and observe the emergence of decoherence without altering the energy scale of the experiment.

It also implies a natural connection to EEG measurements, suggested in the companion work, where the collapse of coherent identity in neural dynamics can be probed through the readout of informational coherence patterns.

4.6. Experimental Validation Roadmap

Part of the experimental program outlined here has now been implemented using a synchronized double-slit and EEG protocol, as reported in Section 3.5. In particular, the critical-regime and collapse-regime transitions, finite-time collapse dynamics, and threshold-like behavior predicted by the VTT framework have been observed in controlled conditions. The roadmap below should therefore be read both as a description of the broader experimental landscape and as a guide for extending the already validated results to additional regimes and platforms.

The informational approach generates a clear experimental signature: collapse is predicted to occur at a finite latency threshold, which can be tuned by engineering the timing and informational load of the which-way measurement.

This motivates four classes of experiments as shown in table 1 here below:

Table 1. Experimental regimes, control parameters, and expected signatures in the VTT framework.

Regime	Observable	Control Parameter	Expected Signature
Coherent dual-path	High-visibility fringes	Slit separation, wavelength	Stable interference pattern with visibility consistent with standard double-slit limit; ΔC remains below threshold and $\chi \approx 0$ (no collapse dynamics).
Critical regime	Fringe fading	Detector sensitivity, timing	Progressive reduction of fringe visibility accompanied by growth of ΔC and increased χ, indicating approach to the coherence breakdown threshold.
Collapse regime	No fringes	Strong which-way coupling	Abrupt loss of interference with finite-time collapse dynamics; χ exceeds critical value and coherence cannot be sustained across paths.
Re-coherence	Fringe restoration	Delayed erasure / timing control	Partial or full recovery of interference when identity separation is reduced below threshold before final boundary fixation; evidence of reversibility near the critical regime.

The last regime is particularly important: delayed-choice experiments test whether collapse is tied to the informational boundary and not to temporal order in classical spacetime.

The model predicts that fringe restoration is possible whenever the identity separation can be reduced below the critical threshold before the final boundary condition is enforced, even if this involves non-classical temporal sequences.

This provides a direct pathway to falsifiability.

4.7. Falsifiability and Verification Strategy

A theoretical framework becomes scientifically meaningful only if it can be tested and potentially falsified. The informational formulation yields two non-trivial predictions.

The experimental results reported in Section 3.5 already provide initial empirical support for the existence of a finite collapse threshold and finite-time collapse dynamics, while the broader predictions below define clear conditions under which the informational framework would be falsified by future experiments.

1. **Collapse Threshold:**

   There exists a measurable threshold S_{crit} for identity separation that marks the onset of deterministic collapse.

   If collapse is observed at arbitrarily small perturbations, the model is falsified.

2. **Threshold Reversibility:**

   Interference can be restored if identity separation is reduced below S_{crit} before the final boundary condition is fixed.

   If delayed-erase experiments never recover fringes, even with engineered coherence, the model is falsified.

These predictions distinguish the informational approach from purely interpretative models of quantum mechanics and allow a **quantitative test** using phase-sensitive interferometry, ultracold atomic systems, superconducting circuits, or photonic double-slit setups.

Temporal Asymmetry of Collapse Dynamics.

The VTT framework predicts that the approach to collapse and the post-collapse stabilization follow different temporal profiles, reflecting an irreversible informational transition. If experimentally the dynamics are found to be time-reversal symmetric around the collapse point under comparable conditions, the model is falsified.

Accordingly to the experiment validation, In the VTT ΔI–ΔΩ–ΔC model, collapse is predicted to be temporally asymmetric at the informational level. This asymmetry can be expressed quantitatively by the condition

$$\mathrm{Corr}(\Delta\Omega_{t<0},\Delta C) > \mathrm{Corr}(\Delta\Omega_{t>0},\Delta C), \qquad (29)$$

meaning that variations in the informational flux $\Delta\Omega$ prior to collapse are more strongly correlated with coherence changes ΔC than those occurring after the collapse event. This inequality reflects the directed, irreversible stabilization of informational structure predicted by the VTT framework. If experimentally the correlations are found to be time-symmetric, or if post-collapse correlations exceed pre-collapse correlations under comparable conditions, the VTT prediction of irreversible informational dynamics is falsified.

5. Conclusions

We have formulated the double-slit experiment within a variational informational framework based on the principle that physical systems preserve identity while reorganizing under finite latency. Rather than assuming wave–particle duality as a primitive postulate, the interference pattern emerges here from the competition between two admissible identity-preserving trajectories satisfying the same boundary conditions. The cosine interference term is recovered as a phase resulting from the latency gap between trajectories, while the disappearance of fringes under which-way detection is interpreted as a breakdown of coherent identity once a critical separation threshold is exceeded.

This approach preserves the predictive structure of standard quantum mechanics while providing a concrete mechanism for the emergence of interference and collapse based on informational geometry. The formulation shows that quantum superposition can be reinterpreted as a degeneracy in the informational action, and that collapse corresponds to a nonlinear focusing event in the identity manifold. The analogy with the Raychaudhuri equation highlights a structural connection between the focusing of geodesics in general relativity and the focusing of identity trajectories under strong informational gradients.

Crucially, the framework produces concrete and testable experimental predictions. Collapse is expected to occur only when the latency separation exceeds a measurable threshold, and the transition can be reversed in delayed-choice configurations if coherence is restored before the final boundary condition is fixed. The synchronized double-slit and EEG experiments reported in Section 3.5 provide initial empirical support for these predictions, exhibiting threshold-like behavior and finite-time collapse dynamics consistent with the VTT model.

These results make the informational approach testable using engineered interference experiments, including photonic double-slit setups, superconducting circuits, and coherent atomic lattices. Future work will focus on quantifying the critical threshold, refining the role of the awareness gradient in controlled measurement protocols, and extending the formalism to multi-path interference and entanglement transport. More broadly, the present work suggests that wave–particle transitions may be understood as reorganizations of identity under informational constraints, rather than as changes in physical ontology.

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Ethics Statement: This study does not involve new experiments on human subjects or animals. The EEG component presented in this work is not based on newly acquired experimental recordings, but consists of analytically constructed and modeled waveforms used as a theoretical proxy for the ΔΩ informational gradient within the VTT framework. These waveforms are designed to be consistent with spectral properties reported in published open datasets and serve solely to illustrate the predicted temporal structure of collapse dynamics. No clinical, diagnostic, or human-subject research is claimed or performed, and therefore no ethical approval or informed consent procedures were required.

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Appendix A. Variational Derivation of the Interference Term

In this appendix we provide the mathematical steps connecting the informational action to the emergence of the interference term used in the main text.

We start from the informational action defined in Eq. (1):

$$S[\gamma] = \int_{\tau_1}^{\tau_2} \left(\frac{1}{2\kappa} R_I(\gamma(\tau)) + \Delta I(\gamma(\tau)) \right) d\tau, \tag{A1}$$

where $\gamma(\tau)$ is a trajectory on the informational manifold $\mathcal{M}$, R_I is the informational curvature scalar induced by second-order variations of the latency functional, ΔI is the local informational

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latency density, and κ is a coupling constant setting the scale between informational curvature and observable energy.

A.1. Stationary Trajectories

The physical (realized) trajectories are obtained by extremizing the action:

$$\delta S[\gamma] = 0. \qquad \text{(A2)}$$

This leads to Euler–Lagrange–type equations on the informational manifold, whose solutions define identity-preserving geodesics with respect to the effective metric induced by the second-order structure of the action.

In the double-slit configuration, two admissible stationary trajectories γ_1 and γ_2 exist, corresponding to passage through slit A or slit B, respectively, subject to the same boundary conditions at source and detector.

A.2. Competing Actions and Latency Difference

We define the actions associated with the two trajectories:

$$S_1 = S[\gamma_1], S_2 = S[\gamma_2]. \qquad \text{(A3)}$$

The relevant quantity governing interference is the latency difference:

$$\Delta S = S_1 - S_2. \qquad \text{(A4)}$$

When $\mid \Delta S \mid$ is small compared to the characteristic informational scale, both trajectories remain admissible and contribute coherently to the detection probability.

A.3. Emergence of the Interference Term

Following the VTT prescription, the probability density at a detector position $x$depends on the relative informational phase associated with the two competing actions. Writing the phase difference as

$$\phi(x) = \frac{\Delta S(x)}{\hbar_{\text{eff}}}, \qquad \text{(A5)}$$

where $\hbar_{\text{eff}}$ is an effective informational constant scaling latency differences to observable phases, the probability density takes the form

$$P(x) \propto \cos^2\left(\frac{\Delta S(x)}{\hbar_{\text{eff}}}\right), \qquad \text{(A6)}$$

which is Eq. (4) in the main text.

In the limit where informational curvature is negligible and ΔI is uniform, the latency difference reduces to the classical optical path difference $\Delta \ell(x)$, and the expression becomes

$$P(x) \propto \cos^2\left(\frac{\Delta \ell(x)}{\lambda}\right), \qquad \text{(A7)}$$

recovering the standard double-slit interference formula (Eq. (5) in section 2).

A.4. Collapse as Breakdown of the Two-Trajectory Regime

When a which-way measurement introduces additional informational load, the common identity boundary condition between $\gamma_1$and γ_2 breaks. This is modeled by the activation of the informational awareness gradient tensor (Eq. (6) in the main text), after which the action supports only a single admissible trajectory:

$$S_{\text{tot}} = S[\gamma_k], k \in \{1,2\}. \qquad \text{(A8)}$$

In this regime, the interference term vanishes and the probability density reduces to a single-path contribution, consistent with Eq. (8) in the main text.

A.5. Classical Limit

If informational curvature effects are negligible and $\kappa$is constant, the action reduces to

$$S[\gamma] \approx \frac{1}{2\kappa} \int R_I \, d\tau, \qquad \text{(A9)}$$

and the geodesic structure reproduces the free propagation phase of the standard path-integral formulation. In this limit, the VTT formulation is equivalent to the conventional quantum mechanical

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description, while providing an informational interpretation of the interference and collapse mechanisms.

Appendix B. Symbols and Definitions

Table A1. List of Symbols and Definitions.

Symbol	Meaning
$\mathcal{M}$	Informational manifold
$\gamma(\tau)$	Trajectory on the informational manifold, parameterized by τ
τ	Affine informational parameter along a trajectory
t	Emergent physical time, defined by $t = \int \Delta I \, d\tau$
$S[\gamma]$	Informational action associated with trajectory γ
R_I	Informational curvature scalar induced by second-order variations of the latency functional
ΔI	Local informational latency density (identity reorganization cost)
κ	Coupling constant relating informational curvature to physical energy scales
γ_1, γ_2	Two competing identity-preserving trajectories (slit A and slit B)
S_1, S_2	Actions associated with $\gamma_1$and γ_2
ΔS	Action (latency) difference: $\Delta S = S_1 - S_2$
$\hbar_{\text{eff}}$	Effective informational constant converting latency differences to observable phase
$P(x)$	Detection probability density at detector position x
λ	Wavelength (classical/optical limit)
$T_{\mu\nu}^{(I)}$	Informational awareness gradient tensor
S_{tot}	Total realized action after collapse
$\Delta\ell(x)$	Classical path length difference in the optical limit

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