

Holographic Information Substrate: A Unified Framework for Observer Physics, Quantum Measurement, and Gravitational Phenomenology

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Abstract

Recent work by Arkani-Hamed and Trnka (2014) demonstrates that scattering amplitudes in certain quantum field theories can be computed from purely geometric objects—the amplituhedron—without reference to spacetime coordinates or local interactions. This 'spacetime elimination' program suggests that familiar spacetime and locality may be emergent bookkeeping conveniences rather than fundamental ontology. Parallel developments in quantum gravity, particularly holographic dualities and the Ryu-Takayanagi formula relating entanglement entropy to area, indicate that spacetime geometry itself may emerge from entanglement structure on lower-dimensional boundaries.

We develop this into an observer-physics framework yielding novel perspectives on three seemingly unrelated problems: (i) the quantum measurement problem, (ii) the nature of phenomenal consciousness and its relation to brain dynamics, and (iii) dark matter phenomenology observed in galaxies and clusters. The central proposal is that there exists a timeless 'surface field'—a holographically encoded information substrate—on which all physically relevant structure is encoded as positive geometries and entanglement patterns. Biological observers function as specialized interfaces that select and interpret particular slices of this substrate. Quantum measurement, on this view, is not physical wavefunction collapse but biological interpretation-path selection: decoherence-stabilized coupling between the surface field and an observer's internal predictive hierarchy.

This framework: (1) dissolves the measurement problem by reconceiving 'collapse' as interface-limited interpretation; (2) reframes the 'hard problem' of consciousness as an interface-coupling problem rather than emergence from matter; (3) naturally produces an effective dark matter component through gravitational coupling to unselected branch structure in semiclassical gravity. We develop the formal foundations, specify biological interface architecture, derive consequences for quantum experiments, neuroscientific signatures, and galactic dynamics, and show compatibility with existing empirical data while yielding novel, falsifiable predictions.

Keywords: *amplituhedron, surfaceology, holographic principle, quantum measurement, decoherence, quantum Darwinism, consciousness, electromagnetic field theories of mind, dark matter, semiclassical gravity, emergent spacetime, observer interfaces*

1. Introduction: Four Persistent Problems

Contemporary physics faces four distinct but potentially related explanatory challenges: (1) the quantum measurement problem, (2) the observer-physics interface problem, (3) the dark matter problem, and (4) the unity problem of integrating quantum theory, spacetime, and observers. These are typically treated in isolation—quantum measurement in foundations, observer-physics in philosophy of mind, dark matter in astrophysics, and unity in quantum gravity. Yet all four involve a common theme: the relationship between information, observers, and spacetime structure.

The standard approach assumes spacetime is fundamental, observers are emergent physical systems within spacetime, and quantum states describe physical systems evolving in time. Measurement then appears as a local, time-asymmetric collapse producing definite outcomes, dark matter as unexplained mass in spacetime, and consciousness as a mysterious byproduct of neural activity. We challenge this hierarchy by reversing the explanatory direction: spacetime, observers, and measurement will all be derived from a more fundamental holographically encoded information structure.

1.1 The Quantum Measurement Problem

Quantum mechanics describes reality through unitary, time-symmetric evolution of probability amplitudes. Yet measurement appears to produce definite, irreversible outcomes. The Copenhagen interpretation addresses this by postulating wavefunction collapse—an intrinsically time-asymmetric, non-unitary process. Attempts to avoid collapse include many-worlds (Everett, 1957), hidden variable theories (Bohm, 1952), and objective collapse models (GRW, Penrose). Each faces conceptual and technical challenges (Maudlin, 1995; Albert, 1992).

Decoherence theory explains the appearance of definiteness through environmental entanglement (Zurek, 2003). When a system interacts with its environment, interference between wavefunction components becomes practically unobservable. The reduced density matrix diagonalizes in a preferred basis, yielding classical-like probabilities. Quantum Darwinism extends this by showing how redundant environmental encoding selects certain states as effectively classical (Zurek, 2009). However, decoherence alone does not solve the measurement problem: it explains why interference terms become unobservable, but not why a particular outcome is realized. As Schlosshauer (2005) notes, decoherence replaces the

collapse postulate with environment-induced superselection but leaves the 'and/or' problem unresolved.

The framework proposed here approaches measurement differently. Rather than asking how quantum states become classical, we ask: what physical structure determines which aspects of the substrate become available to particular observers? Measurement becomes an interface-selection process: biological observers are specialized systems that stably couple to certain informational structures, with decoherence providing stability conditions. Wavefunction collapse is not a physical process but a category error—confusing interface access limitations with changes in fundamental state.

1.2 The Observer-Physics Interface Problem

What constitutes an 'observer' in quantum mechanics? Why do certain systems select definite classical outcomes while others do not? Traditional accounts either treat observers as primitive (Copenhagen) or reduce them to generic physical systems (Everett). Neither has satisfactorily explained why some physical systems instantiate phenomenally unified experience while others do not.

Relational quantum mechanics (Rovelli, 1996) proposes that quantum states represent relations between systems rather than absolute properties. QBism (Fuchs, 2010) interprets quantum states as personalist Bayesian degrees of belief. Both remove the need for observer-independent collapse but leave the physical nature of observers underspecified. As Brukner (2018) notes, relational interpretations struggle to explain emergence of a shared classical world without additional structure.

Neuroscience and consciousness studies attempt to characterize neural correlates of consciousness. Global neuronal workspace theory (Dehaene & Changeux, 2011) and integrated information theory (Tononi, 2016) identify functional and informational properties correlated with conscious experience. Electromagnetic field theories propose that macroscopic EM fields generated by neural activity may constitute the physical substrate of consciousness (McFadden, 2020; Pockett, 2012). However, these accounts typically assume background spacetime and do not integrate with quantum measurement theory or holographic physics.

1.3 The Dark Matter Problem

Astrophysical observations indicate galaxies, clusters, and large-scale structure contain significantly more gravitating mass than visible matter accounts for. Rotation curves of spiral

galaxies remain flat at large radii, gravitational lensing reveals mass concentrations not aligned with luminous matter, and cosmic microwave background anisotropies require additional non-baryonic matter (Planck Collaboration, 2018).

The standard solution is cold dark matter (CDM): weakly interacting massive particles. Despite extensive searches (LUX, XENON1T, LHC), no dark matter particle has been detected. Modified gravity theories propose alternatives (MOND, TeVeS, Verlinde's emergent gravity) but struggle to simultaneously fit rotation curves, cluster dynamics, and cosmological observations (Famaey & McGaugh, 2012). The Bullet Cluster (Clowe et al., 2006) exemplifies the tension: gravitational lensing shows mass peaks offset from baryonic plasma, suggesting collisionless dark matter that modified gravity has difficulty reproducing.

An intriguing alternative was proposed by Mensky (2011): dark matter from quantum branched universes. In this Everettian approach, dark matter arises from contributions of unobserved branches—branches contribute gravitationally but not electromagnetically. However, this proposal has remained underdeveloped. The present framework builds on Mensky's insight, embedding it within holographic information ontology and deriving specific, testable halo profile predictions.

1.4 The Unity Problem and the Surfaceology Revolution

Recent developments suggest spacetime may be emergent from more fundamental combinatorial or geometric structures. The amplituhedron program (Arkani-Hamed & Trnka, 2014) shows that scattering amplitudes in $N=4$ super Yang-Mills theory can be computed from positive geometries in an abstract space, with locality and unitarity emerging from positivity conditions. As Arkani-Hamed (2014) emphasizes: "Spacetime and quantum mechanics are doomed to be replaced by something deeper. One of them has to go, and it's probably spacetime."

This 'surfaceology' approach—physics described by boundary geometries rather than bulk evolution—extends beyond scattering: all physics may be encoded on lower-dimensional structures, with familiar spacetime trajectories emerging as derived, approximate descriptions. The holographic principle (Susskind, 1995; Bousso, 2002) suggests maximum entropy within a region scales with boundary area rather than volume. Van Raamsdonk (2010) and Ryu & Takayanagi (2006) connect spacetime geometry to entanglement entropy, suggesting spacetime itself may emerge from entanglement patterns.

More recent work strengthens this information-theoretic reading. Zizzi (2000) explicitly interprets holographic area bounds as qubit registers on boundary surfaces. The Holographic Information Principle (HIP, 2025) argues that information on such boundaries is ontologically primary, with both quantum field dynamics and spacetime geometry emerging from constraints on boundary information flow. These developments make it increasingly natural to treat holographic surface data—not bulk fields—as the fundamental bearer of physical structure.

We propose this convergence—amplituhedron elimination of spacetime for scattering plus holographic principle eliminating volume for information—as evidence that spacetime is not fundamental. If scattering amplitudes and black hole entropy both arise from boundary geometries, then perhaps all physically relevant structure is encoded on a timeless 'surface field'—a holographic information substrate. Observers and measurement then become questions of how particular biological systems couple to and interpret this substrate.

2. The Holographic Information Substrate

If consciousness functions as an interface and quantum measurement corresponds to biological interpretation, we require an underlying informational structure from which both quantum theory and spacetime geometry can be derived. This section formalizes the 'surface field'—a holographically encoded information substrate—consistent with developments in contemporary physics.

2.1 Holographic Principles in Contemporary Physics

The holographic principle emerged from black hole thermodynamics. Bekenstein (1973) and Hawking (1975) showed that black hole entropy scales with event horizon area, not enclosed volume. Susskind (1995) and 't Hooft (1993) generalized this: maximum entropy in any spacetime region is proportional to boundary area. Bousso (2002) formulated a covariant entropy bound: entropy flux through any light-sheet is bounded by a quarter of its initial surface area in Planck units.

The AdS/CFT correspondence (Maldacena, 1998) provides explicit realization: quantum gravity in (d+1)-dimensional Anti-de Sitter space is dual to conformal field theory on its d-dimensional boundary. Ryu & Takayanagi (2006) showed entanglement entropy of a boundary region equals the area of a minimal bulk surface: $S_A = \text{Area}(\gamma_A)/4G_N$. Van Raamsdonk (2010) argued that spacetime connectivity emerges from entanglement: "Spacetime geometry is built from entanglement patterns."

Critical Caveat: AdS/CFT is established only for Anti-de Sitter space and specific supersymmetric theories. Our universe appears approximately de Sitter rather than Anti-de Sitter, and we lack a full holographic dual for realistic cosmology. Extrapolating holographic principles to general spacetimes is speculative. Nonetheless, the ubiquity of area-entropy relations, entanglement-geometry links, and emergent spacetime constructions suggests some form of holographic encoding applies more generally.

2.2 Information as Ontologically Primary

Contemporary physics increasingly treats information as the primary currency. Quantum information theory rephrases quantum mechanics in terms of qubits, channels, and entropies. Landauer's principle connects information to thermodynamic entropy: "Information is physical." Wheeler's "it from bit" encapsulates the idea that physical reality emerges from information-theoretic principles.

Treating information as fundamental offers conceptual advantages. It naturally accommodates relational state descriptions (Rovelli, 1996), operational quantum states (Fuchs, 2010), and entanglement's central role in quantum gravity. It aligns with phenomenology: conscious experience appears structured by information, not 'matter' as such. From this perspective, matter and fields are ways of organizing information such that certain patterns become stable and manipulable by observers.

The framework adopts strong information ontology: physical reality is fundamentally a structured information field. Spacetime, matter, and fields are emergent organizational schemes used by biological observers to navigate this field. This is not to say nothing exists beyond information; rather, existence is identified with information structure capable of coherent coupling and transformation.

2.3 The Surface Field: Formal Specification

The framework posits a fundamental informational structure—the 'surface field'—characterized by four properties:

Timelessness: No temporal ordering at the fundamental level. Time emerges as an effective parameter describing sequences of interpretation events for particular observers. The surface field is 'static' in that all physically relevant structure is encoded timelessly, consistent with the Wheeler-DeWitt equation's timeless quantum state.

Non-Spatiality: Space emerges through interpretation. The substrate consists of relational structure without pre-existing metric or topology. Spatial relations arise from patterns of informational connectivity and their interpretation by observers.

Holographic: All physically relevant degrees of freedom are encoded on lower-dimensional surfaces. The surface field is defined on abstract 'screens' whose geometry captures entanglement structure and capacity. Bulk spacetime is reconstructed from these screens.

Positivity and Geometricity: The surface field's structure is represented by positive geometries in the sense of Arkani-Hamed et al. (2014): oriented, convex-like regions in abstract kinematic spaces whose canonical forms encode probabilities or amplitudes. Physical processes correspond to transitions between such geometries.

Formally, let Σ denote an abstract 'screen' carrying an information measure I . At each point $p \in \Sigma$, the surface field assigns a local structure $\sigma(p)$ encoding entanglement patterns with other

regions, local degrees of freedom (e.g., qubit configurations), and geometric data (positive geometry parameters). Global physical states correspond to equivalence classes of surface field configurations under gauge symmetries. Dynamics are not fundamental temporal evolutions but constraints relating compatible configurations across different screens.

3. Quantum Measurement as Biological Interpretation

Arkani-Hamed's work demonstrates spacetime can be eliminated from scattering amplitude calculations, with amplitudes encoded in positive geometries. Holography suggests spacetime geometry and bulk fields are reconstructible from boundary entanglement structure. Decoherence and quantum Darwinism show how classical-like pointer states emerge from unitary evolution through environmental entanglement. Together, these developments suggest a radical re-interpretation: rather than wavefunction collapse in spacetime, measurement is biological interpretation of timeless surface field structure.

The measurement problem, on this view, is category error: we ask why a particular outcome occurs in spacetime when the fundamental ontology is not spacetime-based. The correct question is: how do particular biological interfaces couple to the surface field, and how does decoherence shape that coupling? Measurement outcomes become interface-dependent interpretations of timeless geometric structures rather than physical events where a wavefunction collapses.

3.1 Superposition as Pre-Interpretation

On the standard view, quantum superposition is mysterious—a particle is 'in many places at once' until measured. In the surface field framework, superposition is not a physical state in spacetime but a property of surface field geometric structure relative to potential interpretations.

Consider a qubit in superposition $\alpha|0\rangle + \beta|1\rangle$. In Hilbert space, this is a vector. In the surface field, it corresponds to a geometric region whose canonical form yields probabilities $|\alpha|^2$ and $|\beta|^2$ when integrated over appropriate facets. The qubit does not 'have' both values; rather, the surface field encodes correlations corresponding to multiple possible manifestations. Superposition is pre-interpretational structure—a compact encoding of multiple potential classical outcomes.

Interpretation creates definiteness: when a biological interface couples to the surface field, decoherence selects pointer states, and the interface's internal dynamics stabilize one outcome relative to that interface. Other possibilities remain encoded in the surface field but become inaccessible to that interface. Superposition is thus unproblematic at the substrate level; it is only mysterious if we insist on thinking in terms of particles in spacetime.

3.2 Decoherence as Interpretation Stabilization

Zurek's decoherence theory explains why macroscopic objects don't exhibit observable superpositions: environmental interaction entangles system states with environmental degrees of freedom, suppressing interference. Quantum Darwinism extends this: only information redundantly imprinted in the environment becomes 'classical.' These mechanisms explain how certain structures become stable and observable without postulating collapse.

In the surface field framework, decoherence determines which surface structures can stably couple to biological interfaces. Decoherence doesn't destroy superposition in the surface field; it selects which aspects of the surface field can be accessed by interfaces of a given type. Pointer states are not fundamental—they are interface-dependent stable attractors in the coupling dynamics between surface field and observer.

3.3 The Born Rule from Information Geometry

Where do quantum probabilities come from? In standard quantum mechanics, the Born rule assigns probability $|\psi|^2$ to outcome ψ . In the surface field framework, the Born rule is hypothesized to arise from information density in positive geometries.

The amplituhedron program relates scattering amplitudes to volumes in positive geometries (Arkani-Hamed & Trnka, 2014). Probabilities emerge from ratios of volumes corresponding to different outcomes. Analogously, the surface field likely associates outcome probabilities with measures over regions of its positive geometries. Decoherence selects branch structures with measures proportional to $|\psi|^2$ due to stability constraints. Biological interfaces then couple to branch structures with frequencies reflecting these measures.

Open Problem: Complete derivation requires: (1) rigorous model of surface field positive geometries for general processes, (2) proof that decoherence-induced branch structures have measures matching $|\psi|^2$, and (3) demonstration that biological interface coupling frequencies track these measures. The framework treats this as an open research program rather than settled fact.

3.4 Case Study: The Double-Slit Experiment as Interface-Dependent Projection

The double-slit experiment has long been considered the quintessential demonstration of quantum strangeness. Ask a physicist 'Where does the electron go?' and you receive contradictory answers: 'Through both slits as a wave,' 'Through one slit as a particle,' or 'It depends on measurement.' The surface field framework offers a more radical resolution: the

electron goes through neither slit, because 'electron' is a label for an information pattern in the substrate, not an entity with a trajectory in spacetime.

Spacetime itself is an emergent interface construct. What actually occurs is this: the substrate contains geometric information encoding correlation structures. When a detector interface couples to this information, manifestation occurs at the location required to maintain a coherent worldview—the position consistent with all decoherence constraints and conservation laws. The electron does not exist 'between' preparation and detection; information in the substrate manifests as needed, analogous to pixels on a screen that are not present 'between frames' but appear where rendering logic requires.

This interpretation dissolves each aspect of the double-slit puzzle. The interference pattern emerges because substrate geometry permits multiple interpretation paths that have not yet been constrained by decoherence. Which-path information eliminates interference because decoherence has selected a single interpretation path. Delayed-choice experiments pose no paradox because the substrate is timeless—the interface constructs a temporal narrative retrospectively, but no actual 'choice' propagates backward through time.

What appears as wave-particle duality is not a property of the quantum object but an artifact of observer slicing. The so-called 'collapse' upon observation is not a mysterious physical process but a change in slicing conditions: the new slice excludes superposed alternatives that were previously available. The double-slit experiment, far from being paradoxical, directly demonstrates how slice-consistent selection from the holographic surface gives rise to apparently mysterious quantum effects. Interference reflects multi-path geometries within the substrate; detection reflects instantiation of the projection when coherence requires it. The strange is only strange because we mistake projected consistency for underlying ontic processes.

4. Biological Observer Interfaces

If measurement is biological coupling to informational structure, we must specify biological observer interface architecture. This section sketches a two-layer model: Layer 1 (classical neurocomputation: predictive processing, global workspace) determines content—what is experienced; Layer 2 (electromagnetic field-based resonance coupling to the surface field) determines phenomenality—that there is something it is like.

4.1 Layer 1: Classical Neurocomputation

The first layer corresponds to what contemporary neuroscience models well: classical information processing in neural networks. Predictive processing frameworks (Clark, 2013; Friston, 2010) model the brain as a hierarchical generative model minimizing free energy. Global neuronal workspace theory (Dehaene & Changeux, 2011) describes how information becomes globally available when it enters a distributed workspace.

Layer 1 implements sensory encoding, hierarchical prediction, attention and global broadcasting, working memory, and semantic interpretation. It determines content—what appears within consciousness. However, Layer 1 faces fundamental limitations: the binding problem (distributed representations yet unified experience), temporal integration bottleneck (~100ms windows despite millisecond neural timescales), and the anesthesia paradox (consciousness loss despite continued neural activity). These limitations suggest classical neurocomputation alone cannot account for phenomenality.

4.2 Layer 2: Resonance-Based Coupling

The second layer provides the missing component: a mechanism for coupling neural dynamics to the surface field. Electromagnetic field theories of consciousness (McFadden, 2020; Pockett, 2012) propose that macroscopic EM fields generated by synchronous neural firing constitute the physical substrate of consciousness. These fields integrate information across distributed neural populations and exhibit coherent dynamics matching conscious states.

In the surface field framework, Layer 2 consists of spatially extended electromagnetic fields generated by neural activity, resonance structures (oscillations, phase synchrony) creating dynamic boundaries, and coupling mechanisms between these boundaries and the surface field. The key idea is that EM field coherence patterns define effective 'screens' on which the surface field can imprint specific slices. These screens behave as local holographic boundaries: their geometry and resonance properties determine which surface structures can couple. Conscious

experience corresponds to particular surface slices instantiated on these screens through resonance.

Crucially, our proposal does not require quantum coherence in microtubules. It only requires that microtubule structures modulate EM fields such that coherent resonance patterns emerge at relevant frequencies (gamma, theta, etc.). These patterns define effective 'screens' for surface field coupling. The controversial quantum coherence claims of Orch OR become optional; classical EM resonance suffices.

4.3 Reframing the Hard Problem of Consciousness

The 'Hard Problem' of consciousness (Chalmers, 1995) asks: how does phenomenal experience arise from physical processes? Within the standard materialist framework, this question appears intractable—there seems to be an unbridgeable explanatory gap between objective neural activity and subjective experience. However, the surface field framework suggests this formulation embeds a category error, analogous to asking 'what is north of the North Pole?'

The hard problem assumes consciousness must emerge FROM physical processes occurring IN spacetime. But if spacetime is itself an emergent interface construct, then seeking consciousness within spacetime searches in the wrong ontological category. Consciousness does not arise IN the brain, nor does it exist IN the substrate alone. It arises in the COUPLING—the resonance between electromagnetic field patterns (Layer 2) and substrate geometry.

Consider an analogy: music does not exist IN the radio, nor IN the electromagnetic signal alone. Music emerges when the two couple appropriately—when the receiver's dynamics resonate with the signal's structure. Similarly, phenomenal consciousness emerges when biological EM field patterns achieve the coherence required to couple with surface field geometries. The 'mystery' of qualia dissolves when we recognize that phenomenal experience IS the coupling itself, not something produced by either side independently.

This reframing transforms the hard problem from an emergence question to an interface question. We no longer ask 'How does matter generate experience?' but rather 'What coupling conditions between interface and substrate give rise to phenomenality?' The latter question is empirically tractable: it predicts specific relationships between EM field coherence patterns and conscious states, testable via neuroscientific methods. The hard problem's apparent

intractability reflected not a deep metaphysical truth but a misformulation rooted in spacetime-fundamentalist assumptions.

4.4 Electromagnetic Field Integration

Neuronal firing generates overlapping electromagnetic fields integrating activity across cortical regions. These fields are not mere epiphenomena; they influence neuronal dynamics via ephaptic coupling and membrane potential modulation (Anastassiou et al., 2011). As McFadden (2020) notes: "The brain's EM field integrates information from all contributing sources simultaneously."

Two oscillatory regimes are particularly relevant: gamma oscillations (30-120 Hz), associated with perceptual binding and attention, and slower theta and alpha rhythms (4-12 Hz) associated with large-scale coordination. Cross-frequency coupling (theta-gamma, alpha-gamma) appears crucial for organizing information across scales (Canolty & Knight, 2010). Conscious experience correlates with coherent gamma oscillations nested within slower rhythms, matching observed temporal resolution of conscious experience.

If Layer 2 serves as global resonance boundary, it naturally solves the binding problem: distributed neural activity contributes to a single EM field structure that couples to the surface field as a unified screen. Temporal integration emerges from oscillatory cycles: ~100ms windows correspond to a few gamma cycles nested in slower rhythms. The framework predicts specific relations between conscious integration windows and EM resonance parameters, testable via EEG/MEG.

5. Dark Matter as Unselected Branch Structure

If quantum mechanics evolves unitarily and measurement is observer-dependent interface coupling, then all decohered branches of the wavefunction remain encoded in the surface field. Observers access only one branch at a time, but semiclassical gravity couples to expectation values of stress-energy across branch structure. This projection mismatch—between what gravity 'sees' and what observers see electromagnetically—has profound consequences.

5.1 The Gravitational Projection Mismatch

The semiclassical Einstein equation couples geometry to quantum expectation values:

$$G_{\mu\nu} = 8\pi G \langle T_{\mu\nu} \rangle$$

In a universe with decohered branches, the expectation value $\langle T_{\mu\nu} \rangle$ includes contributions from all branches weighted by their quantum amplitudes. Electromagnetic interactions, however, are branch-specific: an observer in one branch interacts electromagnetically only with matter in that branch. Gravity, being sensitive to the full quantum state, couples to all branches.

Consider a simple case: after a measurement, the wavefunction branches into $|\text{outcome}_1\rangle$ and $|\text{outcome}_2\rangle$ with equal amplitude. Observers in branch 1 see only branch 1's matter electromagnetically. But the gravitational field is sourced by:

$$\langle T \rangle = \frac{1}{2}T_1 + \frac{1}{2}T_2$$

This is not ordinary matter superposition; it's a mismatch between what observers access electromagnetically (T_1) and what gravity couples to ($\frac{1}{2}T_1 + \frac{1}{2}T_2$). The 'extra' gravitational contribution from T_2 manifests as effective dark matter: gravitating but electromagnetically invisible.

5.2 Halo Profiles from Branch-Weight Distribution

If dark matter arises from unselected branch structure, halo profiles depend on how branch weights distribute after decoherence. This differs from particle dark matter, where halos form through gravitational collapse of a new particle species. For branch-structured dark matter, the effective dark matter distribution is determined by the spatial dependence of branch-weight distributions and how decoherence timescales vary with environment.

In dense regions, frequent interactions cause rapid decoherence, producing many nearly-equal-weight branches. In sparse regions, decoherence is slower, branch structure is less developed,

and effective dark matter contribution is smaller. This predicts deviations from standard NFW profiles at large radii, where decoherence dynamics differ from dense cores.

5.3 The Bullet Cluster: A Natural Consequence

The Bullet Cluster shows mass concentrations offset from baryonic plasma after cluster collision. Standard interpretation is collisionless dark matter passing through while gas collides and slows. The interface framework predicts this naturally: branch-structured 'dark matter' is effectively collisionless because it represents matter in other branches that don't interact electromagnetically in the observed branch.

In collision events, selected-branch baryons undergo collisions and heating. Unselected branch baryons follow different trajectories. Semiclassical gravity averages over these, effectively producing collisionless mass distribution despite collisional baryons in any given branch. This is typically considered strong evidence against modified gravity alone; in our framework, it becomes evidence for branch-structured gravity rather than particle dark matter.

5.4 Summary: Dark Matter Without New Particles

The unselected branch mechanism provides a conceptually simple and empirically rich explanation for dark matter phenomenology: no new particles required, no modification of gravity at fundamental level. Dark matter arises from projection mismatch between semiclassical gravity (sensitive to all branches) and biological interfaces (sensitive to one branch). Key features include collisionless behavior, halo profiles derived from decoherence-induced branch-weight distributions, Bullet Cluster as natural consequence, and potential resolution of CDM small-scale tensions via decoherence dynamics.

The framework is falsifiable: detection of dark matter particles with CDM properties would refute the unselected branch mechanism. Conversely, observational confirmation of specific halo deviations predicted by decoherence models would support it.

6. Comparative Analysis with Existing Frameworks

6.1 Consciousness Theories

Global Neuronal Workspace (Dehaene & Changeux, 2011): Compatible at Layer 1. Our framework adopts GNW as description of content selection. Conscious access corresponds to information entering a distributed workspace. We add Layer 2 to account for phenomenality: GNW describes which information becomes globally available; Layer 2 specifies how that information couples to the surface field.

Integrated Information Theory (Tononi, 2016): The framework agrees high Φ is necessary but not sufficient. IIT seeks to identify conscious systems based on causal structure alone. We propose high- Φ systems capable of appropriate EM field coherence serve as interfaces to the surface field. Systems with high Φ but lacking appropriate EM boundary conditions may not be conscious, yielding empirical predictions.

Orchestrated Objective Reduction (Penrose & Hameroff, 2014): Shares microtubule emphasis but differs in mechanism. Orch OR posits quantum coherence and objective collapse. Our framework remains agnostic about quantum coherence in microtubules but does not require objective collapse. Microtubules modulate EM fields establishing Layer 2 boundaries for surface field coupling.

6.2 Quantum Interpretations

Relational Quantum Mechanics (Rovelli, 1996): Closely aligned in spirit. Both treat quantum states as relational, not absolute. Our framework adds explicit ontology (surface field) and biological interfaces. RQM's relations become specific interpretation paths through the surface field.

Many-Worlds (Everett, 1957): Our framework inherits many-worlds' unitarity and branching but interprets branches as surface field structures and observers as specific interfaces. Many-worlds' ontological extravagance is tempered by surface field economy: multiple branches are geometric features of one substrate, not separate universes. The framework remains empirically indistinguishable from many-worlds regarding quantum experiments but adds explanatory power for consciousness and dark matter.

QBism and Psi-Epistemic Views (Fuchs, 2010; Spekkens, 2007): Interpret quantum states as information about experiences rather than physical reality. Our framework agrees quantum states are not literal physical waves in spacetime but disagrees they are purely personalist. The

surface field provides objective structure while quantum states represent interface-limited descriptions.

6.3 Dark Matter Theories

Particle Dark Matter (WIMPs/Axions): Requires new particles coupling gravitationally but weakly electromagnetically. Our framework offers an alternative: dark matter phenomenology arises from unselected branch structure. Both approaches make similar large-scale predictions but differ in microphysics. Detection of dark matter particles refutes interface framework.

Modified Gravity (MOND/Verlinde): Modify gravitational law rather than adding dark matter. Our framework aligns with emergent gravity intuition but retains Einstein's equations at semiclassical level, treating dark matter as additional stress-energy from unselected branches.

Mensky's Everettian Dark Matter (2011): Proposed similar idea but without holographic integration or biological interfaces. The present framework refines and extends this: surface field provides substrate for branch structure, semiclassical gravity coupling is constrained by decoherence, and biological interfaces explain why only one branch is electromagnetically accessible.

7. Empirical Assessment and Limitations

7.1 Immediate Empirical Tests

The framework generates testable predictions across domains:

Neuroscience: Specific correlations between EM field coherence (gamma-theta coupling) and conscious integration windows; EM coherence thresholds for phenomenality; anesthesia effects predicted to disrupt EM coherence more than firing rates; inter-brain synchronization effects testable via hyperscanning.

Quantum Foundations: Decoherence timescales correlating with conscious integration windows; macroscopic superposition experiments constraining branch-weight distributions relevant for dark matter; potential Born rule derivation via geometric measures.

Astrophysics: Deviations from NFW halo profiles at large radii linked to decoherence dynamics; Bullet Cluster-like separations predicted in other colliding systems; absence of pure 'dark matter only' structures; reduced dynamical friction in galaxy interactions.

7.2 Falsification Criteria

The framework generates clear falsification criteria:

Dark Matter Particle Detection: Discovery of particles with dark matter properties refutes the unselected-branch mechanism.

Pure Computational Consciousness: Demonstration that purely digital simulations (without EM fields) exhibit phenomenality refutes Layer 2 EM boundary requirement.

Failure of Semiclassical Gravity: Empirical breakdown of semiclassical Einstein equation at galactic/cluster scales undermines projection mismatch mechanism.

Inconsistent Neuroscience Findings: Lack of correlation between EM coherence and conscious states, or robust consciousness without EM field contributions, challenges interface model.

The framework is thus empirically vulnerable in multiple domains. This is a feature, not a bug: speculative unification frameworks must make risky predictions to be scientifically valuable.

7.3 Limitations and Open Problems

The framework is speculative and incomplete. Major limitations include: lack of full surface field formalism beyond analogy with amplituhedron and holography; incomplete Born rule derivation; underspecified neurobiological detail for Layer 2 implementation; and assumption that semiclassical gravity holds at relevant scales.

Despite these limitations, the framework offers coherent narrative unifying measurement, consciousness, and dark matter. It suggests concrete research programs: developing surface field positive geometries for simple systems; modeling EM field coherence and surface coupling in cortical tissue; connecting decoherence models to halo profile predictions; designing experiments probing the EM-consciousness link and branch-structured gravity.

The framework should be judged not by its current completeness but by its capacity to generate fruitful research and testable predictions. It is offered as exploratory synthesis rather than final theory.

8. Conclusion: The Hidden Elegance of Unified Physics

We have developed an observer-physics framework in which spacetime, measurement, consciousness, and dark matter phenomenology all emerge from a more fundamental holographic information substrate—the surface field. The framework takes seriously recent developments in amplituhedron physics and holographic dualities, treating them as evidence that spacetime is emergent rather than fundamental.

The central insight is that biological observers function as specialized interfaces that couple to the surface field, with decoherence providing stability conditions for classical records. Quantum measurement becomes biological interpretation rather than physical collapse. Consciousness corresponds to particular surface slices instantiated at observer interfaces, with classical neural dynamics constraining content and electromagnetic field coherence providing boundary conditions for substrate coupling. Dark matter arises naturally from the projection mismatch between semiclassical gravity (which couples to all branches) and biological interfaces (which access only one branch).

Viewed from this perspective, quantum mechanics reveals a hidden elegance that the standard formulation obscures. Superposition is not paradox but the natural state of pre-interpretation data. Measurement is not collapse but interface-selection. Entanglement is not 'spooky action at a distance' but shared geometry in a substrate where distance itself is emergent. The Born rule, uncertainty, wave-particle duality—all emerge from substrate geometry rather than standing as inexplicable axioms. Just as general relativity became elegant once we understood spacetime geometry, quantum mechanics becomes beautiful when we recognize it as the mathematics of information constraints on holographic boundaries.

The framework integrates insights from multiple fields—quantum foundations, consciousness studies, and cosmology—under a single coherent ontology. While speculative and incomplete, it generates testable predictions and falsification criteria across all three domains. It suggests that the persistent puzzles of measurement, consciousness, and dark matter may not be independent problems requiring separate solutions, but interconnected manifestations of a deeper structure that current physics only partially captures.

The 'mysteries' of quantum mechanics—superposition, measurement, entanglement—were never bugs requiring explanation but features revealing that reality runs deeper than our interface shows. The hard problem of consciousness dissolves when we recognize phenomenal experience as interface-substrate coupling rather than emergence from matter. Dark matter

transforms from missing mass to visible signature of branch structure. Three persistent puzzles resolve into one elegant picture.

The framework is offered not as final theory but as exploratory synthesis—a conceptual framework that may prove fruitful for organizing future research and guiding empirical investigation. Its value lies in providing a coherent narrative that makes sense of disparate phenomena and generates novel, testable predictions. The beauty was always there. We needed only to look beyond the interface to see it.

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