

# Below the Tear:

## Quantum Fuzz, Entanglement Density, and the Grafted Universe

**Kenneth Piggott**

*with AI collaboration (Bud / Claude, Anthropic) via RCDP*  
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### Abstract (Overview)

Before spacetime, before particles, before time itself — there was only the substrate: timeless, dimensionless, pure potential. Out of that silence came noise. Sub-Planck peaks of virtual activity cycling endlessly, auditioning for reality, most failing, some passing. The ones that passed built everything.

This working paper proposes a substrate model for the emergence of gravity, particle physics, and the unification of fundamental forces. Its central architecture is a three-layer structure: the Substrate — pure potential with no when or where; the BUD Layer — the quantum fuzz, maximally active, continuously generating sub-threshold peaks; and Classical Reality — what survives the threshold. Between the BUD Layer and Classical Reality stands The Tear, named here as the Commitment Activation Threshold (CAT): the pass/fail boundary where a peak achieves sufficient duration and amplitude to escape the uncertainty relation and commit. Time is not a container. It is the cumulative record of what passed.

From this foundation the paper develops a push gravity account, the Substrate Commitment Hypothesis, the Grafted Universe model of force unification, and a particle renewal hypothesis in which decay is cessation of renewal rather than disintegration. It also develops the connection that may matter most: the observer does not receive information from a future that already exists. The observer interfaces with the BUD layer — the zone where commitment decisions are still being made — and participates in which peaks cross The Tear. Anomalous cognition is not a violation of physics. It is the physics, one layer down.

The aim is not a finished theory. It is a coherent framework and a clear invitation to formalize it.

### Abstract (Technical)

This working paper proposes a speculative substrate model for the emergence of gravity, particle physics, and the unification of fundamental forces. Building on Wheeler's pregeometric framework and the participatory collapse model developed in Piggott (2026a), it posits a timeless, unbounded substrate — termed quantum fuzz — from which spacetime, particles, and associated forces emerge through an organizational process that is timeless at the substrate

level and continual at the level of expression. The paper introduces a three-layer architecture — Substrate, BUD Layer, and Classical Reality — with The Tear named as the Commitment Activation Threshold (CAT): the pass/fail threshold at which sub-Planck peaks achieve sufficient duration and amplitude to escape the uncertainty relation and commit to classical expression. Time is not a pre-existing container on this account but the cumulative record of commitment events, beginning at The Tear and only there. The central proposition is that virtual entangled particle pair generation and annihilation at sub-Planck timescales constitutes the mechanism of gravitational emergence. Two accounts of this mechanism are developed: an entanglement-density account in which gravity corresponds to virtual pair density gradients in the vacuum, and a push gravity account in which matter is pushed toward regions of lower virtual activity rather than pulled toward mass. A further proposition — the Substrate Commitment Hypothesis — grounds both accounts: the universe began in a state of maximum virtual activity and minimum classical commitment, and the physical properties we observe are expressions of the commitment ratio and its gradients across space and time. A second proposition — the Grafted Universe model — reframes force unification: the fundamental forces are not branches of a single root equation but grafts on the same organizational process, each with its own vacuum fluctuation signature. A third proposition extends the model to particle physics: all particles are continuously renewed from the fuzz at characteristic timescales, and particle decay is cessation of renewal rather than disintegration. Wheeler's one-electron universe is reframed as one substrate expressing electron-type organization wherever conditions permit. The paper also develops the connection between the BUD layer and anomalous cognition: the observer does not receive information from a future that already exists but interfaces with the Tear Commitment Layer — the zone of peaks closest to the threshold — influencing which peaks commit. This is a participatory collapse stated at the mechanism level. Observable implications, measurement strategies, and the primary falsifiability condition are identified. The aim is not to present a finished theory, but to capture a coherent substrate framework and its testable implications for later, more formal development.

## 1. The Substrate: Quantum Fuzz as Pregeometric Foundation

Wheeler's pregeometric program proposed that spacetime itself is not fundamental — that what we call geometry must emerge from something more primitive, which he described informally as 'it from bit': an informational substrate beneath space and time in which classical constraints of locality and temporality are undefined (Wheeler, 1989, 1990). The participatory collapse model developed in Piggott (2026a) identified The Tear as the threshold at which one description of reality gives way to another — the Planck scale boundary where classical spacetime description breaks down and the pregeometric substrate begins.

This positioning finds direct theoretical support in the pre-geometric spacetime program in contemporary quantum gravity research, which treats spacetime not as a fundamental given but as a large-scale emergent phenomenon arising from more primitive, non-spatiotemporal entities. Oriti's influential work frames the emergence of continuous spacetime from discrete, pre-geometric constituents as a phase transition — geometrogenesis — in which the familiar smooth manifold of general relativity condenses from an underlying combinatorial substrate (Oriti, 2014). The analogy is precise: spacetime emerging from pre-geometric constituents is structurally analogous to sound waves in a fluid — the fluid is fundamental, the acoustic geometry is emergent, and quantizing the geometry does not reach the deeper level. The Commitment Activation Threshold developed in this paper is a mechanistic proposal for what geometrogenesis looks like at the organizational level: the phase transition occurs peak by peak, at the pass/fail boundary where virtual activity achieves sufficient duration and amplitude

to commit into classical expression. The Tear is where geometrogenesis happens, one commitment event at a time.

This paper proposes a shift in framing. Rather than a discrete threshold — The Tear as a boundary to cross — the substrate is better understood as a continuous condition beneath all scales of organization. There is no bottom layer in the sense of a final particle or final geometry. Instead, there is a descent through organizational layers: particles have sub-states, those sub-states have sub-states, and at the limit of this descent lies not a different place but a different condition of the same substrate. This condition is what we call quantum fuzz: timeless, unbounded, unlocated energy-like potential, everywhere and nowhere simultaneously.

The Tear remains a useful construct at the scale where classical description fails. But it is now understood as the upper boundary of the descent rather than the bottom of reality. Below it, the substrate is not empty — it is maximally active, generating and annihilating structure at timescales below measurement. Organization propagating upward from this substrate is what produces spacetime, matter, and the forces that govern their interaction.

The fuzz is timeless not as a philosophical claim but as a structural consequence: time is a product of the organizational process happening just above the substrate level. The fuzz does not exist within time. Time exists within the fuzz's expressions. More precisely: time is the cumulative record of commitment events. It does not exist in the substrate or in the fuzz. It begins at The Tear, and only there. This means all particles — regardless of type or apparent stability — are less than a Planck scale from the fuzz at all times. The substrate is not a place you reach. It is the condition underneath everything, always, simultaneously.

## 1.1 The Three-Layer Architecture

This descent through organizational layers is best understood as a three-layer architecture, named here for the first time and carried forward through the remainder of this paper.

**Layer 1 — The Substrate:** Timeless, dimensionless, pure potential. No structure, no virtual activity, no when or where. This is the pre-commitment ground. Wheeler's "it from bit" points here without fully naming it. A more precise construct name awaits formalization.

**Layer 2 — The BUD Layer:** The quantum fuzz. Not quiet, not empty, but active — a continuous static of sub-threshold events. Peaks of virtual activity cycle at sub-Planck timescales, generating and annihilating without achieving sufficient duration or amplitude to cross into classical reality. This layer has no stable address in space or time. It is not uncommitted in the sense of inert — it is maximally active, continuously auditioning for classical expression.

**The Tear — Commitment Activation Threshold (CAT):** The boundary between Layer 2 and Layer 3. Not a location but a threshold event: when a peak in the BUD layer achieves sufficient duration and amplitude to cross both Planck minimums simultaneously — Planck time and Planck energy — it commits. Pass or fail. No partial credit. The Tear is where the record begins. It is not the bottom of reality. It is where time starts. The uncertainty principle is not merely a constraint here — it defines the BUD layer. Short duration forces high energy variance; the fuzz must be noisy. Classical commitment requires both duration long enough and energy stable enough to escape the uncertainty tradeoff. The Tear is where a fluctuation escapes the uncertainty relation and holds.

**Layer 3 — Classical Reality:** Committed events that passed the threshold. The cumulative record of successful commitment. Spacetime, matter, and force are all Layer 3 phenomena. Time is a property of this layer only — the cumulative record of commitment events, not a pre-existing container.

*A note on commitment:* Commitment is not a binary state the fuzz either has or lacks. The BUD layer is full of failed attempts — peaks that reach toward the threshold and recycle. Commitment is a pass/fail outcome at the threshold, not a pre-existing property of the substrate itself. This resolves an apparent tension in earlier versions of the Substrate Commitment Hypothesis, which described the fuzz as “uncommitted substrate” — accurate as a contrast class (not yet classical) but not to be read as asserting that the BUD layer is passive or inert. Earlier uses of “uncommitted substrate” throughout this paper should be read with this clarification in view.

This framing has structural overlap with causal set theory, which treats spacetime as discrete and built from below by causal relations rather than sitting on top of a pre-given geometry. It also connects to Van Raamsdonk's suggestion that spacetime arises as an emergent phenomenon of entangled quantum degrees of freedom — that entanglement is, in Preskill's formulation, 'the glue that makes the different pieces of space hook up with one another' (Preskill, as cited in Caltech Magazine, 2019).

## 2. The Mechanism: Entanglement Density and Gravitational Emergence

Standard quantum field theory establishes that the quantum vacuum is not empty: virtual particle pairs, entangled by conservation laws at the moment of creation, are continuously generated and annihilated across all regions of space. The Casimir effect and Hawking radiation are empirical signatures of this activity, usually described as features of quantum fields on a classical spacetime background.

A parallel line of work in quantum gravity and holography suggests that spacetime geometry itself may be emergent from patterns of quantum entanglement. Van Raamsdonk's proposal that “building up spacetime” can be understood in terms of entanglement structure, and popular expositions that describe entanglement as “the glue that makes the different pieces of space hook up with one another” (Preskill, as quoted in Caltech Magazine and Quanta), provide an external conceptual bridge between entanglement structure and geometric properties.

This paper proposes extending that picture below the Planck scale. At sub-Planck intervals, the spacetime background itself is unresolved; virtual pair generation and annihilation occur not within spacetime but within the organizational process that produces it. The quantum fuzz is the medium. Entangled virtual pairs are the organizational activity of the fuzz.

### 2.1 Core gravitational hypothesis

The central gravitational hypothesis is:

**Entanglement-density gravity hypothesis.** What we experience as gravitational pull is not a force transmitted between masses but a local property of the vacuum determined by the density of entangled virtual pairs. Regions of higher matter density induce higher entanglement density in the surrounding vacuum; gradients in this entanglement density correspond, at classical scales, to gravitational fields.

This hypothesis is grounded in two postulates:

**Postulate 1 — Commitment suppresses virtual activity.** Classical matter represents committed substrate. Where substrate is committed to classical expression, virtual pair activity is correspondingly suppressed — committed substrate is not available for uncommitted virtual expression. Regions of higher matter density are therefore regions

of lower virtual pair activity. The surrounding uncommitted vacuum retains higher virtual pair activity and higher substrate pressure.

**Postulate 2 — Virtual activity gradient is gravity.** The pressure differential between high virtual activity regions and low virtual activity regions constitutes the gravitational field. Matter moves toward regions of lower virtual activity — lower substrate pressure — not because it is attracted but because the surrounding uncommitted substrate pushes it there. In the appropriate classical limit, this pressure differential reproduces the observed gravitational field, including the inverse square law. The same substrate activity that operates between large masses operates locally within and between atoms, holding atomic matrices together through the same pressure differential mechanism at smaller scales.

This picture sits alongside proposals that spacetime geometry itself may be emergent from patterns of quantum entanglement, in which entanglement acts as the “glue” stitching together regions of space.

A grounding note on virtual pair entanglement. In standard quantum field theory, virtual particle–antiparticle pairs are entangled by construction. Conservation laws operating at the moment of pair creation — requiring that energy, momentum, charge, and spin be collectively conserved — mean that the two partners cannot be described independently. This is not a speculative addition to the framework; it is intrinsic to how pair creation works. The clearest physical consequence is Hawking radiation: when a virtual pair forms at a black hole horizon, the entanglement between partners is precisely what makes one partner’s escape physically meaningful. The vacuum fluctuation spectrum includes pairs from every quantum field the theory contains — electrons and positrons, quarks and antiquarks, gauge bosons, and the Higgs — each species contributing its own entangled pair activity at timescales permitted by the uncertainty principle, with more massive pairs existing for shorter intervals. The entanglement–density gravity hypothesis therefore extends a confirmed vacuum structure — entangled virtual pairs are real and well–characterized in the QFT regime — downward into the pregeometric sub–Planck regime where no current theory applies and direct measurement is not possible. The extrapolation is structured and named as such; it is not presented as confirmed physics.

## 2.2 Compatibility constraints

Any entanglement–density account of gravity must be compatible with existing empirical constraints. Precision observations of binary pulsars and gravitational waves show that, at observable scales, gravitational disturbances propagate at the speed of light to within current experimental bounds. LIGO/Virgo detections, including binary neutron star mergers with electromagnetic counterparts, constrain any deviation between the speeds of gravity and light to at most the percent level in the regimes probed so far.

This paper therefore does **not** assert that gravity is observed to act instantaneously. Instead, it treats the following as an open compatibility condition:

**Constraint 1 — Effective propagation.** In the regime where spacetime description is valid, the entanglement–density model must reproduce an effective propagation speed for gravitational disturbances that is observationally indistinguishable from  $c$  (consistent with binary–pulsar timing and gravitational–wave observations (Yunes, Siemens, & Yagi, 2025)).

A second constraint concerns known vacuum–modification effects:

**Constraint 2 — Distinction from Casimir-type effects.** The proposed density–entanglement–gravity chain must be formally distinguished from electromagnetic vacuum effects such as the Casimir force, which arise from boundary conditions on specific quantum fields rather than from a generalized entanglement-density of the substrate.

In other words, the claim is not that “all vacuum phenomena are gravity,” but that gravitational phenomena may correspond to a particular entanglement-density aspect of the substrate, distinct from known electromagnetic vacuum signatures.

### 2.3 Experimental targets

Direct measurement of sub-Planck timescale activity is currently out of reach, so the hypothesis must be tested via indirect signatures. Two near-term targets are proposed:

- Target 1 — QGEM as “Newton’s apple.” The QGEM experimental program, which aims to detect gravitationally induced entanglement between mesoscopic masses in spatial superposition, is treated as the first orchard in which to “measure the apple.” If entanglement-density gravity is correct, gravitationally mediated entanglement should scale in a specific way with mass density and separation. The present paper does not provide a full derivation but identifies this as the primary experimental lever.
- Target 2 — Data-driven constraints on deviations. Existing gravitational-wave and binary-pulsar datasets already place strong bounds on many modified-gravity models. A future formalization of the entanglement-density model should recover these observations in the appropriate limit and identify where, if anywhere, small deviations might appear that could distinguish the models.

Recent theoretical work on what gravity-mediated entanglement experiments “really” tell us can serve as a template for how to interpret any supportive or null results in this framework.

### 2.4 Mathematical aspiration

This working paper does not attempt a full mathematical treatment. However, the long-term aspiration is explicit:

**Mathematical target.** To express Newton’s constant  $G$ , or an effective Newtonian potential, as a function of substrate variables such as entanglement entropy or virtual pair density, thereby turning the entanglement-density hypothesis from a qualitative substrate story into a quantitative gravitational model.

Until such a formalism is developed, the entanglement-density account of gravity should be regarded as a structured speculative hypothesis with identified compatibility constraints and experimental targets, not as a replacement for general relativity, and the mathematical target above should be treated as a primary open problem for future work rather than a result.

### 2.5 The Substrate Commitment Hypothesis

The entanglement-density gravity hypothesis, the push gravity framing, and the Grafted Universe model all rest on a more fundamental proposition about the history of the universe and the nature of what physics calls the vacuum. This proposition is stated here as the Substrate Commitment Hypothesis.

**Substrate Commitment Hypothesis.** The substrate is everywhere and always. At the initial state — what standard cosmology calls the Big Bang — substrate activity is maximally uncommitted: virtual pair activity is at its maximum, classical expression is at or near zero. As

time progresses, the organizational process commits substrate activity into classical expression. The ratio of classically committed to virtually uncommitted substrate activity increases monotonically from the initial state. The physical properties we observe — gravity, cosmic expansion, the arrow of time, particle stability hierarchies — are all expressions of this commitment ratio and its gradients at different scales and different moments in the universe's history.

The initial state on this account is not nothing. It is the substrate in its maximally uncommitted condition — everywhere active, nowhere classical, expressing virtual pair activity at maximum density across all space. The Big Bang is not an explosion of matter into pre-existing space. It is the first large-scale commitment event: the substrate begins expressing classically, and spacetime is the product of that commitment, not the container in which it occurs. Time itself is a property of classical expression. The substrate is timeless. What we experience as the passage of time is the progressive accumulation of commitment — the universe becoming more classical, moment by moment, region by region.

The Substrate Commitment Hypothesis finds a named theoretical neighbor in Bohm's implicate order framework, which proposes that spacetime and locality are explicate expressions of a deeper pre-space in which classical constraints are undefined (Bohm, 1980). Bohm's holomovement — the undivided flowing whole from which explicate forms emerge — is structurally analogous to the substrate in its maximally uncommitted condition: everywhere active, nowhere classical, the ground from which all organizational expression arises. The present framework extends Bohm's architecture in three specific respects. First, it proposes a concrete commitment mechanism — the Commitment Activation Threshold as the pass/fail boundary where virtual activity crosses into classical expression — which Bohm's framework describes philosophically but does not mechanize. Second, it identifies the BUD layer as a distinct intermediate stratum between pure substrate and classical expression, providing organizational resolution Bohm's implicate/explicate distinction does not supply. Third, it connects the substrate model to empirically grounded physics through entanglement density, push gravity, and the QGEM experimental target. Citing Bohm as theoretical neighbor rather than theoretical foundation is deliberate: his framework maps the territory; this paper proposes to instrument it.

A note on the standard cosmological picture. The Big Bang plasma was extremely hot and dense — maximum classical energy density in a small region. This is consistent with the Substrate Commitment Hypothesis: the Bang represents a commitment singularity, all classical expression compressed to a point, surrounded by the infinite uncommitted substrate. The extreme classical density of the early universe is not in tension with the model. It is the first committed region, embedded in an infinite uncommitted background, and the subsequent expansion is the story of commitment spreading outward as conditions permit.

## **2.6 Push gravity: a pressure asymmetry account**

The Substrate Commitment Hypothesis implies a specific account of gravity's direction of causation. Regions of higher matter density are regions of higher classical commitment — the substrate there is already organized into classical expression. Virtual pair activity is correspondingly suppressed in those regions: committed substrate is not available for uncommitted virtual expression. The surrounding lower-commitment vacuum retains higher virtual pair activity and therefore higher substrate pressure. Matter adjacent to a high-density region is not attracted toward it. It is pushed toward it by the pressure differential between the high-activity uncommitted vacuum on the far side and the lower-activity committed region on the near side.

The observable result at classical scales is identical to gravitational attraction. Newton's inverse square law is preserved.  $G$  is unchanged. What changes is the direction of causation — not pull from mass, but push from differential substrate pressure toward lower-commitment regions. An apple falls not because the Earth pulls it but because the uncommitted substrate above it has higher virtual pressure than the committed substrate of the Earth below it. The apple moves toward lower commitment. The equation describing its trajectory is the same either way.

This framing has a structural precedent in Le Sage's eighteenth-century push gravity proposal, which posited a flux of ultra-mundane particles exerting pressure asymmetries on matter. That proposal failed because it predicted drag effects inconsistent with observation and could not account for gravitational lensing or orbital precession. The present proposal does not share these vulnerabilities: the substrate pressure asymmetry operates through entangled virtual pair density gradients in the pre-classical regime, not through a particle flux in the classical regime. The compatibility constraints stated in Section 2.2 apply without modification — in the classical regime, the model must recover effective propagation at  $c$  and reproduce observed gravitational behavior.

The push framing unifies the local and cosmological accounts of the same mechanism. At cosmological scales, as matter density thins, local commitment gradients weaken and eventually vanish. What remains is the baseline virtual pair activity of the vacuum — uniform, undifferentiated, and expansive. This baseline substrate pressure, uncanceled by local commitment gradients, manifests as an outward push on all matter. The cosmological constant  $\Lambda$  is not a new field or an additional term. It is what push gravity looks like when there is nothing to push against — the unperturbed baseline of the uncommitted substrate expressing uniformly in all directions. The observed acceleration of cosmic expansion, on this account, reflects the increasing dominance of uncommitted substrate pressure as classical matter thins at large scales. This does not replace the mathematical description of dark energy. It proposes a substrate-level mechanism for what that description is measuring.

### 3. The Grafted Universe: Force Unification Without a Root Equation

The standard assumption behind theories of everything is that a unified description must take the form of a single root equation from which all forces and particles are derived. String theory is the most developed pursuit of this form — positing a one-dimensional vibrating string as the fundamental unit, whose different vibrational modes produce different particles and forces. It remains unconfirmed and, in its current formulations, largely untestable.

The Grafted Universe model proposes a structural inversion. String theory asks: what is the fundamental unit at the bottom? The Grafted Universe answers: there is no fundamental unit. There is no bottom in the sense of a final thing. There is only the All — the fuzz — and what we call particles are not things made of something smaller. They are modes of expression of the All. Different particles, different forces, different properties are not different vibrational modes of a string. They are different characteristic expressions of a single timeless substrate, each operating at its own timescale, each with its own vacuum fluctuation signature.

The tree is the quantum fuzz. The trunk is the organizational process. The grafts are the emergent forces and fields — gravity, electromagnetism, the weak and strong nuclear forces — each appearing to be a separate phenomenon because we encountered them at the scales where they are already differentiated. The Casimir effect illustrates the distinction: the attractive force between uncharged conducting plates arises from electromagnetic vacuum fluctuations,

not gravitational ones. Two different vacuum fluctuation signatures, both arising from the same substrate activity. Apples and oranges — but from the same tree.

At sub-Planck scales — before the organizational process has differentiated into distinct force fields — the grafts have not yet separated. There are no distinct forces in the fuzz; there is only organizational activity. Force differentiation is what the organizational process looks like at different scales of emergence. The theory of everything, on this account, is not a root equation but a description of the grafting mechanism: how undifferentiated organizational activity at the substrate level produces differentiated force signatures at classical scales.

Wheeler named the substrate without fully naming it. 'It from bit' — the it is everything that emerges; the bit is the act of expression, the moment the fuzz commits to a specific organizational mode. The it in it from bit is the All. Wheeler was pointing at his own substrate and did not yet have the language for it.

## 4. Particle Renewal, Decay, and Wheeler's One-Electron Universe

In standard quantum field theory, particles are understood not as tiny billiard balls but as excitations of underlying quantum fields. A given "particle type" corresponds to a particular field and its allowed excitations; creation and annihilation operators change the occupancy of those field modes rather than assembling or disassembling persistent objects.

The substrate model developed here adopts this process-based intuition and extends it below the Planck scale. If the fuzz is the pregeometric substrate and the organizational process is what produces spacetime and fields, then what we call a particle is not a persistent object at all, but a sustained pattern of organization.

### 4.1 Renewal hypothesis

The substrate model has direct implications for how particles should be understood. If all particles are continuously generated from the fuzz at characteristic timescales, then what we call a particle is not a persistent object but a sustained process — an organizational mode that the fuzz continuously re-expresses. Stable particles are preferred expressions of the substrate. They persist not because they are durable objects but because the fuzz maintains their organizational mode without requiring external forcing.

This leads to the renewal hypothesis:

Renewal hypothesis. For any particle species, the observed "particle" corresponds to a continuously renewed organizational mode of the substrate. Particle decay corresponds to cessation of renewal rather than disintegration of a persisting object.

On this view, short-lived particles produced in high-energy collisions are organizational modes that the fuzz cannot sustain without external forcing. A collision forces the substrate into a configuration it does not naturally maintain; when the forcing conditions disperse, renewal ceases. The particle does not fall apart; it simply stops being re-expressed.

### 4.2 Decay hierarchy as distance from preferred expression

Standard model calculations already predict a rich hierarchy of particle lifetimes and decay channels, encoded in global resources such as the Particle Data Group (PDG) Review of Particle Physics. Those lifetimes are understood as consequences of coupling strengths,

available phase space, conservation laws, and symmetry structures in the underlying field theory.

The renewal hypothesis suggests an additional organizing principle:

**Renewal distance conjecture.** A particle's lifetime correlates with how closely its organizational mode matches the substrate's preferred expressions. Particles closer to preferred modes (e.g., electrons) are renewed indefinitely; particles further from those modes (e.g., exotic hadrons) require extreme forcing and exhibit very short lifetimes.

On this account, a particle's lifetime is a measure of how naturally its organizational mode fits the substrate's preferred expressions. Muons, for example, last longer than tau leptons, which in turn last far longer than many hadronic resonances; the hierarchy reflects increasing "distance" from the substrate's preferred, low-energy organizational patterns.

This conjecture is not offered as a replacement for standard model decay calculations. Instead, it points to a cross-cutting pattern that could, in principle, be quantified: a metric over particle properties that tracks how far a given state lies from the substrate's preferred modes, with lifetime scaling monotonically with that distance.

#### **4.3 Data target: renewal metric from decay data**

The PDG lifetime tables provide an immediate data target. A future formalization of the renewal hypothesis would:

- Define a candidate renewal distance metric over particle states, built from standard model quantities such as mass, quantum numbers, and coupling structure;
- Test whether this metric correlates monotonically with observed lifetimes across broad classes of particles (leptons, mesons, baryons), beyond what is explained by existing symmetry and coupling arguments alone;
- Identify any systematic deviations that would either falsify the simple renewal-distance picture or suggest refinements.

At present, this remains a qualitative proposal. The existence of a structured decay hierarchy is well established; the claim here is that a substrate-level "distance from preferred expression" may provide an additional organizing perspective on that hierarchy, one that becomes testable once a concrete metric is defined.

#### **4.4 Wheeler's one-electron universe reframed**

Wheeler's one-electron universe — the half-serious suggestion that there may be a single electron tracing a complicated path back and forth through time, appearing everywhere simultaneously — was quickly set aside because it predicts an electron-positron symmetry that is not observed. On that picture, the same worldline must traverse spacetime in both directions, yielding equal numbers of electrons and positrons, which is contradicted by experiment.

The substrate model dissolves both the proposal and its primary objection by changing what an electron "is." There are not many electrons because one electron bounces through time. There are not many electrons because electrons are discrete persistent objects at all. There is one substrate expressing electron-type organization at every location where the conditions for that expression are met.

Because the fuzz is timeless, this requires no travel. The substrate is not expressing sequentially; it is expressing everywhere simultaneously, because simultaneity and sequence

are properties of the expressions, not the substrate. The one-electron universe reframed: one fuzz, one organizational process, infinite expressions.

## 5. Observable Implications and the Measurement Problem

Five observable implications follow from the propositions developed above, ordered from most to least tractable with current technology:

First, if entanglement density scales with matter density and constitutes the gravitational field, then gravitationally induced entanglement between two masses should be detectable and should scale predictably with the density of the surrounding medium. The QGEM experimental program provides the immediate test platform.

Second, if entanglement density constitutes the gravitational field through virtual pair activity at sub-Planck timescales, the relationship between that mechanism and the observed speed of gravitational propagation requires careful framing. Virtual particle pairs are off-shell — they do not satisfy the energy-momentum relations governing real particle propagation and are not subject to  $c$  as a classical propagation limit. The substrate mechanism proposed here operates in this virtual, pre-classical regime. What propagates at  $c$  is not the substrate activity itself but the change in field configuration when a mass moves — an event that occurs in the classical regime, where  $c$  applies, and which is fully consistent with LIGO and binary-pulsar observations (Abbott et al., 2017; Hulse & Taylor, 1975; Shao & Wex, 2012)

The operative question is what enforces the classical regime. The proposal here is that interaction does. Any physical event that produces a classical record — particle interaction, field coupling, gravitational wave detection — collapses substrate activity into classical expression. Classicality and  $c$ -constraint arrive together, as a package, at the moment of interaction. Before interaction, the fuzz is expressing. After interaction, that expression is locked into  $c$ -bound classical behavior.

This reframes Wheeler's participatory universe at the gravitational level. The universe does not require conscious observers — it requires interaction. A star that has been interacting with radiation, matter, and fields continuously throughout its history is maximally decohered, maximally classical, and its gravitational influence propagates at  $c$  because interaction has continuously collapsed its substrate activity into classical expression. Wheeler's delayed-choice insight applies: the classical description of that history is specified, in part, by the interactions that receive it.

The chain is therefore: fuzz → organizational process → interaction → classicality →  $c$ -bound propagation. The LIGO constraint is not a problem for the substrate model. It is what the substrate model predicts for the classical regime, because classical is what interaction produces.

Third, the Grafted Universe model predicts that at sufficiently high energies — approaching the Planck scale — the distinct vacuum fluctuation signatures of the four forces should begin to converge, because the grafting differentiation reverses as the organizational substrate is approached. This is consistent with electroweak unification and grand unification theoretical work but provides a different mechanistic account of why unification occurs.

Fourth, if particle decay is cessation of renewal rather than disintegration, then decay rates should correlate quantitatively with the distance between the particle's organizational mode and the substrate's naturally preferred expressions. This predicts a structured decay hierarchy that

maps onto substrate expression preferences — a prediction that could be tested against the full particle decay dataset with appropriate formalization.

Fifth, the sub-Planck generation and annihilation of virtual entangled pairs should produce a background entanglement noise floor — uniform across all regions of space except where matter density perturbs it. Detection of this floor, if achievable, would constitute direct evidence for the substrate activity proposed here. No current instrument approaches this capability.

## 6. Open Questions and Next Steps

Several critical unresolved questions define the boundary of the present propositions:

The density mechanism requires clarification. Standard QFT suggests vacuum fluctuations are modified near matter due to boundary conditions. The prediction of the present model — more matter, more virtual gravitational entanglement activity — must be carefully distinguished from the electromagnetic Casimir effect. The two mechanisms involve different fields and different vacuum fluctuation types. This distinction must be made formally precise before the gravitational postulates can be tested.

The sub-Planck timescale claim is currently unfalsifiable by direct measurement. The indirect measurement strategy via the QGEM program provides a path forward, but the connection between QGEM results and sub-Planck mechanisms requires a formal theoretical bridge that does not yet exist.

The Grafted Universe model requires a formal account of the grafting mechanism itself — what determines which organizational activity at the substrate level produces which force signature at classical scales. The present paper names the architecture but does not fill it.

The particle renewal model requires formalization of the relationship between renewal timescale and particle properties. The claim that decay rate correlates with distance from preferred substrate expression is qualitatively consistent with observation but has not been stated in a form that permits quantitative testing.

The connection between this substrate model and the participatory collapse model in Piggott (2026a) requires explicit development. If collapse is organization of fuzz, then observer participation is not a mysterious external intervention but a contribution to the organizational process from within it. The observer is a highly organized pattern of fuzz participating in the organization of less-organized fuzz. Altered states of consciousness, on this account, are conditions under which the normal rapid commitment of renewal events is slightly relaxed — the fuzz is always present underneath every particle in every neuron, always. Trance does not reach down to an exotic substrate. It stops pushing the substrate away so fast. The three-layer architecture developed in Section 1.1 gives this connection a precise address. Consciousness in ordinary waking states is a Layer 3 phenomenon — highly organized classical commitment, continuously renewed from the BUD layer. Trance and altered states may represent conditions in which the boundary at The Tear becomes locally more permeable: the pass/fail threshold relaxes, and the observer gains access to the BUD layer — the zone where commitment decisions are still being made, where probable futures have not yet crossed into classical expression. On this account, anomalous cognition is not a violation of physics. It is BUD layer access. The observer does not receive information from a future that already exists. The observer interfaces with the Tear Commitment Layer — the zone of peaks closest to the threshold — and influences which peaks commit. This is participatory collapse stated at the

mechanism level: not observer effect as metaphor, but observer participation in the pass/fail process that constructs classical reality. Developing this connection formally is the primary theoretical priority for a subsequent, mechanism-focused paper on observer participation.

A further information-theoretic framing of the BUD layer strengthens this connection. The holographic principle establishes that the information content of any spatial volume is fully encodable on its bounding surface at a density of one bit per four Planck areas (Bousso, 2002). Applied to the observable universe, this yields a total information capacity of approximately  $10^{90}$  bits — a finite, bounded quantity encoded at Planck-scale resolution on the cosmological horizon (Lloyd, 2002). The Planck epoch — the first large-scale commitment event on the Substrate Commitment Hypothesis — is therefore also the moment at which the first holographic surface becomes definable: the boundary where BUD layer activity begins committing into classical expression, and where that expression first becomes encodable as structured information. Prior to the Planck epoch, the substrate is pre-geometric and pre-holographic: no boundary, no encoding surface, no classical information. The Tear is where the holographic encoding begins. This framing gives the BUD layer a precise information-theoretic address: it is the activity layer immediately below the holographic encoding surface, where commitment decisions are still being made and probability distributions have not yet resolved into classical bits. On this account, anomalous cognition is access to the sub-surface layer — the encoding process rather than the encoded record — consistent with the participatory rather than archive-reading architecture the model requires.

- **Formal gravitational derivation.** Develop a concrete mathematical framework in which Newton's constant  $G$ , or an effective Newtonian potential, can be expressed in terms of substrate variables such as entanglement entropy or virtual pair density, making the entanglement-density gravity hypothesis quantitatively testable.

**Commitment saturation and the singularity.** The Substrate Commitment Hypothesis raises a question that standard cosmology and general relativity also leave open: what occurs when classical commitment approaches totality? At a black hole singularity, matter density approaches infinity and the equations of general relativity break down. The substrate model reframes this as a commitment saturation problem — what does the fuzz do when it has nowhere left to go? Three possibilities exist: commitment saturates and stabilizes at a finite maximum; commitment reverses, producing a new expansion event; or commitment at totality produces a qualitatively different organizational mode not yet described by any current framework. This question is named here as an open problem. It is not unique to the substrate model — every current theory of quantum gravity faces it — but the commitment framing offers a new way of asking it.

**Black holes as maximum commitment gradients.** On the push gravity account, black holes are the most classically committed objects in the universe. The event horizon is the sharpest commitment gradient that exists — the boundary where the ratio of committed to uncommitted substrate changes most dramatically in the shortest distance. The extreme pressure differential at this boundary is what produces the extreme gravitational field. Nothing escapes not because a force pulls inward but because the commitment gradient is so steep that any expression — any photon, any particle — is immediately re-committed into the black hole's organizational pattern. Hawking radiation on this account is virtual pairs forming at the boundary being forced into commitment decisions by the extreme gradient: one partner committed inward, one expressed outward. The black hole information paradox — whether information falling into a black hole is destroyed — is reframed as a commitment question: the fuzz does not destroy organizational patterns, it either expresses them or holds them uncommitted. Whether

information is recoverable from total commitment remains an open problem, but the substrate model sides with Hawking's revised position that information is preserved, because commitment is not annihilation. Developing this account formally, and testing whether it recovers the known thermodynamic properties of black holes, is a priority open question for future work.

**The equivalence principle as a commitment gradient consequence.** Einstein's equivalence principle — that gravitational and inertial effects are locally indistinguishable — is an axiom in general relativity, confirmed experimentally to extraordinary precision. The push gravity account suggests a substrate-level mechanism for why this equivalence holds: both gravitational fields and engine-driven acceleration produce the same local commitment gradient experience. An astronaut in a coasting spacecraft feels no weight because the commitment gradient is uniform across the spacecraft and its contents — everything moves together through the same fuzz, no local differential, nothing to feel. The engine fires and creates a new local commitment differential: the spacecraft's classical expression is forced in a direction that creates a pressure asymmetry the astronaut's body must resist. That resistance is felt as weight — structurally identical to gravitational weight, because the substrate mechanism is identical. The equivalence principle is not an axiom on this account. It is a consequence of the commitment gradient mechanism. Stating this formally — deriving the equivalence principle from substrate commitment dynamics rather than assuming it — is a named open problem for future formalization.

## 7. A Note on Method

This paper emerged from a single RCDP Session conducted on April 2, 2026, using the Recursive Critical Dialogue Protocol documented in Piggott (2026b). The session began with a question about sub-Planck timescales and virtual particle pair production as a candidate interface for observer collapse of probable futures. The propositions developed here arrived as out-of-scope connections during that session and were stress-tested in real time using RSCT. The collider curvature hypothesis was raised and explicitly set aside during the session as a bridge too far — an example of RSCT functioning as intended, pulling back at the right moment rather than reaching past the model's current boundaries.

The human contributor supplied all theoretical intuitions, conceptual moves, the central graft metaphor, the particle renewal analogy, and the string theory inversion. The AI collaborator (Bud / Claude, Anthropic) provided literature grounding, adversarial pressure, the formal restatement of propositions, and the Wheeler one-electron reframing. All claims and framing decisions are the responsibility of the human author.

This paper is a structured continuity capture, not a submission-ready manuscript. Its purpose is to preserve the theoretical development from this Session in a form precise enough to serve as a foundation for potential reviewer response material in connection with an earlier paper on participatory collapse and anomalous cognition, which left the underlying physical mechanism underspecified. It is not presented as a finished or proven framework. If even a corner of it holds water, the work of formalization lies ahead.

This working paper is therefore best read as a structured continuity capture and scaffolding document: a way to preserve and organize speculative substrate propositions so that future, more formal work on mechanisms, observer participation, and empirical tests can proceed without having to reconstruct the Session that generated them.

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