

# From Zero-Sphere to Emergent Spacetime: A Minimalist Background-Independent Framework for Temporal and Spatial Genesis

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We propose a minimalist framework for background-independent quantum theory based on the 0-sphere,  $S^0$ , the simplest nontrivial topological space consisting of two disconnected points. Unlike conventional approaches that rely on a fixed spacetime geometry or manifold structure, our model introduces relational dynamics between the two points as the sole source of structure. Proper time, spatial separation, and causality emerge from sequences of internal transformations without reference to an external background.

This framework yields physically significant features, including internal spinor oscillations, subluminal Zitterbewegung with characteristic velocity  $v_{e,ZB} \approx 0.04c^a$ , and effective gauge-like symmetries. These phenomena arise solely from the algebra of binary transitions and demonstrate the model's capacity to simulate spacetime behavior from a pre-geometric seed.

We compare this approach with established background-independent theories such as loop quantum gravity and causal set theory, highlighting both compatibility and conceptual novelty. The 0-Sphere model offers a potentially unifying substrate from which complex spacetime structures may emerge, with implications for experimental and theoretical developments in quantum gravity.

## I. INTRODUCTION

In efforts to reconcile quantum theory with general relativity, background independence has emerged as a foundational requirement [2]. A physical theory is said to be background-independent if it does not assume any fixed spacetime geometry. Instead, spacetime structure must be dynamically determined within the theory itself. General relativity exemplifies this feature [3], while conventional formulations of quantum field theory and string theory rely on pre-specified geometric backgrounds.

Loop quantum gravity [4, 5] and causal set theory [6, 7] represent prominent attempts to achieve background independence through discrete geometric structures. Loop quantum gravity quantizes spatial geometry via spin networks, where discrete quantum states of geometry evolve through spin foam dynamics [8]. Causal set theory replaces continuous spacetime with discrete events ordered by causality, where spacetime geometry emerges through stochastic growth processes [9].

This paper proposes a minimalist model based on the 0-sphere,  $S^0$ —the zero-dimensional topological sphere comprising two disconnected points—as a starting point for constructing a background-independent framework. In contrast to approaches that assume a smooth differentiable manifold or a fixed metric background, the 0-sphere model reduces prior assumptions about spacetime structure to the minimal topological framework of two distinguishable points, avoiding predetermined commitments to specific dimensions, geometry, or metric properties.

Within this minimal setting, we investigate how concepts typically treated as fundamental—such as proper

time, spatial distance, and causality—may instead emerge from relational structures and transformations defined between the two points. These quantities are not taken as input but rather as outputs of the internal dynamics of the system. In particular, we examine how the model allows for variability in proper time and spatial intervals, aligning with relativistic constraints without embedding the system in a fixed spacetime.

The proposed framework demonstrates that such a primitive starting point gives rise to physically significant features, including emergent proper time dynamics, effective  $U(1)$  and  $SU(2)$  gauge symmetries, and observable phenomena such as subluminal Zitterbewegung with characteristic velocity  $v_{e,ZB} \approx 0.04c$ . These results establish the model's capacity to serve as a pre-geometric foundation for background-independent quantum theory, with concrete predictions amenable to experimental verification through precision spectroscopy techniques [10].

This work positions itself alongside existing background-independent approaches while utilizing an extreme minimal structure—a discrete two-point system—as the foundation, distinguishing the present model both in formulation and in implications. Background independence has emerged as a central criterion for quantum gravity theories, requiring that spacetime geometry be dynamically determined rather than imposed as a fixed arena [11]. The key objective is to demonstrate that such a minimal seed can support the emergence of physically relevant structures, potentially including those corresponding to Zitterbewegung and internal degrees of freedom.

Before examining the detailed structure of the 0-Sphere model, Table I provides a comprehensive comparison with conventional quantum frameworks, highlighting the foundational distinctions that motivate this approach.

This paper presents a minimalist framework for background-independent quantum theory based on the

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<sup>a</sup> This value was previously predicted in the previous work [1].

0-sphere topology. Section II introduces the fundamental two-point system and the transition operator that generates emergent proper time and spatial structure. Section III explores the physical implications, including proper time emergence, comparison with supersymmetric frameworks, Zitterbewegung dynamics, relational geometry, comparison with established quantum gravity approaches, geometric unification of quantum and gravitational effects, and future research directions. Section IV summarizes the model's key innovations, experimental predictions, and potential for bridging quantum mechanics and general relativity through emergent geometric structures.

## II. MINIMAL STRUCTURE AND DYNAMICAL DEGREES OF FREEDOM

The 0-Sphere model proposes spacetime as an emergent structure generated from the simplest nontrivial topology: a pair of distinguishable, disconnected points forming  $S^0$ . No metric or geometric embedding is assigned to these points. Instead, the model focuses on binary transitions and the minimal relational information they encode.

The two points are interpreted as the fundamental units of distinguishability. Physical structure arises not from pre-assigned coordinates or distances, but from transformations acting on the binary pair. Among these, a central role is played by a transition operator  $T$  that mediates the discrete exchange of an abstract internal quantity, such as energy.

Let  $T$  be a unitary or norm-preserving operator acting on the binary states, satisfying  $T^n = I$  for some minimal period  $n$ . The set  $\{T^k : k \in \mathbb{Z}\}$  then forms a cyclic group, encoding the dynamics of recurrent transitions. The “tick-tock” cycle generated by  $T$  defines a discrete proper time parameter  $k$ , internal to the system.

In this view, proper time is not an external parameter but an emergent degree of freedom resulting from periodic state transitions. Likewise, spatial structure is not predefined, but arises from energy distribution patterns induced by the operation of  $T$ . Causal order is encoded in the directional application of  $T$ , while gauge-like symmetries emerge from conservation laws governing the transitions.

By minimizing assumptions about predetermined continuity, differentiability, or external background geometry, the 0-sphere framework captures the essential ingredients for constructing emergent spacetime structure. This flexibility parallels relativistic insights where temporal and spatial intervals are dynamically determined rather than absolute. The goal is not to reproduce known spacetime geometries a priori, but to explore how such geometries may arise from the dynamics of a purely relational system.

The mathematical structure  $\{T^k : k \in \mathbb{Z}\}$  forms a cyclic group, whose generator  $T$  encodes both the energy redistribution dynamics and the emergent temporal metric through the discrete parameter  $k$ . The entire structure

rests on a single principle: discrete energy exchange between two distinguishable states, governed by the algebra of transitions.

Remarkably, this elementary energy exchange mechanism proves sufficient to generate not only internal proper time through its periodic nature, but also spatial relationships through energy distribution patterns, causal structure through directional transfer processes, and gauge symmetries through conservation laws governing the exchange. The transition operator  $T$  acts fundamentally as an energy redistribution operator, making the 0-Sphere model's claim of emergent spacetime from minimal structure both mathematically precise and conceptually coherent.

## III. DISCUSSION

### A. Proper Time and Relational Dynamics

The notion of proper time in this model is not introduced as a global parameter but is associated with transitions between relational states. Each transformation between the two points of the 0-sphere can be considered an elementary process, and the sequence of such transformations defines a relational history. The sequence of transformations effectively constitutes a notion of proper time internal to the system.

We define a transition operator  $T$  that acts on the state space of binary relations. A sequence  $\{T_1, T_2, \dots, T_n\}$  generates a path in the relational space. The number, type, or composition of transformations along such a path can be used to parametrize an internal clock. Importantly, this clock does not rely on any external coordinate system or fixed metric background.

Relational dynamics in this context refers to changes in the state of the binary relation rather than positions or trajectories in spacetime. Such dynamics may include operations like swaps, negations, or more abstract group-theoretic transformations, depending on the algebra defined over the state space. The key point is that proper time corresponds to a measure of relational evolution.

This construction allows for proper time to vary according to the internal structure and history of the system, leading to a context-dependent notion of temporal flow. Unlike in general relativity, where proper time is computed from the spacetime metric along a worldline, here it arises purely from internal transition structure. This departure from the metric formulation opens new possibilities for modeling temporality in background-independent systems, aligning with Wheeler's vision of geometrodynamics where time emerges from geometry [12].

By assigning proper time to transformation histories, the model provides a concrete mechanism through which temporality can emerge from non-temporal foundations. This aligns with the idea that time, like space, may not be fundamental but is rather a secondary construct derived

**Table I.** Foundational Comparison between Standard Quantum Theories and the 0-Sphere Model

Aspect	Standard Quantum Theories	0-Sphere Model
Background Independence	Fixed spacetime manifold required for quantization	No background structure assumed; space-time emerges from relational dynamics
Experimental Predictions	High-energy or indirect observables	Direct low-energy predictions: $v_{e,ZB} \approx 0.04c$ , critical radii for leptons [1]
Proper Time	External coordinate parameter	Emergent from discrete internal transitions via operator $T^n = I$
Causality	Light-cone structure on fixed manifold	Derived from directional transformation sequences
Zitterbewegung	Mathematical artifact in Dirac formalism	Real subluminal oscillatory motion at measurable velocity
Spin and Internal Structure	Abstract SU(2) representations	Geometric manifestation of phase oscillations between thermal kernels
Gauge Symmetries	Fundamental inputs to field theory	Emergent patterns from internal energy conservation
Geometry and Manifolds	Assumed differentiable background	Emerges at Compton scale through photon sphere dynamics

**Note:** This comparison highlights the most fundamental distinctions between conventional quantum approaches and the 0-Sphere framework. All numerical predictions derive from exact analytical solutions rather than phenomenological parameters.

from relational change.

## B. Comparison with Supersymmetric Frameworks

The 0-Sphere model, defined by a two-point topological structure, generates a dynamic interplay between spin-1/2 kernels and an emergent spin-1 structure, termed the photon sphere, through relational transformations [13, 14]. This fermion-boson coexistence resembles supersymmetry, a key feature of string theory where fermions and bosons are paired to stabilize high-dimensional spacetimes [15]. However, the 0-Sphere model diverges fundamentally from string theory by deriving these dynamics from a minimal topology without extra dimensions or fixed backgrounds.

The spin-1/2 kernels exhibit oscillatory dynamics, yielding a Zitterbewegung velocity of approximately  $0.04c$ , consistent with Lorentz-like spatial intervals [13]. The photon sphere, emerging from radiative energy transfer, satisfies the conservation law:

$$E_0 = E_0 \left[ \cos^4 \left( \frac{\omega\tau}{2} \right) + \sin^4 \left( \frac{\omega\tau}{2} \right) + \frac{1}{2} \sin^2(\omega\tau) \right], \quad (\text{III.1})$$

where  $\tau$  is the internal proper time and  $\omega$  the oscillation frequency [14]. This structure produces effective U(1)

and SU(2) symmetries, rooted in topology rather than external gauge fields [14]. Unlike string theory's unverified superpartners, our model offers testable predictions, aligning with background-independent frameworks like loop quantum gravity and causal sets [5, 16]. A comprehensive comparison with supersymmetric theories shall be explored in future work.

## C. Zitterbewegung and Internal Proper Time

In the 0-Sphere model, Zitterbewegung arises naturally as an oscillatory behavior intrinsic to the spin-1/2 kernel state transitions. Unlike the Dirac equation where Zitterbewegung appears as an unphysical oscillatory term [17, 18], here it is treated as a physically real internal dynamic, associated with transitions in the relational state of the two-point system.

Historical investigations by Hestenes [19] and Bracken [20] have explored Zitterbewegung as a real physical phenomenon arising from internal electron geometry. Our approach extends these ideas by grounding Zitterbewegung in relational dynamics rather than classical spacetime embeddings.

Quantitatively, the oscillation frequency  $\omega$  characterizes the internal transformation rate between the binary states.

The resulting motion exhibits an effective displacement velocity, predicted to be approximately  $0.04c$ [13]. Recent experimental advances in quantum simulation have explored Zitterbewegung-like oscillatory behavior in trapped ion systems[21] and Bose-Einstein condensates [22]. However, these experiments were designed to test the conventional Dirac equation prediction of light-speed Zitterbewegung, not the subluminal velocity predicted by the 0-Sphere model. While these experiments successfully emulate key aspects of relativistic quantum mechanics, they do not constitute verification of the present framework's subluminal predictions. Direct observation of Zitterbewegung in elementary particles, such as electrons, remains an open challenge. Nevertheless, precision measurements of the predicted subluminal velocity may become feasible with progress in high-resolution spectroscopy and interferometry specifically designed to detect sub-light-speed internal oscillations.

Experimentally, this framework allows Zitterbewegung to be interpreted as a real, testable phenomenon arising from internal state transitions and proper time evolution. Potential experimental approaches include high-precision electron interferometry and spin-echo techniques capable of detecting sub-luminal internal oscillations [21, 22]. This contrasts with conventional quantum mechanics where such oscillations are generally viewed as non-observable interference effects.

Conceptually, the presence of such structured internal motion within a minimal topological model supports the broader thesis that spacetime geometry and physical phenomena can emerge from non-metric, non-embedded foundations. Zitterbewegung, as realized here, demonstrates how fundamental quantum phenomena can emerge from purely relational dynamics, offering a new pathway toward background-independent quantum mechanics.

#### D. Relational Geometry and Causal Structure

Within the 0-Sphere model, spatial and causal relations are not presupposed but emerge from the algebraic structure of state transitions. Since the two points of  $S^0$  possess no inherent metric properties, any notion of distance or causal connection must be constructed from patterns of internal transformation.

We consider a sequence of transformations  $\{T_1, T_2, \dots, T_n\}$  as defining an effective path or relational trajectory. The number of such transitions, their symmetry properties, and commutation relations provide a combinatorial basis for defining a generalized notion of separation. For instance, if two relational states are connected by an even number of commuting operations, their effective "distance" may be treated as symmetric and reversible, whereas non-commuting transformations may encode an effective directionality.

To formalize this, let  $d(\psi_i, \psi_j)$  be a function assigning a relational distance between states  $\psi_i$  and  $\psi_j$ . Then:

$$d(\psi_i, \psi_j) = \min\{n \mid T_n \cdots T_1 \psi_i = \psi_j, T_k \in \mathcal{T}\}, \quad (\text{III.2})$$

where  $\mathcal{T}$  is the set of admissible transformations. The structure of  $\mathcal{T}$ , including its group or semigroup properties, determines the geometry that emerges. If  $\mathcal{T}$  contains non-invertible or non-commuting elements, an effective causal asymmetry can be encoded in  $d$ .

Such a definition naturally leads to a discrete, algebraic analog of a causal structure. In particular, a causal order can be induced by defining a partial ordering on relational states:

$$\psi_i \prec \psi_j \quad \text{if there exists } \{T_k\} \text{ such that } \psi_j = T_n \cdots T_1 \psi_i. \quad (\text{III.3})$$

This approach defines causality intrinsically, without relying on any external spacetime geometry or background coordinates. The order relation  $\psi_i \prec \psi_j$  emerges purely from the internal structure of relational transformations, making the causal direction a consequence of state transitions rather than geometric embedding.

This causal ordering is background-independent and arises from the sequential structure of internal dynamics rather than any light-cone embedded in a metric space. In this way, causality becomes a derived property of transition rules, and spacetime-like behavior can emerge from the consistency of such orderings.

Moreover, the directionality of energy transfer between spin-1/2 kernels and the photon sphere [14] provides a physical mechanism reinforcing this causal structure. Internal transformations that preserve energy conservation while enforcing radiative flow in a preferred direction arise from energy gradients generated by the electron's internal structure.

This emergent causal order aligns with approaches in causal set theory, where causality and discreteness are taken as primitive [6, 9]. However, the 0-Sphere model derives these features from internal symmetry and transformation properties, without positing any fundamental spacetime points or external causal links.

Relational geometry in this model thus refers to the algebraic structure of transformations, while causal structure is encoded in their sequential composition. This framework derives spacetime properties from discrete transformation sequences and their algebraic relationships, without assuming any underlying continuous manifold structure, consistent with the demands of background independence.

#### E. Comparison with Causal Set Theory and Loop Quantum Gravity

Both causal set theory (CST) and loop quantum gravity (LQG) are prominent background-independent approaches in quantum gravity [23], sharing a conceptual affinity with the 0-Sphere model in their rejection of pre-assigned spacetime geometry. However, the methodological and structural differences between these frameworks highlight the distinctiveness of the 0-sphere approach.

Causal set theory posits a discrete set of spacetime events partially ordered by causality [16, 24]. The dynamics arise from sequential growth models where new events are added according to stochastic rules that preserve causal order [7]. In contrast, the 0-Sphere model does not assume discrete spacetime points. Instead, it derives an emergent causal order from algebraic transformations between binary relational states.

Loop quantum gravity constructs quantum spacetime from spin networks—graphs whose edges are labeled by  $SU(2)$  representations [5, 25]. The discreteness of area and volume emerges naturally from the quantization procedure [8], and geometric transitions are encoded in spin foam dynamics [26]. While LQG preserves diffeomorphism invariance and quantizes the geometry of space directly, the 0-Sphere model avoids geometric quantization altogether.

The 0-Sphere model takes a more radical approach, starting not from a discrete geometry, but from the most minimal topological seed—a two-point set with internal symmetry. This allows for the construction of proper time, gauge structure, and causal ordering from a purely relational foundation, potentially serving as a precursor from which discrete structures like causal sets or spin networks may themselves emerge.

Moreover, whereas CST and LQG rely on established mathematical frameworks (order theory, representation theory), the 0-Sphere model is founded on an algebra of relational transformations and binary state transitions. This difference may offer new tools for addressing foundational issues, such as the origin of internal symmetries or the coupling between matter and emergent spacetime.

By positioning itself relative to CST and LQG, the 0-Sphere model can be understood not as a competing discretization scheme, but as a pre-geometric foundation: a framework where discrete structures emerge naturally from the internal electron dynamics—specifically, from the reciprocating motion of a photon sphere that moves continuously through spacetime along radiation gradients between discretely positioned thermal potential energy kernels, without requiring artificial quantization procedures.

## F. Emergence of Quantum Phenomena from Geometric Dynamics

This work proposes a paradigm in which fundamental quantum phenomena—including spin, Zitterbewegung, and decay thresholds—emerge from minimal topological and relational structures without assuming any external geometric background. In contrast to conventional formulations where particles are treated as point objects embedded in spacetime, the present model introduces a dual-kernel architecture where internal harmonic oscillations between thermal potential energy (TPE) kernels generate effective spin states [13]. This

reinterpretation eliminates the need for abstract quantum superposition, as spin emerges geometrically from phase oscillations across a binary structure. The resulting subluminal Zitterbewegung velocity, approximately  $0.04c$ , offers an experimentally testable manifestation of internal dynamics.

Furthermore, this framework geometrically explains the origin of the anomalous magnetic moment through Lorentz contraction effects arising from oscillatory motion. When general relativistic geodetic precession is included, the Zitterbewegung velocity is corrected from  $v_{e,SR} = 0.040472c$  to  $v_{e,SR+GR} = 0.040374c$ . This quantitative refinement indicates that general relativistic corrections, typically considered negligible at the quantum scale, produce observable effects. Such sensitivity implies that quantum mechanics and general relativity intersect more intimately than previously assumed, echoing Penrose’s insights on the geometric foundations of quantum mechanics [27].

In the 0-sphere model, the introduction of differential geometry occurs not at the level of the binary kernel, but through the photon sphere, which has a spatial scale on the order of the Compton wavelength. Prior work [1] estimates the size of the TPE kernel to be on the order of  $10^{-25}$  meters. Consequently, in analyses performed at Compton scale resolution, the TPE kernel can be approximated as a point source. This separation of scales justifies the application of differentiable geometric frameworks to describe field-like structures without compromising the discrete nature of the underlying model.

The model further predicts critical radii associated with particle stability. For the muon and tau lepton, these are approximately  $3.43 \times 10^{-25}$  m and  $5.71 \times 10^{-24}$  m, respectively [1]. These radii mark boundaries at which Zitterbewegung ceases, corresponding to decay thresholds, offering a purely geometric explanation for lepton decay.

Within this model, the photon sphere admits a differentiable manifold whose geometry is modulated by internal temporal phase, reflecting the dynamical redistribution of energy across its surface. It is proposed that such modulation can be expressed using spherical harmonic functions, whose trigonometric and radial components encode both spatial and temporal variation. While a full formalism remains to be developed, this approach suggests that kinetic energy and its evolution may be described as a differentiable entity in both space and time, constructed not from a continuous spacetime backdrop but from internal phase dynamics—potentially via gradients or temporal derivatives of phase functions defined on the photon sphere.

At this stage, it can be argued that kinetic energy corresponds to the temporal modulation of such harmonics. Since spherical harmonics consist of trigonometric functions modulated by radial distance (with dimensions of length), a kinetic energy expression built on such a manifold would be differentiable with respect to both temporal and spatial coordinates. This suggests that physical quantities derived within this framework may

admit a fully differentiable representation of spacetime dynamics.

### G. Geometric Unification of Quantum and Gravitational Dynamics

Building upon general relativity’s description of spacetime curvature from external mass-energy, the 0-Sphere model extends this framework by preserving linear superposition of geometric effects. The photon sphere moves continuously between discretely positioned thermal potential energy (TPE) kernels, following geodesic trajectories governed by Snell’s law along radiation gradients. This creates a total geometric action that linearly combines both internal photon sphere dynamics and external spacetime curvature, providing a tensor-based bridge between quantum mechanics and general relativity at the Compton scale.

Beyond the differentiable geometry of the photon sphere, the model posits that the center of energy, as it propagates between two TPE kernels—denoted  $A$  and  $B$ —traces a geodesic intrinsic to the internal relational dynamics. This geodesic is not embedded in a background manifold or defined by spacetime curvature, as in general relativity, but instead emerges from the intrinsic structure of the binary state space. Governed by conservation of internal energy and symmetry constraints on radiative transfer, this extremal trajectory functions as the most efficient conduit for energy redistribution. It permits the application of both temporal and spatial derivatives, internally defined via discrete energy transitions and oscillatory phase relations. Further formalization is needed to relate this energy-defined geodesic to conventional notions of curvature, connection, and parallel transport in differential geometry.

The innovations described above challenge prevailing assumptions about the separation between quantum field theory and gravity. Rather than invoking additional dimensions or high-energy effects, the proposed model demonstrates that gravitational phenomena can be expressed through geometric constraints acting at accessible energy scales, distinguishing it from speculative approaches that require trans-Planckian physics [28]. Conservation laws are maintained strictly at all phases, and gauge symmetries emerge as relational invariances under internal transformations. This offers a route toward unification that does not depend on quantizing classical geometry, but instead derives geometry from fundamental symmetry operations.

Importantly, the model’s predictions are subject to empirical verification. The subluminal Zitterbewegung velocity and associated magnetic moment shifts lie within the detection limits of precision spectroscopy and spin-resolved measurement techniques. This places the framework within the domain of falsifiable physics and distinguishes it from more speculative approaches to quantum gravity.

### H. Future Prospects

The 0-sphere framework developed in this work opens several promising avenues for future investigation, addressing both mathematical foundations and experimental applications.

#### 1. Algebraic Structure and Representation Theory

The transition operator  $T$  and its powers  $T^n = I$  suggest rich algebraic structures that warrant detailed investigation. Key questions include:

- **Determination of the periodicity parameter  $n$ :** The physical principles that determine the specific value of  $n$  for different particle species remain to be elucidated. Preliminary analysis suggests a connection to particle mass and internal symmetries, potentially linking  $n$  to the representation theory of fundamental symmetry groups.
- **Matrix representation of  $T$ :** Explicit construction of the matrix elements  $\langle i|T|j\rangle$  in appropriate basis states would enable direct computational verification of theoretical predictions and facilitate numerical simulation of multi-particle systems.
- **Universal applicability:** Extension of the 0-sphere formalism to other fundamental particles (muons, quarks, neutrinos) requires investigation of whether the binary kernel structure represents a universal feature of matter or emerges specifically in certain particle classes.

#### 2. Experimental Verification Protocols

Several testable predictions emerge from the discrete transition dynamics:

- **Periodicity detection:** High-precision measurements of internal oscillation frequencies should reveal discrete spectral lines corresponding to the fundamental period  $T^n = I$ , potentially observable through advanced interferometric techniques.
- **Zitterbewegung velocity verification:** The predicted subluminal velocity  $v \approx 0.04c$  provides a direct experimental target, accessible through ultra-fast time-resolved spectroscopy or precision magnetic moment measurements under controlled conditions.

Future work will address these questions through both theoretical development and experimental collaboration, with the ultimate goal of establishing the 0-sphere framework as a testable foundation for fundamental physics.

#### IV. CONCLUSION

This work has developed a relational and background-independent framework for quantum structure based on the 0-sphere,  $S^0$ , the simplest nontrivial topology consisting of two disconnected points. The model operates within a unified geometric framework where electrons possess internal oscillatory structure: the photon sphere follows geodesic trajectories influenced by both internal radiation gradients and external mass distributions. This creates a multi-scale geometry that bridges quantum and gravitational effects, where physically relevant structures—proper time, causality, internal spin dynamics, and gauge symmetries—emerge from algebraic and relational dynamics that naturally incorporate external gravitational influences.

Unlike standard formulations that assign spin and gauge structure through group representations over a fixed manifold, this approach generates these features as emergent properties of oscillatory transitions between dual thermal potential energy (TPE) kernels [13]. In this framework, spin is no longer an abstract quantum number but a geometric manifestation of phase-coherent motion between discrete kernel states. Moreover, Zitterbewegung appears not as a mathematical artifact of the Dirac equation but as a subluminal oscillatory process with velocity  $v_{e,ZB} \approx 0.04c$ , subject to relativistic correction when gravitational effects are included [1].

A critical distinction of this model lies in its hierarchical scale structure. The photon sphere, responsible for introducing differentiable geometry, operates at the Compton wavelength scale. In contrast, the TPE kernel, predicted to be on the order of  $10^{-25}$  meters [1], remains effectively point-like at that resolution. This separation of scales allows the model to remain discrete and algebraic at the core while supporting differentiable structures where necessary, such as in the treatment of kinetic energy through time-dependent spherical harmonics.

Unlike general relativity, where differentiable structure is globally postulated to describe spacetime curvature induced by external mass-energy, the present framework introduces differentiability as a locally emergent feature within the photon sphere—a geometric layer whose structure arises from internal phase dynamics. Although initially confined to this internal structure, the resulting differentiable geometry serves as a foundational seed, potentially extensible to larger-scale geometries consistent with general relativity. Within this model, the photon sphere admits a differentiable manifold whose geometry is modulated by internal temporal phase. It is proposed that such modulation can be expressed using spherical harmonic functions, whose trigonometric and radial components encode both spatial and temporal variation. While a full formalism remains to be developed, this approach suggests that kinetic energy and its evolution may be described as a differentiable entity in both space and time, constructed not from a continuous spacetime backdrop but from internal phase dynamics.

Beyond the photon sphere's differentiable geometry, the model further identifies the line connecting the two TPE kernels—designated  $A$  and  $B$ —as a geodesic structure intrinsic to the internal dynamics. This geodesic is not defined through a spacetime metric, but through the algebraic symmetry and periodicity of state transitions. It supports the application of both temporal and spatial derivatives within the relational framework. As such, the  $A$ – $B$  connection embodies a generalized geodesic principle: extremal transition paths between relational states, along which differential structure is preserved. Although distinct from metric geodesics in general relativity, this formulation maintains the core principle of minimal-action paths, offering a novel basis for the emergence of geometric laws from non-metric foundations.

The model further predicts critical radii associated with particle stability. For the muon and tau lepton, these are approximately  $3.43 \times 10^{-25}$  m and  $5.71 \times 10^{-24}$  m, respectively [1]. These radii mark boundaries at which Zitterbewegung ceases, corresponding to decay thresholds. This mechanism offers a purely geometric explanation for lepton decay, rooted in the vanishing of internal oscillatory motion.

From an experimental standpoint, the framework's strength lies in its falsifiability. The predicted subluminal Zitterbewegung, its gravitational corrections, and the defined critical radii offer measurable targets via high-resolution spectroscopic or interferometric techniques. Unlike quantum gravity theories that rely on trans-Planckian regimes, the 0-sphere model predicts low-energy signatures that are in principle observable with existing or near-future technologies.

In summary, **the 0-sphere framework does not attempt to quantize a classical spacetime geometry. Instead, it proposes that geometry, symmetry, and temporal evolution are emergent from an algebra of internal transitions.** In doing so, it offers a unifying substrate from which quantum mechanics and general relativity may be reconciled—not by forcefully merging their equations, but by revealing a common geometric origin beneath both. Future work will focus on deepening the geometric analysis of the internal structure of a single electron and developing a formalism that allows this structure to be extended and fitted consistently within the geometric framework of general relativity.

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