

Thermal Geodesics in the 0-Sphere Model: Extending General Relativity through Internal Thermodynamic Structure

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We propose a geometric extension to general relativity through the 0-Sphere model, incorporating internal thermal dynamics into Einstein’s field equations [1, 2] via thermal geodesics. Particles are modeled as oscillatory systems composed of two thermal kernels and a mediating photon sphere. Energy transfer between kernel A and kernel B follows temperature-dependent internal geometry, defined by a metric $\mathcal{G}_{\mu\nu}(T)$ [3], giving rise to motion along *thermal geodesics*—paths that minimize thermodynamic action while contributing to external spacetime curvature through thermal stress-energy tensor $T_{\mu\nu}^{(\text{thermal})}$.

This formulation introduces a thermodynamic contribution to temporal evolution, defined by internal oscillation phases that couple to external gravitational time dilation. As temperature approaches absolute zero, oscillatory energy flow diminishes, affecting both internal dynamics and external gravitational contributions. Zitterbewegung emerges as subluminal thermal motion within particles, with temperature-dependent behavior testable in ultra-cold systems [4, 5]. The photon is modeled as a spherical harmonic energy distribution whose center follows thermal geodesics coupled to spacetime geometry.

By integrating thermal geodesics with spacetime geodesics through tensor additivity in Einstein’s field equations [2], the model offers a geometric language that unifies quantum internal dynamics and relativistic motion. This work establishes a mathematical foundation for incorporating internal thermodynamic structure into general relativity, creating a self-consistent framework where quantum thermal effects and gravitational geometry are mutually coupled.

I. INTRODUCTION

This paper complements our previously established quantitative results for electron Zitterbewegung velocities and anomalous magnetic moments [6, 7] by developing the fundamental geometric framework underlying these predictions. While our earlier work demonstrated that electrons exhibit subluminal internal oscillations at $v \approx 0.04c$, the present study provides the conceptual foundation through which such motion couples internal thermal dynamics to spacetime geometry via thermal geodesics.

In general relativity, the motion of particles is described as free fall along geodesics defined by spacetime curvature. These geodesics represent paths of extremal proper time, determined by the background metric $g_{\mu\nu}$ and matter distributions. This geometric view has provided deep insights into gravitation and cosmology, establishing a successful framework for describing gravitational phenomena across scales from solar systems to cosmological horizons.

Quantum mechanics treats particles as point-like entities or wave packets that evolve according to field equations, with internal structure typically addressed through composite particle models or effective field theories. Thermal behavior is introduced through statistical mechanics or finite-temperature field theory. While both frameworks have achieved remarkable success within their respective domains, their unification remains an outstanding challenge in theoretical physics.

The 0-Sphere model addresses this challenge by extending the geometric principles of general relativity to incorporate internal particle structure through thermal dynamics. Recent developments in background-independent quantum theory [8] have demonstrated that complex spacetime structures can emerge from minimal topological foundations, supporting the present approach of deriving gravitational effects from internal thermal dynamics. In this model, particles such as electrons possess internal thermal components—kernel A , kernel B , and an intermediary photon sphere—that define oscillatory systems. Energy oscillates between kernel A and kernel B through the photon sphere, creating internal motion that is both periodic and thermodynamically structured.

To describe the dynamics of energy transfer between internal components, we introduce the concept of *thermal geodesics*: energy transport paths that minimize thermodynamic action defined by an internal temperature-dependent metric $\mathcal{G}_{\mu\nu}(T)$. These thermal geodesics operate within the particle’s internal structure while contributing to external spacetime curvature through thermal stress-energy tensor $T_{\mu\nu}^{(\text{thermal})}$. This creates a self-consistent framework where internal dynamics and external geometry are mutually coupled through Einstein’s field equations.

The distinction between thermal geodesics and spacetime geodesics is both conceptual and mathematical. Thermal geodesics describe energy flow within particles, while spacetime geodesics describe motion through curved spacetime. However, these descriptions are not independent: the internal thermal structure contributes to the stress-energy tensor that determines spacetime curvature, while external gravitational fields influence the internal

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thermal geodesic structure. This bidirectional coupling provides a natural mechanism for quantum-gravitational interaction.

In this framework, time emerges from the phase progression of internal thermal oscillations while remaining coupled to external gravitational effects. The photon sphere mediates energy flow and contributes to the effective geometry that governs both internal dynamics and external motion. As temperature approaches absolute zero, internal oscillations slow, providing a thermodynamic origin for temporal evolution that naturally incorporates relativistic effects.

The 0-Sphere model thus extends general relativity's geometric framework to encompass internal particle dynamics, creating a unified description where quantum thermal effects and gravitational geometry are mathematically integrated through tensor additivity in Einstein's field equations. This approach preserves the proven mathematical structure of general relativity while providing a pathway toward quantum-gravitational unification.

This paper develops a geometric extension of general relativity through thermal geodesics within the 0-Sphere model. Section I establishes the conceptual foundation, introducing thermal geodesics as internal energy transport paths that couple to external spacetime geometry. Section II provides background from previous work on internal energy distributions and clarifies key terminology unique to the thermal geodesic framework. Section III formulates the thermal Lagrangian and derives equations governing energy transport between kernel A and kernel B . Section IV explores the emergence of time from thermal oscillations, reinterprets Zitterbewegung as subluminal thermal motion, and extends thermal geodesics to photon dynamics. Section V develops the temperature-dependent metric formulation and demonstrates how thermal geodesics integrate with general relativistic principles. The conclusion summarizes the model's unified geometric description and identifies testable predictions for experimental validation.

II. MOTIVATION AND BACKGROUND

A. Background from Previous Work

The 0-Sphere model was developed to incorporate internal oscillatory structures within elementary particles, particularly the electron, while maintaining consistency with established physical principles. In earlier work [9, 10], the internal energy distribution was modeled using trigonometric functions that connect oscillations to spin, anomalous magnetic moments, and geometric effects:

$$K_A(t) = \cos^4\left(\frac{\omega t}{2}\right), \quad K_B(t) = \sin^4\left(\frac{\omega t}{2}\right). \quad (\text{II.1})$$

These expressions represent the thermal potential energy (TPE) distributed between two internal regions, kernel

A and kernel B , within a single particle. The periodic exchange of energy between these kernels occurs via an intermediary structure, the photon sphere, which mediates kinetic energy transfer.

This internal motion operates within the particle's structure while remaining coupled to external gravitational fields through the thermal stress-energy tensor. The photon sphere is modeled by a term with 2π periodicity:

$$K_{\text{photon}}(t) = \frac{1}{2} \sin^2(\omega t), \quad (\text{II.2})$$

which represents the kinetic energy component that facilitates energy transitions between kernel A and kernel B . The total internal energy remains conserved:

$$E_0 = E_0 [K_A(t) + K_B(t) + K_{\text{photon}}(t)]. \quad (\text{II.3})$$

The use of $\omega t/2$ in Eq. (II.1) reflects the spinorial characteristics of the system, indicating 4π periodicity consistent with spin-1/2 particles. This internal structure complements the external description of fermions while providing additional geometric insight into their behavior.

In this framework, motion emerges from internal energy flow that couples to external gravitational effects through Einstein's field equations. The alternating dominance of $K_A(t)$ and $K_B(t)$ generates natural oscillations that contribute to phenomena such as Zitterbewegung. This thermal interpretation provides a geometric foundation for quantum effects while maintaining consistency with relativistic principles.

The oscillation frequency ω depends on temperature, with the system approaching equilibrium as temperature decreases toward absolute zero. This temperature dependence suggests that temporal evolution emerges from internal thermal processes while remaining coupled to external gravitational time dilation effects. Time thus arises from both internal oscillatory phases and external relativistic conditions.

These foundational concepts establish the framework for thermal geodesics, which describe energy transport paths within particles that contribute to external spacetime geometry. The following sections develop this internal structure within a geometric formulation that extends general relativity to include thermal contributions through tensor additivity in Einstein's field equations.

B. Key Terms in the 0-Sphere Framework

The 0-Sphere model extends conventional physics terminology to incorporate thermal-geometric concepts. To facilitate understanding of subsequent sections and comparison tables, we clarify how familiar terms are interpreted within our extended framework, emphasizing their integration with established physical principles.

To aid in understanding the comparative framework presented in Table I, we provide explanations for key terms as they appear in the 0-Sphere model, highlighting how

Table. I. Comparison with Existing Theories

Aspect	QFT	General Relativity	0-Sphere Model
Time	External parameter	Coordinate dependent	Flow-generated
Lagrangian	Field-based density	Geometric action	Thermodynamic geometric action
Background	Required	Dynamic but given	Geometrically coupled
Energy	Field excitation	Stress-energy tensor	Intrinsic thermal flow
Particles	Field quanta	Matter source	Oscillatory flow structure

this framework extends rather than replaces conventional interpretations from quantum field theory (QFT) and general relativity (GR).

- **Time: Flow-generated and relativistic**

Time emerges from internal thermal oscillations between kernel A and kernel B while remaining coupled to external gravitational time dilation. The progression of internal phases determines local temporal evolution, which interacts with relativistic effects through the coupling of thermal dynamics to spacetime curvature.

- **Lagrangian: Thermodynamic geometric action**

The thermal Lagrangian incorporates temperature-dependent internal geometry while contributing to external spacetime dynamics through the stress-energy tensor. This extends conventional Lagrangian formulations by including thermal geodesic contributions that couple internal particle structure to gravitational fields.

- **Background: Geometrically coupled**

Internal thermal geometry couples to external spacetime through tensor additivity in Einstein's field equations. Rather than assuming fixed background spacetime, the framework allows bidirectional interaction between internal thermal structure and external gravitational geometry.

- **Energy: Thermal flow with gravitational coupling**

Energy manifests as active thermal flow between internal components that contributes to the external stress-energy tensor. This flow carries geometric information that influences both internal dynamics and external spacetime curvature through gravitational coupling.

- **Particles: Oscillatory systems with gravitational effects**

Particles consist of oscillatory thermal systems with internal architecture defined by kernel A , kernel B , and the photon sphere. This internal structure

contributes to external gravitational fields while responding to external spacetime curvature, creating self-consistent particle-geometry coupling.

This extended terminology emphasizes how the 0-Sphere model integrates internal thermodynamic processes with external gravitational effects. The framework builds upon established physical principles while incorporating thermal contributions that couple quantum internal dynamics to relativistic spacetime geometry through Einstein's field equations.

III. THERMAL GEODESIC FRAMEWORK

A. Background Independence and Thermal Lagrangian

In classical and relativistic physics, particle trajectories are defined with respect to a pre-existing spacetime. Motion is described as either a response to external forces or, in the case of general relativity, as geodesic motion dictated by the curvature of the spacetime manifold [1, 11]. These approaches assume that spacetime itself is a background stage on which all physical processes occur.

The 0-Sphere model extends this geometric framework by incorporating internal thermal dynamics that couple to external spacetime through Einstein's field equations. While maintaining the successful structure of general relativity, the model introduces thermal geodesics that describe energy flow within particles while contributing to external spacetime curvature through thermal stress-energy tensor $T_{\mu\nu}^{(\text{thermal})}$. This creates a self-consistent framework where internal thermal geometry and external spacetime geometry are mutually coupled.

To formalize this idea, we define a *thermal Lagrangian* $\mathcal{L}_{\text{thermal}}$, building on prior work [10], that governs the transport of energy between kernel A and kernel B along a dynamically determined path. The motion is described not in terms of minimizing proper time, as in general relativity, but in terms of minimizing a thermodynamic action:

$$S = \int_{\gamma} \mathcal{L}_{\text{thermal}}(x^{\mu}, \dot{x}^{\mu}; T) d\tau, \quad (\text{III.1})$$

where γ is the path taken by energy within the particle, x^μ are internal coordinates, \dot{x}^μ the tangent vector along the path, and T the local temperature.

We propose that the thermal Lagrangian takes the form:

$$\mathcal{L}_{\text{thermal}} = \mathcal{G}_{\mu\nu}(T) \dot{x}^\mu \dot{x}^\nu, \quad (\text{III.2})$$

where $\mathcal{G}_{\mu\nu}(T)$ is a temperature-dependent internal metric, potentially amenable to noncommutative geometric formulations [3]. This structure defines what we refer to as a *thermal geodesic*—the path of least thermodynamic action within the internal geometry of the particle.

By applying the variational principle $\delta S = 0$, we obtain the thermal geodesic equation:

$$\frac{d^2 x^\mu}{d\tau^2} + \Gamma_{\nu\rho}^\mu(T) \frac{dx^\nu}{d\tau} \frac{dx^\rho}{d\tau} = 0, \quad (\text{III.3})$$

where $\Gamma_{\nu\rho}^\mu(T)$ are the Christoffel symbols associated with the thermal metric $\mathcal{G}_{\mu\nu}(T)$. This form mirrors the geodesic equation of general relativity, but with a crucial distinction: the geometry is not determined by mass-energy content in external spacetime, but by internal thermal structure.

In this framework, motion is no longer a response to an external field or a manifestation of spacetime curvature. Instead, motion is an intrinsic consequence of internal energy gradients. The concept of thermal geodesics thereby provides a bridge between the familiar geodesics of general relativity and the internal, oscillatory dynamics characteristic of quantum systems.

Moreover, this formulation allows us to assign a geometric meaning to energy flow without invoking any external coordinates. Each particle carries within itself the structure needed to define its own geometry, motion, and time. This geometric coupling between internal and external dynamics is a defining feature of the 0-Sphere model, and a key motivation for introducing thermal geodesics as a complement to gravitational geodesics.

In the sections that follow, we will explore the emergence of time from thermal oscillation, the behavior of Zitterbewegung within this framework, and how photon motion can also be understood in terms of thermal geodesics.

B. Conceptual Basis of the Thermal Lagrangian

The concept of a “thermal Lagrangian” is not standard in conventional physics. In classical mechanics and quantum field theory, a Lagrangian is a scalar function constructed from positions, velocities, and field derivatives, defined over an external spacetime manifold. It provides a route to the equations of motion via the variational principle. In contrast, thermodynamics is primarily a theory of equilibrium and state functions, typically devoid of dynamical trajectories or action principles.

Nonetheless, certain modern developments—such as non-equilibrium thermodynamics [12], stochastic thermodynamics, and thermal field theory—have motivated the introduction of Lagrangian-like functionals to describe dissipative or fluctuating systems. These formulations often deal with entropy production, energy dissipation, or probability currents. However, even in those contexts, the Lagrangian structure is either approximate or auxiliary, and rarely fundamental.

In the 0-Sphere model, by contrast, the thermal Lagrangian $\mathcal{L}_{\text{thermal}}$ plays a central, foundational role. It governs the internal transport of thermal potential energy (TPE) between kernel A and kernel B , mediated by the photon sphere. This transport occurs not in external spacetime, but along an emergent thermal geometry characterized by a temperature-dependent metric $\mathcal{G}_{\mu\nu}(T)$. Motion is not externally imposed, but arises from gradients in thermal structure internal to the particle.

The thermal Lagrangian thus serves as a variational tool to derive equations of motion within this internal thermodynamic geometry. Paths of least thermodynamic action—thermal geodesics—replace the geodesics of general relativity. These geodesics describe the natural evolution of internal energy flow, and simultaneously define emergent notions of time, motion, and geometry. This allows us to describe particle dynamics as arising from internal energy redistribution that couples to external spacetime geometry through the thermal stress-energy tensor.

In this framework, the Lagrangian is not merely a mathematical device, but a physical encoding of the structure of internal energy transport. Its temperature dependence reflects the thermodynamic conditions of the system, and its geometric form endows the internal oscillation with directionality and stability. While unconventional, this reinterpretation of the Lagrangian is consistent with the broader aim of extending general relativity to include internal thermodynamic structure through geometric coupling.

IV. THERMODYNAMIC EMERGENCE OF TIME AND MOTION

A. Thermal Origin of Time: Temporal Emergence from Oscillation

In conventional theories, time is a universal parameter, either a coordinate in Newtonian mechanics or part of relativity’s spacetime manifold, independent of material systems. Some approaches to quantum gravity, such as loop quantum gravity and causal set theory, have proposed that time may be emergent rather than fundamental [13]. However, these frameworks typically explore temporality through the quantization of spacetime itself.

In contrast, the 0-Sphere model derives time from internal thermal processes without discretizing space or quantizing geometry. In the 0-Sphere model, **time does**

not pre-exist the system; it is not a background parameter but a derived quantity that emerges from the internal dynamics of thermal energy flow. Unlike approaches that postulate a quantized or background-based notion of time, our model treats temporality as a physical process rooted in the oscillatory transfer of thermal potential energy within the particle itself. This marks a fundamental departure from both classical and quantum treatments of time.

Within each particle, energy oscillates between kernel A and kernel B through the mediation of the photon sphere. This process is governed by a simple harmonic structure, where the total energy remains conserved but periodically redistributed. The oscillation defines a phase $\phi(t)$ given by:

$$\phi(t) = \omega(T)t, \quad (\text{IV.1})$$

where $\omega(T)$ is a temperature-dependent frequency. This phase encapsulates the internal evolution of the particle. Rather than time being an external label assigned to this evolution, it is identified with the evolution itself.

In this view, the progression of time is tied directly to the thermal conditions of the system. As temperature decreases, the oscillation slows. In the limiting case where $T \rightarrow 0$, the frequency $\omega(T)$ approaches zero, and the phase becomes constant:

$$\lim_{T \rightarrow 0} \phi(t) = \text{const.} \quad (\text{IV.2})$$

This corresponds to a cessation of temporal evolution. The particle becomes dynamically frozen—not in space, but in internal phase. There is no longer any progression of internal states, and thus no meaningful passage of time.

This formulation provides a thermodynamic origin of time. **Time does not flow unless energy flows.** The coupling of internal thermal oscillations to gravitational time dilation [7] provides a natural mechanism through which quantum internal dynamics respond to spacetime curvature, demonstrating that temporal evolution emerges from both internal thermal processes and external gravitational effects. Each particle possesses its own temporal evolution, governed by its internal energy redistribution. There is no need for an external clock or global synchronization. Temporal coordination across systems would arise only through interactions that couple their internal energy flows.

The concept has important implications for both relativity and quantum theory. In relativity, time dilation is viewed as a result of relative motion or gravitational potential. In the 0-Sphere model, what appears as time dilation could instead reflect a local slowdown in internal thermal oscillation due to environmental or relativistic factors. In quantum theory, where the time parameter typically appears as an external coordinate in the Schrödinger equation, this model suggests that time evolution originates within each particle's own structure.

By tying the existence and progression of time to thermal oscillation, the 0-Sphere model offers a radical

reinterpretation of temporality. It aligns temporal behavior with the internal dynamics of matter, potentially paving the way for a unified description of time that is consistent across quantum and relativistic regimes.

This model is analogous to an inchworm's locomotion: although the contact points with the environment (kernel A and B) appear discrete, the body of the inchworm (the photon sphere) transmits motion in a continuous manner.

B. Zitterbewegung as Thermal Motion

Zitterbewegung, the rapid trembling motion predicted by the Dirac equation [14], is traditionally attributed to interference between positive and negative energy states. Theoretical studies have explored its physical basis [15, 16], and recent experiments have observed it in quantum simulators [4, 17]. In contrast, we propose a thermodynamic origin for this motion within the 0-Sphere model. However, in the 0-Sphere model, this phenomenon acquires a new physical meaning. It is not the consequence of quantum interference, but the manifestation of an internal thermal oscillation between two energetically distinct configurations: kernel A and kernel B .

In this framework, Zitterbewegung reflects the internal energy exchange governed by the thermal geodesic structure. The motion is deterministic and subluminal, characterized by a well-defined oscillation frequency $\omega(T)$ and amplitude determined by the thermal configuration. Unlike quantum interpretations that regard this motion as mathematically emergent, the 0-Sphere model treats it as a real, physical process embedded within the particle's internal geometry.

At temperatures above absolute zero, this oscillation drives emergent time and kinetic behavior. Our thermal interpretation of Zitterbewegung complements experimental observations [4, 17] and predicts its suppression in ultra-cold systems, potentially testable through precision magnetic moment measurements [5]. However, as the temperature approaches a critical threshold, the internal energy flow diminishes. When $T \rightarrow 0$, the thermal Lagrangian $\mathcal{L}_{\text{thermal}}$ vanishes, and so too does the geodesic motion between kernel A and kernel B .

This leads to a distinctive thermodynamic interpretation of critical behavior:

$$\lim_{T \rightarrow 0} \mathcal{L}_{\text{thermal}} = 0 \quad \Rightarrow \quad \text{Zitterbewegung ceases.} \quad (\text{IV.3})$$

Consequently, not only does motion halt, but the internal phase evolution—and hence the passage of time—comes to a standstill. The particle enters a dynamically frozen state in which neither energy transport nor temporal progression exists.

This thermal suppression of Zitterbewegung contrasts with conventional relativistic explanations, where high-speed motion and Lorentz contraction dominate. The 0-Sphere model suggests that low-temperature

environments could provide an alternative route to halting internal motion, even in the absence of relativistic effects.

Such a mechanism offers intriguing possibilities for ultra-cold experiments. Systems cooled near absolute zero might exhibit suppressed Zitterbewegung, altered magnetic moments, or unexpected inertial behavior, all traceable to the freezing of internal energy dynamics. These predictions provide a path toward empirical validation of the thermal geodesic framework.

By linking Zitterbewegung directly to internal thermal behavior, the model offers a coherent explanation for both its emergence and cessation. This redefinition situates the trembling motion not as a quantum artifact, but as a thermodynamically driven oscillation—a necessary consequence of internal energy flow along thermal geodesics. Table II provides a comprehensive comparison of how the 0-Sphere model fundamentally differs from quantum field theory in its treatment of time, energy flow, and particle structure, highlighting the thermal geodesic framework’s novel approach to these foundational concepts.

C. Photon Motion on Thermal Geodesics

A central feature of general relativity is the observer dependence of physical measurements, including time intervals and spatial distances. In the 0-Sphere model, a similar principle holds, but it arises not from coordinate transformations in spacetime, but from intrinsic differences in internal thermal structure.

Each particle carries within it a temperature-dependent metric $\mathcal{G}_{\mu\nu}(T)$, which governs its internal geometry and the path along which energy flows. Because time and motion emerge from this thermal structure, the perceived rate of internal evolution—and hence the experience of time—is inherently local and contingent on temperature. In general relativity, once the spacetime geometry—via the energy-momentum tensor—is fixed, time dilation naturally follows. From this viewpoint, the oscillatory motion of the photon sphere between kernel A and kernel B slows down in a gravitational field, consistent with relativistic predictions. If one identifies the velocity of this internal motion with temperature, as the present model suggests, then gravity not only dilates time but effectively reduces internal temperature. This implies that temperature, like time, becomes observer-dependent. In this thermodynamic interpretation, a lower observed temperature corresponds to a slower internal evolution, reinforcing the model’s view that both motion and time are emergent from thermal dynamics—and are intrinsically relative.

Consider two particles with different internal temperatures. The one with higher T will experience faster internal oscillations, corresponding to a more rapidly advancing phase $\phi(t)$. The other, closer to absolute zero, will exhibit slower or even halted oscillations. From the standpoint of internal time, these particles evolve at

different rates, even if they are co-located in space.

To an external observer, this results in an apparent time asymmetry. A particle with low thermal energy appears frozen or sluggish, while one with higher energy appears dynamically active. This observer-relative behavior does not stem from motion through a relativistic spacetime, but from variations in internal thermal geometry. It offers an alternative route to phenomena reminiscent of time dilation, grounded in thermodynamics rather than Lorentz symmetry.

Spatial measurements are similarly reinterpreted. In general relativity, distance is determined by integrating the spacetime metric along a path. In the 0-Sphere model, spatial separation between kernels or between successive oscillation states is meaningful only within the thermal metric. The geodesic connecting kernel A to kernel B is not a path in external space, but a route of least thermal action, shaped by internal conditions.

Moreover, the connection between kernel A and kernel B follows a well-defined geodesic within the internal thermal geometry, analogous to spacetime geodesics in general relativity. Radiative flow between the two kernels traces this unique path of least thermal action. The oscillatory energy exchange that defines the particle’s internal dynamics thus occurs along a deterministic geodesic trajectory, representing the optimal route for thermal energy transport.

This geometric determinism distinguishes the 0-Sphere model from quantum mechanical formulations. While Feynman’s path integral approach considers quantum amplitudes over all possible trajectories, the thermal geodesic framework admits a single, causally determined route for energy transfer. The model operates through geometric optimization rather than probabilistic superposition—internal energy flow follows the path that minimizes thermodynamic action, yielding deterministic evolution without intrinsic randomness.

This fundamental difference reflects the model’s classical geometric foundation, where uncertainty arises not from quantum indeterminacy but from incomplete knowledge of thermal boundary conditions.

This perspective reframes notions of simultaneity and causality. Events that are sequential under one internal thermal structure may appear simultaneous or even reversed under another. Because each particle carries its own clock, defined by $\omega(T)$, global synchrony is not assumed. Instead, temporal and geometric coherence across systems must emerge from thermal interactions and coupling.

These insights reinforce the importance of distinguishing thermal geodesics from traditional geodesics in curved spacetime. In the 0-Sphere model, geometry is not solely imposed from the outside but is also generated intrinsically from within. Motion, time, and space all derive from the energy flow internal to each particle, and thus carry an intrinsic observer dependence tied to local thermal conditions.

Table. II. Foundational Comparison between Quantum Field Theory and Thermal Geodesic Framework

Aspect	Quantum Field Theory (QFT)	0-Sphere Model
Time Structure	External, absolute parameter t independent of matter	Emergent from TPE flow; $dt \propto \sqrt{\mathcal{G}_{\mu\nu}(T)}dx^\mu dx^\nu$; ceases when $T \rightarrow 0$; exhibits thermal relativity analogous to gravitational time dilation
Lagrangian Definition	Point-wise field density $\mathcal{L}(\phi, \partial_\mu\phi)$ at each spacetime event	Path-integral over energy transport routes: $S = \int_{\gamma[A \rightarrow B]} \mathcal{L}_{\text{thermal}} d\tau$
Background Dependence	Requires fixed spacetime manifold (Minkowski, de Sitter, etc.) for field quantization	Geometrically coupled; internal thermal geometry $\mathcal{G}_{\mu\nu}(T)$ couples to external spacetime through $T_{\mu\nu}^{(\text{thermal})}$
Energy Flow Paradigm	Energy arises from field excitations and interactions mediated by gauge bosons	Energy transport as fundamental agent; flow defines spacetime structure and temporal evolution
Particle Structure	Point particles or string-like extended objects in fixed dimensional space	Composite structure: dual thermal kernels + photon sphere with internal oscillatory dynamics
Zitterbewegung Interpretation	Mathematical artifact from positive/negative energy interference in Dirac equation [14]	Physical subluminal oscillation ($v \approx 0.04c$) along thermal geodesics between kernels A and B ; temperature-dependent and observer-relative, supported by theoretical [16] and experimental studies [4, 17]
Thermal Effects	Temperature introduced via statistical mechanics or finite-temperature field theory	Temperature as fundamental geometric parameter determining effective metric $\mathcal{G}_{\mu\nu}(T)$
Electromagnetic Interaction	Mediated by virtual photon exchange between charged particles in fixed spacetime	Real photon sphere confined within particle; no emission/absorption when internal oscillation ceases at $T \rightarrow 0$
Critical Temperature Behavior	Phase transitions described by order parameters and spontaneous symmetry breaking	Geometric transitions in thermal geodesic structure; $\mathcal{L}_{\text{thermal}} \rightarrow 0$ as $T \rightarrow 0$
Gauge Symmetry Origin	Fundamental postulate ensuring local conservation laws and renormalizability	Emergent from internal oscillatory patterns; U(1) from photon sphere phase evolution, SU(2) from internal geometric structure; emergent rather than imposed [18]
Renormalization	Required to eliminate ultraviolet divergences in loop calculations	Natural UV cutoff from finite Compton-scale separation between kernels; no divergent integrals
Experimental Accessibility	High-energy experiments needed for fundamental verification	Low-energy testable predictions: electron Zitterbewegung velocity measurement, critical radius effects
Magnetic Moment Origin	Quantum loop corrections from virtual particle interactions	Geometric consequence of Lorentz contraction in subluminal internal oscillatory motion, consistent with precision measurements [5]

Note: This table contrasts the fundamental principles of quantum field theory with the proposed thermal geodesic framework. The thermal geodesic model eliminates the need for external time coordinates and fixed background spacetime by treating energy flow as the primary physical reality. Key predictions include measurable Zitterbewegung velocities and geometric understanding of electromagnetic interactions at low temperatures. All quantitative results derive from exact solutions incorporating experimental anomalous magnetic moments and general relativistic corrections. For the standard formulation of QFT Lagrangians and field quantization, see [19].

V. GEOMETRIC FORMULATION AND PHYSICAL IMPLICATIONS

A. Temperature-Dependent Metric and Thermal Geometry

The energy distribution on the surface of a photon sphere determines not only its internal structure, but also the trajectory of its motion. In the 0-Sphere model, the concept of motion is intimately tied to internal energy geometry, and this applies equally to the photon sphere as to the electron's internal kernels.

We begin with the representation of surface energy density in terms of spherical harmonics, as previously introduced:

$$\rho(\theta, \phi) = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m} Y_{\ell m}(\theta, \phi). \quad (\text{V.1})$$

This distribution defines the spatial configuration of thermal excitation across the spherical shell. The location of the energy center is obtained by integrating over this distribution:

$$\vec{r}_{\text{center}} = \frac{1}{E} \int_{S^2} \rho(\theta, \phi) \vec{r}(\theta, \phi) d\Omega, \quad (\text{V.2})$$

where E is the total energy, $\vec{r}(\theta, \phi)$ denotes position on the shell, and $d\Omega$ is the solid angle element.

Once established, this center of energy becomes the effective point of motion for the photon sphere. However, unlike a classical particle following Newtonian trajectories, the center moves according to the thermal geometry defined by the internal temperature distribution. The path of this motion satisfies the thermal geodesic equation:

$$\frac{d^2 x^\mu}{d\tau^2} + \Gamma_{\nu\rho}^\mu(T) \frac{dx^\nu}{d\tau} \frac{dx^\rho}{d\tau} = 0, \quad (\text{V.3})$$

where the Christoffel symbols $\Gamma_{\nu\rho}^\mu(T)$ are derived from the temperature-dependent thermal metric $\mathcal{G}_{\mu\nu}(T)$.

In this view, the motion of the photon sphere arises from internal thermal geodesics that couple to external spacetime geometry through the spherical harmonic structure. The energy distribution $\rho(\theta, \phi) = \sum a_{\ell m} Y_{\ell m}(\theta, \phi)$ potentially determines the form of an additional thermal stress-energy tensor $T_{\mu\nu}^{(\text{thermal})}$, contributing to Einstein's field equations alongside conventional matter. This suggests a self-consistent framework where $Y_{\ell m}$ mode amplitudes directly influence spacetime curvature while simultaneously following thermal geodesics within that curved geometry.

The photon therefore becomes a self-organizing system whose motion is primarily governed by its internal thermal state, while remaining coupled to external gravitational fields through the thermal stress-energy tensor $T_{\mu\nu}^{(\text{thermal})}$. This challenges conventional field-theoretic notions of passive propagation in fixed spacetime, suggesting instead that particles actively participate in defining the geometry

through which they move via their internal harmonic structure.

This interpretation unifies translational behavior and internal energy configuration, extending thermal geodesics beyond the electron model to encompass photon dynamics. Like Wheeler's geon concept [20], which proposed self-contained gravitational-electromagnetic structures, individual particles in our thermal framework exhibit self-contained dynamics through internal harmonic oscillations. However, when interactions are considered, our model couples to external spacetime geometry through tensor additivity in Einstein's field equations, where the thermal stress-energy tensor $T_{\mu\nu}^{(\text{thermal})}$ contributes linearly alongside conventional matter sources, maintaining full consistency with general relativity. Any oscillatory system with well-defined internal metric structure $\mathcal{G}_{\mu\nu}(T)$ can, in principle, exhibit thermal geodesic motion. The photon sphere therefore serves both as an energy mediator within the 0-Sphere model and as a prototype for understanding how internal harmonic structure can be both self-contained and geometrically coupled to external gravitational fields.

The detailed analysis of spherical harmonic mode interactions, energy distribution stability, and experimental signatures of photon sphere dynamics will be addressed in future work, building upon the foundational framework established here.

B. Comparison with General Relativity Geodesics

The 0-Sphere model extends the geometric framework of general relativity by incorporating internal thermal dynamics as an additional source of spacetime curvature. While general relativity describes motion as geodesic paths determined by external matter distributions, and quantum field theory treats particles as field excitations in fixed spacetime, the present model introduces thermal geodesics that couple internal particle structure to external gravitational fields through tensor additivity in Einstein's field equations [2].

The central innovation is the concept of *thermal geodesics*: energy transport paths that minimize thermodynamic action defined by an internal temperature-dependent metric $\mathcal{G}_{\mu\nu}(T)$. These thermal geodesics operate within the particle's internal structure while contributing to the external stress-energy tensor through $T_{\mu\nu}^{(\text{thermal})}$. This creates a self-consistent framework where internal thermal dynamics influence spacetime geometry, which in turn affects the internal thermal geodesic structure.

In this framework, the photon becomes a spherical shell of oscillating energy whose harmonic structure $\rho(\theta, \phi) = \sum a_{\ell m} Y_{\ell m}(\theta, \phi)$ determines both its internal dynamics and its contribution to external gravitational fields. The motion arises from the geometric center of this energy distribution, following thermal geodesics that couple to spacetime curvature. This provides a unified geometric

basis for electromagnetic phenomena while maintaining consistency with general relativistic principles.

Time emerges as a local phase associated with internal thermal oscillations, with its rate dependent on both internal temperature and external gravitational conditions. This thermodynamic origin of time naturally incorporates relativistic effects: gravitational time dilation corresponds to modifications in internal oscillatory behavior due to external curvature, while the internal thermal state contributes back to the local gravitational field through $T_{\mu\nu}^{(\text{thermal})}$.

The 0-Sphere model thus establishes a bridge between quantum mechanics and general relativity through geometric unification rather than theoretical replacement. It preserves the mathematical elegance of Einstein’s field equations while extending their scope to include internal particle dynamics. Thermal geodesics provide a common geometric language that describes both quantum internal energy flow and relativistic motion within a single, self-consistent framework.

This approach offers several advantages: it maintains the proven mathematical structure of general relativity, provides a natural mechanism for quantum-gravitational coupling, and generates testable predictions such as Zitterbewegung suppression in ultra-cold systems. The framework invites further development in characterizing the explicit form of $T_{\mu\nu}^{(\text{thermal})}$ from spherical harmonic distributions, extending to multi-particle systems, and exploring experimental signatures of thermal geodesic effects.

In summary, thermal geodesics represent not an alternative to spacetime geodesics, but their natural extension to include internal thermodynamic structure. This geometric unification preserves the fundamental insights of both quantum mechanics and general relativity while providing a pathway toward their mathematical integration through the thermal contribution to Einstein’s field equations.

VI. CONCLUSION

This work has introduced a thermodynamically driven extension to particle dynamics through the 0-Sphere model, which incorporates internal thermal structure into the geometric framework of general relativity. In this model, particles consist of internal energy compo-

nents—kernel A , kernel B , and a photon sphere—that interact through periodic thermal oscillation, contributing to spacetime geometry through thermal stress-energy tensor $T_{\mu\nu}^{(\text{thermal})}$.

The key conceptual advancement is the introduction of *thermal geodesics*: energy transport paths governed by internal temperature-dependent metrics $\mathcal{G}_{\mu\nu}(T)$ that couple to external spacetime curvature through Einstein’s field equations. This framework extends general relativity’s geometric principles to encompass quantum internal dynamics while preserving mathematical consistency through tensor additivity. Zitterbewegung emerges as oscillatory motion along thermal geodesics, with its temperature dependence providing testable predictions for ultra-cold systems.

The photon is modeled as a spherical harmonic energy distribution $\rho(\theta, \phi) = \sum a_{\ell m} Y_{\ell m}(\theta, \phi)$ whose center of motion follows thermal geodesics coupled to external gravitational fields. This geometric description provides a unified foundation for electromagnetic phenomena within the broader framework of curved spacetime, connecting quantum harmonic structure to gravitational dynamics.

The 0-Sphere model establishes a bridge between quantum mechanics and general relativity through geometric unification rather than theoretical replacement. By incorporating thermal contributions into Einstein’s field equations, the model creates a self-consistent framework where internal particle dynamics and external spacetime geometry mutually influence each other. Time emerges from thermal oscillations while remaining coupled to relativistic effects, providing a natural mechanism for quantum-gravitational interaction.

Future research will focus on deriving explicit relationships between spherical harmonic coefficients $a_{\ell m}$ and thermal stress-energy components $T_{\mu\nu}^{(\text{thermal})}$, extending the framework to multi-particle systems, and characterizing thermal geodesic behavior near critical temperature thresholds. Experimental validation through precision measurements of electron properties [5], quantum simulations of Zitterbewegung [4, 17], and quantum gravity phenomenology [21] offers promising pathways to test the model’s predictions.

The 0-Sphere model ultimately presents a pathway toward unifying quantum and gravitational physics through the geometric incorporation of internal thermodynamic structure into general relativity’s proven mathematical framework, offering both conceptual clarity and experimental accessibility.

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