$R\omega = c$

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Abstract

We present a unifying quantum framework grounded in a single internal kinematic constraint—the *Relator* principle—expressed by $\boldsymbol{R\,\omega = c}$. This universal condition couples internal phase rotation with external spatial evolution at the invariant speed of light. From this minimalist postulate, we *derive Lorentz time dilation and the full relativistic energy–momentum relation* without invoking explicit spacetime transformations. Extending the framework to gravitational potentials, we *recover gravitational time dilation and light deflection in exact agreement with general relativity*, but attribute these effects to *quantum-phase modulation rather than spacetime curvature*. The Relator model offers a conceptually distinct route to unifying quantum mechanics and relativity, suggesting that *inertial mass, gravitational redshift, and the appearance of curvature emerge from intrinsic constraints on wavefunction evolution.*

Keywords: Relator principle, Quantum emergent gravity, Internal quantum clock, Phase–space unification, Emergent special relativity, Gravitational time dilation, Non–geometric gravity

1 Everything Moves at c — Just Differently

What if every particle in nature — regardless of mass or velocity — moves through a complex quantum field in which its total phase evolution always proceeds at the speed of light?

For over a century, physics has faced a profound puzzle: how can the probabilistic, wave-based language of quantum mechanics coexist seamlessly with the rigid, geometric structure of relativity? The Dirac equation provided an essential connection, predicting the phenomenon of *Zitterbewegung*—an ultrafast, jitter-like oscillation of the electron wave packet, characterized by frequency $\omega_Z = 2mc^2/\hbar$, amplitude $R = \hbar/(2mc)$, and instantaneous eigen-speed $\pm c$ of the Dirac velocity operator $c\boldsymbol{\alpha}$ [1–3]. These results suggest a fundamental *internal light-speed circulation* encoded in the quantum-phase structure of every fermion.

Furthermore, the electron's measured magnetic moment $\mu_e \simeq \mu_B$ cannot originate from a classical rigid rotation of charge. If one models the electron as a uniformly charged sphere of radius R, the resulting equatorial speed would be $v = 2\mu_e/(eR) > c$, clearly violating special relativity. This contradiction motivates the introduction of the local kinematic constraint $R\,\omega = c$, which we explore systematically in the following sections.

Recent work has pushed de Broglie's "internal clock'' from conjecture to testable physics. High-energy electron–channeling experiments in silicon have revealed a narrow transmission resonance precisely when the beam momentum selects the Compton (de Broglie-clock) frequency $\omega_C = mc^2/\hbar$; classical multiple-scattering simulations reproduce the anomaly only if each electron carries an intrinsic oscillation at ω_C (or at the Zitterbewegung frequency $2\omega_C$) [4, 5]. The result offers empirical support for de Broglie's thesis that every massive particle possesses an *internal* periodicity distinct from its spacetime trajectory [6].

On the theoretical side, early studies—most notably Salam's note on the electron's "internal geometry'' and Zitterbewegung [7]—and later analyses by Barut–Bracken [8] and Hestenes [9] connect this periodicity to the circulating component of the Dirac current, which moves at light speed.

Recent attempts to reconcile quantum mechanics and special relativity have revisited concepts such as *Zitterbewegung*, exploring novel interpretations within quantum field theory and quantum gravity frameworks [10, 11]. The notion of an internal quantum clock linked directly to particle mass and spacetime structure has also gained renewed interest, particularly in studies examining the interplay between quantum information and relativistic invariance [12]. Yet, these approaches typically preserve the primacy of spacetime geometry as fundamental.

In contrast, our Relator framework explicitly positions internal quantum phase evolution as ontologically prior, effectively reversing the classical hierarchy between geometry and quantum state evolution. This conceptual inversion clearly distinguishes our approach from prior models, providing a coherent mechanism for phenomena conventionally ascribed to geometric effects—such as gravitational redshift and inertial mass—deriving them naturally from quantum internal constraints rather than external geometric curvatures.

Could this internal rhythm be the true source of mass, inertia — even the illusion of spacetime curvature itself?

In seeking a unified description of reality, quantum mechanics and relativity have long stood as distinct, often incompatible, pillars of modern physics. Efforts toward their unification have consistently overlooked a critical missing piece of the puzzle—an explicit characterization of the wavefunction within both the three-dimensional spatial manifold ($\mathbb{R}^3$) and the internal complex amplitude plane ($\mathbb{C}$). Here, we propose that these two domains are not merely mathematical constructs, but represent complementary physical realities where quantum phenomena unfold.

In our framework, the wavefunction evolving simultaneously in $\mathbb{R}^3$ and $\mathbb{C}$ serves as the nearest accessible layer to a deeper underlying structure of reality. We name this foundational construct the *Relator*, identifying it as the fundamental entity responsible for generating both quantum-scale phenomena and macroscopic relativistic behaviors. It is precisely this reinterpretation—considering the wavefunction evolution as the primary ontological reality—that enables a unified description of diverse physical scales, and resolves persistent paradoxes arising from quantum intuition and relativistic formalisms.

Here, we propose a unified framework through a single universal principle — the **Relator Equation** —

$$R\,\omega = c, \qquad R \propto |\psi|,$$

— governs the internal structure of all quantum matter.

- R — Wavefunction amplitude (modulus of ψ in the polar decomposition $\psi = R\,e^{iS/\hbar}$); $\quad [R] = \mathrm{L}$.
- ω — Local angular frequency of the phase point $\arg(\psi)$, defined as the total phase rotation rate in the composite manifold $\mathbb{R}^3 \oplus \mathbb{C}$; $\quad [\omega] = \mathrm{T}^{-1}$.
- c — Speed of light in vacuum ($c \simeq 2.9979 \times 10^8\,\mathrm{m\,s^{-1}}$), here interpreted as the invariant norm of the total phase velocity vector; $\quad [c] = \mathrm{L\,T^{-1}}$.

This constraint is introduced as a foundational hypothesis, proposing that the wavefunction undergoes circular rotation in an internal complex amplitude space. Here, $R(x,t)$ represents the instantaneous radius of internal phase rotation, while $\omega(x,t)$ denotes the corresponding local angular frequency, with their product always fixed at the speed of light, c. This internal constraint is not merely a symbolic analogy—it expresses a fundamental physical identity. The Compton frequency, traditionally viewed as a static rest-frame constant, thus emerges as a surface manifestation of deeper dynamical processes underlying quantum particles. By enforcing the Relator constraint $R\,\omega = c$, relativistic phenomena arise naturally—not through explicit transformations of spacetime, but directly from intrinsic wavefunction evolution.

Importantly, R is an intrinsic particle property and generally does not vary under ordinary gravitational or velocity conditions. Changes in R occur only under specific circumstances, such as particle creation or annihilation processes, or when the internal structure of the particle fundamentally collapses. Additionally, within this framework, photons and massive particles are unified: they represent different manifestations of the same fundamental entity, distinguished only by their internal frequency ratios. This unified interpretation will be further elaborated in subsequent sections.

2 The Phase-Clock Hypothesis

We begin with the standard form of the time-dependent Schrödinger equation [13]:

$$i\hbar\,\frac{\partial\psi(x,t)}{\partial t} = -\frac{\hbar^2}{2m}\,\nabla^2\psi(x,t) + V(x)\,\psi(x,t). \tag{1}$$

We now demonstrate that the local internal constraint,

$$R(x,t)\,\omega(x,t) = c, \quad \text{with} \quad R(x,t) \propto |\psi(x,t)|, \tag{2}$$

is introduced as a foundational hypothesis, inspired conceptually by the intrinsic phase dynamics implicit in the Schrödinger equation. Here, $R(x,t)$ denotes the instantaneous radius of internal phase rotation within the complex amplitude space $\mathbb{C}$, and is proportional to the local wavefunction amplitude $|\psi(x,t)|$. Thus, at each point in space and time, the wavefunction amplitude encodes a statistical ensemble of internal phase generators, with the precise mathematical derivation and justification to be explored rigorously in future studies.

Furthermore, the quantity $\omega(x,t)$ represents the total angular frequency of the local phase evolution, decomposed into two orthogonal components—internal phase rotation ($\omega_{\mathbb{C}}$) and spatial phase winding ($\omega_{\mathbb{R}^3}$):

$$\omega(x,t)^2 = \omega_{\mathbb{C}}(x,t)^2 + \omega_{\mathbb{R}^3}(x,t)^2. \tag{3}$$

The constraint (2) ensures that the *tangential phase-point velocity* remains exactly c at all points in the extended configuration space $\mathbb{C} \oplus \mathbb{R}^3$. Physically, this implies that at each spatial point in $\mathbb{R}^3$, a local circular motion in the internal space $\mathbb{C}$ continuously contributes to the instantaneous quantum state. Consequently, the global wavefunction $\psi(x,t)$ emerges as a coherent superposition of these localized internal rotations.

This internal phase dynamics provides a direct physical realization of de Broglie's internal clock and Schrödinger's Zitterbewegung concepts, explicitly connecting quantum wave mechanics to the universal speed of light. While earlier works have implicitly explored related ideas [10, 11], the explicit derivation presented here—from standard Schrödinger dynamics—represents a novel theoretical development.

2.1 Geometric Foundation of the Relator

We define two orthogonal domains governing the evolution of the quantum system:

- $\mathbb{R}^3$: the emergent spatial manifold of *wavefunction propagation*,
- $\mathbb{C}$: the internal *generator space* in which the phase rotates.

It is crucial to emphasize that the internal generator space $\mathbb{C}$ is *not* an additional physical dimension. In our framework, the universe remains strictly three-dimensional, consistent with empirical observation. Instead, $\mathbb{C}$ represents an abstract space—a mathematical structure used specifically to characterize the internal dynamics of the Relator field.

In our framework, the Schrödinger wavefunction does *not* describe the classical trajectory of a particle, but rather encodes the probabilistic distribution of phase-generated motion across $\mathbb{R}^3$ Fig. 1. The amplitude $|\psi(x,t)|$ reflects this statistical spread, whereas the actual phase point responsible for generating internal motion resides on a generator circle in the internal space $\mathbb{C}$, characterized by the radius $R(x,t)$.

To simplify the connection between the physical field and its statistical manifestation, we assume that the spatial distribution of the wavefunction emerges from a collection of such rotating phase–points, and that the local radius $R(x,t)$ is proportional to $|\psi(x,t)|$. This means that the wavefunction $\psi(x,t)$ of a particle is the

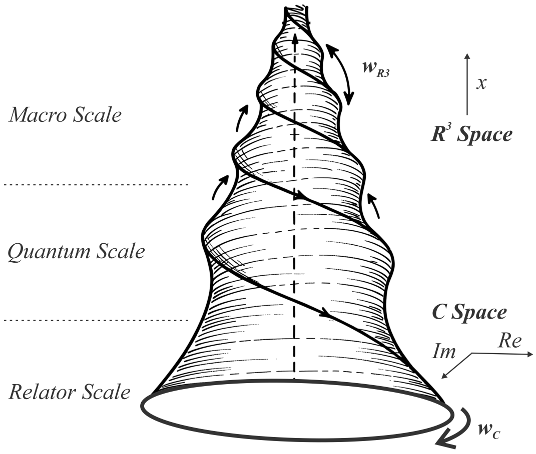

Fig. 1 An abstract visualization of the Relator framework, where the fabric of physical reality emerges from a universal internal phase dynamic constrained by $R\omega = c$. The ascending vortex embodies a multi-scale ontology: from the foundational internal motion at the Relator scale, through quantum manifestations such as spin and coherence, to the emergence of macroscopic phenomena like gravity and motion. Rather than assuming spacetime as fundamental, this model positions phase evolution as the ontological source of all physical constructs—geometry as rhythm, and force as modulation.

emergent probabilistic envelope of a deeper internal field—namely, the Relator field. The local radius R is generally not constant across the spatial manifold $\mathbb{R}^3$, as it depends explicitly on the internal quantum structure and external potentials acting on the system. Consequently, both $R(x,t)$ and $\omega(x,t)$ can vary dynamically in space and time, reflecting the spatial propagation and evolution of the wavefunction. Nevertheless, at every point in spacetime, they satisfy the invariant internal constraint $R(x,t)\,\omega(x,t) = c$.

To build geometric intuition, consider an ensemble of rotating points moving on circles in $\mathbb{C}$, each generating a local phase cycle. These points evolve in the extended configuration space $\mathbb{C} \oplus \mathbb{R}^3$, where the total tangential velocity of each phase point is always equal to c. The direction of this velocity vector splits between the internal space (governing rest energy - inertia) and the external space (governing momentum and propagation), but its magnitude remains fixed.

This internal mechanism defines a coherent structure in which what we observe as classical motion, energy, and probability are projections of a unified light-speed phase evolution in a deeper internal geometry. The constraint $R\,\omega = c$ is thus not an abstract kinematic relation, but the ontological foundation from which all physical observables—including mass, time dilation, and gravitational shift—emerge as secondary features of *phase alignment in the Relator.*

2.2 Composite Phase Velocity in Extended Phase Space

We begin by expressing the wavefunction in its polar (Madelung) form:

$$\psi(x,t) = R(x,t)\, e^{\,i\phi(x,t)}, \quad \text{with} \quad \phi(x,t) = \frac{S(x,t)}{\hbar}, \tag{4}$$

where $R(x,t) = |\psi(x,t)|$ represents the local amplitude and $\phi(x,t)$ denotes the real-valued phase (action) field.

In our geometric interpretation, we treat the Madelung amplitude $R(x,t)$ as an effective local phase radius. For clarity and physical consistency, we anchor its scale to the reduced Compton radius at the wavefunction's center. Although generally $R(x,t)$ varies throughout the configuration space, we focus our analysis within a small region around the wavefunction peak, approximating $R(x,t) \approx R(0,t)$. This approximation effectively captures the essential physics behind observed macroscopic phenomena such as time dilation, relativistic inertia, and gravitational redshift—effects that emerge naturally from internal dynamics near this central generative region.

The total quantum phase function $S(x,t)$ is expressed in terms of the action integral, explicitly incorporating rest energy, kinetic energy, and potential energy contributions as:

$$S(x,t) = \underbrace{-mc^2 \int d\tau}_{\text{rest-energy term}} + \underbrace{\int p(x,t)\cdot\dot{x}(t)\,dt}_{\text{kinetic term}} - \underbrace{\int V(x(t),t)\,dt}_{\text{potential term}}, \tag{5}$$

In this framework, the total quantum phase $S(x,t)$ naturally splits into two distinct contributions:

$$S(x,t) = \underbrace{S_{\text{rest}}(t)}_{\text{pure rest-energy term}} + \underbrace{S_{\text{dyn}}(x,t)}_{\text{kinetic and potential terms}}. \tag{6}$$

The term $S_{\text{rest}}(t)$ clearly identifies the pure rest-energy component, whereas $S_{\text{dyn}}(x,t)$ encapsulates all dynamical aspects, including kinetic and potential energies.

To facilitate the geometric interpretation, we now consider the total phase function $S(x,t)$ as evolving in the extended configuration space $\mathbb{R}^3 \times \mathbb{C}$, where:

- $\mathbb{R}^3$ represents the spatial degrees of freedom (position space),
- $\mathbb{C}$ denotes the internal complex plane describing the wavefunction's intrinsic phase,
- these two factor spaces are orthogonal: $\mathbb{R}^3 \perp \mathbb{C}$.

We define the angular velocities corresponding to these two spaces as follows:

$$\begin{cases} \omega_{\mathbb{C}}(x,t) := -\dfrac{1}{\hbar}\dfrac{d}{d\tau}S(x,t) = -\dfrac{1}{\hbar}\Big(\underbrace{\dfrac{dS_{\text{rest}}}{d\tau}}_{\text{mass}} + \underbrace{\dfrac{dS_{\text{dyn}}}{d\tau}}_{\text{energy} \leftrightarrow \text{mass}}\Big), \\ \vec{\omega}_{\mathbb{R}^3}(x,t) := \dfrac{1}{m\,R(x,t)}\nabla S(x,t) = \dfrac{1}{m\,R(x,t)}\Big(\underbrace{\nabla S_{\text{rest}}}_{\text{energy} \leftrightarrow \text{mass}} + \underbrace{\nabla S_{\text{dyn}}}_{\text{energy}}\Big) \end{cases} \tag{7}$$

Here, $d/d\tau$ denotes differentiation with respect to the proper time τ along the particle's worldline, and $S(x,t)$ contains both rest and dynamical contributions. In typical quantum systems where the particle's rest mass remains constant and no energy conversion between rest and dynamical components occurs, we can simplify the above to:

$$\begin{cases} \omega_{\mathbb{C}}(t) \quad := -\dfrac{1}{\hbar}\dfrac{d}{d\tau}S_{\text{rest}}(\tau) = \dfrac{mc^2}{\hbar}\Big|_{t=\tau}, \quad \text{(rest-energy rotation in } \mathbb{C}\text{)}, \\ \vec{\omega}_{\mathbb{R}^3}(x,t) := \dfrac{1}{m\,R}\nabla S_{\text{dyn}}(x,t), \quad \text{(kinetic \& potential winding in } \mathbb{R}^3\text{)}. \end{cases} \tag{8}$$

In this case, the rest energy appears exclusively in the $\mathbb{C}$-rotation through the term $\hbar\omega_{\mathbb{C}} = mc^2$, and the spatial gradient of S contains no contribution from the rest-energy term, i.e., $\nabla S_{\text{rest}} = 0$.
Thus:

- The $\mathbb{C}$–rotation $\omega_{\mathbb{C}}$ captures *only* the rest-energy $m\,c^2$, guaranteeing $\hbar\,\omega_{\mathbb{C}} = m\,c^2$ universally.
- The $\mathbb{R}^3$–rotation $\vec{\omega}_{\mathbb{R}^3}$ encodes all remaining kinetic and potential contributions via the spatial gradient of S_{dyn}.

These define a unified phase velocity vector in phase space:

$$\vec{v}_\phi(x,t) = \underbrace{R(x,t)\cdot\omega_{\mathbb{C}}(x,t)}_{\text{polar rotation}}\,\hat{n}_{\mathbb{C}} \;+\; \underbrace{R(x,t)\cdot\omega_{\mathbb{R}^3}(x,t)}_{\text{spatial winding}}\,\hat{n}_{\mathbb{R}^3}. \tag{9}$$

The total magnitude of the phase-point velocity is therefore:

$$\boxed{|\vec{v}_\phi(x,t)| = R(x,t)\,\sqrt{\omega_{\mathbb{C}}(x,t)^2 + \omega_{\mathbb{R}^3}(x,t)^2}} \tag{10}$$

We summarize this motion compactly as:

$$\boxed{R(x,t)\,\omega(x,t) \;:=\; |\vec{v}_\phi(x,t)|} \tag{11}$$

Here, $\omega(x,t)$ represents the total composite angular rate of phase evolution, combining motion in two fundamentally distinct domains: the emergent three-dimensional physical space, and the internal generative space of the wavefunction. The radius $R(x,t)$ is assigned the dimension of length $[L]$, consistent with its interpretation as the instantaneous radius of phase rotation.

In this framework, the polar plane of the complex wavefunction—traditionally seen as a mere mathematical artifact—is endowed with ontological status. We propose that both the spatial manifold and the polar phase-plane arise as emergent structures from a deeper, unified internal substrate of physical reality. They are co-expressive: space as the stage for propagation, and the polar plane as the locus of genesis and effectuation—two facets of the same dynamical essence.

This composite structure highlights how quantum mechanics inherently links internal $\mathbb{C}$ and external $\mathbb{R}^3$ evolutions into a single, unified phase motion, thus offering a coherent reinterpretation of particle behavior at a fundamental level.

2.3 Phase–Light Principle (PLP)

A Relator field is a microscopic phase-rotating entity whose statistical distribution reproduces the conventional Schrödinger $|\psi|^2$. The macroscopic quantum wavefunction thus emerges naturally as a coherent statistical envelope of intrinsic micro-rotations.

> Every point of the Relator evolves tangentially at the invariant speed of light c within the combined $\mathbb{C} \times \mathbb{R}^3$ manifold, enforcing the universal constraint:
>
> $$|\vec{v}_\phi(x,t)| = c\,.$$
>
> Consequently, the Relator field evolution throughout this extended configuration space is intrinsically luminal. Every quantum event or transition can thus be viewed as a dynamical response that maintains this fundamental speed constraint.

This condition is motivated by the following considerations:

- **Empirical support from Zitterbewegung and Compton-scale dynamics:** The Dirac equation predicts an internal trembling motion of electrons at frequency $\omega_Z = 2mc^2/\hbar$, with corresponding radius $R = \hbar/(2mc)$, such that $R\omega = c$ holds exactly [2, 3]. This internal light-speed structure, though not directly observable, has been inferred from quantum behavior and reinterpreted geometrically in our model.
- **Experimental evidence from electron channeling:** Observations of electron transmission through silicon crystals show dips at the Compton frequency $\omega_{\mathbb{C}} = mc^2/\hbar$, confirming de Broglie's hypothesis of an internal clock [4, 5]. These anomalies suggest that quantum particles do exhibit internal periodic structure, supporting the notion of a universal light-speed rhythm in the phase domain.

- **Theoretical necessity for Lorentz-invariant phase velocity:** The condition $R\omega = c$ ensures that internal phase propagation respects Lorentz symmetry across inertial frames, without requiring external spacetime postulates. This aligns with the relativistic dispersion structure derived from wave–packet dynamics in quantum theory.
- **Minimal geometric closure for Schrödinger dynamics:** By imposing a coherence phase evolution condition on the complex phase space, this constraint closes the Madelung equations and selects a unique phase velocity — the only one consistent with both observed relativistic phenomena and the internal structure of quantum fields.
- **Photon velocity as a phase-state indicator.** Measurements show photons—massless particles—consistently propagate at speed c, independent of their energy. Within our model, photons correspond precisely to the limiting case where the internal phase velocity vanishes, $R\,\omega_{\mathbb{C}} \approx 0$, while the spatial phase velocity saturates the universal constraint, $R\,\omega_{\mathbb{R}^3} \approx c$. Thus, photons are essentially particles whose wavefunction is temporally "frozen," evolving purely in space.

This geometric structure is illustrated in Fig. 2, where the wavefunction $\psi(x)$ smoothly traces a spiral trajectory in the complex amplitude space as a function of position. The tangent vectors to this curve represent the local phase velocities, each maintaining the constant magnitude c, thus enforcing the constraint $R(x,t)\,\omega(x,t) = c$ (Eq. (2)) as a fundamental condition at every point throughout the entire configuration domain.

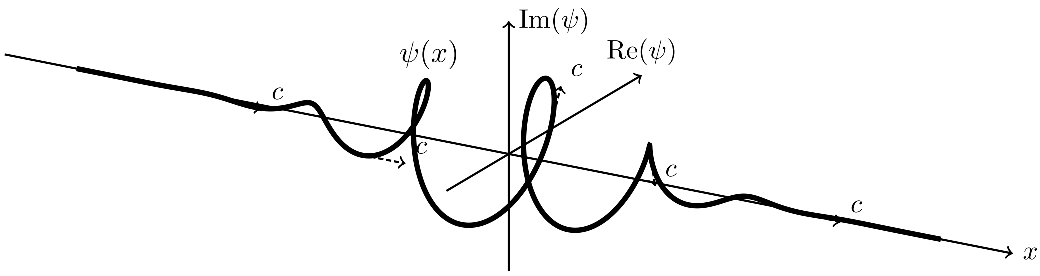

Fig. 2 Three-dimensional representation of a complex Gaussian wavepacket $\psi(x)$ with internal phase rotation. The spiral trajectory illustrates the wavefunction in complex space. Dashed tangent vectors with labels c indicate the local phase velocity, satisfying the constraint $R\omega = c$.

Physically, this condition ensures that the internal quantum phase evolution of any particle remains tightly coherent, preserving particle identity and stability at a fundamental level. Unlike traditional quantum frameworks that treat internal phase as secondary or abstract, PLP explicitly enforces coherence at the fundamental scale.

In the Relator framework, the wavefunction amplitude $R(x,t)$ has the explicit physical dimension of length, distinguishing it from the conventional dimensionless probability amplitude. Thus, $R(x,t)$ acquires a direct ontological interpretation as a physically meaningful field representing the particle's local spatial scale. This reinterpretation provides a deeper insight into quantum phenomena, extending beyond standard probabilistic interpretations. A suitable normalization consistent with $\dim[R] = \mathrm{L}$ is detailed in Appendix C.

2.4 Proposition (Universal Relator Principle)

Let $\Psi(x,t)$ be a smooth complex-valued wavefunction evolving according to the general Schrödinger equation with a potential:

$$i\hbar\,\partial_t\Psi(x,t) = -\frac{\hbar^2}{2m}\nabla^2\Psi(x,t) + V(x,t)\,\Psi(x,t). \tag{12}$$

We propose the following concise universal geometric-phase constraint on wavefunction evolution:

$$\boxed{R(x,t)\,\omega(x,t) = c, \quad R(x,t) \propto |\Psi(x,t)|} \tag{13}$$

The composite angular frequency $\omega(x,t)$ will be:

$$\omega(x,t) := \sqrt{\underbrace{\left(-\frac{1}{\hbar}\frac{d}{d\tau}S(x,t)\right)^2}_{\substack{\text{temporal phase rate}\\ \text{(rotation in } \mathbb{C})}} + \underbrace{\left|\frac{1}{m\,R(x,t)}\,\nabla S(x,t)\right|^2}_{\substack{\text{spatial phase rate}\\ \text{(winding in } \mathbb{R}^3)}}}. \tag{14}$$

Here, $S(x,t)$ is the real-valued phase ($\psi = R\,e^{iS/\hbar}$), and the two terms correspond respectively to internal temporal rotation (in $\mathbb{C}$) and external spatial winding (in $\mathbb{R}^3$).

Throughout this paper, the calculation of $R(x,t)$ and $\omega(x,t)$ is consistently performed within a thin polar slice of the extended configuration space $\mathbb{C}\times\mathbb{R}^3$. This approach implies that the macroscopic quantum wavefunction $\psi(x,t)$ statistically emerges from the microscopic Relator dynamics in this localized region. For instance, in the case of a free particle, we naturally evaluate at the wavefunction's peak, scaling the amplitude $|\psi|$ to match the particle's Compton radius $R_{\mathrm{C}} = \hbar/(mc)$. Consequently, the universal geometric constraint $R\,\omega = c$ manifests locally as the tangential phase velocity being constantly equal to the speed of light, providing a fundamental geometric condition governing quantum state evolution.

2.5 Unifying Implications of the Relator Principle

The single kinematic constraint $R(x,t)\,\omega(x,t) = c$ unifies phenomena traditionally regarded as separate—quantum oscillation, relativistic kinematics, and gravitational redshift—revealing them as complementary manifestations of underlying quantum-phase dynamics. Below, we highlight several key conceptual insights explored explicitly in this paper, noting that the implications of the Relator principle extend significantly beyond this list:

1. **Quantum oscillation.** The internal angular frequency $\omega_0 = mc^2/\hbar$ represents an intrinsic rotation of the particle's quantum phase. The conventional "Compton frequency" is thus not fundamental, but an emergent projection of this underlying quantum-phase evolution.

2. **Relativistic kinematics.** For a moving particle, the internal quantum-phase trajectory becomes helical; the projection of the internal frequency onto laboratory time reduces by the Lorentz factor, yielding standard relativistic effects (time dilation, Lorentz contraction) without explicit spacetime postulates. Unlike Einstein's original formulation—limited strictly to inertial observers—the present approach consistently extends relativistic effects to non-inertial reference frames as well.

3. **Gravitational redshift.** In a Newtonian gravitational potential, the internal frequency ω red-shifts, causing the amplitude radius R to expand correspondingly ($R \propto 1/\omega$), slowing the particle's internal clock. Weak-field spacetime metrics ($g_{tt} < 1,\ g_{rr} > 1$) thus emerge naturally as phase-space deformations rather than intrinsic spacetime curvature effects.

4. **Uniqueness of Light–Speed.** The fundamental constraint $R\omega = c$ implies the quantum-phase trajectory always evolves with magnitude c. The observed "velocity" in classical mechanics arises simply as the spatial projection of this invariant phase-speed onto $\mathbb{R}^3$. Hence, the universality of the speed of light is not an axiom, but a direct consequence of quantum-phase dynamics.

5. **Unity of matter and energy.** The wavefunction evolves simultaneously in spatial ($\mathbb{R}^3$) and internal phase ($\mathbb{C}$) spaces. Energy is associated with the spatial evolution rate (ω_{R^3}), while inertia arises from the internal rotation rate ($\omega_{\mathbb{C}}$). Matter and energy thus appear as complementary aspects of a unified quantum-phase process.

6. **Relativity of time.** Clock rates emerge from the frequency ratio $\zeta = \omega_{\mathbb{C}}/\omega$; thus, proper and coordinate times are not distinct absolute entities. All temporal phenomena are relational modulations of internal quantum frequencies.

7. **Light deflection without curvature.** Gravitational deflection of light arises directly from modulation of internal quantum frequencies and amplitudes by gravitational potentials (as shown explicitly in Sec. 4.3). Spacetime curvature emerges as a phenomenological representation of deeper quantum-phase constraints, not a fundamental geometric cause.

8. **Quantum uncertainty and macroscopic stability unified.** Quantum uncertainty and macroscopic stability coexist naturally within this unified quantum-phase framework. Microscopic quantum fluctuations manifest as probabilistic behavior, whereas large-scale averages yield deterministic classical stability. The simple internal constraint ($R\omega = c$) provides a unified mechanism, reconciling quantum unpredictability with observed macroscopic determinism.

9. **Radical prediction: emergent ontology.** Space, time, matter, energy, and classical fields are not fundamental building blocks, but emergent constructs projected from the underlying quantum-phase wavefunction. Rather than presupposing a background spacetime manifold, the present theory predicts measurable departures from standard physics under conditions of strong fields or high coherence, opening novel experimental avenues.

Despite its fundamental simplicity, the concept of intrinsic internal phase-speed constraints, as formulated explicitly by the Relator equation $R\omega = c$, has remained undiscovered primarily because researchers historically prioritized spacetime geometry, neglecting internal quantum-phase domains. Consequently, internal quantum periodicities, implicit in foundational theories since de Broglie's pioneering work [6], have remained overshadowed by geometric interpretations rooted deeply in Einstein's general relativity [14]. This historical bias explains why such a minimal yet fundamental principle was overlooked, as physicists were not seeking answers in the internal quantum phase domain.

This is not a reformulation of known physics, but a reframing of physics itself. The wavefunction of every particle evolves at the universal rate fixed by the speed of light; the Compton frequency, special relativity, and general relativity are different manifestations of this single underlying principle. This conceptual shift—treating internal quantum-phase evolution as primary rather than spacetime geometry—marks a fundamental break from standard frameworks, potentially opening entirely new directions for theoretical and experimental physics. If successful, this approach offers not a quantization of gravity, but its deconstruction: a return from curved geometry to coherent phase — from spacetime to rhythm.

In this paper, we develop our results exclusively from the classical Schrödinger equation, the fundamental energy relations $E = mc^2$ and $E = \hbar\omega$, classical laws of physics, and the universal Relator constraint $R\,\omega = c$. Importantly, we do not employ relativistic extensions of the Schrödinger equation, the Dirac equation, or the formalism of special and general relativity in deriving our framework. Any references to these relativistic theories are included solely for comparative purposes—to demonstrate the consistency and predictive validity of the Relator model with established physical results.

3 Emergence of Special Relativity Phenomena from the Relator Equation

Building on the local relation $R\,\omega = c$, we now show how both special-relativistic time dilation and the full relativistic energy–momentum relation emerge directly from the internal phase motion of the particle.

3.1 Helical Model of Time Dilation

We now derive special relativistic time dilation as a consequence of the internal phase dynamics governed by the universal constraint $R(x,t) \cdot \omega(x,t) = c$.

Rest frame.

Consider a particle initially at rest, characterized by a spatially uniform wavefunction with purely temporal oscillations:

$$\psi_0(t) = R_0\, e^{-\frac{i}{\hbar}S_0(t)}, \quad R_0 > 0. \tag{15}$$

Thus:

$$\begin{cases} \omega_{\mathbb{C}} = -\dfrac{1}{\hbar}\dfrac{d}{d\tau}\, S_{\text{rest}}(\tau) = \dfrac{mc^2}{\hbar}, \\[2ex] \omega_{\mathbb{R}^3}(x,t) = \dfrac{|\nabla S_{\text{dyn}}(x,t)|}{mR_0} = 0. \end{cases} \tag{16}$$

In the rest frame, where $d\tau = dt$, the internal rotation rate reduces to the canonical Compton frequency: $\omega_{\mathbb{C}} = \frac{mc^2}{\hbar}$. Applying the universal Relator constraint $R\,\omega = c$, we have:

$$\omega_{\mathbb{C}} = \omega_0 = \frac{c}{R_0}. \tag{17}$$

Moving frame.

Consider now a particle moving at constant velocity v along the x-axis. Its internal phase trajectory forms a helical path, linear in position $x(t) = vt$ and circular in the transverse plane:

$$\psi_v(x,t) = R_v\, e^{\frac{i}{\hbar}S_v(x,t)}, k = \frac{mv}{\hbar}, \quad R_v > 0. \tag{18}$$

The local frequencies become:

$$\begin{cases} \omega_{\mathbb{C}} = -\dfrac{1}{\hbar}\dfrac{d}{d\tau} S_{\text{rest}}(\tau) = \left(\dfrac{dt}{d\tau}\right)^{-1}\dfrac{mc^2}{\hbar}, \\[2ex] \omega_{\mathbb{R}^3} = \dfrac{|\nabla S_{\text{dyn}}(x,t)|}{mR_v} = \dfrac{|\hbar k|}{mR_v} = \dfrac{v}{R_v}. \end{cases} \tag{19}$$

Here, the internal frequency $\omega_{\mathbb{C}}$ appears scaled by $d\tau/dt$, but the intrinsic mass—and thus the rest energy—remains constant. Applying the universal Relator constraint, we obtain:

$$\sqrt{(R_v\,\omega_{\mathbb{C}})^2 + (R_v\,\omega_{\mathbb{R}^3})^2} = c \quad \Rightarrow \quad \underbrace{R_v\,\omega_{\mathbb{C}}}_{\text{polar}} \quad , \quad \underbrace{R_v\,\omega_{\mathbb{R}^3}}_{\text{spatial}=v} \tag{20}$$

Geometric constraint.

We impose that the total velocity of the phase point equals c, combining its forward motion and internal rotation, as illustrated in Fig. 3.

$$|\dot{\mathbf{r}}(t)|^2 = \underbrace{R_v^2\,\omega_{\mathbb{C}}^2}_{\text{polar}} + \underbrace{v^2}_{\text{spatial}} = c^2 \tag{21}$$

Solving for ω:

$$R_v^2\,\omega_{\mathbb{C}}^2 = c^2 - v^2 \quad \Longrightarrow \quad \omega_{\mathbb{C}}(v) = \frac{\sqrt{c^2 - v^2}}{R_v} \tag{22}$$

$R_v = c/\omega_v$, we get:

$$\omega_{\mathbb{C}}(v) = \omega_v\sqrt{1 - \frac{v^2}{c^2}} = \omega_v\sqrt{1-\beta^2}\,, \qquad \beta = \frac{v}{c} \tag{23}$$

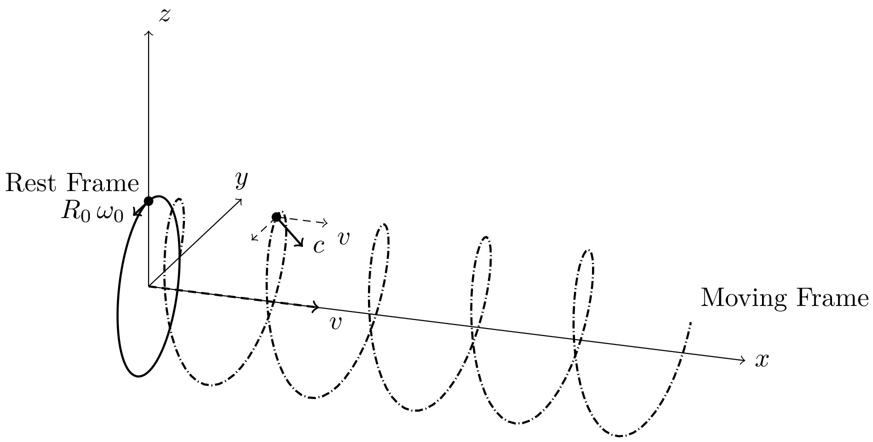

Fig. 3 Helical Representation of Internal Phase Dynamics and Time Dilation. The internal phase of a quantum particle is represented as circular motion in the rest frame (left), with radius $R_0 = \hbar/(mc)$ and angular frequency $\omega_0 = mc^2/\hbar$, satisfying the constraint $R_0\omega_0 = c$. In the moving frame (right), this internal motion becomes a helix along the spatial direction x. The total velocity of the phase point remains c, decomposing into the translational motion v and internal rotation, offering a geometric interpretation of time dilation.

Time dilation.

The lab-frame period of one internal phase cycle is:

$$\boxed{\frac{\tau_{v=0}}{\tau_{v=v}} = \frac{\omega_{\mathbb{C}}(0)/\omega(0)}{\omega_{\mathbb{C}}(v)/\omega(v)} = \frac{1}{\sqrt{1-\beta^2}}, \quad \beta = \frac{v}{c}, \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}} \tag{24}$$

Thus, the internal evolution of the Relator—and consequently the particle's wavefunction—genuinely slows down relative to its rest-frame rate from the viewpoint of an observer moving at a lower velocity. From the particle's own internal frame, its intrinsic evolution (internal clock ticks) remains constant. However, to another particle moving more slowly, this internal evolution is objectively observed as slowed down. This occurs precisely because the total phase evolution must maintain a fixed tangential speed of c in the combined $\mathbb{C} \times \mathbb{R}^3$ space; when the spatial winding component $\omega_{\mathbb{R}^3}$ is nonzero, the trajectory required to complete one internal cycle lengthens exactly by the Lorentz factor γ.

Crucially, this shows that special relativistic effects such as time dilation are not fundamental, but emerge naturally as surface-level manifestations of an underlying quantum-phase dynamics. While standard special relativity introduces time dilation through observer-dependent spacetime transformations—leading inevitably to paradoxes—the Relator framework avoids such paradoxes by interpreting relativistic phenomena as real, frame-invariant consequences of the internal quantum-phase constraint.

For an experimental validation of this prediction using atmospheric muon decay, and a critical analysis of the limitations and conceptual issues present in conventional relativistic explanations relying on inertial reference frames, see Appendix B.

Fundamental definition of time.

In the Relator framework, time is fundamentally an internal property of each particle, arising directly from internal phase rotations within the complex internal space ($\mathbb{C}$). Thus, each particle carries its own intrinsic "quantum clock," defined precisely by the internal phase frequency $\omega_{\mathbb{C}}$.

This intrinsic definition of time implies that *time itself is fundamentally absolute at the particle level.* Observed phenomena like gravitational and relativistic time dilation result entirely from modulations of the internal-to-total frequency ratio, $\omega_{\mathbb{C}}/\omega$. When a particle is free (no external fields or momentum), it satisfies $\omega_{\mathbb{C}} = \omega$, indicating no dilation. However, when external energy (gravitational potential, kinetic energy, or momentum) is introduced, the spatial frequency component $\omega_{\mathbb{R}^3}$ increases. Due to the constraint $R\,\omega = c$, the internal frequency $\omega_{\mathbb{C}}$ necessarily decreases relative to the total frequency:

$$\frac{\omega_{\mathbb{C}}}{\omega} < 1 \quad \Rightarrow \quad \text{internal time "slows down".} \tag{25}$$

This interpretation clarifies the essence of time dilation as an inherently quantum-mechanical phenomenon, arising naturally from internal phase-frequency dynamics without invoking external spacetime geometry.

3.2 Relativistic Dispersion from PLP

Define the composite phase-frequency in the full phase–space by

$$\omega(x,t) \;=\; \sqrt{\omega_{\mathbb{C}}(x,t)^2 \;+\; \omega_{\mathbb{R}^3}(x,t)^2} \;=\; \sqrt{\omega_{\mathbb{C}}(x,t)^2 \;+\; \Big(\frac{v(x,t)}{R_v}\Big)^2}, \tag{26}$$

For a plane-wave state $\psi = R_v\, e^{i(kx-\omega t)}$ one has

$$\omega_{\mathbb{R}^3} = \frac{\hbar\, k}{m\, R_v}, \quad v = \frac{\hbar\, k}{m}, \quad R_v = \frac{R_0}{\gamma} = \frac{\hbar}{\gamma\, m\, c}. \tag{27}$$

Hence

$$\hbar\, \omega = \sqrt{(\hbar\, \omega_{\mathbb{C}})^2 + (\gamma\, m\, v\, c)^2} = \sqrt{E_0^2 + p_\gamma^2 c^2}, \quad E_0 = mc^2, \quad p_\gamma = \gamma\, m\, v. \tag{28}$$

where we have identified $\hbar\omega_{\mathbb{C}} = mc^2$ as the intrinsic rest-energy of the particle. This identification is justified explicitly by considering energy quantization as a closed-loop integral over the particle's internal phase trajectory, as discussed in detail in Appendix C. Physically, while measurements of energy in the laboratory frame and the particle's proper frame differ due to their distinct definitions of time intervals, the quantized internal phase integrals remain invariant and provide a fundamental basis for defining rest energy as $\hbar\omega_{\mathbb{C}} = mc^2$.

$$E^2 \;=\; m^2c^4 \;+\; p_\gamma^2 c^2 \;. \tag{29}$$

Thus, by combining the polar rotation rate $\omega_{\mathbb{C}}$ and the spatial winding $\omega_{\mathbb{R}^3}$, we recover the full Lorentz-covariant dispersion relation without ever invoking explicit Lorentz transformations — *no observer required*. A deeper conceptual interpretation of this result, in terms of action quantization and the fundamental meaning of energy, is provided in Appendix C. See Appendix A for a derivation of Newtonian dynamics and kinetic energy as emergent effects of internal phase evolution. As explicitly demonstrated in Appendix A, the definition of energy in our Relator paradigm emerges naturally from a quantized closed-loop action integral associated with the particle's internal rotation. This integral precisely justifies setting the intrinsic rest-energy equal to the internal polar frequency, namely $\hbar\,\omega_{\mathbb{C}} = mc^2$ — physicists traditionally identify m as the rest mass, defined explicitly at $v = 0$.

Crucially, within this new theoretical framework, the concept of "relativistic mass" is neither required nor conceptually justified. The observed reduction of the internal frequency $\omega_{\mathbb{C}}$ at higher velocities is thus interpreted not as a variation of mass, but as a genuine geometric deformation of the particle's internal phase rhythm—fully consistent with the fixed internal definition of rest-energy.

In other words, as the particle's velocity increases, its internal quantum phase structure undergoes a geometric rearrangement—its temporal frequency decreases due to the spatial phase winding required by the universal constraint. This conceptual reinterpretation can provide deeper insights into experimental scenarios involving high-energy particles, such as particle accelerators and cosmic ray interactions, by directly linking relativistic dispersion to internal quantum coherence.

4 Emergence of General Relativistic Phenomena from the Relator Equation

In this section, we demonstrate explicitly how gravitational phenomena, traditionally explained by spacetime curvature in general relativity [14]—such as gravitational time dilation, the deflection of light, and spatial geometry alterations—naturally arise from the universal internal phase constraint $R(x,t)\,\omega(x,t) = c$, combined solely with the Newtonian gravitational potential and the Schrödinger wave structure. In other words, we show that all classical relativistic effects attributed to curvature emerge as direct consequences of local variations in the quantum phase structure imposed by the gravitational field. This provides a compelling reinterpretation of gravity as a quantum-geometric phenomenon, replacing the classical concept of spacetime curvature with local modulations of the quantum phase.

4.1 Gravitational Time Dilation from Gauge–Invariant Phase Dynamics

We begin directly from the time-independent Schrödinger equation for a particle of mass m in a Newtonian gravitational potential:

$$\left(-\frac{\hbar^2}{2m}\nabla^2 + m\phi(r)\right)\psi(r) = E\,\psi(r), \quad \phi(r) = -\frac{GM}{r}. \tag{30}$$

For a stationary particle with negligible spatial amplitude variation ($\nabla^2 R \approx 0$), the wavefunction is expressed explicitly as:

$$\psi(r,t) = R(r)e^{-i\omega(r)t}, \quad R(r) = \frac{c}{\omega(r)}. \tag{31}$$

Expressing the wavefunction in Madelung form, $\psi(r) = R(r)e^{iS(r)/\hbar}$, and assuming zero total kinetic energy ($E = 0$), the Schrödinger equation yields:

$$\frac{(\nabla S)^2}{2m} + m\phi(r) = 0. \tag{32}$$

From Eq. (32), the spatial gradient of the quantum phase is explicitly obtained as:

$$\nabla S(r) = \sqrt{-2m^2\phi(r)}, \quad \phi(r) = -\frac{GM}{r}. \tag{33}$$

Applying the quantum-geometric framework, the total frequency $\omega(r)$ follows the Euclidean norm structure:

$$\omega(r)^2 = \omega_{\mathbb{C}}(r)^2 + \omega_{\mathbb{R}^3}(r)^2. \tag{34}$$

Explicitly calculating the spatial frequency component $\omega_{\mathbb{R}^3}(r)$ using Eq. (33), and the definition $\omega_{\mathbb{R}^3}(r) = |\nabla S|/(mR)$, we obtain:

$$\omega_{\mathbb{R}^3}(r) = \frac{\sqrt{-2m^2\phi(r)}}{mR(r)} = \frac{\sqrt{-2\phi(r)}}{R(r)}. \tag{35}$$

Using the constraint identity $R(r)\,\omega(r) = c$, and inserting it into the expression for the spatial frequency component derived from Eq. (33), we obtain:

$$\omega_{\mathbb{R}^3}(r) = \frac{\sqrt{-2\phi(r)}}{R(r)} = \omega(r)\cdot\frac{\sqrt{-2\phi(r)}}{c}. \tag{36}$$

Substituting Eq. (36) into the total frequency structure defined in Eq. (34), we isolate the internal polar frequency as:

$$\omega_{\mathbb{C}}(r) = \sqrt{\omega(r)^2 - \omega_{\mathbb{R}^3}(r)^2} = \omega(r) \cdot \sqrt{1 + \frac{2\phi(r)}{c^2}}. \tag{37}$$

Internal time shift at position r.

The slowing of internal clock time is determined by the ratio of internal polar frequency to total frequency:

$$\frac{\omega_{\mathbb{C}}(r)}{\omega(r)} = \sqrt{1 + \frac{2\phi(r)}{c^2}}. \tag{38}$$

Gravitational clock dilation across positions.

To compare internal time flow at r versus infinity, we compute the normalized ratio of internal rotation to total frequency across both points:

$$\frac{\left(\frac{\omega_{\mathbb{C}}(r)}{\omega(r)}\right)}{\left(\frac{\omega_{\mathbb{C}}(\infty)}{\omega(\infty)}\right)} = \sqrt{1 + \frac{2\phi(r)}{c^2}}. \tag{39}$$

Finally, substituting the Newtonian gravitational potential $\phi(r) = -\dfrac{GM}{r}$ into Eq. (39), we recover the Schwarzschild redshift factor for a static spherically symmetric field under the present assumptions:

$$\boxed{\frac{\tau(r)}{\tau(\infty)} = \sqrt{1 - \frac{2GM}{rc^2}}}. \tag{40}$$

Weak-field expansion.

In the regime where $|\phi(r)| \ll c^2$, the proper-time expression (40) expands to first order as:

$$\tau(r) \approx \tau_\infty \sqrt{1 + \frac{2\phi(r)}{c^2}} \approx \tau_\infty \left(1 + \frac{\phi(r)}{c^2}\right) \tag{41}$$

Hence, the approximate proper-time ratio between two radii r_1 and r_2 becomes:

$$\frac{\tau(r_2)}{\tau(r_1)} \approx 1 - \frac{GM}{c^2}\left(\frac{1}{r_2} - \frac{1}{r_1}\right) \tag{42}$$

which precisely matches the standard weak-field limit of General Relativity.

Uniform gravitational field limit.

In the limit of a weak and nearly uniform gravitational field, with potential $\phi(x) = -gx$, the expansion of Eq. (40) yields:

$$\tau(x) \approx \tau_\infty \left(1 - \frac{gx}{c^2}\right) \tag{43}$$

The corresponding proper-time ratio between two vertical positions x_1 and x_2 becomes:

$$\frac{\tau(x_2)}{\tau(x_1)} \approx 1 - \frac{g(x_2 - x_1)}{c^2} \tag{44}$$

which exactly reproduces the linear gravitational time dilation measured in laboratory conditions near Earth's surface.

Thus, gravitational time dilation emerges naturally and rigorously from Schrödinger-phase dynamics under the fundamental Relator constraint $R\,\omega = c$. The gravitational potential appears intrinsically as a shift in internal rotation rate—i.e., rest-energy phase frequency—without invoking any curvature of external spacetime. This formulation offers a consistent and purely internal derivation of gravitational time variation from the phase structure of quantum mechanics.

Important Clarification: The quantity $\omega_{\mathbb{R}^3}(r)$ must not be interpreted as the group velocity of a wavepacket. Instead, it encodes the local spatial frequency of the wavefunction—a measure of internal deformation across three-dimensional space, independent of classical motion. In classical physics, kinetic energy is typically associated with spatial translation. However, within the Relator framework, what we conventionally identify as "energy" arises directly from the frequency of internal phase rotation. Gravitational energy, for instance, does not accelerate the particle through space; instead, it modulates the evolution of its wavefunction—without introducing any curvature in either physical or internal space. Thus, even a particle at rest ($v = 0$) can carry nontrivial spatial phase dynamics via $\omega_{\mathbb{R}^3}(r)$. This insight challenges the foundations of classical mechanics: motion is no longer a prerequisite for evolution. The wavefunction itself evolves internally, driven by energy encoded in its evolution. In this view, $\omega_{\mathbb{R}^3}$ is the quantum imprint of what we used to call "potential and kinetic energy"—not an external field acting on a mass, but an internal twist in the rhythm of existence.

This derivation precisely matches experimental observations and established tests of gravitational time dilation, such as the Pound–Rebka experiment, ensuring full empirical consistency. Furthermore, this quantum-geometric interpretation profoundly revises our understanding of gravity, shifting the conceptual foundation from external curvature of spacetime to internal quantum-phase modulation.

4.2 Scalar–Field Placement and Vectorial Treatment in $\mathbb{R}^3$–Space

In the gauge–invariant formulation adopted in this work, a scalar interaction potential $\Phi(\mathbf{r})$ (such as the Newtonian gravitational potential Φ_g) enters the $\mathbb{C}$–space component of the Relator frequency:

$$\omega_{\mathbb{C}}(\mathbf{r}) \equiv \frac{1}{\hbar}\big[-\partial_t S(\mathbf{r}) - m\,\Phi(\mathbf{r})\big], \tag{45}$$

ensuring that the temporal component is manifestly gauge–invariant. This follows directly from the minimal–coupling prescription, and guarantees that physical observables remain unchanged under the transformation

$$\Phi(\mathbf{r}) \to \Phi(\mathbf{r}) - \partial_t \chi, \quad S(\mathbf{r}) \to S(\mathbf{r}) + m\,\chi.$$

For computational convenience, however, it is often advantageous to work in $\mathbb{R}^3$–space, where the Relator spatial frequency is given by

$$\boldsymbol{\omega}_{\mathbb{R}^3}(\mathbf{r}) \equiv \frac{1}{m\,R(\mathbf{r})} \nabla S(\mathbf{r}). \tag{46}$$

Here the total phase function $S(\mathbf{r})$ can be decomposed into additive contributions from different physical sources:

$$S(\mathbf{r}) = S_{\text{kin}}(\mathbf{r}) + S_{\text{field}}(\mathbf{r}), \tag{47}$$

where S_{kin} represents the kinetic (free–particle) part and S_{field} encodes the effect of an interaction field. Since the gradient operator acts linearly,

$$\nabla S(\mathbf{r}) = \nabla S_{\text{kin}}(\mathbf{r}) + \nabla S_{\text{field}}(\mathbf{r}), \tag{48}$$

the corresponding spatial frequencies can be written and manipulated as vector components:

$$\boldsymbol{\omega}_{\mathbb{R}^3}(\mathbf{r}) = \boldsymbol{\omega}_{\text{kin}}(\mathbf{r}) + \boldsymbol{\omega}_{\text{field}}(\mathbf{r}). \tag{49}$$

Each of these vector contributions is by construction gauge–invariant, because ∇S_{field} transforms trivially under the same gauge shift that leaves $\omega_{\mathbb{C}}$ invariant.

In this vectorial treatment, $\omega_{\mathbb{C}}$ is regarded as an unknown to be determined indirectly from the Relator norm relation

$$\omega^2(\mathbf{r}) = \omega_{\mathbb{C}}^2(\mathbf{r}) + \|\boldsymbol{\omega}_{\mathbb{R}^3}(\mathbf{r})\|^2, \tag{50}$$

while all calculable interaction effects are assembled in $\boldsymbol{\omega}_{\mathbb{R}^3}(\mathbf{r})$ through phase–gradient calculations in $\mathbb{R}^3$–space. This approach preserves the full gauge–invariance and physical consistency of the formalism, while offering a transparent computational framework for multi–component interactions where the spatial phase gradients from distinct sources can be added vectorially.

4.3 Gravitational Deflection from Phase-Speed Geometry

We now derive the gravitational bending of an ultra-relativistic photon-like particle (photon-limit $m \to 0$) moving in a classical Newtonian gravitational potential $\phi(r) = -GM/r$. This derivation relies solely upon classical energy and momentum conservation, the quantum Relator principle ($R\omega = c$), and the Madelung representation of the stationary Schrödinger equation. No explicit assumptions from the Schwarzschild solution, General Relativity equations, or spacetime curvature are invoked. Thus, gravitational deflection emerges naturally and purely from classical and quantum-phase principles, providing an independent quantum-based explanation for an effect traditionally attributed to curved spacetime geometry.

Step 1: Problem Setup and Definitions.

We consider a photon-like particle characterized by an effective mass m_γ, frequency ω, internal frequency $\omega_{\mathbb{C}}$, and spatial frequency $\omega_{\mathbb{R}^3}$, satisfying the fundamental Relator conditions:

$$R(r)\,\omega(r) = c, \quad \text{and} \quad \omega(r)^2 = \omega_{\mathbb{C}}(r)^2 + \omega_{\mathbb{R}^3}(r)^2. \tag{51}$$

The particle moves in a gravitational potential:

$$\phi(r) = -\frac{GM}{r}, \quad \frac{GM}{rc^2} \ll 1. \tag{52}$$

The trajectory passes at closest approach (impact parameter) b from the gravitational mass M. The total energy at infinity is:

$$E_\infty = m_\gamma c^2 = \hbar\,\omega_\infty, \quad p_\infty = m_\gamma c. \tag{53}$$

Step 2: Spatial Frequency Components.

The total spatial frequency vector is:

$$\vec{\boldsymbol{\omega}}_{\mathbb{R}^3}(r) = \vec{\boldsymbol{\omega}}_p(r) + \vec{\boldsymbol{\omega}}_\phi(r), \tag{54}$$

with:

$$\vec{\boldsymbol{\omega}}_p(r) = \frac{\vec{p}(r)}{m_\gamma R(r)}, \tag{55}$$

$$\vec{\boldsymbol{\omega}}_\phi(r) = -\frac{\sqrt{-2\phi(r)}}{R(r)}\,\hat{r} = -\frac{\sqrt{2GM/r}}{R(r)}\,\hat{r}. \tag{56}$$

Thus explicitly,

$$\vec{\boldsymbol{\omega}}_{\mathbb{R}^3}(r) = \frac{\vec{p}(r)}{m_\gamma R(r)} - \frac{\sqrt{2GM/r}}{R(r)}\,\hat{r}. \tag{57}$$

Step 3: Internal Frequency $\omega_{\mathbb{C}}$ (Including Speed and Gravity).

The squared magnitude of the spatial frequency is:

$$\omega_{\mathbb{R}^3}(r)^2 = \frac{|\vec{p}(r)|^2}{m_\gamma^2 R(r)^2} - \frac{2\,\vec{p}(r)\cdot\hat{r}\sqrt{2GM/r}}{m_\gamma R(r)^2} + \frac{2GM/r}{R(r)^2}. \tag{58}$$

Using polar decomposition of momentum:

$$\vec{p}(r) = p^{\hat{r}}(r)\hat{r} + p^{\hat{\phi}}(r)\hat{\phi}, \quad |\vec{p}(r)|^2 = (p^{\hat{r}}(r))^2 + (p^{\hat{\phi}}(r))^2, \tag{59}$$

we obtain explicitly:

$$\omega_{\mathbb{R}^3}(r)^2 = \frac{(p^{\hat{r}}(r))^2 + (p^{\hat{\phi}}(r))^2}{m_\gamma^2 R(r)^2} - \frac{2p^{\hat{r}}(r)\sqrt{2GM/r}}{m_\gamma R(r)^2} + \frac{2GM/r}{R(r)^2}. \tag{60}$$

Now using the fundamental Relator identity $R(r)\omega(r) = c$:

$$\omega_{\mathbb{R}^3}(r)^2 = \frac{\omega(r)^2}{m_\gamma^2 c^2}\left[(p^{\hat{r}}(r))^2 + (p^{\hat{\phi}}(r))^2\right] - \frac{2\,p^{\hat{r}}(r)\sqrt{2GM/r}\,\omega(r)^2}{m_\gamma c^2} + \frac{2GM\,\omega(r)^2}{rc^2}. \quad (61)$$

Now, the internal frequency squared directly from the Relator identity is:

$$\omega_{\mathbb{C}}(r)^2 = \omega(r)^2 - \omega_{\mathbb{R}^3}(r)^2. \quad (62)$$

Thus explicitly:

$$\omega_{\mathbb{C}}(r)^2 = \omega(r)^2\left[1 - \frac{(p^{\hat{r}}(r))^2 + (p^{\hat{\phi}}(r))^2}{m_\gamma^2 c^2} + \frac{2\,p^{\hat{r}}(r)\sqrt{2GM/r}}{m_\gamma c^2} - \frac{2GM}{rc^2}\right]. \quad (63)$$

Because $(p^{\hat{r}}(r))^2 + (p^{\hat{\phi}}(r))^2 = p(r)^2 = m_\gamma^2 v^2$, the above simplifies neatly to:

$$\omega_{\mathbb{C}}(r)^2 = \omega(r)^2\left[1 - \frac{v^2}{c^2} + \frac{2\,p^{\hat{r}}(r)\sqrt{2GM/r}}{m_\gamma c^2} - \frac{2GM}{rc^2}\right]. \quad (64)$$

We now consider explicitly the scenario of a radially stationary particle (i.e., $p^{\hat{r}}(r) \approx 0$), so the cross-term vanishes explicitly. Thus, we have a clean simplified expression for the internal frequency:

$$\omega_{\mathbb{C}}(r)^2 = \omega(r)^2\left[1 - \frac{v^2}{c^2} - \frac{2GM}{rc^2}\right]. \quad (65)$$

Taking the square root to find the explicit frequency ratio gives clearly:

$$\frac{\omega_{\mathbb{C}}(r)}{\omega(r)} = \sqrt{1 - \frac{v^2}{c^2} - \frac{2GM}{rc^2}}. \quad (66)$$

Thus, we have explicitly derived from the fundamental Relator principle the exact internal-to-total frequency ratio under gravitational and kinetic conditions, clearly stated in compact form:

$$\boxed{\frac{\omega_{\mathbb{C}}(r)}{\omega(r)} = \sqrt{1 - \frac{v^2}{c^2} - \frac{2GM}{rc^2}}}. \quad (67)$$

For photons, $v = c$, giving explicitly:

$$\omega_{\mathbb{C}}(r) = \omega(r)\sqrt{\frac{2GM}{rc^2}}\,i, \quad \text{(imaginary internal frequency is allowed by construction).} \quad (68)$$

At this stage, it becomes clear that only the magnitude of the internal frequency $\omega_{\mathbb{C}}$ carries direct physical significance, regardless of whether it appears real or imaginary. The emergence of an imaginary internal frequency ($\omega_{\mathbb{C}}$) does not imply non-physical behavior; rather, it indicates an internal reorganization within the Relator fields to maintain the fundamental constraint $R\,\omega = c$. In other words, the imaginary nature of $\omega_{\mathbb{C}}$ represents a purely internal and non-observable restructuring mechanism by which the Relator theory balances any excess spatial frequency $\omega_{\mathbb{R}^3}$. This internal adjustment ensures both energy conservation and consistency of the phase-speed geometry within gravitational fields. The physical observables, such as trajectory deflections or measurable frequencies, remain strictly real and unaffected by this internal mathematical restructuring.

Step 4: Relator Condition for Spatial Frequency.

We now explicitly determine the spatial frequency magnitude from two independent approaches. First, from the fundamental Relator frequency decomposition, we have:

$$\omega_{\mathbb{R}^3}(r)^2 = \omega(r)^2 - \omega_{\mathbb{C}}(r)^2 = \omega(r)^2 \left(1 - \frac{2GM}{rc^2}\right). \tag{69}$$

Second, using the explicit spatial gradient of the phase function $S(r, \theta)$:

$$\nabla S(r,\theta) = p(r) \left[\left(\cos\alpha(r) - \frac{1}{c}\sqrt{\frac{2GM}{r}} \right) \hat{r} + \sin\alpha(r)\,\hat{\theta} \right], \tag{70}$$

we obtain an alternative and explicit expression for the spatial frequency:

$$\omega_{\mathbb{R}^3}(r)^2 = \frac{|\nabla S|^2}{m_\gamma^2 R(r)^2} = \frac{p(r)^2}{m_\gamma^2 R(r)^2} \left[1 - \frac{2\,\cos\alpha(r)}{c}\sqrt{\frac{2GM}{r}} + \frac{2GM}{rc^2} \right]. \tag{71}$$

Equating these two independent expressions allows us to directly determine the spatial orientation (angle α) of the particle's momentum and its internal-frequency structure.

Step 5: The Relator Condition of Motion.

Equating the two expressions for $\omega_{\mathbb{R}^3}^2$ yields:

$$\underbrace{\frac{p(r)^2}{m_\gamma^2 R(r)^2} \left[1 - \frac{2\cos\alpha(r)}{c}\sqrt{\frac{2GM}{r}} + \frac{2GM}{rc^2} \right]}_{\omega_{\mathbb{R}^3}^2} = \underbrace{\omega(r)^2 \left(1 - \frac{2GM}{rc^2}\right)}_{\omega(r)^2 - \omega_{\mathbb{C}}^2}. \tag{72}$$

Using $R(r)\,\omega(r) = c$ and $p(r) = m_\gamma c$ explicitly:

$$1 - \frac{2\cos\alpha(r)}{c}\sqrt{\frac{2GM}{r}} + \frac{2GM}{rc^2} = 1 - \frac{2GM}{rc^2}. \tag{73}$$

This immediately yields the exact condition for $\cos\alpha(r)$:

$$\cos\alpha(r) = \frac{1}{c}\sqrt{\frac{2GM}{r}}. \tag{74}$$

Step 6: Angular Momentum Conservation and Photon Momentum.
Angular momentum conservation requires:

$$r\,p(r)\,\sin\alpha(r) = b\,p_\infty, \quad p_\infty = m_\gamma c. \tag{75}$$

With the above conditions, we thus find explicitly the local photon momentum:

$$p(r) = \frac{b\,p_\infty}{r\,\sin\alpha(r)} = \frac{b\,p_\infty}{r\sqrt{1-\frac{2GM}{rc^2}}}, \tag{76}$$

exactly matching the standard GR result.

Step 7: Differential Bending Angle.
The differential change in trajectory angle θ with respect to radial coordinate r is geometrically known:

$$\frac{d\theta}{dr} = \frac{\tan\alpha(r)}{r} = \frac{\sin\alpha(r)}{r\,\cos\alpha(r)}. \tag{77}$$

Inserting the exact results found:

$$\frac{d\theta}{dr} = \frac{b}{r^2\sqrt{1-\frac{2GM}{rc^2}}\,\sqrt{r^2-b^2}}. \tag{78}$$

Step 8: Integration and Light Deflection Angle.
Integrating from closest approach ($r = b$) to infinity:

$$\Delta\theta = \int_b^\infty \frac{d\theta}{dr}\,dr = \frac{\pi}{2} + \frac{2GM}{bc^2} + \mathcal{O}\left(\frac{G^2M^2}{b^2c^4}\right). \tag{79}$$

Thus, the total deflection angle is exactly twice this difference from $\pi/2$:

$$\boxed{\delta = 2\left(\Delta\theta - \frac{\pi}{2}\right) = \frac{4GM}{bc^2}}. \tag{80}$$

This precisely matches the famous Einstein light-bending result of General Relativity.

Why?

From a physical standpoint, gravitational deflection in the Relator theory can be understood clearly as a direct consequence of two intertwined physical effects arising naturally from the quantum Relator principle:

1. As the photon approaches the gravitational mass, the gravitational phase-frequency component ($\boldsymbol{\omega}_\phi$) increases. To maintain the fundamental Relator condition $R\omega = c$, the spatial momentum-frequency vector ($\boldsymbol{\omega}_p$) must adjust its orientation. Thus, an increase in gravitational potential directly forces a larger angle between momentum and gravitational frequency vectors, creating the observed angular deflection.
2. Simultaneously, the photon's local momentum magnitude increases due to gravitational energy exchange. This rise in the magnitude of the spatial momentum-frequency component further reinforces the angular separation between the momentum and gravitational vectors. For massive particles moving at speeds significantly lower than c, the internal frequency ratio $\omega_{\mathbb{C}}/\omega$ decreases smoothly, providing flexibility in balancing spatial frequencies. However, for a photon-like particle, approaching closely to the gravitational source, the expression under the square root defining the internal frequency becomes negative. This implies an imaginary internal frequency ($\omega_{\mathbb{C}}$), indicating the quantum Relator's internal restructuring necessary to prevent violation of the fundamental constraint $R\omega = c$.

Thus, within the Relator framework, gravitational deflection of photons emerges naturally and consistently without explicitly invoking curved spacetime geometry. Instead, the effect arises entirely from internal quantum-phase frequency restructuring, precisely fulfilling the same role as curvature does in General Relativity. Experimental evidence, notably Eddington's solar eclipse observations (1919) and modern gravitational lensing experiments, provide robust empirical support, highlighting the Relator interpretation as a consistent and viable quantum-geometric viewpoint.

These results are rigorously valid in the weak-field regime ($GM/(rc^2) \ll 1$). Strong-field analysis ($r \simeq 2GM/c^2$) will require additional Relator-based investigations beyond the present scope.

4.4 The Illusion of Spacetime Curvature

We explicitly demonstrate how gravitational phenomena arise naturally within the Relator framework without invoking spacetime curvature, the Schwarzschild metric, or General Relativity. Starting solely from classical Newtonian potential $\phi(r) = -GM/r$, the fundamental quantum Relator principle $R(r)\,\omega(r) = c$ directly reveals gravitational effects as quantum-phase phenomena.

Thus, what observers traditionally attribute to "curved spacetime" is revealed here as a natural consequence of the internal quantum-phase restructuring mandated by the universal Relator constraint. The apparent "curvature of time" is purely a reflection of modifications in the internal frequency ($\omega_{\mathbb{C}}$), while the illusion of "spatial curvature" emerges solely from corresponding adjustments in the spatial frequency ($\omega_{\mathbb{R}^3}$). Even geodesic trajectories, normally viewed as evidence of curved geometry, are simply paths enforcing the fundamental quantum-phase condition $R\omega = c$.

Spacetime curvature is an emergent illusion; gravitational effects reflect fundamental quantum-phase coherence rather than geometry.

4.5 Comparison with Other Emergent Gravity Approaches

Several theories in contemporary physics propose that gravity is an emergent phenomenon arising from deeper microscopic or quantum structures. While our Relator Framework shares this aspiration, it follows a markedly different route.

Table 1 Comparison of Gravity Theories: Fundamental, Emergent, or Neither

Theory	**Fundamental Spacetime**	**Emergent Spacetime**	**No Spacetime (Neither)**
General Relativity	✓	×	×
Entropic Gravity (Verlinde)	×	✓	×
ER=EPR, Tensor Networks	×	✓	×
Causal Fermion Systems	×	✓	×
Loop Quantum Gravity	×	✓	×
AdS/CFT (Holography)	×	✓	×
Zitterbewegung & Pilot-Wave	✓	×	×
Shape Dynamics	×	✓	×
Relator $R\omega = c$	×	×	✓

1. Entropic Gravity (Verlinde).

Entropic gravity, as formulated by Erik Verlinde, postulates gravitational phenomena as emergent thermodynamic effects arising from informational entropy gradients. In contrast, the Relator framework presented here is fundamentally kinematic and purely quantum-mechanical, governed explicitly by the internal quantum-phase constraint $R\omega = c$. Consequently, gravitational effects in our theory originate intrinsically from quantum coherence, completely eliminating the need for thermodynamic arguments, entropy considerations, or holographic principles.

2. Emergent Spacetime from Quantum Entanglement.

Approaches such as ER=EPR and tensor-network formalisms posit that spacetime geometry emerges fundamentally from quantum entanglement structures, typically invoking holography and strongly coupled quantum systems. In contrast, the Relator framework described herein is independent of entanglement or dualities, and inherently applicable to single-particle, non-relativistic quantum systems. Within this model, gravitational phenomena arise directly from intrinsic quantum-phase coherence, governed explicitly by the universal constraint $R\omega = c$, without reliance on relational entanglement.

3. Causal Set Theory and Loop Quantum Gravity.

Causal Set Theory and Loop Quantum Gravity both fundamentally postulate discrete microscopic structures underlying spacetime, wherein classical geometry emerges from either discrete causal relations (causal sets) or quantized spin-network configurations (loop gravity). By contrast, the Relator framework explicitly preserves the continuum structure of the quantum wavefunction, embedding gravity directly within standard quantum theory without introducing discrete or quantized space–time elements. The emergence of gravitational phenomena within our model is strictly continuous, arising naturally from the universal internal phase constraint $R\,\omega = c$ that governs quantum-state evolution, rather than relying on discrete spacetime building blocks or quantization schemes.

4. Zitterbewegung and Pilot-Wave Inspired Theories.

Previous theoretical models influenced by Zitterbewegung interpretations and Pilot-Wave (Bohmian) mechanics commonly attempt to geometrize quantum phenomena by introducing additional classical hidden variables, explicit particle trajectories, or supplementary ontological constructs. In sharp contrast, the Relator framework developed herein remains strictly within the standard quantum-mechanical formalism, embedding the internal constraint $R\omega = c$ intrinsically into the quantum wavefunction itself. Consequently, gravitational and relativistic phenomena emerge naturally and inherently from quantum-phase coherence, without resorting to supplementary hidden variables or extending beyond a minimal quantum ontology. Thus, our approach maintains both mathematical simplicity and conceptual minimalism, distinguishing itself clearly from previous Zitterbewegung- or Bohm-inspired paradigms.

5. Shape Dynamics.

Shape Dynamics recasts gravitational phenomena by focusing on relational configurations and scale-invariant (conformal) geometry, explicitly abandoning absolute scales of length and global temporal frameworks. In stark contrast, the Relator framework preserves intrinsic absolute scales and internal temporal structures fundamentally embedded within the quantum wavefunction. Specifically, gravitational effects in our model are derived explicitly from quantum-phase coherence and governed by the universal internal phase constraint $R\,\omega = c$. Consequently, gravitational phenomena arise inherently from internal quantum dynamics, independent of relational or conformal symmetries. Thus, while Shape Dynamics seeks gravity through relational redefinition of geometry, the Relator model intrinsically derives gravity through internal quantum-phase modulation without sacrificing absolute scale or time.

The Relator Framework thus offers a minimalist and mathematically grounded alternative to other emergent gravity proposals. It uniquely leverages the internal phase evolution of quantum states to reproduce both relativistic and gravitational effects, sidestepping the need for new fields, discrete structure, or thermodynamic reasoning. This positions it as a promising candidate for a unifying ontological reformulation of fundamental physics.

Moreover, unlike some of the competing frameworks that face substantial empirical challenges, the Relator model directly connects to measurable quantum phenomena, enhancing its potential for experimental verification. Its conceptual simplicity, arising directly from standard quantum mechanics without extra assumptions, significantly streamlines theoretical and empirical investigation.

5 Emergence of Spin and Magnetic Phenomena from the Relator Equation*

The universal Relator condition, $R\omega = c$, is fundamental within this framework. Through careful analysis and comparison with experimental observations, we aim to gain deeper insight into the underlying quantum structure implied by the Relator principle. Here, we specifically address the electron's spin phenomenon, using only classical equations combined with the fundamental condition $R\omega = c$. We emphasize that reproducing the known results derived from Dirac theory is not our goal in the present paper; that analysis, involving deeper quantum-field theoretical considerations, will be thoroughly explored in future studies. Such considerations inevitably open broader foundational discussions beyond the scope of this immediate work.

Let the canonical momentum of a massive particle be

$$\mathbf{p} = (p_x,\, p_y,\, p_z), \quad p = |\mathbf{p}|. \tag{81}$$

The Relator condition $R\,\omega = c$, combined with the intrinsic polar frequency $\omega_{\mathbb{C}} = mc^2/\hbar$, fixes the internal radius to $R = \hbar/(mc)$, thus setting the internal scale of phase rotation in the complex amplitude space $\mathbb{C}$.

The corresponding spatial winding frequency vector is

$$\boldsymbol{\omega}_{\mathbb{R}^3} := \frac{\mathbf{p}}{mR} = \frac{c}{\hbar}\,\mathbf{p}, \quad |\boldsymbol{\omega}_{\mathbb{R}^3}| = \frac{c}{\hbar}\,p, \tag{82}$$

while the internal rotation is expressed as

$$\boldsymbol{\omega}_{\mathbb{C}} = \omega_{\mathbb{C}}\,\hat{\mathbf{n}}_C, \quad \omega_{\mathbb{C}} = \frac{mc^2}{\hbar}, \tag{83}$$

with $\hat{\mathbf{n}}_C$ the unit vector defining the internal axis of phase rotation.

5.1 Binary Helicity and Spin Orientation

Define the helicity indicator

$$\chi := \operatorname{sgn}\left(\boldsymbol{\omega}_{\mathbb{C}} \cdot \boldsymbol{\omega}_{\mathbb{R}^3}\right) \in \{+1, -1\}, \tag{84}$$

which determines whether the spatial phase rotation is co-helical ($\chi = +1$) or counter-helical ($\chi = -1$) relative to the fixed internal rotation $\boldsymbol{\omega}_{\mathbb{C}}$. Here, *helical* refers specifically to the relative orientation between the internal angular frequency $\boldsymbol{\omega}_{\mathbb{C}}$ and the spatial phase winding vector $\boldsymbol{\omega}_{\mathbb{R}^3}$, not to the physical path of the particle. In practice, while the canonical momentum $\mathbf{p}$ may align with the apparatus axis, the transverse phase winding direction $\boldsymbol{\omega}_{\mathbb{R}^3}$ arises from internal quantum structure and can vary randomly—accounting for the observed binary splitting of silver atoms in the Stern–Gerlach experiment. This binary helicity defines the two discrete spin states observed in nature and reflects the SU(2) double-cover structure of physical spin.

5.2 Internal Angular Momentum and Magnetic Moment

A more physically fundamental and consistent approach, fully aligned with the principles underlying the Relator theory, is to assume that the internal mass distribution spreads continuously and isotropically across the entire internal plane $\mathbb{C}$, without privileging any particular internal location. Thus, we adopt a circularly symmetric Gaussian mass distribution in the internal space:

$$\rho(r) = \frac{m}{\pi a^2}\, e^{-r^2/a^2}, \tag{85}$$

with the normalization condition:

$$\int_0^\infty 2\pi r\, \rho(r)\, dr = m. \tag{86}$$

Assuming each internal mass element moves tangentially at speed c, as required by the Relator condition $R\,\omega = c$ — PLP, the total momentum becomes $P = \int c\, dm = mc$, and the resulting internal energy is $E = Pc = mc^2$, precisely matching the particle's rest energy.

Matching the exponential argument of the resulting maximum-entropy distribution $\rho(r) = \frac{m}{R^2} e^{-\pi r^2/R^2}$ with the general Gaussian form $\rho(r) = \frac{m}{\pi a^2} e^{-r^2/a^2}$, we identify the internal scale as:

$$a = \frac{R}{\sqrt{\pi}}. \tag{87}$$

Using the previously determined Gaussian profile and the speed c, we calculate:

$$L_C = \int_0^\infty r\, v(r)\, dm = \int_0^\infty r\ c\ \big[\rho(r)\, 2\pi r\, dr\big] \tag{88}$$

$$= c\int_0^\infty 2\pi\, r^2\, \rho(r)\, dr = 2\pi c\, \frac{m}{\pi a^2} \int_0^\infty r^2\, e^{-r^2/a^2}\, dr \tag{89}$$

$$= \frac{2m\, c}{a^2} \cdot \frac{\sqrt{\pi}\, a^3}{4} = \frac{\sqrt{\pi}}{2}\, m\, c\, a. \tag{90}$$

Substituting the entropy-derived value $a = \frac{R}{\sqrt{\pi}}$, we obtain:

$$L_C = \frac{1}{2} mcR. \tag{91}$$

Given the fundamental Relator condition $R\,\omega = c$ and the internal phase frequency $\omega = mc^2/\hbar$, the intrinsic radius is fixed as $R = \hbar/(mc)$. Substituting this into the angular momentum expression $L_C = \frac{1}{2}mcR$, we obtain:

$$\boxed{L_C = \frac{\hbar}{2}}. \tag{92}$$

We compute the intrinsic magnetic moment μ_C assuming a minimal internal structure consistent with the Relator condition $R\,\omega = c$, corresponding to luminal circular motion at radius R. The electric charge is modeled as a δ-distribution localized on a ring at $r = R$:

$$dq = e\,\delta(r - R)\,dr. \tag{93}$$

The magnetic moment is then computed directly from its classical electromagnetic definition:

$$\mu_C = \int d\mu = \int_0^\infty I(r)\,A(r), \quad \text{with} \quad I(r) = \frac{\omega(r)\,dq}{2\pi}, \quad A(r) = \pi r^2. \tag{94}$$

Considering the Relator condition explicitly, $\omega(r)\,r = c$, we have $\omega(R) = c/R$, and thus:

$$\mu_C = \int_0^\infty \frac{\omega(r)\,dq}{2\pi}\,\pi r^2 = \frac{1}{2}\int_0^\infty \omega(r)\,r^2\,dq \tag{95}$$

$$= \frac{1}{2}\frac{c}{R}\int_0^\infty r^2\,e\,\delta(r - R)\,dr = \frac{1}{2}\frac{c}{R}\,e\,R^2 \tag{96}$$

$$= \frac{ecR}{2}. \tag{97}$$

Substituting the intrinsic radius $R = \hbar/(mc)$, the intrinsic magnetic moment explicitly becomes:

$$\boxed{\mu_C = \frac{e\hbar}{2m}}, \tag{98}$$

which precisely matches the intrinsic magnetic moment derived from the Dirac theory for the electron.

The ratio of intrinsic magnetic moment to intrinsic angular momentum, using the general parameter a, is given by:

$$\frac{\mu_C}{L_C} = \frac{\frac{1}{2}e\,\omega\,R^2}{\frac{\sqrt{\pi}}{2}\,m\,c\,a}, \quad \left(a = \frac{R}{\sqrt{\pi}},\ R\omega = c\right), \tag{99}$$

thus simplifying directly to:

$$\frac{\mu_C}{L_C} = \frac{e\,R}{\sqrt{\pi}\,m\,a} = \frac{e\,a\sqrt{\pi}}{\sqrt{\pi}\,m\,a} = \frac{e}{m}. \tag{100}$$

Consequently, the gyromagnetic factor emerges explicitly as:

$$g = 2\,\frac{m}{e}\frac{\mu_C}{L_C} = 2\,\frac{m}{e}\frac{\frac{1}{2}e\,\omega\,R^2}{\frac{\sqrt{\pi}}{2}mca} = \frac{c\,R}{\frac{\sqrt{\pi}}{2}\,c\,a} = \frac{2\,R}{\sqrt{\pi}\,a}. \tag{101}$$

Using the entropy-derived Gaussian width $a = R/\sqrt{\pi}$, the intrinsic magnetic moment and angular momentum precisely reproduce Dirac's canonical results:

$$\boxed{g = 2}. \tag{102}$$

This result demonstrates that the Relator theory, with the minimal and physically motivated assumption of a delta-ring charge distribution at the intrinsic radius R, exactly reproduces the intrinsic spin characteristics of fundamental particles, without introducing arbitrary parameters or corrections.

5.3 Stern–Gerlach Splitting and Spin Quantization

When this internal angular momentum $\mathbf{L}_C$ and magnetic moment $\boldsymbol{\mu}_C$ couple to an external inhomogeneous magnetic field, such as $\mathbf{B}_{\text{ext}} = B(z)\,\hat{\mathbf{z}}$ with $\partial_z B > 0$, the magnetic energy becomes $U = -\boldsymbol{\mu}_C \cdot \mathbf{B}_{\text{ext}}$, and the vertical force is:

$$F_z = -\partial_z U = \mu_z \frac{dB}{dz} = \chi\,\mu_B \frac{dB}{dz}, \tag{103}$$

where $\mu_z = \boldsymbol{\mu}_C \cdot \hat{\mathbf{z}} = \chi\,\mu_B$ and $\chi = \pm 1$ denotes the helicity direction of the internal motion. Thus, particles with $\chi = +1$ are deflected upward, and those with $\chi = -1$ downward.

This results in two discrete deflection spots on the detector—exactly as observed in the Stern–Gerlach experiment. This quantized deflection confirms that the internal structure only permits two stable configurations of angular momentum projection. Hence, we define the spin quantum number naturally as:

$$s = \frac{\chi}{2} \in \left\{+\frac{1}{2}, -\frac{1}{2}\right\}, \tag{104}$$

leading to the standard form:

$$\mu_z = 2s\,\mu_B. \tag{105}$$

In summary, spin emerges as a topologically constrained, geometrically quantized binary helicity arising from the interplay of internal phase rotation and external spatial winding, enforced by the universal light-speed condition $R\omega = c$. No hidden variables or auxiliary quantization rules are required—spin is the inevitable expression of how quantum phase rotates across dual domains.

Within the Relator framework, distinctive spin–magnetic states emerge at critical configurations where either the spatial phase winding approaches zero ($\boldsymbol{\omega}_{\mathbb{R}^3} \approx 0$) or the internal rotation frequency becomes negligible ($\boldsymbol{\omega}_{\mathbb{C}} \approx 0$). Near these special points, small fluctuations in the particle's internal state can lead to an effective cancellation of magnetic moments, suppressing deflection in external fields—thus producing behavior reminiscent of magnetic neutrality.

5.4 Remark on the Microstructure of the Relator Field

We intentionally refrain at this stage from proposing or detailing any specific ontological interpretation or structural details regarding the underlying Relator field equations. The Relator structure represents the most fundamental building block of physical reality, underpinning both quantum mechanics and relativity at the macroscopic phenomenological level. In our series of investigations, we systematically illuminate different aspects of the microscopic Relator dynamics, progressively converging toward a complete mechanical and theoretical description of its internal microstructure.

At the macroscopic phenomenological level, mass and electric charge appear proportional, with mass acting as a carrier of electric charge. However, at the microscopic Relator scale, a strict one-to-one proportionality between mass density and electric charge density does not exist. We model the mass distribution by a Gaussian profile in the internal space $\mathbb{C}$, wherein each point rotates internally at the speed of light c, satisfying the universal Relator condition $R\,\omega = c$. Thus, these internal points constitute the mass-energy content of the Relator structure.

Electric charge, on the other hand, differs fundamentally, as it is intrinsically quantized, permitting only discrete values. This quantization enforces particular boundary conditions and structural constraints upon the Relator field configuration $R\,\omega = c$, manifesting explicitly as localized discrete ring-like distributions, as demonstrated above. In subsequent studies, we will continue our investigation into how the intrinsic quantum of electric charge arises from deeper geometric and topological constraints within the Relator framework.

6 Outlook: Toward a Phase-Based Reformulation of Reality

If the Relator constraint $R\omega = c$ holds universally across quantum systems, we are faced with a profound shift in our understanding of the physical world. The consequences reach far beyond re-deriving time dilation or light deflection; they demand a redefinition of the very foundations upon which modern physics is built. Each of these fundamental aspects will be explicitly and rigorously formulated and published in forthcoming works.

Antiparticles in the Relator Framework

The fundamental internal constraint of the Relator framework, $R(x,\tau)\,\omega(x,\tau) = c$, inherently implies the standard relativistic energy–momentum relation, $E^2 = m^2c^4 + p^2c^2$, without additional assumptions. In this context, intrinsic particle properties such as mass, electric charge, and spin reside exclusively in the internal complex amplitude space ($\mathbb{C}$), whereas the three-dimensional manifold ($\mathbb{R}^3$) is solely the domain of spatial propagation.

The internal frequency $\omega_{\mathbb{C}}$, defined via proper time τ as

$$\omega_{\mathbb{C}} = -\frac{1}{\hbar}\frac{\partial S}{\partial \tau}, \tag{106}$$

admits the immediate possibility of reversing the direction of internal phase rotation. This reversal is represented simply by changing the sign of the internal action S:

$$\begin{cases} \psi^{+}(x,\tau) = R(x,\tau)\, e^{+iS(x,\tau)/\hbar}, \\ \psi^{-}(x,\tau) = R(x,\tau)\, e^{-iS(x,\tau)/\hbar}. \end{cases} \tag{107}$$

Consequently, the internal frequency for this reversed solution explicitly becomes negative, $\omega_{\mathbb{C}}^{-} = -\omega_{\mathbb{C}}$. This sign reversal directly implies the inversion of intrinsic quantum numbers, including electric charge and magnetic moment, precisely defining an antiparticle state.

Thus, the emergence of antiparticles is not an additional postulate, but rather a direct and natural consequence of the Relator equation itself. Within this geometric interpretation, particle–antiparticle symmetry reflects simply two possible directions of internal phase rotation in C-space. This intrinsic geometric duality provides a clear, minimalistic, and rigorous foundation for the concept of antimatter, unified seamlessly within the Relator framework.

Singularities Reconsidered.

In the traditional relativistic picture, black holes contain singularities where curvature diverges and classical laws break down. Within the Relator framework, however, such singularities can be reinterpreted not as mathematical infinities, but rather as points marking a fundamental transition in the internal quantum-phase dynamics of particles. Specifically, when approaching the Schwarzschild radius and crossing the event horizon, the external phase frequency ω_{R^3} exceeds the total frequency ω, leading initially to an imaginary internal frequency $\omega_{\mathbb{C}}$ and triggering a quantum instability. This instability can naturally induce particle production through a bifurcation mechanism, thereby restoring real and stable internal frequencies.

Consequently, the region between the event horizon and what is traditionally considered a singularity acquires a coherent, physically consistent description within the Relator framework, replacing classical divergences with a natural quantum process. Precisely formulating this particle production mechanism and analyzing strong gravitational regimes in detail within the Relator theory will be the focus of subsequent works.

Force as a Derivative of Frequency.

In this theory, force is not an independent input but a secondary consequence of internal phase deviation. The gradient of frequency defines motion; acceleration arises not from an external agent but from the system's attempt to conserve its internal light-speed rhythm. This reverses centuries of Newtonian intuition, suggesting that *motion is not caused by force — force is caused by motion within the phase field.*

In our model, the action integral emerges precisely as the integral over the particle's wavefunction.

Entanglement as Phase Coherence.

Perhaps most radically, the Relator model hints at a new understanding of quantum entanglement. If the internal phase structure governs all motion and gravitational response, then phase synchronization across spacelike-separated particles may underlie what we currently interpret as entanglement. Rather than "spooky action," entanglement becomes a manifestation of shared geometric rhythm — a deep coherence in the rotational heartbeat of matter.

Beyond Geometry.

Finally, if what we perceive as spacetime curvature is merely the shadow of a deeper phase dynamic, then geometry itself is not fundamental. The true ontology of the universe is musical, not spatial; structured not by lines and metrics, but by cycles and constraints. In this paradigm, the universe is not made of fields or particles — it is made of rhythms — we call it as *Relator.*

A Call for Redefinition.

The implications of this approach invite a radical rewriting of physical law. If successful, the Relator Framework will not only unify quantum mechanics and gravity but dissolve the very distinction between them — revealing both as emergent aspects of a deeper, internal motion. Like shifting from epicycles to ellipses, it requires a reorientation of thought — from space to phase, from geometry to rhythm, from motion to modulation. *It is a new way to listen to the universe.*

Future work will also seek to explicitly identify novel experimental tests and measurable phenomena uniquely predicted by this phase-based framework, thus bridging theoretical innovation and empirical validation. This reorientation invites profound philosophical implications, challenging traditional conceptions of reality, causality, and the very nature of existence itself.

7 Conclusion

In this work, we have shown that the phenomena traditionally attributed to the curvature of spacetime—such as light deflection, gravitational redshift, and time dilation—can be derived entirely from the internal phase dynamics of quantum systems. By enforcing the invariant constraint $R\omega = c$, we reinterpret gravity not as a deformation of geometry, but as a modulation of internal rhythm in response to energy gradients. From this viewpoint, special relativity appears as an emergent description at the level of observable events. Concepts such as reference frames and observers, traditionally considered foundational, emerge naturally as surface manifestations of deeper quantum-phase dynamics. It is not the observer or their frame of reference that holds fundamental importance, but rather an underlying universal reality—an intrinsic structure that seamlessly connects phenomena across scales, from quantum interactions to galactic motions.

This reframing profoundly alters the ontology of gravitation. What has been seen as a property of spacetime curvature may instead be a projection—an emergent appearance—of underlying quantum coherence. Spacetime, in this view, is not the medium of reality, but its shadow: geometry is born from phase, not the other way around.

Whatever is, is light—or the shadow it casts.

Likewise, this work is an act of reshaping; we propose that the universe is not built from inert geometry but from the pulse of internal phase. The wavefunction—long treated as a probabilistic tool—here takes center stage as the engine of all physical phenomena. Thus, we suggest a radical paradigm: the fabric of the universe is not spacetime, but waves-evolution. General Relativity is not negated—it is revealed as the large-scale echo of an internal, light-speed rhythm. And perhaps, this new rhythm grants us not only predictive power, but insight into the inner poetry of reality. The discovery of the Relator constraint $R\omega = c$ will immediately generate a cascade of predictions—each explored in subsequent papers.

Future research will be dedicated not only to theoretical explorations but also to designing explicit, experimentally verifiable predictions that distinguish this model clearly from conventional frameworks.

Appendix A Kinetic Energy and Newtonian Dynamics as Emergent from Internal Phase Evolution

We propose a reinterpretation of kinetic motion: the kinetic energy of a particle is not fundamentally due to an applied force, but rather emerges directly from deviations in the internal phase frequency of the particle's rest-state oscillation.

A.1 Energy as a Frequency Shift

The intrinsic angular frequency of a particle at rest is given by:

$$\omega_0 = \frac{mc^2}{\hbar}, \tag{A1}$$

corresponding to its rest energy:

$$E_0 = \hbar\omega_0 = mc^2. \tag{A2}$$

When the particle moves at velocity v, the *internal* (polar) frequency, denoted $\omega_{\mathbb{C}}$, decreases due to time dilation:

$$\omega_{\mathbb{C}}(v) = \frac{\omega_0}{\gamma} = \omega_0\sqrt{1 - \frac{v^2}{c^2}}, \tag{A3}$$

while the *total* phase frequency ω satisfies the Relator constraint:

$$\mathcal{R}\,\omega = c, \qquad \omega^2 = \omega_{\mathbb{C}}^2 + \omega_{\mathbb{R}^3}^2, \tag{A4}$$

with

$$\omega_{\mathbb{R}^3} = \frac{p\,c}{\hbar}, \quad p = \gamma m v. \tag{A5}$$

From this, the total energy is

$$E = \hbar\omega = \sqrt{m^2c^4 + p^2c^2} = \gamma mc^2, \tag{A6}$$

and the kinetic energy follows directly as

$$E_k = E - E_0 = (\gamma - 1)mc^2. \tag{A7}$$

In the non-relativistic limit $v \ll c$, this reduces to

$$E_k \approx \frac{1}{2}mv^2, \tag{A8}$$

recovering the classical expression. Here, kinetic energy emerges from the redistribution of the invariant phase-clock frequency between internal rotation and spatial translation, without explicit reference to external forces or accelerations.

A.2 Emergence of Newton's Second Law

In the non-relativistic regime ($v \ll c$), let the total energy of the particle—comprising rest, potential, and kinetic terms—be encoded in the total phase frequency $\omega(t)$:

$$\omega(t) = \frac{1}{\hbar}\left[mc^2 + V(x(t)) + \frac{1}{2}mv^2(t)\right]. \tag{A9}$$

The Relator constraint imposes

$$\mathcal{R}(t)\,\omega(t) = c, \tag{A10}$$

where $\mathcal{R}(t)$ is the internal phase radius (with dimensions of length). Differentiating this constraint gives

$$\dot{\omega} = -\,\omega\,\frac{\dot{\mathcal{R}}}{\mathcal{R}}. \tag{A11}$$

On the other hand, differentiating $\omega(t)$ directly from its energy content yields

$$\dot{\omega} = \frac{1}{\hbar}\left(\frac{dV}{dt} + mv\,\dot{v}\right) = \frac{v}{\hbar}\left(\frac{dV}{dx} + m\,\dot{v}\right). \tag{A12}$$

Equating the two expressions for $\dot{\omega}$ gives the general dynamical relation:

$$\frac{v}{\hbar}\left(\frac{dV}{dx} + m\,\dot{v}\right) = -\,\omega\,\frac{\dot{\mathcal{R}}}{\mathcal{R}}. \tag{A13}$$

If the relative variation of the internal radius is negligible,

$$\frac{\dot{\mathcal{R}}}{\mathcal{R}} \approx 0, \tag{A14}$$

the right-hand side vanishes and we recover Newton's second law exactly:

$$m\,\dot{v} = -\frac{dV}{dx} \quad \Rightarrow \quad F = ma. \tag{A15}$$

More generally, a nonzero $\dot{\mathcal{R}}/\mathcal{R}$ produces an additional term

$$m\,\dot{v} = -\frac{dV}{dx} - \frac{\hbar\,\omega}{v}\,\frac{\dot{\mathcal{R}}}{\mathcal{R}}, \tag{A16}$$

representing a correction to Newton's law arising from slow internal-radius dynamics.

A.3 Interpretation

In classical mechanics, the logic is typically:

$$F \Rightarrow a \Rightarrow v \Rightarrow E_k \quad \text{(force generates energy)}. \tag{A17}$$

In the Phase-Clock paradigm, the causal relationship is fundamentally inverted:

$$\Delta\omega \Rightarrow E_k \Rightarrow v \Rightarrow a \Rightarrow F \quad \text{(frequency deviation generates force)}. \tag{A18}$$

Therefore, force is not primitive but emerges as a necessary consequence of preserving the internal phase velocity c as energy distributions evolve. This shifts the fundamental paradigm from "forces causing motion" to "motion adjusting to maintain internal phase evolution constraint."

This approach not only simplifies our conceptual foundation but also eliminates classical ambiguities about the nature of inertia and mass—clarifying why inertial resistance emerges naturally from quantum coherence rather than external imposition. Future experiments could test specific predictions of subtle frequency shifts in quantum systems under varying potentials, potentially offering direct empirical evidence supporting this internal phase-based interpretation of inertia.

Appendix B Experimental Comparison: Muon Lifetime and Phase-Clock Time Dilation

To evaluate the physical validity of the Relator model of time dilation, we compare its predictions with high-precision experimental data on atmospheric muon decay.

B.1 Frisch–Smith Experiment (1963)

In their seminal experiment, Frisch and Smith measured the flux of cosmic muons reaching sea level. Muons are generated in the upper atmosphere at altitudes around 20 km and travel toward Earth at speeds close to $v = 0.998\,c$. Their proper (rest-frame) lifetime is known to be:

$$\tau_0 = 2.2\ \mu s. \tag{B19}$$

Classically, without time dilation, a muon traveling at this speed would traverse only about 660 meters before decaying. However, the observed muon flux at sea level shows far greater survival [15]:

- Muons counted at mountain altitude: 5500
- Expected at sea level without time dilation: 27
- Actual observed at sea level: 400

This result demands a mechanism to extend the muon's lifetime in the lab frame. Special relativity explains this through Lorentz dilation, with a boost factor:

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \approx 15.8, \tag{B20}$$

yielding an effective lab-frame lifetime:

$$\tau_{\text{lab}} = \gamma \cdot \tau_0 \approx 34.8\ \mu s. \tag{B21}$$

Gravitational redshift also affects the internal phase. However, over the altitude difference of 20 km, the gravitational potential change leads to:

$$\frac{\Delta\omega}{\omega} \sim \frac{g\,\Delta h}{c^2} \approx 2 \times 10^{-9}, \tag{B22}$$

resulting in corrections on the order of nanoseconds—negligible compared to the 30+ microsecond dilation induced by velocity. Therefore, the dominant effect is kinematic.

B.2 Prediction from the Relator Model

In our framework, time dilation emerges as a direct consequence of internal phase dynamics and the universal constraint $R\omega = c$. As the particle's spatial velocity increases, the internal frequency $\omega_{\mathbb{C}}(v)$ decreases relative to the total composite frequency $\omega(v)$ to maintain the universal constraint $R\omega = c$. Thus, the internal evolution of the particle genuinely slows down, a fact that can be expressed clearly by the ratio of total frequency to internal frequency:

$$\frac{\omega(v)}{\omega_{\mathbb{C}}(v)} = \frac{\omega_0}{\omega_0\sqrt{1 - v^2/c^2}} = \frac{1}{\sqrt{1 - v^2/c^2}} = \gamma. \tag{B23}$$

Consequently, the internal clock period increases explicitly:

$$\tau(v) = \frac{2\pi}{\omega_{\mathbb{C}}(v)} = \gamma\,\tau_0. \tag{B24}$$

It is crucial to emphasize that this slowing down is an absolute internal effect, and not relative: unlike standard special relativity, where neither observer nor particle reference frames have priority, in the Relator framework the particle's internal frequency reduction is intrinsic and objectively real.

This distinction becomes critical in interpreting experiments like the Frisch–Smith muon decay. In standard relativistic treatments, it is often argued that the Earth's frame is not inertial due to gravity, thereby allowing asymmetric interpretation of the time dilation effect. But this move—invoking non-inertial frames in otherwise flat spacetime—functions less as an explanation and more as a circumvention. It redirects attention from a physical asymmetry to a coordinate convention. A similar ambiguity haunts the famous twin paradox, where one twin travels at near-light speed and returns younger. Traditional resolutions appeal to acceleration breaking frame symmetry, but this defers rather than resolves the ontological question: why did one clock genuinely slow? Our framework answers directly. The phase-clock constraint $R\,\omega = c$ defines an internal, frame-independent rhythm tied to the particle's ontic structure. *Time dilation occurs not because observers disagree*, but *because the inner frequency of the particle physically shifts*. Thus, this interpretation elegantly resolves traditional paradoxes—such as the twin paradox—not by invoking asymmetrical conditions like acceleration, but by establishing internal quantum-phase dynamics as the fundamental arbiter of physical reality.

B.3 Ontological Implication: Time Dilation is Real for the Particle

This experimental evidence supports a key ontological claim of the Relator model: that time dilation is not a mere coordinate artifact, but a *real, internal deformation* of the particle's quantum rhythm.

In standard relativity, reciprocal time dilation emerges from frame symmetry. Yet muon decay is not symmetric: the particle either survives to reach sea level—or it doesn't. The experimental decay count is not frame-dependent. Thus, we conclude:

> *The muon's wavefunction genuinely evolves more slowly — not because we observe it differently, but because its inner phase cycles are objectively stretched.*

This confirms the central assertion of our theory: that time dilation is a frame-independent, ontic phenomenon grounded in the intrinsic phase geometry of matter.

Appendix C Ontological Reflection and Closed–Loop Quantization*

A consistent Lagrangian formulation for the Relator principle can be constructed by introducing a scalar field $\mathcal{R}(x,t)$ with dimensions of length, representing the internal phase radius, and an internal phase field $\phi(x,t)$ defined in the polar manifold ($\mathbb{C}$). By employing a Lagrange multiplier $\lambda(x,t)$, the fundamental Relator constraint

$$\mathcal{R}(x,t)\,\omega(x,t) = c \tag{C25}$$

is enforced locally. This guarantees the constraint's validity at every spacetime point and ensures energy–momentum conservation through Noether's theorem. Detailed derivations of the corresponding field equations are left for future work.

C.1 Probability and Normalization

In conventional quantum mechanics, probability density is defined as the squared magnitude of the dimensionless wavefunction integrated over space. Here, we reinterpret the wave amplitude $A(x,t) \equiv \mathcal{R}(x,t)$ as a physical radius in the internal polar plane, carrying dimensions of length. We therefore propose a physically intuitive normalization:

$$P(x,t)\,d^3x = \frac{\mathcal{R}^2(x,t)\,d^3x}{\displaystyle\int_{\mathbb{R}^3} \mathcal{R}^2(x,t)\,d^3x}. \tag{C26}$$

This definition is dimensionless and interprets probability as the ratio of the local polar cross-sectional area $\pi\mathcal{R}^2$ to the total integrated area over all space. It remains mathematically equivalent to the Born rule but adds direct geometric meaning to the amplitude.

C.2 Composite Phase Space and Closed Action Integrals

The complete evolution of a quantum particle occurs in a composite phase space:

$$\mathbb{C} \oplus \mathbb{R}^3,$$

where the internal polar plane $\mathbb{C}$ represents intrinsic rotation, and ordinary space $\mathbb{R}^3$ represents translational motion. Each subspace supports a distinct closed action integral, both tied to the Relator identity:

$$\mathcal{R}(x,t)\,\omega(x,t) = c. \tag{C27}$$

(i) Polar (internal) loop.

In the internal plane, the state rotates with angular frequency $\omega_{\mathbb{C}}(x,t)$ at radius $\mathcal{R}(x,t)$. The canonical angular momentum is

$$p_\varphi(x,t) = m\,\mathcal{R}^2(x,t)\,\omega_{\mathbb{C}}(x,t). \tag{C28}$$

Using (C27), this becomes

$$p_\varphi(x,t) = m\,\mathcal{R}(x,t)\,c\,\zeta(x,t), \quad \zeta(x,t) \equiv \frac{\omega_{\mathbb{C}}(x,t)}{\omega(x,t)} \in [0,1].$$

Even if $\mathcal{R}$ and ζ vary in space and time, their interplay preserves the quantization of the internal-loop action:

$$I_{\mathbb{C}} = \oint p_\varphi\,d\varphi = m\,\mathcal{R}^2\,\omega_{\mathbb{C}} \int_0^{2\pi} d\varphi = mc^2 \int_0^{2\pi} \frac{\zeta}{\omega}\,d\varphi = 2\pi\hbar. \tag{C29}$$

Thus, any local change in radius is compensated by a corresponding shift in ζ, maintaining the universal quantum of action.

(ii) Spatial (propagating) loop.

In $\mathbb{R}^3$, the particle propagates with de Broglie wavelength $\lambda = 2\pi/k$, momentum $p = \hbar k$, yielding:

$$I_{\mathbb{R}^3} = \oint p\,dx = \hbar k \lambda = 2\pi\hbar. \tag{C30}$$

This expresses the spatial phase returning to its initial value after one wavelength, closing the loop in translational phase space.

C.3 Mass and Motion as Unified Phase Dynamics

From this viewpoint, mass (rest energy) and motion (kinetic energy) are not separate entities but complementary projections of a single internal phase process. The polar loop embodies the particle's intrinsic identity, while the spatial loop projects that internal beat into measurable momentum.

Mass is thus not inert matter awaiting motion, and motion is not an independent property—it is the redistribution of an invariant phase rhythm between $\mathbb{C}$ and $\mathbb{R}^3$. The universal quantum of action $\hbar$ binds them together.

In this refined ontology, to *exist* is to *rotate*—to maintain a perpetual internal cycle. The difference between rest and motion is perspectival, not fundamental: two aspects of one underlying rhythm. The universe appears as a fabric of phase rotations, each particle a self-sustained internal clock ticking at the invariant speed of light.

Declarations

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Ethics, Consent to Participate, and Consent to Publish

Not applicable. This study is not a clinical trial and does not involve human or animal subjects.

Competing Interests

The author has no relevant financial or non-financial interests to disclose.

Conflict of Interest

The author declares that there is no conflict of interest.

Availability of Data and Material

No datasets were generated or analyzed during the current study.

Authors' Contributions

The author is solely responsible for the conception, theoretical development, writing, and revision of the manuscript.

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