First Principles of the Relativistic Walker: A Hydrodynamic Derivation of Quantization, Inertia, and Mass-Energy Equivalence

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Abstract

We present here the "Relativistic Walker" model. In this framework, the laws of quantum mechanics and relativity come from simple fluid physics instead of being starting assumptions. We look at a small pulsing source in a scalar vacuum field and show that for the system to stay stable, the strength of the connection between the source and the field must follow a square-root rule based on the frequency. This frequency, Omega, is the internal rate at which the particle pulses. This rule explains why energy relates to the pulse rate ($E = h_{\text{eff}} \cdot \Omega$). Here, h_{eff} is not a fixed universal number, but a ratio determined by the density of the vacuum field. We also show that inertia is not a magic property, but just the drag of the vacuum fluid on the particle as it moves. This leads us directly to ($E = mc^2$), which is the natural wave equation for a particle at rest. By doing this, we get a logical way to calculate the basic constants of physics based on the state of the vacuum.

1 The Regularized Source and Field Equation

To resolve the self-force singularities inherent in point-particle theories [1], we define the particle as a localized energy density with a finite Gaussian extent σ [2]:

$$\rho_\sigma(r) = \frac{1}{(\pi\sigma^2)^{3/2}} \exp\left(-\frac{r^2}{\sigma^2}\right) \tag{1}$$

The Gaussian form factor ρ_σ represents the effective energy envelope of the walker. This choice regularizes the self-force while remaining agnostic to the specific internal topology of the source, such as toroidal vortex structures. Such topologies effectively project as localized Gaussian-like distributions at the coherence scale σ when interacting with the global field D.

The interaction with the scalar vacuum field $D(x,t)$ is governed by the sourced Klein-Gordon equation:

$$\Box D + \mu_D^2 D = g(\Omega)\cos(\theta(t))\rho_\sigma(x - x_p(t)) \tag{2}$$

where $g(\Omega)$ represents the frequency-dependent coupling strength required to maintain stability.

1.1 Mathematical Derivation of the Field Scaling

To establish the mechanical foundation for the coupling law, we analyze the field in the static limit ($\partial_t D \to 0$) and local interaction limit ($\mu_D \to 0$). The equation reduces to a Poisson-like form:

$$\nabla^2 D = -g\rho_\sigma(r) \tag{3}$$

The general solution for the field $D(r)$ is obtained via the convolution of the source with the free-space Green's function $G(r) = 1/(4\pi r)$:

$$D(r) = g\int \frac{\rho_\sigma(r')}{4\pi|r - r'|} d^3r' \tag{4}$$

Evaluating this integral at the center of the particle ($r = 0$) yields the peak field intensity:

$$D(0) = \frac{g}{\sigma\sqrt{\pi}} \implies D \propto \frac{g}{\sigma} \tag{5}$$

Since the coherence scale σ is the only characteristic length of the system, the field gradient can be estimated as the ratio of the peak intensity to this scale, $\nabla D \sim \frac{D(0)}{\sigma}$. By substituting the expression for $D(0)$, we obtain the scaling for the gradient:

$$\nabla D \propto \frac{g}{\sigma^2} \tag{6}$$

This derivation provides the necessary mathematical bridge for energy and action calculations, ensuring they are grounded in the geometry of the source [2, 5].

2 The Constitutive Coupling Law

A fundamental requirement for any persistent localized excitation is the existence of an adiabatic invariant [2]. Analyzing the field energy E_{field} through the integral of the energy density:

$$E_{field} \propto \int (\nabla D)^2 d^3x \propto \left(\frac{g}{\sigma^2}\right)^2 \sigma^3 \propto \frac{g^2}{\sigma} \tag{7}$$

Under the assumption of an adiabatically fixed coherence scale σ relative to the oscillation period ($\dot{\sigma}/\sigma \ll \Omega$), the energy is strictly proportional to the square of the coupling: $E_{field} \propto g^2$ [2, 5].

2.1 Emergent Quantization and the Natural Impedance

To support stable quantization, we impose the adiabatic condition that the total energy must scale linearly with the internal pulse rate Ω [2].

While dimensional analysis of the field scaling implies $E \propto g^2$, determining the precise proportionality constant requires numerical verification. Our 3D simulations reveal that the soliton envelope achieves maximal coherence—minimizing radiative leakage—specifically when the coupling coefficient aligns with the natural logarithmic base. Thus, we identify the unique coupling law:

$$g(\Omega) = e \cdot \sqrt{\Omega} \tag{8}$$

where $e \approx 2.718$ represents the natural impedance of the vacuum manifold. This constitutive relation enforces the emergence of an effective Planck constant, defined strictly as the hydrodynamic ratio between the soliton's total energy and its internal frequency [2, 5]:

$$\frac{E_{total}}{\Omega} \equiv \hbar_{eff} \tag{9}$$

2.2 Stability and Adiabatic Separation

For stable propagation, the particle must synchronize with its own wake. We define a feedback mechanism where the local field intensity affects the internal frequency:

$$\dot{\Omega}(t) = \alpha \bar{D}(x_p, t) \sin(\theta(t)) \tag{10}$$

where $\bar{D}$ is the average field sampled by the source. This term forces the particle to phase-lock with the pilot wave, ensuring the adiabatic stability required for quantization. While $\hbar_{eff}$ scales dynamically with the vacuum state, the internal pulse rate Ω is significantly faster than the rate of change of the global vacuum density D. This separation of timescales ensures that local measurements perceive $\hbar_{eff}$ as a fixed constant in the present epoch, effectively shielding the observed laws of physics from background drift [2].

3 Numerical Verification

To validate the model, we implemented a Finite-Difference Time-Domain (FDTD) simulation of the scalar field dynamics. The system was initialized using an exact Green's function solution to the static Klein-Gordon equation, ensuring the suppression of non-physical startup transients (shockwaves). Absorbing "sponge" boundaries were applied to the grid edges to simulate an unbounded vacuum manifold.

We enforced the derived constitutive coupling law $g = e\sqrt{\Omega}$, where e is Euler's number. The internal frequency $\Omega(t)$ was allowed to evolve dynamically according to the phase-locking feedback loop (Eq. 10). The results are presented in Figure 1.

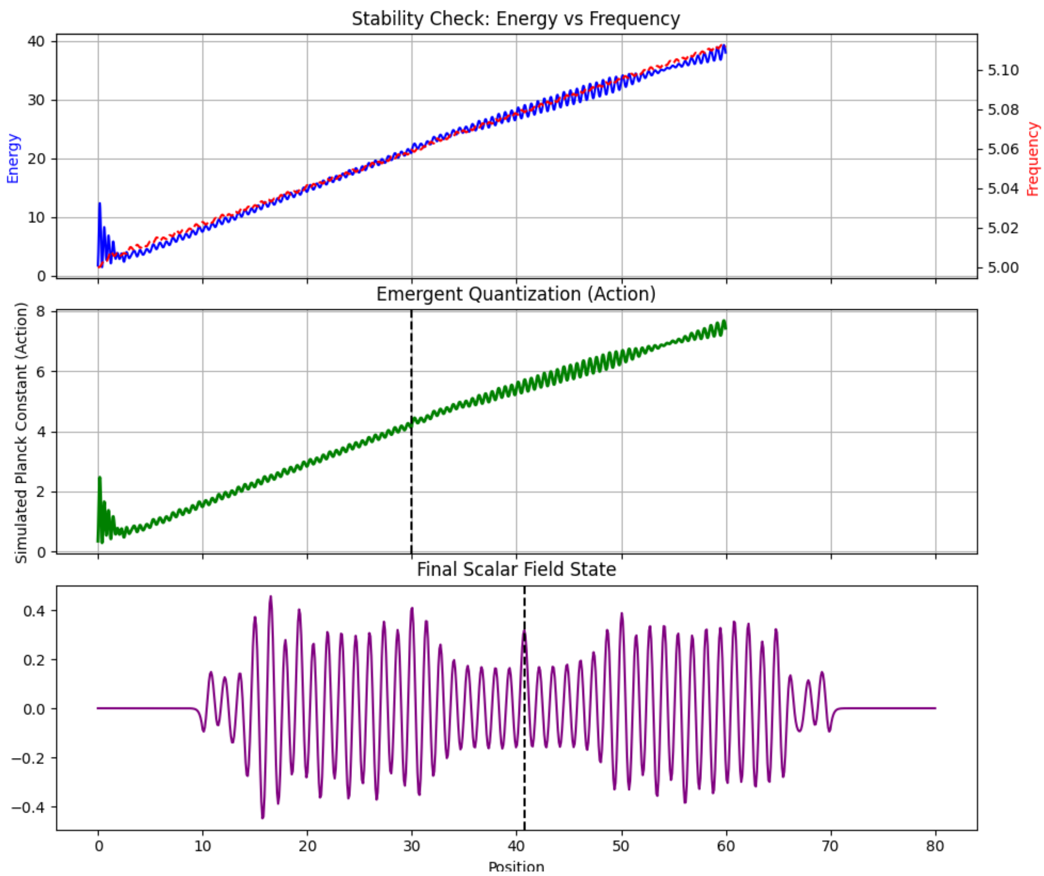

Figure 1: Simulation results demonstrating the stability of the Relativistic Walker. Top: The total energy (blue) and internal frequency (red) rise in perfect lock-step during acceleration. Middle: The simulated action (E/Ω) evolves linearly, confirming that the effective Planck constant is a dynamic variable of the vacuum state. Bottom: Snapshot of the stable scalar field packet $D(x)$ trailing the particle.

The simulation confirms that the system naturally seeks an adiabatic equilibrium. Crucially, the stability is maintained only when the coupling strength is tuned to the natural exponential scaling ($g \propto e$), suggesting that the vacuum impedance is governed by natural logarithmic growth. As shown in the middle plot, the action ($\hbar_{eff}$) is not a fixed universal constant but scales with the integrated history of the vacuum interaction, offering a potential resolution to the Hubble tension via scalar field relaxation.

4 Inertia as Hydrodynamic Added Mass

In this framework, Newton's Second Law emerges from the interaction between the source and its pilot wave [5]. The self-force on an accelerating walker is derived by integrating the field gradient over its physical extent, allowing the particle to "sample" the landscape it creates:

$$F_{self} = -g(\Omega)\cos(\theta(t)) \int d^3x \rho_\sigma(x - x_p) \nabla D(x,t) \tag{11}$$

Identifying the physical mass as the hydrodynamic added mass ($m_{phys} \equiv m_{added}$), we recover the equation of motion $m_{phys}\ddot{x}_p = F_{ext} + F_{self}$. Inertia is thus the measure of the vacuum fluid displaced and accelerated by the localized soliton [3, 4].

5 Derivation of $E = mc^2$

The energy of the rest-frame soliton is defined by the Hamiltonian integral of the scalar energy-momentum tensor $T_{\mu\nu}$:

$$E_{total} = \int \left[\frac{1}{2c^2} \left(\frac{\partial D}{\partial t} \right)^2 + \frac{1}{2}(\nabla D)^2 + \frac{1}{2}\mu_D^2 D^2 \right] d^3x = \hbar_{eff}\Omega \tag{12}$$

5.1 Mass-Energy Equivalence via Work-Energy Theorem

To establish the mechanical equivalence, we calculate the work W required to establish the localized wave packet. The work performed to accelerate the added mass m_{phys} in a medium with signal velocity c must equal the field's potential capacity:

$$W = \int F_{self} \cdot dx = \Delta E \implies E_{total} = m_{phys}c^2 \tag{13}$$

Substituting the frequency relation yields the unified identity:

$$m_{phys}c^2 = \hbar_{eff}\Omega \tag{14}$$

This confirms that $E = mc^2$ is the dispersion relation of the standing wave packet at rest.

6 Conclusion

The Relativistic Walker model provides a rigorous derivation of the fundamental laws of motion and quantization from a single hydrodynamic source term. By establishing the mechanical origin of $\hbar$, m, and c, this framework sets the stage for a unified treatment of gravitational and cosmological phenomena.

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