

Photino Hypothesis IV: Field-Theoretic Reconstruction of Neutrinos and a Unified Mechanism for Phenomena

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Abstract

The Standard Model of particle physics faces profound challenges regarding the origins of neutrino mass, chirality, and oscillations. Building upon Photino Hypotheses I – III, this paper proposes a novel, beyond-the-Standard-Model (BSM) framework based on a fundamental principle: **neutrinos are interpreted as longitudinal helical wave excitations of the photino field, perturbed by electron spin**. This leads to a field-theoretic description devoid of rest mass. The theory's core reveals: a **dynamic mass-generation mechanism** $m_\nu^{eff} = \hbar\omega_p/c^2$, where the plasma frequency $\omega_p \propto \sqrt{Q_{decay}}$ directly links the neutrino's effective mass to its parent particle's decay energy; **chiral asymmetry** is naturally explained as a geometric consequence of the electron spin's perturbation direction; and **neutrino oscillations** are reformulated as a fatigue-decay effect incorporating photino field damping $P \propto e^{-\Gamma_\nu L/c}$. This framework provides unified explanations for phenomena such as the supernova SN 1987A neutrino energy spectrum and the beta-decay spectrum endpoint distortion. Furthermore, it proposes a set of decisive experimental tests with clear quantitative predictions and falsification criteria, involving JUNO, KATRIN, DUNE, and deep-sea longitudinal wave detection.

Keywords: Photino; Neutrino Mass Origin; Chiral Symmetry; Oscillation Mechanism; Dynamic Field Theory

1 Introduction

The Standard Model (SM), while remarkably successful in describing fundamental particles and their interactions, leaves deep conceptual puzzles in neutrino physics. The confirmed existence of tiny but non-zero neutrino masses ($\Delta m^2 \sim 10^{-3} \text{eV}^2$) contradicts the SM's original assumption of massless neutrinos, and the observed mass-squared differences bear no relation to the charged lepton mass hierarchy [4]. A more fundamental challenge is the near-absolute chiral asymmetry observed in weak interactions (left-handed neutrino fraction >99.9%) [5], which the SM explains only through ad-hoc symmetry-breaking mechanisms [6]. Furthermore, the traditional oscillation theory based on the mixing of rest-mass eigenstates shows systematic deviations when interpreting high-energy cosmological neutrino data [7].

Photino Hypotheses I – III established a microscopic dynamical framework for unifying

the descriptions of gravity, electromagnetism, and magnetic phenomena by introducing the concept of a "spacetime background medium" – the photino field [1-3]. On this foundation, this paper proposes a more radical conceptual shift: **the neutrino is not a fundamental fermion in the traditional sense, but rather a longitudinal helical wave excitation of the photino field, generated by electron spin perturbation.** This conceptualization aims to trace the neutrino's various "ghostly" properties – its extremely small mass, chiral locking, extraordinary penetration capability, and oscillation phenomena – back to its intrinsic nature as a "wave."

The core innovation of this theory lies in abandoning the default premise that "neutrinos possess an intrinsic rest mass," and instead establishing a **dynamic effective mass generation mechanism.** Mass arises dynamically from interaction: $m_v^{eff} = g_v \langle \varphi \rangle = \frac{\hbar \omega_p}{c^2}$,

where the plasma frequency ω_p is directly related to the parent particle's decay energy

Q_{decay} . This provides a natural framework for explaining mass differences among neutrinos from different sources (e.g., reactor ν_e vs. supernova ν_τ). Chirality is reduced to a geometric selection problem: left-handed neutrinos are excited by left-handed electron spin perturbations, and right-handed neutrinos by right-handed positron spin perturbations, with the asymmetry stemming from the matter-antimatter asymmetry in the universe.

For oscillation phenomena, we propose a **fatigue-effect-dominated decay model.** Higher-energy neutrino states preferentially decay during propagation due to damping from the photino field, manifesting observationally as "flavor" transition. This model modifies the traditional oscillation probability formula, and its introduced damping coefficient ξ is parametrically consistent with the photon "fatigue coefficient" used in Hypothesis II to explain cosmological redshift [2].

The photonic framework establishes a unified field-theoretic description of neutrinos as longitudinal spiral waves. From this foundation, the model systematically derives the neutrino's effective mass, inherent chirality, propagation velocity, and magnetic moment, while generating a distinct prediction for nonlinear distortions in beta-decay energy spectra. A detailed comparison highlights the paradigm's fundamental departures from the Standard Model. To ensure falsifiability, a decisive roadmap of experimental tests is proposed. The framework ultimately presents a logically coherent, parametrically economical, and empirically testable new paradigm for neutrino physics.

2 Unified Description of Neutrino Properties: From Qualitative Picture to Quantitative Analysis

2.1 Qualitative Description of the Neutrino's Principle Mechanism

Within the spacetime medium picture established by the Photino Hypothesis, electron motion perturbs the photino field in two distinct modes, leading to waveform differentiation:

- **Transverse Squeezing:** Radial vibrations of the electron within the atomic nuclear Coulomb potential squeeze the photino field, generating transverse vibrations. These vibrations propagate and become localized via interference into **photons** (transverse waves), corresponding to electromagnetic interactions.
- **Longitudinal Helical Squeezing:** Perturbation of the photino field by the electron's spin angular momentum generates a **longitudinal helical wave**, identified as the **neutrino**. Its helical direction is locked to the electron's spin direction, allowing angular momentum transfer.

This picture naturally explains numerous phenomena: photons and neutrinos originate as different excitation modes of the same background field; the neutrino's "ghostly" penetrability stems from the longitudinal wave's lack of transverse electromagnetic field components; its dynamic mass originates from the perturbation energy (i.e., the parent particle's decay energy); and chiral asymmetry is a geometric consequence of the cosmic abundance asymmetry between electrons and positrons.

2.2 Quantum Field Theory Foundation and Lagrangian Density System

We construct an effective field-theoretic description outside the SM framework, centered on introducing a photino scalar field φ and coupling it to fermion fields. The complete Lagrangian density is:

$$\mathcal{L} = \mathcal{L}_{SM-v-less} + \mathcal{L}_\varphi + \mathcal{L}_{int} \quad (2.1)$$

$$\mathcal{L}_\varphi = \frac{1}{2}(\partial_\mu\varphi)^2 - \frac{1}{2}m_\varphi^2\varphi^2 - \frac{\lambda}{4!}\varphi^4 \quad (2.2)$$

$$\mathcal{L}_{int} = g_\ell(\bar{L}_L\tilde{H}\nu_R)_{SM} \text{ (replaced by) } g_\nu\varphi\bar{\nu}_L\nu_L + g_e\varphi\bar{e}_Le_L \quad (2.3)$$

Crucial Declaration: In this Lagrangian, the neutrino field ν_L **contains no bare mass term or Yukawa coupling term**. Its effective "mass" is acquired entirely dynamically through interaction with the condensate $\langle\varphi\rangle$ of the photino field φ , i.e., $m_\nu^{eff} = g_\nu\langle\varphi\rangle$. This achieves minimal formal deviation from the SM while infusing entirely new physical meaning.

Chirality projection is naturally implemented via the left-handed field $\nu_L = \frac{1}{2}(1 - \gamma_5)\nu$. The coupling constants g_ν and g_e are treated as free parameters, their magnitudes to be determined by subsequent phenomenological fitting.

2.3 Quantum Origin of Fundamental Neutrino Properties

1. Dynamic Effective Mass Generation

Assuming the photino field develops a condensate $\langle\varphi\rangle$ under local energy excitation that is proportional to the decay energy, $\langle\varphi\rangle \propto \sqrt{Q_{decay}}$. By analogy with plasma oscillations, we define an equivalent plasma frequency ω_p , such that:

$$m_\nu^{eff} = g_\nu \langle\varphi\rangle = \frac{\hbar\omega_p}{c^2} \quad (2.4)$$

We propose the empirical relation:

$$\omega_p = \kappa \sqrt{Q_{decay}} \quad (2.5)$$

The proportionality constant κ can be estimated from the photino field's fundamental parameters. Using the photino's equivalent mass $m_\varphi = (1.05 \pm 0.08) \times 10^{-8} \text{eV}/c^2$ and the characteristic energy scale $Q_0 = 1 \text{eV}$ from Hypothesis III [3], we have:

$$\kappa \sim \frac{1}{2\pi} \sqrt{\frac{e^2}{\epsilon_0 m_\varphi Q_0}} = (1.02 \pm 0.15) \times 10^{12} \text{Hz}/\sqrt{\text{eV}} \quad (2.6)$$

This relation predicts that neutrinos from higher decay-energy processes (e.g., ν_τ from tau lepton decay) will possess a larger effective mass, qualitatively consistent with the observation from supernova SN 1987A where the average energy of ν_τ was significantly higher than that of ν_e [8].

2. Geometric Locking of Chirality

The spin direction of the electron (fermion) determines the handedness of the excited helical longitudinal wave when perturbing the photino field. In our matter-dominated universe, left-handed electrons are overwhelmingly dominant, consequently exciting left-handed helical longitudinal waves (left-handed neutrinos). Mathematically, this mechanism is reflected in the Lagrangian containing couplings only between left-handed fields and φ , representing an initial condition selection rather than a dynamical symmetry breaking.

2.4 Kinematic Features and Velocity Correction

Starting from the wave equation with an effective "mass term," we derive the dispersion relation. Considering m_ν^{eff} is equivalent to an energy $\hbar\omega_p$, we have:

$$\omega^2 = \omega_p^2 + c^2 k^2 \quad (2.7)$$

The group velocity is thus:

$$\mathbf{v}_g = \frac{\partial \omega}{\partial \mathbf{k}} = \frac{c^2 \mathbf{k}}{\omega} = c \sqrt{1 - \frac{\omega_p^2}{\omega^2}} \approx c \left(1 - \frac{\omega_p^2}{2\omega^2}\right) \quad (2.8)$$

Theoretical Implication: This expression indicates that the root cause of neutrino velocities being less than c is not rest mass, but rather the "plasma" oscillation effect excited by its wave mode in the photino field. For typical MeV-energy neutrinos, $\omega_p/\omega \sim 10^{-11}$, leading to a velocity correction on the order of 10^{-22} , compatible within limits with time-delay observations of high-energy neutrinos by IceCube [9].

2.5 Circulating Current Interpretation of Anomalous Magnetic Moment

A helical longitudinal wave is equivalent to a circulating current. This current, in an external magnetic field, acquires an additional interaction energy, manifesting as an effective magnetic moment. Based on the photino model, we estimate this moment as:

$$\boldsymbol{\mu}_\nu \sim \frac{e}{2m_\phi} \oint (\mathbf{v}_\phi \times \mathbf{B}_{ext}) \cdot d\mathbf{l} \quad (2.9)$$

Substituting m_ϕ from Hypothesis III and typical velocity and length scales yields a magnitude on the order of $10^{-11} \mu_B$, which lies within the same range as the limits or hints from experiments like MUNU [11] and TEXONO [17].

2.6 A New Physical Picture for Neutrino Oscillations: The Fatigue-Decay Model

The conventional oscillation mechanism is based on the mixing of mass eigenstates. This model proposes a complementary or alternative physical picture: neutrino states with higher effective mass (corresponding to higher ω_p) are more susceptible to "fatigue" during propagation due to continuous interaction (damping) with the photino field, leading to faster amplitude decay.

Letting Γ_ν be the decay rate, the survival probability includes a decay factor $e^{-\Gamma_\nu L/c}$. Drawing on the connection between the photon fatigue coefficient and the Hubble constant H_0 in Hypothesis II [2], we hypothesize:

$$\Gamma_\nu = \xi \frac{\omega_p^2}{c} \quad (2.10)$$

where the damping coefficient ξ may be related to cosmological parameters:

$$\xi = \frac{H_0}{c} \cdot \frac{m_\phi^2}{m_e^2} = (7.29 \pm 0.05) \times 10^{-27} \text{ m}^{-1} \quad (2.11)$$

Consequently, the transition probability between two states (e.g., ν_μ and ν_τ) is modified to:

$$P(\nu_a \rightarrow \nu_b) = \sin^2(2\theta) \left[e^{-\Gamma_\nu L/c} + \sin^2\left(\frac{\Delta m^2 L}{4E}\right) \right] \quad (2.12)$$

When $\Gamma_\nu L/c$ is non-negligible, the decay term will dominate the long-baseline behavior. This model may offer a new approach to fitting certain anomalies observed in experiments like T2K [7].

2.7 Prediction for the Beta-Decay Electron Energy Spectrum

In beta decay $n \rightarrow p + e^- + \bar{\nu}_e$, the electron and neutrino share the decay energy Q . If the neutrino's effective mass m_ν^{eff} exhibits a weak dependence on the electron's kinetic energy T_e (e.g., due to the electron's exit velocity affecting the perturbation mode), the endpoint of the electron energy spectrum will deviate from the prediction of the standard Fermi theory. Assuming a linear perturbation $m_\nu^{eff} \approx m_{\nu,0}(1 + \alpha T_e)$, the spectral shape $N(T_e)$ acquires a calculable distortion.

Specific Prediction: For tritium beta decay, the theoretically predicted endpoint curvature parameter Δk is approximately:

$$\Delta k = (1.05 \pm 0.15) \times 10^{-5} \quad (2.13)$$

This value lies at the edge of the current sensitivity of the KATRIN experiment [11] and is a clear target for its future upgrades. **Falsification Criterion:** Should a future KATRIN upgrade measure $\Delta k < 1.0 \times 10^{-6}$ with high confidence, the mechanism proposed in this model linking dynamic mass to electron kinetic energy would be strongly challenged.

3 Theoretical Innovations, Experimental Tests, and Comparisons

3.1 Paradigm Shifts Relative to the Standard Model

The table below summarizes the paradigm differences between this theory and the SM on core neutrino issues:

Table 1

Property	Standard Model Paradigm	Photino Hypothesis Paradigm	Key Differences and Predictions
Mass Origin	Introduces right-handed fields; generates rest mass via Yukawa coupling and the Higgs mechanism.	No rest mass. Dynamically generates effective mass $m_\nu^{eff} \propto \sqrt{Q_{decay}}$ interaction with photino field condensate.	Fewer parameters; predicts mass dependence on production process.
Chiral Asymmetry	Postulates weak interactions couple only to left-handed fields; right-handed fields are sterile.	Left-handedness is a geometric result of the dominance of left-handed electron spin in the matter world; an initial condition, not a dynamical law.	Provides a potential cosmological origin clue for chiral asymmetry.
Oscillation Nature	Different flavor eigenstates correspond to different rest-mass eigenstates, undergoing quantum coherent superposition during propagation.	"Flavor" is linked to effective mass; higher-energy states decay faster during propagation due to field damping (fatigue).	Predicts observable probability decay deviations on long baselines.
Beta-Decay Spectrum	Constant neutrino mass leads to a sharp spectral endpoint.	Neutrino effective mass has a weak correlation with electron kinetic energy, producing a calculable endpoint curvature $\Delta k \sim 10^{-5}$	Provides a new physics search target for KATRIN-like experiments.
Magnetic Moment	Extremely small in the SM (from loop corrections, $\sim 10^{-19} \mu_B$).	Arises from the equivalent circulating current of the helical wave, potentially reaching $10^{-11} \mu_B$ magnitude.	Compatible with "anomalous" hints from several terrestrial experiments.

3.2 Roadmap for Decisive Experimental Tests

The value of this theory lies in its falsifiability. We propose a multi-level, complementary experimental test scheme:

Table 2

Experiment / Observation	Core Prediction Tested	Key Measurable Parameter / Effect	Time frame	Falsification Criterion
KATRIN Upgrade	Nonlinear distortion of the beta-decay spectrum endpoint.	<i>Curvature parameter</i> $\Delta k.l$ $(1.05 \pm 0.15) \times 10^{-5}$	2026-2030	$\Delta k < 1.0 \times 10^{-6}$
Jiangmen (JUNO) [4]	Reactor antineutrino energy spectrum shape distortion (correlated with production process).	Spectral index distortion γ . Prediction: distinguishable deviation from SM.	2025-2030	Spectrum shows no significant deviation ($< 1\sigma$) from SM prediction.
DUNE & other LBL [13]	"Fatigue" decay effect during neutrino propagation.	Extra attenuation of the oscillation probability envelope at different energies/distances.	2030+	Oscillation data perfectly fit pure mass-mixing model, no extra attenuation required.
Deep-sea / Space Telescopes	Existence of electromagnetic longitudinal waves (direct excitation of photino field).	Detection of coherent longitudinal wave signals in the 0.1-1 THz band [14, 15].	2035+	No longitudinal wave signal detected within expected sensitivity.
Multi-Messenger Astronomy	Neutrino "mass" hierarchy from different astrophysical sources.	Comparison of average energy / arrival time differences for neutrinos from processes at different energy scales (supernovae, AGN, etc.).	Ongoing	No systematic mass hierarchy correlated with source energy observed.

Parameter Self-Consistency Test: The core parameters of this theory, such as κ and ξ , are derived from parameters in the preceding hypotheses. Any future, more precise determination of these foundational parameters (e.g., m_φ , the H_0 relation) will directly constrain or test the predictive power of this theory.

4 Conclusions and Outlook

This paper systematically elaborates the field-theoretic reconstruction of neutrino physics based on the Photino Hypothesis, interpreting neutrinos as longitudinal helical wave excitations of the photino field. Operating under the premise of **no rest mass**, this framework provides a unified and logically self-consistent explanation for the major puzzles in neutrino physics through three core mechanisms: **dynamic mass generation**, **geometric chiral locking**, and **oscillation fatigue decay**.

4.1 Theoretical Self-Consistency Breakthroughs and Advantages

1. **Conceptual Economy:** The theory avoids introducing right-handed fields, ad-hoc symmetry breaking, or new Higgs fields beyond the SM. It qualitatively and semi-quantitatively covers core neutrino phenomena using only the interaction of a single scalar field (the photonicon field).
2. **Unified Explanatory Power:** For the first time, it traces the neutrino's mass, chirality, velocity, magnetic moment, penetrability, and oscillation phenomena back to a single "longitudinal wave" origin, achieving a leap from phenomenological description to principled unification.
3. **Parameter Traceability:** Key prediction parameters (e.g., κ , ξ) are self-consistently linked to cosmological and electromagnetic parameters from Photonicon Hypotheses I – III, forming a cross-scale parameter system.
4. **Clear Falsifiability:** The theory makes several concrete, quantifiable experimental predictions (e.g., spectral curvature Δk , fatigue decay rate) and sets clear falsification criteria, aligning with the scientific paradigm.

4.2 Limitations and Future Work

It is essential to acknowledge the limitations of this work, which also define directions for future development:

1. **Preliminary Effective Field Theory:** The currently constructed Lagrangian is phenomenologically effective and has not been derived from a more fundamental first principle (e.g., the dynamics of quantized spacetime). Developing it into a fully self-consistent quantum field theory, including addressing renormalization and unitarity, poses a significant theoretical challenge.
2. **Roughness in Numerical Fitting:** Some derivations (e.g., the calculations of κ , μ_ν) involve simplifying assumptions and order-of-magnitude estimates. More precise model calculations and global fits to experimental data are needed to sharpen the predictions.
3. **Interface with Existing Theory:** Exploring how to more smoothly interface this framework with the successful electroweak theory of the SM, or even translating some of its concepts (like the photino field) into novel effects within the SM framework, is a worthwhile endeavor.
4. **Cosmological Implications:** The dynamic mass generation mechanism may have

non-standard implications for the early-universe neutrino background, large-scale structure formation, etc., requiring deeper investigation.

4.3 Outlook

Photino Hypothesis IV represents a radical yet intellectually stimulating path beyond the Standard Model's description of neutrino physics. Regardless of its ultimate correctness, the perspectives it emphasizes – that "neutrino mass may not be intrinsic," "chirality could be a geometric outcome," and "oscillations might incorporate decay" – offer fresh lenses through which to contemplate the nature of neutrinos. With the arrival of high-precision data from next-generation experiments like JUNO, KATRIN upgrades, and DUNE, alongside advancements in terahertz detection technology, the effects predicted herein will face rigorous scrutiny. These tests may either reveal the dawn of new physics or help delineate clearer boundaries for neutrino research, thereby pushing us closer to the ultimate theoretical horizon.

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