Dark Matter and Dark Energy in Unified Fractal Quantum Field Theory (UFQFT): Neutral Resonances and Non-Material Oscillations

Haci Sogukpinar.

Department of Physics, Faculty of Art and Sciences, and Department of Electric and Energy, Vocational School, University of Adiyaman, Adiyaman, 02040, TURKEY.

Corresponding author: hsogukpinar@adiyaman.edu.tr, orcid.org/0000-0002-9467-2005

Abstract

The nature of dark matter and dark energy remains one of the central unresolved challenges in contemporary cosmology. Within the standard ΛCDM paradigm, dark matter is postulated as an unknown form of matter, while dark energy is reduced to a cosmological constant, yet neither has been directly explained by the Standard Model of particle physics. This study proposes an alternative interpretation based on the Unified Fractal Quantum Field Theory (UFQFT). UFQFT defines elementary particles as resonance states of two fundamental fields, the energy field (Φ) and the charge field (Ψ), within a fractal spacetime of dimension $D \approx 2.70$. According to this framework, dark matter corresponds to neutral resonances—such as neutrinos and their resonance families—that coexist with ordinary matter but do not integrate into baryonic structures, an "ady-positioned" form of matter. Dark energy, by contrast, is described as non-material resonances, oscillatory modes of the Φ–Ψ fields that never condensed into particles, manifesting instead as a persistent tension in the fabric of spacetime that drives cosmic acceleration. Conceptually, these invisible but influential structures can be metaphorically compared to unseen entities such as angels or jinn—accepted as real within cultural traditions though beyond direct perception. This resonance-based interpretation not only reframes the dark sector in physical terms but also offers novel philosophical perspectives, while providing testable differences from ΛCDM through neutrino anomalies, CMB irregularities, and gravitational lensing signatures.

Keywords:dark matter, dark energy, cosmic inflation, bubble universe, quantum gravity, geometric resonance, energy-charge fields, emergent cosmology.

1.Introduction

Although the ΛCDM model—comprising a cosmological constant (Λ) and Cold Dark Matter—has achieved remarkable success in describing large-scale structure and cosmic evolution, it faces persistent theoretical and observational challenges. One of the most severe issues is the cosmological constant problem, where theoretical predictions of vacuum energy exceed the observed value by over a hundred orders of magnitude (Weinberg, 1989; Martin, 2012). The cosmic coincidence problem—why the densities of dark matter and dark energy are comparable today despite evolving differently—remains equally unresolved (Steinhardt, 1997; Zlatev et al., 1999). On smaller scales, ΛCDM predicts cuspy dark matter halos and an overabundance of dwarf galaxies, in conflict with observations (Moore, 1994; Bullock, 2013; Del Popolo and Le Delliou, 2017). Dark matter itself, modeled as collisionless particles such as WIMPs or axions, has yet to be directly detected despite extensive experimental efforts (Bertone et al., 2005; Aprile et al., 2018). Within the standard ΛCDM framework, dark energy is generally considered a static cosmological constant with the state parameter $w = -1$. However, despite its success in fitting observations, this definition lacks a clear physical basis (Frieman et al., 2008; Copeland et al., 2007; Peebles and Ratra, 2003). In addition to this difficulty, persistent tensions in modern cosmological data (such as the Hubble tension and the σ_8 discrepancy) strongly suggest that ΛCDM may not be a complete picture (Riess et al., 2019; Verde et al., 2019; Di Valentino et al., 2021).

In this context, Unified Fractal Quantum Field Theory (UFQFT) has been proposed as a new attempt to rethink the foundations of matter, spacetime, and cosmology (Soğukpınar, 2025a; 2025b; 2025c). Recent developments include the reinterpretation of the proton spin puzzle in terms of fractal structure (Soğukpınar, 2025d), the geometric derivation of the arrow of time (Soğukpınar, 2025e), and the reformulation of gravity as a manifestation of fractal field symmetries rather than a fundamental force (Soğukpınar, 2025f). At the cosmological scale, the Φ_0–Ψ_0 fractal sea has been suggested as a common origin for ordinary matter, dark matter, and even inflationary dynamics before the Big Bang (Soğukpınar, 2025g).UFQFT further extends to particle and nuclear physics, recasting all known particles as resonance states of energy (Φ) and charge (Ψ) fields (Sogukpinar, 2025h; 2025k), while its fractal framework naturally accounts for exotic systems such as halo nuclei that lie beyond the reach of the traditional shell model (Sogukpinar, 2025l). Building on this, the Bubble-UFQFT model integrates dark energy, quantum gravity, and cosmic structure formation into a single fractal-dimensional picture of the universe (Sogukpinar, 2025b; 2025m).

In this study, we take these ideas a step further by proposing that dark matter and dark energy are not mysterious substances but instead resonance states of fundamental fractal fields within a spacetime of effective dimension D ≈ 2.70. In this view, dark matter corresponds to neutral, long-lived resonances that remain decoupled from baryonic matter because of fractal dimensional limits, while dark energy arises from unstable, non-material resonances that create negative pressure and drive cosmic acceleration. By framing both phenomena as outcomes of the same underlying field dynamics, UFQFT offers a natural explanation for the fine-tuning of Λ, the lack of direct detection, and the small-scale anomalies—pointing toward a more unified and physically grounded alternative to the standard cosmological model.

2. Theoretical Background

2.1 Unified Fractal Quantum Field Theory

Core postulates: Φ–Ψ fields on a fractal spacetime (D ≈ 2.70)

Postulate 1: Fractal Spacetime Manifold
The UFQFT framework is built upon the foundational premise that the spacetime background upon which quantum fields propagate is not a smooth, integer-dimensional manifold but possesses a fractal structure. This is characterized by its Hausdorff dimension, D, which is an effective measure of the dimension across relevant physical scales. Crucially, the theory posits a critical dimension threshold $D_c \approx 2.70$ that governs the stability and very formation of particulate matter. Standard 4-dimensional spacetime is recovered as a limiting case ($D \rightarrow 4$). The fractal nature implies a scale-dependent, self-similar geometry at microscopic scales, which modifies the dynamics of fields and the concept of a point-like particle.This fractal dimension is not static but can be an effective, scale-dependent property, emerging from a more fundamental quantum gravitational substrate. The value $D_c \approx 2.70$ is phenomenologically determined as the threshold below which stable, composite bound states (like protons and atoms) can form.

Postulate 2: The Fundamental Φ–Ψ Field Duality
UFQFT reduces the Standard Model's particle zoo to excitations of two fundamental real scalar fields defined on this fractal spacetime:

- **The Energy Field ($\Phi(x)$):** This field is associated with the energy content and mass of structures. Its excitations and amplitudes are linked to the manifestation of mass-energy.Variations in its local amplitude directly contribute to the stress-energy tensor and thus gravitation

- **The Charge Field ($\Psi(x)$):** This field is associated with charge properties and interactions. Its excitations and configurations determine the electromagnetic and other charge-related characteristics of a resonance.A nonzero value of its associated Noether charge Q_Ψ (defined below) is the source of electromagnetic interaction.

All known particles, and their hypothetical counterparts, emerge as stable, quantized resonance patterns (solitonic solutions) in this coupled Φ–Ψ system.

UFQFT posits two fundamental real scalar fields defined on a fractal spacetime of effective Hausdorff dimension $D \approx 2.70$ an energy field Φ(x) and a charge field Ψ(x). Dynamics occur with respect to an effective measure $d\mu_D(x)$ and a fractional kinetic operator $\Box_{\mathrm{D}}$ that reduce to the standard forms when D→4.

We write the action

$$S[\Phi,\Psi] = \int d\mu_D(x)\; L_D(\Phi,\Psi,\partial\Phi,\partial\Psi), \tag{1}$$

with

$$L_D = \frac{1}{2}\,\partial_\mu\Phi\,\partial_\mu\Phi + \frac{1}{2}\,\partial_\mu\Psi\,\partial_\mu\Psi - V(\Phi,\Psi) + I_D(\Phi,\Psi) \tag{2}$$

Here I_D encodes the departure from integer dimension (e.g., fractional d'Alembertian or measure corrections). A minimal representation is

$$I_D(\Phi,\Psi) = -\frac{\alpha_{\mathrm{D}}}{2}\,\Phi\,\Box_{D-4}\Phi - \frac{\beta_{\mathrm{D}}}{2}\,\Psi\,\Box_{D-4}\Psi, \tag{3}$$

where $\Box_{\mathrm{D}-4}$ is a fractional operator and α_{D},β_{D} vanish at D=4.A symmetry-respecting interaction potential capturing Φ–Ψ coupling and self-interactions is

$$V(\Phi,\Psi) = \frac{m_\Phi^2}{2}\Phi^2 + \frac{m_\Psi^2}{2}\Psi^2 + \frac{\lambda_\Phi}{4}\Phi^4 + \frac{\lambda_\Psi}{4}\Psi^4 + \frac{g}{2}\Phi^2\Psi^2 + \kappa\,\Phi\,\Psi \tag{4}$$

where g controls Φ–Ψ mixing; κ softly breaks the $\Phi \;\rightarrow\; -\Phi$, Ψ→−Ψ parity if nonzero. Euler–Lagrange equations on the fractal background read

$$\Box_D\Phi + \partial_\Phi V - \frac{\delta I_D}{\delta\Phi} = 0, \Box_D\Psi + \partial_\Psi V - \frac{\delta I_D}{\delta\Psi} = 0 \tag{5}$$

The conserved "charge" associated with Ψ (neutrality criterion) follows from the canonical momentum density

$$\pi_\Psi \equiv \frac{\partial L_D}{\partial(\partial_0\Psi)} = \partial_0\Psi, Q_\Psi \equiv \int_{\Sigma_t} d\Sigma_{D-1}\;\pi_\Psi \tag{6}$$

(where $d\Sigma_{\mathrm{D}-1}$ is the spatial slice measure). Neutral resonances satisfy Q_Ψ=0.

In UFQFT, elementary particles are stationary resonance states $\varphi_n = (\Phi_n,\Psi_n)$ solving (5) with appropriate boundary conditions. Linearizing around a background ($\bar{\Phi}$,$\bar{\Psi}$) yields the mode equation

$$K_D\,\eta = \omega^2\,\eta,\quad \eta = (\delta\Phi,\delta\Psi)^\top \tag{7}$$

with K_D the fractal fluctuation operator. Resonances correspond to discrete (or quasi-discrete) ω_{n}^2>0 satisfying a Bohr–Sommerfeld–type quantization adapted to the fractal measure,

$$\oint_\Gamma\; p_D\,dq_D = 2\pi\hbar_{eff}(D)\left(n+\frac{1}{2}\right) \tag{8}$$

where the effective phase-space element (p_D, q_D) and $\hbar_{\text{eff}}$(D) encode dimensional running. The rest mass of a resonance is identified as

$$m_n^2(D) \equiv \omega_n^2(k = 0; D) \tag{9}$$

A resonance constitutes material (baryonic/leptonic) matter if it is (i) spectrally stable, (ii) energetically bounded, and (iii) dynamically integrable into composite bound states. Sufficient criteria:

- Spectral stability: real, positive spectrum

$$\omega_n^2(D) > 0, Spec(K_D) \subset R + \tag{10}$$

- Local energetic stability: positive Hessian of the potential on the resonance orbit

$$H \equiv \begin{pmatrix} \partial^2_{\Phi\Phi}V) & \partial^2_{\Phi\Psi}V \\ \partial^2_{\Psi\Phi}V & \partial^2_{\Psi\Psi}V \end{pmatrix}_{(\Phi n, \Psi n)} \succ 0 \tag{11}$$

- Fractal dimension threshold (materialization condition):

D<D_c≃2.70 ⇒ matter-forming resonance, $D \geq D_c$ ⇒ non-material (dark) resonance. (12)

- Neutrality classification (dark-matter candidacy):

$$Q_\Psi = 0 \ and \ \omega_n^2 > 0 \Rightarrow \text{neutral, gravitationally active resonance.} \tag{13}$$

Within this scheme, the up quark, electron, and neutrino are the foundational material resonances (with D<D_c), while neutrino-like neutral resonances and other $Q_\Psi = 0$ states with D≥D_c populate the dark sector.

2.2 Limitations of the Standard Model and ΛCDM

Missing explanations for dark matter and dark energy in the ΛCDM paradigm, the background expansion is governed by (Weinberg 1989)

$$H^2(a) = \frac{8\pi G}{3}[\rho_b(a) + \rho_{dm}(a) + \rho_r(a)] + \frac{\Lambda}{3} - \frac{k}{a^2} \tag{14}$$

with ρ_{dm}an unspecified dark-matter density and Λ the cosmological constant. Standard Model (SM) quantum fields do not supply a viable particle for ρ_{dm}, nor do they resolve the vacuum energy discrepancy

$$\rho_{vac}^{QFT} \sim \frac{\hbar}{2}\sum_k \omega_k \quad vs. \quad \rho_\Lambda^{obs} = \frac{\Lambda}{8\pi G}, \tag{15}$$

which famously differs by many orders of magnitude under naive cutoffs.

UFQFT replaces these placeholders with resonance physics:

- Dark matter: neutral resonances with Q_Ψ=0, spectrally stable (ω^2>0, but non-integrable into baryonic structures (effectively D≥D_c); they interact gravitationally yet remain electromagnetically silent.

- Dark energy: non-material oscillations of the Φ–Ψ system that never cross the materialization threshold (D≥D_c and/or Hessian not positive definite for particle formation). Their net effect is a persistent tension in the stress–energy tensor:

$$\langle T_{\mu\nu}\rangle_D^{(non-mat)} = \langle \partial_\mu \Phi\, \partial_\nu \Phi + \partial_\mu \Psi\, \partial_\nu \Psi - g_{\mu\nu} L_D \rangle_{non-material\ modes}, \tag{16}$$

which acts as an effective dark-energy component with equation-of-state $w \approx -1$ if the resonance energy is potential-dominated. Neutrinos are the canonical SM neutral species: weakly interacting, Q_Ψ=0 analogs in UFQFT language. In ΛCDM+SM they contribute

$$\Omega_\nu h^2 = \frac{\sum_i m\nu_i}{93.14\, eV}, \tag{17}$$

insufficient to explain Ω_{dm} . UFQFT generalizes this by introducing an entire family of neutrino-like neutral resonances (including "minor neutral quanta" and larger neutral clusters) that can supply the required dark-matter abundance without electromagnetic signatures. For vacuum energy, SM zero-point fluctuations (15) do not match observations. In UFQFT the relevant contribution is restricted to non-material Φ–Ψ modes, yielding a renormalized effective density

$$\rho_{DE}^{UFQFT} = \frac{1}{V_D} \int d_\mu D(x)\ \langle V(\Phi,\Psi) - I_D(\Phi,\Psi)\rangle_{non-material}, \tag{18}$$

which can mimic Λ while being dynamically tied to the resonance spectrum and to D.

Persistent gaps—identity of dark matter, magnitude and nature of dark energy, and hints of large-scale anomalies—motivate a move from "unknown substances" to structural dynamics. UFQFT provides:

1. A materialization criterion (12) linking particle formation to the fractal dimension D and local stability (11).
2. A unified classification by neutrality and integrability (13), naturally producing dark-matter candidates without adding ad-hoc particles.
3. A dark-energy mechanism via non-material resonances (16)–(18), not a rigid constant but an emergent property of the Φ–Ψ sector.

In short, a fractal resonance framework reinterprets the dark sector as a spectrum of neutral and matterless modes of the same underlying fields that also generate ordinary matter—preserving unity while explaining invisibility and gravitational influence.

3. Dark Matter in UFQFT

3.1 Neutrinos as the Prototype of Neutral Resonances

The historical inference of the neutrino provides the quintessential archetype for a dark-matter candidate within the Unified Fractal Quantum Field Theory (UFQFT) framework. First postulated by Wolfgang Pauli in 1930 to explain missing energy in β-decay, and subsequently incorporated by Enrico Fermi into his theory of weak interactions, the neutrino was not discovered through direct detection but rather deduced from the conservation of energy, momentum, and angular momentum. This epistemological pathway—existence inferred from the necessity of symmetry and conservation—is precisely the principle UFQFT elevates to a universal mechanism: resonances that must exist to satisfy the fundamental symmetries of the field equations do exist.

In the Standard Model (SM), neutrinos interact only via the weak interaction and gravity. Their elusive nature arises from the extremely small weak-interaction cross section, scaling approximately as $\sigma \sim G_F^2 E^2$, where G_{F} is the Fermi constant. Within UFQFT, the neutrino is reformulated as a stable resonance solution

$$\varphi_\nu \equiv (\Phi_\nu, \Psi_\nu), \tag{19}$$

of the field equations (Eq. 5). Its defining characteristic is the vanishing Noether charge

$$Q_\Psi(\varphi_\nu) = 0 \tag{20}$$

as introduced in Eq. (6). This neutrality explains its invisibility to electromagnetic processes: it does not couple to the photon field.

Despite being a matter-forming resonance ($D_\nu < D_c \simeq 2.70$, the neutrino does not participate in the architecture of nuclei or atoms. Its weak interactions permit oscillations and production in nuclear reactions, but it contributes negligibly to baryonic structures. Thus, within UFQFT it is classified as the first and most familiar example of "ady-matter": a resonance that coexists with baryonic matter yet does not integrate into its composite structures.

3.2 Beyond Neutrinos: Fractal Resonance Families

UFQFT extends the neutrino paradigm to an entire spectrum of neutral resonances, predicted by the fractal structure of spacetime and the complexity of the Φ–Ψ potential (Eq. 4). These fall into three broad categories:

(a) Resonance Twins of Neutrinos (D≥D_c)

Fractal corrections encoded in $I_D(\Phi, \Psi)$ (Eq. 3) generate solutions structurally similar to neutrinos but shifted to higher effective Hausdorff dimension. These **"**fractal twins**"** or sterile counterparts satisfy the neutrality condition (Eq. 20) but acquire larger effective masses,

$$m^2_{\nu,twin}(D) \equiv \omega^2(k = 0; D) \gg m^2_\nu, D \geq D_c \tag{21}$$

As non-material resonances, they cannot be produced via weak interactions. Their interactions are purely gravitational, rendering them compelling candidates for cold dark matter.

(b) Small-Scale Neutral Resonances ("Minor Neutral Quanta")

The fractal Φ–Ψ potential also admits a hierarchy of low-amplitude localized solutions with masses

$$m_{minor} \ll 1\ eV \tag{22}$$

These minor neutral quanta could have been abundantly produced in the early universe. Their high number density makes them suitable contributors to hot or warm dark matter, leaving observable imprints in the Cosmic Microwave Background (CMB) and in the suppression of small-scale cosmological structures.

(c) Large-Scale Neutral Clusters

UFQFT predicts the possibility of coherent soliton-like clusters of Φ–Ψ oscillations—macroscopic, stable resonances that manifest as galactic or sub-galactic halos. Their gravitational potential is determined by the stress–energy tensor of the cluster solution $\varphi_{halo}(x)$:

$$\nabla^2\Phi_{grav} = 4\pi G \langle\, 0 \mid T_{00}(\varphi_{halo}) \mid 0 \,\rangle \tag{23}$$

where T_{00} is derived from the Lagrangian (Eq. 2). These large-scale resonances provide a natural theoretical basis for the dark matter halos inferred from galactic rotation curves.

3.3 Properties of UFQFT Dark Matter

The UFQFT framework yields a distinctive characterization of dark matter, setting it apart from conventional candidates such as weakly interacting massive particles (WIMPs). All UFQFT dark matter candidates satisfy

$$Q_{\Psi} = 0 \tag{24}$$

ensuring decoupling from the electromagnetic field. The UFQFT framework provides a distinct characterization of dark matter, fundamentally differentiating it from conventional candidates like WIMPs. At its core, all UFQFT dark matter candidates are defined by their inherent neutrality, meaning they do not possess the necessary charges to interact via electromagnetic or nuclear forces. Their influence on the universe is solely gravitational, a direct consequence of their energy content warping spacetime. This isn't a matter of being "hard to detect"—it's a fundamental feature of their existence.

UFQFT introduces the concept of ady-matter to describe this state. Ady-matter coexists with the ordinary matter that makes up stars and planets, but it remains completely separate, unable to integrate into atoms or molecules. It is present, influential through gravity, yet forever isolated, a direct result of existing in a state just beyond the threshold required to become "real" particulate matter.

This perspective naturally solves key cosmological puzzles. The gravitational pull of large-scale ady-matter clusters elegantly explains the flat rotation curves of galaxies without invoking exotic particles. Furthermore, the theory predicts a spectrum of ady-matter, from heavy, slow-moving components that seed galaxy formation to lighter, faster-moving ones that prevent an overabundance of small dwarf galaxies. Most importantly, it explains why decades of sophisticated experiments have found nothing: there are no particles to collide with. The only way to confirm ady-matter is through its gravitational signature—by mapping its invisible hand shaping the cosmos on the largest scales. In this view, dark matter is not an missing puzzle piece from the Standard Model, but a necessary and natural feature of a universe built on fractal fields.

4. Dark Energy in UFQFT

4.1 Definition: Non-Material Resonances

Within UFQFT, dark energy is identified with the ensemble of non-material resonance solutions of the coupled field system (Φ,Ψ) These solutions satisfy the equations of motion (Eq. (5)) but fail one or more materialization/stability criteria from Section 2 (e.g., D≥D_c from Eq. (12), non-positive Hessian from Eq. (11), or spectral instability). The equations of motion may be written schematically as

$$\Box_D \Phi + \frac{\partial V}{\partial \Phi} + \frac{\delta I_D}{\delta \Phi} = 0, \Box_D \Psi + \frac{\partial V}{\partial \Psi} + \frac{\delta I_D}{\delta \Psi} = 0 \tag{25}$$

where $\Box_D$ and I_D encode the fractal-dimensional dynamics (see Eqs. (1)–(5)). We decompose the full field configurations into material, dark-matter, and dark-energy sectors:

$$\Phi(x) = \Phi_m(x) + \Phi_{dm}(x) + \Phi_{de}(x),\ \Psi(x) = \Psi_m(x) + \Psi_{dm}(x) + \Psi_{de}(x) \tag{26}$$

Here (Φ_{de}, Ψ_{de}) denote the non-material resonances: modes that (a) typically have effective dimension D≥D_c, (b) lack a positive-definite Hessian H on their orbit, or (c) present complex/imaginary spectral components $\omega^2 < 0$ (delocalized or tachyonic behaviour), preventing particle formation.

4.2 Energetic Role in Cosmic Expansion

The contribution of these modes to spacetime curvature is given by their stress–energy tensor. From the UFQFT Lagrangian (Eq. (2)),

$$T_{\mu\nu}[\Phi,\Psi] = \partial_\mu\Phi\,\partial_\nu\Phi + \partial_\mu\Psi\,\partial_\nu\Psi - g_{\mu\nu}\left(\frac{1}{2}\partial\alpha\Phi\partial^\alpha\Phi + \frac{1}{2}\partial\alpha\Psi\partial^\alpha\Psi - V(\Phi,\Psi) + I_D(\Phi,\Psi)\right) \tag{27}$$

Restricting the expectation value to the non-material sector defines the effective dark-energy stress–energy:

$$\langle T_{\mu\nu}\rangle_{DE} \equiv \langle T_{\mu\nu}[\Phi_{de},\Psi_{de}]\rangle \tag{28}$$

For a spatially homogeneous and isotropic background (Friedmann–Lemaître–Robertson–Walker), the effective energy density and pressure attributed to the non-material resonances are

$$\rho_{DE} \equiv \langle T_{00}\rangle_{DE} \approx \langle V(\Phi,\Psi) - I_D(\Phi,\Psi)\rangle_{non-material} \tag{29}$$

$$p_{DE} \equiv \frac{1}{3}\sum_{i=1}^{3}\langle T_{ii}\rangle_{DE} \approx -\langle V(\Phi,\Psi) - I_D(\Phi,\Psi)\rangle_{non-material} = -\rho_{DE} \tag{30}$$

where the approximations assume kinetic terms of the non-material modes are subdominant on cosmological scales (diffuse/delocalized modes). From (29)–(30) we obtain the equation-of-state parameter

$$w \equiv \frac{pDE}{\rho DE} \approx -1 \tag{31}$$

recovering the observed behaviour of dark energy while providing a dynamical microscopic origin.

Two points of contrast with the cosmological constant are immediate:

1. Dynamical origin: ρ_{DE} in UFQFT depends on field dynamics and on the fractal interaction term I_{D}; it can evolve if the spectral composition or the effective dimension D evolves.
2. Microscopic basis: Unlike a bare Λ , ρ_{DE} is derived from the same Φ–Ψ sector that produces material and dark-matter resonances; this recasts fine-tuning questions into the parameter space of V(Φ,Ψ) and the dimensional flow of D.

If the fractal dimension evolves slowly with cosmic time, D=D(t), the dark-energy density inherits a time dependence:

$$\rho_{DE}(t) \approx \langle V(\Phi,\Psi) - I_D(t)(\Phi,\Psi)\rangle_{non-material} \tag{32}$$

which permits departures from a pure constant $w = -1$ and yields potential observational signatures (see Section 5.2).

4.3 Conceptual and Metaphorical Interpretation

UFQFT prompts a reclassification of ontological status in physics. Non-material resonances are *real* field configurations with gravitational influence yet devoid of particle attributes (charge, localized mass eigenstate, well-defined spin). Calling this state **"**matterless existence**"** highlights that reality in UFQFT spans a continuum:

- Material resonances: stable, localized, particle-forming ($D < D_c, H \succ 0,\ \omega^2 > 0$).
- Neutral non-material resonances (dark matter): stable but non-integrated (Q_Ψ=0, typically spectrally real, $D \geq Dc$).
- Unstable/diffuse non-material resonances (dark energy): delocalized, potential-dominated, $w \approx -1$.

A metaphorical analogy—e.g., with cultural concepts of unseen agencies—serves pedagogically to communicate that physical reality can include influential, non-particulate sectors. This analogy should be understood as heuristic rather than ontological claim.

By identifying dark energy with non-material resonances of the Φ–Ψ system, UFQFT provides a field-theoretic, fractal-geometric account of cosmic acceleration. Equations (25)–(32) show how the same fundamental sector that generates particles and dark matter naturally yields a vacuum-like energy density: a dynamical, physically grounded alternative to a bare cosmological constant, with clear avenues for observational tests (time evolution of w, spectral imprints tied to dimensional flow, and correlations with fractal-dependent resonance spectra).

5. Comparative Analysis

5.1 UFQFT vs. ΛCDM Predictions

The Unified Fractal Quantum Field Theory (UFQFT) and the standard ΛCDM framework provide fundamentally distinct ontological accounts of the dark sector, which propagate into different phenomenological predictions.

1. Nature of Dark Matter: Particles vs. Resonances

a.ΛCDM

Dark matter is postulated to consist of discrete, weakly interacting particles—typically WIMPs or axions—that behave as a collisionless, pressureless fluid. Their dynamics follow the collisionless Boltzmann equation within gravitational potentials. The benchmark prediction for direct detection is a differential nuclear recoil spectrum(Bertone 2005):

$$\frac{dR}{dE_R} = \frac{N_T \rho_0 \sigma}{2m_{dm}\mu^2} F^2(E_R) \int_{v_{min}}^{v_{max}} \frac{f(v)}{v} dv \tag{33}$$

where N_{T} is the number of target nuclei, ρ_0 the local DM density, σ the DM–nucleon cross-section, m_{dm} the DM mass, μ the reduced mass, F(E_{R}) the form factor, and f(v) the velocity distribution.

b.UFQFT

In contrast, UFQFT identifies dark matter not as particles but as a spectrum of neutral (Q_{Ψ}=0), non-material (D≥D_c) resonances of the fundamental (Φ,Ψ) fields. These include "minor neutral quanta," heavier "fractal twins," and macroscopic solitonic clusters. Because such resonances lack gauge charges, their direct interaction cross-section with baryonic matter vanishes identically:

$$\sigma_{UFQFT} \equiv 0(\text{beyond gravity}) \tag{34}$$

a sharp contrast with the finite σ expected in WIMP-based ΛCDM. As a consequence, UFQFT predicts a complete absence of nuclear recoil events in underground direct detection experiments, while still accounting for astrophysical signatures of dark matter through gravitational clustering.

2. Nature of Dark Energy: Constant vs. Resonances

a.ΛCDM

Dark energy is modeled as a pure cosmological constant Λ, with fixed equation of state

$$\rho_\Lambda = \frac{\Lambda c^2}{8\pi G}, w_\Lambda \equiv \frac{p\Lambda}{\rho\Lambda} = -1 \tag{35}$$

This quantity is constant in both space and time.

b.UFQFT

By contrast, UFQFT attributes dark energy to the energy density of non-material resonances (see Sec. 4). Its effective equation of state can deviate from -1 if the spectral composition of the resonances evolves:

$$w(a) = -1 + \frac{1}{3}\frac{dln\,\delta_{DE}}{dln\,a} \tag{36}$$

where $\delta_{DE} \equiv \delta\rho_{DE}/\rho_{DE}$ is the fractional density perturbation and a the scale factor. Since ρ_{DE} depends on the fractal dimension D(t) and the vacuum expectation value of V$-I_{\mathrm{D}}$, UFQFT generically predicts mild dynamics in w(z), in contrast to ΛCDM's static -1.

3. Testable Differences

Key observational discriminants include:

- **Direct Detection:** Persistent null results (XENONnT, LZ) are a natural UFQFT outcome but increasingly problematic for WIMP ΛCDM.
- **Dark Energy Dynamics:** Evidence for $w \neq -1\ or\ dw/dz \neq 0$ (e.g. from DESI, Euclid) would support UFQFT's dynamic resonance picture.
- **Dark Matter Properties:** Signs of self-interaction, wave-like behaviour, or solitonic cores in dwarf galaxies align with UFQFT's resonance-based dark matter rather than ΛCDM's collisionless particle fluid.

5.2 Observational Signatures

1. Neutrino Oscillation Anomalies

Several anomalies (LSND, MiniBooNE, reactor antineutrinos) suggest sterile neutrinos. In UFQFT these arise naturally as fractal twins of neutrinos. The extended oscillation probability reads

$$P(\nu_e \to \nu_\mu) = \delta e\mu - 4\textstyle\sum_{i>j} \Re\,(U_{ei}U_{\mu i}^{*}U_{ej}^{*}U_{\mu j})sin^2\,(\frac{\Delta m_{ij}^2 L}{4E}) \tag{37}$$

where $U_{\alpha\mathrm{i}}$ is the extended PMNS matrix including sterile states, with masses tied to the fractal dimension spectrum:

$$m_{sterile}^2 \propto \omega^2(D), D \geq D_c \tag{38}$$

This link provides a natural UFQFT explanation for the observed mass-squared splittings.

2. CMB Large-Scale Anomalies

The CMB exhibits anomalies at low multipoles (ℓ) inconsistent with isotropic ΛCDM inflation. In UFQFT, spatial fluctuations of the non-material dark energy field Φ_{de}(x) generate additional isocurvature contributions:

$$C_\ell^{total} = C_\ell^{adi} + C_\ell^{iso} + C_\ell^{corr} \tag{39}$$

where C_ℓ^{iso} stems from dark energy resonance inhomogeneities. This mechanism provides a testable signature of UFQFT beyond ΛCDM.

3. Gravitational Lensing and Structure Formation

UFQFT predicts a structured dark sector with distinctive imprints on lensing and the matter power spectrum P(k).

- **Wave-like Suppression:** Ultra-light "minor quanta" ($m \sim 10^{-22}$ eV) produce a small-scale cutoff:

$$k_{cut-off} \simeq \left(\frac{m}{2\hbar}\right)^{\frac{1}{2}} H_0 \, \Omega_m^{\frac{1}{4}} \tag{40}$$

suppressing dwarf galaxy formation and addressing the "missing satellites" problem.

- **Solitonic Cores:** Resonant solitons generate cored density profiles in galaxies:

$$\rho_{sol}(r) \approx \rho_0 \left[1 + 0.091 \left(\frac{r}{r_c}\right)^2\right]^{-8} \tag{41}$$

consistent with observed dwarf spheroidal rotation curves, unlike NFW cusps.

- **Strong Lensing Substructure:** UFQFT predicts granular interference patterns in halo substructure, yielding distinct strong-lensing anomalies detectable with JWST/HST.

ΛCDM and UFQFT differ at every level: ontology (particles vs. resonances), dynamics (constant vs. evolving dark energy), and phenomenology (direct detection, neutrino physics, CMB, lensing). Equations (33)–(41) formalize the predictions, which will be stringently tested in the next decade by DESI, Euclid, CMB-S4, Rubin Observatory, and JWST.

Conclusion

This paper has presented the Unified Fractal Quantum Field Theory (UFQFT) as a comprehensive framework for explaining the dark sector of the universe. By positing a fractal spacetime background with a critical Hausdorff dimension of $D_c \approx 2.70$ and two fundamental scalar fields—the energy field Φ and the charge field Ψ—UFQFT offers a unified origin for both ordinary and dark matter. The theory reinterprets elementary particles as stable resonance patterns within this system, with their properties dictated by stability criteria and the fractal dimension at their scale.

The UFQFT-based explanation for dark matter is that it consists of a spectrum of neutral ($Q_\Psi = 0$), non-material ($D \geq D_c$) resonances of the Φ–Ψ fields. This includes neutrino-like fractal twins, minor neutral quanta, and large-scale clusters. This formulation naturally accounts for its gravitational influence and its pervasive yet elusive nature, explaining the null results from direct detection experiments not as a failure of observation but as a fundamental consequence of its non-integrable, ady-state existence. Dark energy, in turn, is explained not as a cosmological constant but as the latent energy of non-material oscillations—resonances that failed to achieve the coherence required to become particulate matter. This results in a persistent, negative-pressure tension in the spacetime fabric that drives accelerated expansion. Thus, UFQFT demystifies the dark sector by deriving it from the same underlying principles and fields as ordinary matter, presenting a cosmos where darkness is not a substance but a state of existence dictated by the fractal geometry of the vacuum.

The true test of UFQFT lies in its integration with next-generation cosmological observations. The theory makes definitive, testable predictions that will be probed by ongoing and future missions. The Dark Energy Spectroscopic Instrument (DESI) and the Euclid space telescope will provide unprecedented constraints on the equation-of-state of dark energy w(z). UFQFT predicts the possibility of dynamic evolution in *w*, a clear signature that would distinguish it from a static cosmological constant. Furthermore, these surveys, along with projects like the Vera C. Rubin Observatory's Legacy

Survey of Space and Time (LSST), will map the matter distribution of the universe with exquisite detail. The specific suppression of small-scale structure and the potential presence of solitonic cores in dark matter halos predicted by UFQFT's resonance spectrum will be confronted with this data. Finally, future CMB-S4 observations will scrutinize the large-scale anomalies in the Cosmic Microwave Background, searching for the tell-tale signs of isocurvature perturbations that could be seeded by inhomogeneities in the UFQFT dark energy field.

Despite its promise, UFQFT opens several avenues for further research and faces open problems. A primary task is the formal development of the fractal field theory formalism, particularly a rigorous mathematical definition of the fractional operators and measure $d\mu_D$ in a cosmological context. The origin of the critical dimension $D_c \approx 2.70$ must be derived from first principles within the theory, rather than being set phenomenologically. Furthermore, a detailed numerical simulation of structure formation under the influence of a spectrum of UFQFT dark matter resonances is essential to generate precise, quantitative predictions for the matter power spectrum and halo properties. Finally, the theory must eventually be reconciled with, or derived from, a theory of quantum gravity, exploring how the effective fractal dimension D emerges from the dynamics of spacetime itself.

In conclusion, UFQFT moves beyond the standard practice of populating the universe with ad-hoc particles and constants. Instead, it proposes a profound shift in understanding: the dark universe is not made of unknown *things* but is composed of the unmet *potential* of the known fields, its character shaped by the fractal geometry of spacetime. It is a theory that seeks not just to describe the contents of the cosmos, but to explain why those contents must exist in the forms that they do. By attributing the properties of the dark sector to the foundational principles of resonance and dimensionality, UFQFT provides a powerful, unified, and ultimately more elegant narrative for the composition and evolution of the universe.

References

Aprile, E., et al. “Dark Matter Search Results from a One Ton-Year Exposure of XENON1T.” *Physical Review Letters*, vol. 121, no. 11, 2018, 111302.

Bertone, Gianfranco, et al. “Particle Dark Matter: Evidence, Candidates and Constraints.” *Physics Reports*, vol. 405, no. 5–6, 2005, pp. 279–390.

Bullock, J. A. M. E. S. "Notes on the missing satellites problem." Local Group Cosmology 20 (2013): 95.

Copeland, Edmund J. "Dynamics of dark energy." AIP Conference Proceedings. Vol. 957. No. 1. American Institute of Physics, 2007.

Del Popolo, Antonino, and Morgan Le Delliou. “Small Scale Problems of the ΛCDM Model: A Short Review.” *Galaxies*, vol. 5, no. 1, 2017, p. 17.

Di Valentino, Eleonora, et al. “In the Realm of the Hubble Tension—A Review of Solutions.” *Classical and Quantum Gravity*, vol. 38, no. 15, 2021, 153001.

Frieman, Joshua A., Michael S. Turner, and Dragan Huterer. "Dark energy and the accelerating universe." Annu. Rev. Astron. Astrophys. 46.1 (2008): 385-432.

Martin, Jérôme. “Everything You Always Wanted to Know About the Cosmological Constant Problem (but Were Afraid to Ask).” *Comptes Rendus Physique*, vol. 13, no. 6–7, 2012, pp. 566–665.

Moore, Ben. “Evidence against Dissipative Dark Matter from Observations of Galaxy Halos.” *Nature*, vol. 370, 1994, pp. 629–631.

Peebles, P. J. E., and Bharat Ratra. “The Cosmological Constant and Dark Energy.” *Reviews of Modern Physics*, vol. 75, no. 2, 2003, p. 559.

Riess, Adam G., et al. “Large Magellanic Cloud Cepheid Standards Provide a 1% Foundation for the Determination of the Hubble Constant and Stronger Evidence for Physics beyond ΛCDM.” *The Astrophysical Journal*, vol. 876, no. 1, 2019, 85.

Sogukpinar, H. (2025a). *Unified Fractal Quantum Field Theory (UFQFT): Matter as Geometric Resonances of Unified Energy-Charge Fields*. Engineering Archive

Sogukpinar, H. (2025b). *The Bubble-UFQFT Framework: Unifying Quantum Gravity, Dark Energy, and Cosmological Structure*. Engineering Archive.

Sogukpinar, H. (2025c). *The Bubble Theory of the Universe: A Quantum Fluid Perspective on Cosmological Emergence*. Engineering Archive.

Sogukpinar, H. (2025d). *Proton Spin Structure Reinterpreted through UFQFT*. Engineering Archive.

Sogukpinar, H. (2025e). *What is Time: Deriving the Arrow of Fractal Spacetime Framework from UFQFT*. Engineering Archive.

Sogukpinar, H. (2025f). *Gravity and Gravitation in UFQFT: An Emergent Phenomenon from Fractal Field Symmetry*. Engineering Archive.

Sogukpinar, H. (2025g). *The* Φ_0–Ψ_0 *Fractal Sea of Pre-Big Bang Universe : A Unified Origin of Matter, Dark Matter, and Cosmic Inflation from UFQFT*. Engineering Archive.

Sogukpinar, H. (2025h). *A Fractal Framework for Elementary Particle Hierarchy*. Engineering Archive.

Sogukpinar, H. (2025k). *Fractal Geometry in Atomic Nuclei: A New Paradigm for Nuclear Structure and Decay*. Engineering Archive.

Sogukpinar, H. (2025l). *HALO Nuclei Beyond the Shell Model: A Fractal-Dimensional Approach*. Engineering Archive.

Sogukpinar, H. (2025m). *Fractal Quantum Architecture of Matter: A Unified Framework for Particle Physics*. Engineering Archive

Steinhardt, Paul J. “Critical Problems in Physics.” *Princeton University Press*, 1997.

Verde, Licia, Tommaso Treu, and Adam G. Riess. "Tensions between the early and late Universe." Nature Astronomy 3.10 (2019): 891-895.

Weinberg, Steven. “The Cosmological Constant Problem.” *Reviews of Modern Physics*, vol. 61, no. 1, 1989, p. 1.

Zlatev, Ivaylo, et al. “Quintessence, Cosmic Coincidence, and the Cosmological Constant.” *Physical Review Letters*, vol. 82, no. 5, 1999, p. 896.