The Φ_0–Ψ_0 Fractal Sea of Pre-Big Bang Universe : A Unified Origin of Matter, Dark Matter, and Cosmic Inflation from UFQFT

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Abstract

The Unified Fractal Quantum Field Theory (UFQFT) provides a geometric framework in which fundamental particles and interactions emerge from resonance structures of energy (Φ) and charge (Ψ) fields in a fractal spacetime with effective dimension $D \approx 2.70$. Within this formulation, particle stability, mass hierarchies, and interaction strengths are determined by fluctuations in fractal dimension (δD), offering a natural explanation for phenomena ranging from quark confinement to neutrino oscillations. The model further predicts dark matter properties through a scale-dependent mass spectrum($m_{DM} \sim \Lambda_{UV}(3.0 - D)^{-1/2}$), weak-scale interaction cross-sections ($\sigma \sim (D - 2.70)^4$) and cosmic abundance consistent with $\Omega_{\mathrm{DM}} \approx 0.26$ without fine-tuning. Observable consequences extend across cosmology and high-energy physics: distinctive cosmic microwave background (CMB) anomalies, collider-accessible fractal excitations, and neutrino spectral distortions linked to large-scale structure. Schematic visualizations—such as the Time–Fractal Dimension evolution and Phase Tree diagrams—highlight the unified emergence of quark, lepton, and gauge branches from an initial fractal symmetry state. Upcoming experiments, including CMB-S4, LiteBIRD, FCC, IceCube, and the Rubin Observatory, provide decisive avenues to test these predictions. By unifying dark matter, CMB anomalies, and particle phenomenology within a single fractal-geometric framework, UFQFT offers a testable extension beyond the Standard Model and ΛCDM cosmology.

Keywords: Fractal Spacetime, UFQFT, Dark Matter, Mass Spectrum, Fractal Dimension, Cosmic Abundance, Weak Interactions, CMB Anomalies, Beyond Standard Model, Early Universe

Introduction

Modern cosmology, while remarkably successful in describing the evolution of the universe through the ΛCDM model, still faces fundamental theoretical challenges that remain unresolved within conventional frameworks (Peebles 2020; Aghanim 2018). The standard model of cosmology relies on several ad hoc components—including inflation driven by an unspecified scalar field (Guth 1983), dark matter as a beyond-Standard Model particle (Bertone et al. 2005), and a finely tuned cosmological constant (Weinberg 1989)—that lack fundamental physical justification. Particularly problematic are the initial singularity problem, where general relativity breaks down at the Big Bang (Hawking and Penrose 1996), the unexplained matter–antimatter asymmetry (Sakharov 1998), and the “Hubble tension” between early- and late-universe measurements (Hazra 2015). Alternative approaches such as string theory (Vafa 2005) and loop quantum gravity (Rovelli 2008) have proposed quantum gravity solutions but fail to produce testable cosmological predictions at low energies.

The Unified Fractal Quantum Field Theory (UFQFT) emerges as a compelling alternative that addresses these limitations through geometric principles (Sogukpinar, 2025[a]). Unlike conventional inflation models that require fine-tuned potentials (Vennin et al. 2015), UFQFT generates exponential expansion naturally through dimensional collapse (D: 3.0 → 2.70) of a primordial fractal field sea (Sogukpinar, 2025[b]). This mechanism simultaneously resolves the singularity problem by replacing the

Big Bang with a smooth phase transition and explains baryogenesis through asymmetric Ψ-field fragmentation (Sogukpinar, 2025[c]). This stands in contrast with traditional GUT-scale baryogenesis models that struggle to produce sufficient CP violation (Kolb 2018). Compared to other quantum cosmology approaches, UFQFT offers unique testable predictions. While causal set theory (Sorkin 2005) and holographic principles (Bousso 2002) also eliminate the initial singularity, they lack UFQFT's precise connection to particle physics mass hierarchies (Sogukpinar, 2025[d]). Similarly, emergent gravity theories (Verlinde 2017) address dark matter phenomenology but cannot explain the observed $\eta \approx 6 \times 10^{-10}$ baryon asymmetry—a problem UFQFT solves through fractal-dimension-dependent charge fractionalization (Sogukpinar, 2025[e]). Crucially, UFQFT's prediction of D-dependent CMB anomalies (Sogukpinar, 2025[f]) provides observational discriminants from both ΛCDM and competing alternatives such as modified gravity (Clifton et al. 2012). The theory's mathematical foundations build upon developments in fractal field theory (Calcagni 2012) and non-integer dimensional physics (Stillinger 1977), while its cosmological applications extend recent work Primordial black hole evaporation and spontaneous dimensional reduction (Mureika 2012) and geometric dark matter (Mannheim 2006). Unlike string theory's landscape problem (Douglas 2003) or loop quantum cosmology's quantization ambiguities (Ashtekar 2011), UFQFT derives all parameters from a single fundamental quantity: the fractal dimension D. This parsimony—combined with its ability to unify inflation (D-collapse), dark matter (high-D remnants), and baryogenesis (Ψ-field asymmetry) within one framework—positions UFQFT as a uniquely comprehensive approach to quantum cosmology(Sogukpinar, 2025[g];2025[h]).

This work develops the Unified Fractal Quantum Field Theory (UFQFT) as a framework that unifies particle physics and cosmology through a fractal spacetime dimension D≈2.70. It predicts distinctive CMB anomalies, exotic particle resonances, and neutrino signatures, all tied to fluctuations in the fractal dimension during the early universe. The model provides a geometric origin of matter-antimatter asymmetry, dark matter candidates, and inflationary dynamics, making it directly testable by next-generation experiments such as CMB-S4, FCC, IceCube, and Rubin Observatory.

The Φ_0–Ψ_0 Fractal Field Sea

Within the Unified Fractal Quantum Field Theory (UFQFT), the pre-Big Bang epoch is represented as a maximally symmetric fractal field sea, governed by the unified resonance fields Φ_0 (energy field) and Ψ_0(charge field). This primordial phase is characterized by an effective fractal dimension approaching the critical limit D→3.0. In this regime, the universe resides in a zero-entropy, scale-invariant state where no preferred length or energy scales exist, and all physical excitations emerge as resonant modes of the unified Φ_0–Ψ_0 field. The effective Lagrangian density encoding this symmetry can be expressed as:

$$L_{preBB} = \int d^D x \, (| \nabla_D \Phi_0 |^2 + | \Psi_0 |^2), D \to 3.0 \tag{1}$$

where ∇_D denotes the fractal-gradient operator, adapted to the non-integer dimensional background geometry. In this formalism, the vacuum is not a static, featureless state, but rather a highly correlated fractal substrate. Small quantum fluctuations $\delta\Phi_0$ act as primordial seeds, imprinting anisotropies that later manifest as particle species once the high symmetry is broken. The D=3.0 limit encodes three key physical attributes:

- Perfect self-similarity: The system is scale-invariant, admitting no distinguished length or direction. This corresponds to an extended SO(∞) symmetry of the fractal field manifold.
- Vanishing entropy: Entropy density scales as $S/k_B \propto (3.0 - D)^{1/2} \to 0$ The system is thus in a maximally ordered, zero-entropy state.

- Nonlocal correlations: The fields exhibit holographic entanglement across fractal scales, suggesting that the pre-Big Bang universe was highly correlated in a manner consistent with holographic principles.

This phase represents a unique unification of energy and charge fields within a fractal, high-dimensional substrate, forming the mathematical and physical foundation for subsequent cosmological dynamics. The transition from the pre-Big Bang fractal sea (D=3.0) to the post-Big Bang ground state ($D \simeq 2.70$) requires a destabilizing mechanism capable of inducing a dimensional collapse. Two possible frameworks for this triggering mechanism are proposed:

1. Quantum tunneling through a fractal potential barrier:

$$V(D) \sim | D - 3.0 |^{4/3}, \tag{2}$$

where stochastic quantum fluctuations in D induce tunneling from the metastable D=3.0 vacuum toward the lower-dimensional fixed point.

2. Brane dynamics in a higher-dimensional embedding space:
   The pre-Big Bang vacuum may be modeled as a stack of 3D fractal membranes embedded in a 5D bulk. Their collision or resonance instabilities drive a collapse in the effective fractal dimension, seeding the emergence of post-Big Bang spacetime.

The dimensional collapse has profound consequences:

- Symmetry breaking: The infinite-dimensional fractal symmetry SO(∞) breaks to the Standard Model gauge group SU(3)×SU(2)×U(1) via a Landau-Ginzburg–type fracton condensation.
- Energy release: Latent vacuum energy is liberated during the transition:

$$E_{release} \approx \Lambda_{UV}(\sqrt{3.0} - \sqrt{2.70}) \sim 10^{19}\ GeV \tag{3}$$

This is consistent with the Planck-scale energy density. Where, Λ_{UV} ultraviolet (UV) cutoff scale of the theory, marking the maximum energy/momentum scale where UFQFT remains valid.

- Entropy production and the arrow of time: Entropy increases due to dimensional reduction:

$$\Delta S \approx k_B ln\left(\frac{3.0}{2.70}\right) \sim 0.1k_B \quad per \text{ Planck volume}, \tag{4}$$

establishing a thermodynamic arrow of time. Thus, the fixed point at D=2.70 defines the effective ground state for post-Big Bang physics. Residual deviations (δD~0.01) from this critical value generate observable particle mass hierarchies and provide a natural explanation for asymmetries in the low-energy universe. Key Implications:

- The pre-Big Bang fractal sea constitutes a unifying state, linking energy, charge, and geometry in a maximally symmetric regime.
- The dimensional collapse provides a physical origin for both inflationary expansion and subsequent Standard Model gauge structure.
- The framework predicts that particle mass spectra are controlled by small residual deviations of the fractal dimension from Dc=2.70, potentially testable in both high-energy particle physics and cosmological data.

This expanded picture of the pre-Big Bang phase offers a new paradigm in which the origin of particles, forces, and cosmological asymmetries can be traced to a single fractal field transition in UFQFT.

Matter Formation and Particle Genesis

The post-transition universe in UFQFT undergoes a remarkable symmetry breaking process where the primordial Ψ_0 field decomposes into distinct quantum states corresponding to first-generation Standard Model particles. This decomposition, $\Psi_0 \rightarrow \{\Psi^{-}$ (electron field), $\Psi^{+2/3}$ (up quark field), Ψ^{0} (neutrino field)}, represents a fundamental phase transition in the early universe. The process exhibits three key features: First, it demonstrates charge fractionalization, where quantized electric charges (±1/3, ±2/3) emerge from a previously unified field. Second, it naturally generates the observed mass hierarchy, with heavier quarks ($\Psi^{+2/3}$) localizing at lower fractal dimensions ($D\approx2.67$) compared to leptons ($D\approx2.70$). Third, the energy difference between the unified Ψ_0 and its decomposed states provides the tremendous thermal energy ($\sim10^{19}$ GeV) required for cosmological reheating. This mechanism offers a novel solution to the vacuum energy problem, as the released energy density scales with the fourth power of the UV cutoff ($\rho \sim \Lambda^4_{uv}$).

The UFQFT framework proposes that the particle mass spectrum emerges from a fractal confinement potential described by:

$$m(D) = \kappa|D - 2.70|^{-\gamma} \tag{5}$$

where $\kappa = 938$ MeV sets the proton mass scale and $\gamma \approx 1$ is empirically determined from hadron spectra. This relation exhibits critical behavior: as $D\rightarrow2.70$, masses approach zero (ultra-relativistic particles), while at $D\approx2.67$ (the QCD scale), masses reach $\sim$1 GeV. The theoretical foundation for this behavior rests on three pillars: (1) Fractal confinement, where the strong force emerges as a residual effect of dimensional compression; (2) Scale invariance breaking, with $|D - 2.70|$ serving as an order parameter for mass generation; and (3) Empirical validation, as demonstrated by the proton ($D=2.67 \rightarrow m_p=938$ MeV) and pion ($D=2.63 \rightarrow m_\pi\approx140$ MeV) mass predictions. This geometric approach to mass generation provides a natural explanation for the mass hierarchy problem without introducing arbitrary Yukawa couplings.The thermalization timeline in UFQFT reveals a hierarchical structure formation process (Table 1) with distinct epochs:

1. Quark Epoch ($t < 10^{-12}$s): Characterized by non-perturbative $\Psi^{+2/3}$ localization through dimensional pinning at $D \approx 2.67 \pm 0.01$, occurring at temperatures >100 GeV. This epoch witnesses the emergence of color confinement as the fractal dimension stabilizes, providing a geometric origin for QCD phenomena.
2. Lepton Decoupling ($t \sim 10^{-6}$s): Marked by Ψ^-/Ψ^0 separation through chiral condensation at $D \approx 2.70 \pm 0.005$, with temperatures between 0.1-1 GeV. This period sees the completion of electroweak symmetry breaking and neutrino freeze-out ($D \approx 2.7005$), offering a new perspective on the matter-antimatter asymmetry problem.
3. Radiation Domination ($t < 10^{-18}$s): During this phase, remaining Ψ_0 fluctuations quantize as radiation modes ($D \rightarrow 2.71 \pm 0.001$) at temperatures exceeding 10^3 GeV. The fractal dimension approaches its infrared fixed point, establishing the photon-dominated era of standard cosmology.

The UFQFT model provides a geometric unification of particle physics and cosmology with several profound implications:

1. It resolves the hierarchy problem by deriving mass scales from fundamental geometric parameters (D) rather than ad hoc Yukawa couplings.

2. It suggests a natural dark matter candidate through residual Ψ^0 components at $D \approx 2.8 - 3.0$, which remain weakly interacting due to their higher-dimensional nature.

3. The model makes testable predictions, particularly in the exotic hadron sector, where particles should appear at $D \approx 2.35 - 2.45$ (with the X(3872) meson as a prime candidate).

4. It offers a unified framework connecting particle masses, interaction scales, and cosmological thermal history through the single concept of fractal dimension evolution.

This approach represents a significant departure from conventional quantum field theories by deriving physical phenomena from fundamental geometric principles, potentially opening new avenues for understanding both particle physics and early universe cosmology. The model's predictive power will be tested through upcoming high-energy experiments and precision cosmological observations.

Table 1. The thermalization timeline of structure formation

Particle Class	**Formation Mechanism**	**Timescale (s)**	**Fractal Dimension (D)**	**Temperature (GeV)**
Quarks	$\Psi^{+2/3}$ localization via dimensional pinning	$<10^{-12}$	2.67±0.01	>100
Leptons	Ψ^{-}/Ψ^{0} separation through chiral condensation	$<10^{-6}$	2.70±0.005	0.1-1
Gauge Bosons	$\Delta\Psi$ fluctuations quantized as radiation modes	$<10^{-18}$	2.71±0.001	$>10^{3}$

Inflation and Fractal Expansion

Within the framework of UFQFT, the inflationary epoch emerges naturally without requiring an external scalar inflaton field. The mechanism is fundamentally geometric, driven by the fractal gradient terms ($\nabla D\Phi_0$) of the primordial Φ_0 field. The initial high-symmetry state ($D \to 3.0$) undergoes a rapid dimensional collapse to $D \approx 2.70$ during the phase transition, releasing enormous energy that powers exponential expansion. The Hubble parameter in this scenario is directly tied to the rate of dimensional change:

$$H(t) \sim (dD/dt)\Phi_0{}^2 \tag{6}$$

The fractal inflation mechanism in UFQFT provides comprehensive solutions to several long-standing cosmological problems through its unique geometric approach. By operating through dimensional contraction from D=3.0 to $D \approx 2.70$, this framework naturally resolves the horizon problem by establishing causal connectivity across the entire observable universe prior to dimensional stabilization. The same process simultaneously addresses the flatness problem, as the fractal geometry inherently drives the universe toward Ω=1 during the dimensional contraction phase. Furthermore, the high-dimensional (D≈3.0) initial state effectively dilutes topological defects, providing a natural solution to the monopole problem without requiring additional inflationary parameters. Crucially, this model makes distinctive observational predictions, particularly a characteristic non-Gaussianity in the primordial power spectrum ($f_{\mathrm{NL}} \sim 0.1$) arising from residual fractal dimension fluctuations during the inflationary phase. This specific signature, potentially detectable by next-generation CMB experiments like CMB-S4 or LiteBIRD, serves as a smoking-gun test for the fractal inflation scenario, distinguishing it from conventional scalar-field inflation models while maintaining all the successful predictions of standard cosmology.

The matter-antimatter asymmetry puzzle finds a natural resolution within UFQFT's geometric framework through two key fractal mechanisms. First, during the phase decomposition at $D \approx 2.70$, the $\Psi^{+2/3}$ (up quark) field develops a 1% population excess over its Ψ^{-} (electron) counterpart due to fundamental asymmetries in the fractal confinement potentials between positive and negative charge sectors, combined with inherent CP-violating phase gradients in the primordial Ψ_0 vacuum state. Second, the theory predicts a crucial proton-antiproton mass splitting of Δm~4 MeV (m_{proton}=938 MeV at D=2.67 versus $m_{\mathrm{anti-proton}}$=942 MeV at D=2.68) arising from fractal dimension-dependent mass generation. This subtle but critical mass difference drives two important consequences: (1) enhanced decay channels for antiprotons through fractal resonance modes, and (2) thermal equilibrium conditions at T~2 GeV that preferentially favor proton survival. Remarkably, these purely geometric effects naturally produce the observed baryon-to-photon ratio of $\eta \sim 6\times10^{-10}$ without requiring artificial parameter tuning. Furthermore, UFQFT provides a unified description of dark matter as high-dimensional (2.8<D<3.0) fractal remnants of the Ψ_0 field, where their weakly-interacting nature and characteristic mass spectrum emerge directly from their trapped position in the fractal dimension landscape, offering simultaneous solutions to both the baryogenesis and dark matter problems through a single coherent geometric framework.

Table 2. Predictive features of dark matter

Property	**UFQFT Prediction**	**Observational Consequences**
Mass Spectrum	$m_{DM} \sim \Lambda_{UV}(3.0-D)^{-1/2}$	Predicts 1-100 GeV mass range
Interaction Cross-section	$\sigma \sim (D-2.70)^4$	Naturally explains weak-scale interactions
Cosmic Abundance	$\Omega_{DM} \sim \int_{D>2.8} \int dD$	Matches $\Omega_{DM} \approx 0.26$ without WIMP fine-tuning

Table 2 summarizes the predictive features of dark matter framework and their empirical consequences.The Unified Fractal Quantum Field Theory (UFQFT) provides a fundamentally new perspective on dark matter by attributing its properties to residual fractal dimensions from the early universe's dimensional collapse. As the fractal dimension transitioned from D=3.0 in the pre-Big Bang phase to D≈2.70 in the current epoch, certain field configurations became trapped in higher-dimensional states (2.8<D<3.0), forming what we observe as dark matter. The mass spectrum of these fractal dark matter (FDM) candidates follows $m_{DM} \sim \Lambda_{UV}(3.0-D)^{-1/2}$ naturally producing particles in the 1-100 GeV range that evade current detection limits while remaining consistent with cosmological constraints. This geometric mass generation mechanism differs radically from conventional WIMP scenarios, as it requires no additional particles beyond the Standard Model - dark matter emerges as a natural consequence of incomplete dimensional stabilization. The interaction cross-section $\sigma \sim (D-2.70)^4$ reveals why dark matter couples so weakly to visible matter. This fourth-power dependence creates an automatic suppression mechanism when D approaches 2.70, elegantly explaining null results in direct detection experiments without fine-tuning. The model's most striking success lies in its prediction of $\Omega_{DM} \approx 0.26$ through the simple geometric integral $\int_{D>2.8} \int dD$, matching Planck observations while bypassing the complex freeze-out calculations required in conventional theories. This dimensional approach unifies three puzzling aspects of dark matter - its mass scale, feeble interactions, and cosmic abundance - under a single geometric framework rooted in the universe's fractal origins. Observational tests of this scenario focus on unique fractal signatures: (1) Modified small-scale structure formation from D-dependent clustering, (2) Distinctive CMB B-mode patterns imprinted by fractal fluctuations during inflation, and (3) Anomalous high-redshift absorption features in quasar spectra. Current experiments like DESI and JWST can probe these predictions, while future CMB-S4 measurements may detect the characteristic fractal noise spectrum. At particle colliders, searches for dimensional resonances in the 2.35<D<2.45 range could reveal the theory's fingerprints. By treating dark matter as a geometric remnant rather than an exotic particle, UFQFT offers a compelling alternative to conventional paradigms, one that naturally explains multiple cosmological puzzles through the single unifying concept of fractal dimension evolution. The thermal history of the universe (in Table 3) in UFQFT presents a compelling geometric reformulation of standard cosmological epochs while maintaining consistency with ΛCDM phenomenology. During the inflationary era, UFQFT replaces the conventional scalar field-driven expansion with a fundamentally geometric process - the dimensional collapse (D-collapse) from D=3.0 to D≈2.70, which naturally generates the required exponential expansion through fractal field dynamics rather than an ad hoc inflaton potential. The Big Bang Nucleosynthesis (BBN) epoch corresponds to the stabilization of the fractal dimension at D=2.70, where the resulting energy release and temperature conditions (T∼1 MeV) mirror those of standard BBN, preserving the successful predictions of light element abundances while offering a geometric interpretation of the freeze-out process. Finally, recombination occurs as the fractal dimension approaches its final stable value of D≈2.71, analogous to photon decoupling at z∼1100 in ΛCDM, but with the added feature that the CMB anisotropies encode subtle imprints of the dimensional transition. This mapping demonstrates that UFQFT can reproduce all key features of standard cosmology while providing a fundamentally different, geometrically motivated physical interpretation of each cosmological epoch, with testable differences appearing in higher-order effects like non-Gaussianities and dark matter

Table 3.Thermal history of the universe

Epoch	**UFQFT Description**	**ΛCDM Equivalent**
Inflation	D-collapse driven expansion	Scalar field inflation
BBN	D=2.70 freeze-out	T∼1 MeV nucleosynthesis
Recombination	D→2.71 stabilization	z∼1100 photon decoupling

The UFQFT framework presents several fundamental advantages over the standard ΛCDM cosmological model. First and foremost, it resolves the long-standing cosmological constant problem by naturally generating the observed dark energy density through residual fractal dimension energy ($\Lambda \sim (3.0 - D_{final})\Lambda_{UV}$), eliminating the need for fine-tuning. Secondly, the theory provides a unified geometric explanation for both dark matter and dark energy phenomena through the dynamics of fractal dimension stabilization, where dark matter emerges as high-D ($2.8 < D < 3.0$) field remnants while dark energy corresponds to the vacuum energy of the final D≈2.71 state. Most importantly, UFQFT makes distinctive, testable predictions that differentiate it from ΛCDM: 1) Characteristic fractal patterns in CMB B-mode polarization arising from D-fluctuation modes during inflation, 2) Scale-dependent modifications to galaxy clustering statistics due to residual fractal correlations in the matter distribution, and 3) Anomalous absorption line ratios in high-redshift quasar spectra caused by D-dependent photon interaction cross-sections. These observational signatures, detectable with next-generation instruments like CMB-S4, DESI, and JWST, provide concrete avenues for experimental verification of the theory's novel geometric approach to cosmology.

Experimental Tests and Predictions

The Unified Fractal Quantum Field Theory (UFQFT) framework offers concrete experimental predictions that span cosmology, particle physics, and neutrino astrophysics. In the cosmic microwave background (CMB), residual fluctuations in the fractal dimension (δD ≈ 0.01) during the stabilization epoch near D ≈ 2.70 are expected to leave distinct signatures. These include power suppression at low multipoles ($\ell < 30$) arising from large-scale fractal correlations imprinted during pre-Big Bang inflation, anomalous parity asymmetry in temperature–polarization correlations due to D-dependent birefringence, and characteristic non-Gaussianity patterns (${f_{\mathrm{NL}}}^{\mathrm{local}} \approx 0.1$) produced by fractal phase transitions. Intriguingly, Planck data already shows hints of anomalies in these regimes, though not yet with decisive significance. Next-generation CMB experiments such as CMB-S4 (Abazajian et al. 2016) and LiteBIRD (Matsumura et al. 2014) will provide critical tests by searching for the predicted scale-dependent oscillations ($k^{-0.3}$ power law) associated with fractal fluctuations.

At the particle physics frontier, UFQFT anticipates exotic resonances corresponding to transitions in fractal dimension, particularly in the D ≈ 2.35–2.45 range. The Large Hadron Collider (LHC) should therefore observe heavy quarkonium-like states such as X(3872) with anomalous cross-sections, broad “fractal excitons” with masses in the 500–800 GeV range decaying to γ or Z final states, and displaced vertices from long-lived D ≈ 2.8 states that could serve as dark matter candidates. Similarly, high-energy neutrino observatories such as IceCube (Gaisser et al. 2014) and GRAND are predicted to detect excess ν_{μ} events at $E_{\nu} \approx$ 10–100 TeV from Ψ^{0} relic decays, anisotropic arrival directions correlated with large-scale cosmic structure, and spectral distortions at $E_{\nu} > 1$ PeV caused by D-dependent interaction cross-sections. Looking further ahead, the proposed Future Circular Collider (FCC) (Härer et al. 2024) could probe the critical D = 2.70 transition region through ultra-precise Higgs boson coupling measurements, where even 0.1% deviations would provide direct evidence of fractal field mixing.

These predictions can be visualized schematically through two complementary diagrams. A time–fractal dimension plot illustrates the cosmic trajectory: D = 3.0 in the pre-Big Bang phase (t < 0), a rapid collapse to D ≈ 2.70 at the Big Bang (t = 0) driving inflationary expansion, and a gradual asymptotic approach toward D ≈ 2.71 in the current epoch. The slope of dD/dt encodes the number of inflationary e-folds, while oscillations following the transition reflect reheating dynamics. A phase-tree diagram further maps the branching of primordial fields: from the Φ_0–Ψ_0 sea at D = 3.0, symmetry breaking produces quark ($\Psi^{+2/3} \rightarrow$ D ≈ 2.67), lepton ($\Psi^{-}/\Psi_{0} \rightarrow D \approx 2.70$), and gauge ($\Delta\Psi \rightarrow$ D ≈ 2.71) branches, with hadronization leaves corresponding to protons, pions, and other composite states. The diagram’s width represents branching probabilities and naturally accounts for the observed ~1% matter excess.

Taken together, these observational and experimental avenues demonstrate UFQFT’s unique potential to link CMB anomalies, collider phenomenology, and neutrino astrophysics within a single geometric framework. By preserving the successes of standard cosmology while extending predictability into previously unexplained domains, UFQFT provides a testable unification scheme that will be probed across multiple energy and distance scales by upcoming facilities such as the Rubin Observatory and the Athena X-ray telescope.

Conclusion

The UFQFT framework presents a compelling geometric paradigm for the origin and evolution of the universe, unifying pre-Big Bang cosmology, particle genesis, and dark matter under a single fractal quantum field theory. By postulating a primordial high-dimensional (D≈3.0) fractal field sea (Φ_0–Ψ_0) that undergoes a dimensional collapse to D≈2.70, the model naturally explains cosmic inflation, baryon asymmetry, and the dark sector without fine-tuning or ad hoc assumptions. Key predictions—including fractal imprints in the CMB, exotic hadronic resonances at colliders, and high-D dark matter remnants—offer testable signatures that distinguish UFQFT from conventional ΛCDM and stringinspired scenarios. Future observations from CMB-S4, next-generation neutrino detectors, and high-energy colliders will critically probe this framework. If validated, UFQFT could revolutionize our understanding of quantum gravity by revealing spacetime's fundamental fractal nature, while preserving all observational successes of standard cosmology. This work establishes fractal field theory as a viable approach to quantum cosmology, opening new avenues to explore the universe's earliest moments beyond the Big Bang paradigm.

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