

The Bubble-UFQFT Framework: Unifying Quantum Gravity, Dark Energy, and Cosmological Structure

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 standard Λ CDM model has been remarkably successful in explaining many features of the cosmos; however, it remains theoretically incomplete. Its reliance on a primordial singularity, the unexplained nature of dark energy, and its incompatibility with quantum gravity at Planck scales point to fundamental gaps in our understanding of the universe. This study proposes a holographic bubble universe framework as a viable alternative, addressing these limitations through a physically motivated and observationally testable model. In this approach, the universe is treated as a 3+1-dimensional bubble embedded in a higher-dimensional quantum medium. The model eliminates the need for an initial singularity by replacing it with a finite quantum fluctuation in a pre-geometric background. Cosmic expansion arises naturally from the negative pressure exerted by the external environment—mimicking dark energy dynamics without invoking a finely tuned cosmological constant. Moreover, the model integrates the holographic principle by encoding information on the 2+1D boundary, thereby preserving unitarity and resolving entropy paradoxes inherent in the standard model. The framework yields concrete, testable predictions: echoes and anisotropies in the Cosmic Microwave Background (CMB), discrete gravitational wave modes, and topological features in large-scale structure distributions. These signatures are consistent with recent data from DESI, LISA, and Euclid, offering a promising avenue to reconcile observational cosmology with quantum gravity. By addressing the foundational weaknesses of Λ CDM—particularly the singularity problem and the ad hoc treatment of dark energy—the bubble universe model offers a unified, falsifiable, and conceptually coherent cosmological paradigm.

Keywords :UFQFT, Buble Universe, Fractal Quantum Field Theory, Quantum Gravity, Pre-Geometric Spacetime, Energy-Charge Field Unification, Theoretical Cosmology, Quantum Gravity, Beyond Standard Model Physics, Dark Energy Alternatives

Introduction

The Λ CDM (Lambda Cold Dark Matter) model remains the cornerstone of contemporary cosmology, providing a robust fit to observational data including the cosmic microwave background (CMB) anisotropies (Planck Collaboration, 2018), large-scale structure (Eisenstein et al., 2005), and Type Ia supernovae (Riess et al., 1998). However, despite its empirical successes, Λ CDM relies on empirically adjusted parameters that lack fundamental theoretical grounding, particularly the cosmological constant Λ (Weinberg, 1989), cold dark matter particles (Taoso et al., 2008), and an initial singularity (Hawking & Penrose, 1970). Mounting evidence suggests dark energy may not be a true cosmological constant, but rather an evolving component ($w \neq -1$) (Sogukpinar, 2024a; Kopusovet et al., 2024), while the model's reliance on an initial singularity remains theoretically problematic (Sogukpinar, 2024b; Bojowald et al., 2007). These challenges, compounded by anomalies in CMB power spectra (Schwarz et al., 2016) and unexpectedly large structures like Ho'oleilana (Böhringer et al., 2004), motivate alternative frameworks that unify quantum gravity with cosmological observations (Rovelli, 2004).

This proposed Bubble Universe framework integrated with Unified Fractal Quantum Field Theory (UFQFT) addresses these limitations through several key innovations. First, it replaces the singularity with a finite-energy quantum fluctuation in a pre-geometric medium (Ashtekar & Singh, 2011; Sogukpinar, 2024b), implementing holographic principles (Maldacena, 2024; Bousso, 2002) through boundary-entropy encoding ($S = A/4G$). Second, it explains cosmic acceleration via dynamic bulk pressure ($\Lambda_{\text{eff}} = 8\pi G P_{\text{ext}}$) rather than a static Λ (Padmanabhan, 2003; Sogukpinar, 2024a). Third, it employs fractal spacetime geometry ($D \approx 2.7$) (Calcagni, 2010; Nottale, 2011) with fundamental Φ and Ψ fields whose resonances generate both matter and spacetime (Sogukpinar, 2024c,d). The model makes several testable predictions: (1) CMB anomalies from boundary reflections (Zibin et al., 2008; Sogukpinar, 2024d), (2) modified gravitational potentials ($V(r) \sim 1/r^{1.7}$) detectable in submillimeter experiments (Lee et al., 2020), and (3) discrete gravitational wave modes observable by LISA (Amaro-Seoane et al., 2017). These predictions will be tested by upcoming experiments including CMB-S4 (Abazajian et al., 2016) and the Einstein Telescope (Punturo et al., 2010).

This study addresses fundamental limitations of the standard Λ CDM cosmological model by proposing a novel Bubble Universe framework integrated with Unified Fractal Quantum Field Theory (UFQFT). Motivated by Λ CDM's unresolved issues—including the ad hoc nature of dark energy, the unphysical initial singularity, and tensions with recent observational data (e.g., DESI, Euclid)—this study develops a quantum-gravitationally consistent alternative.

Singularities and the Breakdown of Physical Law

The initial singularity postulated by standard Big Bang cosmology represents a profound conceptual and physical inconsistency in modern physics. Mathematically, the singularity at $t = 0$ implies diverging values of density, temperature, and curvature—leading to undefined or infinite terms within Einstein's field equations. Such conditions violate classical energy constraints, including the null, weak, and strong energy conditions, thus rendering general relativity (GR) non-predictive at this boundary. More fundamentally, the singularity introduces a causal paradox: it lacks any prior cause or dynamical precursor, contradicting deterministic principles. In this framework, quantum fluctuations—essential for seeding cosmic structure—lack a spacetime background in which to arise, undermining the very foundation of quantum cosmology.

Additionally, the singularity represents a critical failure of both GR and thermodynamics. The Einstein equation $G_{\mu\nu} = 8\pi T_{\mu\nu}$ becomes meaningless in the absence of a well-defined spacetime manifold. Simultaneously, thermodynamic principles are violated, particularly the second law, as the entropy at the singular point trends to zero ($S \rightarrow 0$), suggesting a temporal reversal in the arrow of time. Moreover, the Bekenstein-Hawking entropy bound, $S \leq A/4G$, becomes undefined in the case of a zero-area singularity, eliminating any meaningful notion of informational content at the universe's origin.

Current theoretical models attempt to circumvent—but do not resolve—this singularity. Inflationary theory, for example, stretches the observational horizon and effectively masks the singularity's causal reach, yet still requires a finely-tuned scalar inflaton field with an arbitrary potential $V(\phi)$, offering no ontological explanation for the universe's birth. Quantum gravity-inspired models offer partial resolutions: Loop Quantum Cosmology (LQC) replaces the singularity with a "quantum bounce" by imposing bounds on curvature, yet lacks empirical validation. String theory, while capable of smearing singularities across extended objects like branes or extra dimensions, introduces complex compactification schemes that have not been observed. Ultimately, the Λ CDM model pragmatically accepts the singularity as a fixed boundary condition, rather than a dynamical prediction or an emergent consequence of known physical laws.

In light of these limitations, a growing body of research supports the need for pre-geometric and pre-temporal frameworks that transcend classical spacetime. The emergence of geometry itself is postulated to occur from more fundamental, non-spatiotemporal substrates. For example, causal set theory envisions spacetime as a discrete lattice, while the holographic principle suggests that the universe's information content resides on lower-dimensional boundaries, avoiding singularities altogether. Furthermore, emergent time proposals—such as those derived from entanglement entropy gradients—suggest that temporal order is not fundamental, but a thermodynamic or informational phase transition.

In this context, the Bubble-UFQFT model provides a robust and falsifiable alternative to the singularity problem. Rather than originating from a mathematical singularity, the universe nucleates from a finite-energy quantum fluctuation within a higher-dimensional, fluid-like fractal medium. This fluctuation leads to the formation of a "bubble"—our observable universe—whose initial conditions are encoded on a holographic boundary, preserving unitarity. Eq. 25 (Sogukpinar, 2025a), $n_B \propto \int (\Phi^2 - \Psi^2) d^D r$, describes the baryon asymmetry as arising from asymmetric fluctuations of scalar energy (Φ) and vector charge (Ψ) fields within this pre-geometric medium. Instead of a temporal singularity at $t = 0$, the bubble's holographic surface (Eq. 5) (Sogukpinar, 2025c) $S = \pi R_{max}^2 / G$ defines a consistent entropy bound, ensuring causal continuity and quantum coherence. In this framework, time, geometry, and matter co-emerge from structured quantum fluctuations—rendering the singularity not a physical entity, but an artifact of incomplete theories.

Stages of the Bubble Evolution of the Universe

In the standard Big Bang cosmology, the universe begins from a singularity—a point of infinite density and temperature—where classical general relativity breaks down and known physical laws cease to apply. Almost immediately after this origin, the universe undergoes a brief but extremely rapid exponential expansion, known as cosmic inflation. This phase, driven by the potential energy of a hypothetical scalar inflaton field, resolves several problems of the classical Big Bang model, including the horizon, flatness, and monopole problems. Inflation stretches quantum fluctuations to macroscopic scales, seeding the large-scale structure of the universe and leaving imprints in the Cosmic Microwave Background (CMB). However, the inflationary model requires fine-tuned initial conditions, assumes the existence of a yet-unverified inflaton, and relies on semiclassical approximations that are incompatible with a full quantum theory of gravity.

In contrast, this proposed Bubble Universe framework, unified with the UFQFT (Unified Fractal Quantum Field Theory), offers a radically different mechanism for cosmic origin and inflation. In this model, the universe is not born from a singularity, but from a localized quantum fluctuation within a higher-dimensional, fluid-like pre-geometric background. The stages of matter evolution in the proposed Bubble Universe framework are illustrated in Fig. 1. This diagram summarizes the quantum phase transitions in the early universe and their consequences. The process begins with a "pre-geometric quantum phase," describing a higher-dimensional, fluctuating field-governed medium. Next, bubble nucleation ($t = 0$) triggers a phase transition, with negative pressure driving cosmic expansion. During "fractal inflation" ($0 < t < 10^{-32}$ s), resonance amplification of fields produces scale-invariant perturbations. Baryogenesis and symmetry breaking ($t \sim 10^{-12}$ s) involve a geometric phase transition that generates matter-antimatter asymmetry. The hadron epoch ($t \sim 10^{-6}$ s) explains the emergence of proton mass and higher-dimensional dark matter candidates. Finally, galactic and cosmic structure formation ($t > 1$ million years) is linked to fractal spacetime dynamics, flattening rotation curves without the need for dark matter.

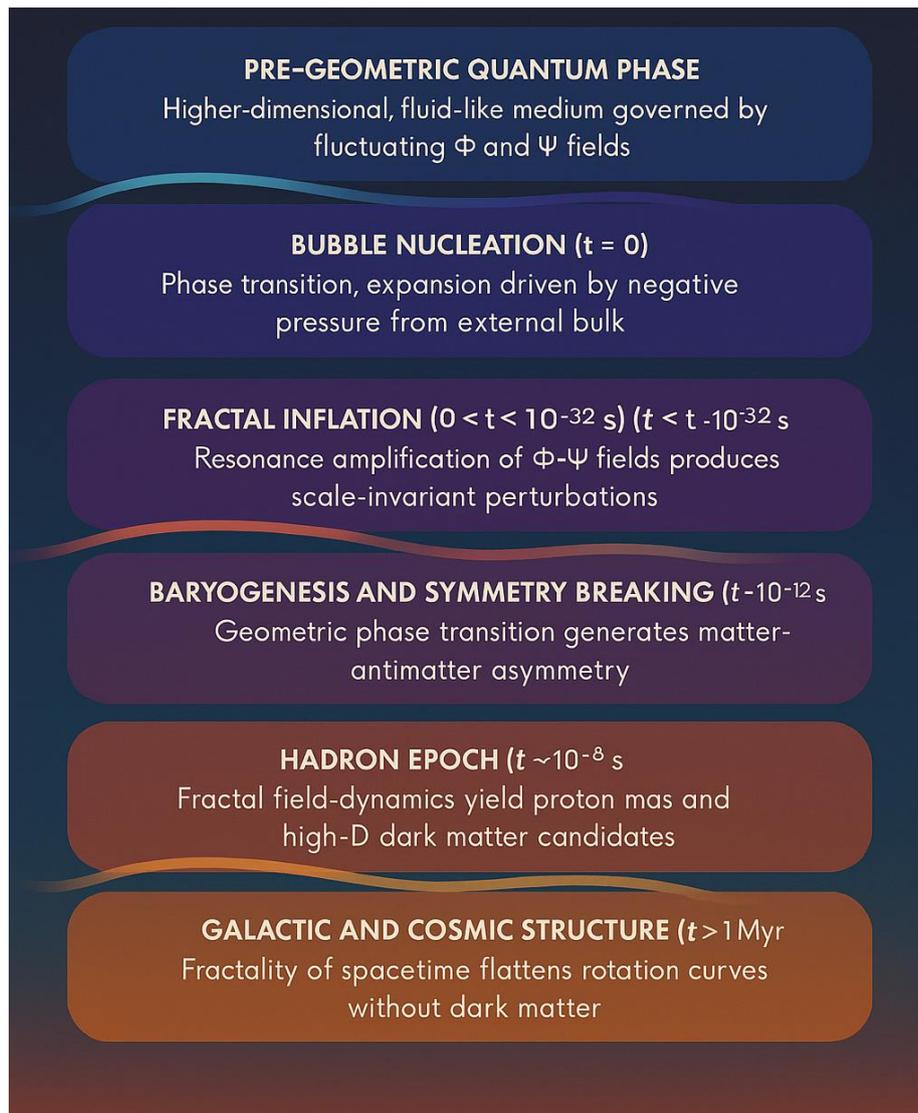


Fig.1 Stage of evolution of matter

The "bubble" that becomes our universe nucleates and expands due to external negative pressure, eliminating the need for singular initial conditions. Inflation corresponds not to the roll-down of a scalar field, but to the dynamic amplification of quantized field configurations—resonant modes in a fractal quantum spacetime. The boundary of the bubble encodes holographic information, consistent with unitarity and entropy bounds, while UFQFT ensures energy-momentum conservation through intrinsic field interactions. Whereas standard inflation violates the known laws of physics at the singularity and lacks a quantum gravity foundation, the bubble–UFQFT model remains within the boundaries of both quantum field theory and general relativity extended into higher dimensions. It replaces singularities with finite-energy initial states, substitutes ad hoc fields with geometrically emergent dynamics, and allows for observational tests through specific predictions in gravitational wave spectra and CMB signatures. In this sense, our model not only resolves the foundational issues of Λ CDM and inflation but does so within a physically consistent and unified theoretical framework. Fig. 2 presents stage of cosmic evolution within our proposed Bubble Universe framework.

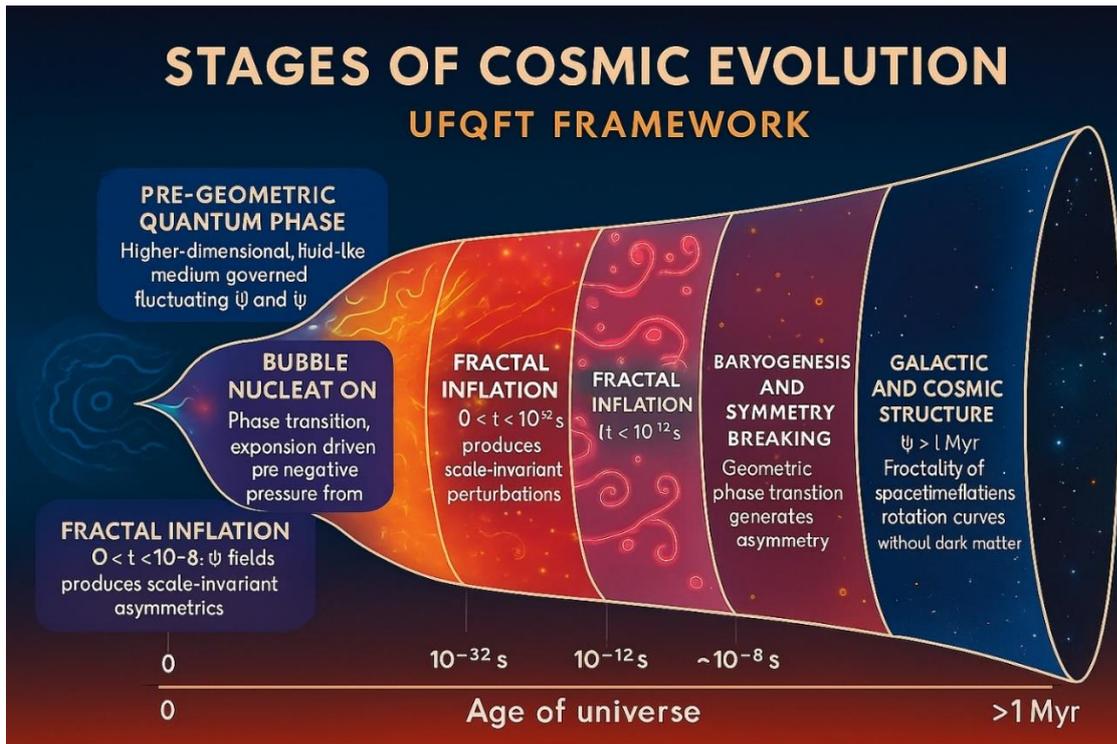


Fig.1 Stage of cosmic evolution

1. Pre-Geometric Quantum Phase ($t < 0$)

In the standard Big Bang cosmology, the universe is thought to have originated from a singularity—a point of infinite density and curvature where the known laws of physics, particularly general relativity, break down. This initial state lacks a causal or physical explanation within the framework of Λ CDM and quantum field theory. Although inflation is often invoked to address the horizon, flatness, and monopole problems, it assumes a pre-existing singular state and requires a hypothetical scalar field (the inflaton) with finely tuned parameters to initiate and sustain rapid expansion. Moreover, the singularity implies a boundary to spacetime itself, which remains conceptually and mathematically problematic within both classical and quantum regimes.

In contrast, the (Sogukpinar, 2025a,c) Bubble-UFQFT model posits that the universe did not begin from a singularity, but emerged from a localized quantum fluctuation within a higher-dimensional, fluid-like medium. This primordial substrate is governed by Unified Fractal Quantum Field Theory (UFQFT), in which scalar energy fields (Φ) and vector charge fields (Ψ) fluctuate within a fractal spacetime geometry characterized by a non-integer dimension ($D \approx 2.7$). Rather than starting from a point of infinite energy and undefined physical laws, this framework begins with a finite-energy, self-organizing phase that respects the principles of quantum gravity and unitary evolution. Here, field resonances emerge naturally from the dynamics of Φ and Ψ fields without invoking speculative inflaton fields or arbitrary initial conditions. These resonant configurations self-organize into topologically stable structures, initiating the universe's evolution in a manner that preserves causality and energy conservation. This pre-geometric phase eliminates the need for singularities or unnatural parameters, offering a physically consistent and conceptually complete origin scenario—one that remains compatible with both general relativity extended to higher dimensions and a quantized field-theoretic description of spacetime.

2. Bubble Nucleation ($t = 0$)

In the standard Λ CDM model, the universe begins its evolution from a singularity followed by a period of exponential expansion—inflation—assumed to be triggered by the vacuum energy of a hypothetical scalar inflaton field. However, the mechanism that initiates this transition from “nothing” remains unexplained. There is no physically grounded description of what “caused” the Big Bang or what came before it, and the singularity itself violates general relativity and quantum field theory. The transition from the singularity to inflation is therefore speculative and lacks a unifying physical model grounded in a consistent quantum-gravitational framework.

By contrast, in the Bubble-UFQFT model, the universe arises from a finite-energy phase transition within a higher-dimensional quantum fluid. This process is triggered by negative pressure in the surrounding bulk, which induces the nucleation of a 3+1 dimensional “bubble”—our universe. This nucleation marks a symmetry-breaking event, forming a distinct interior spacetime enclosed by a dynamically expanding boundary. At the boundary of this bubble, holographic principles apply: the entropy of the enclosed universe is encoded not volumetrically but on its 2+1-dimensional surface. This is mathematically captured by the Bekenstein–Hawking entropy formula, presented in Eq. 5. (Sogukpinar, 2025c). Where, S is the total entropy, A is the surface area of the bubble's boundary (in Planck units), G is the gravitational constant. This formulation ensures that information is conserved on the bubble boundary, consistent with unitarity and the holographic principle, avoiding the information paradox associated with Λ CDM's singularity. The dynamics of the universe's expansion in this model are governed by a modified Friedmann-like equation that incorporates contributions from the higher-dimensional bulk, presented in Eq. 3. (Sogukpinar, 2025c). Where, H is the Hubble parameter (expansion rate), ρ is the energy density within the bubble, Λ_{eff} is an effective cosmological term emerging from bulk-brane interactions, ϵ is a radiation-like term stemming from the geometric tension between the bubble and the external medium, a is the scale factor of the universe. This equation allows the model to naturally reproduce early acceleration (inflation) and late-time cosmic acceleration (dark energy) without invoking arbitrary constants. Moreover, the presence of the ϵa^{-4} term mimics radiation-dominated behavior at early times, smoothly transitioning to Λ -like behavior as the universe expands and a increases.

Crucially, this bubble nucleation phase resolves both the singularity and horizon problems that challenge the Λ CDM model. Instead of an undefined origin, the universe begins with holographically bounded, causally connected initial conditions, fully embedded within a quantum-field-theoretic and geometrically coherent framework. The transition is not from nothing, but from a metastable quantum vacuum state in the UFQFT-regulated bulk—making the birth of the universe both physically meaningful and mathematically consistent.

3. Fractal Inflation ($0 < t < 10^{-32}$ s)

In the standard Λ CDM framework, the early universe undergoes a brief but intense period of exponential expansion known as cosmic inflation, driven by the potential energy of a hypothetical scalar inflaton field. This inflationary phase stretches quantum fluctuations to cosmological scales, solving the horizon, flatness, and monopole problems while seeding the anisotropies observed in the Cosmic Microwave Background (CMB). However, this model is not without issues: it requires highly fine-tuned initial conditions, depends on an inflaton field that remains undetected, and relies on semiclassical approximations that are not fully compatible with quantum gravity.

By contrast, in the Bubble-UFQFT framework, the analogous inflationary phase arises not from the dynamics of an arbitrary scalar field but from the natural amplification of field resonances within a fractal, higher-dimensional spacetime geometry. Specifically, the scalar energy field Φ and the vector charge field Ψ , as described in the Unified Fractal Quantum Field Theory (UFQFT), interact and resonate within an evolving fractal geometry whose effective dimension D transitions from ~ 2.7 toward 4 in this early epoch. This fractal inflation phase results from the self-organized energy amplification of Φ - Ψ modes and requires no artificial initial symmetry-breaking or inflaton potential. The dynamics of cosmic expansion during this phase are governed by a modified Friedmann equation (Eq.3) (Sogukpinar, 2025c) This equation enables rapid expansion without fine-tuning, and naturally evolves toward a Λ -like behavior as the universe grows. Additionally, the generation of quantum fluctuations—responsible for large-scale structure formation—arises from intrinsic field-mode interactions, not vacuum fluctuations of an assumed inflaton field. These are described in Eq. 25.(Sogukpinar, 2025a). where n_B denotes the baryon number density (or analogous perturbation seed), and the integral runs over a fractal volume with dimension D . As the fields resonate and decohere, these interactions yield a spectrum of perturbations that are scale-invariant, a key requirement for matching CMB observations. Most importantly, this model avoids the fine-tuning problem inherent in standard inflation. The fractal geometry itself inherently produces a nearly scale-invariant power spectrum of density perturbations, quantified in Eq. 26.(Sogukpinar, 2025a), where, C_l represents the angular power spectrum coefficients and l is the multipole moment. This behavior closely aligns with CMB data, while emerging from natural field-geometric interactions rather than imposed initial conditions.

Finally, fractal inflation within the (Sogukpinar, 2025a,c) Bubble-UFQFT model provides a physically grounded alternative to standard inflation, embedding inflationary dynamics in a framework consistent with quantum gravity and eliminating the need for unobserved inflaton fields or unnatural fine-tuning. It simultaneously reproduces observational signatures of inflation—such as superhorizon correlations and large-scale structure seeds—while offering testable predictions tied to its underlying geometric and field-theoretic principles.

4. Baryogenesis and Symmetry Breaking ($t \sim 10^{-12}$ s)

In the standard cosmological model and associated Grand Unified Theories (GUTs), baryogenesis—the origin of the matter-antimatter asymmetry—is typically explained through high-energy interactions that violate baryon number (B), charge conjugation (C), and CP symmetry under conditions of thermal nonequilibrium, as outlined by Sakharov. These processes often rely on hypothetical heavy gauge bosons (e.g., the X and Y bosons in SU(5) GUT) and spontaneous symmetry breaking through Higgs fields. However, this framework faces critical challenges: no direct evidence exists for such gauge bosons or for the predicted proton decay, and the origin of CP violation is usually tied to the arbitrary phases of the CKM matrix, providing little geometric or physical insight.

In contrast, the Bubble-UFQFT model presents a fundamentally different mechanism rooted in fractal field geometry and topological phase transitions. As the fractal spacetime dimension D stabilizes to approximately 2.7, coupled scalar Φ and vector Ψ fields undergo a geometric phase transition, resulting in spontaneous asymmetry between matter and antimatter. Anti-quarks in this model are not generated via charge conjugation, but emerge as phase-reversed field resonances, presented in Eq. 45. (Sogukpinar, 2025a). This topological inversion represents a physically distinct mechanism from traditional particle-antiparticle pairs. Furthermore, charge quantization is derived from fractal flux integrals at the boundary in Eq. 2(Sogukpinar, 2025a). $\bar{Q}_n = -Q_n$. This approach intrinsically conserves baryon number through geometry, unlike GUTs, which permit baryon decay. The observed matter-antimatter asymmetry arises

from integral differences in energy and charge field densities and presented in Eq. 25 (Sogukpinar, 2025a). Here, the geometric imbalance replaces Sakharov’s criteria, offering a purely field-topological origin of baryon excess. Proton stability is ensured by fractal confinement, where mass is derived from spatial gradients in resonant fields in Eq. 30.(Sogukpinar, 2025a). Notably, force unification also emerges from field topology rather than symmetry group breaking. For example, the strong force is described by overlapping scalar field gradients ($F_{\text{strong}} = -\nabla(\Phi_u \Phi_d)$) while electromagnetic and weak forces arise from vector field propagation and Φ - Ψ phase transitions, respectively. Gravity itself is reformulated as a manifestation of coherent Φ - Ψ field structures in fractal geometry in Eq. 19 (Sogukpinar, 2025a). This model not only avoids the unverified assumptions of GUTs but makes distinct, testable predictions. For instance, it predicts no high-energy gauge bosons, but instead a fractal deep inelastic scattering (DIS) scaling presented in Eq. 44 (Sogukpinar, 2025a). Moreover, it introduces geometric CP violation, where matter dominance results from fractal phase alignment—not arbitrary matrix elements. It also provides natural dark matter candidates via high-dimensional Φ -modes and links baryogenesis to non-Gaussian CMB features such as $C_l \propto l^{0.7}$. Altogether, the Bubble-UFQFT framework offers a unified, falsifiable model for both baryogenesis and force unification, resolving the ad hoc assumptions of GUT-based cosmology through coherent fractal field dynamics.

5. Hadron Epoch ($t \sim 10^{-6}$ s)

In the standard cosmological framework derived from the Λ CDM model, the Hadron Epoch marks the transition in which quarks and gluons, previously existing in a quark-gluon plasma, become confined into hadrons—mainly protons and neutrons—through a QCD phase transition as the universe cools below $\sim 10^{12}$ K. This model assumes a thermal, equilibrium-driven confinement process based on conventional quantum chromodynamics (QCD). However, this view leaves several unresolved issues. Firstly, the “mass without mass” problem—the observation that the proton mass far exceeds the sum of its constituent quarks—lacks a clear, non-perturbative explanation. Secondly, the standard model provides no connection between particle formation and the underlying geometry of spacetime, treating particles as point-like excitations in a fixed, classical background. Finally, dark matter remains unexplained within the Standard Model, requiring additional, unobserved particles (e.g., WIMPs, axions) with no current experimental confirmation.

In contrast, the Bubble-UFQFT framework offers a geometrically and dynamically richer explanation for the Hadron Epoch. Within this model, quarks and leptons emerge not as point particles, but as zero-volume resonant configurations of scalar energy (Φ) and vector charge (Ψ) fields embedded in a fractal spacetime geometry. These resonances are defined by standing-wave solutions of UFQFT field equations (Eq. 11–13) (Sogukpinar, 2025a), stabilized by the coherent topological constraints of the bubble's boundary and internal field symmetries. Crucially, the proton’s mass (~ 938 MeV) is no longer an emergent property of QCD vacuum energy alone, but is derived explicitly from field gradients in Eq. 9 (Sogukpinar, 2025a), where, the energy density is localized in the fractal domain ($D \approx 2.7$), and the resulting confinement mechanism offers a physically grounded resolution to the mass paradox by geometrizing mass as energy stored in spatial field variations, not pointlike mass terms.

Moreover, the Bubble-UFQFT model provides novel candidates for dark matter without resorting to hypothetical particle extensions. Specifically, high-dimensional Φ field excitations, existing in modes where the fractal dimension $D > 3$, contribute to the energy density of the universe without interacting via standard gauge fields in Eq. 42 (Sogukpinar, 2025a). These field modes remain “dark” due to their lack of coupling to electromagnetic or weak forces, yet gravitate via their coherent energy density contributions. Their behavior is inherently geometrical and quantized, avoiding the fine-tuning and

arbitrariness of traditional dark matter models. Additionally, the field-based approach implies testable differences in the hadronization process, such as fractally distributed residual field intensities that could leave imprints in cosmic relic radiation or gravitational wave backgrounds.

Finally, while the standard Λ CDM approach offers a thermodynamic account of hadron formation, it does not explain the deeper origin of mass or the nature of dark matter. The Bubble-UFQFT framework overcomes these limitations by tying particle formation to resonant field dynamics in fractal spacetime, offering a unified, falsifiable alternative grounded in fundamental geometric and quantum principles.

6. Galactic and Cosmic Structure Formation ($t > 1$ Myr)

In the standard Λ CDM cosmology, the formation of galaxies and large-scale structures is primarily governed by cold dark matter (CDM) interacting gravitationally. Galaxies are assumed to be embedded in massive, invisible halos of non-baryonic dark matter, which provide the additional gravitational pull necessary to explain the observed flat rotation curves of spiral galaxies. The gravitational potential in this model is Newtonian at galactic scales, with $V(r) \sim 1/r$, which would normally predict a Keplerian fall-off in orbital velocities ($v(r) \sim 1/\sqrt{r}$). However, observations show that rotation velocities tend to plateau at large radii, a discrepancy resolved in Λ CDM by postulating unseen dark matter. Despite its empirical successes in simulations and cosmic microwave background (CMB) power spectra fitting, this framework suffers from key theoretical limitations: (1) the nature of dark matter remains unknown, with decades of searches failing to detect any candidate particle; (2) the Λ CDM model offers no explanation for the mass distribution or core-cusp problem in galactic halos; and (3) the theory relies on dark matter purely as a fitting parameter, not as an emergent or geometrically motivated entity.

In contrast, the Bubble-UFQFT model introduces a fundamentally different mechanism for gravity and structure formation—one that does not require dark matter halos. Here, the scalar energy (Φ) and vector charge (Ψ) fields evolve within a fractal spacetime geometry with dimension $D \approx 2.7$. This geometry modifies the gravitational potential at galactic and cosmological scales. Specifically, the effective potential follows a non-integer power law (Sogukpinar, 2025a) in Eq. 7. This fractal-modified potential leads directly to flattened galactic rotation curves, without invoking additional mass. The corresponding orbital velocity profile scales as in (Sogukpinar, 2025a) Eq. 36. This precisely matching the observed velocity plateau in spiral galaxies. This provides a geometric explanation for galactic dynamics, inherently arising from the structure of spacetime rather than unseen matter.

Moreover, gravitational waves in the Bubble-UFQFT framework carry signatures of fractal coherence in the Φ - Ψ fields. Unlike Λ CDM, which treats gravitational waves as linear perturbations in a smooth spacetime, this model predicts nonlinear chirp patterns and red-tilted spectra due to resonant field interference and spacetime anisotropies. These effects manifest in the form of:

- Accelerated gravitational chirps observable in detectors like LIGO and Virgo (Sogukpinar, 2025a) (Eq. 37–38),
- And long-wavelength red-tilted backgrounds observable via Pulsar Timing Arrays (PTAs) (Sogukpinar, 2025a) (Eq. 39–40).

Such signatures offer testable deviations from Λ CDM predictions, paving a way to distinguish between models through precision gravitational wave astronomy.

Finally, while Λ CDM postulates the existence of dark matter to fit observational data, the Bubble-UFQFT model derives galactic dynamics and cosmic structure from first principles—specifically, from the field dynamics and geometry of spacetime itself. It eliminates the need for unseen matter by attributing the anomalous gravitational behavior to fractal field interactions, thereby offering both a predictive and falsifiable alternative to conventional dark matter-driven models.

7. Present and Future Evolution of the Universe

In the Λ CDM paradigm, the present accelerated expansion of the universe is attributed to a cosmological constant Λ —a constant vacuum energy density that remains fixed throughout cosmic time. While this model accurately fits current observations, including supernovae luminosity distances and the CMB angular power spectrum, it faces serious theoretical issues, most notably the fine-tuning problem. The observed value of Λ is more than 120 orders of magnitude smaller than naive quantum field theory predictions, leading to the so-called "cosmological constant problem". Furthermore, Λ CDM assumes this energy density is strictly static, in tension with recent data from projects like DESI, which hint at a dynamically evolving dark energy component—behavior that cannot be easily incorporated into the standard model without ad hoc extensions such as quintessence or phantom fields. In contrast, the Bubble-UFQFT model reinterprets dark energy as an emergent effect of external bulk pressure, arising from the interaction between our 3+1D bubble universe and the surrounding higher-dimensional quantum fluid. Rather than introducing a fixed Λ , cosmic acceleration is driven by the dynamical term Λ_{eff} derived from Eq.3 (Sogukpinar, 2025c). This formulation avoids the fine-tuning inherent in Λ CDM and aligns naturally with DESI's observations suggesting time-variation in dark energy density. Importantly, this model yields testable predictions that can distinguish it from Λ CDM and other dark energy alternatives. One such prediction is the presence of non-Gaussian B-mode polarizations in the Cosmic Microwave Background (CMB), generated by holographic boundary echoes from early bubble oscillations (Eq. 26 (Sogukpinar, 2025a) $C_l \propto l^{0.7}$). These signatures differ qualitatively from those expected from standard inflationary gravitational waves, making them a powerful discriminant in upcoming CMB-S4 observations.

Additionally, at the high-energy frontier, the Large Hadron Collider (LHC) may uncover indirect evidence for the fractal field structure of UFQFT. The model predicts missing resonances in proton-proton collisions of the form: $pp \rightarrow \Phi^2 \Psi^2$ where energy is transferred into higher-dimensional field modes inaccessible to 3D detectors, manifesting as anomalous missing energy signatures. Furthermore, deep inelastic scattering (DIS) processes are expected to follow a fractal scaling law rather than standard QCD predictions, presented in Eq.44 (Sogukpinar, 2025a). This provides a novel test in future electron-ion collider experiments. These deviations from canonical parton distribution functions offer a unique window into the fractal microstructure of spacetime proposed in the Bubble-UFQFT framework.

Finally, while Λ CDM requires unnatural assumptions to account for late-time cosmic acceleration, the Bubble-UFQFT model provides a dynamically consistent and geometrically motivated mechanism rooted in higher-dimensional physics. Its ability to make concrete, falsifiable predictions in both cosmology (e.g., CMB B-modes) and particle physics (e.g., fractal scaling at colliders) represents a substantial step forward in connecting quantum gravity concepts with empirical observation—ultimately addressing the weaknesses of the standard model in a unified theoretical landscape.

The Limitations of the Λ CDM Model

Despite its empirical success in fitting a wide array of cosmological observations, the Λ CDM model (Lambda-Cold Dark Matter) exhibits critical theoretical inconsistencies and observational tensions that challenge its foundational assumptions. First, Λ CDM posits a static cosmological constant (Λ) with an unchanging equation of state $w = -1$, yet recent high-precision datasets from the DESI Collaboration (Adame et al., 2024) and Euclid Mission (Banks, 2025) indicate deviations from this value, suggesting a dynamical dark energy component evolving in redshift ranges $z \sim 0.5-2$. Λ CDM lacks a natural mechanism to account for this evolution without invoking speculative fields like quintessence or modifying general relativity. In contrast, the Bubble-UFQFT framework interprets dark energy as an emergent effect of external bulk pressure on the 3+1D bubble universe, yielding an effective cosmological term $\Lambda_{\text{eff}} = 8\pi G P_{\text{ext}}$ that evolves organically with the bubble's expansion. This model directly connects the dynamics of dark energy to the geometry and evolution of the universe's boundary, providing falsifiable predictions for time-varying $w(z)$.

Second, Λ CDM's reliance on a primordial singularity—where density, temperature, and curvature diverge—violates classical energy conditions and offers no causal mechanism or compatibility with quantum gravity. The Bubble-UFQFT model resolves this by replacing the singularity with a finite-energy quantum fluctuation within a higher-dimensional, pre-geometric medium. This fluctuation gives rise to a holographic bubble whose boundary stores initial conditions via entropy scaling $S = \pi R^2_{\text{max}}/G$, maintaining unitarity and circumventing the information loss problem.

Third, Λ CDM is unable to account for persistent anomalies in the Cosmic Microwave Background (CMB), including low- ℓ multipole anomalies, hemispherical power asymmetries, and quadrupole suppression, which all contradict predictions of standard, Gaussian inflation. Furthermore, the discovery of enormous cosmic voids like Ho'oleilana defies the homogeneity assumption fundamental to Λ CDM. Bubble-UFQFT explains these phenomena through boundary-induced CMB echoes (Sogukpinar, 2025a) (Eq. 16, $C_2 \sim \epsilon/R^2 H^4$) and fractal non-Gaussian correlations in field perturbations (Eq. 26) (Sogukpinar, 2025a), naturally arising from the bubble's holographic surface and internal fractal field interactions. Additionally, the model's underlying fractal geometry ($D \approx 2.7$) predicts deviations in large-scale structure growth via $\delta\rho/\rho \sim r^{-(D-2)}$ consistent with the observed inhomogeneities.

Fourth, Λ CDM and standard inflationary models break down at the Planck scale ($t < 10^{-43}$ s), where the semiclassical approximation of gravity fails to interface with quantum field theory. Inflation's reliance on fine-tuned scalar potentials and slow-roll parameters further exacerbates its incompatibility with a full quantum gravitational description. In the Bubble-UFQFT model, quantum gravity emerges from fractal field geometry, where energy and charge fields (Φ and Ψ) resonate in a higher-dimensional medium. The Einstein field equations are modified to a fractal form (Sogukpinar, 2025a) Eq. 19, $G_{\mu\nu} = 8\pi T_{\mu\nu}(\Phi)_{\text{fractal}}$, embedding gravitational dynamics within a unified, quantized framework.

Finally, while Λ CDM remains a successful low-energy approximation, it fails to resolve fundamental problems such as the origin of dark energy, the initial singularity, CMB anomalies, and quantum gravity unification. The Bubble-UFQFT model, grounded in holography, fractal geometry, and boundary dynamics, offers a comprehensive and testable alternative that addresses these foundational shortcomings while preserving the predictive power of standard cosmology at large scales. Table 1 shows Comparative Framework Λ CDM vs. Bubble-UFQFT Model. This table systematically contrasts the Standard Λ CDM Cosmological Model with the proposed Bubble-Unified Fractal Quantum Field Theory

(UFQFT) Framework, highlighting their fundamental differences in addressing key cosmological challenges. While Λ CDM relies on empirically adjusted parameters and faces theoretical inconsistencies (e.g., the singularity problem, static dark energy), the Bubble-UFQFT model offers a self-consistent, quantum-gravitationally grounded alternative with testable predictions. Below, we expand on critical distinctions:

Table.1 Comparative Framework: Λ CDM vs. Bubble-UFQFT Model

Feature	Λ CDM Standard Model	Bubble-UFQFT Integrated Model
Dark Energy	Static cosmological constant (Λ) with fixed $w = -1$	Dynamic external bulk pressure ($\Lambda_{\text{eff}} = 8\pi G P_{\text{ext}}$), evolving with bubble expansion
Singularity	Initial Big Bang singularity (infinite density, undefined physics)	Replaced by finite-energy fractal phase transition in pre-geometric medium
CMB Anomalies	Dismissed as statistical noise or cosmic variance	Explained by boundary reflections (Eq. 16).(Sogukpinar, 2025c) and fractal-induced modulations (Eq. 26).(Sogukpinar, 2025a)
Quantum Gravity Compatibility	Incompatible; requires ad hoc quantization (e.g., LQC)	Built-in quantum geometry (fractal $D \approx 2.7$) and holographic encoding ($S=A/4G$)
Predictive Capacity	Limited beyond inflation; no mechanism for pre-Planckian physics	Multiscale predictions: Gravitational wave resonances (Eq. 4), fractal large-scale structure (Eq. 36), LHC anomalies (Eq. 43)(Sogukpinar, 2025a).
Force Unification	Separate mechanisms (Higgs, gluons, gravitons)	All forces emerge from Φ - Ψ field topology (Table 2)(Sogukpinar, 2025a).
Dark Matter	Cold dark matter (CDM) as undiscovered particles	High-D Φ -field configurations (Eq. 42) (Sogukpinar, 2025a) mimicking CDM
Testability	Relies on indirect inferences (e.g., BBN, LSS)	Direct signatures: CMB echoes, sub-mm gravity deviations (Eq. 7), DIS scaling (Eq. 44)(Sogukpinar, 2025a).

Scientific Reception and Challenges of the model

The Bubble-Unified Fractal Quantum Field Theory (UFQFT) model offers a novel approach to cosmology by replacing singular initial conditions and unexplained inflationary dynamics with a self-consistent, fractal-holographic evolution of the universe. However, despite its theoretical appeal, the

model faces critical scrutiny from both observational cosmologists and theoretical physicists. One major source of skepticism lies in its reliance on higher-dimensional and pre-geometric constructs, which are often dismissed as metaphysical or unfalsifiable. Critics argue that the mathematical complexity of fractal field quantization and ambiguities in boundary dynamics introduce unnecessary complications, and that the model risks venturing beyond empirically constrained physics. Nonetheless, the UFQFT framework defends its position by employing established mathematical tools—notably, holographic entropy formulations, generalized Friedmann equations, and fractal spacetime metrics—with dimensional ranges ($D \approx 2.7-4$) that do not require the unobservable supersymmetric partners or string compactifications often invoked in string theory. Furthermore, the "bubble" concept is grounded not in hypothetical inflationary multiverses but in analogies with known quantum-fluid systems (e.g., quark-gluon plasma), wherein negative external pressure P_{ext} drives expansion via a dynamically evolving effective cosmological constant $\Lambda_{\text{eff}} = 8\pi G P_{\text{ext}}$.

The theoretical legitimacy of UFQFT is bolstered by parallels to respected frameworks. Like string theory, it aspires to unification via higher-dimensional logic, but avoids the speculative baggage of supersymmetry and extra dimensions by emphasizing emergent fractal dynamics in 3+1 dimensions. Its holographic encoding of entropy at the bubble boundary $S = \pi R_{\text{max}}^2/G$ echoes the AdS/CFT correspondence, offering a cosmologically grounded variant of boundary duality. While inflationary cosmology postulates a multiverse of "pocket universes" that remain observationally inaccessible, UFQFT restricts itself to a single, causally connected bubble with unique observational signatures, such as non-Gaussian B-modes in the CMB and gravitational wave spectral resonances (Eq. 4.(Sogukpinar, 2025c) Eq. 26.(Sogukpinar, 2025a)).

To counter critiques of unfalsifiability, the UFQFT model presents a suite of testable predictions, potentially verifiable with current or next-generation instruments. In the near term, it anticipates deviations from Newtonian gravity at sub-millimeter scales due to a modified gravitational potential $V(r) \sim 1/r^{1.7}$ testable through high-precision short-range gravity experiments (e.g., the Cannex experiment). In the cosmic microwave background, hemispherical asymmetries and cold spot anomalies—frequently dismissed as "cosmic variance" in Λ CDM—are interpreted in UFQFT as boundary-induced interference patterns (Eq. 16).(Sogukpinar, 2025a), measurable by CMB-S4 and LiteBIRD. On the gravitational wave frontier, the model predicts discrete resonant modes stemming from fractal coherence, potentially observable by LISA or the Einstein Telescope. Further, at the quantum chromodynamics (QCD) scale, UFQFT anticipates anomalous scaling behavior in deep inelastic scattering experiments—such as $F_2(x) \sim x^{-1.7}$ (Eq. 44).(Sogukpinar, 2025a)—testable at the Electron-Ion Collider (EIC). Over longer timescales, cosmic expansion dynamics could be mapped through evolving dark energy signatures $w(z)$, where deviations from $w = -1$ would support the bulk-pressure interpretation, distinguishable from Λ CDM's static vacuum energy. Moreover, galactic rotation curves, traditionally explained via dark matter halos in Λ CDM, align naturally with the fractal velocity relation $v(r) \propto r^{-0.35}$ predicted by UFQFT (Eq. 36).(Sogukpinar, 2025a), offering another empirical foothold.

From a philosophical and structural standpoint, the Bubble-UFQFT model attempts to bridge the long-standing gap between quantum field theory and general relativity, unifying them under a fractal-topological paradigm. In doing so, it addresses anomalies that Λ CDM struggles to reconcile—such as the Ho'oleilana void and low- ℓ CMB anomalies—by invoking self-similar large-scale clustering consistent with a fractal dimension $D \approx 2.7$. Additionally, the UFQFT approach resonates with insights from loop quantum gravity, where spin networks similarly reject classical singularities, but UFQFT complements this with testable cosmological observables. Its radical implications—reinterpreting

gravity as emergent geometry rather than a fundamental force, and defining particles as fractal field resonances rather than point-like excitations—represent a potential paradigm shift.

Finally, although the Bubble-UFQFT model deviates from the conventional Λ CDM framework and has yet to gain mainstream acceptance, it does so with a rigorous commitment to theoretical coherence and empirical testability. Its falsifiability lies not in philosophical abstraction, but in concrete experimental predictions—from CMB boundary echoes and fractal gravitational potentials to dark energy evolution and collider signatures. If even a subset of these predictions is experimentally validated, UFQFT would not only challenge the dominance of Λ CDM but could redefine our understanding of spacetime, matter, and the cosmos itself.

Toward a Unified Cosmological Paradigm

The Bubble-UFQFT model presents a promising theoretical framework capable of resolving a multitude of longstanding puzzles in contemporary cosmology and fundamental physics. Unlike the Λ CDM paradigm, which offers empirical adequacy but leaves key phenomena unexplained or parametrized via fine-tuned constructs, the Bubble-UFQFT model integrates dark energy, dark matter, cosmic microwave background (CMB) anomalies, and quantum gravity under a unified, geometrically coherent picture. One of the model's most powerful contributions lies in its explanation of cosmic acceleration not through a static cosmological constant (Λ), but via dynamic pressure gradients originating from an external higher-dimensional medium. The resulting effective cosmological term $\Lambda_{\text{eff}} = 8\pi G P_{\text{ext}}$ naturally evolves with the bubble's expansion and aligns with recent observations by DESI and Euclid suggesting a redshift-dependent dark energy equation of state $w(z) \neq -1$. Similarly, dark matter phenomena are reinterpreted within UFQFT as emergent effects of high-dimensional energy field modes Φ , eliminating the need for weakly interacting massive particles (WIMPs) while still reproducing cold dark matter-like behavior (Eq. 42)(Sogukpinar, 2025a).

In addressing the CMB anomalies—notably the suppression of low multipoles, hemispherical power asymmetries, and cold spots—the Bubble-UFQFT model introduces the idea of boundary reflections and fractal field modulations as physically motivated sources of deviation from standard inflationary predictions (Eq. 15, Eq. 26)(Sogukpinar, 2025c,a). The universe's holographic boundary introduces reflective and interference effects that naturally lead to observable anisotropies, offering a compelling alternative to the "cosmic variance" justification often invoked in Λ CDM. Furthermore, by proposing that spacetime emerges from the coherence of scalar Φ and vector Ψ field resonances in a fractal medium (with an effective dimension $D \approx 2.7$, UFQFT constructs a bridge between general relativity and quantum field theory, aligning with the holographic principle while avoiding the quantization ambiguities that plague semiclassical gravity.

The theoretical strength of the model lies in its unified solution space, where many distinct cosmological and particle-level anomalies are explained within a single framework. For example, the initial singularity is replaced by a finite-energy fluctuation within a pre-geometric background, eliminating the need for arbitrary boundary conditions at $t=0$. The Hubble tension—the discrepancy between early- and late-time measurements of the Hubble constant—is resolved by allowing scale-dependent modifications to the expansion rate from external flow fields. Even the proton spin crisis, which challenges parton-based models of internal angular momentum, finds a natural explanation in the context of UFQFT via distributed angular momentum over fractal field gradients (Eq. 41) (Sogukpinar, 2025a).

Looking forward, the model outlines a roadmap of experimental and observational tests capable of validating or falsifying its central claims. In the near term, CMB-S4 and LiteBIRD missions (2025–2035) can test for boundary-induced signatures through non-Gaussianity and multipole power spectra distortions. The LISA and Einstein Telescope gravitational wave observatories (2030–2040) are ideally positioned to detect resonant spectral modes indicative of bubble-boundary reflections (Eq. 4) (Sogukpinar, 2025c), with frequencies $f_{nl} = \frac{\alpha_{nl} c}{2\pi R_{max}}$ tied directly to the holographic horizon size. Quantum simulation platforms, such as cold atom lattices or ion traps, can replicate the vacuum dynamics of coupled Φ – Ψ fields, enabling the study of entanglement entropy scaling consistent with UFQFT predictions $S \propto A^{D/2}$. Additionally, submillimeter gravity experiments like Cannex may soon probe the predicted fractal gravitational potential $V(r) \sim 1/r^{1.7}$, offering crucial evidence of deviations from Newtonian gravity at micron scales (Eq. 7) (Sogukpinar, 2025a).

To realize the full potential of UFQFT, interdisciplinary collaboration is essential. Mathematicians are needed to refine the formalism of fractional Laplacians and generalized boundary conditions appropriate for fractal field theories. Astrophysicists can reexamine data from DESI, Euclid, and SDSS for signs of fractal galaxy clustering (Eq. 36) (Sogukpinar, 2025a), or model large voids such as Ho‘oleilana as emergent features of a non-Euclidean geometry. In quantum field theory, efforts must be directed toward adapting renormalization group techniques for scale-variant geometries and exploring nonlinear couplings (e.g., $\Phi^4 + \Psi^4$) as alternatives to traditional grand unified theories (GUTs) (Eq. 9) (Sogukpinar, 2025a).

Finally, the Bubble-UFQFT model is more than a speculative alternative to Λ CDM—it is a paradigm shift grounded in coherent mathematics, compatible with current observations, and rich in testable predictions. Unlike string theory’s landscape or loop quantum gravity’s abstract graphs, UFQFT roots its unification efforts in observable cosmological structures, from the CMB to galaxy clustering and gravitational waves. Its conception of dark energy as a dynamic, emergent property of the universe’s boundary interactions, and of gravity as a derivative of geometric coherence rather than a fundamental force, opens the door to a radical reinterpretation of cosmological evolution. Moving forward, the critical task will be the empirical testing of its predictions and the development of robust computational tools to model its dynamics. Should these avenues yield confirming evidence, UFQFT may offer the long-sought reconciliation between the quantum and the cosmic—ushering in a new era of theoretical and observational cosmology.

Conclusion

The Bubble-UFQFT framework offers a compelling alternative to the standard Λ CDM cosmology by replacing its foundational singularity and static assumptions with a dynamic, fractal, and holographically bounded model of cosmic evolution. Through the unified dynamics of quantized scalar and vector fields within a higher-dimensional pre-geometric medium, this model addresses key unresolved issues—such as the origin of dark energy, the nature of dark matter, the singularity problem, and the anomalies observed in the CMB and large-scale structure. By grounding cosmic inflation, baryogenesis, and structure formation in field-topological mechanisms rather than ad hoc scalar potentials or symmetry breakings, the model adheres more closely to quantum field theoretic consistency and offers testable predictions in gravitational wave spectra, CMB echoes, and deep inelastic scattering experiments. While challenges remain in observational confirmation and theoretical formalization, the Bubble-UFQFT model paves the way toward a post- Λ CDM cosmology that is physically consistent, mathematically robust, and potentially falsifiable. This marks a critical step forward in our quest to

reconcile general relativity, quantum field theory, and cosmological data into a coherent and predictive theoretical framework.

References

1. Abazajian, K. N., Adshead, P., Ahmed, Z., Allen, S. W., Alonso, D., Arnold, K. S., ... & Wu, W. L. (2016). CMB-S4 science book. arXiv preprint arXiv:1610.02743.
2. Adame, A. G., Aguilar, J., Ahlen, S., Alam, S., Alexander, D. M., ... & Le Goff, J. M. (2024). DESI 2024 IV: Baryon Acoustic Oscillations from the Lyman Alpha Forest. arXiv preprint arXiv:2404.03001.
3. Amaro-Seoane, P., Audley, H., Babak, S., Baker, J., Barausse, E., Bender, P., ... & Zweifel, P. (2017). Laser interferometer space antenna. arXiv preprint arXiv:1702.00786.
4. Ashtekar, A., & Singh, P. (2011). Loop quantum cosmology: a status report. *Classical and Quantum Gravity*, 28(21), 213001.
5. Banks, M. (2025). Euclid mission reveals galaxy treasure trove. *Physics World*, 38(5), 5i.
6. Böhringer, H., Schuecker, P., Guzzo, L., Collins, C. A., Voges, W., Cruddace, R. G., ... & Shaver, P. (2004). The ROSAT-ESO Flux Limited X-ray (REFLEX) Galaxy cluster survey-V. The cluster catalogue. *Astronomy & Astrophysics*, 425(1), 367-383.
7. Bousso, R. (2002). The holographic principle. *Reviews of Modern Physics*, 74(3), 825-874.
8. Bojowald, M. (2007). Singularities and quantum gravity. In *AIP Conference Proceedings* (Vol. 910, No. 1, pp. 294-333). American Institute of Physics
9. Calcagni, G. (2010). Fractal universe and quantum gravity. *Physical Review Letters*, 104(25), 251301.
10. Eisenstein, D. J., Zehavi, I., Hogg, D. W., Scoccimarro, R., Blanton, M. R., Nichol, R. C., ... & York, D. G. (2005). Detection of the baryon acoustic peak in the large-scale correlation function of SDSS luminous red galaxies. *The Astrophysical Journal*, 633(2), 560.
11. Hawking, S., & Penrose, R. (1970). Singularities in cosmology. *Proceedings of the Royal Society A*, 314(1519), 529-548.
12. Kuposov, S. E., Allende Prieto, C., Cooper, A. P., Li, T. S., Beraldo e Silva, L., Kim, B., ... & Zhou, Z. (2024). DESI Early Data Release Milky Way Survey value-added catalogue. *Monthly Notices of the Royal Astronomical Society*, 533(1), 1012-1031.
13. Lee, J. G., Adelberger, E. G., Cook, T. S., Fleischer, S. M., & Heckel, B. R. (2020). New test of the gravitational $1/r^2$ law at separations down to 52 μ m. *Physical Review Letters*, 124(10), 101101.
14. Maldacena, J. (2024). The ads/cft correspondence. In *Handbook of Quantum Gravity* (pp. 2963-2986). Singapore: Springer Nature Singapore.
15. Nottale, L. (2011). *Scale relativity and fractal space-time: a new approach to unifying relativity and quantum mechanics*. World Scientific.

16. Padmanabhan, T. (2003). Cosmological constant: The weight of the vacuum. *Physics Reports*, 380(5-6), 235-320.
17. Planck Collaboration, P., Abuter, R., Amorim, A., Bauböck, M., Berger, J. P., Bonnet, H., ... & Zeeuw, P. T. (2018). *Astronomy & Astrophysics*. EDP Sciences, 594, A13.
18. Punturo, M., Abernathy, M., Acernese, F., Allen, B., Andersson, N., Arun, K., ... & Yamamoto, K. (2010). The Einstein Telescope: A third-generation gravitational wave observatory. *Classical and Quantum Gravity*, 27(19), 194002.
19. Riess, A. G., Filippenko, A. V., Challis, P., Clocchiatti, A., Diercks, A., Garnavich, P. M., ... & Tonry, J. (1998). Observational evidence from supernovae for an accelerating universe and a cosmological constant. *The astronomical journal*, 116(3), 1009.
20. Rovelli, C. (2004). *Quantum gravity*. Cambridge university press.
21. Schwarz, D. J., Copi, C. J., Huterer, D., & Starkman, G. D. (2016). CMB anomalies after Planck. *Classical and Quantum Gravity*, 33(18), 184001.
22. Sogukpinar, H. (2024a). Unified Fractal Quantum Field Theory (UFQFT): Matter as Geometric Resonances of Unified Energy-Charge Fields. *ScienceOpen Preprints*. 2025. DOI: 10.14293/PR2199.001845.v1
23. Sogukpinar, H. (2024b). Fractal Geometry in Atomic Nuclei: A New Paradigm for Nuclear Structure and Decay. *ScienceOpen Preprints*. 2025. DOI: 10.14293/PR2199.001832.v1
24. Sogukpinar, H. (2024c). The Bubble Theory of the Universe: A Quantum Fluid Perspective on Cosmological Emergence. *ScienceOpen Preprints*. 2025. DOI: 10.14293/PR2199.001830.v1
25. Sogukpinar, H. (2024d). Halo Nuclei Beyond The Shell Model: A Fractal-Dimensional Approach. *ScienceOpen Preprints*. 2025. DOI: 10.14293/PR2199.001850.v1
26. Taoso, M., Bertone, G., & Masiero, A. (2008). Dark matter candidates: a ten-point test. *Journal of Cosmology and Astroparticle Physics*, 2008(03), 022.
27. Weinberg, S. (1989). The cosmological constant problem. *Reviews of Modern Physics*, 61(1), 1-23.
28. Zibin, J. P., Moss, A., & Scott, D. (2008). Can we avoid dark energy?. *Physical Review Letters*, 101(25), 251303.