

Neutron Stars as Fractal Dipole Liquids: A Unified Fractal Quantum Field Theory Approach

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Abstract

Neutron stars represent one of the most extreme laboratories in the universe, where nuclear matter is compressed beyond terrestrial densities yet does not collapse into a black hole. In conventional astrophysics, neutron star stability is explained through nuclear degeneracy pressure and superfluid phases of neutrons. In this work, we propose a novel reinterpretation based on the Unified Fractal Quantum Field Theory (UFQFT). We argue that nucleons retain their fundamental structure under extreme gravitational confinement but undergo a collective phase transition into a “fractal dipole liquid.” In this state, neutrons form molecular-like bound configurations stabilized by their intrinsic dipole moments, preventing weak decay and producing a macroscopic “neutron sea.” Proton-to-neutron conversion via electron capture further enhances this stability while driving an effective cooling mechanism. Within this framework, neutron stars occupy a distinct phase space between ordinary nuclear matter and black hole cores, characterized by a fractal dimension $D \approx 2.65-2.7$. The transition from neutron star to black hole is interpreted as a shift from a multi-nucleon dipole-resonant liquid to a single-core fractal nucleon, achievable only through accretion or stellar mergers that increase mass beyond a critical threshold. We discuss observational implications for cooling curves, gravitational wave signatures, and high-energy transients, providing a pathway to distinguish neutron stars from low-mass black holes. This approach unifies nuclear stability, stellar evolution, and black hole formation under a single fractal field-theoretic paradigm.

Keywords: neutron stars, neutron liquid, dipole resonance, Unified Fractal Quantum Field Theory (UFQFT), black hole transition, nucleon stability, equation of state, electron capture, gravitational collapse, neutron star mergers

1. Introduction

The study of neutron stars represents one of the most challenging problems in theoretical astrophysics, sitting at the intersection of nuclear physics, particle physics, and general relativity. Conventional models describe these objects through the lens of the Equation of State (EoS) of ultra-dense matter, where stability is achieved by a balance between gravitational collapse and the pressure from degenerate neutrons and repulsive nuclear interactions (Lattimer and Prakash 2007). However, significant uncertainties persist at supra-nuclear densities, leading to a wide range of predicted masses and radii and opening the door for alternative theoretical frameworks like the Unified Fractal Quantum Field Theory (UFQFT). The standard paradigm heavily relies on quantum many-body phenomena. A cornerstone of this model is the concept of neutron superfluidity and proton superconductivity in the core, first proposed by Migdal (1959) and elaborated by Baym et al. (1969), Ravenhall et al. (1983), and Demorest et al. (2010). These phases are invoked to explain observable phenomena such as pulsar glitches and thermal evolution. Furthermore, the transition from the solid crust to the liquid core is theorized to involve exotic “nuclear pasta” phases—a hierarchy of rod-like and slab-like nuclear structures that minimize the system's energy at densities near nuclear saturation (Ravenhall et al. (1983), Pethick et al. (1995), and Woosley et al. (1994)). While these models are sophisticated, they face persistent challenges, most notably the “hyperon puzzle,” where the introduction of new degrees of

freedom often softens the EoS, making it difficult to reconcile with the observed existence of very massive neutron stars (Demorest et al. 2010; Antoniadis et al. 2013).

The UFQFT framework, as developed in a series of foundational papers by Sogukpinar (2025^a), posits a radical reinterpretation of physical structures, from elementary particles to cosmological scales, based on fractal geometry and field resonances (Sogukpinar, 2025^b). This framework challenges the standard model by suggesting that phenomena like superfluidity are not emergent from attractive pairing interactions alone but are manifestations of a deeper, fractal organization of dipole resonances within a fundamental charge field (Ψ). This perspective recasts the nuclear pasta phases not as distinct geometric shapes but as intermediate states in a continuous "dimensional flow" of the fractal structure as density increases, transitioning from a quasi-3D state ($D \approx 3$) to a fractal liquid with $D \approx 2.7$. This concept of dimensional flow is central to UFQFT and is argued to be a universal principle. A key strength of the UFQFT approach is its proposed solution to the stability of neutrons against weak decay. While the standard model relies on Pauli blocking within a degenerate Fermi gas to inhibit the beta-decay phase space, UFQFT posits a more direct suppression mechanism. It suggests that the integration of neutrons into a collective fractal dipole resonance lattice energetically disfavors individual particle decay, effectively locking them into a stable configuration. This aligns with the observed stability but offers a fundamentally different microscopic explanation, rooted in the same principles used to reinterpret other fundamental problems like the proton spin structure (Sogukpinar, 2025^c). Finally, the UFQFT provides a novel interpretation of the maximum mass limit and the transition to a black hole (Sogukpinar, 2025^d). Conventional theory is governed by the Tolman-Oppenheimer-Volkoff limit within General Relativity, where collapse is inevitable once a critical mass is surpassed. In contrast, the UFQFT frames this transition as a phase change in the fractal dimension of the matter itself—from a multi-nucleon fractal liquid ($D \approx 2.7$) to a single-core fractal nucleon ($D \rightarrow 2$). This shift in paradigm naturally allows for a stiffer EoS capable of supporting higher-mass neutron stars without invoking exotic particles, potentially offering an explanation for recent astronomical observations of massive compact objects. This cosmological-scale phase transition mirrors the UFQFT's approach to other grand challenges, such as unifying dark matter and dark energy as manifestations of a neutral fractal resonance field (Sogukpinar, 2025^e).

This work reinterprets neutron stars within the framework of Unified Fractal Quantum Field Theory (UFQFT). Instead of being supported solely by degeneracy pressure, neutron stars are described as collective neutron liquids, where fractal dipole resonances stabilize nucleons against decay under extreme gravity. Proton-to-neutron conversion via electron capture provides a natural cooling mechanism, while the density-dependent fractal dimension ($D \sim 2.65-2.7$) stiffens the equation of state and prevents collapse. In this view, neutron stars represent a stable multi-nucleon fractal phase, distinct from black holes, which correspond to a single-core fractal condensate.

2. Structure and Composition of Neutron Stars

In conventional astrophysics, the structure of a neutron star is governed by the balance between gravitational compression and the internal pressure arising from degenerate fermionic matter. The equation of state (EoS) at supra-nuclear densities ($\rho \gtrsim 10^{14} \text{ g cm}^{-3}$) determines the maximum mass, radius, and stability of neutron stars. The classical description treats the stellar core as a degenerate Fermi gas of neutrons with additional contributions from protons, electrons, and, at higher densities, hyperons or quark matter (Lattimer and Prakash 2007). The EoS remains uncertain due to the lack of direct experimental constraints on nuclear interactions at such extreme densities, leading to a wide range of theoretical models from purely nucleonic matter to exotic phases.

In the UFQFT framework, however, the EoS emerges not from particle degeneracy alone but from the collective resonance of fractal fields. Neutrons are not isolated fermions but elements of a fractal dipole liquid, where their intrinsic dipole moments couple through the charge-like Ψ -field. This interaction produces a fractal-dependent pressure term that stiffens the EoS compared to classical models. Consequently, the UFQFT predicts that neutron stars can achieve stability without invoking exotic matter phases, as the fractal resonance effectively enhances resistance against gravitational collapse. A generalized EoS incorporating this new pressure component can be expressed as:

$$P_{total} = P_{deg} + P_{nuc} + P_{\Psi} \quad (1)$$

where P_{deg} is the degeneracy pressure of neutrons, P_{nuc} represents contributions from nuclear forces, and P_{Ψ} denotes the repulsive pressure arising from fractal dipole resonances. The UFQFT contribution can be parameterized as:

$$P_{\Psi} = K(D) \rho^{\Gamma(D)} \quad (2)$$

Where, $K(D)$ is a fractal-dependent proportionality constant and $\Gamma(D)$ is an effective polytropic index that stiffens as the fractal dimension approaches the holographic limit $D \rightarrow 2$. In the standard picture, neutrons dominate the stellar interior, while protons and electrons remain in equilibrium through beta processes:



At sufficiently high densities, protons capture electrons to form neutrons, increasing the neutron fraction. The star therefore evolves toward a neutron-rich composition, with residual protons and electrons maintaining charge neutrality.

In UFQFT, this equilibrium is reinterpreted as a field phase transition. The conversion of protons into neutrons corresponds to a shift in the resonance balance between Φ (energy) and Ψ (charge) fields. Neutrons thus become the energetically favored resonance configuration under extreme compression. Importantly, the collective organization of neutrons into dipole-resonant clusters suppresses weak decay, explaining why neutrons within the star remain stable despite the short lifetime (~ 880 s) of free neutrons in vacuum. Electrons act not only as charge balancers but as mediators of energy transfer into the fractal core, contributing to the cooling dynamics of neutron stars.

Classical nuclear physics views neutron star matter as stabilized by a competition between short-range strong interactions and long-range gravitational attraction. As the gravitational field intensifies, neutrons are compressed into a superfluid state where pairing correlations further enhance stability. However, beyond a certain critical mass (the Tolman–Oppenheimer–Volkoff limit), gravity overwhelms nuclear forces, leading to collapse into a black hole.

In the UFQFT paradigm, gravitational confinement is counterbalanced not only by degeneracy and strong nuclear forces but also by the repulsive component of the Ψ -field. The effective fractal pressure arising from dipole resonances provides an additional stabilizing term that delays collapse. This predicts a higher effective mass limit for neutron stars compared to classical estimates, offering a natural explanation for observations of massive neutron stars exceeding $2 M_{\odot}$. Furthermore, the UFQFT framework positions neutron stars as an intermediate phase between ordinary nuclear matter and black hole cores: a multi-nucleon fractal liquid that transitions to a single-core fractal nucleon only when sufficient mass is accreted.

3. Conventional Theoretical Models

In the conventional framework of nuclear astrophysics, neutron stars are modeled as exhibiting exotic quantum states of matter due to their extreme densities and low temperatures relative to the Fermi energy. Neutrons in the inner crust and outer core are predicted to form Cooper pairs, leading to superfluidity, while protons—being charged—are expected to enter a type-II superconducting state (Migdal 1959; Baym, Pethick, and Pines 1969). These collective phases are invoked to explain observed phenomena such as pulsar glitches, rapid post-glitch relaxation, and the thermal evolution of neutron stars. The superfluid and superconducting components are believed to coexist with a rigid crust, resulting in a complex interplay of vortices and flux tubes that govern stellar dynamics.

From the perspective of the Unified Fractal Quantum Field Theory (UFQFT), these superfluid and superconducting phases are not emergent many-body states in the traditional sense but manifestations of fractal dipole resonances within the Ψ -field. Neutron pairing arises not merely from attractive nuclear forces but from the collective alignment of their intrinsic dipole moments under extreme compression, forming a fractal liquid lattice rather than a conventional BCS condensate. Similarly, proton superconductivity is reinterpreted as a fractal resonance stabilization process, where charge coherence emerges from the underlying fractal geometry of the fields. Thus, the UFQFT reframes superfluidity and superconductivity as geometric consequences of fractal field interactions rather than solely quantum many-body effects.

In standard models, the crust-core transition is governed by the dissolution of neutron-rich nuclei into a uniform nuclear medium. The outer crust consists of heavy nuclei embedded in a degenerate electron gas, while the inner crust contains neutron-rich nuclei coexisting with free neutrons. At densities above the nuclear saturation density ($\rho \sim 2.8 \times 10^{14} \text{ g cm}^{-3}$), the nuclei dissolve completely, giving way to a homogeneous neutron-rich core. Intermediate structures—“nuclear pasta” phases—are thought to exist in the transition region, featuring rod-like and slab-like nuclear configurations that minimize the system’s energy (Ravenhall, Pethick, and Wilson 1983).

In the UFQFT framework, the crust-core transition is interpreted as a dimensional flow of the fractal structure. At lower densities, matter retains a quasi-three-dimensional character ($D \approx 3$), supporting nuclear clustering. As density increases, the effective fractal dimension approaches $D \approx 2.7$, and the system transitions into a collective neutron dipole liquid where individual nuclear identities dissolve into the fractal field. What conventional models describe as nuclear pasta is thus recast as intermediate fractal resonance states, emergent from the progressive reorganization of Φ and Ψ fields.

While conventional models capture many macroscopic features of neutron stars, they face several unresolved issues. The uncertainty in the nuclear equation of state at supra-nuclear densities leads to wide variations in predicted neutron star masses and radii (Lattimer and Prakash 2007). The presence of hyperons, meson condensates, or quark matter in the core further complicates modeling, often leading to the so-called “hyperon puzzle,” where the inclusion of exotic particles softens the EoS excessively, contradicting observations of neutron stars above two solar masses. Furthermore, general relativity (GR) predicts that sufficiently massive neutron stars inevitably collapse into black holes once the Tolman–Oppenheimer–Volkoff limit is surpassed, leaving open the question of how nature accommodates massive compact objects that seem to exceed these theoretical constraints.

The UFQFT framework addresses these limitations by replacing the singular-collapse paradigm with a fractal field stabilization mechanism. Instead of invoking exotic degrees of freedom or relying on uncertain nuclear potentials, UFQFT introduces a repulsive pressure term (P_Ψ) arising from the fractal resonance of neutron dipoles. This term stiffens the EoS naturally, allowing neutron stars to support larger masses without collapsing. Moreover, UFQFT avoids the conceptual difficulties of singularities by positioning neutron stars and black holes along a continuous fractal phase diagram: neutron stars

correspond to multi-nucleon fractal liquids ($D \sim 2.65-2.7$), whereas black holes emerge only when the system transitions to a single-core fractal nucleon with $D \rightarrow 2$.

4. Unified Fractal Quantum Field Theory (UFQFT) Perspective

The conventional description of neutron stars relies on nuclear interactions and gravitational confinement, but within the Unified Fractal Quantum Field Theory (UFQFT), the structure of neutron matter is governed by fractal dipole resonances of the fundamental Φ (energy) and Ψ (charge) fields. In this view, neutron stars are stabilized not solely by degeneracy pressure or nuclear forces but by the collective resonance of nucleon dipoles, which organize into a fractal liquid structure.

Each neutron possesses a finite electric dipole moment p_n , which under extreme compression aligns with neighboring dipoles, forming resonance chains. The macroscopic stabilization pressure is thus a fractal sum of microscopic dipole-dipole interactions:

$$P_\Psi \propto \sum_{i,j} \frac{p_i p_j}{r_{ij}^3} \sim \rho^\beta D_f \quad (4)$$

Where, r_{ij} is the inter-nucleon distance, ρ is the baryon density, β is an exponent capturing the dipole scaling, D_f is the effective fractal dimension of the neutron liquid. In the limit of strong compression, constructive resonance enhances P_Ψ , leading to a repulsive stabilization mechanism that counterbalances gravity.

Unlike black holes, where nucleons dissolve into a single fractal quantum entity, neutron stars preserve individual nucleonic identity. UFQFT interprets this as the persistence of a multi-core fractal configuration. The effective potential for a neutron star core can be written as:

$$V_{eff}(r) = V_N(r) + V_\Psi(r) - \frac{GMm}{r} \quad (5)$$

Where, V_N is the residual nuclear interaction, $V_\Psi(r) \sim \frac{p_n^2}{r^3}$ represents the dipole resonance potential, $\frac{GMm}{r}$ is the gravitational term. Equilibrium is reached when:

$$\frac{dV_{eff}}{dr} = 0 \Rightarrow F_N + F_\Psi = F_G \quad (6)$$

showing that neutron stability under compression is a direct balance between nuclear, dipolar, and gravitational forces. The key UFQFT insight is that the effective fractal dimension of neutron matter evolves with density. At low densities, nucleons remain quasi-classical ($D \approx 3$). At neutron star densities, the system transitions toward a fractal liquid:

$$D(\rho) = 3 - \gamma \left(\frac{\rho}{\rho_c} \right) \quad (7)$$

Where, $\rho_c \sim 2.8 \times 10^{14} \text{ g cm}^{-3}$ is the nuclear saturation density, γ is a proportionality constant ($\gamma \approx 0.3$). Thus, for neutron stars: $D \sim 2.65-2.7$ which corresponds to a stable fractal dipole liquid phase. Collapse into a black hole occurs only when $D \rightarrow 2$, marking the transition from multi-nucleon resonance to a single-core fractal entity. Combining the above, the pressure in a neutron star within UFQFT can be modeled as:

$$P_{UFQFT}(\rho) = P_{deg}(\rho) + A \rho^\beta D(\rho) \quad (8)$$

Where, $P_{deg}(\rho)$ is the standard Fermi degeneracy pressure, A is a coupling constant linking dipole resonance to density, $D(\rho)$ is the fractal dimension function. This stiffens the equation of state compared

to standard nuclear models, allowing neutron stars to remain stable at higher masses and delaying collapse into black holes.

5. The Neutron Liquid and Collective Stability

In the UFQFT framework, nucleons within neutron stars do not behave as isolated particles but instead form molecular-like dipole bound states. Each neutron carries a small intrinsic dipole moment p_n , and under extreme compression, neighboring dipoles align to minimize energy. The interaction energy of such a dipolar cluster can be approximated as:

$$E_{dipole} \approx -\sum_{i,j} \sum_{i,j} \frac{p_i p_j}{r_{ij}^3} \cos \theta_{ij} \quad (9)$$

where θ_{ij} is the relative alignment angle. In the collective phase, constructive alignment ($\cos \theta_{ij} \approx 1$) stabilizes the system into a fractal neutron liquid lattice, analogous to molecular bonds in condensed matter systems.

In isolation, neutrons undergo weak decay with a mean lifetime of $\tau_n \approx 880$ s. However, within the collective fractal phase, this decay channel is suppressed. The suppression arises because the dipole resonance locks neutrons into correlated states that energetically disfavor single-particle decay. The decay rate can be modeled as:

$$\Gamma_{eff} = \Gamma_0 e^{-\lambda D_f} \quad (10)$$

Where, Γ_0 is the free neutron decay rate, D_f is the fractal dimension of the neutron liquid, λ is a suppression constant. For $D_f \sim 2.65-2.7$, the exponential suppression reduces the decay probability by many orders of magnitude, explaining the effective stability of neutrons inside neutron stars. At sufficiently high densities, protons in the stellar interior undergo electron capture: $p + e^- \leftrightarrow n + \nu_e$. This process converts residual protons into neutrons, further populating the neutron sea while releasing neutrinos that escape the star, providing an efficient cooling channel. The UFQFT interpretation modifies this by including dipole resonance energy in the balance:

$$\mu_p + \mu_e = \mu_n + \mu_\nu + \Delta E_\psi \quad (11)$$

where ΔE_ψ accounts for the energy contribution of the fractal dipole field. Thus, electron capture is not only a weak interaction process but also mediated by the fractal stabilization of the neutron lattice, enhancing cooling efficiency. The collective stabilization of neutrons and proton-to-neutron conversion result in the emergence of a macroscopic neutron sea, a quantum liquid in which individual nucleonic identities blur into a coherent fractal field. The effective pressure of this phase can be written as:

$$P_{neutron-sea} = P_{deg} + P_\psi \quad (12)$$

with

$$P_\psi \sim \rho^\beta D_f \quad (13)$$

where P_{deg} is the degeneracy pressure, and P_ψ arises from dipole resonance. This combined pressure explains why neutron stars can resist collapse into black holes up to several solar masses, maintaining structural integrity as a fractal neutron sea rather than collapsing directly into a singularity.

6. Evolution and Transition Scenarios

Neutron stars in binary systems or dense stellar environments often accrete matter from companion stars or interstellar gas. Accretion increases both the total mass M and the central density ρ_c , driving the system closer to instability. Within the UFQFT framework, accretion enhances the fractal dipole density ρ_ψ , modifying the balance between degeneracy pressure and gravitational pull: $P_{total} = P_{deg} + P_\psi - P_{grav}$. As the stellar mass grows, the fractal dimension approaches a critical threshold ($D \rightarrow 2.7$), stiffening the equation of state but also reducing the margin of stability. Once the mass surpasses the Tolman–Oppenheimer–Volkoff (TOV) limit, conventional models predict collapse. However, in UFQFT, this collapse is delayed by repulsive dipole resonance effects until a new critical transition mass M_{crit} is reached.

When two neutron stars merge, the combined mass often exceeds the stability range of a single neutron star. Classical GR (General Relativity) predicts rapid collapse into a black hole; however, the UFQFT model introduces an intermediate hyper-massive neutron sea phase. During the merger, the fractal dipole fields amplify due to extreme compression, producing transient oscillations in the effective repulsive pressure:

$$P_\psi(t) \sim P_{\psi,0}[1 + \delta \sin(\omega t)] \quad (14)$$

where δ quantifies oscillation amplitude and ω the resonance frequency. These oscillations may leave imprints in the post-merger gravitational wave spectrum, observable as deviations from standard GR templates in detectors such as LIGO, Virgo, and future LISA.

Additionally, kilonova emission results from mass ejection during this unstable phase. UFQFT predicts that the amount of ejecta depends not only on angular momentum redistribution but also on the dipole resonance energy budget, potentially explaining variations in kilonova luminosity across observed events. The transition from a neutron star to a black hole occurs when gravitational binding energy per baryon exceeds the stabilizing contribution of the fractal dipole resonances. This condition can be expressed as:

$$\frac{GM^2}{R} \geq \kappa N E_\psi \quad (15)$$

Where, M is the neutron star mass, R its radius, N the number of nucleons, E_ψ the average dipole resonance energy per nucleon, κ a geometric factor related to fractal coherence. If this inequality is satisfied, the neutron sea collapses into a single-core state characterized by a fractal black hole interior (UFQFT core). In the UFQFT description, the fundamental difference between neutron stars and black holes is structural coherence:

- In neutron stars, nucleons remain as individual resonant dipoles within a correlated neutron liquid (N-body fractal state).
- In black holes, the system undergoes a phase transition into a single coherent resonance (1-body fractal state), where all nucleons lose individuality and merge into a unified fractal wavefunction $\Xi(r)$.

Mathematically, this can be represented as the limit:

$$\lim_{M \rightarrow M_{crit}} \sum_{i=1}^N \psi_i(r) \rightarrow \Xi(r) \quad (16)$$

where ψ_i are individual nucleon wavefunctions and $\Xi(r)$ the collective black hole core wavefunction. This transition corresponds to the collapse of a neutron sea into a fractal quark–field lattice, marking the birth of a black hole.

7. Observational Consequences and Astrophysical Tests

Rotating neutron stars (pulsars) provide precise natural clocks, and deviations in their timing, known as glitches, reveal information about the star's internal structure. Conventional models attribute glitches to superfluid vortex unpinning in the crust. However, within the UFQFT framework, glitches are interpreted as collective rearrangements of fractal dipole resonances inside the neutron liquid. These rearrangements can lead to sudden angular momentum transfer between the superfluid core and the crust. Prediction:

$$\Delta\nu \propto \frac{\Delta E_\psi}{I} \quad (17)$$

where $\Delta\nu$ is the observed change in pulsar frequency, ΔE_ψ the released resonance energy, and I the moment of inertia. This establishes a direct correlation between glitch magnitude and fractal resonance activity, testable through long-term pulsar timing surveys.

Binary neutron star (BNS) mergers and neutron star–black hole mergers are primary sources of gravitational waves. In classical GR, post-merger oscillations quickly dampen into black hole ringdown signatures. The UFQFT scenario predicts additional oscillatory features due to the temporary formation of a hyper-massive neutron sea sustained by dipole resonance pressure.

These features may manifest as post-merger spectral peaks in the kHz range:

$$f_\psi \sim \frac{1}{2\pi} \sqrt{\frac{P_\psi}{\rho R^2}} \quad (18)$$

where P_ψ is the resonance pressure, ρ the density, and R the core radius. Detection of such deviations by LIGO, Virgo, KAGRA, or future LISA would provide a strong observational probe of UFQFT physics.

Electromagnetic counterparts of BNS mergers (kilonovae) are powered by r-process nucleosynthesis in ejected matter. Standard nuclear models predict ejecta mass based primarily on angular momentum redistribution. UFQFT, however, predicts that dipole resonance energy release contributes an additional heating mechanism, potentially enhancing luminosity.

Observable signature: unusually bright or asymmetric kilonova events could signal resonance-driven energy contributions. Future observations with JWST and next-generation optical/infrared surveys may test this hypothesis.

Observationally, SMBHs rarely exceed masses of $\sim 10^{10} M_\odot$. In UFQFT, this limit emerges naturally from the critical charge-to-mass ratio (α_*) that sets the maximum stable black hole mass. Once $M > M_{\text{crit}}$ (Sogukpinar, 2025^d), the fractal repulsion dominates, halting further accretion or triggering mass-shedding instabilities. Prediction: galaxies hosting SMBHs near M_{crit} should display suppressed accretion signatures, unstable jet activity, or explosive feedback episodes, observable in high-resolution quasar surveys with the Event Horizon Telescope (EHT) and future radio interferometers.

Although direct probes of black hole interiors remain inaccessible, laboratory analogs—such as acoustic black holes, optical horizon systems, and cold-atom condensates—provide test beds for Hawking-like radiation. The UFQFT model predicts that such analog systems should exhibit fractal-like correlations in emitted spectra, reflecting the underlying microstate encoding. Detecting these correlations experimentally would indirectly support the UFQFT mechanism for information storage and release. Finally, UFQFT yields distinct, testable observational consequences that extend beyond the predictions of standard GR and nuclear physics: (1) pulsar glitch scaling with fractal resonance energy,

(2) post-merger gravitational wave anomalies, (3) enhanced kilonova luminosities, (4) SMBH mass cutoff signatures, and (5) fractal correlations in laboratory analogs. Each of these phenomena provides an empirical pathway to validate—or falsify—the fractal quantum field description of neutron stars and black holes.

Conclusion

In this work, we have re-examined the physics of neutron stars within the framework of Unified Fractal Quantum Field Theory (UFQFT). Unlike conventional approaches that rely primarily on neutron degeneracy pressure and nuclear interactions, the UFQFT perspective introduces the concept of fractal dipole resonances, providing a new mechanism for the stability of neutron matter under extreme gravitational confinement. Our analysis suggests that neutrons within the star do not exist as isolated fermions but form a collective liquid-like state—a “neutron sea”—where dipole interactions between nucleons establish molecular-like correlations. This collective binding explains the suppression of weak decay processes that would otherwise destabilize free neutrons, ensuring the persistence of the star. Moreover, the proton-to-neutron conversion via electron capture acts as a natural cooling channel, allowing the system to regulate its thermal evolution while enhancing the overall neutron fraction.

From the UFQFT standpoint, the stability of neutron stars is a balance between two competing effects: gravitational confinement, which drives matter toward collapse, and the fractal resonance pressure, which emerges from the self-organizing properties of dense nucleon matter. This resonance can be formally connected to a density-dependent fractal dimension $D \sim 2.65\text{--}2.7$, which stiffens the effective equation of state (EoS) and delays the transition to a black hole phase. Importantly, this framework explains why neutron stars maintain nucleonic integrity, while black holes represent a distinct phase where matter condenses into a single-core fractal condensate.

The conclusions drawn here have direct astrophysical implications. Pulsar timing irregularities (glitches), thermal evolution curves, and kilonova emissions in neutron star mergers may all carry imprints of the fractal neutron liquid. In particular, the suppression of weak decay and the resilience of the neutron sea provide a natural explanation for the observed long-term stability of massive neutron stars approaching two solar masses.

Finally, the UFQFT model reframes neutron stars as macroscopic nuclear fluids stabilized by fractal dipole resonances, rather than merely by degeneracy pressure. This new picture resolves key inconsistencies in standard nuclear/GR-based models and establishes a coherent theoretical foundation for understanding neutron star structure, stability, and evolution. Further work—both theoretical and observational—is required to refine the quantitative predictions of the model and to identify clear signatures that can distinguish it from conventional frameworks.

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