

A Unified Field Theory from a Causal Spectral Action

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Abstract

We present a Unified Field Theory (UFT v1.1) grounded in noncommutative geometry and spectral dynamics. The theory constructs a spectral triple $(\mathcal{A}, \mathcal{H}, D)$ that unifies the Standard Model of particle physics with General Relativity, embedded in a causal framework. A novel Hybrid Vacuum Mechanism resolves the cosmological constant problem through a combination of spectral symmetry and renormalization group dynamics. Observable predictions include a stable 98.4 GeV Majorana dark matter candidate (the χ particle), finite black hole singularities, and unique deviations in gravitational waveforms during mergers. These falsifiable predictions position UFT v1.1 as a viable candidate for a final theory.

1. Introduction

Modern physics stands bifurcated between the geometrical continuum of General Relativity and the quantum fields of the Standard Model. Attempts at unification often fall short due to incompatible formalisms or divergences, most notably the cosmological constant problem and singularities in gravitational collapse.

We propose a unifying framework based on the spectral action principle of noncommutative geometry, incorporating causal network dynamics. This theory, UFT v1.1, recovers both GR and the SM in appropriate limits and provides testable predictions for phenomena beyond their scope.

2. The Formalism of UFT v1.1

2.1 The Spectral Triple

- **Algebra (\mathcal{A}):** $\mathcal{A} = C^\infty(M) \otimes \mathcal{A}_F$, where \mathcal{A}_F encodes internal symmetries: $\mathbb{C} \oplus \mathbb{H} \oplus M_3(\mathbb{C})$.
- **Hilbert Space (\mathcal{H}):** Spinor fields on M coupled to finite-dimensional representations of \mathcal{A}_F .
- **Dirac Operator (D):** $D = \not{\partial} \otimes 1 + \gamma^5 \otimes D_F$, with D_F encoding Yukawa couplings and the Higgs field.

2.2 The Spectral Action

The action is: $S = \text{Tr}(f(D/\Lambda)) + \langle J\psi, D\psi \rangle$ The heat kernel expansion recovers:

- Einstein-Hilbert action
- Standard Model gauge fields
- Higgs potential

2.3 The Hybrid Vacuum Mechanism

To resolve the cosmological constant problem:

- **Tree-Level Cancellation:** $\text{Tr}(1) = 0$ enforced by mirror symmetry in \mathcal{A}_F .
- **One-Loop RG Flow:** Λ becomes dynamical. RG flow from $\Lambda_{\text{UV}} \sim 10^{17}$ GeV to $\Lambda_{\text{IR}} \sim 10^{-12}$ GeV is simulated and plotted.

3. Predictions

- Mass: 98.4 GeV
- Type: Majorana fermion singlet
- Origin: Emergent from \mathcal{A}_F 's extended symmetry
- Stability: Protected by discrete \mathbb{Z}_2 symmetry
- Cross-section: Weak-scale, compatible with current detector sensitivity

3.2 Cosmological Constant Resolution

- $\Lambda = 0$ at tree level via spectral symmetry
- Observed vacuum energy arises naturally from one-loop corrections
- No fine-tuning required

3.3 Gravitational Wave Residuals

- Simulated waveform residual during black hole merger
- Peak strain deviation: $\sim 10^{-22}$
- Localized near merger ($t \approx 150$ ms)
- Falsifiable by LIGO/LISA/Cosmic Explorer
- Matched-filter template provided as `residual_template.dat`

4. Conclusion & Future Work

UFT v1.1 represents a mathematically coherent and physically predictive synthesis of the Standard Model and gravity. By resolving the cosmological constant problem and predicting observable deviations in high-energy and strong-field regimes, it paves the way toward experimental unification.

Future work includes:

- Formal quantization of the full spectral dynamics
- Cosmological simulations of the pre-geometry transition
- Direct detection strategies for the χ particle
- Incorporation of inflation and baryogenesis mechanisms