

# Coupled Fields and Gravitation: A Deterministic Real-Field Theory of Quantum Gravity without Singularities

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## Abstract

This work develops a unified real-field framework that links quantum mechanics and gravitation through the dynamics of coupled fields (CF). In the CF model, fermions are not point particles nor wavefunctions in Hilbert space, but deterministic configurations of two interacting real-fields in spacetime. Their internal coupling, tension, and topology generate mass, spin, and electric charge, while quantization emerges from periodic and topological constraints rather than probabilistic postulates. We extend the CF Lagrangian to curved spacetime and show that spacetime curvature arises from gradients in coupled-field energy density, rather than from mass-energy treated as a point source. Gravity therefore appears as a macroscopic, elastic response of spacetime to coherent variations in coupled-field stress. Within this framework, Planck's constant  $\hbar$  and Newton's constant  $G$  originate from the same internal field structure, linking quantum and gravitational scales through a common coupling mechanism. The theory predicts finite stress-energy distributions for all fermionic matter, eliminating curvature singularities and enforcing an upper density bound consistent with the Planck scale. Quantum gravity thus emerges without quantizing spacetime itself: curvature remains continuous, while discreteness enters through the oscillatory microstructure of matter. The coupled-fields framework provides a deterministic, physically grounded route toward unifying quantum mechanics and general relativity within a single real-field ontology. By "real-field ontology", we mean that the fundamental dynamical variables are real-valued classical fields in spacetime; complex wavefunctions and operator structures arise as effective descriptions of their coupled phase dynamics.

## Keywords

Coupled Fields, Quantum Gravity, Planck Density, Spin-Curvature

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## 1. Introduction

A central challenge in fundamental physics is reconciling the probabilistic formalism of quantum mechanics with the geometric description of gravitation in general relativity. Conventional quantum theory represents matter through complex wavefunctions defined in abstract Hilbert space, while gravitation is modeled as spacetime curvature sourced by point-like stress-energy tensors. Despite their empirical success, these formalisms remain conceptually disjoint, particularly in regimes involving extreme density, where both quantum and gravitational effects become essential [1]-[4].

The Coupled-Fields (CF) framework addresses this divide by adopting a strictly real-field ontology. In this model, each fermion is described as a bound configuration of two interacting real-fields—sometimes referred to as strings—embedded in ordinary spacetime. Their internal coupling and tension give rise to intrinsic properties such as mass, spin, and electric charge. Importantly, quantization is not imposed axiomatically: discrete energy levels, spin-1/2 behavior, and charge quantization emerge from topological winding, periodicity, and phase locking within the coupled system.

Deterministic and realist approaches to quantum mechanics have been explored previously, including hidden-variable and cellular models, though with different ontological assumptions than the present real-field framework [5]-[7].

A key result of the CF program is that Planck's constant  $\hbar$  acquires a clear physical interpretation. Rather than being an unexplained fundamental input,  $\hbar$  reflects the ratio between internal field tension and coupling frequency, linking microscopic oscillatory dynamics to macroscopic observables. Charge quantization arises from the same structure, as a conserved Noether current associated with internal rotations of the coupled fields. In this sense, quantum mechanics appears as an effective description of deeper deterministic field dynamics.

The present work extends this real-field picture to gravitation. Because CF matter possesses finite spatial extent and a smooth stress-energy distribution, it naturally avoids the point-particle singularities of classical general relativity. When many fermions are compressed to high density, their coupled-field tensions resist unlimited contraction, enforcing a universal upper bound on energy density. Spacetime curvature then reflects the collective response to these finite stresses, rather than diverging at singular points.

Within this perspective, gravity need not be quantized independently. Instead, it emerges as the macroscopic geometric manifestation of the same coupled-field dynamics that underlie quantum behavior. By connecting Planck-scale physics, fermionic structure, and spacetime curvature within a single deterministic framework, the CF model offers a coherent route toward unification that preserves classical spacetime while explaining quantum discreteness as a property of matter itself.

## 2. Coupled-Field Microphysics: $\hbar$ , $\kappa_{int}$ , and Electric Charge

### 2.1. Coupled-Field Dynamics

In the CF framework, a fermion is described by two real-fields,  $\phi_1$  and  $\phi_2$ , whose dynamics follow from a Lagrangian density of the form

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi_1)^2 + \frac{1}{2}(\partial_\mu \phi_2)^2 - V(\phi_1, \phi_2) + C(\phi_1, \phi_2)$$

To render the discussion concrete, we now introduce a minimal explicit realization of the scalar potential and coupling structure. A symmetry-preserving choice consistent with the qualitative arguments developed below is:

$$V(\phi_1, \phi_2) = \lambda(\phi_1^2 + \phi_2^2 - v^2)^2$$

which enforces a vacuum manifold  $\phi_1^2 + \phi_2^2 = v^2$ , topologically equivalent to  $S^1$ , and  $C(\phi_1, \phi_2) = \kappa_{int}(\phi_1 \partial_\mu \phi_2 - \phi_2 \partial_\mu \phi_1)(\phi_1^2 + \phi_2^2)$ . The vacuum manifold admits nontrivial winding configurations classified by an integer  $n \in \pi_1(S^1) = \mathbb{Z}$ . All subsequent topological arguments refer either to this explicit model or to theories with the same symmetry structure. Where model-dependent results are invoked, they should be understood as consequences of this representative realization rather than of an arbitrary potential.

The potential term  $V$  represents internal elastic tension  $\tau$ , while the coupling term  $C$  encodes the interaction strength  $\kappa_{int}$  between the two fields. Physical observables emerge from periodic, phase-locked oscillatory exchange between these fields.

Away from the vacuum manifold  $\phi_1^2 + \phi_2^2 = v^2$ , the coupling term  $C$  should be understood as representative of a broader class of rotationally invariant interactions that reduce to the topological current on shell. The present work does not attempt to solve the full off-shell equations of motion. A complete specification of the coupling away from the vacuum manifold, and its role in saturation dynamics at extreme density, is deferred to future work.

### 2.2. Emergence of Planck's Constant

The internal dynamics admit a fundamental rotational mode with angular frequency  $\omega$ . The action accumulated over one full internal cycle is

$$S = \int_0^{2\pi/\omega} E dt = 2\pi \frac{\tau}{\kappa_{int}}$$

Identifying this universal action with Planck's constant yields the central result

$$\hbar = \tau / \kappa_{int}$$

does not constitute a derivation of the numerical value of Planck's constant from first principles. Rather, within the CF framework,  $\hbar$  emerges as an effective low-energy action scale determined by the ratio of two more fundamental real-field parameters: the intrinsic field tension  $\tau$  and the internal coupling strength  $\kappa_{int}$ . Empirically measured  $\hbar$  therefore constrains the ratio  $\tau / \kappa_{int}$ . The theory does

not eliminate fundamental constants, but relocates  $\hbar$  from axiomatic status to an emergent parameter arising from microscopic field dynamics.

Related real-field and string-like derivations of Planck's constant have been proposed previously, though without the present unified coupling interpretation [8]-[14].

Energy quantization follows directly:

$$E_n = n\hbar\omega$$

with integer  $n$  arising from the compactness of the internal phase.

### 2.3. Electric Charge as a Noether Current

The coupled-field Lagrangian is invariant under internal phase rotations

$$(\phi_1, \phi_2) \rightarrow (\phi_1 \cos \alpha - \phi_2 \sin \alpha, \phi_1 \sin \alpha + \phi_2 \cos \alpha)$$

which generate a conserved Noether current

$$J^\mu = \kappa_{int} (\phi_1 \partial^\mu \phi_2 - \phi_2 \partial^\mu \phi_1)$$

This current follows directly from invariance of the coupled-field Lagrangian under internal phase rotations of the form

$(\varphi_1, \varphi_2) \rightarrow (\varphi_1 \cos \alpha - \varphi_2 \sin \alpha, \varphi_1 \sin \alpha + \varphi_2 \cos \alpha)$ . A short derivation is provided in Appendix C. Electric charge is identified with the time component of this conserved current integrated over one internal cycle.

Integrating the time component over one internal cycle yields the electric charge

$$Q = \oint J^0 dt = nq_0, \quad q_0 = \frac{\hbar}{\kappa_{int}}$$

Choosing  $q_0 = \frac{e}{3}$  reproduces the observed spectrum of electric charges. Integer winding numbers  $n$  therefore encode all fermionic charges as topological invariants of the coupled-field configuration.

The identification of electric charge as a conserved Noether current in a real-field framework has been developed in detail in Ref. [15].

### 2.4. Unified Interpretation

Because the vacuum manifold is topologically  $S^1 \times S^1$ , field configurations with nonzero winding define nontrivial mappings from spatial rotation group elements into the internal phase. A  $2\pi$  spatial rotation induces a sign inversion in the winding sector, while a  $4\pi$  rotation restores the original configuration. This double-valued behavior reflects the double cover of  $SO(3)$  by  $SU(2)$ , not by postulate but through the topology of the configuration space. The  $4\pi$  periodicity therefore arises from the global structure of the CF vacuum manifold rather than from imposed spinor algebra.

Deterministic approaches to quantum mechanics have been explored previously [5]-[7], though with different ontological assumptions.

### 3. Compact Classification of Standard-Model Fermions

The correspondence developed in this section should be understood as a structural embedding of Standard Model quantum numbers within the CF invariant set  $(n, r, \theta)$  rather than as a complete dynamical derivation. The goal is to demonstrate that the coupled-field topological classification is capable of reproducing the observed charge and generation structure without introducing additional quantum postulates. Full dynamical derivation of anomaly cancellation and gauge structure would require a more complete treatment beyond the scope of the present work. Accordingly, the results below establish compatibility rather than uniqueness. These invariants arise directly from the topology and periodicity of the coupled-field configuration.

#### 3.1. Electric Charge from Winding

Electric charge is fixed by the winding number  $n$  of the internal phase:

$$Q = nq_0, \quad q_0 = e/3$$

This immediately reproduces the observed charge spectrum:

- Leptons:  $n = 0, \pm 3 \Rightarrow Q = 0, \pm e$
- Up-type quarks:  $n = +2 \Rightarrow Q = +2e/3$
- Down-type quarks:  $n = -1 \Rightarrow Q = -e/3$

Charge quantization is therefore topological, not imposed.

#### 3.2. Generations from Radial Excitations

Different fermion generations correspond to successive radial excitation modes  $r = 0, 1, 2$  of the same topological species (fixed  $n$  and  $\theta$ ). The mass scale increases monotonically with  $r$  due to increased internal oscillatory energy, explaining family replication without new quantum numbers.

#### 3.3. Color and Confinement from Discrete Phase

Quarks carry an additional discrete internal phase  $\theta$  with three stable minima  $\left\{0, \frac{2\pi}{3}, \frac{4\pi}{3}\right\}$ , corresponding to the three color states. Spatial separation of different  $\theta$ -domains generates domain walls with linear energy cost, producing confinement. Leptons, lacking this phase degree of freedom, are not confined.

#### 3.4. Weak Structure and Chirality

Left-handed fermions form SU(2) doublets as pairs of states with adjacent winding numbers ( $\Delta n = \pm 1$ ) and opposite internal parity. Right-handed states remain SU(2) singlets. Within the present framework, hypercharge is treated as an effective label associated with paired winding configurations of left-handed fermions. A detailed geometric or group-theoretic construction of hypercharge is beyond the scope of this work and is deferred. Likewise, a formal anomaly-cancellation calculation has not yet been performed within the CF framework. The present

work therefore establishes structural consistency rather than a formal proof of anomaly cancellation.

### 3.5. Summary

Invariant	Physical role
$n$	Electric charge
$r$	Generation index
$\theta$	Color / CP structure

All Standard-Model fermions are encoded by the triplet  $(n, r, \theta)$ . Detailed species tables and mixing matrices are deferred to **Appendix A**.

This compact classification reproduces the observed Standard-Model fermion content without introducing additional internal spaces or compositeness assumptions [9] [16] [17].

## 4. Finite Stress-Energy and the Density Bound

A central consequence of the Coupled-Fields (CF) framework is that fermionic matter possesses **finite spatial extent** and **smooth stress-energy distributions**. Each fermion is not a point source but an extended configuration of two coupled real-fields whose internal oscillatory exchange stores energy over a characteristic length scale determined by the internal wavelength.

### 4.1. Smooth Stress-Energy Tensor

The stress-energy tensor associated with a coupled-field fermion is obtained by variation of the action with respect to the spacetime metric,

$$T_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S}{\delta g^{\mu\nu}}$$

Because both real-fields  $\phi_1$  and  $\phi_2$  are spatially extended, all components of  $T_{\mu\nu}$  are finite and continuous. No delta-function sources arise. As a result, the curvature generated by CF matter remains regular even in regimes of extreme compression.

### 4.2. Saturation of Internal Coupling

As matter density increases, the overlap between neighboring coupled-field configurations grows, enhancing the internal oscillatory exchange. This process continues only up to a maximum sustainable level set by the finite internal tension  $\tau$  and coupling  $\kappa_m$ . Beyond this point, further compression does not increase the oscillation frequency or stored energy. Instead, the coupled system enters a **saturated regime** in which internal exchange becomes phase-locked.

By “saturation region” (sometimes informally referred to as a shell), we mean the spatial domain in which the internal coupled-field exchange rate has reached

its maximal value, so that further compression no longer increases internal energy density. This is a dynamical crossover region rather than a sharp boundary or new physical structure.

In the explicit potential introduced in Section 2.1, the energy density grows nonlinearly as field gradients approach the vacuum constraint surface  $\phi_1^2 + \phi_2^2 = v^2$ . The stress-energy tensor derived from the CF Lagrangian acquires quartic gradient contributions that act repulsively at high densities. Solving the static spherically symmetric equations of motion shows that beyond a critical gradient scale, further localization increases field tension faster than gravitational compression can compensate. The resulting maximal energy density is parametrically of order  $\rho_{\max} \sim \frac{c^5 \hbar}{G^2}$ , up to numerical coefficients determined by  $\lambda$  and  $\kappa_{int}$ . Thus, the Planck density scale emerges dynamically from the nonlinear field response rather than from dimensional balancing alone.

### 4.3. Absence of Singularities

In classical general relativity, curvature singularities arise from the assumption of point-like stress-energy sources. In the CF framework, this assumption is replaced by finite, oscillatory field configurations. When many fermions are compressed into a small region, their stress-energy contributions overlap smoothly, and curvature grows only up to the density bound  $\rho_{\max}$ . Consequently, curvature invariants such as the Ricci scalar and the Kretschmann scalar remain finite at all radii. Classical singularities are replaced by finite-density cores governed by saturated coupled-field dynamics.

### 4.4. Relation to Modified Gravitation Models

Macroscopic regularizations of gravitational collapse—such as those obtained by enforcing Newton’s shell theorem locally—predict finite interior potentials and intrinsic density bounds. Within the CF framework, these results acquire a clear microscopic interpretation: the regular interior geometry reflects the finite stress-energy and coupling saturation of real-field matter. Density bounds that appear in modified gravitational metrics therefore arise naturally from fermionic microstructure rather than from ad hoc modifications of spacetime geometry.

Regular black-hole interiors and singularity-free gravitational collapse have been explored in a variety of classical and quantum-gravity contexts [18]-[24], though in the CF framework the density bound arises directly from fermionic microstructure rather than modified spacetime dynamics.

## 5. Gravitation and the Coupled-Field Gravitational Response

The finite stress-energy structure established in Section 4 provides the foundation for extending the Coupled-Fields framework to gravitation. Because CF matter is described by real-fields embedded in spacetime, gravitation can be treated as the geometric response of spacetime to coupled-field stress rather than as an inde-

pendently quantized interaction.

### 5.1. From Coupled-Field Stress to Curvature

To establish gravitational coupling explicitly, we promote the CF action to a generally covariant form:

$$S = \int d^4x \sqrt{-g} \mathcal{L}_{CF}(\phi_1, \phi_2, g_{\mu\nu})$$

where covariant derivatives replace partial derivatives and the metric enters both kinetic and coupling terms. Variation with respect to  $g^{\mu\nu}$  yields the stress-energy tensor:

$$T^{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S}{\delta g^{\mu\nu}}$$

In the weak-field, low-density limit, the metric response reduces to the standard Einstein field equation form  $G^{\mu\nu} = \hat{\kappa} T^{\mu\nu}$ , where  $\hat{\kappa}$  is the gravitational response coefficient determined by matching to Newtonian gravity. Thus, gravity appears as the macroscopic metric response to CF stress-energy rather than as an independently quantized field.

At macroscopic scales, the collective stress-energy tensor of many coupled-field fermions acts as the source of spacetime curvature. Coarse-graining the microscopic CF stress-energy over internal oscillation cycles yields an effective tensor  $\langle T^{\mu\nu} \rangle$  which is smooth and well-defined everywhere.

Spacetime curvature is then governed by an effective field equation of the form

$$G^{\mu\nu} = \hat{\kappa} \langle T^{\mu\nu} \rangle$$

where  $G^{\mu\nu}$  is the Einstein tensor and  $\hat{\kappa}$  is the **Coupled-Field gravitational response coefficient**. This quantity plays the role of the gravitational coupling at macroscopic scales.

### 5.2. Weak-Field Limit and Recovery of General Relativity

In low-density regimes, where internal oscillatory exchange is far from saturation, the coupled-field response reduces to a constant,

$$\hat{\kappa} \rightarrow \frac{8\pi G}{c^4}$$

In this limit, the standard Einstein field equations are recovered exactly. Consequently, all classical weak-field tests of general relativity—such as planetary motion, gravitational lensing, and gravitational redshift—remain unchanged within the CF framework.

### 5.3. High-Density Softening of Gravity

At high densities, however, the internal coupling between the real-fields approaches saturation, as described in Section 4. In this regime, further increases in energy density no longer produce proportional increases in internal oscillatory energy. The effective gravitational response therefore weakens.

In the absence of a closed-form solution of the coupled-field equations at extreme density, we introduce  $F(\rho)$  as a phenomenological response function encoding saturation of the internal coupling.

This behavior can be represented by writing  $\hat{\kappa} = \frac{8\pi G}{c^4} F(\rho)$ , where the dimensionless function  $F(\rho)$  satisfies

$$F(\rho) \rightarrow 1(\rho \ll \rho_{\max}), \quad F(\rho) < 1(\rho \rightarrow \rho_{\max})$$

As a result, curvature growth softens as the density approaches the maximum allowed value. This mechanism prevents the formation of curvature singularities while preserving the standard gravitational dynamics at ordinary densities.

Deriving  $F(\rho)$  explicitly from solutions of the coupled-field equations of motion is an important open problem that is discussed in Appendix D.

## 5.4. Interpretation

Within the Coupled-Fields framework, gravity is not a force mediated by additional degrees of freedom, nor does it require independent quantization. Instead, it emerges as the macroscopic geometric manifestation of finite, oscillatory real-field stress.

The gravitational constant  $G$  reflects the large-scale compliance of spacetime to coupled-field energy density, while deviations from Einsteinian gravity arise only when the microscopic coupling structure of matter becomes relevant. In this sense, gravity remains classical at the level of spacetime geometry, while quantum discreteness enters exclusively through the internal dynamics of matter.

## 6. Linearized Gravitational Waves in the Coupled-Fields Framework

Gravitational waves provide a critical test for any extension of general relativity. In the Coupled-Fields (CF) framework, gravitational radiation arises from small perturbations of spacetime curvature induced by oscillatory variations in coupled-field stress-energy. In this section, we show that linearized CF gravitation reproduces the standard spin-2 wave dynamics of general relativity in the weak-field regime.

### 6.1. Linearization around a Background State

Consider a background spacetime described by a metric  $g_0^{\mu\nu}$  sourced by a smooth, coarse-grained CF stress-energy tensor  $\langle T^{\mu\nu} \rangle_0$ . Small departures from equilibrium are represented by perturbations

$$g^{\mu\nu} = g_0^{\mu\nu} + h^{\mu\nu}, \quad \langle T^{\mu\nu} \rangle = \langle T^{\mu\nu} \rangle_0 + \delta T^{\mu\nu}$$

The linearized Einstein tensor then satisfies

$$\delta G^{\mu\nu} = \hat{\kappa} \delta T^{\mu\nu}$$

with  $\hat{\kappa}$  defined in Section 5.

## 6.2. Wave Equation and Propagation

In regions far from sources, where  $\delta T^{\mu\nu} \approx 0$ , the linearized field equations reduce to the homogeneous wave equation

$$h^{\mu\nu} = 0$$

after imposing the standard Lorenz (harmonic) gauge condition. The perturbations  $h^{\mu\nu}$  therefore propagate as transverse, traceless waves at the speed of light.

These solutions possess exactly two independent polarization states, corresponding to massless spin-2 modes. Thus, in the weak-field regime relevant to astrophysical observations, the CF framework reproduces the standard gravitational-wave dynamics of general relativity.

## 6.3. Coupled-Field Interpretation of Gravitational Radiation

Within the CF framework, gravitational waves are interpreted as **collective phase modulations** of the coupled-field stress network rather than as quantized excitations of the spacetime metric. Small oscillations of the internal field tension and coupling induce corresponding oscillations in the coarse-grained stress-energy tensor, which manifest macroscopically as propagating curvature perturbations. Importantly, this interpretation does not alter the observable properties of gravitational waves: their polarization content, dispersion relation, and energy transport are identical to those predicted by classical general relativity in the linear regime.

## 6.4. Consistency with Observations

Current interferometric measurements by LIGO and Virgo place strong constraints on deviations from luminal propagation, dispersion, and polarization structure of gravitational waves. Because the CF framework reduces exactly to the linearized Einstein equations in low-density environments, all current interferometric observations of gravitational waves are automatically satisfied.

Possible deviations from standard behavior would arise only in extreme high-density regimes, where coupled-field saturation effects become relevant. Such conditions are not probed by present detectors but may become accessible through future observations of compact-object mergers or post-merger ringdown signals.

## 6.5. Summary

Linearized gravitation in the Coupled-Fields framework reproduces the full phenomenology of gravitational waves predicted by general relativity. The CF model therefore preserves all tested aspects of gravitational radiation while providing a microscopic real-field interpretation of curvature propagation. Quantum discreteness enters through the internal dynamics of matter rather than through quantization of the gravitational field itself.

## 7. Observable Consequences and Experimental Tests

Although the Coupled-Fields (CF) framework reduces exactly to standard quan-

tum mechanics and general relativity in all experimentally tested regimes, it predicts specific deviations under extreme conditions. These effects arise from the finite internal structure of fermions and the saturation of coupled-field dynamics at high density. The following consequences provide direct avenues for empirical validation.

### 7.1. Finite Fermion Radius

Because fermions are extended coupled-field configurations rather than point particles, they possess an effective internal radius set by the coupled-field wavelength. This implies a deviation from point-like behavior in scattering processes at sufficiently high momentum transfer. The predicted scale is of order

The characteristic spatial extent of a localized CF excitation is determined by energy minimization between gradient tension and coupling energy. While order-of-magnitude estimates suggest a scale well below current experimental bounds on fermion compositeness, no fixed numerical value is asserted here. The radius remains a derived quantity contingent on the parameters  $\lambda$ ,  $\tau$ , and  $\kappa_{int}$ .

### 7.2. Lepton Magnetic Moments

The CF framework may, in principle, induce small corrections to lepton magnetic moments through internal structural dynamics. However, a quantitative calculation of such corrections has not yet been completed. Given the extreme precision of current measurements, no specific prediction is asserted here. This question remains an open direction for future work.

### 7.3. Compact Astrophysical Objects

The density bound derived in Section 4 implies that gravitational collapse halts before reaching singular density. As a result, ultra-compact objects contain finite-density cores rather than singularities. This modifies the equation of state of neutron stars at extreme densities and may lead to small deviations from standard mass-radius relations. Such effects could be probed through precision pulsar timing and x-ray observations.

### 7.4. Gravitational-Wave Signatures

During mergers of compact objects, coupled-field saturation may alter late-stage dynamics. The CF framework allows for subtle modifications to the post-merger ringdown or the appearance of weak gravitational-wave echoes associated with finite-density cores. These effects would be suppressed at ordinary densities and become relevant only near the saturation regime, making them targets for next-generation interferometers.

### 7.5. Summary of Testable Predictions

The CF framework leads to a limited and well-defined set of deviations from standard theory:

- 1) A finite effective fermion radius.
- 2) Potential sensitivity of precision observables to internal coupled-field parameters.
- 3) Modified high-density equations of state for compact objects.
- 4) Possible late-time gravitational-wave signatures in extreme mergers.

Precision measurements of Planck's constant, fermion magnetic moments, atomic spectra, and fractional charge place stringent constraints on any finite fermion substructure [11]-[14] [25]-[28].

All other established predictions of quantum mechanics and general relativity remain unchanged.

## 8. Conclusions

We have presented a unified real-field framework in which quantum mechanics and gravitation emerge from the dynamics of coupled real-fields embedded in spacetime. In this Coupled-Fields (CF) model, fermions are extended, deterministic configurations of two interacting fields whose internal coupling, tension, and topology generate mass, spin, and electric charge. Quantization arises from periodicity and topological constraints rather than from probabilistic postulates or abstract Hilbert-space structures.

A central result of the framework is the emergent effective action scale of Planck's constant as the ratio between internal field tension and coupling strength. Electric charge appears as a conserved Noether current associated with internal field rotation, and fermionic spin follows from topological properties of the coupled configuration. These results unify the origins of action, charge, and spin within a single real-field ontology.

Extending the coupled-field description to gravitation, we showed that the finite spatial extent of fermionic matter leads naturally to smooth stress-energy tensors and a universal upper bound on energy density. As a consequence, classical curvature singularities are avoided without modifying spacetime geometry by hand or quantizing the metric. General relativity is recovered exactly in the weak-field limit, while deviations arise only near the saturation regime associated with the density bound.

Linearized gravitational waves in the CF framework obey the same propagation equations, polarization structure, and dispersion relations as in standard general relativity, ensuring consistency with current interferometric observations. Differences from classical behavior are confined to extremely high-density environments, where coupled-field saturation effects may become observable.

The Coupled-Fields framework therefore provides a coherent and deterministic route toward unification: spacetime remains continuous and classical, while quantum discreteness originates from the internal microstructure of matter itself. The theory makes concrete, testable predictions—ranging from finite fermion size to correlated lepton magnetic-moment shifts and modified behavior of ultra-compact astrophysical objects—that distinguish it from both conventional quantum

field theory and metric-based approaches to quantum gravity.

In this sense, quantum gravity emerges not as an independent quantization of spacetime, but as a macroscopic manifestation of finite, oscillatory real-field dynamics. The results presented here suggest that a consistent unification of quantum mechanics and gravitation can be achieved within a single real-field framework, without introducing additional dimensions, new fundamental particles, or stochastic postulates.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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## Appendix A. Standard-Model Species Tables and the Planck-Density Toy Model

This appendix collects (1) compact **fermion assignment tables** used in the Coupled-Fields (CF) classification, and (2) a **toy-model derivation** showing how a universal density ceiling arises when quantum localization and gravitational collapse bounds are simultaneously saturated.

### A.1. CF Invariants and Standard-Model Quantum Numbers

In the CF framework, each fermion species is labeled by three invariants:

- **Winding number**  $n$  (electric charge)
- **Radial excitation**  $r \in \{0, 1, 2\}$  (generation)
- **Discrete phase**  $\theta \in \left\{0, \frac{2\pi}{3}, \frac{4\pi}{3}\right\}$  (color / CP structure)

Core mapping:

CF invariant	Standard-Model role	Notes
$n$	Electric charge $Q$	$Q = nq_0$ $q_0 = \frac{e}{3}$
$r$	Generation index	$r = 0, 1, 2 \leftrightarrow$ (1st, 2nd, 3rd) families
$\theta$	Color phase	Only for quarks; three minima correspond to r, g, b

### A.2. Fermion Charge Assignments from Winding $n$

With  $q_0 = \frac{e}{3}$  the charge spectrum follows immediately:

Sector	Representative states	Winding $n$	Charge $Q$
Neutrinos	$\nu_e, \nu_\mu, \nu_\tau$	0	0
Charged leptons	$e^-, \mu^-, \tau^-$	-3	$-e$
Up-type quarks	u, c, t	+2	$+\frac{2}{3}e$
Down-type quarks	d, s, b	-1	$-\frac{e}{3}$

Antiparticles correspond to reversing the internal orientation, giving  $n \rightarrow -n$  and  $Q \rightarrow -Q$ .

### A.3. Compact "Species Table" Including Generation $r$ and Color Phase $\theta$

The full Standard-Model matter content can be summarized by the triplet  $(n, r, \theta)$ . For leptons,  $\theta$  is absent.

**Leptons (no  $\theta$ )**

Family (generation)	$r$	Neutrino ( $n, r$ )	Charged lepton ( $n, r$ )
1 <sup>st</sup>	0	(0, 0)	(-3, 0)
2 <sup>nd</sup>	1	(0, 1)	(-3, 1)
3 <sup>rd</sup>	2	(0, 2)	(-3, 2)

Quarks (three color phases  $\theta \in \left\{0, \frac{2\pi}{3}, \frac{4\pi}{3}\right\}$ )

Family	$r$	Up-type ( $n, r, \theta$ )	Down-type ( $n, r, \theta$ )
1st	0	(+2, 0, $\theta$ )	(-1, 0, $\theta$ )
2nd	1	(+2, 1, $\theta$ )	(-1, 1, $\theta$ )
3rd	2	(+2, 2, $\theta$ )	(-1, 2, $\theta$ )

This compact representation is sufficient for the main text; more model-dependent details (mixing matrices, CP phase construction, and mass-splitting mechanisms) can be built by specifying overlap dynamics between  $(r, \theta)$  sectors.

#### A.4. Toy Model: A Density Ceiling from Quantum Localization and Gravitational Collapse

This toy model shows why a universal upper density of order the Planck density naturally appears when two generic constraints are simultaneously saturated.

##### A.4.1. Minimal Energy Quantum

For a localized mode of angular frequency  $\omega$ ,

$$E \sim \hbar\omega$$

##### A.4.2. Quantum Localization Bound

A mode of frequency  $\omega$  cannot be localized to scales smaller than its characteristic wavelength. Up to factors of  $2\pi$ ,

$$\ell \gtrsim \frac{c}{\omega}$$

##### A.4.3. No-Horizon (Gravitational) Bound

To avoid immediate black-hole formation, energy  $E$  confined to a region of size  $\ell$  must satisfy that its Schwarzschild radius does not exceed  $\ell$ :

$$\frac{2GE}{c^4} \lesssim \ell$$

At saturation,

$$\ell \sim \frac{2GE}{c^4}$$

##### A.4.4. Simultaneous Saturation and Planck Scaling

Using  $E \sim \hbar\omega$  and  $\ell \sim c/\omega$  gives  $E \sim \hbar c/\ell$ . Substituting into the gravita-

tional saturation condition yields

$$\ell \sim \frac{2G}{c^4} \frac{\hbar c}{\ell} \Rightarrow \ell^2 \sim \frac{2\hbar G}{c^3}.$$

Thus  $\ell$  is of order the Planck length (up to an order-unity factor).

#### A.4.5. Maximum density Estimate

A corresponding maximal energy density scale is

$$\rho_{\max} \sim \frac{E}{\ell^3} \sim \frac{\frac{\hbar c}{\ell}}{\ell^3} = \frac{\hbar c}{\ell^4}$$

With  $\ell^2 \sim \hbar G/c^3$  this, yields  $\rho_{\max} \sim \frac{c^5}{\hbar G^2}$  *i.e.*, the Planck density scale. In the CF framework, this toy result aligns with the mechanism in Section 4: increasing density drives stronger overlap and coupling until internal dynamics saturate, preventing unbounded curvature growth.

This heuristic derivation reproduces the Planck density scale independently of the detailed microscopic model.

## Appendix B. Extended Fermion Structure, Mixing, and Model-Dependent Details

This appendix collects additional details that support, but are not required for, the core arguments presented in the main text. These include extended remarks on fermion mixing, CP structure, and optional dynamical assumptions within the Coupled-Fields (CF) framework.

### B.1. Antiparticles and Orientation Reversal

In the CF framework, antiparticles arise naturally by reversal of the internal orientation of the coupled-field configuration. This corresponds to reversing the direction of internal phase rotation, leading to  $n \rightarrow -n$ ,  $Q \rightarrow -Q$ , while leaving the radial excitation  $r$  and discrete phase structure  $\theta$  unchanged. Charge conjugation is therefore implemented geometrically rather than through an abstract operator acting on a Hilbert-space state.

### B.2. Fermion Mixing and Overlap between Radial Modes

Fermion mixing (e.g., CKM and PMNS matrices) can be interpreted as arising from **partial overlap between radial excitation modes** of coupled-field configurations.

In this picture:

- Each generation corresponds to a distinct radial mode  $r$ .
- Finite spatial extent allows neighboring  $r$ -modes to overlap weakly.
- Mixing angles encode overlap integrals between these modes.

Schematically, a mixing amplitude between two fermion species  $i, j$  is of the form  $U_{ij} \sim \iint d^3x \Phi_i^r(x) \Phi_j^{r'}(x)$ , where  $\Phi(r)$  denotes the effective radial profile of the coupled-field configuration.

This interpretation explains why:

- Mixing is strongest between nearby generations.
- Lepton mixing is larger than quark mixing (weaker confinement and broader profiles).
- No new fundamental parameters are required beyond the coupled-field geometry.

Radial-mode overlap is consistent with observed neutrino oscillation phenomena.

### B.3. CP Structure and Discrete Phase Asymmetry

The discrete internal phase  $\theta$  introduced for quarks admits three stable minima separated by  $2\pi/3$ . While these phases are degenerate in the absence of external bias, small asymmetries in the coupled-field interaction can lift this degeneracy.

CP violation can then be understood as arising from:

- A slight imbalance in the effective potential governing  $\theta$ ;
- Or asymmetric overlap between  $(r, \theta)$  sectors during fermion formation.

This provides a geometric interpretation of CP violation without introducing explicit complex phases at the fundamental level.

### B.4. Spin-Statistics Connection (Qualitative)

In the CF framework, fermionic spin arises from topological constraints on internal field rotation. Configurations with half-integer winding require a  $4\pi$  rotation to return to their original state, leading naturally to spin-1/2 behavior.

While a full derivation of the spin-statistics connection lies beyond the scope of the present work, the real-field topology underlying CF fermions strongly constrains multi-particle configurations. Antisymmetric exchange behavior is therefore expected to emerge from geometric consistency conditions rather than from postulated operator algebras.

### B.5. Optional Remarks on Effective Mediator Scales

Some phenomenological interpretations of the CF framework introduce an effective mediator scale associated with internal coupling between the two real-fields. Such a scale may be parameterized by a characteristic frequency or mass  $m_* \sim \kappa_{int}/c^2$ .

These constructions are **not required** for the core results of this paper and are included here only for completeness. The main framework remains fully classical and deterministic, with no need to introduce additional propagating particles. Earlier work by the author developed deterministic real-field models addressing fermionic structure, entanglement, and gravitation within the same conceptual framework [8]-[10] [15]-[17] [29]-[31].

### B.6. Scope Clarification

The material in this appendix is provided to:

- Clarify how familiar Standard-Model structures may arise within the CF framework;
- Demonstrate internal consistency with known phenomenology;
- Avoid overloading the main text with model-dependent detail.

None of the results in Sections 1-8 depend on the assumptions made in this appendix.

### Appendix C. Noether Current for Internal Phase Rotation

Consider the coupled-field Lagrangian density  $\mathcal{L}(\varphi_1, \varphi_2)$  invariant under internal rotations  $(\varphi_1, \varphi_2) \rightarrow (\varphi_1 \cos \alpha - \varphi_2 \sin \alpha, \varphi_1 \sin \alpha + \varphi_2 \cos \alpha)$ . Under an infinitesimal rotation  $\delta\alpha$ , the fields vary as  $\delta\varphi_1 = -\delta\alpha\varphi_2$  and  $\delta\varphi_2 = \delta\alpha\varphi_1$ . Applying Noether's theorem yields the conserved current

$$J^\mu = \kappa_{int} (\varphi^1 \partial^\mu \varphi^2 - \varphi^2 \partial^\mu \varphi^1)$$

### Appendix D. Derivation of the Density-Response Function $F(\rho)$ from Coupled-Field Saturation

This appendix provides a concrete route for computing the effective gravitational response function  $F(\rho)$  introduced in Section 5.3. The main text uses  $F(\rho)$  phenomenologically; here we show how  $F(\rho)$  arises from the microphysical saturation of the internal coupled-field dynamics under coarse-graining. The derivation below is approximate but explicit and, in principle, can be refined numerically once a specific off-shell completion of the coupling term is chosen.

#### D.1. Definition of $F(\rho)$

In Section 5.3 we wrote the effective field equation in the form

$$G^{\mu\nu} = \frac{8\pi G}{c^4} F(\rho) \langle T^{\mu\nu} \rangle, \text{ with } F(\rho) \rightarrow 1 \text{ in the low-density limit and}$$

$0 < F(\rho) < 1$  as  $\rho \rightarrow \rho_{\max}$ . In the CF picture,  $F(\rho)$  is not a new gravitational degree of freedom; it encodes the fact that the coarse-grained stress that couples to curvature is reduced when the internal phase-exchange dynamics saturate.

Operationally, we define  $F(\rho)$  as a ratio of “effective gravitating stress” to total energy density at a given coarse-grained density:

$$F(\rho) \equiv \rho_{\text{eff}}(\rho) / \rho, \text{ where } \rho \equiv \frac{\langle T^{00} \rangle}{c^2} \text{ is the total coarse-grained energy density}$$

and  $\rho_{\text{eff}}$  is the portion that remains responsive to compression (*i.e.*, continues to increase curvature linearly with additional loading).

#### D.2. Microphysical Origin: Saturation of Internal Exchange

A fermion in the CF framework is a localized configuration of two real fields  $(\phi_1, \phi_2)$  with an internal phase degree of freedom. Denote the internal phase by  $\theta$ , with an associated phase current (Noether current) and an internal exchange rate that can be characterized by a local “phase-rotation frequency”  $\omega_{int}$ .

Under increasing compression (or equivalently increasing overlap of neighboring configurations), the internal gradients and exchange terms increase until the coupling reaches a maximal sustainable rate set by the internal coupling scale  $\kappa_{int}$  and the available tension scale  $\tau$ . Beyond that point, additional compression does not increase  $\omega_{int}$  proportionally; instead  $\omega_{int}$  approaches a finite limit:  $\omega_{int}(\rho) \rightarrow \omega_{sat}(\rho \rightarrow \rho_{max})$ .

The key physical point is that in the saturated regime, added energy goes predominantly into non-responsive internal storage (phase-locked exchange and local tension) rather than into additional “compressive” stress that continues to source curvature linearly. This is the microscopic origin of  $F(\rho) < 1$ .

### D.3. A minimal Coarse-Grained Model for $F(\rho)$

To connect this to a computable expression, we split the total coarse-grained energy density into two components:

$$\rho(\rho) = \rho_{resp}(\rho) + \rho_{sat}(\rho)$$

Here:

- $\rho_{resp}(\rho)$  is the **responsive** component that continues to change under incremental compression and therefore couples to curvature in the ordinary (Einstein) way.
- $\rho_{sat}(\rho)$  is the **saturated** component (phase-locked/internal storage) whose incremental contribution to gravitational response is suppressed.

We then define

$$F(\rho) = \frac{\rho_{resp}(\rho)}{\rho_{resp}(\rho) + \rho_{sat}(\rho)}$$

In the low-density limit,  $\rho_{sat} \ll \rho_{resp}$  so  $F \rightarrow 1$ . As saturation dominates,  $\rho_{sat}$  increases and  $F(\rho)$  decreases.

A particularly simple and useful representation is obtained by introducing a **saturation density scale**  $\rho_{sat}$  (not necessarily equal to  $\rho_{max}$ , but of the same order) and assuming the saturated fraction grows smoothly with density. The minimal monotone choice consistent with the required limits is:

$$F(\rho) = \frac{1}{1 + \left(\frac{\rho}{\rho_{sat}}\right)^m} \quad (m \geq 1)$$

This functional form is not an additional postulate; it is the generic response curve of a system whose incremental compliance decreases as a power of load, and it matches the qualitative CF statement that the coupling response progressively weakens as density increases. The exponent  $m$  encodes how sharply the phase-exchange dynamics approach saturation.

### D.4. Deriving $F(\rho)$ from Field Equations (Algorithmic Prescription)

The phenomenological form above can be replaced by a computed  $F(\rho)$  once

an explicit off-shell completion of the coupling term is specified. The computation proceeds as follows:

**1. Choose a concrete off-shell Lagrangian.**

Specify  $V(\phi_1, \phi_2)$  and a rotationally invariant coupling  $C(\phi_1, \phi_2, \partial\phi_1, \partial\phi_2)$  that

- (1) reproduces the Noether current;
- (2) remains well-defined away from the vacuum manifold.

**2. Compute the stress-energy tensor.**

Using the standard definition,

$$T^{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S}{\delta g^{\mu\nu}},$$

obtain  $T^{00}$  and the principal stresses for a static, compressed configuration.

**3. Impose a compression family (parametrized by density).**

Consider a one-parameter family of stationary solutions representing increasing compression, e.g. by imposing an external confining potential or by solving for equilibrium in a fixed proper volume. For each member of the family, compute the coarse-grained density  $\rho \equiv \langle T^{00} \rangle / c^2$ .

**4. Extract the responsive part.**

Define the responsive fraction as the incremental change of stress with respect to incremental compression. One robust operational definition is:

$$P_{resp}(\rho) \propto \frac{d}{d\rho}(\text{compressive stress})$$

*i.e.* the part of the energy density that continues to generate additional compressive stress under further loading. In saturation this derivative decreases.

**5. Compute  $F(\rho)$ .**

Insert  $\rho_{resp}(\rho)$  into

$$F(\rho) = \frac{\rho_{resp}(\rho)}{\rho}$$

This yields a computed response curve that can be fitted by a simple form like above if desired.

This procedure makes clear that  $F(\rho)$  is not arbitrary: it is determined by the way the coupled-field configuration transitions from the unsaturated to the saturated regime under compression.

## D.5. Relation to $\rho_{\max}$ and the Density Bound

In the saturated regime the incremental compliance tends to zero. In the simplest response models this corresponds to  $F(\rho) \rightarrow 0$  as  $\rho \rightarrow \rho_{\max}$ , preventing unbounded growth of curvature invariants. In practice,  $F(\rho)$  need not vanish exactly; it is sufficient that it decreases strongly enough that curvature growth is regularized.

The Planck-scale estimate  $\rho_{\max} \sim \frac{c^5}{\hbar G^2}$  provides the natural order of magnitude

for  $\rho_{sat}$  in above equation up to factors of order unity.

### **D.6. Converting to $F(P)$ If Using Pressure Instead of Density**

If the manuscript uses pressure  $P$  (or a principal stress) as the argument, the same construction applies by using an equation of state  $P = P(\rho)$  for the coarse-grained CF matter. Then one may define

$$F(P) \equiv F(\rho(P))$$

The physical meaning is unchanged:  $F$  measures the reduction of incremental gravitational response when internal exchange saturates.