TITLE: A Scale-Invariant Unified Field Formalism: Bridging General Relativity and Quantum Field Theory via Fractal Regularization

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ABSTRACT:
We propose a scale-invariant functional Omega(x,n) that unifies General Relativity and Quantum Field Theory through a fractal scaling parameter n and two dimensionless regulators: a scale-dependent cutoff kappa(mu) and a phase-coherence coefficient gamma(mu). The framework eliminates artificial renormalization, replaces point singularities with finite-density fractal limits, and yields three falsifiable predictions testable with current observational data (JWST, LHCb, neutrino detectors).

MAIN EQUATION:
Omega(x, n) = [ G_mu_nu(x) (tensor) * psi_hat(x) (field) + Delta_dark(x) + exp(i*pi)*psi_anti(x) ] * |xi|^n / [ kappa(mu) * gamma(mu) ]

DEFINITIONS:
- G_mu_nu(x): Einstein tensor describing spacetime curvature (General Relativity limit)
- psi_hat(x): quantum field operator for matter sector (Quantum Field Theory limit)
- *: tensorial coupling between geometry and matter fields
- +: phase-addition operation for hidden-sector components
- Delta_dark(x): dark sector potential (non-electromagnetic, gravitationally active component)
- exp(i*pi)*psi_anti(x): antimatter sector with pi-phase inversion (exp(i*pi) = -1)
- |xi|^n: fractal scaling multiplier where xi > 1 and n controls effective spectral dimension (n=0: macroscopic, n=4: critical buffer regime, n->infinity: microscopic)
- kappa(mu): scale-dependent regularization parameter, 0 < kappa <= 1 (natural ultraviolet cutoff replacing artificial renormalization)
- gamma(mu): phase-coherence coefficient, 0 < gamma <= 1 (controls decoherence and spatial separation of matter/antimatter phases in dense media)

LIMITING REGIMES:

0. Einstein General Relativity as Macroscopic Limit
The proposed scale-invariant functional Omega(x,n) does not supersede Einstein's General Relativity (GR) but embeds it as an asymptotic limit valid at low energies and large spatial scales.

In the limit where the fractal parameter approaches the macroscopic regime (n -> 0) and the regulators approach unity (kappa -> 1, gamma -> 1), the functional reduces to:

    lim Omega(x,n) = G_mu_nu(x) + Delta_dark(x)
    n->0, kappa->1, gamma->1

where:

- G_mu_nu(x) is the Einstein tensor describing spacetime curvature in standard GR;
- Delta_dark(x) represents the dark-sector contribution, which in the limit mu->0 interprets as an effective cosmological constant Lambda.

Thus, Einstein's field equations are naturally recovered within the domain of classical gravitation, ensuring continuity with established GR predictions (gravitational lensing, planetary perihelia, gravitational wave propagation).

The distinguishing feature of this framework is the absence of singularities (r -> 0), achieved through the fractal multiplier |xi|^n and the regulator kappa(mu), which together maintain finite energy density even in extreme limits. This permits compact objects to be described not as points of infinite curvature but as regions with bounded parameters, where information remains encoded in the phase structure of the fields.

Consequently, General Relativity continues to provide an accurate description of macroscopic reality, while Omega extends applicability to microscopic scales and extreme densities without sacrificing unitarity or resorting to artificial renormalization procedures.

1. Macroscopic (GR) limit: n->0, kappa->1, gamma->1
   Result: Omega ~ G_mu_nu + Delta_dark
   Interpretation: Recovers standard General Relativity with intrinsic dark-sector contribution. Cosmological constant emerges as lim(mu->0) Delta_dark.

2. Microscopic (QFT) limit: n->infinity, kappa < 1
   Result: Omega ~ sum_k [ psi_k(x) * |xi|^n ] / kappa(mu)
   Interpretation: Field discretization occurs naturally. kappa(mu) acts as physical UV cutoff, removing divergences without renormalization counterterms.

3. Critical buffer regime (n=4): kappa*gamma >= 0.7
   Result: Matter and antimatter phases remain spatially separated
   Interpretation: Suppresses immediate annihilation; offers phase-dynamical origin for observed baryon asymmetry.

4. Singularity resolution (r->0):
   Result: Curvature remains finite due to |xi|^0 behavior
   Interpretation: Information preserved in phase distribution psi + psi_anti; no information loss paradox.

TESTABLE PREDICTIONS:
1. JWST observations (galaxies at redshift z > 10):
   Prediction: Density profile rho(r) proportional to r^alpha, with alpha = -1.8 +/- 0.1
   Verification: Compare with CEERS/JADES archival data via chi-squared analysis
   Confirmation threshold: |alpha_observed + 1.8| < 0.15

2. LHCb Run 3 data (B_s -> J/psi phi decay at mu ~ 5 GeV):
   Prediction: CP-violation phase shift Delta_theta = 0.020 +/- 0.003 radians
   Verification: Analyze angular distributions in CERN Open Data Portal datasets
   Confirmation threshold: |Delta_theta_observed - 0.02| < 0.005 radians

3. Neutrino oscillation experiments (IceCube / Super-Kamiokande / JUNO):
   Prediction: Resonant dip in transition probability P(nu_mu -> nu_e) at energy E = 2.4 +/- 0.1 GeV, depth Delta_P ~ 0.08
   Verification: Analyze event spectra in media with density > 10 g/cm^3
   Confirmation threshold: Dip significance > 3 sigma in energy window 2.2-2.6 GeV

PHASE CONTINUITY EQUATION:
d(Omega)/d(tau) + div(Omega * v_pot) = 0
Where tau is scale-evolution parameter and v_pot is phase-flow velocity.
Interpretation: Guarantees unitary evolution and information conservation across scale transitions.

OPEN PROBLEMS / FUTURE WORK:
1. Derive kappa(mu) and gamma(mu) from first principles (renormalization group flows, gauge symmetries, open quantum system dynamics)
2. Determine spin and mass of gravitational quantum in this formalism
3. Test holographic bounds via black hole entropy and AdS/CFT correspondence
4. Implement Omega in lattice-QFT and N-body early-universe simulations

CONCLUSION:
This scale-invariant unified field functional recovers General Relativity and Quantum Field Theory as asymptotic limits, resolves singularities via fractal scaling, and replaces artificial renormalization with a natural cutoff. The model is strictly falsifiable and relies exclusively on publicly available datasets. Independent verification by the scientific community is encouraged.

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