# Research Plan: Expanding the Emergent Gravity Framework from Quantum Entanglement

The HoloCosmo Project

April 9, 2025

## 1. Motivation and Epistemic Context

The HoloCosmo Project has proposed and demonstrated an effective gravitational field theory derived from the structure of entanglement entropy in quantum many-body systems. The model reproduces gravitational-like behavior (notably the inverse-square law) through entropic curvature constructs without relying on particle-based dark matter.

This research plan aims to extend the framework with an emphasis on epistemic rigor and falsifiability, investigating whether emergent entanglement structures can quantitatively and qualitatively explain gravitational anomalies traditionally attributed to dark matter, across multiple cosmic scales.

## 2. Research Objectives

1. Validate and extend the inverse-square law behavior from entanglement curvature across larger, heterogeneous models.
2. Simulate galaxy rotation curves using entropic potential wells and compare with observational data.
3. Model gravitational lensing as informational geodesic bending in entanglement fields.
4. Analyze cluster-scale phenomena (e.g., Bullet Cluster) via overlapping entanglement networks.
5. Investigate time-dependent behavior of entanglement-induced curvature to explore structure formation dynamics.
6. Identify observable signatures unique to the entanglement gravity framework.

# 3. Methodology

## 3.1 Lattice Simulations

- Extend the PEPS-based transverse-field Ising model to include variable lattice densities and anisotropies.
- Increase lattice resolution and bond dimension to test scaling of curvature behavior.
- Introduce localized entanglement defects to simulate galactic and cluster-like structures.

## 3.2 Entropic Potential and Rotation Curves

- Use the entropic Laplacian field $\nabla^2 S(r)$ to compute effective potentials $\Phi(r) = \kappa_E S(r)$.
- Derive velocity profiles via $v(r) = \sqrt{r \frac{d\Phi}{dr}}$.
- Compare to SPARC and other galaxy rotation curve datasets.

## 3.3 Cluster Simulations and Lensing

- Simulate overlapping entropy fields and track geodesics via Dijkstra-based cost minimization.
- Generate mock lensing maps using curvature gradients.
- Compare to Bullet Cluster, Abell 520, and gravitational lensing surveys (DES, KiDS).

## 3.4 Correlation Analysis

- Enhance statistical sampling of spatial correlation from Laplacian fields.
- Analyze scaling behavior of $\langle (\Delta \text{Laplacian})^2 \rangle$ with separation.
- Fit to power-law and compare with classical gravitational analogs.

## 3.5 Time Evolution

- Introduce dynamic updates to the entanglement network to simulate cosmic evolution.
- Track geodesic deviation and entropic structure formation over time.
- Compare growth rates with predictions from $\Lambda$CDM.

## 4. Epistemic Considerations

- Ensure falsifiability at every stage: specify predictions distinguishable from dark matter models.
- Emphasize model transparency: open-source all simulation code and data.
- Engage in cross-disciplinary peer review with both gravitational theorists and quantum information scientists.

## 5. Deliverables

- A series of publications addressing galaxy-scale, cluster-scale, and cosmological-scale implications.
- Open simulation framework for entanglement-curvature modeling.
- Experimental proposals for analog quantum simulator platforms.

## 6. Timeline (Tentative)

- **Months 1–3:** Refactor and scale PEPS simulation code; initial entropy profile models.
- **Months 4–6:** Galaxy rotation curve modeling and comparison.
- **Months 7–9:** Cluster-scale simulations and lensing analysis.
- **Months 10–12:** Temporal evolution studies and final synthesis.

## 7. Conclusion

This plan outlines a scientifically cautious but ambitious approach to probing the informational structure underlying gravity. Whether it ultimately replaces or complements conventional gravitational theory, this research aims to contribute lasting, testable insights at the intersection of geometry and entanglement.