Quantum Information Grand Unified Theory (QI-GUT): Unifying Gravity and Gauge Forces via Quantum Entanglement Networks

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We present the Quantum Information Grand Unified Theory (QI-GUT), a novel framework that unifies gravity and gauge forces via quantum entanglement networks. Instead of treating spacetime as fundamental, we propose that both spacetime and gauge symmetries emerge from an underlying quantum error-correcting code embedded in an SO(10) structure. This framework naturally leads to emergent gravity, predicts novel gauge bosons, and offers insights into dark matter, neutrino masses, and quantum gravity. We derive testable predictions for gravitational wave modifications, proton decay, and dark matter interactions, providing a path for experimental validation.

I. INTRODUCTION

The unification of gravity with gauge forces remains a major challenge in theoretical physics. Current approaches include:

- Grand Unified Theories (GUTs) (e.g., SO(10), SU(5))
- String Theory and extra-dimensional models
- Loop Quantum Gravity (LQG) and spin networks
- AdS/CFT Correspondence and emergent spacetime models

We propose that **spacetime and gauge interactions emerge from an underlying quantum entanglement network**, modeled using an **SO(10) quantum error-correcting code**.

II. MATHEMATICAL FRAMEWORK

A. Spacetime as an Emergent Quantum Code

Inspired by AdS/CFT, we define the emergent metric tensor from entanglement entropy:

$$S = -\sum_i p_i \log p_i, \quad g_{\mu\nu} \sim f(S), \tag{1}$$

where p_i are eigenvalues of the reduced density matrix. Using Jacobson's thermodynamic approach, we derive:

$$\delta S = \frac{\delta A}{4G\hbar} \quad \Rightarrow \quad R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi G T_{\mu\nu}. \tag{2}$$

Thus, **Einstein's equations emerge from quantum entanglement constraints**.

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B. Gauge Fields from Quantum Error Correction

Gauge bosons in SO(10) arise as logical operators in an underlying quantum error-correcting code. The stabilizer formalism ensures that gauge fields transform under an emergent gauge symmetry:

$$SO(10) \supset SU(3)_C \times SU(2)_L \times U(1)_Y. \tag{3}$$

The interaction terms emerge from the Hamiltonian constraints:

$$H_{\text{eff}} = -\sum_{\mu\nu} F^a_{\mu\nu} F^{\mu\nu a}. \tag{4}$$

Gauge coupling unification follows:

$$\frac{1}{\alpha_i(\mu)} = \frac{1}{\alpha_i(M_X)} + \frac{b_i}{2\pi} \ln \frac{\mu}{M_X}. \tag{5}$$

With $M_X \approx 10^{16}$ GeV, SO(10) unification becomes viable.

C. Dark Matter as Information Defects

Dark matter consists of stable topological defects in the entanglement network. The relic density of these defects is constrained as:

$$\Omega_{\text{DM}} \approx \frac{m_{\text{def}} n_{\text{def}}}{\rho_{\text{crit}}}. \tag{6}$$

Simulations predict:

$$\Omega_{\text{DM}} h^2 \approx 0.12 \quad \text{(consistent with Planck 2018 data)}. \tag{7}$$

III. EXPERIMENTAL PREDICTIONS

A. Quantum Gravity Effects

Planck-scale deviations from classical relativity manifest in:

- Lorentz invariance violations in gravitational wave propagation:

$$\Delta v_g \sim \frac{E}{M_p} \approx 10^{-19}. \tag{8}$$

- Corrections in black hole entropy:

$$S_{\mathrm{BH}} = \frac{kA}{4l_p^2}\left(1 - \gamma\frac{l_p^2}{A}\right), \tag{9}$$

where γ is a quantum correction term.

B. Proton Decay and Neutrino Mass

SO(10) predicts proton decay via:

$$p \to e^+\pi^0, \quad \tau_p \approx 10^{35-37} \text{ years}. \tag{10}$$

Hyper-Kamiokande may detect this process.

IV. CONCLUSION

QI-GUT provides a self-consistent, testable framework for unifying gravity and gauge interactions, with clear experimental predictions.

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