DATED HISTORY

v2- 4-17-25 - Emergent Physical Laws from Self-Referential Quantum-Information Dynamics

Version 2.0, April 17, 2025. The later SSRN manuscript states the bounded-Hamiltonian locality result. Repaired numerical diagnostics distinguish threshold arrivals from the mathematical bound.

Manuscript · p. 1, April 2025 draft

SRQID locality bound

Evidence · QATNU/SRQID dated scientific review / Clock integrity repair · November 12

Emergent Physical Laws from Self-Referential Quantum-Information Dynamics

A Fully Linear, No-Signalling, and Computationally Tractable Framework

Date: 17 April 2025
Version: 2.0 — "Verifiably-Consistent Draft"

Executive Summary

We present a background-independent theory in which **spacetime geometry and physical laws arise from the adaptive entanglement structure of a finite quantum network**. All dynamics are **strictly linear**, guaranteeing compliance with the no-signalling theorem validated by loophole-free Bell tests Nature. Geometry is encoded in dedicated *graph qubits*whose states are updated by a fixed, time-independent Hamiltonian acting on the joint Hilbert space of *matter qubits* ⊗ *graph qubits*. Because the generator of evolution is state-independent, the global map remains unitary; nevertheless, feedback between matter entanglement and graph topology is preserved, realising the sought self-referential loop without superluminal communication.

A Lieb–Robinson bound for bounded-degree hypergraphs ensures a finite emergent "speed of light" Physical Review. The model is minimal (qubits only), fully specified, and **polynomial-time simulable** so long as a fixed degree cap is imposed. We outline a phased programme—exact diagonalisation ($N \leq 16$), tensor-network simulation ($N \approx 10^4$), and astrophysical tests—that can falsify or confirm key predictions within the next decade.

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1 Introduction & Motivation

Reconciling quantum mechanics with general relativity demands (i) background-independence and (ii) an information-theoretic account of geometry. Holographic dualities, black-hole thermodynamics, and thousands of Bell tests point to **quantum information as the primitive**

substrate of reality. Prior discrete approaches (Loop QG, CDT, tensor-network holography) either fix the graph in advance or introduce non-linear update rules that conflict with the no-signalling principle. Our framework solves this tension by:

1. **Promoting connectivity to quantum degrees of freedom** (graph qubits).
2. **Keeping the Hamiltonian fixed and Hermitian**, thereby preserving linearity.
3. **Driving link dynamics with local entanglement measures**, so geometry genuinely responds to quantum correlations.

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2 Hilbert Space & Degrees of Freedom

H=(C2)⊗N ⊗ (C2)⊗ N(N−1)2 H=(C2)⊗N ⊗ (C2)⊗2N(N−1)

- **Matter qubits σix,y,zσix,y,z** at nodes i=1,…,Ni=1,…,N.
- **Graph qubit σijx,y,zσijx,y,z** encodes presence (∣1⟩∣1⟩) or absence (∣0⟩∣0⟩) of link ⟨i,j⟩⟨i,j⟩.

To keep simulations tractable we enforce a hard **degree cap** kmaxkmax via projectors that disable further link flips once either endpoint reaches kmaxkmax.

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3 Fixed, Linear Hamiltonian

H=∑iω2 σix(on-site rotation) + J0∑i<j1+σijz2 σizσjz(Ising if link present) + g∑i<j[Δij−η] σijx Πkmax(link flip driven by entanglement).H=i∑2ωσix+J0i<j∑21+σijzσizσjz+gi<j∑[Δij−η]σijxΠkmax(on-site rotation)(Ising if link present)(link flip driven by entanglement).

- **Smooth entanglement proxy**
  Δij=1−Trρi2−Trρj2+Trρij2(0 ≤ Δij ≤ 1).Δij=1−Trρi2−Trρj2+Trρij2(0≤Δij≤1).
  Quadratic in density matrices and hence measurable with two-copy swap circuits.
- **Threshold ηη** sets the correlation level above which links grow.
- **ΠkmaxΠkmax** projects onto states where both endpoints have degree < kmaxkmax.

Because HH is *state-independent* and Hermitian, time evolution U(t)=e−iHtU(t)=e−iHt is unitary, satisfies CPT, and obeys the no-signalling theorem by construction.

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4 Causality & Finite Propagation Speed

For any bounded-degree, finite-range Hamiltonian the Lieb–Robinson velocity obeys

vLR ≤ 2e ∣J0∣ kmax,vLR≤2e∣J0∣kmax,

even on dynamically flipping graphs Physical Review. Thus the theory possesses an emergent causal cone mimicking special-relativistic light-speed c~vLRc~vLR.

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5 Emergent Phenomena (Macroscopic Expectations)

Layer	Mechanism in Model	Expected IR Behaviour
Geometry	Link density ⟨σijz⟩⟨σijz⟩ → adjacency matrix	Metric via correlation decay
3 + 1 D	Degree cap + link-cost energetics	Network flows to low-dim phase
Relativity	Lieb–Robinson bound	Universal speed limit cc
Gravity	Energy transfer to graph qubits	Curvature sourced by energy density
Matter fields	Topological defects / degenerate eigenspaces of HH	Stable particle excitations

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6 Validation Road-Map

Phase	Toolset	Target N	Goal
0 (2025-26)	Exact diagonalisation (QuTiP)	≤ 16	Verify bounded light cone; observe link-growth threshold behaviour
I (2026-28)	Adaptive tensor networks (ITensor, χ ≤ 256)	10^3–10^4	Detect dimensional reduction & area-law entanglement surfaces
II (2028-30)	Effective-field-theory extraction	–	Predict Planck-suppressed Lorentz-violation terms
III (2030-35)	CTA, IceCube-Gen2, LISA waveform templating	–	Search for modified dispersion, GW echoes, stochastic background shifts

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7 Risk Analysis & Mitigations

Risk	Mitigation
No 3 + 1 D fixed point	Vary kmax,η,J0/gkmax,η,J0/g; add qudit matter DOFs
Tensor-network blow-up	Enforce stricter degree caps; use entanglement-filtered truncation
Null astrophysical signals	Sharpen predictions to tight falsification windows

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8 Conclusions

By embedding geometry in **explicit quantum registers** and coupling them to matter through a strictly linear Hamiltonian, we obtain a **self-referential yet no-signalling** model of emergent spacetime. All equations are dimensionally consistent, Hermitian, and backed by known Lieb–Robinson results, while experimental non-signalling is guaranteed by linearity and borne out by loophole-free Bell tests Nature. The framework is therefore *internally coherent and empirically compliant*, yet boldly predicts Planck-scale deviations that can be hunted in the next generation of astrophysical observatories.

Key References

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2. T. Kuwahara & K. Saito, "Lieb-Robinson Bound and Almost-Linear Light Cone in Interacting Boson Systems," *Phys. Rev. Lett.* **127**, 070403 (2021). Physical Review
3. S. Lloyd, *Programming the Universe* (Vintage, 2006).
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