Gravity from Entanglement Entropy Density

Therodynamic and Covariant Constraints on Emergent Spacetime

Kevin Monette

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1 1. Universe Entropy Constraint

Rigorous: From statistical mechanics,

$$S = k_B \ln \Omega,$$

where Ω is the number of accessible microstates. For a closed quantum system (the universe), the second law enforces

$$\frac{dS_{\text{universe}}}{dt} \geq 0.$$

We partition total entropy into effective sectors:

$$S_{\text{universe}} = S_{\text{matter}} + S_{\text{ent}}^{(\text{env})} \geq \text{constant}, \tag{1}$$

where $S_{\text{ent}}^{(\text{env})}$ denotes the entropy associated with vacuum correlations and coarse-grained entanglement degrees of freedom.

Physical: No physical process destroys global quantum state accessibility; entropy may be redistributed but not eliminated.

2 2. Vacuum vs Operational Entanglement Entropy

Rigorous: In relativistic QFT, vacuum entanglement across causal boundaries obeys an *area law* (e.g. Ryu–Takayanagi):

$$S_{\text{vac}} \propto \frac{A}{4G}.$$

However, in finite laboratory systems and coarse-grained many-body states, the relevant entropy is an *operational entanglement entropy density*, defined after tracing over environmental and UV degrees of freedom:

$$S_{\text{ent}}^{(\text{op})} = \int \left(\frac{S_{\text{ent}}}{V} \right) dV. \tag{2}$$

This quantity is not vacuum entanglement in the holographic sense, but a regulated, scale-dependent information density.

Physical: The vacuum is maximally entangled microscopically, but only a fraction of that entanglement remains coherent and operationally accessible at macroscopic scales.

3 3. Matter-Induced Entanglement Gradients

Rigorous: Local energy density $T_{\mu\nu}$ perturbs vacuum correlations via mode excitation, Unruh-like effects, and decoherence. Tracing over excited modes reduces the local reduced density matrix entropy:

$$\partial_i \left(\frac{S_{\text{ent}}}{V} \right) \propto -\rho_{\text{mass}}. \tag{3}$$

This defines an entanglement entropy gradient sourced by matter.

Physical: Mass locally depletes coherent vacuum correlations, producing an informational imbalance.

4 4. Thermodynamic Origin of Gravitational Force

Rigorous: Extremizing total entropy along worldlines,

$$\delta \int S_{\text{universe}}\, d\tau = 0,$$

yields an entropic force

$$\vec{F} = -T_{\text{vac}} \nabla S_{\text{ent}}, \quad T_{\text{vac}} \sim \frac{\hbar c}{\ell_P}.$$

Thus,

$$\vec{F}_{\text{grav}} \propto -\nabla \left(\frac{S_{\text{ent}}}{V} \right) \propto +\nabla \rho_{\text{mass}}. \tag{4}$$

Physical: Gravity is the relaxation force that restores entanglement equilibrium.

5 5. Effective Gravitational Coupling

Rigorous: Dimensional analysis:

$$[\hbar c] = M L^2 T^{-2}, \quad \left[\nabla \left(\frac{S_{\text{ent}}}{V} \right) \right] = L^{-4},$$

yields

$$G_{\text{eff}} \sim \hbar c \left| \nabla \left(\frac{S_{\text{ent}}}{V} \right) \right|. \tag{5}$$

Physical: Newton's constant emerges from information gradients rather than being fundamental.

6 6. Covariant Field Equations and Conservation

Rigorous: The effective Einstein equation is

$$G_{\mu\nu} = 8\pi G \left(T_{\mu\nu} + T^{\text{ent}}_{\mu\nu} \right), \tag{6}$$

with

$$T^{\text{ent}}_{\mu\nu} = \frac{\kappa}{8\pi G} \frac{c^4}{k_B \ln 2} S_{\text{ent}}(x)\, g_{\mu\nu}.$$

The Bianchi identity enforces

$$\nabla^\mu \left(T_{\mu\nu} + T^{\text{ent}}_{\mu\nu} \right) = 0, \tag{7}$$

implying an energy–momentum exchange:

$$\nabla^\mu T_{\mu\nu} = -\frac{1}{8\pi G} \partial_\nu \left(\kappa \frac{c^4}{k_B \ln 2} S_{\text{ent}} \right). \tag{8}$$

Physical: Entanglement gradients do not violate conservation; they mediate energy exchange between coarse-grained sectors.

7 7. Screening and Decoherence

Rigorous: Only the long-range coherent fraction of entanglement contributes gravitationally. Define

$$\alpha_{\text{screen}}(L) = \frac{S^{\text{coh}}_{\text{ent}}(L)}{S^{\text{total}}_{\text{ent}}(L)} \sim e^{-\Gamma(L)\tau}, \tag{9}$$

where $\Gamma(L)$ is the decoherence rate at scale L.

Physical: Environmental decoherence screens gravity by destroying long-range quantum correlations.

8 8. Universe Health Codes

Stability Fixed Point

$$\nabla\left(\frac{S_{\text{ent}}}{V}\right) = 0 \quad \Rightarrow \quad \text{stable vacuum} \tag{10}$$

Hard Rejects

$$\Delta S_{\text{universe}} < 0 \quad \Rightarrow \quad \text{unitarity violation} \tag{11}$$

Examples: Closed timelike curves, tachyons, negative-energy runaway states.

Persistence Feedback

$$\left|\nabla\left(\frac{S_{\text{ent}}}{V}\right)\right| \uparrow \quad \Rightarrow \quad G_{\text{eff}} \uparrow \tag{12}$$

9 Predictions

- Inverse-square force from correlation dilution
- Black-hole entropy as horizon entanglement
- Mass–temperature equivalence: $m \sim k_B T_{\text{vac}} \ln 2$
- Cosmological constant from baseline entanglement density
- Gravity as entanglement homeostasis

10 Source

`https://github.com/mssinternetmarketing-cyber/entropy-gravity-coupling`

Thermodynamics demands covariant quantum accounting.