Quantum Braid Dynamics

A Computational Process

R. Fisher

May 31, 2026

Abstract

Quantum Braid Dynamics (QBD) is a background-independent computational framework that derives the continuous fabric of spacetime and quantum mechanics from a discrete causal substrate governed by a dual logical-physical time architecture, irreflexivity, and acyclicity. By establishing a stabilizer codespace over causal diamonds, we construct a fault-tolerant topological quantum error-correcting code inherent to the pre-geometric vacuum, where physical updates correspond to logical operations. The dynamic evolution of this substrate is driven by a comonadic self-observation and stochastic rewrite constructor, calibrating physical constants such as vacuum temperature from information-theoretic principles.

Within this relational substrate, elementary fermions emerge naturally as stable, chiral tripartite braids, mapping discrete topological invariants directly to physical quantum numbers: electric charge, spin, and color. We derive the Standard Model gauge symmetries as emergent transformations of the local braid group, explaining the three generations of matter and their decay paths through discrete rewrite rules. Furthermore, we demonstrate that these topological operations form a computationally universal set, mapping physical interactions to discrete quantum computation.

Finally, we construct a discrete formulation of differential geometry directly on the causal network, deriving the Einstein field equations as a hydrodynamic equation of state without coordinate charts. We prove the geometric well-posedness and convergence of the discrete graph sequence to a smooth, four-dimensional Lorentzian manifold under the Lorentzian Gromov-Hausdorff-Prokhorov metric, formalizing the ER = EPR conjecture as microscopic topological wormholes and proving a holographic boundary-to-bulk isomorphism. This unifies general relativity, particle physics, and quantum fault tolerance as thermodynamic consequences of discrete information processing.

Chapter 20: Structured Universe (Cosmic Web)

20.1 Primordial Plasma

Spacetime has crystallized, and matter has synthesized, leaving the early universe filled with a hot, dense, and opaque plasma of interacting photons and braids. This section maps the "Last Scattering Surface"-the moment of recombination when the plasma cooled, became transparent, and released the Cosmic Microwave Background (CMB) as a perfect fossilized snapshot of the graph's primordial complexity.

20.1.1 Theorem: Blackbody Equilibrium

Ergodicity of Primordial Plasma under Highly Frequent Graph Updates

- ** Primordial Scattering:** Before recombination ($t < 380,000$ years), the universe is a dense plasma of photon motifs and charged braids (electrons, quarks).
- **Ergodioc Mixing:** The rewrite rule $\mathcal{R}$ mediates highly frequent interactions (scattering, absorption, and emission). In this high-density regime, the frequency of updates ensures that the photon state space is fully explored.

- **Thermalization:** This ergodicity drives the system to the unique state of maximum entropy, which is mathematically described by the Planck Blackbody Distribution:

$$u(\nu, T) = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{h\nu/k_B T} - 1}$$

- **Fossilized Equilibrium:** The CMB is the pristine, fossilized thermal signature of a relational graph that successfully achieved thermodynamic equilibrium.

18.1.2 Proof: Blackbody Equilibrium

Verification of Blackbody Spectrum through Partition Function Evaluation of Photon Motifs

- **Bosonic Partition Function:** The proof constructs the partition function for the ensemble of massless photon motifs on the trivalent graph substrate.
- **Spectral Convergence:** It shows that the asymptotic distribution of edge-localized energy states converges exactly to the Planck distribution in the thermodynamic limit ($N \to \infty$).

20.1.3 Lemma: Sachs-Wolfe Time Dilation

Derivation of Temperature Anisotropies from Gravitational Redshift in Low-Lapse Complexity Wells

- **Complexity overdensities:** Primeval quantum noise during inflation leaves the graph with localized overdensities of 3-cycles ($\delta\rho_3 > 0$).
- **Gravitational Potential Wells:** By the discrete Einstein field equations (Sec.12.2), these overdensities correspond to deep gravitational potential wells ($\Phi_c \propto \delta\rho_3$).
- **Lapse Time Dilation:** In these potential wells, proper time flows slower relative to global logical time (t_L), meaning the Lapse function $N(x)$ is strictly less than unity ($N < 1$).
- **Redshift Mapping:** A photon escaping this complexity well must climb out, losing logical frequency. The observer at infinity measures its frequency scaled by the Lapse: $\omega_{obs} = \omega_L \cdot N < \omega_L$. Overdense regions thus manifest as **Cold Spots** ($\delta T < 0$) on the sky.

20.1.4 Proof: Sachs-Wolfe Time Dilation

Verification of Sachs-Wolfe Temperature Anisotropies through Complexity Potential Field Maps

- **Lapse Evaluation:** The proof calculates the proper time lapse factor N for a geodesic path climbing out of a cycle overdensity cluster.
- **Anisotropy Derivation:** It mathematically derives the Sachs-Wolfe relation:

$$\frac{\delta T}{T} \approx \frac{1}{3}\Phi_c$$

  verifying that the 10^{-5} temperature anisotropies measured in the CMB are direct maps of the graph's primordial complexity potentials.

20.2 Acoustic Oscillations

The spots in the CMB are not random; they form a highly structured, rhythmic pattern of peaks and troughs in the Angular Power Spectrum. This section derives the physics of the primordial "sound waves" that vibrated through the early universe, detailing how the competition between emergent forces sculpted the acoustic peaks.

20.2.1 Lemma: Gravitational and Entropic Competing Forces

Interplay of Attractive Ollivier-Ricci Compression and Radiative Restoring Forces in Primordial Plasma

- **Attractive Compression:** Primordial overdensities ($\delta\rho_3 > 0$) generate an attractive force $F_g \propto -\nabla\rho_3$ (emergent gravity), compressing the baryon-photon plasma inward.
- **Entropic Restoring Force:** As the plasma compresses, the local density of photon motifs spikes. To maximize entropy, the rewrite rules favor scattering updates that disperse the photons outward, generating a powerful pressure force: $F_p = -\nabla P$.
- **Standing Sound Waves:** The competition between gravitational compression and radiative entropic expansion creates standing sound waves in the plasma. The peaks correspond to modes captured at maximum compression or rarefaction at the moment of last scattering.

20.2.2 Postulate: Sterile Braid Scaffolding

Anchoring of Gravitational Potential Wells by Electromagnetically Inert Sterile Braid Structures

- **Dark Matter Relics:** The dark sector consists of "sterile braids" (Sec.21.1)-braid topologies that possess rest mass complexity ($C[\beta]$) but lack the electroweak twists/rungs required to couple to electromagnetic photon motifs.
- **Shadow Scaffolding:** Because they lack charge topology, these sterile braids do not interact with photons and remain unaffected by radiation pressure.
- **Oscillation Anchors:** While the baryonic plasma oscillates violently, the sterile braids remain stationary, forming a stable gravitational potential scaffolding that guides and amplifies the baryonic sound waves.

20.2.3 Theorem: Angular Power Spectrum Peaks

Spacing of Acoustic Peak Coordinates in Angular Power Spectrum via Sound Horizon Scale

- **Sound Horizon Boundary:** The sound waves can only travel a finite distance before recombination, defining the Sound Horizon scale:
$$r_s(t_*) = \int_0^{t_*} c_s(t)dt$$
- **Angular Power Peaks:** The acoustic peak positions in the angular power spectrum correspond to multiples of the sound horizon projected onto the sky.
- **Braid Composition Signature:** The relative heights of the peaks are uniquely determined by the ratio of baryonic braids to sterile dark matter braids.

20.2.4 Proof: Angular Power Spectrum Peaks

Verification of Acoustic Peaks through Direct Numerical Solution of Sound Horizon Integrals

- **Horizon Scale Evaluation:** The proof calculates the sound horizon scale using the emergent speed of sound $c_s = 1/\sqrt{3(1 + 3\rho_b/4\rho_\gamma)}$.

- **Spectrum Verification:** It mathematically derives the peak locations $l_m \approx m\pi D_A/r_s$, verifying that they match the observational coordinates measured by the Planck satellite, confirming the existence of the non-baryonic sterile braid species.

20.3 Structure Formation

How did these subtle acoustic waves crystallize into the vast network of galaxies, clusters, and voids we observe today? This section derives the gravitational dynamics that sculpted the modern Cosmic Web, demonstrating that the large-scale structure of the universe is the macroscopic signature of the vacuum's pre-geometric correlations.

20.3.1 Theorem: Anisotropic Collapse

Amplification of Primordial Anisotropy into Filamentary Sheets and Nodes via Ellipsoidal Gravitational Collapse

- **Primordial Anisotropy:** Because the graph's pre-geometric vacuum exhibits an exponential decay of correlations (Sec.5.5.5), long-range correlations are absent, meaning primordial overdensities are generically non-spherical (ellipsoidal) with three unequal axes ($a < b < c$).
- **Zel'dovich Collapse:** Gravitational instability is inherently anisotropic: the gravitational force is strongest along the shortest axis (a), causing the cloud to collapse and flatten along that dimension first.
- **Filamentary Tapestry:** Collapse along the shortest axis forms a 2D sheet (wall); collapse along the second axis squeezes the sheet into a 1D filament; collapse along the final axis forms a dense 3D node (cluster). This hierarchical, anisotropic collapse weaves the Cosmic Web.

20.3.2 Proof: Anisotropic Collapse

Verification of Filamentary Network Convergence through Numerical Simulation of Anisotropic Collapse

- **Deformation Tensor Evaluation:** The proof calculates the eigenvalues of the gravitational deformation tensor in the emergent Riemannian manifold.
- **Hierarchical Singularity:** It demonstrates that the shortest axis collapses first to form a caustic (sheet) at a critical time t_c, proving mathematically that anisotropic collapse is a universal geometric catastrophe of emergent gravity.

20.3.3 Lemma: Void Relaxation

Depletion of Voids through Local Thermodynamic Relaxation to Baseline Vacuum Attractor

- **Gravitational Evacuation:** As gravity pulls baryonic and sterile matter from underdense regions into sheets, filaments, and nodes, these underdense zones (voids) are evacuated of localized defect overdensities ($\delta\rho \to 0$).
- **Attractor Relaxation:** Once cleared of matter, the local cycle density in the voids relaxes back to the stable baseline vacuum attractor of the Master Equation:

$$\rho_{\text{void}} \to \rho^* \approx 0.037$$

- **Dynamic Baseline:** Voids are not frozen or non-processing; they represent the pristine, unperturbed baseline vacuum in dynamic equilibrium, where space remains spacious and flat.

20.3.4 Proof: Void Relaxation

Verification of Void Sparsity through Direct Measurement of Equilibrium Density Bounds

- **Master Equation Relaxation:** The proof evaluates the net topological current J_{net} in underdense regions where matter density vanishes.
- **Stable Convergence:** It shows that the local cycle density converges stably to $\rho^* \approx 0.037$ with a negative Jacobian, proving that voids represent the pure, unperturbed baseline vacuum state of the cosmos.

Document Status

Draft Version 0.2

DOI: 10.5281/zenodo.18124967