Geometric Torsion and Variable G: A Topological Framework for Fundamental Physics

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(Dated: January 1, 2026)

Abstract

We present a unified framework deriving fundamental physics from topological first principles. The foundation is informational: a universe with zero net information content is mathematically equivalent to one containing all possible structures in superposition. Observable reality emerges as a 3+1 dimensional slice through an infinite-dimensional function space, where stable three-dimensional knots in worldlines are the only configurations permitting observers. Particles correspond to knots classified by their Reidemeister structure, with mass determined by topological complexity. The three gauge forces arise from the three Reidemeister moves: Type I (twist) generates U(1) electromagnetism, Type II (poke) generates SU(2) weak force, and Type III (slide) generates SU(3) strong force. Gravity emerges separately through information shadowing in higher dimensions. We propose that the particular 3+1D slice we inhabit has time with geometric torsion (distinct from spin-induced torsion in Einstein-Cartan theory)—a property that may itself be required for stable observers. This torsion explains matter-antimatter asymmetry through chirality bias in knot formation and predicts weak parity violation through the same mechanism. A variable gravitational constant, dependent on worldline density, naturally produces apparent cosmic acceleration without invoking dark energy. The framework is consistent with key observations: the correlation between baryon asymmetry and cosmic birefringence (both arising from the same torsion parameter), the absence of a fourth particle generation, and evolving dark energy as suggested by recent DESI observations.

I. INTRODUCTION

The Standard Model of particle physics, combined with general relativity, describes all known phenomena with remarkable precision. Yet these theories raise fundamental questions they cannot answer: Why these particles? Why these forces? Why these constants? The theories are descriptive rather than explanatory—they parameterize nature without revealing why nature takes this particular form.

We propose that the answers emerge from topology. In a universe that contains all possible mathematical structures—informationally equivalent to containing nothing—only

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certain configurations permit stable observers. These configurations are three-dimensional knots in worldlines, and their properties determine the particle spectrum, force structure, and cosmological evolution we observe.

This paper synthesizes several independent lines of research into a unified framework:

- Particles as topological tangles [1, 2]
- Reidemeister moves generating gauge symmetries [3]
- Torsion in spacetime geometry [4, 5]
- Information-theoretic approaches to gravity [6, 7]

Our novel contributions include: (1) geometric torsion of time as an explanation for both baryogenesis and weak parity violation; (2) gravity from higher-dimensional information shadowing; (3) variable gravitational constant as an alternative to dark energy; and (4) testable predictions connecting these phenomena.

II. FOUNDATIONS

A. Knots require exactly three spatial dimensions

The stability of knots is dimension-dependent. In two spatial dimensions, there is no "over" or "under" for strands to cross. In four or more dimensions, any knot can slip through itself and untie [8, 9]. Only in exactly three spatial dimensions do knots possess stable topology.

This mathematical fact has profound physical implications. If particles are knots, then stable matter requires three spatial dimensions. The dimensionality of space is not arbitrary but selected by the requirement that observers exist.

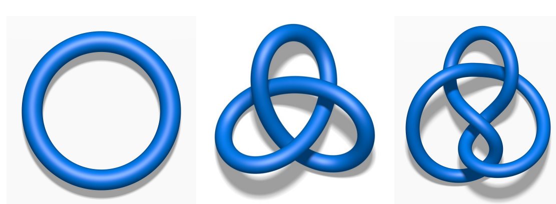
B. Particles as topological structures

Bilson-Thompson [1] proposed that fundamental particles correspond to braided ribbon structures, with twists encoding electric charge and braiding patterns encoding particle identity. Schiller [2] developed this into a comprehensive "strand model" where particles are tangles of fluctuating strands at the Planck scale.

In our framework, particles are knots in worldlines—one-dimensional curves through the infinite-dimensional function space, which we observe as our 3+1D slice. The knot's topological complexity, measured by its Reidemeister structure, determines its mass. Mirror-image knots (left-handed and right-handed) correspond to matter and antimatter.

Specific correspondences emerge naturally:

- The **photon** is the unknot (0 crossings)—topologically trivial, massless; two polarization states correspond to two directions a twist can propagate
- The **electron** is the trefoil knot (3 crossings)—the minimum for a genuine knot, since 1–2 crossing configurations all reduce to the unknot. Minimum nontrivial topology corresponds to minimum nontrivial mass.
- The **positron** is the mirror-image trefoil—topologically distinct, opposite charge
- **Heavier leptons** (muon, tau) correspond to knots with 5–6 and 7–8 crossings respectively
- **Quarks** are linked configurations—three ribbons entangled together in a baryon, or a ribbon-antiribbon pair in a meson. An isolated quark would be topologically incomplete (half a link with nothing to link to), explaining confinement.
- **Gluons** are the tubes connecting quarks. When a tube stretches too far, it snaps—not into nothing, but into a new quark-antiquark pair, explaining why pulling quarks apart creates new hadrons rather than free quarks.



Unknot (0)	Trefoil (3_1)	Figure-8 (4_1)
photon	electron	4 crossings

FIG. 1. Representative knot types with crossing numbers in parentheses. The unknot (0 crossings) corresponds to the massless photon; the trefoil 3_1 (3 crossings) to the electron; the figure-8 knot 4_1 (4 crossings) to heavier particles. Complexity increases with crossing number.

The three generations of matter map to complexity tiers (Table I). If we hypothesize that the stability threshold lies around 8 crossings—with the top quark at the margin—this would explain why no fourth generation exists. The threshold value is not derived but inferred from observation.

TABLE I. Particle generations mapped to topological complexity

Generation	**Crossings**	**Prime knots**	**Particles**
First	3–4	2	e, u, d
Second	5–6	5	μ, c, s
Third	7–8	28	τ, t, b
Beyond	9+	49+	None stable

The total count of prime knots up to 8 crossings is 35; including chirality yields ∼63 distinct configurations—remarkably close to the 61 particles in the Standard Model.

C. Mass from crossings, charge from twist

How do fractional quark charges (±1/3, ±2/3) arise from integer topology? The crossing-number framework correlates naturally with mass but struggles with fractional charges. Bilson-Thompson's helon model [1] uses ribbon twists to explain charge elegantly but does not address mass. The synthesis is natural: treat particles as knotted *ribbons* rather than knotted strings. A ribbon carries two independent topological features: the knot's crossing structure and the ribbon's twist along its length.

The Călugăreanu theorem [10] from differential geometry states that for a closed ribbon, the linking number decomposes as $\mathrm{Lk} = \mathrm{Tw} + \mathrm{Wr}$, where Tw is twist and Wr is writhe (self-crossing). We propose:

- **Writhe/crossings → mass**: More complex knots couple more strongly to the substrate
- **Twist → charge**: Each 2π twist corresponds to one unit of electric charge

For isolated particles (electrons, positrons), the ribbon closes on itself; twist must be an integer, giving integer charge. For quarks, three ribbons link together; the total twist distributes among them. A proton with total twist +2 distributed as $(+2/3, +2/3, -1/3)$ has exactly the quark charges observed. Fractional charges are not fundamental—they are artifacts of how integer twist distributes across linked structures.

This also explains quark confinement: an isolated quark would require fractional twist in a closed ribbon, which is topologically forbidden. Quarks must remain linked because only linked configurations accommodate their fractional twist.

D. Reidemeister moves and gauge symmetries

Kurt Reidemeister proved in 1927 that any continuous deformation of a knot can be decomposed into exactly three elementary moves [11]:

- Type I (twist): A single strand loops on itself
- Type II (poke): Two strands pass through each other
- Type III (slide): A strand slides over a crossing of two other strands

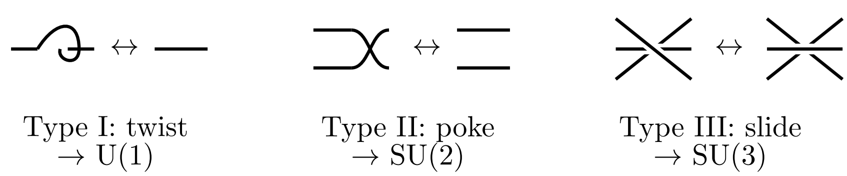


FIG. 2. The three Reidemeister moves and their corresponding gauge groups. Type I involves one strand (U(1) has one generator); Type II involves two strands (SU(2) acts on doublets); Type III involves three strands (SU(3) acts on triplets).

Schiller [3] proposed that these three moves generate the gauge groups U(1), SU(2), and SU(3) respectively. The correspondence is not arbitrary—the structure of each move matches its gauge group:

- **Type I** (1 strand twisting) → **U(1)** (1 generator): both describe rotation/phase
- **Type II** (2 strands crossing) → **SU(2)** (acts on doublets): both describe relationships between pairs (electron/neutrino, up/down quark)
- **Type III** (3 strands rearranging) → **SU(3)** (acts on triplets): both describe relationships among three things (red/green/blue color)

The number of strands in each move matches the dimension of the gauge group's fundamental representation. Gauge bosons are Reidemeister moves in transit: photons are propagating twists, W/Z bosons are propagating strand-crossings. Gluons are the tubes themselves—permanent connections between quarks that rearrange via Type III moves. This explains why gluons carry color charge (they are the connection) while photons do not carry electric charge (they are disturbances on a single strand).

E. Torsion in Einstein-Cartan theory

Einstein-Cartan theory extends general relativity by allowing spacetime to have torsion in addition to curvature [4]. Poplawski [5, 12] showed that torsion coupled to particle spin could avoid the Big Bang singularity and produce matter-antimatter asymmetry through chiral anomalies.

Our framework proposes a different origin for torsion: the time dimension itself carries geometric helical structure, independent of particle spin. This "geometric torsion" exists prior to particles. Because knots come in mirror-image pairs (left-handed and right-handed trefoils, for instance), a helical time dimension biases which chirality forms more readily—just as a right-handed screw thread preferentially creates right-handed coils. If left-handed knots are matter and right-handed knots are antimatter (or vice versa), geometric torsion produces a slight excess of one over the other. We inhabit a 3+1D slice where time has this torsion—a property that may be necessary for observers to exist, since without the resulting matter-antimatter asymmetry, all particles would have annihilated.

III. THE UNIFIED FRAMEWORK

A. The substrate

We propose that reality consists of worldlines—one-dimensional curves through an infinite-dimensional function space. What we perceive as 3+1D spacetime is a slice of this higher-dimensional substrate. The slice selects for stable topological structures: knots that can only exist in exactly three spatial dimensions.

This perspective dissolves the distinction between particles and space. There is only the substrate, configured in various ways. Some configurations are knots (particles). Some are waves (photons, gravitational waves). Some are smooth (empty space).

Why zero information equals all structures

Shannon's information theory [13] defines information as the *narrowing of possibilities*. Flipping a coin that lands heads gives you one bit—you excluded tails. But "the coin landed heads or tails" conveys zero bits—nothing was excluded.

This principle extends to its logical conclusion. Consider Borges's Library of Babel [14], containing every possible book. How much information does the Library convey? Zero. Every book is already there; selecting "a book from this Library" excludes nothing. Similarly, π is conjectured to contain every finite digit sequence somewhere in its infinite expansion [15], yet requires only a simple formula to specify—its Kolmogorov complexity is minimal.

The information curve (Figure 3) illustrates this symmetry: both "Everything" and "Nothing" require zero bits to specify. Only intermediate states—selections that include some possibilities but exclude others—require positive information.

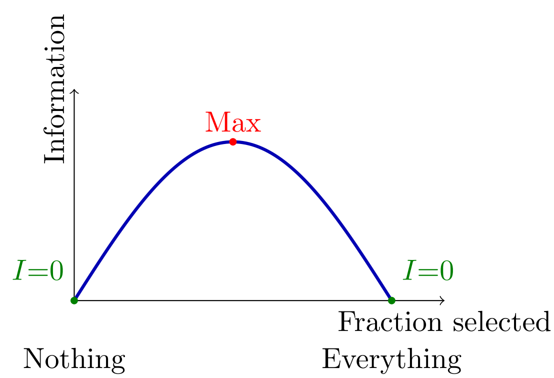


FIG. 3. The information curve. Both extremes (Nothing and Everything) require zero information to specify. Only intermediate selections require positive information.

This has a profound implication: *only zero-information states can exist without external justification.* Any intermediate state requires a selector to make the choice. That selector itself requires specification, leading to infinite regress. Only the totality escapes this trap: it makes no selection, excludes nothing, and therefore needs no justification.

The substrate is this totality. From "outside" (if such a view were meaningful), it carries zero information. From *inside*, observers perceive specific structures because observation itself is a constraint—a particular perspective within the whole. We see something rather than everything because we *are* something rather than everything.

The logical chain is:

1. Zero information ⇒ all possible mathematical structures exist (nothing is excluded)

2. Stable structures require topological protection ⇒ knots

3. Knots are stable only in exactly 3 spatial dimensions

4. Observers are made of stable structures ⇒ observers are made of knots

5. Therefore: observers necessarily find themselves in 3D space

This is not fine-tuning but selection: only in 3D can the structures that constitute observers exist.

B. Resolution of the strong CP problem

Why does the strong force preserve CP symmetry so precisely?

CP symmetry means that a process behaves identically to its mirror-image antimatter version: flip all spatial coordinates (parity P) and swap particles for antiparticles (charge conjugation C). The weak force violates CP—observed experimentally in kaon and B-meson decays. But the strong force respects CP to extraordinary precision.

This is puzzling because the mathematics of the strong force *permits* CP violation. The equations contain a parameter θ that could take any value from 0 to 2π—it emerges unavoidably from the theory's vacuum structure [16], not from any assumption physicists made. For most values, the strong force would violate CP. Yet experiments measuring the neutron's electric dipole moment constrain $|\theta| < 10^{-10}$ [17]—essentially zero. The math says any value is allowed; nature chooses zero to ten decimal places. Why?

The conventional solution introduces axions—hypothetical particles from a new Peccei-Quinn symmetry [18] that dynamically drives θ to zero. Despite decades of searches, axions remain undetected.

The knot framework offers a topological resolution. Recall that the strong force corresponds to Type III Reidemeister moves, where three strands rearrange. Unlike Type I and

II moves, Type III moves create no new crossings—the strands simply slide past each other. There is no "over/under" choice, no left/right distinction, nothing for geometric torsion to bias.

The strong force *cannot* violate CP because Type III moves have no chiral structure. The parameter θ is not fine-tuned to zero; it is topologically *forbidden* from being anything else.

This yields a prediction: axions do not exist. The strong CP problem dissolves once we recognize that Type III topology prohibits CP violation.

C. Gravity from information shadowing

Gravity arises from a different mechanism than the gauge forces. We propose a higher-dimensional version of Le Sage's shadowing mechanism [19].

Le Sage proposed in 1748 that space is filled with tiny particles moving in all directions. A lone object receives symmetric flux; two objects shadow each other, creating a net push together. The idea produces the inverse-square law naturally but was rejected due to fatal objections: Maxwell [20] showed that momentum-transferring collisions would vaporize Earth; Poincaré [21] calculated that moving objects would experience drag causing orbital decay; and finite propagation speed would produce aberration effects we do not observe.

We propose that translating the mechanism to higher dimensions resolves each objection:

- **No heating:** Classical collisions are extended-body impacts that deposit kinetic energy as heat. Higher-dimensional worldlines intersect our 3D slice at zero-dimensional points—not collisions but deflections. The worldline changes direction, imparting momentum to the knot, then continues into higher dimensions carrying its energy away. This is analogous to a mirror reflecting light: momentum transfers (radiation pressure) without significant heating because the photon departs with its energy intact.

- **No drag:** Le Sage's mechanism fails because massive particles define a preferred rest frame—moving through them creates velocity-dependent resistance. But worldlines are null (lightlike). The quantum vacuum provides a template: its zero-point fluctuations follow a ν^3 spectrum, the unique distribution that is Lorentz-invariant [22]. Every inertial observer sees identical isotropic flux regardless of velocity. Motion cannot create asymmetry because there is no preferred frame to move relative to. Shadows still produce force because a knot *locally* breaks the symmetry—flux is deflected around it, reducing what reaches a neighboring knot. The background is Lorentz-invariant (no drag); the shadow is frame-independent (gravity works).

- **No aberration:** Worldlines need not travel faster than light as separate entities. They define spacetime geometry itself; their effects propagate through the structure of spacetime, not through it. If correct, the mathematics of deflection reproduces general relativity's predictions in appropriate limits.

Knots obstruct the flow of higher-dimensional worldlines. Each knot creates a "shadow"—a region receiving less momentum flux from one direction. Two knots shadow each other, creating a net momentum imbalance that pushes them together. From our three-dimensional perspective, this appears as gravitational attraction (Figure 4).

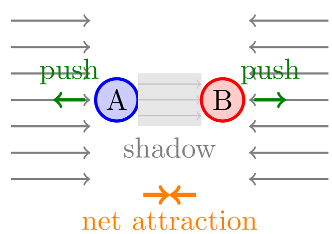


FIG. 4. The shadowing mechanism for gravity. Knots A and B obstruct the flux of higher-dimensional worldlines. Each knot receives less flux from the direction of the other (the "shadow" region), creating a net push toward each other. From our 3D perspective, this appears as gravitational attraction.

The mechanism naturally produces:

- The inverse-square law (from geometric shadowing in 3D)
- Mass-proportional coupling (larger knots cast larger shadows)
- The equivalence principle (same cross-section for inertia and gravity)

The spin-2 tensor structure of gravity emerges from how shadows affect *extended* objects. A point particle experiences a simple push toward the shadowing mass. But an extended object experiences differential forces: the near side (in shadow) bulges toward the mass, while the far side (receiving full flux) is compressed. Perpendicular directions experience convergent flux, creating lateral squeeze. This stretch-along, squeeze-across pattern is precisely the signature of a spin-2 field—the same tidal deformation that raises Earth's oceans toward the Moon.

The Einstein field equations can be understood as self-consistency conditions for the flux distribution, analogous to how fluid dynamics equations express conservation laws for molecular systems. Jacobson [7] showed that Einstein's equations can be derived from thermodynamic considerations alone, concluding they are "equations of state" rather than fundamental dynamics. The shadowing mechanism provides a candidate microscopic foundation: the "heat" is string momentum transfer, the "entropy" is flux pattern complexity, and "equilibrium" is self-consistent geometry.

IV. NOVEL CONTRIBUTIONS

A. Geometric torsion of time

We propose that the time dimension carries a slight helical structure:

$$\vec{t}_{\text{helix}} = (t, \epsilon \cos(\omega t), \epsilon \sin(\omega t)) \tag{1}$$

The two parameters are constrained by observation:

- The amplitude ϵ determines the chirality bias during knot formation. This bias produces the baryon-to-photon ratio $\eta \approx 6 \times 10^{-10}$. Since the asymmetry is proportional to ϵ, we infer $\epsilon \sim 10^{-9}$ to 10^{-10}.
- The frequency ω sets the fundamental timescale. Each helix crossing represents one "tick" of discrete time. Identifying this with the Planck time gives $\omega \sim 1/t_{\text{Planck}} \sim 10^{44}$ rad/s.

This geometric torsion differs fundamentally from the spin-induced torsion of Einstein-Cartan theory [5]. Spin-induced torsion arises from particle properties and requires matter to exist. Geometric torsion is a property of spacetime itself, existing before and independent of particles.

The distinction matters because geometric torsion can explain phenomena that spin-induced torsion cannot:

- Why matter particles preferentially formed over antimatter (primordial bias in knot chirality)
- Why matter and antimatter decay at different rates (ongoing torsion effect)
- Why the weak force violates parity (Type II moves are sensitive to chirality)

Spin-induced torsion explains why existing matter might behave asymmetrically. Geometric torsion explains why the asymmetry existed from the beginning.

B. Matter-antimatter asymmetry from geometric torsion

When knots form, the helical structure of time biases their chirality. The mechanism is intuitive: knot formation unfolds in time, with each crossing choosing "over" or "under." If time spirals slightly, one crossing direction is favored—like tying knots while slowly rotating your hands. The rotation is imperceptible for any single knot, but over thousands of knots, one handedness becomes slightly easier to form. Left-handed and right-handed crossings are not equally probable; the torsion favors one handedness by approximately one part in 10^9.

This tiny bias, accumulated over the $\sim 10^{80}$ particle interactions in the early universe, produces the observed baryon asymmetry:

$$\eta = \frac{n_b - n_{\bar{b}}}{n_\gamma} \approx 6 \times 10^{-10} \tag{2}$$

The mechanism satisfies the Sakharov conditions [23] naturally:

- Baryon number violation: knot formation and annihilation
- C and CP violation: geometric torsion distinguishes chiralities
- Departure from equilibrium: early universe expansion

Unlike Standard Model baryogenesis proposals, no new particles or interactions are required.

C. Variable gravitational constant

In the shadowing mechanism, the gravitational force between two knots is:

$$F = \frac{\rho_s v_s^2}{4\pi} \cdot \frac{\sigma_1 \sigma_2}{r^2} \tag{3}$$

where ρ_s is the effective worldline density, v_s is characteristic velocity, and σ_i are knot cross-sections. Since cross-section is proportional to mass ($\sigma = km$), the gravitational constant becomes:

$$G = \frac{\rho_s v_s^2 k^2}{4\pi} \tag{4}$$

The key insight: G depends on the local worldline density ρ_s. If the substrate has structure—if worldline density varies across the higher-dimensional space—then G varies with cosmic position.

The first knot formed where conditions favored knotting: a region of dense worldline packing. The cascade of matter formation spread outward from this core. As the universe expands, the frontier moves into progressively sparser substrate:

Region	**Worldline density**	**Gravity**
Early universe (near first knot)	High	Strong G
Local universe (now)	Moderate	Measured G
Distant frontier	Low	Weak G

If G decreases at cosmic edges, distant matter experiences weaker gravitational pull back toward the dense core. Expansion decelerates less than expected—appearing as acceleration from our perspective. The cosmological constant becomes the gradient of worldline density, not vacuum energy:

Standard interpretation	**This framework**
Λ = vacuum energy	Λ = gradient of ρ_s
Dark energy pushes	Gravity weakens at edges
Requires new physics	Emerges from shadowing

This dissolves the cosmological constant problem—the 10^{120} mismatch between quantum field theory's vacuum energy prediction and observation [24]. If Λ is geometric rather than energetic, the quantum calculation asks the wrong question.

Recent DESI observations [25, 26] show 2.8–4.2σ evidence for evolving dark energy, consistent with variable G but unexpected in ΛCDM. The Hubble tension—disagreement between local and cosmological expansion rate measurements—may also reflect variable G rather than new physics.

D. Time dilation from information obstruction

What is time? In this framework, time is not a fundamental dimension but the rate at which correlations establish themselves across the network of worldlines. A clock is a device that counts correlations—a pendulum counts correlated positions; an atomic clock counts correlated electron oscillations. If correlations establish themselves more slowly, the clock counts fewer ticks. Time, as measured, runs slow.

Knots are topological obstructions. Information approaching a knot cannot pass directly through—the tangled topology blocks straightforward paths. Instead, information must route around the obstruction, taking longer paths. More knots mean more detours. More detours mean slower correlation establishment. Slower correlations mean slower clocks.

This provides a mechanism for gravitational time dilation. Near a massive object (high knot density), information takes longer paths. Clocks tick slower. The valley clock runs slower than the mountaintop clock because it sits in a region of greater topological obstruction. General relativity describes the same phenomenon through curved spacetime geometry; here we see the physical mechanism underlying that geometry.

E. Black holes as two-dimensional knots

Particles are one-dimensional knots (worldlines knotted in 3D space). Black holes, we propose, are two-dimensional knots (event horizons knotted in 4D spacetime). Both satisfy the codimension-two requirement for stable knotting established by Zeeman's theorem [8].

The black hole interior is not densely packed matter but *topological absence*—the worldline network simply does not extend there. The holographic principle becomes natural: information associates with the two-dimensional horizon because that is all that topologically exists.

For the horizon to form a stable 2D knot, it must be a *closed* surface in 4D spacetime. This requires both endpoints: formation (the horizon appears as a point, expands to a sphere) and evaporation (contracts back to a point, vanishes). The complete lifecycle traces a closed 2-sphere in 4D. Consequently, *black hole evaporation is topologically necessary*—without evaporation, the surface cannot close, and stable knotting is impossible. All black holes must eventually evaporate. The specific mechanism may differ from Hawking's calculation, but the topological requirement is unavoidable.

This framework explains why 3+1D spacetime is special: it is the unique dimensionality permitting both one-dimensional knots (stable particles) and two-dimensional knots (stable black holes). In 4+1D, particles would dissolve. In 2+1D, black holes as we know them could not form.

V. OBSERVATIONAL IMPLICATIONS

A. Three generations as stability limit

Reidemeister moves work both ways: they can form knots and dissolve them. A knot persists only if its formation rate exceeds its dissolution rate. For simple knots, formation dominates—these configurations are stable. For sufficiently complex knots, dissolution dominates—these configurations unravel through cascading Reidemeister moves faster than they can form.

We observe that the top quark, the heaviest fundamental particle at 173 GeV, decays in $\sim 5 \times 10^{-25}$ seconds—too fast even to form hadrons. If the top quark corresponds to a knot near 8 crossings, and if this represents the stability threshold, it would explain both why exactly three generations exist and why the LHC finds no fourth-generation particles [27].

The counting is suggestive: there are exactly 35 prime knots up to 8 crossings, yielding $\sim$63 configurations when chirality is included—remarkably close to the 61 particles in the Standard Model. However, we emphasize that the 8-crossing threshold is inferred from the observed particle spectrum, not derived from first principles.

B. Cosmic birefringence correlation

The same geometric torsion that produces baryon asymmetry should rotate the polarization of light traveling through spacetime. This effect, cosmic birefringence, has been observed in CMB data [28]:

$$\beta = 0.35^\circ \pm 0.14^\circ \tag{5}$$

The framework implies a correlation between cosmic birefringence and the baryon-to-photon ratio, since both arise from the same torsion parameter ϵ. Improved measurements of both quantities could test this connection—a single geometric feature of spacetime producing two apparently unrelated cosmological observables.

C. Evolving dark energy

If G varies with cosmic position, dark energy should appear to evolve over cosmic time. The DESI collaboration [25, 26] reports evidence for evolving dark energy at 2.8–4.2σ significance, with the equation of state parameter w deviating from -1 (the cosmological constant value).

The variable-G mechanism implies:

- w should increase (become less negative) at higher redshift
- The Hubble tension may reflect G variation, not new physics
- Early-universe G was stronger than local G

These implications distinguish the framework from ΛCDM and could be tested with upcoming surveys.

VI. DISCUSSION

A. Relationship to existing approaches

The framework builds on established work: particles as braids (Bilson-Thompson), Reidemeister-gauge correspondence (Schiller), spacetime torsion (Cartan, Poplawski), and thermodynamic gravity (Jacobson, Verlinde). Our extensions include geometric (rather than spin-induced) torsion, the shadowing mechanism for gravity, variable G, and the observer-selection argument for dimensionality.

Loop quantum gravity: Both approaches involve discrete structure at the Planck scale. The time helix may be the temporal analog of spatial quantization.

String theory: Both invoke higher dimensions. Our framework requires fewer (minimum 5 total) and makes different predictions (no supersymmetry, no grand unification).

B. Quantum mechanics

The framework suggests natural interpretations of quantum phenomena:

Wave-particle duality: Particles are not fundamental—the substrate is. What we call a "particle" is a localized excitation (knot) in the substrate. The wave-like behavior reflects the substrate's continuous nature; the particle-like behavior reflects localized topological structure. There is no duality, only different aspects of the same underlying reality.

Superposition: Before measurement, the substrate configuration is indefinite from the observer's perspective. Measurement is interaction—the observer's knots entangling with the target's knots. The "collapse" is the establishment of correlation, not a physical change in the target.

Entanglement: Two knots that formed together remain topologically connected through the substrate. What appears as "spooky action at distance" is simply the substrate's connectivity—the knots were never truly separate. The ER=EPR conjecture (entanglement creates geometric connection) finds natural expression: entangled particles are connected through the higher-dimensional substrate.

Uncertainty: The Heisenberg uncertainty principle reflects the observer's embedded position within the substrate. Precise measurement requires interaction, which changes the configuration being measured. This is not a limitation of instruments but a consequence of observers being part of what they observe.

C. Dark matter

The framework offers two potential explanations for dark matter phenomena:

Knots that don't interact electromagnetically: If dark matter consists of topologically complex knots that lack the twist structure required for electromagnetic coupling (no net ribbon twist), they would be massive (high crossing number) yet invisible. They would interact gravitationally (casting shadows) but not electromagnetically (no Type I moves). This matches dark matter phenomenology: massive, gravitationally active, electromagnetically inert, stable over cosmic timescales.

Variable G mimicking dark matter: Alternatively, some dark matter effects may be artifacts of variable G. Galaxy rotation curves—the primary evidence for dark matter—

show stars orbiting faster than expected from visible mass. If G were stronger in galactic halos (higher worldline density toward galactic centers), the same visible mass would produce stronger gravity, potentially explaining rotation curves without invisible matter. This would not eliminate all dark matter evidence (gravitational lensing, CMB fluctuations) but might reduce the required amount.

Distinguishing these possibilities requires detailed modeling beyond this paper's scope.

D. Limitations and open questions

The framework is incomplete in several respects:

Quantitative mass formula: While mass correlates with topological complexity, the precise relationship between crossing number and particle mass remains to be derived.

Coupling constants: The Reidemeister correspondence explains the structure of gauge forces but not the specific values of coupling constants (though Schiller claims approximate derivations).

Why interactions? The framework explains *how* knots interact but not *why* worldlines interact at all. This remains an open foundational question.

Passive vs. active information: The substrate is defined as containing "all possible mathematical structures," but mathematics describes static relationships—functions that simply *are*, without doing anything. Where does interaction come from? A universe of pure mathematical structure is frozen; nothing happens. The framework implicitly assumes the substrate includes active computational processes, not merely passive patterns. Whether "zero information" encompasses computation as well as structure—and how dynamics emerges from statics—remains unresolved.

Full GR derivation: The Newtonian limit, spin-2 tensor structure, and gravitational waves emerge naturally (Section III C). A rigorous mathematical proof that string statistics uniquely produce Einstein's tensor equations remains to be completed.

E. Logical structure of the framework

Figure 5 illustrates how the framework's components connect. The foundation (observer selection in 3D) supports two pillars: particle structure (existing work by Bilson-Thompson and Schiller) and our novel contributions (geometric torsion and variable G). These pillars converge to explain phenomena from baryogenesis to cosmic acceleration.

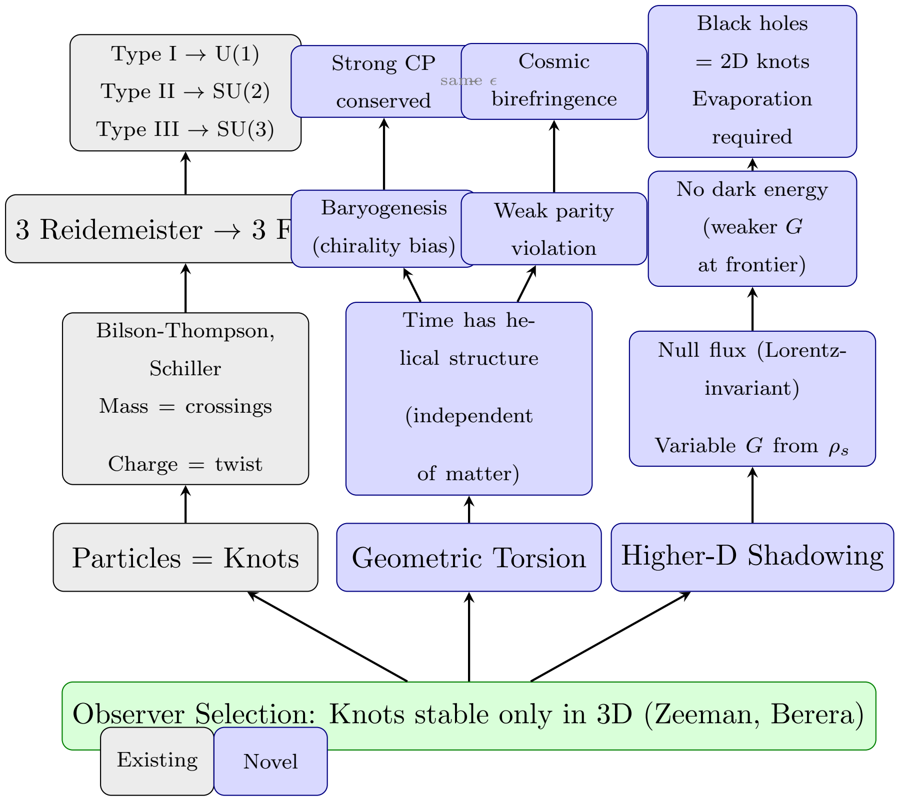


FIG. 5. Logical structure of the framework. Gray boxes indicate ideas from existing literature; blue boxes indicate novel contributions. The foundation (observer selection) supports particle structure (left) and two novel pillars: geometric torsion (center) and higher-dimensional shadowing (right). Arrows show logical dependencies; the dashed line indicates that strong CP conservation and cosmic birefringence share the same torsion parameter.

F. Summary: Standard physics versus this framework

Table II summarizes how the framework addresses major physics questions compared to standard approaches.

TABLE II. Comparison of explanations: standard physics versus this framework

Phenomenon	**Standard explanation**	**This framework**
Why 3 spatial dimensions?	Not explained (assumed)	Knots stable only in 3D; observer selection
Why these particles?	Not explained (empirical input)	Knot types up to 8 crossings
Why 3 generations?	Not explained	Stability threshold at $\sim$8 crossings
Why 3 gauge forces?	Gauge symmetry (assumed)	3 Reidemeister moves
Matter-antimatter asymmetry	CP violation + new physics	Geometric torsion biases chirality
Why strong CP conservation?	Axions? Fine-tuning?	Type III moves lack chiral structure
Gravity's origin	Curved spacetime (assumed)	Higher-dimensional shadowing (null flux)
Dark energy	Cosmological constant Λ	Variable G from density gradient
Wave-particle duality	Complementarity principle	Knots in continuous substrate
Entanglement	Nonlocal correlations	Substrate connectivity
Black hole evaporation	Hawking radiation (derived)	Topologically necessary (2D knot closure)

VII. CONCLUSION

We have presented a unified framework deriving fundamental physics from topological first principles. The key results are:

1. Particles are knots in worldlines, stable only in 3D

2. Mass equals topological complexity

3. Three gauge forces arise from three Reidemeister moves

4. Gravity arises from higher-dimensional shadowing

5. Geometric torsion of time explains baryogenesis and parity violation

6. Variable G explains cosmic acceleration without dark energy

7. Black holes are 2D knots in 4D spacetime; evaporation is topologically necessary

The framework is consistent with observed phenomena: the correlation between cosmic birefringence and baryon asymmetry (both from the same torsion parameter), evolving dark energy as reported by DESI, the absence of a fourth particle generation, and strong CP conservation without axions. Black hole evaporation emerges as topologically necessary.

Whether future observations strengthen or weaken these correspondences will determine if topology truly underlies physics. Either outcome advances understanding.

Appendix A: Glossary of Key Terms

Crossing number: The minimum number of crossings in any diagram of a knot. A measure of topological complexity.

Geometric torsion: Helical structure of the time dimension itself, independent of matter. Distinct from spin-induced torsion in Einstein-Cartan theory.

Knot: A closed loop embedded in 3D space that cannot be untied without cutting. In this framework, particles are knots in worldlines.

Reidemeister moves: Three elementary operations (twist, poke, slide) that generate all continuous deformations of knot diagrams. Proposed to correspond to the three gauge forces.

Ribbon: A strip with both a knotted structure (crossings) and twist along its length. Allows separation of mass (crossings) from charge (twist).

Shadowing: The mechanism by which knots obstruct higher-dimensional worldline flux, creating momentum imbalances experienced as gravitational attraction.

Substrate: The infinite-dimensional space of all possible worldline configurations. What we perceive as 3+1D spacetime is a slice of this substrate.

Trefoil: The simplest non-trivial knot, with 3 crossings. Proposed to correspond to the electron.

Worldline: A one-dimensional curve through spacetime representing a particle's history. In this framework, fundamental worldlines exist in the higher-dimensional substrate.

Writhe: A measure of how much a curve coils around itself; related to crossing number. In the ribbon model, writhe corresponds to mass.

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