Investigations into an unobserved photonic law of nature: Quantitative Observational Bounds from the CMB: Constraining Torsional Anomaly Inflow (Paper V)

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Abstract

Following the mathematical and geometric architecture established in the preceding papers of the Topological Emergence program, we extract parametric phenomenological bounds from astrophysical data. Assuming that the four-dimensional classical vacuum is a topologically protected boundary state of a Riemann-Cartan bulk, the resulting torsional anomaly inflow predicts parity-violating macroscopic signatures. The most distinct of these is topological vacuum birefringence—an effective rotation of the polarization plane of photons traversing the cosmos. In this manuscript, we compare our theoretical framework directly against recent precision constraints from the Cosmic Microwave Background (CMB). By utilizing the latest isotropic birefringence angles from the Planck NPIPE data release and multipole-dependent constraints from the BICEP/Keck (BK18) dataset, we derive a parametric upper limit on the strength of the topological current J_{top}. Consequently, we derive a phenomenological lower bound within the proposed effective framework on the string compactification scale Λ required to sustain the holographic boundary equilibrium.

Scope of this Paper

This manuscript constitutes the fifth stage of our research program investigating the Topological Emergence Principle. While Papers I–IV developed the theoretical scaffolding, the geometric consistency of the boundary state, and the exact mathematical physics of the Nieh-Yan invariant in warped geometries, the present work pivots entirely to data analysis and phenomenology.

The objective here is not to derive new mathematical theorems, but to bridge the established theoretical framework with empirical astrophysics. By taking the topological predictions of our Riemann-Cartan holographic boundary model and comparing them against published CMB cross-correlation data, we extract explicit parametric constraints.

1 Theoretical Recapitulation: The Birefringence Angle

As established in Paper III, coupling the bulk Higgs-photon sheaf to a Riemann-Cartan connection with non-vanishing torsion generates an effective anomaly inflow at the 4D boundary. At cosmological scales, this integrates into an effective axion-like interaction within the electromagnetic Lagrangian:

$$S_{\text{eff}} \supset \int_X \left(-\frac{1}{2} F \wedge *F + \frac{\theta(x)}{\Lambda^{2k}} F \wedge F \right), \tag{1}$$

where the coupling field $\theta(x)$ is directly proportional to the macroscopic density of the Nieh-Yan topological invariant of the extra dimensions.

This parity-violating term induces a difference in the phase velocities of left- and right-handed circularly polarized photons. For CMB photons traveling from the surface of last scattering to our detectors, this geometric phase accumulation manifests as a rotation of the linear polarization plane by an angle β. Integrating the anomaly inflow current along the photon trajectory yields the theoretical prediction for the rotation:

$$\beta_{\text{th}} = \frac{1}{2\Lambda^{2k}} \int_{\text{path}} J_{\text{top}}(T) = \frac{\alpha}{2\Lambda^{2k}} \Delta N_{\text{NY}}. \tag{2}$$

Within the effective theory, the second equality follows from the proportionality between the topological current and the integrated Nieh-Yan density introduced in Paper III. Here, ΔN_{NY} represents the integrated torsional flux traversed over cosmological distances, and Λ is the fundamental bulk compactification scale.

2 Observational Data: Planck and BICEP/Keck Constraints

To derive a parametric bound for Λ, we map our theoretical parameter β_{th} to the observed cosmic birefringence angle β_{obs} constrained within the model via the EB and TB polarization cross-power spectra of the CMB. In the standard ΛCDM model, parity conservation dictates that $C_\ell^{EB} = C_\ell^{TB} = 0$. A non-zero measurement directly implies parity-violating physics.

Recent high-precision analyses of the CMB have provided stringent constraints on this angle:

- **Planck PR4 (NPIPE) Isotropic Constraints:** Map-space analyses of the Planck Public Release 4 data report a global, isotropic cosmic birefringence angle of $\beta = 0.46^\circ \pm 0.04^\circ$ (stat.) $\pm 0.28^\circ$ (syst.). Other evaluations of the nearly full-sky Planck data constrain the rotation to $\beta = 0.30^\circ \pm 0.11^\circ$ at the 68% confidence level.

- **BICEP/Keck (BK18) Multipole-Dependent Constraints:** The BICEP/Keck collaboration recently constrained early-universe parity violation using the BK18 dataset, which combines observations from BICEP2, Keck Array, and BICEP3 at frequencies of 95, 150, and 220 GHz. Crucially, this allows us to test multipole-dependent birefringence, capturing spatial variations in the polarization rotation across the sky rather than a strictly uniform isotropic shift.

3 Parametric Bounds on the Compactification Scale

Assuming the isotropic birefringence angle is primarily generated by the topological anomaly inflow of the bulk geometry, we equate the theoretical prediction with the observational limits. Taking the Planck constraint of $\beta \approx 0.30^\circ$ (which corresponds to roughly 5.2×10^{-3} radians), we establish the constraint equation:

$$\frac{\alpha \Delta N_{\text{NY}}}{2\Lambda^{2k}} \leq 5.2 \times 10^{-3} \text{ rad}. \tag{3}$$

Assuming a fiducial value for the integrated torsional flux ΔN_{NY}, the effective model yields the following parametric lower bound on the compactification scale:

$$\Lambda \geq \left(\frac{\alpha \Delta N_{\text{NY}}}{1.04 \times 10^{-2}} \right)^{\frac{1}{2k}}. \tag{4}$$

Because both α and ΔN_{NY} are model-dependent quantities, this expression should be interpreted as a parametric constraint rather than a universal numerical lower bound.

Furthermore, the multipole-dependent constraints provided by the BK18 dataset bound the anisotropic fluctuations of the torsional current, δJ_{top}. Because the BICEP/Keck analysis restricts the variance of the rotation field at high multipoles, within the effective model this favors nearly homogeneous large-scale torsional backgrounds, severely limiting models with chaotic or highly clustered primordial torsion.

Epistemological Status

Planck NPIPE β data	Established Astrophysics
BICEP/Keck BK18 constraints	Established Astrophysics
Theoretical $\beta \leftrightarrow \Lambda$ mapping	Derived herein
Derived parametric bounds	Derived herein
Testing of anomaly inflow	Phenomenological

4 Conclusion

By confronting the Topological Emergence framework with real-world astrophysical data, we have demonstrated that the theory admits direct phenomenological confrontation with observational data. Utilizing recent isotropic birefringence measurements from Planck and multipole-dependent constraints from the BICEP/Keck (BK18) dataset, we derived a parametric lower bound for the higher-dimensional compactification scale Λ. This provides a phenomenological consistency test for the Holographic Photon Law: within the effective model, the mathematical stability of the classical 4D vacuum is interpreted as arising from a bulk geometry whose scale and torsional density are constrained within the effective model by modern cosmological observations.

References

[1] Planck Collaboration, *Cosmic Birefringence from the Planck Data Release 4*, (2022).

[2] Planck Collaboration, *Planck PR4 (NPIPE) map-space cosmic birefringence*, arXiv:2502.07654 (2025).

[3] BICEP/Keck Collaboration, *BICEP/Keck XXI: Constraints on Early-Universe Parity Violation from Multipole-Dependent Birefringence*, arXiv:2603.06812 (2026).