Chiral Vacuum Eversion and the Redshift-Dependent Scaling of Cosmic Birefringence

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Abstract

Observations of the Cosmic Microwave Background (CMB) polarization planes indicate a tiny rotation angle ($\beta \approx 0.3^\circ$), known as cosmic birefringence. In standard field theories, this parity-violating rotation is modeled via dynamical axion-like fields or Chern-Simons terms. We present a first-principles topological alternative: the vacuum is modeled as a discrete S^3 torus-knot lattice. The expansion of space is driven by the conformal eversion of this lattice. Because the $T(2,3)$ trefoil knot is chiral, the eversion process is handedness-asymmetric, naturally rotating photon polarization vectors in transit. We derive the resulting polarization rotation angle $\beta(z)$ and show that it scales linearly with redshift, providing a sharp, falsifiable test to distinguish CPT cosmology from axion-field models.

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1. Chiral Vacuum Eversion on the S^3 Torus-Knot Lattice

Under the CPT framework, the physical vacuum is not an empty continuum but a discrete lattice of charge-circulating torus knots. Space-time is the emergent representation of this lattice. The expansion of the universe is driven by a conformal topological phase transition—the eversion (turning inside out) of the vacuum cells.

The fundamental vacuum cell is a $T(2,3)$ trefoil knot projected onto the three-sphere (S^3). The trefoil knot is chiral; it cannot be rotated into its mirror image. During the eversion phase transition: 1. **Handedness Selection:** The eversion process chooses a preferred chiral direction (left- or right-handed eversion) determined by the winding parameters $p=2, q=3$. 2. **Parity Violation:** This selection breaks parity (CP-symmetry) globally across the eversion epoch. 3. **Vacuum Birefringence:** Photons propagating through this chiral lattice experience a differential phase velocity between left- and right-circularly polarized states, leading to a rotation of the linear polarization plane.

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2. Conformal Scaling of the Polarization Rotation Angle

In standard electromagnetism, birefringence arises from a difference in refractive indices $n_L \neq n_R$. In the chiral everted vacuum, the differential phase shift $d\theta$ per unit conformal path length ds is determined by the chiral coupling constant Δ_c, which is a topological invariant of the $T(2,3)$ lattice: $$d\theta = \Delta_c ds$$

Converting this to cosmological coordinates where the line element is $ds = c dt / a(t) = c(1+z) dt$, the cumulative rotation angle $\beta(z)$ for a photon emitted at redshift z and observed today ($z=0$) is: $$\beta(z) = \Delta_c \int_{0}^{z} (1+z') \frac{dz'}{H(z')}$$

Using the eversion-driven scale factor expansion profile $H(z) = H_0 (1+z)$, the integral simplifies directly to: $$\beta(z) = \frac{\Delta_c}{H_0} z$$

Substituting the observed CMB birefringence value ($\beta \approx 0.3^\circ$ at $z \approx 1100$), we calibrate the chiral coupling parameter: $$\frac{\Delta_c}{H_0} \approx 2.7 \times 10^{-4}\text{ degrees per unit redshift}$$

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3. Distinguishing CPT Birefringence from Axion Models

Standard axion-like field models parameterize cosmic birefringence via the coupling of an axion field ϕ to the electromagnetic field tensor: $$\mathcal{L}_{\text{int}} = \frac{g_{a\gamma}}{4} \phi F_{\mu\nu} \tilde{F}^{\mu\nu}$$ This yields a polarization rotation angle proportional to the net change in the axion field value between emission and detection: $$\beta = \frac{1}{2} g_{a\gamma} \Delta \phi$$

This field-based model has two severe limitations: 1. **Fine-Tuning:** The axion mass and coupling must be fine-tuned to match the observed β without producing unobserved axion dark matter signatures. 2. **Global Redshift Saturation:** Because the axion field settles into its minimum value at late times ($z < 10$), standard models predict that the rotation angle β saturates and is practically identical for all sources at $z > 1$.

In contrast, the CPT framework derives the birefringence directly from the metric expansion of the chiral vacuum cells. There is no scalar field, and the rotation is accumulated continuously as the photon traverses the everting lattice.

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4. Falsifiable Predictions

1. **Linear Redshift Dependence:** The rotation angle β scales strictly linearly with cosmological distance: $$\beta(z) \propto z$$ Measuring the polarization rotation of high-redshift radio galaxies

and quasars at $z \approx 2-6$ will show a rotation angle $\beta \approx 0.0005^\circ - 0.0016^\circ$, which is significantly smaller than the CMB value of 0.3°.

2. **No Spatial Clustering:** Because the eversion is a global conformal property of the vacuum lattice, the rotation angle β will be statistically isotropic across the sky, with zero spatial correlation power spectrum $C_\ell^{\beta\beta} \approx 0$ for $\ell > 10$.
3. **Wavelength Independence:** The rotation angle is achromatic (independent of photon frequency), distinguishing it from Faraday rotation which scales as λ^2.