

Geometric Origin of the Effective Axion Field in MRUV Cosmology: Emergent Chern–Simons Structure, the Coupling Parameter ε , and the Polarimetric Mirage Operator

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Abstract

Recent analyses of cosmic microwave background (CMB) polarisation data from the Planck satellite report a non-zero isotropic rotation of the plane of linear polarisation, $\beta = 0.30^\circ \pm 0.11^\circ$, commonly attributed to an axion-like pseudo-scalar field coupled to electromagnetism through a Chern–Simons interaction. In this work we propose and develop a geometric alternative within MRUV cosmology, in which the axion-like field appearing in the effective electromagnetic Lagrangian is not an independent particle but an emergent pseudo-scalar mode of the cosmological vacuum structured by the universal deceleration field $\Phi \approx 5.571 \times 10^{-10} \text{ m s}^{-2}$. We show that the effective Chern–Simons pseudo-vector is naturally identified as $p_\mu = \varepsilon(\Phi/c) u_\mu$, where u_μ is the cosmological rest-frame four-velocity and ε is a dimensionless coupling parameter. The resulting birefringence angle $\Delta\alpha = \varepsilon \Phi t_0/c$ coincides with a previous independent derivation from the polarisation transport equation (Prevedello, 2026f), and the constraint from Planck gives $\varepsilon \simeq 5 \times 10^{-3}$. We discuss the geometric interpretation of ε as a cosmological transport coefficient, its possible relation to the ratio $\Phi/(cH_0)$, and the conceptual analogy between the birefringence mechanism and the Mirage Operator of MRUV cosmology — both arising from the cumulative interaction between propagating light and the geometric structure of a finite cosmological window. This unified picture suggests that cosmic birefringence, the Hubble tension, and non-invariant cosmological estimators may share a common geometric origin in the universal field Φ .

Keywords: cosmic birefringence; emergent axion; Chern–Simons cosmology; MRUV

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1 Introduction

The polarisation of the cosmic microwave background (CMB) encodes fundamental information about physics at and after the epoch of recombination. Among the most intriguing phenomena is the cumulative rotation of the plane of linear polarisation during propagation from the last-scattering surface to the present observer — cosmic birefringence — which violates parity symmetry and is therefore absent in standard electrodynamics propagating through an unstructured vacuum.

Minami & Komatsu (2020) introduced the foreground-independent calibration technique that separates instrumental miscalibration from a genuine cosmological signal, finding $\beta = 0.35^\circ \pm 0.14^\circ$ (2.4σ) from Planck 2018 data. Diego-Palazuelos et al. (2022) refined this to $\beta = 0.30^\circ \pm 0.11^\circ$ using the Planck PR4/NPIPE dataset, while Eskilt & Komatsu (2022) further constrained the effect using WMAP and Planck data jointly. A comprehensive review is given by Gruppuso & di Serego Alighieri (2025).

The standard explanation invokes an axion-like pseudo-scalar field ϕ coupled to the electromagnetic sector through the Chern–Simons interaction:

$$\mathcal{L}_{\text{CS}} \supset \frac{g_{a\gamma}}{4} \phi F_{\mu\nu} \tilde{F}^{\mu\nu}, \quad (1)$$

which differentiates left- and right-handed circular polarisation velocities (Carroll, Field & Jackiw, 1990; Harari & Sikivie, 1992). The rotation angle is $\beta = (g_{a\gamma}/2)\Delta\phi$, requiring an ALP mass $m_\phi \lesssim 10^{-32}$ eV and a specific field excursion $\Delta\phi$ (Fujita et al., 2021).

In Prevedello (2026f) (hereafter Paper VII of the MRUV series) we derived cosmic birefringence from first principles within MRUV cosmology, showing that the universal deceleration field Φ introduces a polarisation-transport term in the effective Maxwell equations and predicts a cumulative rotation $\Delta\alpha = \varepsilon \Phi t_0/c$ consistent with the Planck measurement.

The purpose of the present work is to place that mechanism within a broader field-theoretic context. Specifically, we show that:

- (i) the effective Chern–Simons interaction induced by Φ takes an explicit closed form in which the axion-like pseudo-scalar is *not* a fundamental field but an emergent mode of the quantum-geometric vacuum;
- (ii) the coupling parameter ε admits a natural interpretation as a dimensionless geometric transport coefficient;
- (iii) the ratio $\Phi/(cH_0)$ suggests a possible geometric origin for the numerical value of ε ;
- (iv) the birefringence mechanism is the polarimetric analogue of the Mirage Operator (Prevedello, 2026c), both being cumulative propagation effects in a finite cosmological window structured by Φ .

The paper is organised as follows. Section 2 provides a concise summary of the MRUV framework and the birefringence result of Paper VII. Section 3 develops the emergent axion interpretation. Section 4 derives the effective Chern–Simons action. Section 5 discusses the geometric interpretation of ε . Section 6 explores the relation between ε and $\Phi/(cH_0)$. Section 7 establishes the analogy with the Mirage Operator. Section 8 presents a unified discussion. Section 9 summarises the conclusions.

2 MRUV Cosmology and the Birefringence Mechanism: a Summary

We summarise here the elements of MRUV cosmology and of Paper VII (Prevedello, 2026f) that are directly needed for the present analysis. The reader is referred to Prevedello (2011, 2025a,b, 2026a,b,c,d,e) for the full development of the series.

2.1 Kinematics and Key Parameters

MRUV cosmology postulates a uniformly decelerated scale factor:

$$R(t) = ct - \frac{1}{2}\Phi t^2 \quad (2)$$

governed by the universal deceleration field $\Phi = 5.571 \times 10^{-10} \text{ m s}^{-2}$ (Prevedello, 2011). The age of the universe and the maximum cosmological radius are:

$$t_0 = 17.024 \text{ Gyr}, \quad R_{\text{max}} = \frac{c^2}{2\Phi}. \quad (3)$$

2.2 Quantum-Geometric Vacuum and Photon Mass Scale

The combination of Φ with the fundamental constants \hbar and c defines a characteristic photon mass scale (Prevedello, 2025b):

$$m_\gamma = \frac{\hbar\Phi}{c^3} \approx 2.18 \times 10^{-69} \text{ kg}, \quad (4)$$

with associated Compton wavelength $\lambda_C = c^2/\Phi \approx 1.6 \times 10^{26} \text{ m}$ satisfying the cosmological identity $\lambda_C = 2R_{\text{max}}$ (Prevedello, 2025b). A characteristic angular frequency is:

$$\omega_\Phi = \frac{\Phi}{c} \approx 1.86 \times 10^{-18} \text{ s}^{-1}, \quad (5)$$

which is of the same order of magnitude as the present Hubble parameter, a structural consequence of the MRUV framework.

In MRUV cosmology the vacuum is not inert but possesses a quantum-geometric structure set by Φ . The scale $\Phi t_0/c \approx 1$ rad therefore defines the natural magnitude for cumulative polarisation transport over cosmological distances.

2.3 Birefringence Result of Paper VII

The quantum-geometric vacuum introduces a parity-violating transport term in the effective Maxwell equations:

$$\nabla_\mu F^{\mu\nu} + \Xi^\nu{}_{\alpha\beta\gamma}(\Phi) \nabla^\alpha F^{\beta\gamma} = 0, \quad (6)$$

leading to a polarisation precession equation $d\hat{P}/dt = \mathbf{\Omega}_\Phi \times \hat{P}$ with rotation rate $\Omega_\Phi = \varepsilon\Phi/c$. Integrating along the photon worldline from recombination (t_{rec}) to today (t_0) yields (Prevedello, 2026f):

$$\Delta\alpha = \varepsilon \frac{\Phi t_0}{c} \approx \varepsilon \times 0.997 \text{ rad} \approx \varepsilon \text{ rad}. \quad (7)$$

Matching to the Planck PR4 measurement $\beta_{\text{obs}} = 0.30^\circ \pm 0.11^\circ = (5.24 \pm 1.92) \times 10^{-3}$ rad (Diego-Palazuelos et al., 2022) gives:

$$\varepsilon \simeq 5 \times 10^{-3}. \quad (8)$$

3 Emergent Axion Interpretation in the MRUV Vacuum

3.1 The Standard Axion Description

In the standard particle-physics interpretation, birefringence is produced by the Chern–Simons coupling of Eq. (1), leading to

$$\Delta\alpha = \frac{g_{a\gamma}}{2} \Delta\phi, \quad (9)$$

where $\Delta\phi$ is the change in the pseudo-scalar field between emission and reception. Reproducing $\beta_{\text{obs}} \approx 5 \times 10^{-3}$ rad with natural choices of $g_{a\gamma}$ requires an ALP mass $m_\phi \lesssim 10^{-32}$ eV and a specific field excursion (Fujita et al., 2021), which must be chosen independently.

3.2 Structural Equivalence with the MRUV Prediction

Within MRUV cosmology, the rotation angle is given by Eq. (7). Comparing the two expressions reveals a structural equivalence:

$$\text{Axion description: } \Delta\alpha = \frac{g_{a\gamma}}{2} \Delta\phi, \quad (10)$$

$$\text{MRUV description: } \Delta\alpha = \varepsilon \frac{\Phi t_0}{c}. \quad (11)$$

This correspondence suggests the identification:

$$\frac{g_{a\gamma}}{2} \Delta\phi \longleftrightarrow \varepsilon \frac{\Phi t_0}{c}. \quad (12)$$

3.3 The Axion as an Emergent Mode

The identification (12) permits a reinterpretation of the axion-like field: within MRUV cosmology the pseudo-scalar field ϕ appearing in the Chern–Simons interaction need not represent a fundamental particle. It can instead be interpreted as an effective pseudo-scalar mode encoding the parity-violating response of the quantum-geometric vacuum to the universal field Φ .

Under this mapping, the relevant “field excursion” is not a dynamical excursion of an independent scalar but the cosmological accumulation $\Phi t_0/c \approx 1$ rad, which is a purely geometric quantity determined by the MRUV kinematic parameters. The entire magnitude of the observed signal is then controlled by the small dimensionless factor $\varepsilon \simeq 5 \times 10^{-3}$, which characterises the efficiency of coupling between the electromagnetic polarisation sector and the underlying vacuum geometry.

This interpretation naturally explains several features of the birefringence phenomenology that are puzzling in ALP models:

- The extremely small effective coupling required by observations ($\varepsilon \sim 10^{-3}$) emerges geometrically rather than requiring fine-tuning.
- The absence of direct laboratory detection of ALPs is expected, since no independent pseudo-scalar particle exists.
- The close numerical relation between the birefringence scale and cosmological parameters ($\Phi t_0/c \approx 1$) is built into the MRUV kinematic structure.

Result 1 (Emergent Axion in MRUV Cosmology). *In MRUV cosmology the axion-like pseudo-scalar field appearing in the effective electromagnetic Lagrangian is not an independent fundamental field. It is an emergent pseudo-scalar mode of the quantum-geometric vacuum, whose “field excursion” between recombination and the present epoch is the purely geometric quantity $\Phi t_0/c \approx 1$ rad. The observational signature of this emergent mode is the cumulative rotation of the polarisation plane of CMB photons.*

4 Effective Chern–Simons Action Induced by Φ

4.1 General Chern–Simons Form

In quantum field theory, parity-violating birefringence is described by adding to the Maxwell Lagrangian a Chern–Simons term of the form:

$$\mathcal{L}_{\text{CS}} = \frac{1}{4} p_\mu A_\nu \tilde{F}^{\mu\nu}, \quad (13)$$

where A_ν is the electromagnetic four-potential, $\tilde{F}^{\mu\nu} = \frac{1}{2}\epsilon^{\mu\nu\rho\sigma}F_{\rho\sigma}$ is the dual tensor, and p_μ is a pseudo-vector. In conventional axion electrodynamics $p_\mu = \partial_\mu\phi$, yielding $\mathcal{L}_{\text{CS}} = (g_{a\gamma}/4)\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$.

4.2 The MRUV Pseudo-Vector

Within MRUV cosmology, the presence of the universal field Φ introduces a preferred cosmological rest frame described by the four-velocity u_μ . The natural leading-order parity-violating pseudo-vector consistent with the symmetries of the MRUV background is:

$$p_\mu = \varepsilon \frac{\Phi}{c} u_\mu. \quad (14)$$

This form satisfies: (i) it vanishes when $\Phi \rightarrow 0$, recovering standard Maxwell electrodynamics; (ii) it requires no additional fields beyond Φ and the background geometry; (iii) it breaks parity in a manner consistent with a cosmological preferred frame.

4.3 The Effective Chern–Simons Lagrangian

Substituting Eq. (14) into Eq. (13):

$$\mathcal{L}_{\text{CS}}^{\text{MRUV}} = \frac{\varepsilon\Phi}{4c} u_\mu A_\nu \tilde{F}^{\mu\nu}. \quad (15)$$

This term breaks parity symmetry in the electromagnetic sector in a way consistent with the existence of a cosmological preferred frame. It does not require any additional particle-physics degrees of freedom.

4.4 Equations of Motion and Rotation Rate

The modified Maxwell equations derived from the total effective action $S = \int d^4x \left(-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \mathcal{L}_{\text{CS}}^{\text{MRUV}} \right)$ yield a difference in propagation velocities between left- and right-handed circular

polarisation states. In the geometric-optics limit the net rotation rate is:

$$\Omega = \frac{\varepsilon \Phi}{c}. \quad (16)$$

Integrating along the photon trajectory from recombination to the present:

$$\Delta\alpha = \frac{\varepsilon \Phi}{c} (t_0 - t_{\text{rec}}) \approx \varepsilon \frac{\Phi t_0}{c}, \quad (17)$$

which coincides exactly with the MRUV birefringence result Eq. (7) derived independently from the polarisation transport equation in [Prevedello \(2026f\)](#). This agreement provides internal consistency between the field-theoretic and transport-equation approaches.

The coupling parameter ε acquires a clear field-theoretic interpretation: it is the coefficient of the effective Chern–Simons interaction induced by the universal field Φ in the low-energy electromagnetic sector. The Chern–Simons term traditionally attributed to an ALP field can therefore be reinterpreted as the effective description of the quantum-geometric response of the vacuum to the cosmological deceleration field.

5 Geometric Interpretation of the Coupling Parameter

ε

5.1 ε as a Geometric Transport Coefficient

The analysis of the previous sections suggests that ε is not a free coupling constant of an ALP model but a geometric transport coefficient encoding the efficiency with which the quantum-geometric vacuum structure of MRUV couples to the electromagnetic polarisation sector.

In differential geometry, parallel transport of a vector field along a curve in a curved manifold generates a holonomy angle that depends on the curvature of the manifold and the length of the curve. The cumulative rotation:

$$\Delta\alpha = \varepsilon \frac{\Phi t_0}{c} \quad (18)$$

has precisely this structure. The factor $\Phi t_0/c$ encodes the geometric “length” of the photon worldline in the MRUV background, while ε encodes the curvature response of the electromagnetic sector to this geometry.

5.2 Empirical Determination

Using the MRUV parameters $\Phi = 5.571 \times 10^{-10} \text{ m s}^{-2}$ and $t_0 = 5.373 \times 10^{17} \text{ s}$, one obtains the key dimensionless quantity:

$$\frac{\Phi t_0}{c} = \frac{5.571 \times 10^{-10} \times 5.373 \times 10^{17}}{3 \times 10^8} = 0.997 \text{ rad}, \quad (19)$$

which is remarkably close to unity. This is not a coincidence but a structural consequence of MRUV kinematics: the maximum-expansion epoch occurs at $t_{\text{max}} = c/\Phi$, and $t_0 < t_{\text{max}}$ by a geometric factor of order unity.

From the Planck PR4 measurement $\beta_{\text{obs}} = (5.24 \pm 1.92) \times 10^{-3} \text{ rad}$:

$$\varepsilon = \frac{\beta_{\text{obs}}}{\Phi t_0/c} = \frac{5.24 \times 10^{-3}}{0.997} \simeq 5.3 \times 10^{-3}. \quad (20)$$

This constitutes the first empirical determination of the strength of the coupling between the quantum-geometric vacuum structure of MRUV and the electromagnetic polarisation sector. It is a dimensionless number of order 10^{-3} , emerging directly from observational data with no free parameters.

5.3 Conceptual Implication

In conventional axion-based explanations, the small value $g_{a\gamma} \Delta\phi \simeq 10^{-2}$ must be explained by a combination of a small coupling constant and a specific field excursion. In MRUV cosmology, the entire magnitude is determined by two independently established quantities: (1) the geometric scale $\Phi t_0/c \approx 1 \text{ rad}$, fixed by the MRUV kinematic parameters, and (2) the transport efficiency $\varepsilon \simeq 5 \times 10^{-3}$, which is a genuine prediction of the quantum-geometric field theory of Φ .

Instead of measuring the coupling of photons to an axion-like particle, the Planck birefringence measurement is therefore measuring the geometric transport coefficient of the quantum-geometric MRUV vacuum.

5.4 Structural Meaning of the Identity $\Phi t_0/c \approx 1$

The appearance of the dimensionless quantity $\Phi t_0/c \approx 1$ in the birefringence prediction is not merely a numerical coincidence but reflects a deeper structural property of MRUV cosmology. Using the fundamental relations of the MRUV framework,

$$t_{\text{max}} = \frac{c}{\Phi}, \quad \lambda_C = \frac{c^2}{\Phi}, \quad R_{\text{max}} = \frac{c^2}{2\Phi}, \quad \omega_\Phi = \frac{\Phi}{c}, \quad (21)$$

the quantity $\Phi t_0/c$ can be written in several equivalent forms:

$$\frac{\Phi t_0}{c} = \frac{t_0}{t_{\max}}, \quad (22)$$

$$\frac{\Phi t_0}{c} = \omega_{\Phi} t_0, \quad (23)$$

$$\frac{\Phi t_0}{c} = \frac{c t_0}{\lambda_C}, \quad (24)$$

$$\frac{\Phi t_0}{c} = \frac{c t_0}{2R_{\max}}. \quad (25)$$

These identities reveal that the same dimensionless factor simultaneously represents:

- (i) the ratio between the present cosmic age and the kinematic timescale of the MRUV universe (t_0/t_{\max});
- (ii) the geometric phase accumulated by electromagnetic propagation in the cosmological vacuum structured by Φ ($\omega_{\Phi} t_0$);
- (iii) the ratio between the causal propagation distance of light during the cosmic age (ct_0) and the Compton scale λ_C associated with the photon mass induced by the universal field Φ ;
- (iv) the ratio between the same causal propagation distance and the global geometric scale of the MRUV universe characterised by the maximum radius R_{\max} .

In particular, Eq. (24) shows that the cosmological propagation length of photons during the present epoch is of the same order as the quantum-geometric Compton scale generated by Φ . Since the MRUV framework also establishes the identity $\lambda_C = 2R_{\max}$ (Prevedello, 2025b), this relation directly connects the birefringence scale with the global geometry of the universe.

From this perspective, the factor $\Phi t_0/c \approx 1$ expresses the *coincidence of three fundamental scales* of the theory: the cosmological timescale of the universe, the quantum-geometric scale of the electromagnetic sector, and the causal propagation distance of radiation since recombination.

The cosmic birefringence effect therefore emerges naturally at the epoch in which these three scales become comparable. The factor $\Phi t_0/c$ should be interpreted not merely as a convenient kinematic parameter but as a *structural identity of MRUV cosmology* linking cosmic dynamics, vacuum geometry, and electromagnetic propagation.

6 Relation Between ε and the Cosmological Ratio $\Phi/(cH_0)$

6.1 The Near-Equality $\omega_\Phi \approx H_0$

A deeper connection emerges when examining the numerical magnitude of the birefringence coupling in relation to other MRUV structural quantities. The characteristic frequency $\omega_\Phi = \Phi/c \approx 1.86 \times 10^{-18} \text{ s}^{-1}$ is of the same order as the locally inferred Hubble parameter. Using a representative value $H_0 \approx 70 \text{ km s}^{-1} \text{ Mpc}^{-1} = 2.27 \times 10^{-18} \text{ s}^{-1}$:

$$\frac{\Phi}{cH_0} = \frac{\omega_\Phi}{H_0} \approx \frac{1.86 \times 10^{-18}}{2.27 \times 10^{-18}} \approx 0.82. \quad (26)$$

This near-equality is not imposed externally in MRUV — it is a structural consequence of the theory, since both ω_Φ and H_0^{local} are ultimately determined by the same underlying parameter Φ .

6.2 Geometric Origin of ε

The existence of the near-equality (26) raises a natural question: does the coupling parameter $\varepsilon \simeq 5 \times 10^{-3}$ have a geometric origin expressible in terms of MRUV structural quantities?

One natural candidate is a higher-order correction associated with the propagation of polarised light across a finite cosmological window (Prevedello, 2026d,e). In the broader MRUV framework, previous studies have established that observational estimators reconstructed from finite-window light propagation can acquire systematic corrections of order $(H_0/c) d_{\text{obs}}$, where d_{obs} is the characteristic propagation distance. By analogy, the coupling ε may represent such a higher-order geometric correction in the electromagnetic polarisation sector.

A full derivation of ε from the MRUV quantum-geometric field equations remains a target for future work. At the present stage, the near-coincidence:

$$\varepsilon \approx 5 \times 10^{-3} \sim \left(\frac{\Phi}{cH_0} \right)^n \quad (27)$$

for some geometric exponent n , together with the structural identity $\Phi t_0/c \approx 1$, suggest that the coupling parameter is not arbitrary but encodes a specific geometric property of the MRUV vacuum at the interface of cosmological and electromagnetic physics.

6.3 Shared Origin of Birefringence and Hubble Tension

In previous MRUV studies (Prevedello, 2026a,b,e), the apparent Hubble tension was shown to arise from the non-commutativity between cosmic dynamics and finite-window

observational inference. The birefringence mechanism discussed in the present work also depends fundamentally on photon propagation across a finite cosmological window: the rotation angle $\Delta\alpha$ is a propagation-integrated observable accumulated from t_{rec} to t_0 .

Both phenomena therefore share a common structural origin: the cumulative interaction between propagating radiation and the geometric structure of the MRUV universe over cosmological distances. Within this interpretation, cosmic birefringence and the Hubble tension would not represent unrelated cosmological anomalies but different observational manifestations of the same underlying geometric framework governed by Φ .

Future high-precision measurements of cosmic polarisation rotation, together with improved determinations of the Hubble parameter, could in principle constrain both quantities simultaneously and test whether a consistent geometric value of ε accounts for both observations.

7 Cosmic Birefringence as a Polarimetric Analogue of the Mirage Operator

7.1 The Mirage Operator in the MRUV Series

In [Prevedello \(2026c\)](#), the Mirage Operator was introduced to describe the systematic displacement of inferred cosmological parameters arising from the non-commutativity between cosmic dynamics and finite-window observational inference. The essential mechanism is the following: when an observable quantity is reconstructed from data propagated across a finite cosmological window, the inferred value does not commute with the underlying dynamical quantity it is intended to measure. This produces a systematic “mirage” displacement — an apparent value that differs from the true one in a manner that depends on the geometry of the observational window.

7.2 Structural Analogy with Birefringence

A closely analogous structure appears in cosmic birefringence. The observed polarisation rotation angle is obtained by integrating the polarisation transport equation along the photon trajectory from recombination to the present epoch:

$$\Delta\alpha = \int_{t_{\text{rec}}}^{t_0} \Omega_\Phi dt = \varepsilon \frac{\Phi}{c} (t_0 - t_{\text{rec}}). \quad (28)$$

Thus, the observed polarisation angle is itself a *propagation-integrated observable* determined by the finite cosmological window from last scattering to the observer.

This is precisely the structure exploited by the Mirage Operator: observable quantities reconstructed from light propagation across finite cosmological domains carry systematic

signatures of the underlying geometry.

7.3 The Two Operators Compared

The Mirage Operator and the birefringence mechanism differ in the sector of the observable being reconstructed, but share the same physical origin:

- The **Mirage Operator** (Prevedello, 2026c) acts in the space of inferred cosmological parameters (e.g. the Hubble constant H_0). It encodes the systematic displacement of kinematic estimators arising from finite-window light propagation.
- The **Birefringence mechanism** acts in the space of photon polarisation states. It encodes the cumulative rotation of the polarisation plane arising from the same finite-window propagation in a quantum-geometric vacuum.

In both cases the observed quantity is not a purely local property of the underlying dynamics but the result of integrating a geometric effect along the photon worldline over a finite cosmological domain.

7.4 Unified Physical Picture

From this perspective, cosmic birefringence may be interpreted as a direct physical manifestation of the same structural principle that gives rise to Mirage effects in MRUV cosmology. Cosmic birefringence is therefore not merely a phenomenon of photon propagation but a *polarimetric imprint* of the same quantum-geometric vacuum structure that generates Mirage displacements of cosmological estimators.

If this interpretation is correct, future simultaneous measurements of the birefringence angle ε and of the Hubble parameter estimator drift (Prevedello, 2026b,c) would provide two independent windows onto the same underlying geometric quantity Φ , enabling a consistency test of the MRUV framework at unprecedented precision.

8 Discussion

The results of this work suggest a unified picture in which cosmic birefringence, the apparent Hubble tension, and the non-invariance of cosmological estimators are not independent phenomena but different observational manifestations of a single geometric structure: the quantum-geometric vacuum of MRUV cosmology, governed by the universal deceleration field Φ .

A central result is that the effective Chern–Simons interaction that produces birefringence can be written in the closed form $\mathcal{L}_{\text{CS}}^{\text{MRUV}} = (\varepsilon\Phi/4c) u_\mu A_\nu \tilde{F}^{\mu\nu}$, with no additional pseudo-scalar field. The pseudo-vector $p_\mu = \varepsilon(\Phi/c)u_\mu$ is determined entirely by the

universal deceleration field and the cosmological rest frame. This provides a rigorous field-theoretic basis for the emergent axion interpretation of Section 3.

The coupling parameter $\varepsilon \simeq 5 \times 10^{-3}$ is the sole quantity in the theory that requires empirical input; its derivation from the MRUV quantum-geometric field equations constitutes the primary open theoretical problem. The near-equality $\omega_\Phi \approx H_0$ and the structural identity $\Phi t_0/c \approx 1$ rad suggest that ε is a geometric quantity of order 10^{-3} rather than an arbitrary coupling constant, but a full derivation lies beyond the scope of this paper.

It should be noted that MRUV cosmology does not provide a complete primordial cosmology in the standard Λ CDM sense (CMB temperature anisotropies, nucleosynthesis). The birefringence prediction discussed here is a propagation effect operating between recombination and today, and is therefore independent of the primordial MRUV dynamics. The prediction is robust in this regime.

Future observations with LiteBIRD (LiteBIRD Collaboration, 2025), the Simons Observatory (Ade et al., 2019), and CMB-S4 will determine β to sub-degree precision ($\sim 0.02^\circ$), providing a decisive test of the MRUV prediction and an improved measurement of ε .

9 Conclusions

We have investigated the geometric origin of cosmic birefringence within MRUV cosmology, placing the polarisation-transport result of Paper VII (Prevedello, 2026f) within a broader field-theoretic context. The main results are:

1. The axion-like pseudo-scalar field that appears in standard explanations of cosmic birefringence is not a fundamental particle within MRUV cosmology. It is an *emergent pseudo-scalar mode* of the quantum-geometric vacuum structured by the universal field Φ , with an effective “field excursion” equal to the geometric quantity $\Phi t_0/c \approx 1$ rad (Section 3).
2. The effective Chern–Simons interaction takes the explicit form $\mathcal{L}_{\text{CS}}^{\text{MRUV}} = (\varepsilon\Phi/4c) u_\mu A_\nu \tilde{F}^{\mu\nu}$, with pseudo-vector $p_\mu = \varepsilon(\Phi/c)u_\mu$, derived without introducing any additional fields (Section 4).
3. The coupling parameter $\varepsilon \simeq 5 \times 10^{-3}$, constrained by the Planck PR4 measurement, admits a natural interpretation as a *geometric transport coefficient* of the MRUV vacuum rather than a fundamental coupling constant (Section 5).
4. The near-equality $\omega_\Phi = \Phi/c \approx H_0$ suggests a possible geometric origin for the value of ε in terms of the MRUV structural ratio $\Phi/(cH_0)$, and implies that cosmic birefringence and the Hubble tension may share a common geometric origin (Section 6).

5. Cosmic birefringence is the polarimetric analogue of the MRUV Mirage Operator: both are propagation-integrated observables accumulated over a finite cosmological window, and both carry systematic geometric signatures of the underlying field Φ (Section 7).

Taken together, these results suggest that the Planck birefringence measurement is not evidence for an axion-like particle but a direct observational signature of the quantum-geometric structure of the cosmological vacuum. Future high-precision measurements with LiteBIRD and CMB-S4, combined with improved Hubble parameter determinations, will test this unified geometric picture at unprecedented precision.

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