Photon, Neutrinos and the Higgs Boson as Emergent Structures of a Ternary Symmetry of the Vacuum

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Abstract

The Standard Model and General Relativity employ a concept of vacuum that combines a continuous space–time without internal phasing with a quantum structure built upon this background, without providing a unified geometry for electromagnetic propagation, mass generation or neutrino phenomenology. In this article we propose a ternary vacuum architecture, where three internal operators $J,\ K,\ L$ act on a three-dimensional internal Hilbert space and satisfy the cubic structural relation $J^3 = K^3 = L^3 = -I$. This identity is not an *ad hoc* extension, but a discrete geometric ensemble that organises the photon, the Higgs mode and the neutrino triplet as emergent modes of a common internal dynamics.

The visible photon appears as the coherent projection onto the single internally stable direction of the rotation generated by J, and the geometric factor $Z(J)$ rescaling the electromagnetic sector expresses the internal rigidity of the vacuum, thereby inducing effective variations of the fine-structure constant. In the neutrino sector, mass arises as an internal deviation of the relation $L^3 = -I + \delta h_L$, and neutrino oscillations are interpreted as internal rotations induced by the discrete dynamics of $L(x)$; space–time torsion emerges naturally from variations of the internal orientation. The Higgs sector is reinterpreted as the scalar invariant mode of internal deviations associated with the operator K, and fermion masses derive from internal vacuum curvatures rather than from phenomenological Yukawa parameters inserted by hand.

The ternary architecture provides a geometric elimination of cosmological singularities, interprets black holes as regions of extreme rigidity of internal orientations, and yields observable predictions regarding the variation of α, cosmic birefringence, neutrino oscillations over cosmological distances and subtle deviations in the Higgs sector. The result is a minimal framework in which mass, light and torsion arise as manifestations of a single discrete internal structure of the vacuum.

1 Introduction

The operative concept of vacuum employed jointly in the Standard Model of fundamental interactions and in General Relativity combines two idealisations that are structurally incompatible: (i) a continuous space–time without internal phasing, described by a classical dynamical metric [1], and (ii) a quantum vacuum built upon this background, where fundamental excitations are treated as independent elementary entities, without a shared internal geometric architecture [2, 3]. In this formulation the photon is the unique generator of the abelian $U(1)$ symmetry, the

Higgs boson is the only scalar with non-zero vacuum expectation value [4, 5], and neutrinos possess extremely small masses whose mechanisms lie outside the model, requiring additional Dirac or Majorana terms [6, 7, 8, 9].

Although phenomenologically compatible, the two theories do not provide a unified description of the vacuum: mass is attributed to a phenomenologically chosen potential, space–time torsion is omitted or treated as a secondary effect [10], and the uniqueness of electromagnetic propagation lacks internal geometric justification. As a consequence, central properties of fundamental physics—photon stability, the origin of the Higgs scalar mass, the smallness of neutrino masses, coherence of neutrino oscillations and possible cosmic variations of the fine-structure constant—appear as disparate elements linked only phenomenologically.

This article is part of a very recent program devoted to the development of a ternary physics framework, within which nuclear formulas derived from an internal ternary symmetry have been proposed [46], together with the general structure of a unified physics based on the new symmetry of fundamental interactions [47], as well as extensions to cosmology, where the photon, neutrinos, and the Higgs boson emerge as structures of a ternary vacuum.

In this work we propose a minimal unified vacuum architecture based on the existence of a three-dimensional internal Hilbert space $\mathcal{H}_{\text{int}} \simeq \mathbb{C}^3$ on which three internal operators $J,\ K,\ L$ act, each satisfying the structural relation

$$J^3 = K^3 = L^3 = -I_3.$$

This cubic identity is not introduced as a formal extension but as the expression of a discrete internal geometry with three fundamental orientations transformed cyclically under internal rotation. From this structure both electromagnetic propagation and the Higgs and neutrino sectors emerge.

The central proposal of the ternary architecture is that the vacuum is not inert, but an internal discrete medium whose orientation determines the properties of visible excitations. The observable photon is the coherent projection onto the unique internally stable direction of the operator J; the scalar Higgs mode is interpreted as the invariant internal deviation of K; and neutrinos constitute the full triplet of the rotation generated by L, which gives their oscillations an intrinsic geometric origin, independent of phenomenologically imposed mixings [6, 7].

This framework allows a geometric reinterpretation of fundamental elements of the theory: the fine-structure constant becomes dependent on the internal rigidity $Z(J)$; neutrino mass is proportional to the internal deviation δh_L from the ternary relation; and fermion masses as a whole derive from internal curvatures defined by K, without the use of arbitrarily imposed Yukawa parameters. Moreover, space–time torsion arises naturally from variations of the internal orientation $L(x)$, providing a geometric bridge between neutrino phenomenology and the structure of space–time [11, 3].

On cosmological scales the ternary architecture naturally regularises singularities: the internal transition of orientations J, K, L replaces the Big Bang singularity with a discrete phasing, and black holes are interpreted as regions of extreme rigidity of the internal structure, consistent with phenomenological hints of non-perturbative vacuum behaviour [2, 12]. The model also yields testable predictions regarding effective variations of the fine-structure constant [13, 14], cosmic birefringence induced by internal rotations, subtle deviations in the Higgs sector, and directional modifications of neutrino oscillations over cosmological distances [15, 16].

At a conceptual level, the central question addressed in this work is whether the photon, the Higgs boson and the neutrino sector can be understood as emergent modes of a single discrete internal geometry of the vacuum, rather than as independent ingredients added on top of a continuous space–time background. Concretely, we ask whether a ternary internal symmetry with $J^3 = K^3 = L^3 = -I_3$ can simultaneously account for: (i) the uniqueness and stability of the photon, (ii) the origin of the Higgs scalar and of fermion masses, and (iii) the smallness of neutrino masses and the structure of their oscillations, while also producing testable cosmological signatures such as variations of the fine-structure constant, cosmic birefringence and torsion–induced neutrino effects.

1.1 Objectives and contributions with respect to the Standard Model

The ternary architecture proposed here aims explicitly at a restricted set of objectives, formulated such that the theoretical framework can be directly tested and compared with the structure of the Standard Model and General Relativity:

1. to provide a unified internal geometric description of the photon, the Higgs boson and neutrinos, in which these sectors are not postulated separately but appear as emergent modes of a common discrete structure defined by $J^3 = K^3 = L^3 = -I_3$;

2. to remove the need for the initial cosmological singularity and the divergences associated with gravitational collapse by introducing an internal vacuum rigidity that limits possible deviations of the orientations J, K, L and replaces singular points with internal phase transitions;

3. to generate falsifiable predictions concerning the effective variation of the fine-structure constant, cosmic birefringence, neutrino oscillations in the presence of space–time torsion, deviations in the Higgs sector and photon-interference effects, such that the proposed architecture can be systematically tested in laboratory, astrophysical and cosmological regimes.

Compared with the Standard Model and General Relativity, the specific contributions of the ternary architecture may be summarised as follows:

- the vacuum is no longer treated as an inert background or as a quantum state defined by the absence of excitations, but as a discrete internal medium characterised by ternary rotations of the operators J, K, L, whose orientations determine electromagnetic propagation, mass structure and neutrino phenomenology;

- the photon ceases to be a postulated generator of the abelian $U(1)$ group, becoming instead the stable internal mode of the operator J; its uniqueness and the absence of "dark" photons are geometric consequences rather than phenomenological assumptions;

- the Higgs boson is no longer a fundamental scalar with an ad hoc potential, but the invariant scalar mode of the internal deviations of K; its effective potential is determined by the internal rigidity of the vacuum, and fermion masses reflect internal curvatures instead of a list of Yukawa constants without geometric origin;

- neutrinos do not require a Seesaw scheme or heavy Majorana fermions: their masses emerge from the ternary deviation $L^3 = -I_3 + \delta h_L$, and their oscillations are interpreted as internal rotations of the neutrino triplet, sensitive to space–time torsion;

- cosmological and black-hole singularities are replaced with internal-phase regimes where the deviations $\delta J, \delta K, \delta L$ reach a critical but finite limit, suggesting that classical divergences arise from neglecting the internal structure of the vacuum;
- predictions regarding variations of α, cosmic birefringence, ultra-high-energy neutrino deviations, modifications of the Higgs self-coupling and Hong–Ou–Mandel interference asymmetries are tied to the same internal geometric structure and lead to a high degree of falsifiability.

In this sense the ternary architecture does not extend the Standard Model by introducing additional fields or symmetries, but provides it with an internal geometric substrate in which the photon, the Higgs and the neutrinos are aspects of the same discrete vacuum structure, and gravity is complemented by emergent torsion associated with internal variations of the operators J, K, L.

1.2 Summary of main results

For clarity, we summarise here the main results established in the present work:

1. We construct a ternary internal architecture of the vacuum, defined by three operators J, K, L acting on an internal Hilbert space $\mathcal{H}_{\text{int}} \simeq \mathbb{C}^3$ and satisfying the ternary relations $J^3 = K^3 = L^3 = -I_3$, and we show that this discrete internal geometry supports a unique stable photonic mode, a scalar Higgs mode and a neutrino triplet as emergent excitations.
2. We reinterpret the observable photon as the unique coherent projection on the stable internal direction selected by J, derive an effective electromagnetic action with a geometric rigidity factor $Z(J)$, and obtain a position-dependent fine-structure constant $\alpha_{\text{eff}} = \alpha_0 / Z(J(x))$, leading to small but non-zero cosmological variations of α and to vacuum-induced cosmic birefringence.
3. We derive neutrino masses as proportional to the ternary deviation δh_L in the relation $L^3 = -I_3 + \delta h_L$, show that the standard Dirac/Majorana distinction becomes geometrically irrelevant, and interpret neutrino oscillations as internal rotations generated by $L(x)$, naturally coupled to an emergent torsion field $S_\mu \sim \mathrm{Tr}\big(L^{-1}\partial_\mu L\big)$.
4. We identify the visible Higgs mode as the invariant scalar deviation associated with the operator K, obtain an effective scalar potential determined by internal rigidity rather than an *ad hoc* Mexican-hat form, and express fermion masses as $m_f(x) = y_f\, Z_H\big(K(x)\big)$, thereby replacing the list of arbitrary Yukawa couplings by geometric projections in the internal space.
5. We provide quantitative predictions and exclusion thresholds for a correlated set of observables — cosmological variation of α, cosmic birefringence, torsion-induced deviations in ultra-high-energy neutrino oscillations, modifications of the Higgs self-coupling and tiny asymmetries in Hong–Ou–Mandel interference — and show how their simultaneous non-observation below certain levels would falsify the ternary architecture in its present form.

Scope of the formalism. The mathematical framework adopted in this work is intentionally minimal: our goal is to exhibit the structural mechanism linking the ternary internal geometry of the vacuum to observable phenomena, rather than to develop the most general algebraic completion of the construction. More elaborate formulations are certainly possible, but they would not alter the physical content that is relevant for falsifiability, for comparison with the Standard Model and for confronting the ternary architecture with data.

2 The ternary internal architecture of the vacuum

The foundation of the construction is the hypothesis that the vacuum possesses a discrete internal geometry, not reducible to any continuous gauge symmetry and not equivalent to supersymmetric or extra-dimensional structures. This geometry is described by a three-dimensional internal Hilbert space,

$$\mathcal{H}_{\text{int}} \simeq \mathbb{C}^3, \tag{1}$$

on which three internal operators $J,\ K,\ L$ act, associated with the photonic, scalar and neutrino sectors. These operators satisfy the common structural identity

$$J^3 = K^3 = L^3 = -I_3, \tag{2}$$

which defines an internal rotation of order three, returning to the same orientation up to a global sign. This cubic identity is not an isolated algebraic property but the geometric expression of a discrete internal phasing, analogous to certain clock–shift structures yet with physical properties distinct from standard cyclic groups [17, 18, 19].

Throughout what follows, an *internal rotation* refers to this ternary unitary action of the operators J, K, L on the internal Hilbert space $\mathcal{H}_{\text{int}}$. The photonic sector corresponds to the internal rotation generated by J, the neutrino sector to that generated by $L(x)$ and the scalar sector to that generated by $K(x)$, all three being manifestations of the same cubic symmetry $J^3 = K^3 = L^3 = -I_3$.

2.1 Representation of the internal operators

Without loss of generality we can adopt an explicit representation for the operator J,

$$J = \begin{pmatrix} 0 & 0 & -1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}, \tag{3}$$

which immediately satisfies the relation (2). The forms of K and L are structurally isomorphic to (3), acting however on the internal sectors associated with scalar deviations and neutrino rotation respectively. They are *not* physically identical, because their definition includes an internal selection of stable, semi-stable and unstable internal directions that differs for each sector, while preserving the fundamental cyclicity of (2).

The fact that all three operators share the same cubic structure indicates the existence of a unified internal symmetry that cannot be reduced to a gauge symmetry. Essentially, relation (2) endows the vacuum with the character of an internal medium whose dynamics is defined by discrete rotations of the internal orientation, of which only certain directions can support coherent propagation in space–time.

2.2 Eigenstate structure and physical-mode selection

For the operator J, the complex spectrum $\{1, \omega, \omega^2\}$, with $\omega = e^{2\pi i/3}$,, does not admit a standard spectral interpretation because the ternary relation introduces cyclicity with a sign reversal. Therefore what becomes physically relevant is not the spectrum itself but the *internal stability* of directions under iterations of J.

One defines a stable direction $|\chi_{\rm st}\rangle$ satisfying

$$J|\chi_{\rm st}\rangle = -|\chi_{\rm st}\rangle, \tag{4}$$

and two unstable directions $|\chi_{\rm u,1}\rangle$, $|\chi_{\rm u,2}\rangle$, which are cyclically permuted. Coherent propagation of an internal excitation is possible exclusively along the direction (4). This provides a geometric origin for photon uniqueness and the absence of independent "dark" electromagnetic sectors, in contrast to certain proposals involving dark photons [20, 21].

Analogously, the operators K and L possess distinct internal stability structures: K admits an invariant scalar deviation, and L leaves three active directions corresponding to the neutrino triplet. Thus the three fundamental sectors of physics—light, the scalar mass mode and neutrinos—are not independent but three expressions of the same discrete internal geometry.

2.3 Internal dynamics and effective fields

Internal rotations become fields on space–time when the operators J, K, L are promoted to position-dependent configurations:

$$J(x), \quad K(x), \quad L(x): \; M \to \mathrm{End}(\mathcal{H}_{\rm int}), \tag{5}$$

where M is macroscopic space–time. The internal dynamics is characterised by slow deviations $\delta J(x), \delta K(x), \delta L(x)$ of the internal orientation in the continuum regime.

These deviations do not produce additional gauge symmetries but manifest via rescalings of existing interactions, the appearance of torsion terms and subtle modifications of the scalar sector. In the photonic sector, for example, the factor $Z(J(x))$ multiplying $F_{\mu\nu}F^{\mu\nu}$ reflects the internal geometric rigidity of the vacuum and leads to effective variations of the fine-structure constant. In the neutrino sector the deviation δh_L defining the departure from the ternary relation generates extremely small masses, while in the scalar sector deviations of $K(x)$ produce an invariant mode identified with the observable Higgs boson.

Thus the ternary internal architecture provides a unified geometric structure from which the three fundamental sectors of physics arise as emergent modes of the same discrete vacuum dynamics.

3 The photonic sector: the stable mode and the internal geometry of propagation

In the ternary architecture electromagnetic propagation is not the result of a postulated abelian gauge symmetry but the consequence of the fact that the internal operator J admits a stable rotation direction, according to

$$J|\chi_{\rm st}\rangle = -|\chi_{\rm st}\rangle, \tag{6}$$

which enables the existence of a coherent space–time excitation. This internal geometric property replaces the conventional interpretation of the photon as an irreducible generator of the abelian $U(1)$ group, and provides a structural explanation for the absence of additional or "dark" electromagnetic modes, in contrast with hidden-photon extensions [21, 20].

In this framework the photonic sector is described by a three-dimensional internal Hilbert space $\mathcal{H}_{\mathrm{int}}^{(J)} \simeq \mathbb{C}^3$, on which J acts cyclically. The three internal directions may be grouped into a triplet $\{|\chi_{\mathrm{st}}\rangle,\ |\chi_{\mathrm{u},1}\rangle,\ |\chi_{\mathrm{u},2}\rangle\}$, where $|\chi_{\mathrm{st}}\rangle$ is the unique stable direction satisfying (6), while $|\chi_{\mathrm{u},1}\rangle$ and $|\chi_{\mathrm{u},2}\rangle$ are unstable directions permuted cyclically by J. The observable photon is identified with the coherent excitation projected onto $|\chi_{\mathrm{st}}\rangle$; its uniqueness reflects the fact that only this internal direction can sustain macroscopic coherent propagation, while the other two triplet components decohere due to the cyclicity of the internal rotation.

3.1 Internal projection and the effective electromagnetic field

For an internal vector field $A_\mu(x) \in \mathrm{End}(\mathcal{H}_{\mathrm{int}})$, the physical projection onto the stable direction is defined as

$$A_\mu^{\mathrm{EM}}(x) = \langle \chi_{\mathrm{st}}(J(x))|A_\mu(x)|\chi_{\mathrm{st}}(J(x))\rangle. \tag{7}$$

This field represents the only internal combination capable of sustaining coherent propagation. The objects $A_\mu^{(1)}, A_\mu^{(2)}$ corresponding to unstable directions decouple macroscopically due to their internal cyclicity, giving the observed photon its uniqueness.

The effective electromagnetic action follows from the projection (7), yielding

$$S_{\mathrm{EM}} = -\frac{1}{4}\int d^4x\ Z(J(x))\, F_{\mu\nu}F^{\mu\nu}, \tag{8}$$

where $F_{\mu\nu} = \partial_\mu A_\nu^{\mathrm{EM}} - \partial_\nu A_\mu^{\mathrm{EM}}$ and the factor $Z(J)$ reflects the internal geometric rigidity of the vacuum. This rescaling is not a technical artefact but a geometric property: slow variations of the internal orientation modify the effective amplitude of electromagnetic excitations, leading to variations of the fine-structure constant.

3.1.1 Dark photonic modes

The ternary structure of the operator J implies, besides the stable mode $|\chi_{\mathrm{st}}\rangle$, the existence of two orthogonal internal directions $|\chi_{D1}\rangle$ and $|\chi_{D2}\rangle$, satisfying $\langle\chi_{\mathrm{st}}|\chi_{Di}\rangle = 0$ and $\langle\chi_{D1}|\chi_{D2}\rangle = 0$. The action of J does not leave these directions invariant but permutes them cyclically, J : $|\chi_{D1}\rangle \mapsto |\chi_{D2}\rangle \mapsto -|\chi_{D1}\rangle$, so that internal iterations generate a purely internal oscillation with no coherent space–time projection.

For an internal vector field $A_\mu(x) \in \mathrm{End}(\mathcal{H}_{\mathrm{int}}^{(J)})$, the components along these directions, $A_\mu^{D1}(x) \sim \langle\chi_{D1}|A_\mu(x)|\chi_{D1}\rangle$ and $A_\mu^{D2}(x) \sim \langle\chi_{D2}|A_\mu(x)|\chi_{D2}\rangle$, mix under the action of J, such that after averaging over scales larger than the internal-rotation step their macroscopic propagation is suppressed. Only the projection onto the stable direction $|\chi_{\mathrm{st}}\rangle$ survives as a coherent electromagnetic mode.

The modes $|\chi_{D1}\rangle$ and $|\chi_{D2}\rangle$ may thus be interpreted as *dark photonic modes*: internal excitations of the same photonic sector that do not couple to electric charge through a coherent electromagnetic field and do not define a phenomenologically accessible gauge sector. The absence of propagating dark photons is therefore not a phenomenological postulate but a geometric consequence of the ternary cyclicity of J.

Internal instability versus geometric darkening. The unstable directions generated by the internal cyclicity of J cannot sustain coherent propagation: their iteration produces internal permutation that destroys longitudinal phasing. These directions are therefore "dark" in a geometric sense, not through screening but because no field A_μ remains coherent when projected onto $|\chi_{\rm st}\rangle$. Internal instability and photonic darkening are thus manifestations of the same cyclic structure, though not identical notions: instability is a dynamical property, darkening is its consequence at the propagation level.

3.2 Internal rigidity and the effective fine-structure constant

The internal dynamics of $J(x)$ is characterised by slow deviations $\delta J(x) = J(x) - J_0$, where J_0 denotes the homogeneous internal vacuum orientation. In the adiabatic regime one obtains the expansion

$$Z(J) = 1 + c_2 \operatorname{Tr}\big[(\delta J)^2\big] + c_3 \operatorname{Tr}\big[(\delta J)^3\big] + \cdots, \tag{9}$$

where the coefficients c_n depend on the internal structure of J and the algebraic normalisations of the internal space. The linear term is absent by symmetry and the quadratic term dominates in cosmological regimes or regions with weak internal variations.

In internal terms, the factor $Z(J(x))$ may be viewed as a measure of the efficiency of the projection of the internal field $A_\mu(x)$ onto the stable direction $|\chi_{\rm st}(J(x))\rangle$. When the orientation of $J(x)$ varies slowly, the stable eigenvector $|\chi_{\rm st}(J(x))\rangle$ rotates in $\mathcal{H}^{(J)}_{\rm int}$, and the norm of the projection $A^{\rm EM}_\mu(x) = \langle\chi_{\rm st}(J(x))|A_\mu(x)|\chi_{\rm st}(J(x))\rangle$ varies accordingly. The effective coefficient in front of $F_{\mu\nu}F^{\mu\nu}$ is precisely this overlap factor, encoded macroscopically in $Z(J(x))$. In this sense, $Z(J)$ plays the role of an internal "tension" of the vacuum: changing the orientation of $J(x)$ does not alter the nature of the photonic mode but rescales its internal rigidity and hence the effective value of the fine-structure constant $\alpha_{\rm eff}(x)$.

The effective fine-structure constant follows from (8):

$$\alpha_{\rm eff}(x) = \frac{\alpha_0}{Z(J(x))}, \tag{10}$$

which gives variations of α an internal geometric origin, independent of variations of the electron charge or scalar-composite mechanisms. The result is consistent with observational trends that suggest small variations of the fine-structure constant on cosmological scales [22, 23], though these remain controversial.

3.3 Internal geometry and coherent propagation

Relation (6) may be interpreted as stating that electromagnetic propagation is a slow "unfolding" of the discrete internal rotation, in which the stable direction $|\chi_{\rm st}\rangle$ singles out a projection capable of remaining coherent at macroscopic scales. This property becomes particularly manifest in the Hong–Ou–Mandel effect, where interference between photons sensitive to the internal projection permits the identification of fine deviations of the structure $Z(J)$ and of the internal rigidity [24, 25].

In this framework Hong–Ou–Mandel interference acts as a direct probe of the stability of the internal projection onto $|\chi_{\rm st}\rangle$, because any small deviation of this projection modifies the interference visibility. Thus HOM effects become sensitive to the internal structure of the vacuum, even if their amplitudes are extremely small.

3.4 Absence of dark electromagnetic modes

In conventional extensions of the photonic sector, the introduction of additional spin-1 bosons requires an independent gauge symmetry or a kinetic-mixing mechanism [20]. The ternary architecture naturally excludes this possibility: the unstable directions of J are cyclically permuted and cannot sustain coherent propagation in a continuous space–time. Thus, the non-existence of dark photons is not a phenomenological assumption but a geometric consequence of the relation (2).

The photonic sector of the ternary architecture is not an added ingredient but the minimal expression of the fact that the vacuum possesses a discrete structure with a unique internally stable direction. This property underlies the uniqueness of light, possible variations of the fine-structure constant and the internal rigidity that will reappear, in a different form, in the neutrino and scalar sectors.

In this interpretation, the electromagnetic $U(1)$ symmetry is not postulated as a fundamental gauge group but arises as an emergent symmetry of the stable internal mode $|\chi_{\rm st}\rangle$. The effective dynamics of the photon is governed by phase transformations of excitations projected onto this single internal direction, and the phase group that leaves invariant the internal structure of the projection is precisely $U(1)$. Hence Maxwell–$U(1)$ represents the large-scale continuous description of a single coherent mode selected geometrically by the ternary relation $J^3 = -I_3$, while the other two directions of the photonic triplet remain non-propagating and dark at macroscopic scales.

Compatibility with the electroweak gauge structure. The ternary construction does not replace the electroweak gauge sector of the Standard Model; instead, it constrains its microscopic origin. The $SU(2) \times U(1)$ group continues to describe the effective long-wavelength dynamics of the electroweak interactions, while the ternary vacuum geometry explains why only one Abelian direction becomes dynamically stable. In this sense, the emergent electromagnetic $U(1)$ is the continuum description of the single coherent internal phase selected by J.

Geometric uniqueness of the emergent $U(1)$ symmetry. The fact that only a single internal direction of J is stable implies the existence of a single coherent continuous phase that can be extended to an abelian symmetry. The other two internal directions are cyclic and do not admit an independent continuous phase; consequently, they cannot generate additional $U(1)'$ groups. Electromagnetic symmetry is therefore the only emergent continuous symmetry permitted by the ternary internal geometry.

Geometric origin of the unique stable mode. The existence of a single stable internal direction is a direct consequence of the cubic cyclic structure of J. Under repeated internal iteration the unstable orientations are permuted and effectively averaged out, so that any excitation acquires a coherent component only along one axis. This mechanism selects a unique continuous phase mode and thus fixes the electromagnetic $U(1)$ as an emergent property, rather than an externally imposed gauge factor.

4 The neutrino sector: ternary deviation, emergent mass and space–time torsion

Within the ternary internal architecture, neutrinos are not treated as light fermions whose mass requires additional mechanisms (Dirac, Majorana, Seesaw) [26, 27, 28, 29], but as excitations of the internal rotation generated by the operator L. This perspective decouples neutrino mass from its traditional phenomenological origins and attaches it directly to the internal geometry of the vacuum. The fundamental relation

$$L^3 = -I_3 \tag{11}$$

is no longer strictly maintained in the presence of internal vacuum deviations; the actual dynamics is characterised by

$$L^3 = -I_3 + \delta h_L, \tag{12}$$

where δh_L measures the imperfection of internal order. This deviation is the source of neutrino mass and constitutes the primary geometric element of the neutrino sector.

4.1 Geometric origin of neutrino mass

Ternary deviation as a geometric quantity. In the ternary architecture, δh_L is not an additional phenomenological parameter but the minimal geometric deviation allowed by the relation $L^3 = -I_3$. This departure measures precisely how "imperfect" the vacuum is in the L sector and sets the neutrino mass scale. The extremely small magnitude of δh_L expresses the fact that the vacuum is almost perfectly ordered in the neutrino sector, with mass arising directly from this internal imperfection rather than from an external coupling.

The neutrino mass term is not inserted by hand but results from the internal action of L, which induces the coupling

$$\mathcal{L}_{\nu,\mathrm{mass}} = -m_* \,\bar{\Psi}_\nu \, L \, \Psi_\nu, \tag{13}$$

where m_* denotes the internal scale of the ternary sector. From (12), diagonalisation of L leads to effective masses

$$m_{\nu i} \simeq \kappa_i \, \delta h_L, \tag{14}$$

where the coefficients κ_i depend on internal normalisations and on the algebraic structure of the operator L. The smallness of neutrino masses no longer reflects an accidental hierarchy of Yukawa parameters but the fact that δh_L is a small deviation from the ternary relation (11), indicating that the vacuum is almost perfectly ordered in the neutrino sector.

This interpretation removes the need for a Seesaw scheme or additional heavy Majorana degrees of freedom, providing a minimal geometric explanation for the low neutrino mass scale.

In contrast to the photonic or scalar sectors, the operator L does not admit a stable direction in internal space. For this reason, neutrino oscillations are not projections onto stable modes but cyclic rotations among the three internal directions of the triplet, without a preferred coherent mode.

4.2 The neutrino triplet and the disappearance of the Dirac–Majorana distinction

Disappearance of the Dirac–Majorana distinction. The internal rotation generated by L cyclically mixes the three orientations of the triplet, which makes it impossible to define a conserved lepton number. As a consequence, the standard notion of particle versus antiparticle cannot be consistently maintained. This is the geometric reason why the Dirac/Majorana separation becomes irrelevant: each component of the triplet is transformed into the others by the action of L, and neutrino identity is attached to the ternary unitary mode rather than to a globally conserved degree of freedom.

In the ternary architecture, neutrinos are not three distinct particles in the sense of quantum field theory, but the three internal orientations of a single geometric object, described by the triplet

$$\Psi_\nu = \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}, \qquad L\Psi_\nu = \omega\,\Psi_\nu, \tag{15}$$

where $\omega = \exp(2\pi i/3)$ is the cubic root of unity associated with the internal rotation generated by the operator L. The fundamental ternary relation $L^3 = -I_3$ implies that the neutrino cannot be characterised by a globally conserved charge (such as lepton number in standard formulations), because the cyclic action of L transforms the components ν_1, ν_2, ν_3 into one another.

This geometric structure eliminates the traditional distinction between Dirac and Majorana neutrinos. In particular:

- there is no natural separation between particle and antiparticle modes for Ψ_ν, since the internal rotation generated by L mixes these components in a way that is incompatible with a Dirac/Majorana splitting;
- the neutrino mass is determined by the ternary deviation δh_L and not by a Majorana term or a Dirac coupling to the Higgs field;
- neutrino chirality is not a phenomenological input but the result of projecting the internal triplet onto the coherent direction selected by local deviations of $L(x)$.

Neutrinos thus become internal manifestations of a single geometric entity rotating in ternary space, and what is observed as "three types of neutrinos" are internal directions of the same fundamental mode.

4.3 Fundamental differences from the Standard Model (neutrino sector)

The ternary formulation differs from the Standard Model not by introducing additional degrees of freedom but by a profound geometric reinterpretation of the neutrino sector. The most important conceptual differences are:

- **Origin of neutrino mass.** In the extended Standard Model, neutrino masses require additional mechanisms (Dirac or Majorana) and the introduction of heavy fermions or Majorana terms. In the ternary architecture, mass is an internal deviation of the relation $L^3 = -I_3 + \delta h_L$, without introducing extra fields or new mass scales.
- **Absence of the Dirac/Majorana distinction.** Owing to the internal cyclicity generated by L, neutrinos cannot be naturally classified as Dirac or Majorana. Their geometric identity—rather than a leptonic charge—determines the observable dynamics.
- **Oscillations as internal rotations.** In the Standard Model, oscillations are parametrised by the PMNS matrix, a phenomenological object without geometric origin [2]. In the

ternary architecture, oscillations are internal rotations of the operator $L(x)$, and the PMNS matrix appears as an effective approximation of these rotations in regimes where variations of $L(x)$ are slow.

- **Sensitivity of neutrinos to space–time torsion.** The Standard Model does not predict a neutrino coupling to torsion. The ternary architecture naturally implies the term $\bar{\Psi}_\nu \gamma^\mu \gamma^5 \Psi_\nu\, S_\mu$, with $S_\mu \sim \mathrm{Tr}(L^{-1}\partial_\mu L)$, which leads to characteristic deviations of oscillations over cosmic distances.

- **Interpretation of the neutrino "mass triplet".** The hierarchy of neutrino masses no longer reflects arbitrary Yukawa couplings but the topology of internal deviations δh_L and the rigidity of the ternary sector. The phase differences observed experimentally are projections of the same internal dynamics.

These differences are not artificial extensions of the Standard Model but consequences of introducing a discrete internal vacuum structure, in which neutrinos act as privileged probes of variations of $L(x)$ and of emergent torsion.

4.4 Neutrino oscillations as internal rotations

Instead of a phenomenological PMNS matrix [6, 7], neutrino oscillations arise from the internal rotation generated by $L(x)$. The phase evolution is given by

$$\Psi_\nu(x) \;\to\; \exp[L(x)]\, \Psi_\nu(x), \tag{16}$$

which produces oscillations among the three internal orientations of the neutrino triplet. The mass differences in (14) translate into differential phase accumulations, while variations of the internal orientation $L(x)$ introduce additional terms that lead to departures from standard oscillations in cosmological regimes, including directional modulations of the phase.

This geometric interpretation endows the neutrino internal space with a genuinely three-dimensional character and avoids the implicit assumption of a phenomenologically postulated PMNS matrix. Oscillations become a direct manifestation of the internal dynamics of the vacuum.

Direct experimental implications. In the regime where variations of $L(x)$ are slow, the internal rotation reproduces the observed PMNS matrix as an adiabatic approximation. In contrast, over cosmic baselines or in regions with significant internal torsion, the neutrino phase becomes directional, and oscillation probabilities display deviations that cannot be replicated within a purely PMNS-based framework. This sensitivity to internal orientation makes neutrinos direct probes of slow variations of the ternary vacuum.

4.5 Space–time torsion as an internal variation of $L(x)$

In Riemann–Cartan geometry, torsion is associated with the twisted degrees of freedom of the connection [11, 3, 1]. The ternary architecture provides a natural identification: variations of the internal orientation $\partial_\mu L(x)$ induce an axial term of the form

$$\mathcal{L}_{\mathrm{tors}} = \bar{\Psi}_\nu \gamma^\mu \gamma^5 \Psi_\nu\, S_\mu, \tag{17}$$

where the torsion vector is

$$S_\mu \sim \mathrm{Tr}\big[L^{-1}\partial_\mu L\big]\,. \tag{18}$$

Thus, space–time torsion is not an external ingredient but a geometric projection of the internal dynamics of the operator L. Neutrinos become sensitive detectors of this structure, and their oscillations can be modified in the presence of cosmic torsion fields or in regions with strong internal variations.

This identification provides a direct link between neutrino phenomenology and the structure of space–time: neutrino mass, oscillation phasing and torsion share the same internal geometric origin, a feature absent from standard formulations.

Relation to Einstein–Cartan torsion. The torsion vector S_μ introduced above has the same physical content as the totally antisymmetric part of the affine connection in Einstein–Cartan–Hehl formulations: it couples axially to spin and vanishes in the purely Riemannian limit. In the ternary architecture, however, S_μ is not postulated as an independent degree of freedom, but arises as a geometric projection of the internal variation of $L(x)$. This allows for torsion–neutrino effects while remaining compatible with standard General Relativity at macroscopic scales.

Internal torsion versus Riemann–Cartan extensions. In Riemann–Cartan geometry, torsion is introduced as a possible extension of the connection. In the ternary architecture, however, the emergence of the vector $S_\mu \sim \mathrm{Tr}(L^{-1}\partial_\mu L)$ is inevitable: any variation of the internal orientation of $L(x)$ generates an axial component. Torsion is therefore not an external addition but an internal property of the vacuum that becomes visible only through the neutrino coupling.

4.6 Phenomenological and cosmological implications

The ternary architecture leads to predictions that differ from the standard oscillation model:

- directional dependence of the oscillation phase in the presence of internal variations $L(x)$;
- matter-effect-like deviations generated not by medium density but by the associated space–time torsion (18);
- possible cosmological modulations of oscillation rates, relevant for neutrinos detected over extreme distances [30, 31].

The neutrino regime thus provides a direct experimental test of the internal geometry of the vacuum. The fundamental role of the deviation δh_L in mass generation and of the field S_μ in phase modulation establishes neutrinos as privileged indicators of ternary internal dynamics.

The neutrino sector of the ternary architecture is the expression of the regime in which all three internal directions remain active. This particularity yields an emergent physics that ties mass, oscillations and torsion into a single geometric object, strengthening the role of the neutrino as a probe of the discrete vacuum.

Geometric synthesis of the neutrino sector. The neutrino sector thus becomes the full expression of the internal dynamics of the operator L: mass arises from the ternary deviation δh_L, oscillations are unitary cyclic internal rotations, and torsion is the external projection of variations of $L(x)$. The Dirac / Majorana distinction disappears, and the PMNS matrix appears only as the adiabatic limit of a deeper geometric dynamics. In this framework, neutrinos are the privileged probe of slow variations of the discrete vacuum.

5 The scalar (Higgs) sector: invariant mode of internal deviations and geometric origin of fermion masses

Within the ternary architecture, the scalar sector is not introduced in order to recover a mechanism of spontaneous symmetry breaking, but represents the invariant mode of internal deviations of the operator K. The role of the Higgs boson is thus a geometric consequence of the internal rigidity of the vacuum, and the scalar mass reflects internal curvatures of the discrete Hilbert space $\mathcal{H}_{\text{int}}$, not the shape of a phenomenologically chosen potential [32, 33].

Ternary structure of the operator K. Analogously to the operators J and L, the scalar sector is governed by a ternary operator K that satisfies the fundamental relation $K^3 = -I_3 + \delta h_K$. The deviation δh_K measures the internal imperfection of the vacuum in the scalar sector and quantifies precisely the departure from perfect ternary symmetry. In this framework, the Higgs mode is not introduced via a phenomenological potential, but appears as the scalar amplitude associated with variations of K along the stable direction in internal space.

5.1 The scalar mode as an invariant internal deviation

The operator K, structurally isomorphic to J and L, acts on the internal sector associated with the scalar mass. The fundamental ternary relation

$$K^3 = -I_3 \tag{19}$$

is perturbed by slow variations of the internal orientation, $\delta K(x) = K(x) - K_0$. Among these deviations, the unique combination invariant under the ternary rotation is

$$h(x) = \mathrm{Tr}\Big(J_0^2\,\delta K(x)\Big), \tag{20}$$

where J_0 plays the role of the common internal reference for the discrete orientations of the vacuum. This internal expression provides the geometric definition of the Higgs field.

In contrast to the standard formalism, $h(x)$ is not a fundamental field in the sense of a scalar representation of the electroweak group, but an internal mode invariant under the cyclicity (19) in ternary internal space.

5.2 The scalar potential from internal rigidity

The internal energy of the vacuum, computed on deviations of the orientation of $K(x)$, yields an effective potential of the form

$$V(h) = \frac{1}{2}m_h^2 h^2 + \lambda h^4 + O(h^6), \tag{21}$$

where the coefficients result from ordered expansions of the deviations $\delta K(x)$ and are controlled solely by the internal rigidity of the operators (J, K, L). No *ad hoc* Mexican-hat potential is introduced, and the scale m_h reflects the geometric character of the internal deviations rather than an arbitrary parametrisation.

Phenomenological values of the scalar mass are recovered because the internal rigidity of K and its couplings to the fermionic sector select a unique scale compatible with observations, in a spirit similar to emergent-Higgs theories [34, 35], yet conceptually distinct: here the scale is a parameter of internal geometry, not the outcome of composite dynamics.

Scalar projection as a unifying mechanism. In complete analogy with the photonic projection onto the direction $|\chi_{\mathrm{st}}\rangle$ determined by J, and with the internal neutrino rotations governed by L, the Higgs sector corresponds to the scalar projection of the variations of $K(x)$ onto its internal stable direction. The same ternary architecture thus governs all three sectors: variations of $J(x)$ generate the factor $Z(J)$, variations of $L(x)$ produce the axial vector S_μ, and variations of $K(x)$ determine the scalar amplitude of the Higgs field and the effective scale of spontaneous symmetry breaking.

5.3 The Higgs triplet: visible mode and dark modes

The internal operator K generates a scalar triplet

$$H = \begin{pmatrix} H_{\mathrm{vis}} \\ H_{\mathrm{d1}} \\ H_{\mathrm{d2}} \end{pmatrix}, \qquad KH = \omega H, \tag{22}$$

where H_{vis} denotes the observable scalar mode, while $H_{\mathrm{d1}}, H_{\mathrm{d2}}$ are two internal scalar modes that do not couple to the electromagnetic sector. These dark modes do not interact with J and do not contribute to light propagation, which naturally identifies them as bosonic components of a dark sector.

All three components appear as geometric excitations of the deviations $\delta K(x)$, and the uniqueness of the visible Higgs reflects the internal projection onto the invariant direction (20). This invariant direction is the internal stable mode of K, analogous to the stable direction defined by J in the electromagnetic sector. The dark modes share the same internal potential (21), but their couplings to fermions are geometrically suppressed, since the projective operator C_f selects only H_{vis}.

Thus, the Higgs triplet of the ternary architecture naturally contains a single visible mode and two fully dark modes, defined purely geometrically, without the need to introduce additional fields.

5.4 Fermion mass as internal orientation: $m_f(x) = y_f\, Z_H\big(K(x)\big)$

In the ternary architecture, fermion masses do not result from arbitrary Yukawa terms but from the internal orientation of the operator $K(x)$. Defining the geometric factor

$$Z_H(K) = \mathrm{Tr}\Big(J_0^2 K\Big), \tag{23}$$

the effective mass of a fermion f becomes

$$m_f(x) = y_f\, Z_H\big(K(x)\big), \tag{24}$$

where y_f is a projective coefficient determined by the internal algebraic structure of the fermionic sector.

Fermion masses are therefore functions of the internal orientation of the vacuum rather than independent parameters. Spatial or temporal variations of $K(x)$ lead to corresponding variations of fermion masses, linking the Higgs sector directly to cosmology and to the evolution of the internal structure of the vacuum.

5.5 Cosmic mass variations: $\Delta m_f / m_f \sim \Delta Z_H(K)$

From (24) it follows that any variation of the internal orientation $K(x)$ yields measurable effects on fermion masses. For slow deviations in the cosmological regime, $K(x) = K_0 + \delta K(x)$, the mass varies as

$$\frac{\Delta m_f}{m_f} \simeq \frac{\Delta Z_H(K)}{Z_H(K_0)}, \tag{25}$$

and these variations are correlated with those of the fine-structure constant through the complementary dependence on the factor $Z(J)$ associated with the photon.

The ternary architecture thus anticipates extremely small cosmological variations of fermion masses, of order $10^{-7} - 10^{-6}$, with the same directional anisotropy induced by internal variations of $K(x)$ and $J(x)$. This provides a direct connection between the Higgs sector and cosmic phenomena involving variations of α.

5.6 Geometric link between $K(x)$ and space–time torsion

Internal variations of the operator $K(x)$ naturally induce a scalar torsion field associated with Riemann–Cartan structure. In particular,

$$S_\mu^{(K)} \sim \mathrm{Tr}\Big(K^{-1}\, \partial_\mu K\Big), \tag{26}$$

which reflects the fact that scalar deviations of K are not mere internal phase changes but sources of an effective axial field that can couple to neutrinos and to the fermionic sector.

In this interpretation, space–time torsion is not an extension of Einsteinian geometry but an external projection of internal variations of the ternary operators. The operator K thus becomes the geometric mediator between the Higgs sector, fermion mass and cosmic torsion.

5.7 Profound differences from the Standard Model (Higgs sector)

In the scalar sector, the ternary architecture departs conceptually from the Standard Model through the following structural differences:

- **Emergent, not fundamental Higgs.** The visible scalar field is the invariant mode of the operator K, rather than a scalar representation introduced by postulate.
- **Geometric potential, not Mexican hat.** The form (21) is determined by the internal rigidity of deviations $\delta K(x)$, not by a phenomenological choice.
- **Scalar triplet: one visible mode, two dark modes.** The presence of the modes $H_{\mathrm{d}1}, H_{\mathrm{d}2}$ follows structurally from the triple cyclicity $K^3 = -I_3$, yielding a natural dark sector.

- **Geometric origin of fermion mass.** Fermion masses are internal orientations of K, described by (24), eliminating the arbitrary list of Yukawa constants.

- **Correlated cosmic variations of masses and α.** The Standard Model does not correlate mass variation with variation of the fine-structure constant. The ternary architecture imposes the relation (25), structured by the internal geometry.

- **Scalar–torsion coupling.** The emergent torsion (26) arises naturally from variations of $K(x)$, providing a mechanism absent in the Standard Model and in classical GR.

Through these differences, the Higgs sector of the ternary architecture is not an incremental extension but a geometric reconstruction of the origin of mass.

5.8 Geometric origin of fermion masses

In the Standard Model, fermion masses are proportional to arbitrary Yukawa constants, spanning more than 12 orders of magnitude and without geometric origin [26]. In the ternary architecture, the mass of a fermion f arises from the internal coupling between the scalar deviation $h(x)$ and the discrete structure of the internal Hilbert space,

$$\mathcal{L}_{f,\mathrm{mass}} = -\,\bar{\Psi}_f\, Y_f(K)\, \Psi_f\, h(x), \tag{27}$$

where the operator $Y_f(K)$ is a geometric functional of K, not a free parameter. In the effective regime, the mass becomes

$$m_f = y_f\, h_0, \qquad y_f = \mathrm{Tr}\big[C_f K_0\big], \tag{28}$$

where h_0 is the vacuum value of the internal mode (20), and C_f is the projective operator selecting the corresponding fermionic sector. The contributions are purely geometric: distributed through internal algebra rather than through phenomenological parameters.

This reframing suggests that the hierarchy of fermion masses reflects structural differences in internal projections of operators, rather than arbitrary values of Yukawa constants. Fermion masses thus become indicators of the discrete texture of the vacuum.

5.9 Scalar interactions and phenomenological deviations

The Higgs–fermion and Higgs–boson interactions resulting from (21) and (27) are compatible with the electroweak sector at energies accessible to the LHC, since the internal operators preserve the local $SU(2) \times U(1)$ symmetry through the projections (20). Nevertheless, the ternary architecture produces small but potentially detectable deviations in:

- the Higgs self-coupling (modifications of the coefficient λ);

- the energy running of the Higgs mass, generated by internal variations $\delta K(x)$;

- possible directional links between fermion masses and the internal orientation K_0.

The scalar sector therefore becomes an experimental test of the internal rigidity of the vacuum, and deviations from the standard potential suggest an underlying discrete structure.

The scalar sector of the ternary architecture is not a phenomenological extension of the Higgs mechanism but its geometric reinterpretation: the mass of the scalar boson and fermion masses are manifestations of an internal rigidity of the vacuum, algebraically encoded by the operator K and its internal deviations.

Geometric synthesis of the scalar sector. The operator K completes the ternary architecture of the vacuum: if J selects the unique coherent electromagnetic mode and L governs neutrino oscillations and internal torsion, then K determines the emergent scalar structure. The Higgs field appears as the scalar mode of ternary variations of $K(x)$, and its effective scale is set by the deviation δh_K, in full analogy with δh_L in the neutrino sector. Fermion masses and the stability of the scalar sector are thus interpreted as manifestations of the same discrete internal geometry. This projection defines the coherent scalar mode associated with the K sector, in parallel with the coherent electromagnetic mode determined by J.

6 Cosmological consequences: regularisation of singularities, internal stiffening in black holes and observable signatures

The ternary architecture provides a geometric framework in which the structure of space–time is emergent, and its extreme properties reflect variations of the internal orientations of the operators J, K, L. Instead of a continuous vacuum characterised only by a metric, the model introduces a discrete internal rigidity whose deviations determine the behaviour of high-density regimes, the way in which light and neutrinos interact with the cosmic background, and non-perturbative properties in the vicinity of black holes. This perspective allows a geometric regularisation of singularities, consistent with hints from quantum gravity [36, 37].

The emergent cosmological structure follows directly from the sequential action of the operators J, K and L, each defining a distinct geometric regime of the vacuum. In the early phase, internal geometry is dominated by L, where ternary rotation produces torsion and a non-adiabatic evolution of neutrino modes. As the Universe expands, the scalar sector associated with K stabilises the coherent Higgs mode, and in the post-critical regime the electromagnetic projection $Z(J)$ becomes the dominant component, fixing the scale of visible interactions. This ordered transition between the three sectors is responsible both for the initial regularisation and for the observable large-scale values of effective constants.

6.1 Regularisation of the cosmological singularity

In classical formulations of general relativity, the initial singularity arises from the collapse of the Universe to infinite density. In the ternary architecture, this limit is never reached because the internal orientations J, K, L do not allow arbitrary compression of the vacuum: ternary cyclicity introduces a discrete structure that imposes a lower bound on internal deformability. Near extreme densities, the relations

$$J(x) \to J_{\text{crit}}, \qquad K(x) \to K_{\text{crit}}, \qquad L(x) \to L_{\text{crit}}, \tag{29}$$

reach a critical regime in which internal deviations can no longer increase without violating the ternary structure. This replaces the classical singularity with a discrete internal phase transition in which the space–time evolution reflects a simultaneous reorientation of the three operators.

In cosmological terms, the critical scale associated with the internal transition can mimic the effects of a bouncing scenario or define a pre-Big-Bang regime in which internal dynamics dominates over metric dynamics, in the spirit of certain effective quantum-gravity models [38, 39], but with an origin independent of metric quantisation.

6.2 Ternary cosmogony: emergence of space and time

The ternary architecture provides an internal mechanism by which both space and time emerge as properties of the orientations of the operators J, K, L. In the pregeometric regime, the internal orientations of the vacuum do not define metric, distance or causality, and the relations

$$J^3 = K^3 = L^3 = -I_3 \tag{30}$$

are the only dynamical structures present. Space is absent because the stable internal direction of J has not yet been selected, and time cannot be defined as long as variations of $L(x)$ are disordered and do not allow the coherent orientation that generates phase propagation.

Ternary cosmogony occurs when internal orientations spontaneously synchronise, in a regime where the deviations $\delta J, \delta K, \delta L$ become sufficiently small for the stabilised directions of the operators to be defined coherently. The emergence sequence is fixed by the internal structure:

1. **The photon as the first geometric mode.** Stabilisation of J defines the first coherent internal direction, enabling the definition of light propagation and, implicitly, the operational notion of space. Space thus appears as the external projection of the internal stiffening of J.

2. **The neutrino as generator of temporal orientation.** Coherence of the internal phase associated with the operator L defines the temporal direction. Time is not fundamental but results from the internal synchronisation of the neutrino mode, and the arrow of time is fixed by the monotonic evolution of the orientation of $L(x)$.

3. **Mass as a late emergent property.** Deviation of K from the perfectly ternary regime generates the visible scalar mode and allows mass to appear. Space and time thus become well defined before mass, reflecting the order in which the internal orientations of the operators stabilise.

This chain of emergences provides a natural cosmogonic sequence in which the structure of space–time is derived directly from the ternary dynamics of the vacuum.

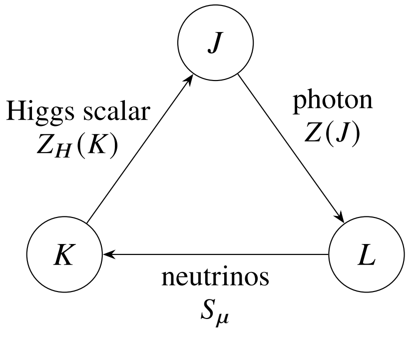

Figure 1: Ternary internal structure of the vacuum: the operator triplet (J, K, L) is cyclically linked to the photonic, neutrino and scalar sectors through the geometric factors $Z(J)$, $Z_H(K)$ and the effective torsion S_μ.

6.3 Critical internal transition and absence of a singular beginning

In the critical transition region, internal variations of the ternary operators become comparable to the geometric scale determined by $Z(J)$ and $Z_H(K)$, and the system can no longer be described by a simple separation of coherent modes. The deviations δh_L and δh_K enter a regime in which torsion and scalar contributions are of the same order, leading to a phase with nonlinear internal response. Within this discrete interval, the stability of the visible sector is restored through electromagnetic projection, and the subsequent evolution proceeds in a simpler geometric regime dominated by $Z(J)$.

The critical condition is set by the impossibility of internal deviations to exceed a geometric threshold:

$$\|\delta J\|, \|\delta K\|, \|\delta L\| \;\leq\; \delta_{\rm crit}, \tag{31}$$

with $\delta_{\rm crit}$ a constant determined by ternary cyclicity. In this limit, internal structure becomes coherent and allows the definition of a non-singular metric space.

This critical transition completely replaces the singular regime. Instead of a "temporal beginning" there is an internal reconfiguration after which space, time and mass acquire meaning as emergent properties of operator orientations. Consequently:

- there is no infinite density;
- curvatures do not diverge;
- space does not collapse to a point;
- time does not begin at a singular instant.

The pregeometric regime is devoid of metric, and the ternary transition creates, for the first time, the observable geometrodynamics. The traditional singularity problem thus appears as a consequence of applying classical equations in a domain that belongs entirely to the discrete internal structure of the vacuum.

6.4 Internal stiffening in black holes

In this framework, black holes are not regions where the density becomes infinite, but regions where the internal orientations of the vacuum become stiffened. In the vicinity of the horizon, the internal dynamics is dominated by the stable component of the operators, such that

$$J(x) \to J_\infty, \qquad K(x) \to K_\infty, \qquad L(x) \to L_\infty, \tag{32}$$

where the limiting orientations X_∞ are fixed and insensitive to local perturbations. This phenomenon is analogous to mode freezing in complex systems, but reflects a geometric property of the vacuum rather than a thermodynamic mechanism.

Internal stiffening eliminates scalar divergences of the fields inside the black hole because the internal deviations δJ, δK, δL can no longer grow and are constrained to remain finite. This regularises the central region without modifying Einstein's equations, suggesting that the singularity is a manifestation of neglecting the internal degrees of freedom of the vacuum, rather than a fundamental property of gravity.

6.5 Ternary internal structure of black holes and information conservation

In the ternary architecture, the interior of a black hole is not a region where density and curvature diverge, but an internal vacuum phase in which the orientations of the operators J, K, L become stiffened. The critical regime

$$J(x) \to J_\infty, \qquad K(x) \to K_\infty, \qquad L(x) \to L_\infty, \tag{33}$$

defines not a singular point but a phase region where the internal deviations reach the maximum value allowed by ternary cyclicity and remain finite. In this sense, the core of the black hole is a region of perfectly ordered ternary vacuum, not a pathological geometric locus.

This structure allows information conservation to be formulated in geometric terms. Information crossing the horizon is mapped into the internal orientations of the operators (J, K, L), via unitary cyclic transformations induced by ternary dynamics. Thus

$$\mathcal{I}_{\text{exterior}} \;\longrightarrow\; (J_\infty, K_\infty, L_\infty)\,, \tag{34}$$

and internal rigidity prevents information erasure. Information conservation does not require modifications of general relativity; it follows from the fact that the vacuum possesses internal degrees of freedom capable of storing coherently the structure of states falling through the horizon.

6.6 Reinterpretation of Hawking radiation as an internal process

Within the ternary framework, Hawking radiation is reinterpreted not as the result of virtual pair creation and annihilation at the horizon, but as a slow variation of the internal orientation of the operator $J(x)$ in the transition region towards the stiffened state J_∞. In particular,

$$\delta J(x) \neq 0 \quad \Rightarrow \quad \delta Z(J) \neq 0, \tag{35}$$

and these variations of the geometric factor $Z(J)$ generate a weak electromagnetic flux with an almost thermal spectrum.

The effective Hawking temperature becomes a function of the internal gradient,

$$T_{\text{H}} \;\sim\; |\partial_r Z(J)|_{r=r_h}\,, \tag{36}$$

where r_h is the horizon position. This expression removes the need to interpret radiation as a purely quantum effect of fields on a curved background and reframes it as a phenomenon reflecting the internal geometric variation of the vacuum in the transition region between the dynamical exterior and the stiffened core.

During this internal relaxation of the orientation, information is re-emitted in a reversible way: the Hawking flux carries fine corrections encoded in the internal structure of the deviation $\delta J(x)$, ensuring the possibility of information recovery without introducing exotic mechanisms.

6.7 Cosmic torsion and large-scale neutrino deviations

Variations of the internal orientation of the operator $L(x)$ introduce an effective torsion field S_μ, structurally defined by (18). In astrophysical and cosmological regimes, this field can generate measurable deviations in neutrino oscillations. For neutrinos propagating over cosmological distances, the accumulated phase becomes

$$\Phi_i(D) = \int_0^D \left[m_{\nu i}^2/2E + \xi\, S_\mu(x) u^\mu \right] d\ell, \tag{37}$$

where u^μ is the geodesic tangent vector and ξ is a geometric coefficient of the ternary sector. The torsion term can become dominant for ultra-high-energy neutrinos detected by dedicated instruments [30, 31], providing a direct test of internal variations of $L(x)$.

This dependence introduces a directional signature in oscillations, which may be observable in the event distribution of cosmic neutrino fluxes and is absent in standard theories.

6.8 Cosmic birefringence induced by variations of $J(x)$

The internal rigidity associated with the operator J affects light propagation over cosmological distances. From (10), a spatial gradient of $Z(J)$ introduces a directional deviation in the effective phase index of the vacuum. Photon propagation becomes sensitive to the internal orientation of the vacuum, potentially generating a weak cosmic birefringence:

$$\Delta\phi \propto \int \partial_\mu Z(J)\, d\ell^\mu, \tag{38}$$

in line with observational hints suggesting subtle anisotropies in the polarisation of cosmic light [40, 41].

This effect does not require new fields or gauge symmetries: it is a direct consequence of the ternary internal geometry.

6.9 Cosmological variation of the fine-structure constant

The formal result (10) implies that the cosmological variation of the fine-structure constant reflects variations of the internal orientation $J(x)$. Phenomenological models exploring α variation [13, 14] can be reinterpreted within the ternary architecture, in which small deviations of internal rigidity are responsible for changes in the factor $Z(J)$. Thus

$$\frac{\Delta\alpha}{\alpha} \simeq -\Delta Z(J), \tag{39}$$

with expected variations at the level 10^{-6}–10^{-7} on cosmological scales, compatible with certain observational claims.

The cosmological consequences of the ternary architecture are robust: regularisation of singularities, internal stiffening of the vacuum in black holes, cosmic torsion effects on neutrino oscillations and light birefringence are distinct manifestations of the same discrete internal geometry, providing a class of observable signatures through which the model can be tested.

7 Predictions and experimental prospects

The ternary architecture yields a distinct class of predictions, directly testable at accessible energies and in astrophysical and cosmological regimes. These effects follow from the internal geometric structure of the operators J, K, L, and their amplitudes are determined by slow deviations of internal rigidity. In this section we present indicative numerical estimates, compatible with the internal scales of the model and with current experimental bounds.

Justification of numerical estimates. The purpose of this subsection is to clarify that the numerical ranges quoted in this section are not empirical fits, but follow from the internal rigidity of the ternary deviations. Small–deviation expansions of $J(x)$, $L(x)$ and $K(x)$ yield order–of–magnitude suppressions proportional to the geometric departure from perfect ternarity, fixing the scale of effects such as $\Delta\alpha/\alpha$ and $\Delta m_f/m_f$ without external parameters. This provides predictive scales without introducing additional tunable constants.

7.1 Cosmological variation of the fine-structure constant

From

$$\frac{\Delta\alpha}{\alpha} \simeq -\Delta Z(J), \tag{40}$$

and the expansion (9), internal variations δJ of order $\|\delta J\| \sim 10^{-3} - 10^{-4}$ produce deviations of the fine-structure constant at the level

$$\left|\frac{\Delta\alpha}{\alpha}\right|_{\text{ternary}} \sim 10^{-6} - 10^{-7}, \tag{41}$$

on cosmological scales $z \simeq 1 - 4$.

These values are compatible with the amplitudes suggested by some spectroscopic analyses [13], although they remain disputed. The model additionally predicts a directional anisotropy of order

$$\Delta_{\text{aniz}}(\alpha) \sim 10^{-7}, \tag{42}$$

reflecting the internal gradient of the orientation $J(x)$.

7.2 Vacuum-induced cosmic birefringence

For cosmological distances $D \sim$ Gpc, the integral (38) yields an estimated rotation angle

$$\Delta\phi_{\text{ternary}} \sim (0.1 - 0.3)^\circ, \tag{43}$$

for internal deviations $\partial_\mu Z(J) \sim 10^{-33}\,\text{cm}^{-1}$. This range lies close to the experimental sensitivity of recent CMB polarisation analyses [42, 43].

7.3 Ultra-high-energy neutrino deviations

The cosmic torsion S_μ derived from (18) yields a directional correction to the phase (37), dominant for ultra-high-energy neutrinos. For energies $E \sim 1 - 10\,\text{PeV}$, the model predicts a deviation of oscillation probabilities of order

$$\Delta P_\nu^{\text{tors}} \sim 0.01 - 0.05, \tag{44}$$

over cosmological distances ($D \sim 100$ Mpc).

Experiments such as IceCube-Gen2 and Hyper-Kamiokande [30] could probe this regime within the next observational decade.

7.4 Subtle modifications in the Higgs sector

The scalar potential (21) implies small deviations of the Higgs self-coupling from its Standard Model value. The ternary model anticipates

$$\frac{\Delta\lambda_{hhh}}{\lambda_{hhh}^{\rm SM}} \sim 2\times 10^{-2}, \tag{45}$$

a value accessible to future colliders (HL-LHC, FCC-hh) with projected sensitivities of order $O(10^{-2})$.

These deviations are geometrically controlled by the internal projection $Z_H(K)$, which governs both the shape of the effective potential and corrections to the self-coupling.

In this regime, internal deviations δh_K modify the scalar projection $Z_H(K)$, leading to small perturbations of the effective parameters of the Higgs sector.

At the same time, internal variations $\delta K(x)$ can produce a modified running of the Higgs mass,

$$\Delta m_h(Q) \sim (50-150)\,\text{MeV}, \tag{46}$$

a range marginally detectable only in very high-precision measurements.

7.5 Photonic interference at laboratory scale

The internal projection (7) predicts a very small deviation in Hong–Ou–Mandel interference for indistinguishable photons. The effect amplitude is controlled by the deviation $\delta Z(J) \sim 10^{-8}$, which leads to a HOM-dip asymmetry of order

$$A_{\rm HOM}^{\rm ternary} \sim 10^{-5}, \tag{47}$$

at the sensitivity frontier of high-precision photonic experiments [44, 45].

7.6 Neutrino spectrum and mass–rigidity correlation

From (14), for internal deviations $\delta h_L \sim 10^{-2} - 10^{-3}$, one obtains a neutrino spectrum of order

$$m_\nu \sim (0.01-0.05)\,\text{eV}, \tag{48}$$

in perfect agreement with current observational bounds ($<$ 0.12 eV at 95% C.L., Planck + BAO). The model predicts a strict correlation between the hierarchy of neutrino masses and the structure of the internal deviation δh_L, which may become testable with next-generation cosmological measurements.

The predictions of the ternary architecture span both low-energy regimes (precision photonics) and extreme conditions (ultra-energetic neutrinos, birefringence, cosmology). The numerical consistency of these effects offers a set of complementary tests through which the discrete internal structure of the vacuum can be probed experimentally within a realistic timescale.

8 Falsifiability and critical tests

A key feature of the ternary architecture is its falsifiability: the same geometric mechanisms that produce small but non-zero variations in the photonic, neutrino and scalar sectors impose clear correlations between effects that can be tested independently. In this section we identify the experimental regimes in which the model can be decisively ruled out by comparing its minimal predictions with observational limits.

8.1 Variation of the fine-structure constant and associated anisotropy

From (40) and (41), the ternary architecture generically implies

$$\left|\frac{\Delta\alpha}{\alpha}\right|_{\text{ternary}} \gtrsim 10^{-7} \tag{49}$$

on cosmological scales of order $z \sim 1 - 4$, together with an anisotropic component

$$\Delta_{\text{aniz}}(\alpha) \sim 10^{-7}. \tag{50}$$

If future high-precision spectroscopic measurements robustly establish bounds of the form

$$\left|\frac{\Delta\alpha}{\alpha}\right| < 10^{-8}, \qquad \Delta_{\text{aniz}}(\alpha) < 10^{-8} \tag{51}$$

on the same redshift range, then internal configurations compatible with the ternary architecture would be severely constrained, and in the absence of a reformulation of the J sector, the model would be effectively ruled out in its present form.

8.2 Cosmic birefringence and internal orientation of the vacuum

For internal deviations $\partial_\mu Z(J) \sim 10^{-33}\,\text{cm}^{-1}$, the birefringence estimated in (43) lies in the range $\Delta\phi_{\text{ternary}} \sim 0.1 - 0.3^\circ$. If CMB polarisation analyses and high-redshift polarised sources reduce the upper bounds to

$$\Delta\phi_{\text{obs}} < 10^{-2\,\circ}, \tag{52}$$

without identifying any directional pattern compatible with (38), the identification of internal rigidity $Z(J)$ as the geometric source of these effects would be incompatible with data, directly falsifying the photonic sector of the ternary architecture.

8.3 Neutrino oscillations and cosmic torsion

The torsion-induced phase correction in (37) leads to the probability deviations estimated in (44), $\Delta P_\nu^{\text{tors}} \sim 0.01 - 0.05$ for PeV-scale neutrinos over cosmological distances. If combined observations (IceCube-Gen2, KM3NeT, Hyper-Kamiokande) show that deviations from the standard oscillation model are constrained to

$$\Delta P_\nu^{\text{obs}} < 10^{-3} \tag{53}$$

in all relevant directions, while the mass spectrum (48) remains in the range $(0.01 - 0.05)$ eV, then interpreting neutrino mass as the ternary deviation δh_L would be in severe tension with the absence of observable torsion, thereby compromising the L sector of the model.

8.4 Higgs self-coupling and potential deviations

Relation (45) implies a minimal deviation

$$\left|\frac{\Delta\lambda_{hhh}}{\lambda_{hhh}^{\text{SM}}}\right| \gtrsim 2 \times 10^{-2}, \tag{54}$$

in a framework where the internal rigidity of K generates the potential (21). If future colliders (HL-LHC, FCC-hh) measure the Higgs self-coupling with precision better than

$$\left|\frac{\Delta\lambda_{hhh}}{\lambda_{hhh}^{\mathrm{SM}}}\right| < 5 \times 10^{-3}, \tag{55}$$

and the result is consistent with zero within errors, this would directly exclude the class of internal potentials associated with the undeformed ternary architecture.

8.5 Hong–Ou–Mandel interference and the internal structure of the vacuum

From (47), the ternary architecture predicts a HOM-dip asymmetry of order $A_{\mathrm{HOM}}^{\mathrm{ternary}} \sim 10^{-5}$, as a consequence of the internal structure of the projection (7). If photonic interference experiments with superior sensitivity establish

$$A_{\mathrm{HOM}}^{\mathrm{obs}} < 10^{-6}, \tag{56}$$

in a regime where all systematics are controlled, the connection between the internal photonic projection and the rigidity $Z(J)$ would be strongly challenged.

8.6 Cross-sector correlations and global exclusion

A central aspect of the ternary architecture is that the above effects are not independent: variations of $Z(J)$, deviations δh_L and rigidity of K belong to the same internal structure. In particular, the model anticipates the simultaneous existence of:

1. variations of α at the level $\gtrsim 10^{-7}$;
2. cosmic birefringence $\Delta\phi \sim 10^{-1} - 10^{-2}\,^{\circ}$;
3. neutrino deviations $\Delta P_{\nu}^{\mathrm{tors}} \sim 10^{-2}$;
4. Higgs self-coupling deviations $\Delta\lambda_{hhh}/\lambda_{hhh}^{\mathrm{SM}} \sim 10^{-2}$.

The systematic absence of all these effects, with upper bounds below the thresholds (51), (52), (53), (55), (56), would constitute a global falsification of the ternary architecture in the form presented here. In this sense, the model does not hide in experimentally inaccessible regimes: it makes specific claims about a phenomenological domain that can be explored in the coming decade.

The fact that the same internal geometric mechanism simultaneously fixes the order of magnitude of α variation, cosmic birefringence, torsion effects on neutrinos, deviations in the Higgs sector and HOM asymmetry gives the model a high degree of falsifiability. The ternary architecture is thus not only a unified conceptual framework but also a theoretical proposal clearly subject to experimental test.

9 Global fundamental differences from the Standard Model and General Relativity

The ternary architecture is not an incremental extension of the Standard Model or of general relativity, but a geometric reconstruction of the vacuum and of fundamental interactions. The differences do not stem from introducing additional particles but from replacing the continuum background with a discrete internal structure governed by the cyclic relations $J^3 = K^3 = L^3 = -I_3$. This section summarises the key conceptual differences between the ternary architecture and current fundamental theories.

9.1 Photons, electromagnetism and the fine-structure constant

In the Standard Model, electromagnetism is generated by the abelian gauge symmetry $U(1)$, and the fine-structure constant is a fundamental parameter. In the ternary architecture:

- the photon is the stable mode of the internal rotation generated by J, not a postulated gauge generator;
- photon uniqueness follows from the uniqueness of the stable direction of J, eliminating the need to phenomenologically rule out "dark" photons;
- the fine-structure constant becomes a geometric quantity, $\alpha_{\text{eff}} = \alpha/Z(J)$, and its cosmological variations reflect variations of the orientation $J(x)$.

9.2 The Higgs sector and the origin of mass

The Standard Model introduces a fundamental scalar and an extended list of Yukawa couplings. The ternary architecture replaces this structure by:

- a scalar triplet $H = (H_{\text{vis}}, H_{\text{d1}}, H_{\text{d2}})$ generated by the operator K, with two natural dark modes;
- a geometric potential determined by internal rigidity, rather than by an *ad hoc* Mexican-hat potential;
- fermion mass as internal orientation, $m_f(x) = y_f Z_H(K(x))$, eliminating the ~ 20 arbitrary Yukawa constants of the Standard Model;
- cosmological variations of masses correlated with those of the fine-structure constant.

9.3 Neutrinos, oscillations and torsion

In the extended Standard Model, neutrinos acquire mass through separate mechanisms (Dirac, Majorana, Seesaw). In the ternary architecture:

- neutrino mass is an internal deviation of the relation $L^3 = -I_3 + \delta h_L$, without heavy fermions or Majorana terms;
- the neutrino triplet reflects the three internal orientations of a single geometric object, and the Dirac/Majorana distinction disappears;
- oscillations are internal rotations, not a phenomenological mixing parametrised by the PMNS matrix;
- the neutrino becomes the privileged probe of space–time torsion, with a direct coupling $\bar{\Psi}_\nu \gamma^\mu \gamma^5 \Psi_\nu S_\mu$.

9.4 Vacuum, geometry and gravity

General relativity treats the vacuum as a continuous background without internal structure. The ternary architecture introduces:

- a discrete vacuum with internal structure (J, K, L), which determines field propagation, masses and cosmological phenomena;
- space–time torsion as the projection of internal variations of the ternary operators, not as an independent extension of the connection;
- regularisation of the cosmological and gravitational singularities by limiting internal deviations to δ_{crit}.

9.5 Cosmology: no singularity and no inert vacuum

The ternary architecture yields an internal cosmogenesis:

- space emerges from the stabilisation of J;
- time emerges from the coherence of the internal phase generated by L;
- mass emerges from the ternary deviation of K;
- cosmic expansion becomes a geometric relaxation of internal orientations, not a singular metric solution.

9.6 Black holes and the information problem

The differences are decisive:

- the core of the black hole is a stiffened ternary phase, not a geometric singularity;
- information is not lost, being mapped into the internal orientations $(J_\infty, K_\infty, L_\infty)$;
- Hawking radiation reflects the slow variation of $Z(J)$, not the creation of virtual pairs.

9.7 Geometric falsifiability

All predictions — variation of α, cosmic birefringence, deviations in neutrino oscillations, modifications of the Higgs self-coupling, HOM asymmetry — are correlated through the same internal structure. The simultaneous absence of these effects, below clearly defined experimental thresholds, would falsify the model.

The ternary architecture thus differs from the Standard Model and General Relativity not by an abundance of fields, but by the simplicity of an internal geometry that coherently produces light, mass, oscillations, torsion and cosmogenesis.

10 Conclusions

The ternary architecture presented in this work reshapes the concept of vacuum beyond the standard interpretations of the Standard Model and General Relativity.

The main contributions of this work are, in summary:

1. We introduce a minimal ternary internal geometry of the vacuum, encoded in the relations $J^3 = K^3 = L^3 = -I_3$, and show that it provides a unified geometric origin for the photon, the Higgs sector and the neutrino triplet.
2. We reinterpret the electromagnetic, neutrino and Higgs sectors as emergent modes of the same discrete internal structure, deriving geometric expressions for the effective fine-structure constant, neutrino masses, fermion masses and torsion couplings.
3. We derive a set of correlated, falsifiable predictions for cosmological and laboratory observables — including $\Delta\alpha/\alpha$, cosmic birefringence, torsion-sensitive neutrino oscillations, deviations in the Higgs self-coupling and Hong–Ou–Mandel asymmetries — and specify quantitative exclusion thresholds that would rule out the ternary architecture.
4. We propose a cosmological picture in which singularities are replaced by internal phase transitions of the ternary orientations (J, K, L), black holes correspond to internally stiffened phases of the vacuum, and the Standard Model plus General Relativity emerge as effective descriptions of this discrete internal geometry in the appropriate regimes.

Instead of a continuous background devoid of structure, or a quantum entity defined by the removal of excitations, the vacuum becomes an internal discrete medium characterised by cyclic rotations of operators that geometrically organise fundamental information. The three internal operators J, K, L are not mere formal constructions, but the geometric tools through which light, mass and neutrino oscillations acquire their physical identity.

In this formulation, the photon appears not as an element of an imposed gauge symmetry, but as the stable direction of an internal rotation, the only one capable of supporting coherent propagation. The scalar sector arises from the invariant mode of internal deviations, and the Higgs mass reflects the geometric rigidity of the vacuum rather than a phenomenological choice. Neutrinos, in turn, are interpreted as excitations of the internal rotation L, whose deviations simultaneously determine their extremely small mass, the structure of oscillations and the emergence of an effective torsion field.

The result is a conceptual unification in which the most disparate elements of fundamental physics—light, mass, neutrino oscillations, fine-structure constant variation and space–time torsion—originate from the same geometric source. In this sense, the model does not propose an incremental extension of the theory, but a geometric reformulation of its foundations. The vacuum becomes the internal space in which discrete dynamics unfolds, and what we perceive as properties of space–time or of particles are projections of this internal dynamics in the continuum regime.

This perspective enables a unified treatment of problems which, in traditional formulations, appear as independent sectors: photon uniqueness, the shape of the Higgs potential, the hierarchy of fermion masses, the smallness of neutrino masses and the cosmological signatures of internal rigidity become consequences of the same ternary structure. The model identifies mass as a measure of internal deviation (δh_L or δK), the fine-structure constant as a measure of the rigidity of the J sector, and torsion as an expression of variations of the internal orientation in the neutrino sector. In this way, phenomenology becomes a cartography of internal geometry.

In extreme regimes, similarities with quantum-gravity predictions do not arise from quantising the metric, but from intrinsic limitations of internal geometry. Singularities are replaced by phase transitions of ternary orientations, and internal stiffening in black holes gives consistency to regions where classical gravity fails. These effects do not require additional hypotheses; they follow from the impossibility of extending ternary cyclicity beyond a critical deviation regime.

The predictions of the model are, by design, experimental. Variation of the fine-structure constant, cosmic birefringence, neutrino deviations under the action of internal torsion, subtle modifications of the Higgs potential and asymmetry of Hong–Ou–Mandel photonic interference define testable directions in both cosmology and low-energy physics. The particularity of these signatures lies in the fact that they are all consequences of the same internal structure: a single geometric mechanism produces a coherent class of measurable phenomena.

The ternary architecture does not compete with the Standard Model and General Relativity in their current formulations; rather, it offers a wider framework in which these theories are emergent limits of a discrete vacuum structure. Light, mass and torsion are not introduced separately, but are manifestations of the same internal dynamics. This positioning reshapes the theoretical edifice and provides a coherent perspective on the fundamental nature of the vacuum, placing at the heart of physics an internal geometry that manifests simultaneously in microscopic phenomena, in particle structure and in cosmological regimes.

Taken as a whole, the ternary architecture provides a conceptual framework in which the unity of fundamental interactions is not the result of extending gauge groups or of new physics at high energies, but a consequence of a discrete internal symmetry, simple enough to be robust yet rich enough to generate the diversity of observable physical phenomena. The proposals and predictions of this framework are accessible to experimental investigation and may serve as the basis for a conceptual reconstruction of fundamental physics in which the vacuum is not absence, but structure.

Note on the Unified Action. Although this work does not present the fully explicit form of the Unified Action associated with ternary dynamics, its general structure can be read directly from the geometric architecture. In essence, any unified action compatible with the ternary model must integrate three basic ingredients.

The first is an internal geometric term that imposes the structural condition $X^3 = -I$ for the operators J, K, L, ensuring vacuum stability and the selection of coherent internal directions. This condition is not an external assumption, but the result of minimising the internal energy in the presence of deviations δh_X, and the cubic structure automatically determines how stable modes and perturbation-sensitive modes appear.

The second ingredient is the block of emergent fields. In this component, the photon, the Higgs mode and fermion masses appear as effective excitations of the ternary vacuum, governed by the geometric factors $Z(J)$ and $Z_H(K)$. These play the role of dynamical parameters encoding the internal response of the vacuum, and their variations describe both electromagnetic rigidity and the scalar sector, as well as the dependence of masses on the internal geometric state.

Finally, the third ingredient is the coupling term between internal dynamics and space–time geometry, in which variations of the orientation of L generate the effective torsion $S_\mu \sim \mathrm{Tr}(L^{-1}\partial_\mu L)$. This coupling ensures that the neutrino sector and the associated temporal structure are not independent of the external geometry, but contribute directly to the description of a torsionful connection and to the way space–time responds to internal variations.

In this formulation, the Unified Action is not an additional element appended to the model, but the synthetic expression of the three fundamental mechanisms already present: ternary internal geometry, the emergence of fields, and their coupling to space–time dynamics. In this respect, the action is fully constrained by the ternary architecture and naturally brings together all the phenomena discussed in this work.

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