Neutrino Mass and Oscillation

As Minimal Coherence Structure in a Closure-Constrained Framework

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Abstract

Neutrino oscillations demonstrate that flavor states do not coincide with propagation eigenstates and that neutrino mass differences are nonzero. In the Standard Model, this is accommodated by extending the mass sector, but no structural explanation is provided for why neutrino masses exist or why mixing occurs.

Within the coherence-relational blockworld (cRBW) [1] and its Mathematical Model (MM) [2], physical structure is determined by global relational closure constraints rather than dynamical evolution. In this framework, internal degrees of freedom are represented as coherence modes defined over relational structure, and observable phenomena arise from admissible projections of a globally consistent configuration. We show that:

1. A strictly degenerate internal spectrum (including the massless limit) collapses coherence transport and eliminates observable oscillation structure.
2. Nonzero eigenvalue differences are required for nontrivial phase differences assigned along relational edges.
3. Mixing arises as a geometric misalignment between relational laminations of the same internal coherence sector.
4. The observed structure of neutrino oscillations follows from minimal degeneracy lifting required for admissible coherence transport.

These results do not derive numerical neutrino masses but establish that nontrivial neutrino mass-difference structure is a necessary condition for oscillation-supporting relational readout within the lepton-flavor realization of the closure-first framework.

The present analysis is neutral with respect to Dirac versus Majorana mass structure. The question of whether lepton-number-carrying capacity chains close under BBP constraints,

and how this relates to Majorana phases, remains an open structural problem within the framework.

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1. Introduction

Neutrino oscillation experiments establish three central features of the lepton sector:

- flavor states do not coincide with propagation eigenstates,
- nonzero neutrino mass-squared differences are required for oscillation-supporting readout,
- and mixing angles are large relative to those observed in the quark sector.

Within the Standard Model, neutrinos are originally massless, and oscillations are accommodated only through extension of the mass sector. The required mass terms and mixing parameters are introduced phenomenologically, with no underlying structural account of why they must exist or why they take the qualitative form observed.

The situation is therefore not merely one of parameter determination, but of structural incompleteness: the existence of neutrino mass differences and mixing is empirically established, but not structurally explained.

Reframing the problem

The standard formulation asks: *What mechanism generates neutrino masses and mixing?*

In a closure-first framework, this question is not primary. The relevant question is instead: What minimal internal structure is required for neutrino oscillations to be admissible at all?

This shifts the focus from dynamical generation to structural necessity.

cRBW/MM perspective

Within the coherence-relational blockworld (cRBW) [1] and its Mathematical Model (MM) [2]:

- physical structure is not generated dynamically,
- admissibility is determined globally under relational constraints,
- and observable phenomena arise from projection relations within a fixed configuration.

In this setting, features such as “mass,” “mixing,” and “oscillation” must be understood as manifestations of admissible relational structure, not as the result of time-evolving processes.

The minimal internal coherence structure required for nontrivial relational closure, CP-odd invariants, and generational organization has been developed in The 3-Mode Coherence Sector framework [3].

Scope of this work

The goal of this work is therefore not to model oscillation dynamics or derive numerical parameters, but to determine the minimal internal coherence structure required for the existence of oscillation phenomena.

Result (preview)
We show that:

- a fully degenerate internal coherence spectrum eliminates all nontrivial relational structure required for oscillations,
- while minimal lifting of this degeneracy restores coherence transport, projection distinction, and mixing geometry.

Thus, nonzero eigenvalue differences are not optional parameters but necessary conditions for the existence of neutrino oscillations within a closure-constrained relational framework.

Interpretive stance
This result does not explain neutrino mass in terms of an underlying mechanism. Instead, it identifies neutrino mass differences as the minimal spectral structure required for admissible relational differentiation.

In this sense, the existence of neutrino oscillations is not produced by additional dynamics, but is a direct consequence of the internal structure required for globally consistent configurations.

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2. Internal Coherence Sector within cRBW/MM

In the coherence-relational blockworld (cRBW) and its Mathematical Model (MM), physical structure is not generated through dynamical evolution but is specified by **globally admissible configurations** satisfying relational constraints.

These constraints include:

- **Adynamical Global Constraint (AGC):**
  admissibility is determined over the entire configuration, not by temporal evolution.
- **Boundary of Boundaries Principle (BBP):**
  $\partial^2 = 0$, enforcing closure of relational cycles.
- **No Preferred Reference Frame (NPRF):**
  admissibility is invariant under representational decomposition.
- **Relational Coherence Conditions (RCC):**
  admissible configurations must support consistent internal relational structure.

2.1 Internal Sector as Coherence Fiber

In MM [2], each relational locus carries a *capacity fiber*. The three-mode coherence sector construction [3] establishes that a three-dimensional internal coherence structure is the minimal admissible sector supporting non-Abelian relational closure, CP-odd invariants, and nontrivial holonomy. In the present work, this structure is taken as given, and we examine the additional spectral conditions required for oscillation phenomena. In particular, the present work does not re-derive the dimensionality of the internal sector, but examines the spectral conditions required for nontrivial relational structure within that sector.

This internal sector is not an added degree of freedom but a minimal representational structure required for admissibility under closure constraints.

2.2 Projection Residual Geometry

Within Projection Residual Geometry (PRG) [4]:

- physical observables arise from projections of admissible configurations
- distinct “bases” correspond to different admissible projections

Thus:

- “mass basis” and “flavor basis” are not separate ontologies
- they are distinct projections of the same internal coherence structure

Mixing is therefore a projection misalignment between admissible subspaces.

2.3 Coherence Transport as Relational Structure

We consider an internal coherence sector represented by a finite-dimensional complex vector space with eigenstructure:

- Hermitian operator H with eigenvalues $\{\lambda_i\}$
- Internal modes corresponding to eigenvectors $\{|\ v_i\rangle\ \}$

Relational structure is defined over a discrete complex (e.g., Regge/DEC), with edges $e = (v \to v')$ in the underlying complex.

Internal structure along edges is encoded by a *coherence cochain*:

$$\Delta\phi[e] = \phi(v') - \phi(v). \tag{2.1}$$

This defines internal coherence transport along relational adjacency; it represents:

- relational differences between adjacent loci
- internal phase-like structure
- admissible variation across the configuration

No dynamical propagation is assumed. This is a structural assignment over admissible configurations.

Phase differences along an edge are associated with eigenstructure:

$$\Delta\phi_i[e] \propto \lambda_i\tau \tag{2.2}$$

and relative phase:

$$\Delta\phi_{ij}[e] \propto (\lambda_i - \lambda_j)\tau \tag{2.3}$$

2.4 Spectral Structure as Capacity

Eigenvalues $\{\lambda_i\}$ correspond to capacity structure within the internal coherence sector. They are not interpreted as intrinsic particle properties but as:

- invariants associated with admissible relational configurations
- generators of distinguishability across projections

Key reframing
The problem is not: “why do neutrinos have mass?” but: “what internal structure is required for admissible coherence transport across relational structure?”

3. Degenerate Limit and Collapse of Coherence Structure

We now analyze the degenerate internal spectrum:

$$\lambda_1 = \lambda_2 = \lambda_3 \tag{3.1}$$

This includes the massless limit as a special case.

3.1 Collapse of Coherence Transport

From Section 2:

$$\Delta\phi_i[e] \propto \lambda_i \tau \tag{3.2}$$

Thus:

$$\Delta\phi_{ij}[e] \propto (\lambda_i - \lambda_j)\tau \tag{3.3}$$

Under degeneracy:

$$\lambda_i - \lambda_j = 0 \forall i, j \tag{3.4}$$

So:

$$\Delta\phi_{ij}[e] = 0. \tag{3.5}$$

Consequence

- No relative phase difference exists
- Internal modes are indistinguishable along all relational paths

Thus, coherence transport becomes trivial.

3.2 Collapse of Projection Structure (PRG)

In Projection Residual Geometry (PRG) [4], physical structure arises from:

$$R = \| V - P_{\mathcal{A}_{adm}}(V) \| \tag{3.6}$$

where distinguishability between projections depends on internal structure.

With degenerate spectrum:

- all eigenvectors correspond to the same eigenvalue
- internal subspace becomes isotropic

Therefore:

- projections become indistinguishable

- residual structure collapses to zero or trivial equivalence classes

Consequence
No nontrivial projection distinction exists between “mass” and “flavor” bases.

3.3 Collapse of Mixing Geometry

Mixing is defined by:

$$U \in \mathfrak{su}(3) \tag{3.7}$$

and principal angles:

$$\cos\ \Theta_{ij} = |\ \langle u_i \mid d_j \rangle\ | \tag{3.8}$$

But if all eigenvalues are equal:

- any orthonormal basis diagonalizes H
- basis choice is arbitrary

Thus:

- all unitary transformations are equivalent
- principal angles lose invariant meaning

Consequence
Mixing becomes physically undefined.

There is no preferred or distinguishable misalignment.

3.4 Collapse of Variational Structure

Mixing-selection functional:

$$E_{PA}(U) = \sum_{i<j} W_{ij}\,\Theta_{ij}^2 \tag{3.9}$$

with:

$$W_{ij} \propto (\lambda_i - \lambda_j)^2 \tag{3.10}$$

Under degeneracy:

$$W_{ij} = 0 \tag{3.11}$$

Thus:

$$E_{PA}(U) = 0 \forall U \tag{3.12}$$

Consequence

- all configurations have equal cost
- no structure is selected
- no preferred mixing exists

3.5 Collapse of CP Structure

CP-odd invariant:

$$\mathcal{J} = \frac{1}{2i}\mathrm{Tr}([H, K]^3) \tag{3.13}$$

Under degeneracy:

- $H \propto I$
- $[H, K] = 0$

Thus, $\mathcal{J} = 0$.

Consequence

No CP-sensitive structure exists.

3.6 Structural Summary of Degeneracy

Under a fully degenerate spectrum:

Structure	Result
Coherence transport	trivial
Projection structure	indistinguishable
Mixing geometry	undefined
Variational selection	flat
CP invariants	vanish

3.7 Final Conclusion of Section 3

A fully degenerate internal coherence spectrum does not support any nontrivial relational structure required for oscillation, mixing, or CP-sensitive phenomena.

This is not a failure of dynamics but a structure that is excluded from the admissible class within a closure-constrained framework. Under RCC-8 (nontrivial relational asymmetry) and RCC-2 (closed non-Abelian structure), degenerate configurations fail to support required internal structure and are therefore excluded from the admissible class.

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4. Minimal Degeneracy Lifting and Emergence of Oscillation Structure

Section 3 established that a fully degenerate internal spectrum collapses all nontrivial relational structure:

- coherence transport becomes trivial,
- projection distinctions vanish,
- mixing geometry becomes undefined,
- variational structure becomes flat,
- and CP-sensitive invariants vanish.

Within a closure-constrained framework, such configurations are structurally deficient: they do not support the relational distinctions required for observable structure.

The question is therefore not whether degeneracy may be lifted, but what is the minimal modification required to restore admissible relational structure?

4.1 Minimal Lifting of Internal Spectrum

Let the internal coherence sector be defined by eigenvalues $\{\lambda_1, \lambda_2, \lambda_3\}$. Minimal lifting consists of introducing non-equality:

$$\exists\, i \neq j \text{ such that } \lambda_i \neq \lambda_j \tag{4.1}$$

with no additional structure imposed.

This is the smallest deviation from degeneracy compatible with:

- RCC minimality (no gratuitous structure),
- NPRF (no preferred embedding),
- and BBP closure (no inconsistent cycles).

4.2 Admissible Coherence Transport

From Section 2:

$$\Delta\phi_{ij}[e] \propto (\lambda_i - \lambda_j)\tau \tag{4.2}$$

Under minimal lifting:

$$\lambda_i - \lambda_j \neq 0 \tag{4.3}$$

Thus:

$$\Delta\phi_{ij}[e] \neq 0 \tag{4.4}$$

Consequence

- Relative phase differences become nonzero
- Internal modes become distinguishable along relational paths

Thus, coherence transport is restored as a nontrivial relational structure.

This is the minimal condition under which path-dependent distinctions exist.

4.3 Restoration of Projection Structure (PRG)

In Projection Residual Geometry:

- distinct projections correspond to distinct admissible subspaces
- distinguishability requires nontrivial internal structure

With lifted eigenvalues:

- internal directions acquire spectral differentiation
- projection operators no longer commute trivially

Degeneracy reduces the internal operator algebra to scalar multiples of the identity, eliminating nontrivial commutator structure required for projection distinction.

Thus, projection residuals become nonzero and admissible subspaces become distinguishable.

Consequence

The distinction between “propagation basis” and “interaction basis” becomes structurally meaningful. Mixing is therefore not introduced—it becomes definable.

4.4 Emergence of Mixing Geometry

Let:

- H: propagation (mass-like) operator
- K: interaction (flavor-like) operator

With non-degenerate spectra:

- eigenbases of H and K need not coincide
- relative orientation becomes invariantly defined

Thus:

$$U \in \mathfrak{su}(3) \tag{4.5}$$

represents a physically meaningful transformation between two relational laminations. The appearance of an $\mathfrak{su}(3)$-type structure follows from the minimal three-mode coherence sector identified in [3], within which mixing corresponds to relative orientation between admissible laminations.

Principal angles, Θ_{ij}, become nontrivial invariants.

Consequence
Mixing emerges as a geometric property of the internal coherence sector under admissible projection.

It is not an added degree of freedom but a necessary relation between distinct admissible bases.

4.5 Emergence of Variational Structure

The mixing-selection functional:

$$E_{PA}(U) = \sum_{i<j} W_{ij}\,\Theta_{ij}^2 \tag{4.6}$$

depends on:

$$W_{ij} \propto (\lambda_i - \lambda_j)^2 \tag{4.7}$$

Under minimal lifting:

$$W_{ij} \neq 0 \tag{4.8}$$

Consequence

- the cost functional becomes non-flat
- preferred configurations exist
- mixing angles become constrained

Interpretation

- large eigenvalue gaps → stiff directions → suppressed mixing
- small gaps → soft directions → large mixing

This yields:

sector-dependent mixing structure as a direct consequence of spectral geometry

4.6 Emergence of Oscillation Structure

With nonzero phase differences:

$$\Delta\phi_{ij}[e] \neq 0 \tag{4.9}$$

and nontrivial mixing:

$$U \neq I \tag{4.10}$$

interference structure is present under projection.

Consequence
Oscillation-supporting readout appears as a relational interference effect arising from coherence transport across misaligned projections.

This corresponds, under phenomenological mapping, to:

$$\Delta\phi_{ij} \sim \frac{\Delta m_{ij}^2}{2E} L \tag{4.11}$$

but here arises from:

- eigenvalue differences (internal capacity structure),
- relational path structure (edge transport),
- and projection misalignment (mixing geometry).

4.7 Structural Minimality of the Result

The lifting introduced here:

- does not add new degrees of freedom,
- does not specify numerical values,
- and does not impose additional symmetry structure.

It is the **minimal deviation from degeneracy** required to restore:

- coherence transport,
- projection distinguishability,
- mixing geometry,
- and oscillation structure.

4.8 Final Conclusion of Section 4

Minimal degeneracy lifting of the internal coherence spectrum is sufficient—and structurally necessary—to restore nontrivial relational structure within a closure-constrained framework.

Combined with Section 3:

- degeneracy ⇒ structural collapse
- minimal lifting ⇒ admissible structure exists only under non-degeneracy

Key statement

Nonzero eigenvalue differences are not optional parameters but the minimal structural condition required for coherence transport, mixing, and oscillation phenomena to exist.

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5. Mixing as Geometric Misalignment

Let:

- H: propagation (mass-like) operator
- K: interaction (flavor-like) operator

Both act on the same internal coherence sector but define distinct admissible laminations.

Mixing is defined by:

$$| d_i\rangle = U \mid u_i\rangle, \qquad U \in SU(3) \tag{5.1}$$

The $\mathfrak{su}$ (3)-type structure follows from the minimal three-mode coherence sector identified in [3]. This is not an added transformation but the invariant relation between two admissible projections of the same internal structure.

5.1 Misalignment as invariant structure

Principal angles:

$$\cos\ \Theta_{ij} = | \langle u_i \mid d_j\rangle \mid \tag{5.2}$$

provide a basis-independent measure of projection misalignment.

These angles are only well-defined when the internal spectrum is non-degenerate and eigenbases are distinct. Thus, mixing exists only when degeneracy is lifted.

5.2 Capacity-weighted geometry

Misalignment is constrained by spectral structure:

$$E_{PA}(U) = \sum_{i<j} W_{ij}\,\Theta_{ij}^2 \text{ with } W_{ij} \propto (\lambda_i - \lambda_j)^2 \tag{5.3}$$

Interpretation

- large eigenvalue differences → stiff directions → suppressed misalignment
- small eigenvalue differences → soft directions → large misalignment

5.3 Neutrino sector

For small spectral gaps $W_{ij} \ll 1$, Θ_{ij} may be large without violating admissibility.

Conclusion

Large PMNS mixing is not anomalous but a direct consequence of weak spectral differentiation within the internal coherence sector.

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6. Relation to Observed Oscillation Structure

Standard oscillation expressions take the form:

$$\Delta\phi_{ij} \sim \frac{\Delta m_{ij}^2}{2E} L \tag{6.1}$$

In the present framework, phase differences arise from the internal spectral structure of the coherence sector:

$$\Delta\phi_{ij}[e] \propto (\lambda_i - \lambda_j)\, \tau_e, \tag{6.2}$$

where τ_e is a parameter associated with relational edge structure. The identification of τ_e with $L/2E$ is a phenomenological representation; its derivation from the underlying Regge/DEC structure remains an explicit calibration problem within the framework and is not derived in the present work; the mapping to $L/2E$ should therefore be understood as a phenomenological identification rather than a structural derivation. This relation identifies internal spectral differences as the source of phase structure, with standard oscillation expressions arising as a particular representation of relational parameters under phenomenological identification.

Under phenomenological identification,

$$(\lambda_i - \lambda_j) \;\leftrightarrow\; \Delta m_{ij}^2, \qquad \tau_e \;\leftrightarrow\; \frac{L}{2E}, \tag{6.3}$$

recovering the standard oscillation phase relation. Within this framework:

- eigenvalue differences: for phase transport $\Delta m_{ij}^2 \leftrightarrow (\lambda_i - \lambda_j)$, for stiffness $W_{ij} \propto (\lambda_i - \lambda_j)^2$.
- relational path structure: $L \leftrightarrow$ edge-based relational length
- energy dependence: $E \leftrightarrow$ boost-sector coupling

Key point

This mapping does not introduce dynamics, but identifies the standard oscillation phase as a representation of coherence differences defined over admissible relational structure. This calibration follows the invariant-ratio discipline developed in Structural Invariants [5].

Conclusion

Standard oscillation formulas arise as a representation of coherence transport within the internal sector, without requiring wavefunction ontology or dynamical propagation. The numerical eigenvalues used in the 3-Mode coherence-sector [3] phenomenological

comparison are representational calibration inputs, not quantities derived in the present work.

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7. Structural Necessity of Neutrino Mass Differences

From Sections 3–6:

- degenerate spectrum ⇒ no coherence transport
- ⇒ no projection distinction
- ⇒ no mixing
- ⇒ oscillation-supporting readout

Minimal lifting yields:

- nonzero phase differences
- nontrivial projection relations
- admissible mixing geometry

Therefore: Oscillation-supporting readout requires both nonzero internal spectral differences and nontrivial projection misalignment:

$$\exists\, i \neq j : \lambda_i \neq \lambda_j \text{ and } [H, K] \neq 0. \qquad (7.1)$$

The first condition supplies nontrivial phase differentiation, while the second prevents simultaneous diagonalization of propagation and flavor bases. Both are required for oscillation-supporting projection structure. This requirement applies to spectral differences only; configurations in which one eigenvalue vanishes while others remain distinct are compatible with oscillation-supporting readout. This equivalence is structural and does not depend on any dynamical model of propagation.

Interpretation
Nonzero eigenvalue differences are not phenomenological additions but necessary conditions for admissible relational structure.

Important limitation
This result does not determine:

- absolute eigenvalue scale
- numerical spectrum

It establishes only that the exclusion of the fully degenerate (massless) limit from the admissible class of configurations.

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8. Interpretation within cRBW/MM

Within the coherence-relational blockworld (cRBW) [1] and its Mathematical Model (MM) [2], physical structure is specified by globally admissible configurations subject to relational closure constraints. In this setting, quantities such as "mass" are not primitive attributes of localized entities but arise from invariant structure within the internal coherence sector.

8.1 Mass as Internal Spectral Structure

The eigenvalues $\{\lambda_i\}$ of the internal coherence sector are interpreted as capacity parameters encoding admissible distinctions within the internal relational structure.

They do not represent intrinsic properties carried by particles, but:

- invariants of the admissible configuration,
- generators of distinguishability between internal modes,
- and parameters governing projection structure across relational laminations.

Thus, mass corresponds to eigenstructure within the internal coherence sector, not to an independent ontic substance.

8.2 Necessity of Mass Differences

Sections 3 and 4 establish that a fully degenerate spectrum collapses all nontrivial relational structure, while minimal lifting restores coherence transport, projection distinction, and mixing. Therefore, neutrino mass differences represent the minimal spectral structure required for admissible relational differentiation.

They are not introduced to explain oscillations; rather the oscillation structure exists only because such differentiation is present.

8.3 Oscillation as Projection Structure

Within PRG, observable structure arises from projection between admissible subspaces. In this context:

- the "mass basis" and "flavor basis" are distinct projections of the same internal sector,
- mixing encodes their relative orientation,
- and phase differences encode relational distinctions across edges.

Oscillation is therefore a projection-level manifestation of coherence structure defined over the internal sector. No dynamical propagation or wavefunction ontology is required.

8.4 Slice-Indexed Description

In accordance with the Slice-Indexed Descriptive Principle (SIDP), oscillation is not a process occurring in time but a slice-indexed description of relational structure across the global configuration.

Apparent temporal variation corresponds to:
differences between projections across slices,

not to evolution of an underlying state.

8.5 Final Interpretation

Combining these results:

- mass corresponds to internal spectral structure,
- mass differences encode minimal relational differentiation,
- mixing arises from projection misalignment,
- oscillation reflects coherence structure across relational paths.

Key statement

> Neutrino mass differences are the minimal internal structure required for the existence of nontrivial projection relations within a globally constrained relational configuration, and neutrino oscillations are the slice-indexed manifestation of this structure.

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9. Conclusion

We have examined the internal coherence structure required for neutrino oscillations within a closure-constrained relational framework.

The analysis establishes a strict structural dichotomy:

- a fully degenerate internal spectrum eliminates coherence transport, projection distinction, and mixing geometry,
- while minimal lifting of this degeneracy restores nontrivial relational structure across all levels.

In particular:

- relative phase structure exists if and only if eigenvalue differences are nonzero,
- mixing arises as an invariant geometric relation between distinct admissible projections,
- and oscillation-supporting readout appears as a projection-level manifestation of coherence transport within the internal sector.

These results do not introduce additional dynamical assumptions or new degrees of freedom. They follow directly from the requirement that admissible configurations support nontrivial relational differentiation under the constraints of cRBW/MM.

Combined structural interpretation

The 3-mode coherence sector is the minimal internal structure supporting CP-odd invariants, mixing geometry, and closure-compatible generational organization. The Standard Model flavor sector is one realization of this structure. Within the lepton-flavor realization, oscillation-supporting readout requires both nonzero spectral differences and nontrivial projection misalignment.

Final statement

> Neutrino mass differences are not free parameters appended to an otherwise complete theory, but the minimal internal spectral structure required for admissible relational differentiation; neutrino oscillations exist if and only if this structure is present.

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