

LSC 5.5: Unified Theory of Gravitationally Modulated Neutrino Propagation and Tensor Energy Reconstruction

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2026-04-25

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Abstract

We present a curated and integrated final working version of the LSC 5.5 framework, unifying two previously separate lines of development: LSC 4.2 ULTRA, which describes gravitational modulation of neutrino oscillations near compact environments and effective primordial black hole (PBH) backgrounds, and LSC 5.00, which interprets part of the neutrino-anomaly landscape as a consequence of nonlinear energy reconstruction in the detector. In the final version the central claim is that observed anomalies may arise from the joint action of curved-spacetime propagation and anisotropic detector response. The detection effect is parameterized by a tensor $D_{\{\mu\nu\}}$, extending the scalar energy-shift parameter Δ into a directional and geometric object. The model does not require a dark-neutrino sector as the main explanation of the anomalies; instead, it preserves a falsifiable phenomenological structure with testable predictions involving energy dependence, anisotropy, and experiment-to-experiment response differences. This document organizes the formalism, states its regime of validity, and records the main changes relative to earlier versions.

1. Introduction

Neutrino physics already possesses a strong and experimentally successful description of flavor oscillations. Nevertheless, several classes of anomalies have been interpreted either as evidence for beyond-standard-model states or as manifestations of incompletely modeled measurement effects. Sterile-neutrino interpretations belong to the first class; imperfect energy reconstruction and detector response belong to the second.

Within the LSC family of documents, two major tracks emerged:

1. LSC 4.2 ULTRA: an additional gravitational modulation of neutrino propagation, especially in environments with an effective PBH contribution.
2. LSC 5.00: a nonlinear energy-reconstruction effect capable of producing nontrivial deviations in observed event counts.

LSC 5.5 merges these tracks. The final version no longer relies on the claim that PBHs are the primary energy source of the signal, nor on the requirement of introducing a new particle as the central degree of freedom. Its theoretical backbone is instead the combination

curved-spacetime propagation + resonant geometric modulation + nonlinear tensor energy reconstruction.

2. Scope and status of the final version

The final version is an effective and phenomenological theory. This means:

- it is not claimed to be a complete fundamental theory of gravity and measurement,
- it uses an effective operator $H_{\{\mathrm{LSC}\}}$,
- it treats the tensor $D_{\{\mu\nu\}}$ as an effective detector-response object tied to local geometry and direction dependence,
- it prioritizes a coherent chain from assumption to equation to observable over maximal ontological ambition.

Accordingly, the model should be judged primarily by:

- dimensional consistency and sensible limits,

- testable predictions,
- its ability to explain classes of anomalies without unnecessary extra states.

3. Effective propagation formalism

We describe flavor evolution with the effective Hamiltonian

$$H_{\text{eff}} = H_{\text{vac}} + H_{\text{matter}} + H_{\text{grav}} + H_{\text{LSC}}.$$

The vacuum term is

$$H_{\text{vac}} = \frac{1}{2E} U M^2 U^\dagger,$$

where U is the mixing matrix and M^2 is the diagonal mass-squared matrix.

The matter term is

$$H_{\text{matter}} = \text{diag}(V_e, 0, 0), \quad V_e = \sqrt{2} G_F n_e(r).$$

The minimal gravitational contribution is written as

$$H_{\text{grav}} = \frac{E}{c^2} \Phi(r), \quad \Phi(r) = -\frac{GM}{r}.$$

The effective LSC operator parameterizes the additional geometric modulation associated with PBH-like environments:

$$H_{\text{LSC}} = \alpha_{\text{LSC}} \left(\frac{GM}{rc^2} \right) F(E) \Xi.$$

Here:

- α_{LSC} is a dimensionless coupling,
- $F(E)$ sets the energy scaling,
- Ξ is a flavor-space operator structure.

For the minimal high-energy version,

$$F(E) = \frac{E}{E_0}, \quad E_0 = 1 \text{ PeV}.$$

The required limits are:

1. $H_{\text{LSC}} \rightarrow 0$ as $M \rightarrow 0$ or $r \rightarrow \infty$,
2. the standard oscillation picture is recovered in the flat-space limit,
3. the new term can remain subdominant at low energy.

4. Resonance condition and PBH modulation

The resonance branch preserves the MSW-like insight that even a weak additional potential may strongly alter conversion probabilities if it enters the correct kinematic regime. In an effective two-state reduction we write

$$\Delta m^2 \cos(2\theta) = 2E (V_{\text{matter}} + V_{\text{LSC}}),$$

with

$$V_{\text{LSC}} = \alpha_{\text{LSC}} \left(\frac{GM}{rc^2} \right) F(E).$$

In this form the model does not assert that PBHs inject energy into the neutrino. They instead act as modulators of phase, mixing, and local resonance conditions. That interpretive shift is one of the main cleanups relative to more speculative earlier versions.

The oscillation probability is treated effectively as

$$P_{\alpha \rightarrow \beta}(L, E) = \sin^2(2\theta_{\text{eff}}) \sin^2 \left(\frac{\Delta m_{\text{eff}}^2 L}{4E} \right),$$

where θ_{eff} and Δm_{eff}^2 absorb the corrections induced by $H_{\text{grav}} + H_{\text{LSC}}$.

5. Energy-reconstruction model

The second pillar of the theory concerns measurement rather than propagation. In LSC 5.00 the core ansatz was

$$E_{\text{true}} = E_{\text{obs}}(1 + \delta),$$

with δ a small correction parameter. This is useful as a first-order approximation but does not encode direction dependence, local geometry, or tensor structure.

The final version upgrades this to

$$\Delta_D = D_{\mu\nu} p^\mu p^\nu,$$

$$E_{\text{true}} = E_{\text{obs}} (1 + \alpha_D \Delta_D),$$

where:

- p^μ is the neutrino four-momentum,
- $D_{\mu\nu}$ is a symmetric detector-response tensor,
- α_D sets the detector-coupling scale.

The scalar limit is recovered by

$$D_{\mu\nu} = \delta \eta_{\mu\nu} \quad \Rightarrow \quad \Delta_D \propto \delta.$$

This extension is useful because it:

1. admits anisotropy,
2. allows a geometric interpretation of reconstruction bias,
3. reduces to the earlier scalar model when the extra structure is switched off.

6. Event rate and amplification of a small bias

The observed event count is written as

$$N_{\text{obs}} = \int dE \Phi(E) P_{\alpha \rightarrow \beta}(E) \sigma(E) R_{\text{det}}(E),$$

where $R_{\text{det}}(E)$ encodes the detector response.

If the relevant cross section scales approximately as

$$\sigma(E) \propto E^2,$$

then a small energy bias can be amplified at the level of event counts. To first order,

$$\frac{\Delta N}{N} \approx \frac{\partial \ln \Phi}{\partial \ln E} \frac{\Delta E}{E} + \frac{\partial \ln P}{\partial \ln E} \frac{\Delta E}{E} + \frac{\partial \ln \sigma}{\partial \ln E} \frac{\Delta E}{E}.$$

Because $\partial \ln \sigma / \partial \ln E \simeq 2$, even a few-percent energy reconstruction shift may become phenomenologically important after integration. This is the core mechanism behind the gallium-anomaly part of the framework.

7. Coupling geometry to detector response

The final version assumes that propagation and detection should not be modeled as completely unrelated sectors. The simplest effective bridge is

$$D_{\mu\nu} = a \eta_{\mu\nu} + b h_{\mu\nu} + c R_{\mu\nu},$$

where:

- $\eta_{\mu\nu}$ is the Minkowski metric,
- $h_{\mu\nu}$ is a local geometric perturbation,
- $R_{\mu\nu}$ is the Ricci tensor,
- a, b, c are effective coefficients.

This equation is not yet a first-principles derivation. It is, however, a useful working ansatz because it:

- reduces to the scalar model in the flat limit,
- permits anisotropic detector effects,
- makes later data-driven fitting possible.

8. Covariant formulation

An effective covariant Lagrangian density for the integrated model can be written as

$$\mathcal{L}_{\text{tot}} = \sqrt{-g} \left[i\bar{\psi}\gamma^\mu\nabla_\mu\psi - m_{\text{eff}}\bar{\psi}\psi - G_D\bar{\psi}\gamma^\mu D_{\mu\nu}\gamma^\nu\psi \right].$$

The three terms represent:

- neutrino propagation in curved spacetime,
- an effective mass or phase correction,
- coupling to the detector-response tensor.

This formulation remains effective rather than fundamental, but it places the model into a consistent covariant language while preserving the distinction between propagation physics and measurement physics.

9. Application to two anomaly classes

9.1. Gallium-type anomalies

At low energy the reconstruction mechanism may dominate. In this regime the tensor generalization of LSC 5.00 is more central than the PBH resonance mechanism.

The main statement is:

- a small systematic mapping $E_{\{\text{obs}\}} \rightarrow E_{\{\text{true}\}}$ may generate a much larger shift in event counts once the cross section and detector response are folded into the calculation.

9.2. TeV-PeV events

At high energy the gravitational and resonant branches may become more relevant. In this regime the model predicts:

- energy-dependent modulation,
- possible directional dependence,
- localized enhancement of flavor conversion inside a narrow parameter window.

The KM3-230213A event should be treated as a case study rather than as the single foundation of the theory. The final version deliberately avoids claiming that the model already explains the entire energy budget of such an event.

10. Testable predictions

The framework yields several classes of falsifiable predictions:

1. event-count anomalies should show nonlinear energy dependence,
2. some configurations may generate anisotropy through $D_{\{\mu\nu\}}$,
3. different detectors may reconstruct similar neutrino populations with systematic offsets,
4. high-energy anomalies may appear as resonance windows rather than smooth distortions,
5. the tensor formulation can be falsified if directional correlations are absent where the model predicts them.

11. Limitations

The main limitations are:

- $H_{\{\mathrm{LSC}\}}$ is still an effective operator, not a microscopically derived fundamental interaction,
- $D_{\{\mu\nu\}}$ is still an effective parameterization,
- a full global fit across all experiments has not yet been performed,
- the connection to a realistic PBH population remains to be quantitatively constrained,
- the dark-neutrino branch is not required for the mainline and is therefore not retained as the central mechanism here.

12. Changes relative to earlier versions

This section records the main editorial and physical changes.

12.1. Relative to LSC 3.5 and early darkNeutrino

- information-theoretic and philosophical language was removed from the mainline,
- the dark-neutrino sector is no longer treated as mandatory,
- only those ideas that can be rewritten in terms of effective Hamiltonians and observables are retained.

12.2. Relative to PBHRM 3.3

- the PBH-regulator motif is preserved in weakened and cleaner form,
- strongly speculative environmental claims were removed from the core theory,
- the emphasis shifts from regulatory language to a propagation-and-detection framework.

12.3. Relative to LSC 4.2 ULTRA

- the $H_{\{\mathrm{eff}\}}$ formalism is preserved,
- PBHs are reframed as resonance and phase modulators rather than direct energy sources,
- the QUE branch is not retained in the final mainline because it is less constrained and less clearly testable.

12.4. Relative to LSC 5.0@

- the central energy-reconstruction mechanism is preserved,
- the scalar parameter δ is upgraded to the tensor $D_{\{\mu\nu\}}$,
- propagation and measurement are explicitly separated before being coupled.

12.5. Relative to LSC 5.5

- the integrated geometry-plus-detection idea is preserved,
- the formal status is clarified: not every equation is a first-principles derivation,
- the discussion of limits, interpretation, and testability is strengthened,
- duplicates and over-strong interpretive claims are removed.

13. Minimal next-step program

To move from this working version toward a stronger preprint, the next tasks are:

1. dimensional and scale analysis for α_{LSC} and α_D ,
2. selection of one explicit flavor-space choice for χ_i ,
3. order-of-magnitude estimates for BEST, SAGE, and GALLEX,
4. a parameter table summarizing the observationally allowed ranges,
5. a simple scan or fit demonstrating when the effect becomes measurable.

14. Conclusion

The final LSC 5.5 version presents one coherent effective theory in which neutrino anomalies may arise from the combination of modified propagation in curved spacetime and nonlinear, direction-dependent energy reconstruction in the detector. The main advance relative to earlier versions is the cleanup of unnecessary extra entities and conflicting interpretations, together with a clearer separation between physical claims and effective parameterizations.

In this form the model is suitable as the core of a working preprint. Its next stage should focus less on adding new ontological layers and more on parameter control, scale estimates, and quantitative comparison with data.