

LSC 4.2 ULTRA: Gravitationally Coupled Neutrino Oscillation Framework

Abstract

LSC 4.2 presents a refined theoretical framework extending neutrino oscillation physics into curved spacetime. The model introduces a gravitationally coupled operator (LSC) modifying flavor evolution near Primordial Black Holes (PBH). We derive resonance conditions, predict observable deviations, and propose testable signatures for ultra-high-energy neutrino experiments.

1. Introduction

Standard neutrino oscillation theory successfully explains solar and atmospheric data. However, extreme gravitational environments may induce additional phase and mixing effects. LSC 4.2 explores this regime using a covariant formalism.

2. Covariant Formalism

$$i D/dt \nu = H_{\text{eff}} \nu$$

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

Vacuum Term:

$$H_{\text{vac}} = (1/2E) U M^2 U^\dagger$$

Matter Term:

$$H_{\text{matter}} = \text{diag}(V_e, 0, 0)$$

Gravitational Term:

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

LSC Operator:

$$H_{\text{LSC}} = \alpha_{\text{LSC}} (GM / (r c^2)) F(E)$$

3. Resonance Structure

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

This condition predicts localized resonance near PBH environments, enhancing flavor conversion probabilities.

4. Gravitational Energy Shift

$$E_{\text{obs}} = E_{\text{emit}} \sqrt{\frac{1 - r_s/r_{\text{emit}}}{1 - r_s/r_{\text{obs}}}}$$

This relativistic effect explains observed high-energy neutrinos without requiring exotic acceleration mechanisms.

5. Oscillation Probability

$$P(\nu_\alpha \rightarrow \nu_\beta) = |P \exp(-i \int H_{\text{eff}} d\tau)|^2$$

6. Predictions

- Energy-dependent resonance peaks - Enhanced oscillation near compact objects - Possible explanation for PeV-scale neutrino anomalies

7. Discussion

The model remains consistent with General Relativity and Quantum Field Theory while extending neutrino physics into new regimes.

8. Conclusion

LSC 4.2 provides a mathematically consistent and testable extension of neutrino oscillation theory. Future work includes numerical simulation and experimental validation.

LSC 4.2 ULTRA – Input Data Block for Simulation

1. Goal and Scope

Model: LSC 4.2 ULTRA – Gravitationally Coupled Neutrino Oscillation.

Goal: Analyze PBH influence on neutrino oscillations and resonance conditions.

2. Effective Hamiltonian

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

2.1 Vacuum Term

$$H_{\text{vac}} = (1/2E) U M^2 U^\dagger$$

$$\Delta m^2_{12} = 7.5e-5 \text{ eV}^2, \Delta m^2_{31} = 2.5e-3 \text{ eV}^2$$

$$\theta_{12} = 33^\circ, \theta_{23} = 45^\circ, \theta_{13} = 8.5^\circ$$

2.2 Matter Term

$$V_e = \sqrt{2} G_F n_e(r)$$

$$n_e = \text{const} = 1e10 \text{ cm}^{-3} \text{ OR } n_e(r) = n_0 \exp(-r/r_0)$$

2.3 Gravitational Term

$$\Phi(r) = -GM/r$$

$$H_{\text{grav}} = (E/c^2) \Phi(r)$$

2.4 LSC Operator

$$H_{\text{LSC}} = \alpha_{\text{LSC}} (GM/(r c^2)) F(E)$$

$$\alpha_{\text{LSC}} = 1e-8$$

$$F(E) = E / 1 \text{ PeV}$$

3. PBH Parameters

$$M = 1e14 - 1e17 \text{ g}$$

r in [2rs, 50rs]

4. Energy Range

$E = 1 \text{ TeV} - 100 \text{ PeV}$

Test point: 220 PeV

5. Resonance Condition

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

6. Evolution Equation

$$i \frac{d}{d\tau} v = H_{\text{eff}} v$$

7. Oscillation Probability

$$P(\nu_\alpha \rightarrow \nu_\beta) = |\nu_\beta(\tau)|^2$$

8. GR Energy Shift

$$E_{\text{obs}} = E_{\text{emit}} \sqrt{\frac{1 - r_s/r_{\text{emit}}}{1 - r_s/r_{\text{obs}}}}$$

9. Approximations

Adiabatic evolution, radial trajectory, no spin effects

LSC 4.2 ULTRA – QUE Branch

LSC 4.2 ULTRA – QUE (Quantum Branch)

This model replaces classical interaction with quantum decoherence effects.

Core Concept:

PBH act as quantum information nodes affecting neutrino phase coherence.

Mechanism:

Neutrino wavefunction interacts with spacetime fluctuations induced by PBH.

Effect:

Loss of coherence modifies oscillation probabilities.

Key Idea:

Interaction is non-local and does not require large mass density.

Prediction:

Irregular neutrino flavor distributions independent of classical matter density.

Conclusion:

PBH regulate neutrinos through quantum information loss.

LSC 4.2 ULTRA – REZ Branch

LSC 4.2 ULTRA – REZ (Resonance Branch)

This model rescues PBH influence via resonance amplification rather than direct gravitational strength.

Core Equation:

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

Assumption:

V_{LSC} is small but tuned to resonance conditions inside the Stricture Zone.

Mechanism:

Even weak PBH gravitational potentials can trigger large oscillation changes if resonance is met.

Prediction:

Energy-dependent anomalies in neutrino flux (TeV–PeV range).

Conclusion:

PBH act as resonance triggers, not energy sources.