Contribution ID: **46** Type: **Talk in a parallel session**

Gravitational Influence on the Quantum Speed Limit in Neutrino-Antineutrino Oscillations

Tuesday, 9 July 2024 17:25 (25 minutes)

We investigate the quantum speed limit (QSL) during the time evolution of neutrinos and antineutrinos under the influence of a gravitational field. We derive an analytical expression for the four-vector gravitational potential in the underlying Hermitian Dirac Hamiltonian using the Boyer-Lindquist coordinates. This gravitational potential leads to an axial vector in the Dirac equation in curved spacetime, contributing to the effective mass matrix of the neutrino-antineutrino systems. Our findings indicate that the gravitational field, depending on its strength, significantly influences the transition probabilities in both one- and two-flavor neutrino-antineutrino oscillations. While the former corresponds to neutrino-antineutrino oscillation, the latter is for flavor oscillations as well. We then apply the expression for transition probabilities between states to analyze the Bures angle, which quantifies the closeness between the initial and final states of the time-evolved flavor state. We use this concept to probe the QSL for the time-continuous evolution of the initial flavor neutrino state. Finally, we discuss the implications of entanglement in neutrino-antineutrino oscillations in the vicinity of a spinning primordial black hole.

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Session Classification: Unveiling neutrino secrets through cosmology: current status and future developments

Track Classification: Neutrinos (NU): Unveiling neutrino secrets through cosmology: current status and future developments