

Widen the Resonance: Probing a New Regime of Neutrino Self-Interactions with Astrophysical Neutrinos

Neutrino self-interactions beyond the standard model have profound implications in astrophysics and cosmology. In this work, we study an uncharted scenario in which one of the three neutrino species has a mass smaller than the temperature of the cosmic neutrino background. This results in a relativistic component that significantly broadens the absorption feature on the astrophysical neutrino spectra, in contrast to the sharply peaked absorption expected in the extensively studied scenarios assuming a fully nonrelativistic cosmic neutrino background. By solving the Boltzmann equations for neutrino absorption and regeneration, we demonstrate that this mechanism provides novel sensitivity to sub-keV mediator masses, well below the traditional $\sim 1\text{--}100$ MeV range.

Future observations of the diffuse supernova neutrino background with Hyper-Kamiokande could probe coupling strengths down to $g \sim 10^{-8}$, surpassing existing constraints by orders of magnitude. These findings open new directions for discoveries and offer crucial insights into the interplay between neutrinos and the dark sector.

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