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Present and future constraints on flavor-dependent long-range interactions of high-energy astrophysical neutrinos

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The discovery of new, flavor-dependent neutrino interactions would provide compelling evidence of physics beyond the Standard Model. We focus on interactions generated by the anomaly-free, gauged, abelian lepton-number symmetries, specifically $L_e - L_\mu$, $L_e - L_\tau$, and $L_\mu - L_\tau$, that introduce a new matter potential sourced by electrons and neutrons, potentially impacting neutrino flavor oscillations. We revisit, revamp, and improve the constraints on these interactions that can be placed via the flavor composition of the diffuse flux of high-energy astrophysical neutrinos, with TeV-PeV energies, i.e., the proportion of ν_e, ν_μ, and ν_τ in the flux. Because we consider mediators of these new interactions to be ultra-light, lighter than 10^{-10} eV, the interaction range is ultra-long, from km to Gpc, allowing vast numbers of electrons and neutrons in celestial bodies and the cosmological matter distribution to contribute to this new potential. We leverage the present-day and future sensitivity of high-energy neutrino telescopes and of oscillation experiments to estimate the constraints that could be placed on the coupling strength of these interactions. We find that, already today, the IceCube neutrino telescope demonstrates potential to constrain flavor-dependent long-range interactions significantly better than existing constraints, motivating further analysis. We also estimate the improvement in the sensitivity due to the next-generation neutrino telescopes such as IceCube-Gen2, Baikal-GVD, KM3NeT, P-ONE,
and TAMBO.

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