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Phasing out of Darkness: From Sterile Neutrino Dark Matter to Neutrino Masses via Time-Dependent Mixing

by F. Goertz, M. Hager, G. Laverda, and J. Rubio

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www.ucm.es/iparcos/

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Abstract

Sterile neutrinos offer a compelling solution to the dual challenges of generating neutrino masses and elucidating the nature of dark matter. Astrophysical X-ray observations impose, however, stringent constraints on the active-sterile mixing required for producing simultaneously the correct left-handed neutrino spectrum and keV-scale right-handed neutrino dark matter within a type-I seesaw framework. In this study we demonstrate how these X-ray constraints can be circumvented through a time-dependent approach, thereby reviving a broad range of active-sterile mixing scenarios. Our minimal model incorporates two right-handed neutrinos, which form a two-component DM candidate, and an auxiliary scalar field that experiences a very late and still ongoing phase transition, leading to the spontaneous breaking of a global U(1)N symmetry. Prior to this phase transition, only the right-handed neutrinos are massive, while the left-handed neutrinos remain massless due to the scalar field's vanishing expectation value. As the phase transition develops, the growing expectation value of the scalar field increases the active-sterile mixing, allowing it to be consistent with astrophysical constraints for keV sterile neutrino DM as well as current measurements of left-handed neutrino masses. The anticipated level of active-sterile mixing today is within the detection capabilities of the forthcoming TRISTAN tritium-beta decay project. Additionally, cosmological surveys such as DESI or EUCLID and supernova neutrino observations can test the prediction of massless left-handed neutrinos prior to the phase transition.

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