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Model-independent Astrophysical Constraints on Leptophilic Dark Matter in the Framework of Tsallis Statistics

We derive model-independent astrophysical constraints on leptophilic dark matter (DM), considering its thermal production in a supernova core and taking into account core temperature fluctuations within the framework of q-deformed Tsallis statistics. In an effective field theory approach, where the DM fermions interact with the Standard Model via dimension-six operators of either scalar-pseudoscalar, vector-axial vector, or tensor-axial tensor type, we obtain lower bounds on the effective cut-off scale Λ from supernova cooling and free-streaming of DM from supernova core, and upper bounds on Λ from thermal relic density considerations, depending on the DM mass and the q-deformation parameter. Using Raffelt's criterion on the energy loss rate from SN1987A, we obtain a lower bound on $\Lambda >= 3$ (12) TeV corresponding to $q = 1.0$ (1.1) and an average supernova core temperature of $T_{\rm SN} = 30$ MeV. From the optical depth criterion on the free-streaming of DM fermions from the outer 10\% of the SN1987A core, we obtain a weaker lower bound on $\Lambda >= 1$ TeV. Both cooling and free-streaming bounds are insensitive to the DM mass m_χ for $m_\chi <= T_{\rm SN}$, whereas for $m_\chi \gg T_{\rm SN}$, the bounds weaken significantly due to the Boltzmann-suppression of the DM number density. We also calculate the thermal relic density of the DM particles in this setup and find that it imposes an upper bound on Λ^4/m_χ^2, which is in conflict with the supernova cooling/free-streaming bounds for a wide range of DM mass. From this, we obtain a model-independent lower bound of $m_\chi >=$ 200 MeV-1 GeV on the leptophilic DM, which only depends on the operator type and q-deformation parameter.
Keywords: Dark Matter, Supernova, Effective Field Theory, Tsallis Statistics.

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