PROCEEDINGS OF SCIENCE

Energy-dependent boosted DM from DSNB

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The diffuse supernova neutrino background (DSNB) offers a unique way to probe MeV-scale dark matter (DM) by boosting DM particles in the Milky Way to detectable energies. Considering minimal models of DM-electron and DM-neutrino interactions, we study energy-dependent scattering cross sections and analyse DM attenuation due to electron scattering in the Earth. New bounds on these interactions are set using electron recoil data from XENONnT. We show that energy-dependent cross sections can significantly alter previous constraints based on energy independent cross sections, highlighting the need for studies on a model-by-model basis.

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1. Introduction

Traditionally, dark matter (DM) is searched for in experiments that seek to detect the energy deposition from a nuclear recoil upon interaction with the ambient DM from the Galactic halo. However, this search strategy fails in the sub-GeV low-mass regime, where the small energy deposition from nuclear or electron recoils is difficult to detect.

In recent years, the concept of boosted DM promised as an alternative to get around this kinematic suppression. First proposed in [1] for boosting light DM on energetic hadronic cosmic rays, it has since been refined and extended to a wide range of mechanisms for boosting DM. Boosting of light DM on the DSNB was first discussed in [2]. We revisit the upscattering of DM by neutrinos from the DSNB and improve on previous studies. This includes electron recoil signals in XENONnT, consideration of the overburden of the detector, and realistic models of the DM-neutrino and DM-electron interaction respectively. We also perform a detailed analysis of the model dependence of the results and the general role of energy-dependent interactions in searches for boosted DM [3].

2. Boosting DM with the DSNB

Neutrinos from the DSNB can scatter off ambient DM particles, thereby transferring a part of their energy to boost a small fraction of the total DM to high energies. Boosted DM particles may have kinetic energies that significantly exceed the energy from motion in the Galactic halo, which is usually the limiting factor for direct detection of MeV-scale DM candidates.

For realistic signal predictions, scatterings of boosted DM with electrons in the atmosphere and the Earth need to be considered. This leads to energy loss and attenuation of the BDM flux at detector site. We use the commonly employed energy loss equation $\frac{dT_\chi}{dx}(x) = -\sum_i n_i(x) \int_0^{T_i^{\max}} dT_i\, T_i \frac{d\sigma_{i\chi}}{dT_i}$, although it should be emphasised that this approach is limited and cannot replace full Monte Carlo simulations. We find that the often used approximate solutions are not valid in the case of boosted DM scattering on electrons – this necessitates a full numerical solution. Limits of energy loss equation approach, as well as a comparison and detailed discussion of numerical and analytic solutions can be found in [3, 4].

To explicitly study the role of energy-dependence, we consider boosting, attenuation and subsequent detection for a simple leptophilic massive vector toy model coupling universally to all leptons and to a MeV-scale fermionic DM candidate. We also compute limits for an energy-independent cross section $\sigma_{\nu\chi} = \sigma_{e\chi}$, which allows us to compare with previous results and infer the role of energy dependence. Limits for the constant cross section case and for different masses of the vector mediator are presented in Fig. 1. The limits exhibited a strong dependence on the model and mediator mass. This feature promises to be generic for studies of boosted DM, as boosting leads to large enough momentum transfers in interactions to resolve the underlying interaction, thus leading to a pronounced model dependence.

3. Conclusions

Non-standard interactions of neutrinos remain popular options for physics beyond the Standard Model, and in particular, interactions of DM with neutrinos have attracted increasing interest. These

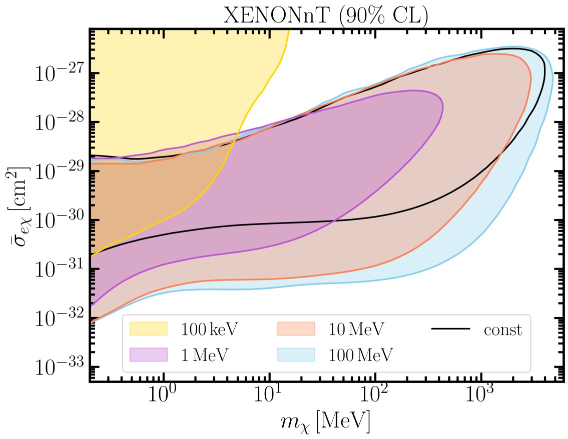

Figure 1: Limits on the parameter space of boosted DM from the DSNB. We compare different mediator masses for the leptophilic vector mediated toy model with the constant cross section reference case by mapping the former on the commonly used effective cross section $\bar{\sigma}_{e\chi} = g^4 \mu_{e\chi}^2 / \pi \left(\alpha m_e{}^2 + m_{\text{med}}^2 \right)^2$. The result shows a strong model-dependence, highlighting the need for case-by-case studies to obtain reliable limits on boosted DM.

interactions arise naturally in models of leptophilic DM, where the upscattering of DM by energetic neutrinos from the DSNB provides a unique window to probe such interactions jointly for the e-DM and ν-DM channels, which is difficult to achieve in other experimental configurations.

The demonstrated importance of the attenuation due to detector overburden, and in particular the explicit model dependence, has previously been underestimated. In fact, the energy dependence of such interactions can often be resolved in boosting DM. This means that viable studies of boosted DM need to be designed on a case-by-case basis, but also that boosted DM offers unique opportunities to resolve new physics involved and to discriminate between models. With the expected discovery of the DSNB in this decade, it is timely to determine the potential of the DSNB as a probe of new physics.

References

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