

Energy-dependent boosted Dark Matter from Diffuse Supernova Neutrino Background

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New Physics Directions in the LHC era and beyond



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Kicking Dark Matter with supernova neutrinos

Idea: Use the DSNB to boost
light Dark Matter so we can find
it in direct detection!

DSNB boosted DM
gives complimentary
constraints &
is a lab for ν -DM
interaction

Now with full **energy-
dependence** &
improved **attenuation**

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detection experiments and for galactic DM in direct detection searches.

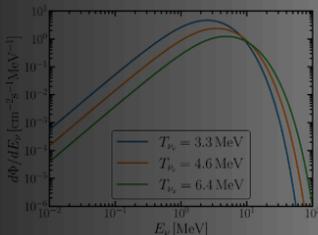
- Solution: Regain sensitivity by boosting DM to energies $T_{DM} \gg m_{DM} v_{halo}^2$ and thus overcome the loss of sensitivity at the low mass frontier.
- How? Upscattering by ambient energetic particles. We already assume some interaction for direct detection searches. Is there also a suitable source of particles with the right interaction to produce a significant flux of BDM?
- A promising source is the **Diffuse Supernova Neutrino Background (DSNB)**.

- this decade.
- Interactions with neutral leptons arise naturally in the neutrino interaction, which is a popular target for direct detection.
 - Has been studied before [1, 2] but incomplete picture. Some models are overlooked or not satisfyingly addressed, which we aim to fix.

1. What is the role of energy-dependent cross-sections?
2. What is the effect of attenuation of the BDM?

From DSNB to direct detection of BDM

- The rate of core-collapse-supernovae (CCSNe) in the observable universe is of the order of one per second, with about 99% of the energy being carried away by neutrinos.
- Accumulation of past CCSNe forms the DSNB.



Rate of CCSN per comoving volume

$$\frac{d\Phi_{\nu\alpha}}{dE_\nu} = \int_0^{z_{\max}} dz \frac{R_{\text{CCSN}}(z)}{H(z)} F_{\nu\alpha}(E_{\nu\alpha}) \Big|_{E_\nu = E_\nu^s(1+z)}$$

Individual CCSN spectra corrected for redshift

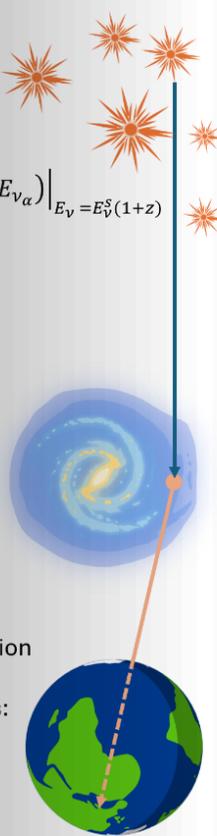
- DSNB neutrinos travel cosmological distances and upscatter ambient DM from the Milky Way halo.
- BDM flux at Earth is rate of DM upscattering along a fixed line of sight (l.o.s.) integrated over all possible l.o.s.:

$$\frac{d\Phi_\chi}{dT_\chi} = \int_\Omega \frac{d\Omega}{4\pi} \int_{\text{l.o.s.}} dl \rho_{\text{MW}}(r(l, \Omega)) \int dE_\nu \frac{1}{m_\chi} \frac{d\sigma_{\nu\chi}}{dT_\chi} \frac{d\Phi_\nu^{\text{DSNB}}}{dE_\nu}$$

- The same interaction used for upscattering and direct detection causes DM particles to lose energy from elastic scattering in the Earth. We model this by calculating the mean energy loss:

$$\frac{dT_\chi}{dz} = -n_e \int_0^{T_\chi^{\max}} \frac{d\sigma_{e\chi}}{dT_e} T_e dT_e$$

- To improve on previous estimates, we solve the energy loss equation numerically.

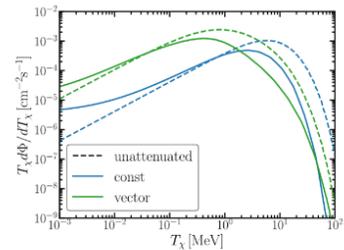
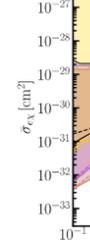


Results

Including energy-dependent interactions and improved DM profiles results drastically! We highlight this for an interaction with a scalar mediator arising from

$$\mathcal{L} \supset g_e \bar{e} \gamma^\mu e Z'_\mu + g_\nu \bar{\nu} \gamma^\mu \nu Z'_\mu$$

and also show an equivalent constant cross-section

Left: BDM fluxes for benchmark point $\sigma_{e\chi} = 10^{-30} \text{ cm}^2$

Right: Constraints cast by XENONnT on parameters of the aforementioned models. Unattenuated results are shown in dashed lines.

What can we learn from these results in regard to direct detection?

1. Energy-dependent cross-sections affect upscattering and direct detection. The flux of BDM and likewise constraints are significantly changed compared to an equivalent constant cross-section.
2. Strong interaction leads to full attenuation of the BDM flux in the detector for many models and a sharp upturn in the flux that can be tested arises for these models. This upturn in flux to smaller energies can enhance constraints on the cross-section.