Neutrinos from captured dark matter annihilation in a galactic population of neutron stars

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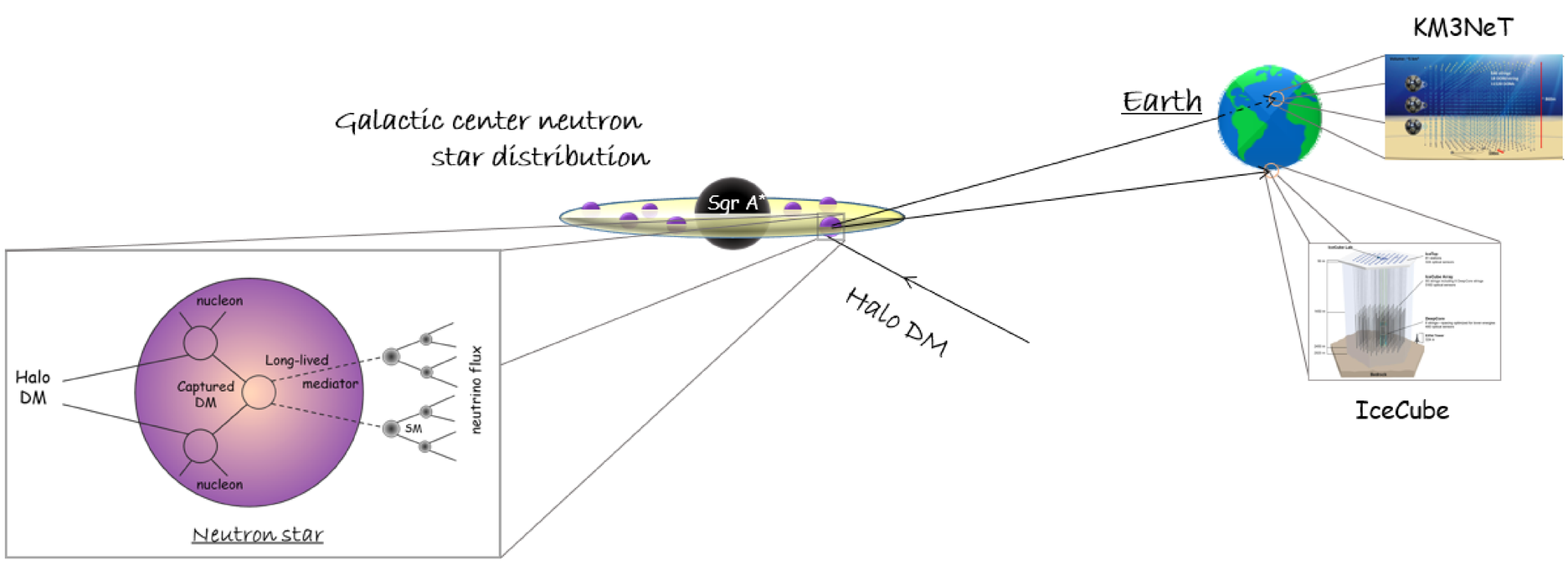
Abstract

Particulate dark matter captured by a population of neutron stars distributed around the galactic center while annihilating through long-lived mediators can give rise to an observable neutrino flux. We examine the prospect of an idealised gigaton detector like IceCube/KM3NeT in probing such scenarios. Within this framework, we report an improved reach in spin-dependent and spin-independent dark matter nucleon cross-section below the current limits for dark matter masses in the TeV-PeV range.

Schematic Representation



Capture Rate

- Within the multi-scatter framework, the capture rate of dark matter within a celestial body is given by

$$C(r) = \sum_N C_N = \sum_N \underbrace{\pi R^2}_{\text{Area of the object}} \underbrace{p_N}_{\text{Probability of N scattering}} \underbrace{n_\chi(r) \int du \frac{f(u)}{u}(u^2 + v_{\rm esc}^2)}_{\text{DM inward flux}} \underbrace{g_N}_{\text{Capture probability after N scattering}}$$

- The generalization of the DM capture due to a population of NS is straightforward and can be written as

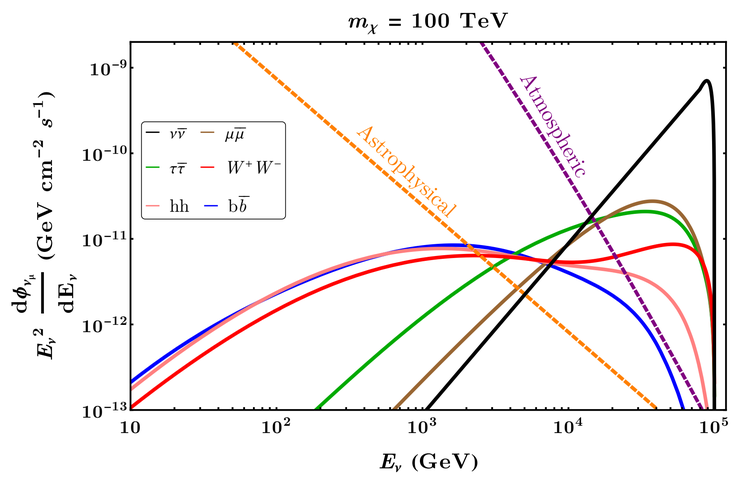
$$C_{\rm tot} = 4\pi \int r^2 \underbrace{n_{\rm NS}(r)}_{\text{Neutron star density}} \underbrace{C(r)}_{\text{Capture rate of DM in a single neutron star}} dr$$

We have considered the galactic center distribution of neutron stars.

Neutrino Flux

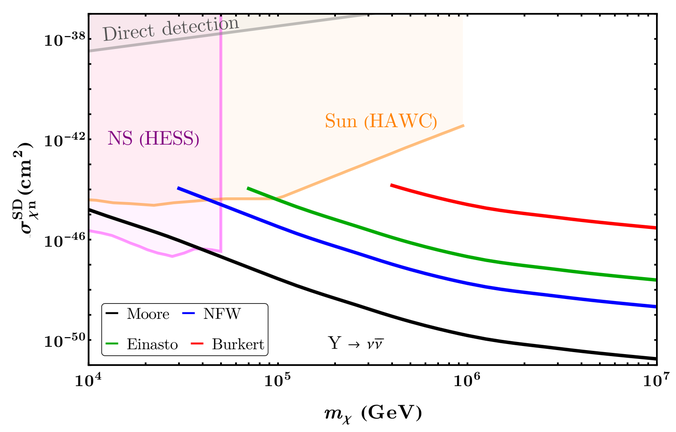
- The differential muon neutrino flux reaching Earth from the captured DM annihilation through the long-lived mediator is given by

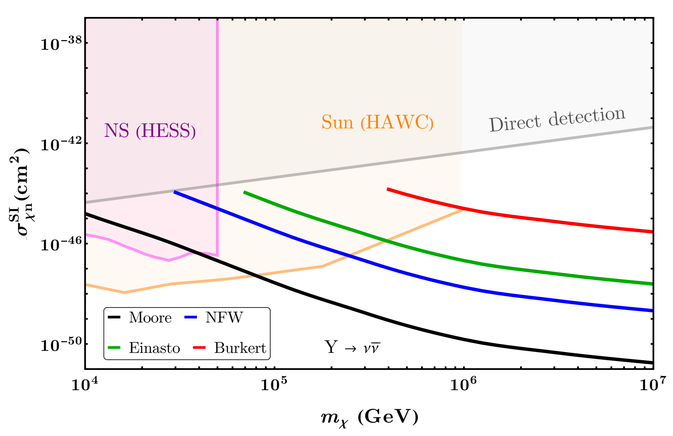
$$E_\nu^2 \frac{d\phi_\nu}{dE_\nu} = \underbrace{\frac{\Gamma_{\rm ann}}{4\pi D^2}}_{\substack{\text{Annihilation rate} \\ \text{Galactic center distance}}} \underbrace{E_\nu^2 \frac{dN_\nu}{dE_\nu}}_{\text{Neutrino spectrum}} \underbrace{Br\left(Y \to SMS\bar{M}\right)}_{\text{Branching ratio}} \times \underbrace{\left(e^{-\frac{R}{\eta c\tau}} - e^{-\frac{D}{\eta c\tau}}\right)}_{\text{Survival probability}}$$



- Dominant backgrounds - Atmospheric and Astrophysical neutrinos
- The limits on DM-nucleon scattering cross-section have been obtained by equating the signal events with the background events to remain conservative.

Results





Conclusions

- In this work, we have analyzed neutrino signals from DM captured in the galactic center distribution of neutron stars. Within this framework, we can probe DM-nucleon scattering cross-section orders of magnitude below the existing limits in the TeV-PeV DM mass range.

Reference

D. Bose, T. N. Maity and T. S. Ray, JCAP 05 (2022) 05 001, [arXiv:2108.12420]