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

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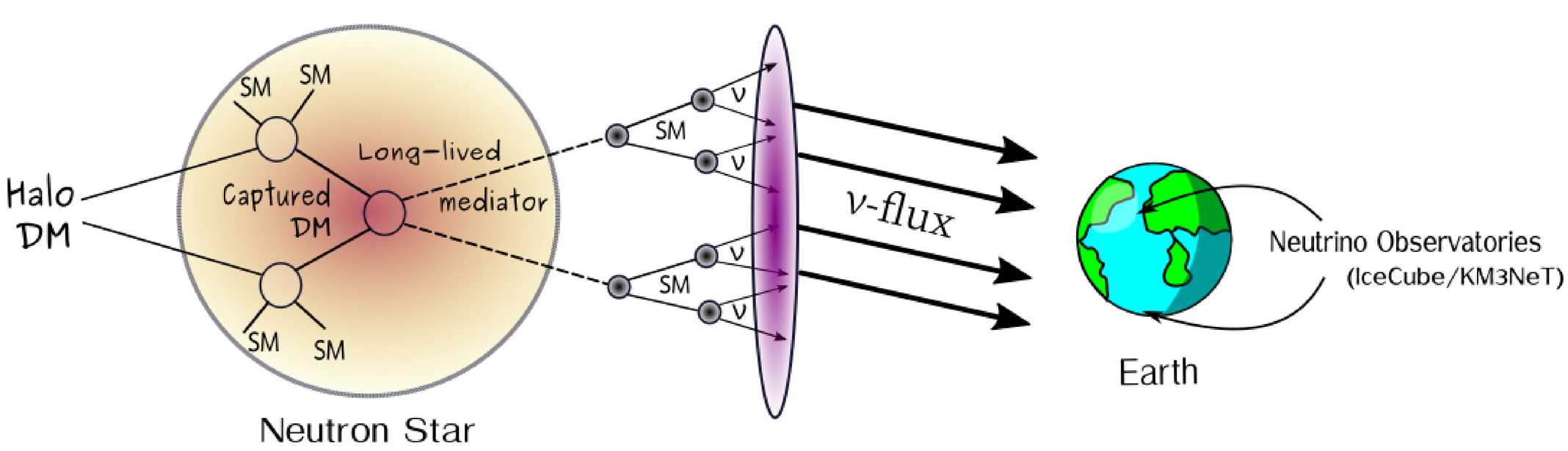
Abstract

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



Motivation

- Can we go beyond the reach of current and upcoming dark matter (DM) detectors ?

– As the astrophysical bodies host standard model (SM) particles at extreme scenarios, we can use these natural laboratories to probe non gravitational interactions of DM. Due to high density, neutron stars are ideal candidates to probe very low DM-nucleon cross-section through DM capture. Looking for the neutrino signals from the captured DM in a population of neutron stars can be very interesting to hunt down high mass DM particles.

Capture Rate

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

$$C = \sum_N C_N = \sum_N \underbrace{\pi R^2}_{\text{area of the object}} \times \overbrace{p_N}^{\text{probability for N scattering}} \times \underbrace{n_\chi \int du \frac{f(u)}{u}(u^2 + v_{esc}^2)}_{\text{DM flux}} \times \overbrace{g_N(u)}^{\text{capture probability after N collisions}}$$

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

$$C_{tot} = 4\pi \int_{r_1}^{r_2} dr\, r^2\, n_{NS}(r)\, C(r)$$

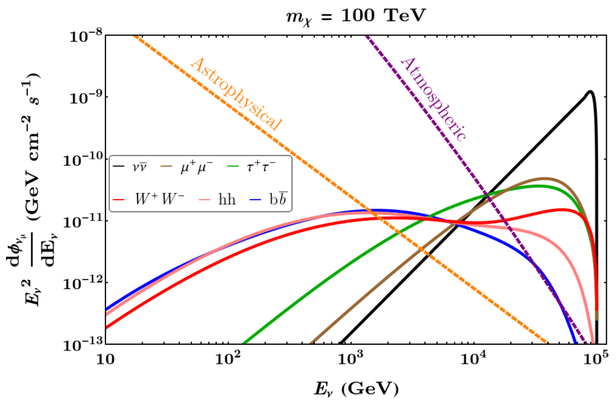
We have considered the galactic center distribution of neutron stars.

Neutrino Flux

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

$$E_\nu^2 \frac{d\phi_{\nu_\mu}}{dE_\nu} = \frac{\Gamma_{\rm ann}}{4\pi R^2} \mathrm{Br}(\mathrm{Y} \to \mathrm{SM}\bar{\mathrm{S}}\bar{\mathrm{M}}) \left(e^{-\frac{R}{\eta c \tau}} - e^{-\frac{D}{\eta c \tau}}\right)$$

- Dominant backgrounds - Atmospheric and Astrophysical neutrinos



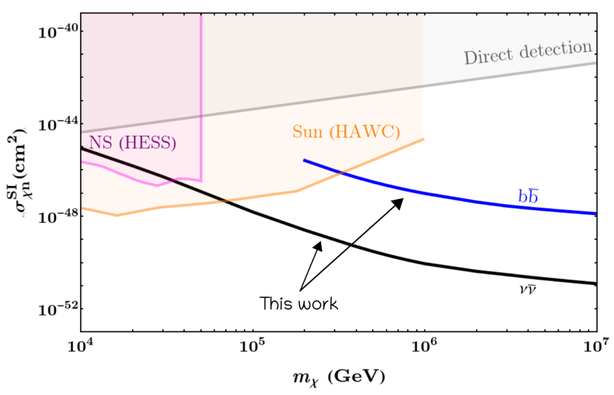
Detector sensitivity

- The annihilated neutrino signal can be detected in ground-based neutrino observatories like IceCube/KM3NeT.

- We have explored muon track-like events produced through charge-current (CC) interactions of muon neutrinos.

- We have put conservative limits by requiring the signal event to be as high as the background events.

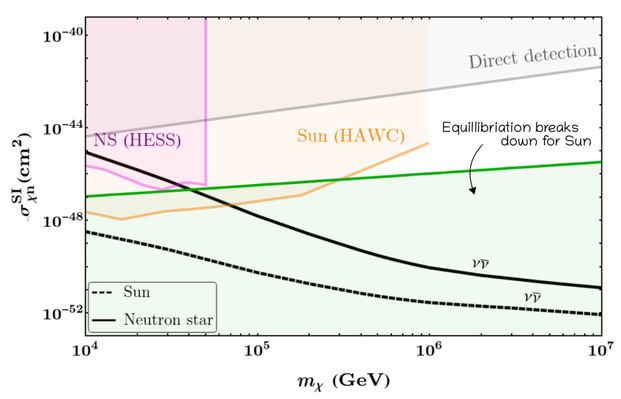
Results



- The spin independent DM-nucleon cross-section bounds are shown here with the black and blue solid lines. Similar bounds are expected for spin-dependent DM-nucleon cross-section.

- **Looking at the neutrino signals from DM captured collectively by the galactic center population of neutron stars, we can probe new regions in the DM parameter space.**

- We have shown an equivalent bound from the captured DM annihilation in the Sun with the black dashed line. The green shaded region depicts the region where the equilibration assumption breaks down for Sun making the solar line much relaxed than that shown here.



Conclusions

- In this work, we have analyzed neutrino signals from DM captured in the galactic center distribution of neutron stars.
- The limits have been obtained by equating the signal events with the background events.
- In this framework, we can probe DM-nucleon scattering cross-section orders of magnitude below the existing limits in the TeV-PeV DM mass range.

References

∗ D. Bose, T. N. Maity, and T. S. Ray, (2021), (arXiv:2108.12420)