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

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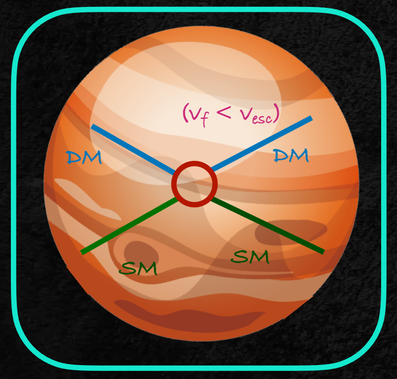
Schematic Approach :

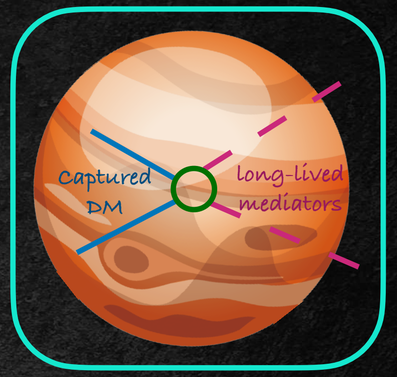
Step 1

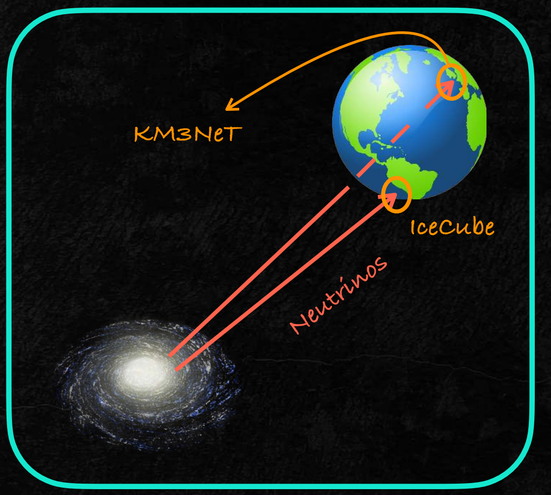
Dark Matter capture in a distribution of neutron stars near the galactic center



Step 2

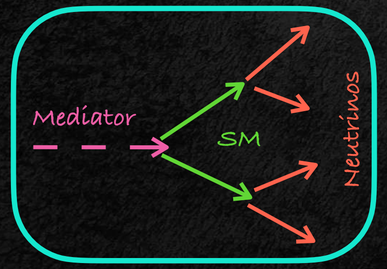
DM annihilation to long-lived mediators that can escape from stellar interior





Step 3

Mediator decay to standard model states that can give rise to neutrino flux



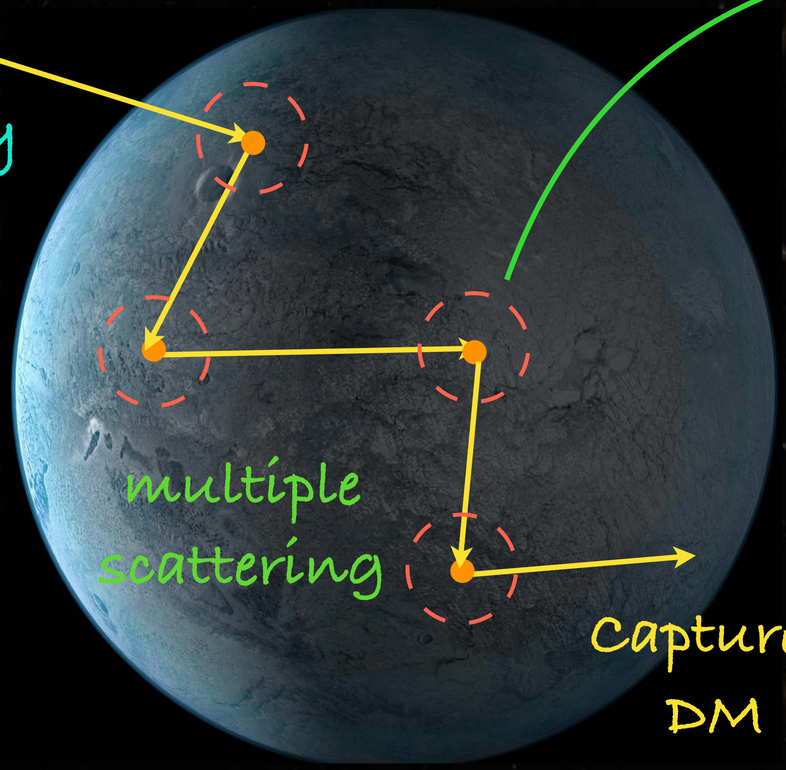
Step 4

Neutrinos can be detected at Earth based neutrino detectors

Capture Mechanism (Step 1)

Halo DM

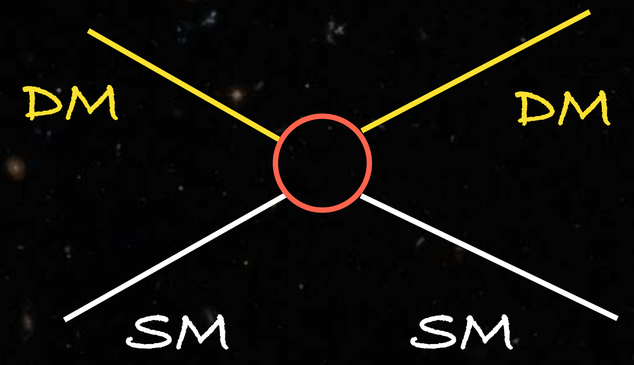
gravitationally focused



multiple scattering

Captured DM

($v_f < v_{esc}$)



2-2 Elastic Scattering

Outcomes :

- Heating of celestial objects
- Annihilation signatures
- Black Hole formation
- Supernova ignition, ...

Capture Rate

Probability of N scattering

DM flux

DM velocity distribution

Capture probability after N scattering

$$C = \sum_N C_N = \sum_N \pi R^2 \, p_N \, n_\chi \int_0^{u_{\rm esc}} du \, \frac{f(u)}{u} \left(u^2 + v_{\rm esc}^2\right) g_N(u)$$

Area of the object

Number density, $n_\chi = \dfrac{\rho_\chi}{m_\chi}$

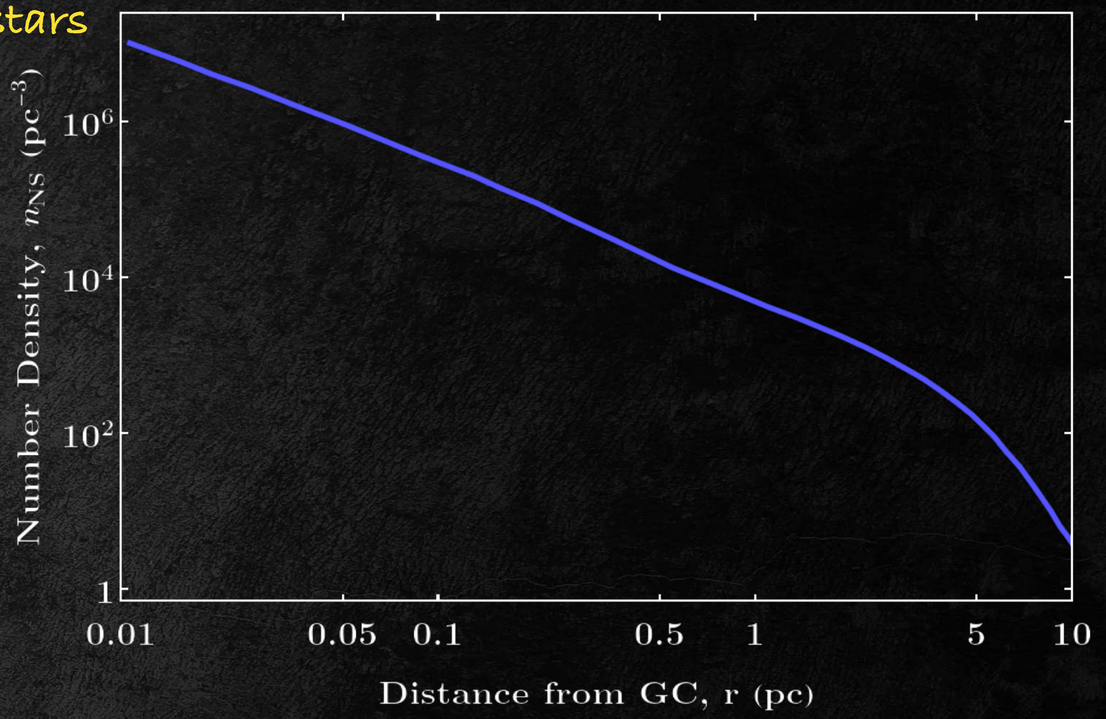
DM energy density at the celestial neighborhood

DM mass

DM Capture by stellar distribution

Number Density of neutron stars

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



Distance from the galactic center

Capture rate by a single neutron star

Depends on DM distributions

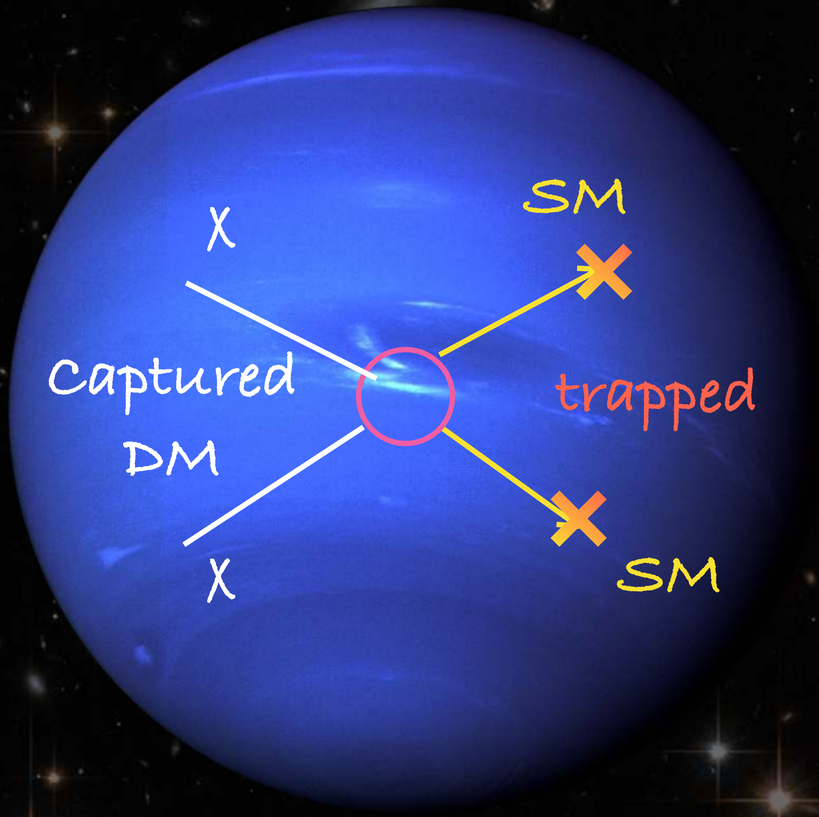
Dense neutron star population at galactic center !!

Capture rate for NS ($m_\chi = 10^3$ GeV)

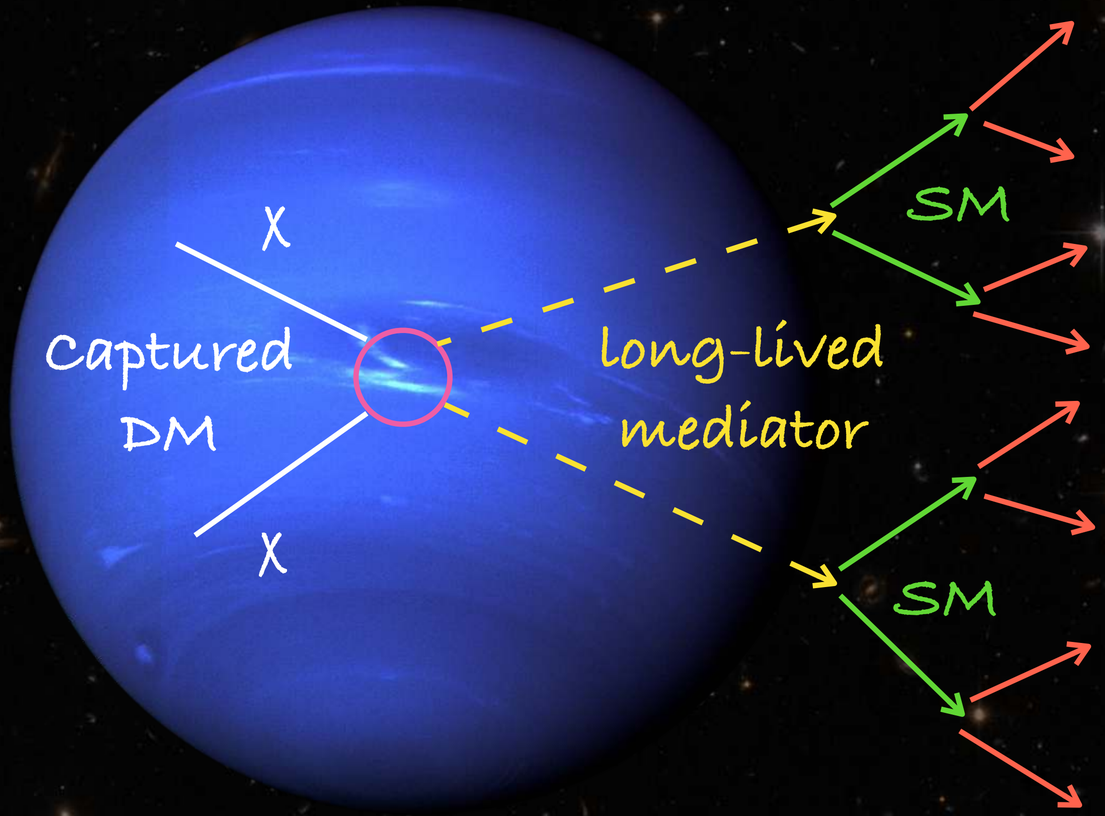
$C_{\rm NS} = 10^{27}$ /s (single) $\longrightarrow$ $C_{\rm tot} = 10^{33}$ /s (distribution)

Large Enhancement !!

Annihilation Signatures (Step 2 and 3)



Heating Signatures



Annihilation Products
through long-lived mediator

Annihilation Spectra

Differential Neutrino Flux :

Neutrino spectra

Branching Ratio

Survival Probability

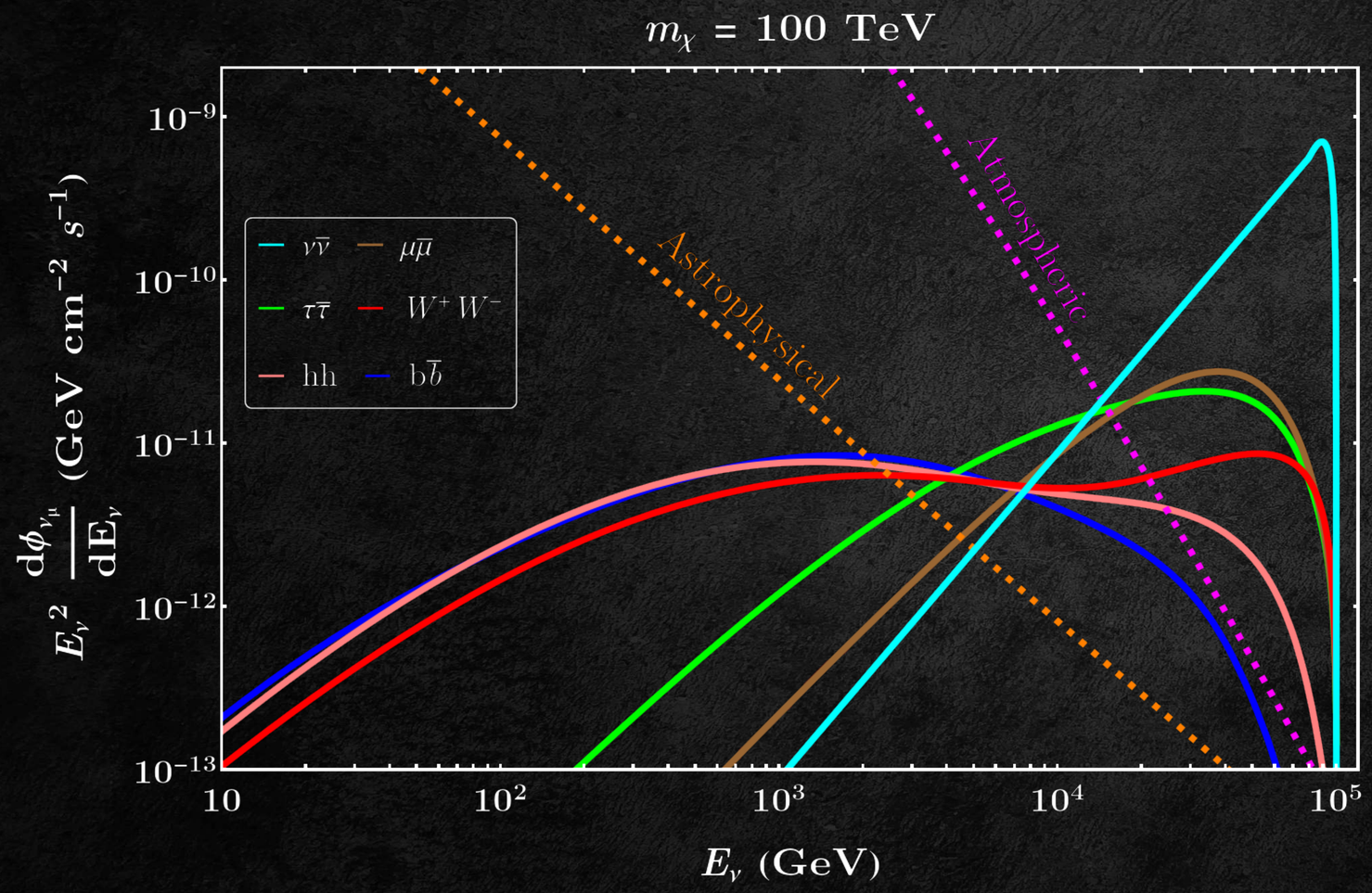
$$E_\nu^2 \frac{d\phi_\nu}{dE_\nu} = \frac{\Gamma_{\rm ann}}{4\pi D^2} E_\nu^2 \frac{dN_\nu}{dE_\nu} \, {\rm Br}\left(Y \to SM\bar{SM}\right) \left(e^{-\frac{R}{\eta c \tau_Y}} - e^{-\frac{D}{\eta c \tau_Y}} \right)$$

Annihilation rate

$$\Gamma_{\rm ann} = \frac{1}{2} C_{\rm ann} N_\chi^2 = \frac{1}{2} C_{\rm tot}$$

Following equilibrium condition

Neutrino Flux



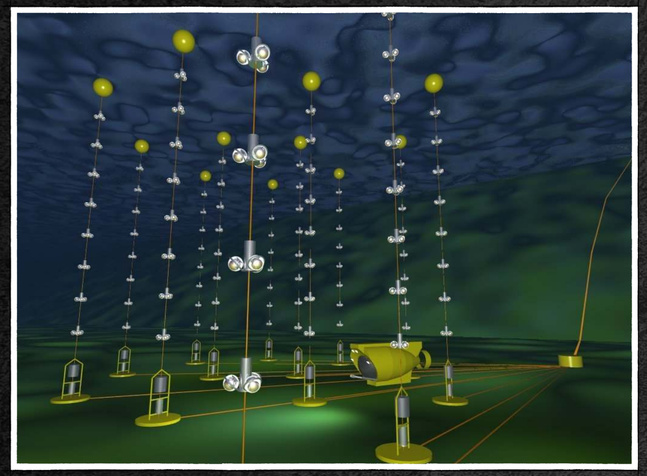
Assumptions:

1. Mediator mass, m_Y = 2 TeV

2. DM-nucleon scattering cross-section 10^{-45} cm^2

3. 100% branching ratio to each channel

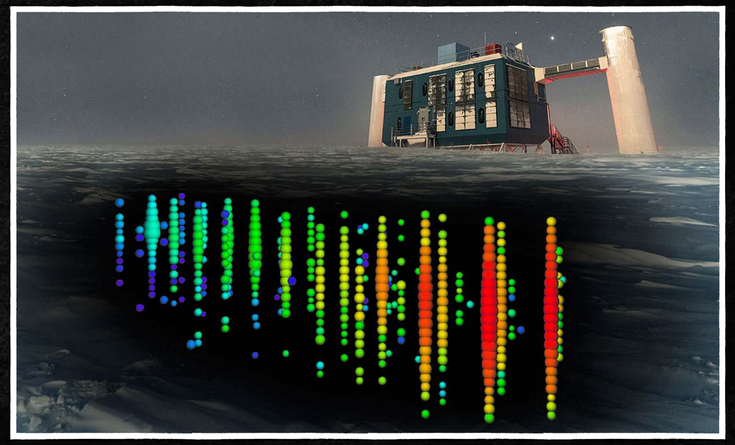
Detection Prospects



KM3NeT

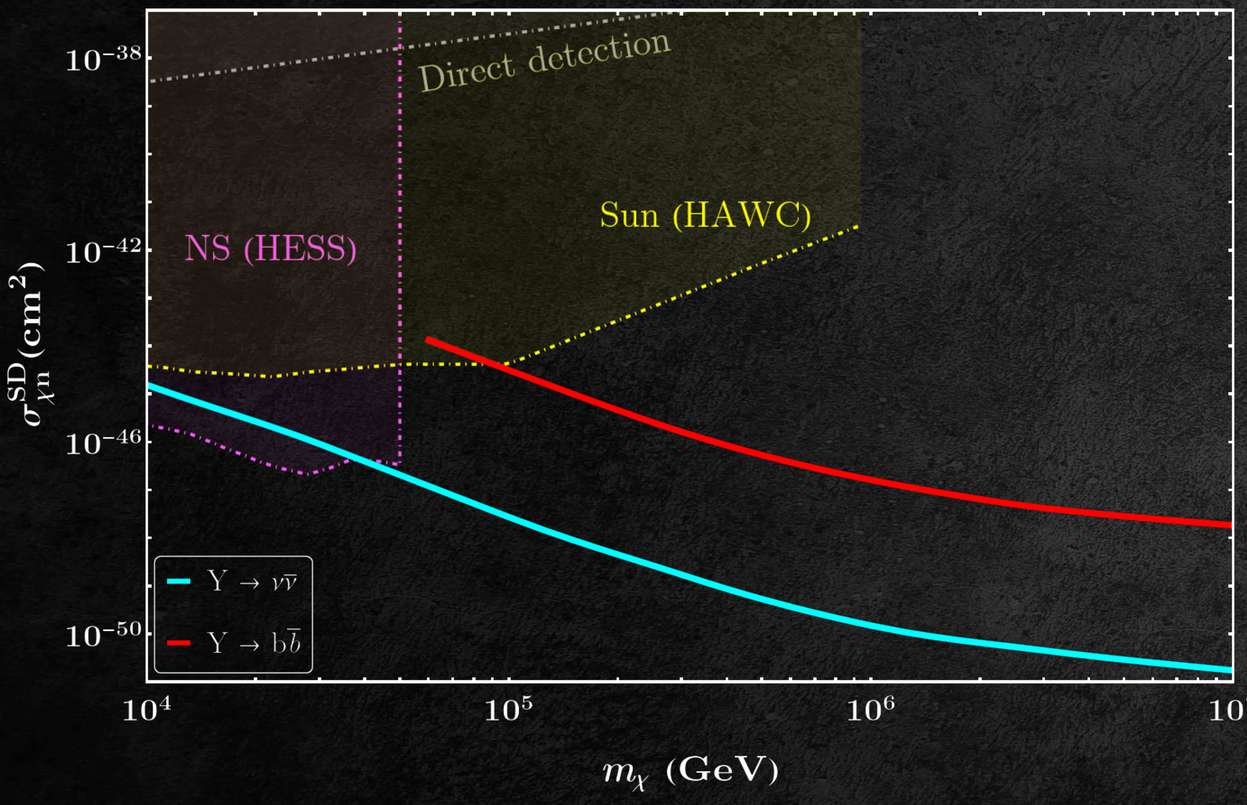
Neutrino

IceCube



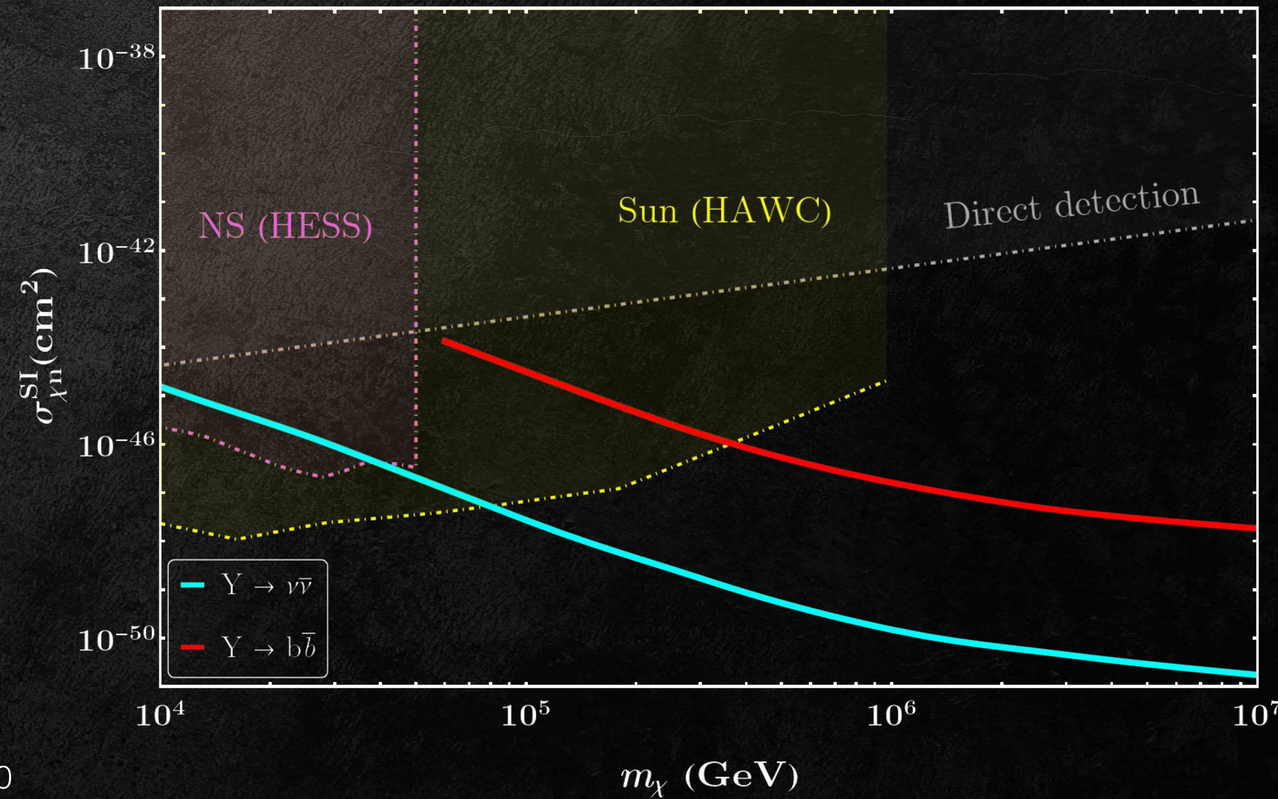
Galactic Center

Results



Spin dependent Limits

Spin independent Limits



Conclusions

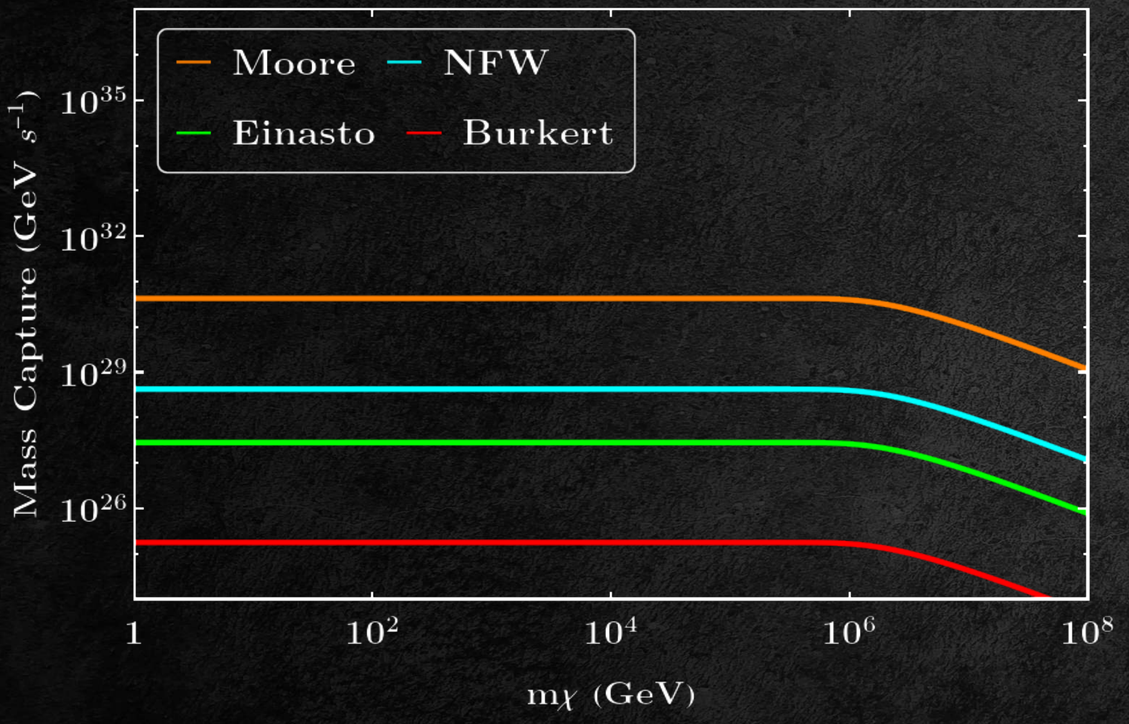
- Interesting to probe non-gravitational interactions between DM and SM by detecting annihilation spectra in Earth based experiments
- We have analyzed neutrino signals from DM captured in the galactic center distribution of neutron stars
- Conservative limits obtained by requiring signal events with the leading background events
- For SD and SI interactions, galactic center neutron star population can give more stringent limits in the TeV-PeV DM mass range

Thank You

Back up Slides

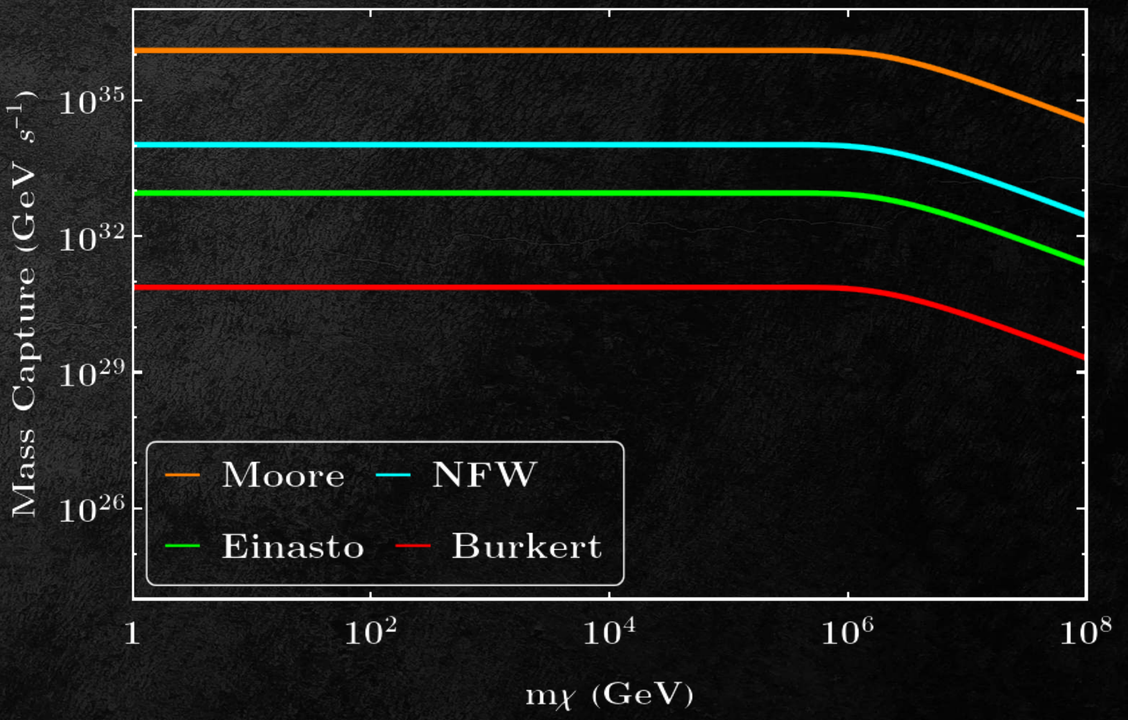
Dark Matter Distributions

Burkert Einasto NFW Moore



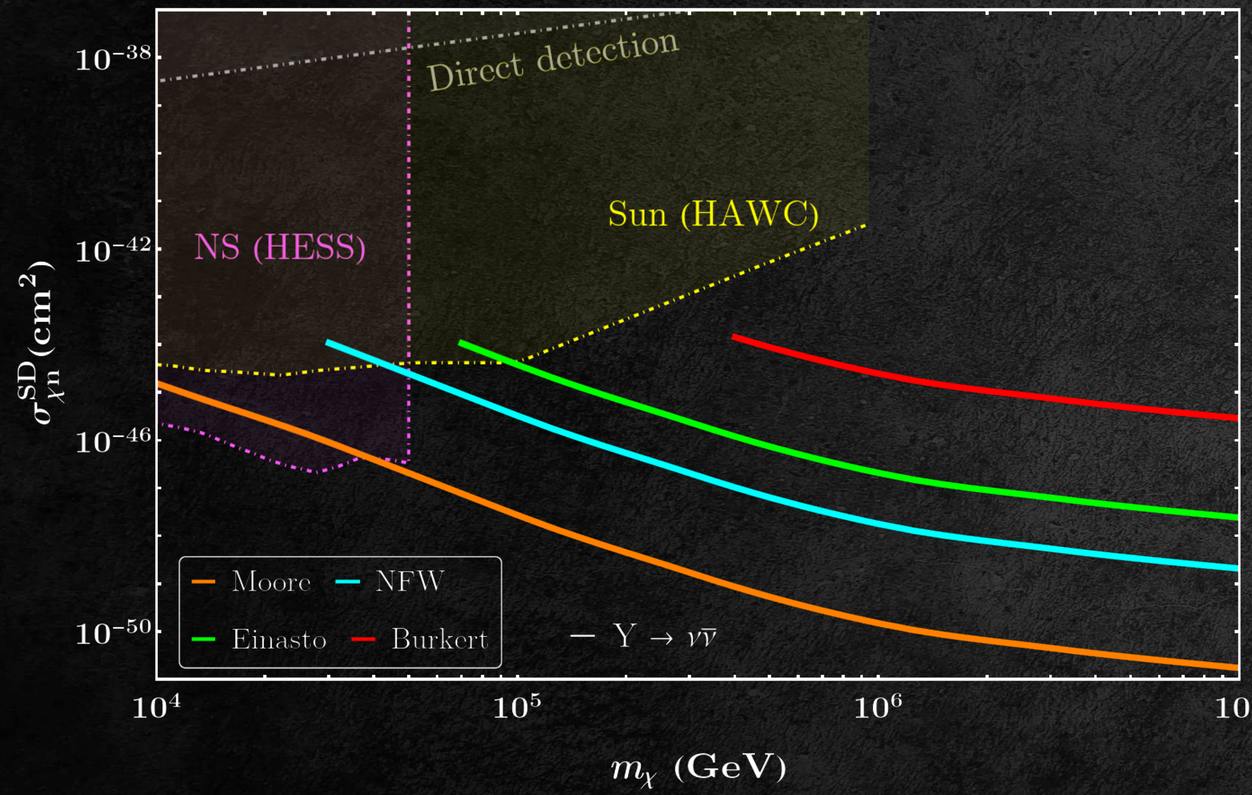
Capture by a single Neutron Star

Capture by collection of Neutron Stars



Huge Enhancement !!

Results for different distributions



Spin dependent Limits

Spin independent Limits