Neutrino Lines from MeV Dark Matter Annihilation and Decay in JUNO

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Abstract and Conclusions

We discuss the discovery potential of JUNO experiment for neutrino lines from MeV dark matter (DM) annihilation and decay in a model independent way. We find that JUNO will be able to give severe constraints on the cross section of DM annihilating into neutrinos and on the lifetime of DM decaying into neutrinos.

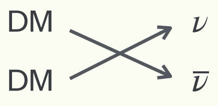
More concretely, with 20 years of data-taking in the fiducial volume 17 kton, the cross section will be constrained smaller than $4 \times 10^{-26}\,\mathrm{cm^2\,sec^{-1}}$ for the mass of a DM particle $15\,\mathrm{MeV} \lesssim m_\chi \lesssim 50\,\mathrm{MeV}$ at 90% C.L., which might be strong enough to test thermal production mechanism of DM particles for such range of DM mass.
The lifetime will be constrained as strong as $1 \times 10^{24}\,\mathrm{sec}$ for the mass of a DM particle $m_\chi \simeq 100\,\mathrm{MeV}$ at 90% C.L..

Introduction

- Dark Matter (DM) is unknown massive substance in our universe. There are still many possibilities for mass and interaction of DM so that detection of them has been strongly desired.
- Unfortunately, current direct and optical DM detections have not succeeded in finding DM signals but discovered strong constraints on DM interaction with standard model particles.
- We discuss DM searches through neutrino detection, which is one of the least constrained channels. It has the following complementary strengths compared to optical and direct detections: (1) less background, (2) electrically neutral so that signals are stable and preserve straightness, (3) detection on the ground has been succeeded and next-generation detectors are designed and under preparation/ construction.
- We focus on JUNO experiment and analyzed the future constraints on DM annihilation and decay into a pair of neutrino and anti-neutrino.

Neutrino lines from DM in Milky Way

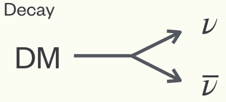
- Annihilation



$$\frac{d\Phi_{\mathrm{anni}}}{dE_\nu} = \Phi_{\mathrm{anni}}\delta\left(E_\nu - m_{\mathrm{DM}}\right)\,, \qquad \Phi_{\mathrm{anni}} = \frac{1}{6}\int \frac{ds\,d\Omega}{4\pi}\langle\sigma_{\mathrm{anni}}v\rangle\left(\frac{\rho_{\mathrm{DM}}}{m_{\mathrm{DM}}}\right)^2$$

$$\frac{d\Phi_{\mathrm{dec}}}{dE_\nu} = \Phi_{\mathrm{dec}}\delta\left(E_\nu - \frac{m_{\mathrm{DM}}}{2}\right)\,, \qquad \Phi_{\mathrm{dec}} = \frac{1}{6}\int \frac{ds\,d\Omega}{4\pi}\,\frac{2}{\tau}\left(\frac{\rho_{\mathrm{DM}}}{m_{\mathrm{DM}}}\right)$$

- Decay



- One to one correspondence (E_ν & m_{DM})
- Φ gets smaller as m_{DM} gets larger

DM profile uncertainty

- Annihilation

$$\mathscr{J} = \int ds\,d\Omega\,\rho_{\mathrm{DM}}^2$$

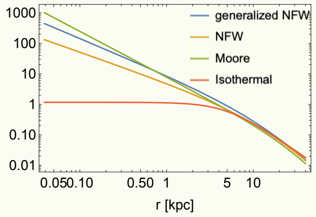
- Decay

$$\mathscr{D} = \int ds\,d\Omega\,\rho_{\mathrm{DM}}$$

	$\mathscr{J}$	$\mathscr{D}$
Generalized NFW	2.3	2.5
NFW	0.88	1.9
Moore	2.7	2.5
Isothermal	0.53	1.9

$\mathscr{J}\,[10^{23}\,\mathrm{GeV^2cm^{-5}}]$, $\mathscr{D}\,[10^{23}\,\mathrm{GeVcm^{-2}}]$

Factor 4 of uncertainty in annihilation



Detection principle

JUNO expriment : Future Neutrino detector with large volume (20 kton) and high energy resolution (3% at 1 MeV)

	KamLAND	Super Kamiokande	JUNO
Detection	liquid scintillator	Water Cherenkov	liquid scintillator
Volume	$\simeq 1$ kton	$\simeq 22.5$ kton	17 kton
Resolution	6 % at 1 MeV	$\simeq 40$ % at 1 MeV [Palomares-Ruiz et al. [0710.5420]]	3 % at 1 MeV

Detection channel

Inversed beta decay ($\overline{\nu_e} + p \rightarrow e^+ + n$)

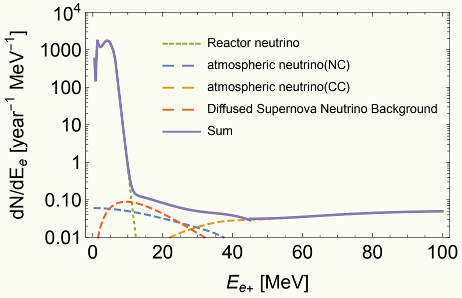
- Scatter with free proton
- Small smearing effect : $\Delta E_{e^+} \equiv E_{\max} - E_{\min} \sim 5\,\mathrm{MeV}\left(\frac{E_\nu}{50\,\mathrm{MeV}}\right)^2$

→ Help to distinguish neutrino lines from background

Background

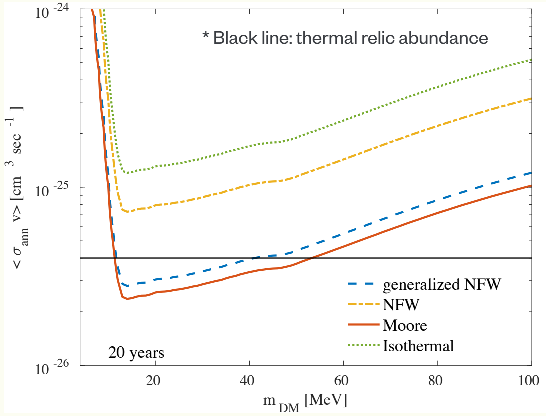
$$\frac{dN}{dE_{e^+}} = \epsilon N_{\mathrm{t}}T\int \frac{d\sigma}{dE}(E_{e^+}, E_\nu)\frac{d\Phi}{dE_\nu}dE_\nu$$

- $\epsilon = 0.6$: detector efficiency
- $N_{\mathrm{t}} = 1.21 \times 10^{33}$: number of targets
- T : number of years of data-taking



Results

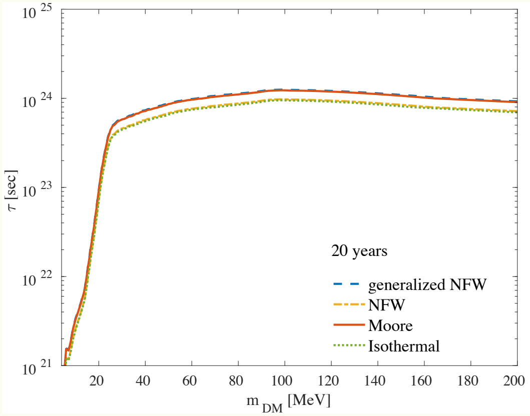
Annihilation cross section (20years, 90% C.L.)



- JUNO may test the thermal relic abundance in $10\,\mathrm{MeV} \leq m_{\mathrm{DM}} \leq 60\,\mathrm{MeV}$
- Factor 5 of uncertainty due to DM profile
- $\Phi_{\mathrm{anni}} \propto m_{\mathrm{DM}}^{-2}$: weaker constraint in the higher energy

...Best constraint in $E_\nu \simeq 10\,\mathrm{MeV}$ where reactor neutrino suppressed

Lifetime (20years, 90% C.L.)



- $\tau \simeq 1 \times 10^{24}\,\mathrm{sec}$ in $30\,\mathrm{MeV} \leq m_{\mathrm{DM}} \leq 200\,\mathrm{MeV}$
- Factor 2 of uncertainty due to DM profile
- $\Phi_{\mathrm{dec}} \propto m_{\mathrm{DM}}^{-1}$: weaker constraint in the higher energy

... Compared to annihilation, weakening effect is little

... Best constraint in $E_\nu \simeq 50\,\mathrm{MeV}$ where BG gets its minimum