

Neutrino portals to sub-GeV dark matter: some new additions

[Based on Phys. Rev. D 111 (2025)]

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Dark Matter (DM)

- Universe's constituents

* Dark Energy (Λ) ~ 71%

* Dark Matter ~ 24%

* Visible Matter ~ 5%

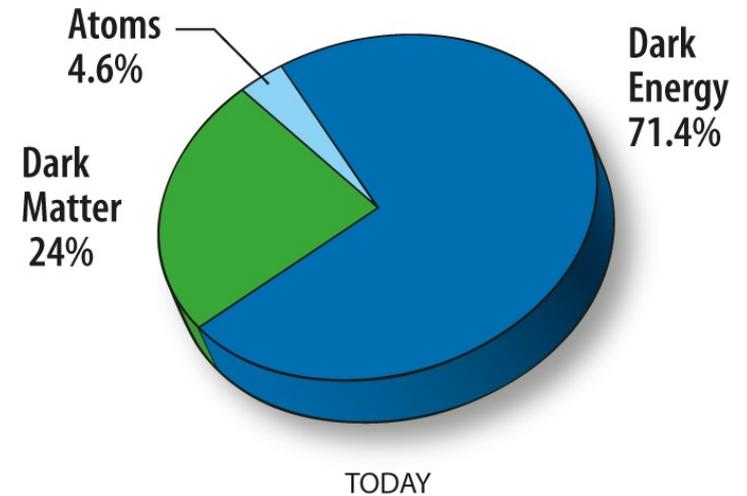
- What we know about Dark Matter?

* Matter-like pressure-less objects

* Non-luminous \rightarrow No electromagnetic and strong interactions

* Weakly-interacting

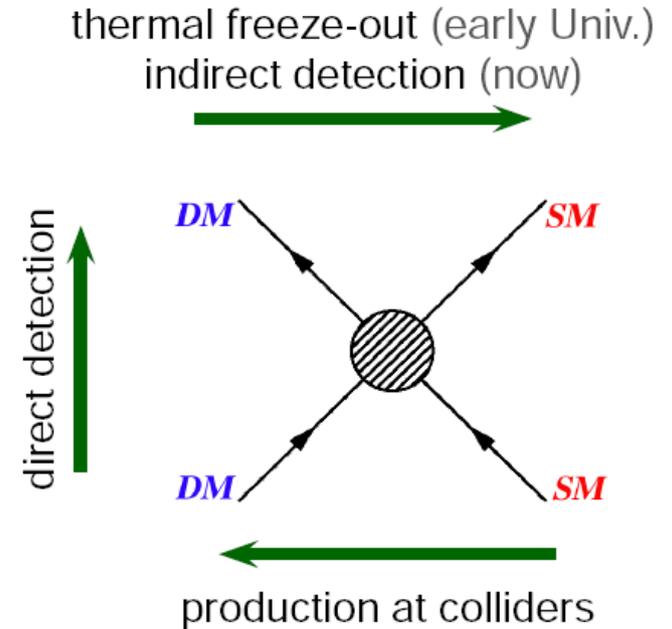
* May be an elementary particle (an interesting possibility)...



Thermal DM

How was DM abundance set in the Early Universe?

- * DM was in thermal equilibrium with the SM plasma
- * When DM interaction rate falls below Hubble rate (H)
 - ➡ DM Freeze-out ➡ DM abundance is set
- * Simplest situation is $2 \rightarrow 2$ annihilations
 - ➡ *Weakly Interacting Massive Particles (WIMPs)*
- * Same interaction that dictates DM abundance can be responsible for its detection
- * Unfortunately, no conclusive evidence of thermal DM is obtained yet



**Thermal WIMPs
(10 MeV–100 TeV)**

Thermal DM

- * Indirect searches put very strong constraints
- * Specifically,
 - BBN: WIMPs allowed for $m_\chi > O(10 \text{ MeV})$ [JCAP 01 (2020) 004]
 - CMB: Rules out WIMPs for $m_\chi < O(5 \text{ GeV})$ [PRD 98, 023016 (2018)]
 - Fermi-LAT & AMS-02: Strong constraints for $m_\chi = 5 \text{ GeV} - 10 \text{ TeV}$
- * But CMB constraints are applicable to $\chi\chi \rightarrow \text{SM SM}$ ($\text{SM} \neq \nu$)
- * WIMPs with $O(10 \text{ MeV}) < m_\chi < O(5 \text{ GeV})$ is allowed only if $\chi\chi \rightarrow \nu\nu$
 - ➡ Neutrino-portal sub-GeV WIMPs

Neutrino-Portal WIMPs

How to couple DM to SM neutrinos?

* SM neutrinos (ν) are part of $SU(2)_L$ Lepton doublet: $L = (\nu, l)$, Hypercharge $Y = -1/2$

* Possible interaction structures:

- χ is $SU(2)_L$ singlet, $U(1)_Y$ singlet: $\chi L \Phi^\dagger$, Φ $SU(2)_L$ doublet, Hypercharge $Y = -1/2$

[JHEP 03 (2023) 010]

- χ is neutral component of $SU(2)_L$ doublet, $U(1)_Y$ charge $1/2$: $\chi L \Phi^\dagger$, Φ $SU(2)_L$ singlet, Hypercharge $Y = 0$

[Phys. Rev. D 109, 075007]

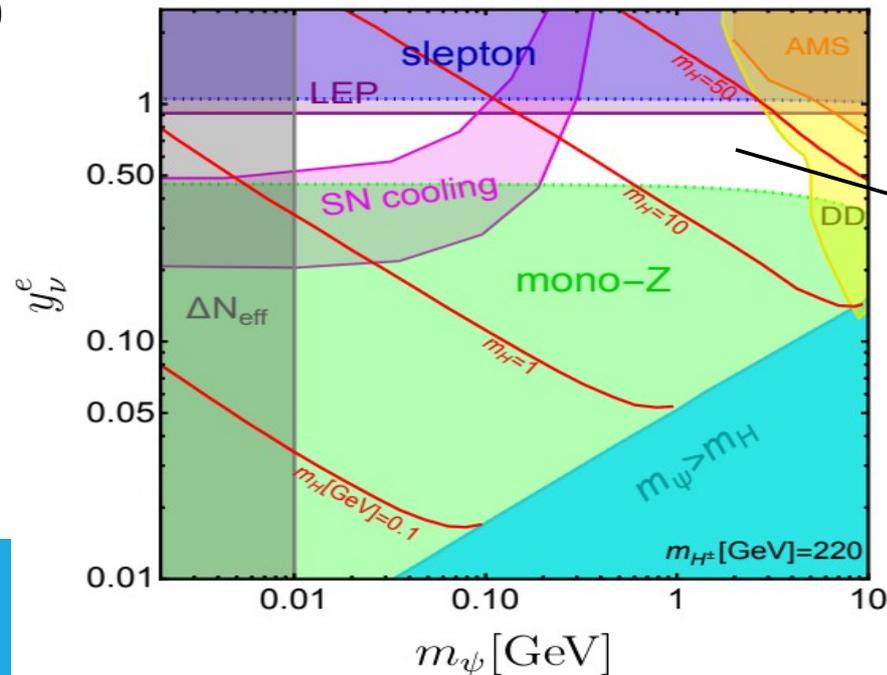


Fig courtesy: JHEP 03 (2023) 010

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- χ is $SU(2)_L$ singlet, $U(1)_Y$ singlet: $NLH + \chi N \Phi$ ($\chi \chi \Phi + N N \Phi$) [Phys. Rev. D 82, 123529 (2010)]

* N : SM singlet right-handed sterile state

* Φ : SM singlet, same charge as DM stabilising charge (Mediator state)

* H : SM higgs doublet

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Neutrino-portal

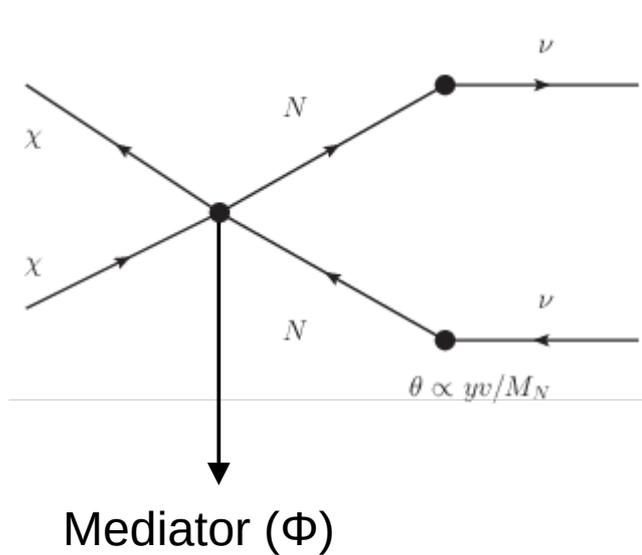
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Neutrino-Portal WIMPs



Characteristics of neutrino-portal WIMPs

- DM annihilation to neutrinos depends on θ^2
- In canonical see-saw models θ is dictated by neutrino mass m_ν : $\theta \sim m_\nu/M_N$
- *Linear/Inverse see-saw* framework provides freedom to choose large θ satisfying $m_\nu \sim 0.01$ eV

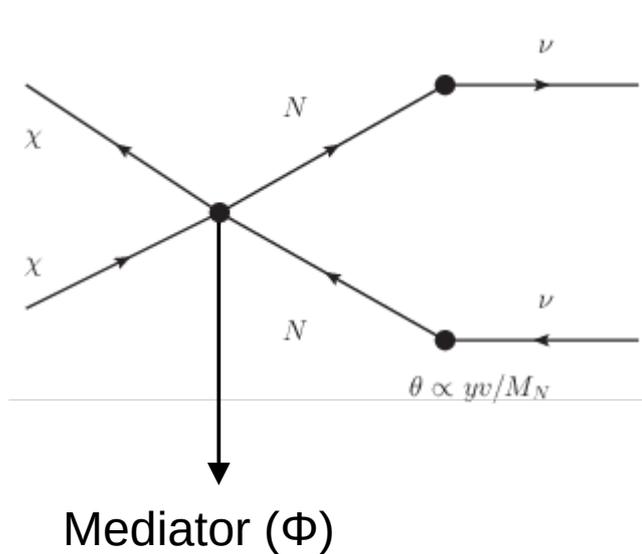
[PRD 97, 075016 (2018), EPJC 79, 555 (2019)]

$$-\mathcal{L}_\nu = m_N \overline{S}_R^c N_R + y_\nu \overline{l}_L \tilde{H} N_R + \text{H. c.},$$

Mixes with ν

Does not mix with ν

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Detection of neutrino-portal WIMPs

- Indirect search observations: Super-K, IceCube, ANTARES, Hyper-K, JUNO
- Only possible if $\chi\chi \rightarrow \nu\nu$ has a s-wave piece

Neutrino-Portal WIMPs

Status of neutrino-portal WIMPs with s-wave annihilation (till late 2024)

Dark Matter	Channel type	Mediator type	Reference
Fermion	s-channel	Pseudoscalar	X
Fermion	t-channel	Scalar	EPJC 79, 555 (2019), JHEP 08 (2022) 085, PRD 97, 075016 (2018), JHEP 04 (2015) 170, JHEP 02 (2021) 231, JHEP 03 (2023) 010
Fermion	s-channel	Vector	EPJC 79, 555 (2019), JHEP 08 (2022) 085, arXiv:1411.1071
Scalar	t-channel	Fermion	EPJC 79, 555 (2019), PRD 97, 075016 (2018), JHEP 04 (2015) 170, JHEP 02 (2021) 231, JHEP 03 (2023) 010
Scalar	s-channel	Scalar	X
Scalar	s-channel	Vector	Not possible (p-wave suppressed)

Neutrino-Portal WIMPs

Status of neutrino-portal WIMPs with s-wave annihilation (since early 2025)

Dark Matter	Channel type	Mediator type	Reference
Fermion	s-channel	Pseudoscalar	<i>PRD III (2025)</i> <i>N F Bell, M J Dolan, AG,</i> <i>M Virgito</i>
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Neutrino-Portal WIMPs: Scalar DM with scalar Mediator

Particle content :

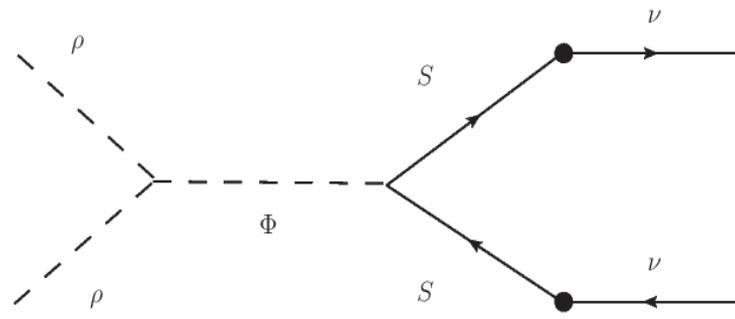
	ρ (DM)	Φ (Mediator)	N_R	S_R
Global $U(1)_L$	+1	+2	+1	-1

Lagrangian :

$$\mathcal{L} = \mathcal{L}_\nu + \left(\frac{\lambda_{S\phi}}{2} \bar{S}_R^c S_R \Phi + \frac{\lambda_{N\phi}}{2} \bar{N}_R N_R^c \Phi + h.c. \right) + V(H, \Phi, \rho)$$

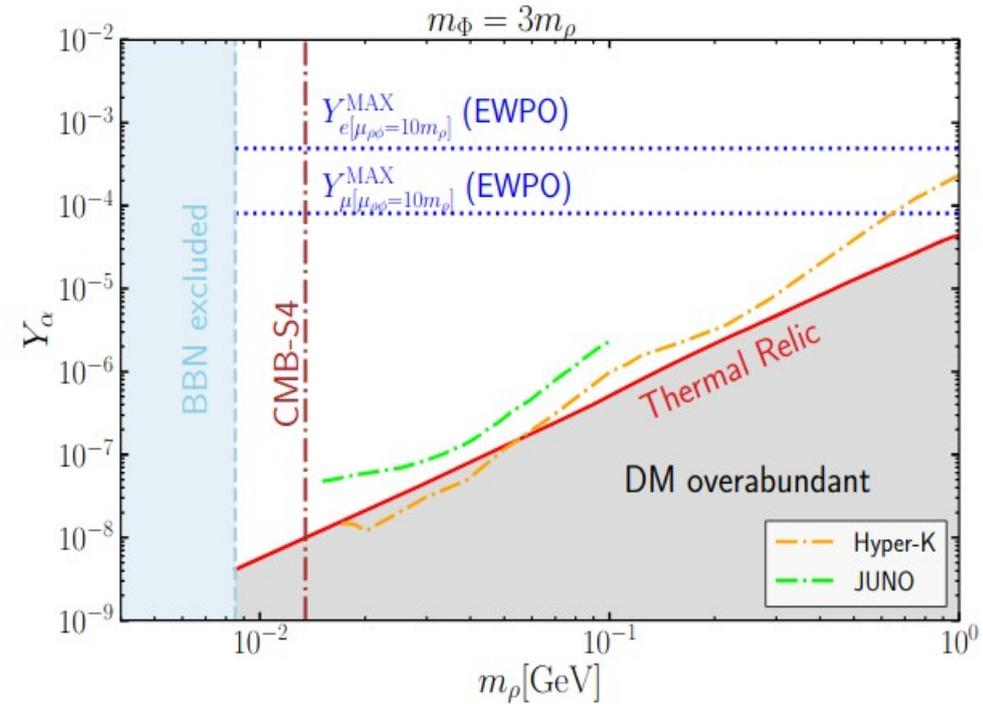
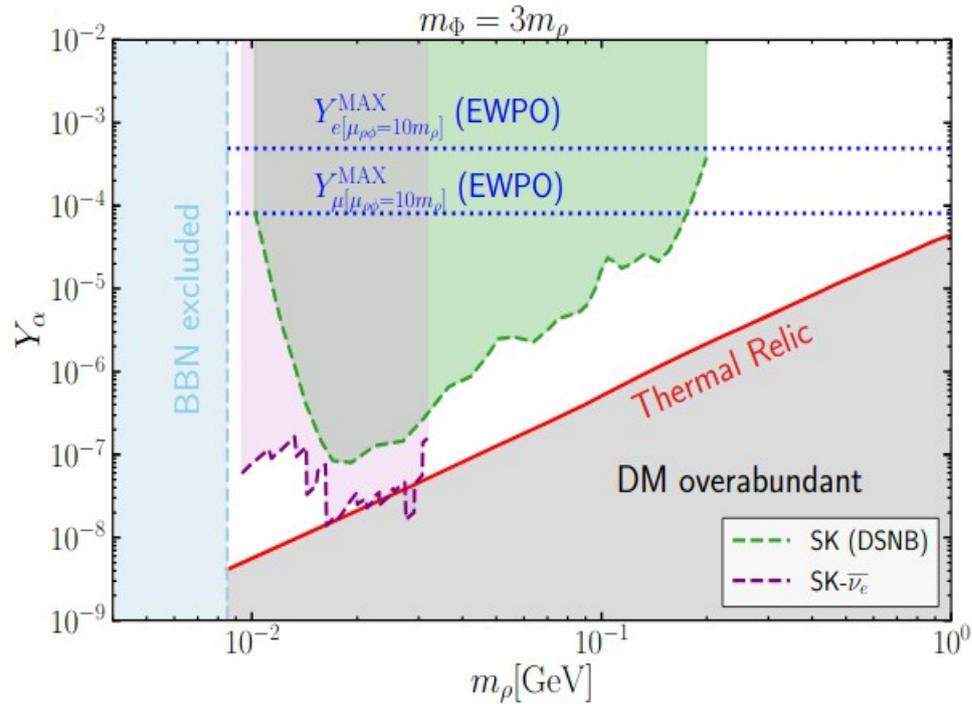
$$\Rightarrow V(H, \Phi, \rho) \supset \frac{1}{2} m_\rho^2 \rho^2 + \frac{\mu_{\rho\phi}}{2} (\rho^2 \Phi + h.c.)$$

DM annihilation:



$$Y_\alpha = \left(\frac{\mu_{\rho\phi}}{m_\rho} \lambda_{S\phi} |U_{\alpha 4}|^2 \right)^2$$

Neutrino-Portal WIMPs: Scalar DM with scalar Mediator



* Hyper-K will probe relic line for DM mass 18 MeV – 53 MeV

Hyper-K [JCAP 09 (2020) 019]

BBN & CMB-S4 [JCAP 01 (2020) 004]

JUNO [JCAP 09 (2023) 001]

Neutrino-Portal WIMPs: Fermionic DM with pseudoscalar Mediator

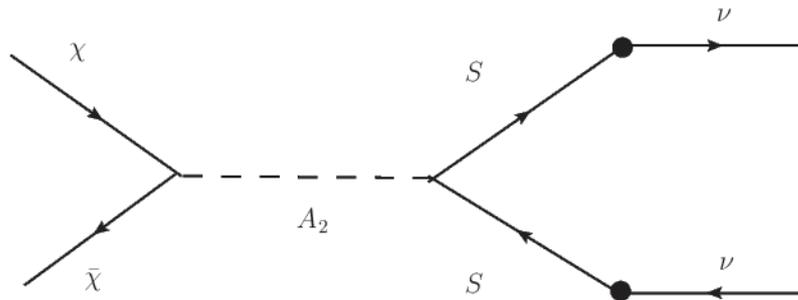
Particle content :

	χ (DM)	ρ (Mediator)	Φ (Mediator)	N_R	S_R
Global $U(1)_L$	+1/2	+1	+2	+1	-1

Lagrangian : $\mathcal{L} = \mathcal{L}_\nu + \left(\frac{1}{2} m_\chi \bar{\chi} \chi + \frac{\lambda_{\chi\rho}}{2} \rho \bar{\chi} \chi + \frac{\lambda_{S\phi}}{2} \bar{S}_R^c S_R \Phi + \frac{\lambda_{N\phi}}{2} \bar{N}_R^c N_R \Phi + h.c. \right) + \tilde{V}(H, \Phi, \rho)$

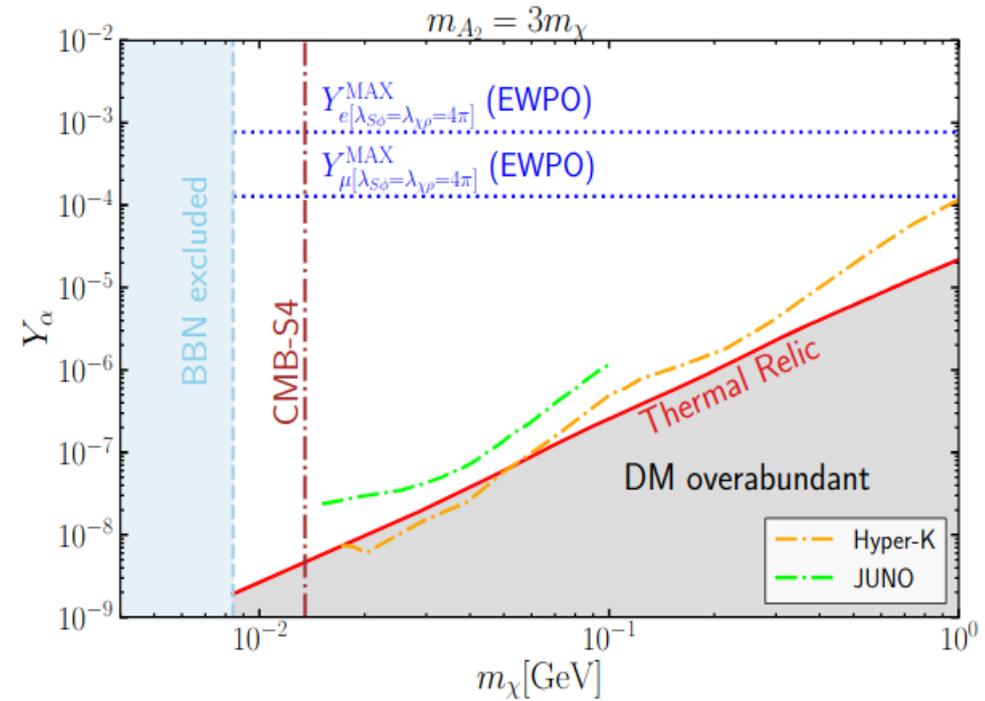
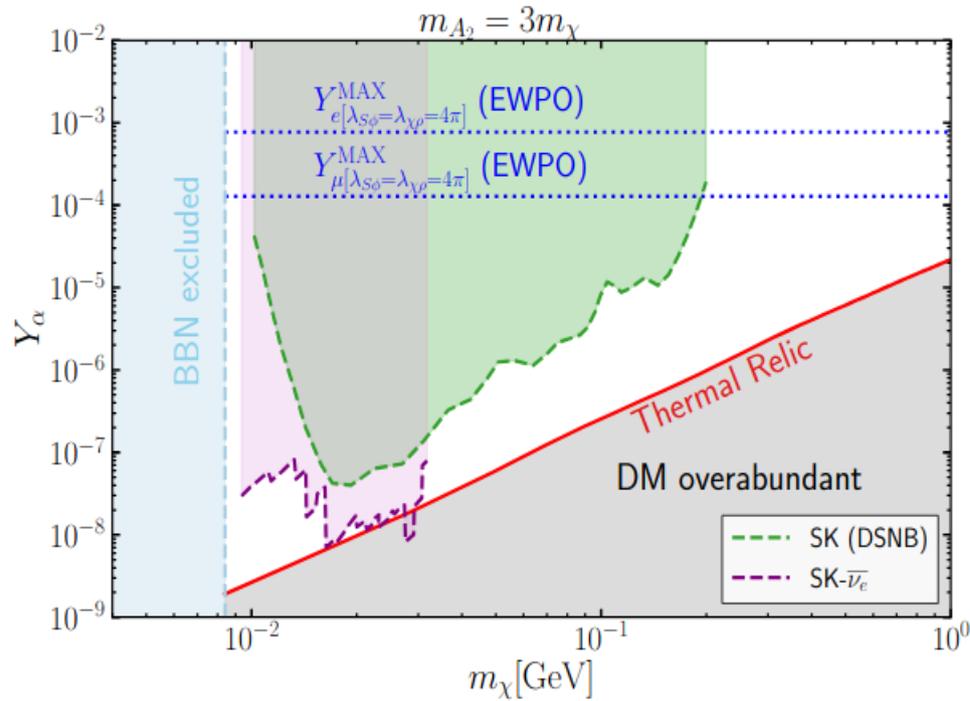
$\rightarrow \tilde{V}(H, \Phi, \rho) = V(H, \Phi, \rho) + \underbrace{\tilde{\mu}_{\rho\phi} (\rho \Phi^* + h.c.)}_{\text{Mixes } \Phi \text{ and } \rho \text{ and gives pseudoscalars: } A_{1,2}}$

DM annihilation:



$$Y_\alpha = (\lambda_{\chi\rho} \lambda_{S\phi} \sin 2\theta)^2 |U_{\alpha 4}|^4.$$

Neutrino-Portal WIMPs: Fermionic DM with pseudoscalar Mediator



* Hyper-K will probe relic line for DM mass 18 MeV – 53 MeV

Conclusion

- * Thermal WIMPs with $O(10 \text{ MeV}) < m_\chi < O(5 \text{ GeV})$ ruled-out by CMB (with visible SM final states)
- * Only possibility for sub-GeV WIMPs ➡ **neutrino-portal WIMPs**
- * Sub-GeV neutrino-portal WIMPs can only be detected by neutrino telescopes
➡ **Only if they have s-wave annihilation**
- * Sub-GeV neutrino-portal WIMP models with spin-0 mediators were not available in the literature
- * We provide models for sub-GeV neutrino-portal WIMPs
➡ Our models are testable by upcoming neutrino observations

Thank you!

