FPCP2024

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Asymmetric Self-interacting Dark Matter via Dirac Leptogenesis

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COLD & COLLISIONLESS DARK MATTER: ΛCDM

- CMB Anisotropy
- Bullet Cluster
- Gravitational Lensing
- Galaxy Rotation Curves
- Example: **WIMPs**

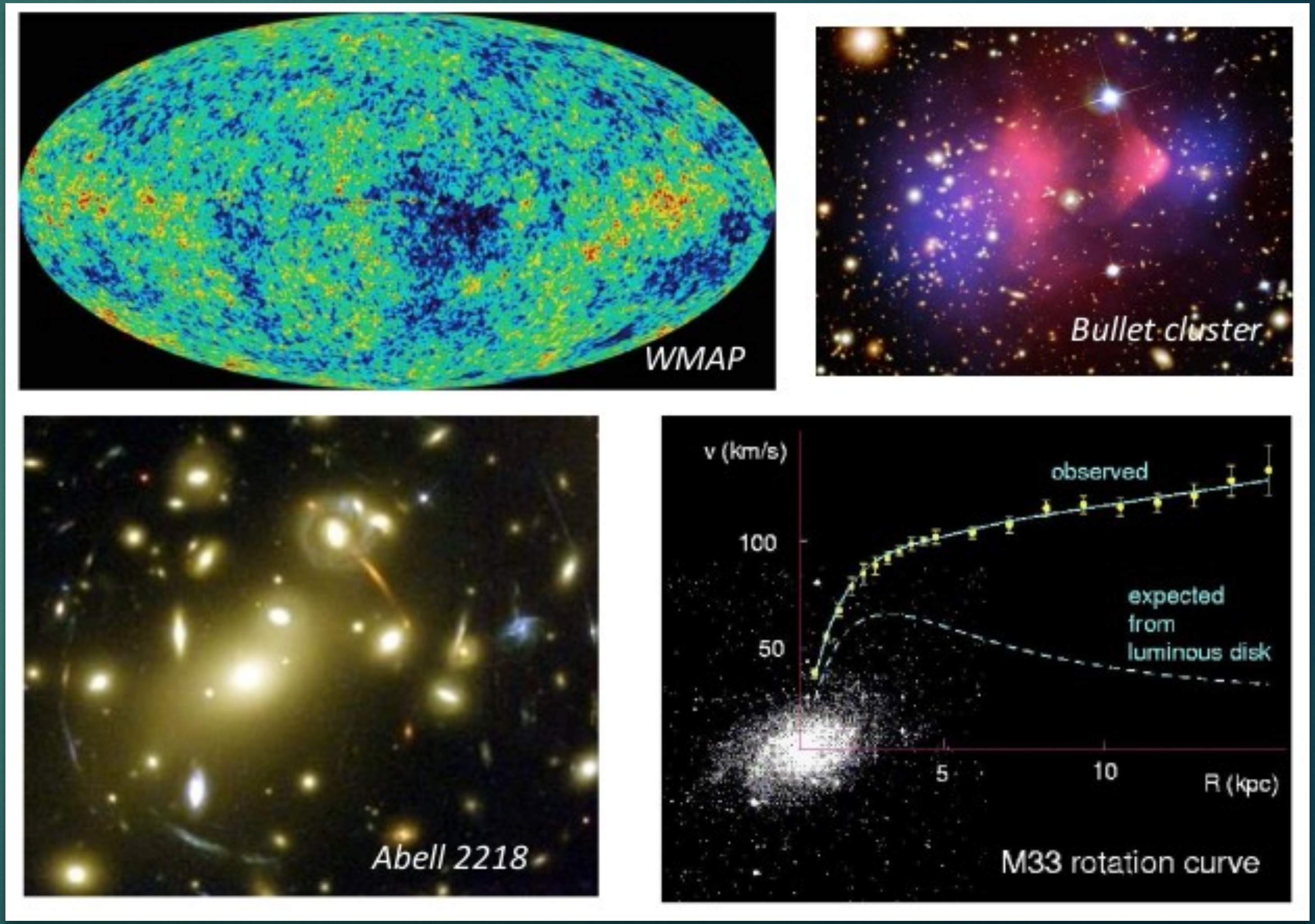
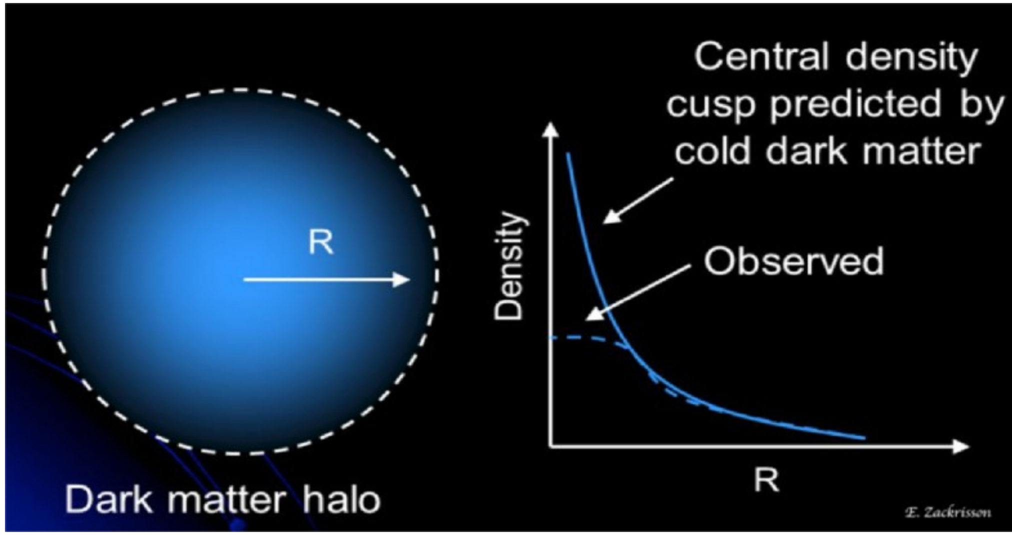


Image Courtesy: Sean Tulin, Frascati'15

COLD DARK MATTER: DISADVANTAGES

- **Cusp-Core problem**
- Missing Satellite Problem
- Too-Big-to-Fail Problem
- Prominent at Dwarf Scale
- Less prominent at Cluster scale



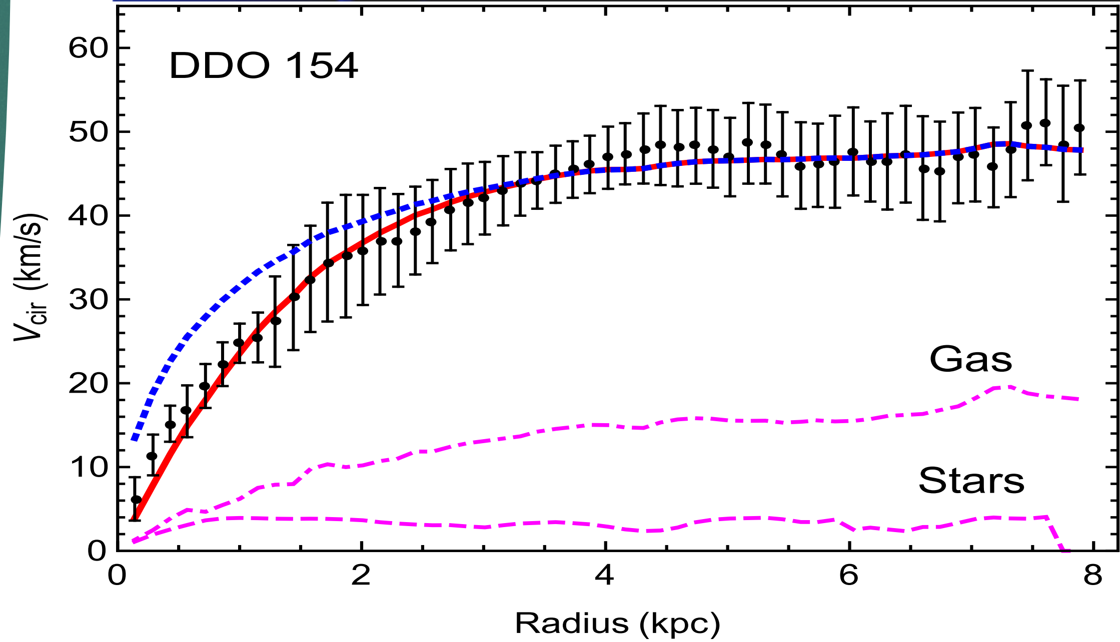
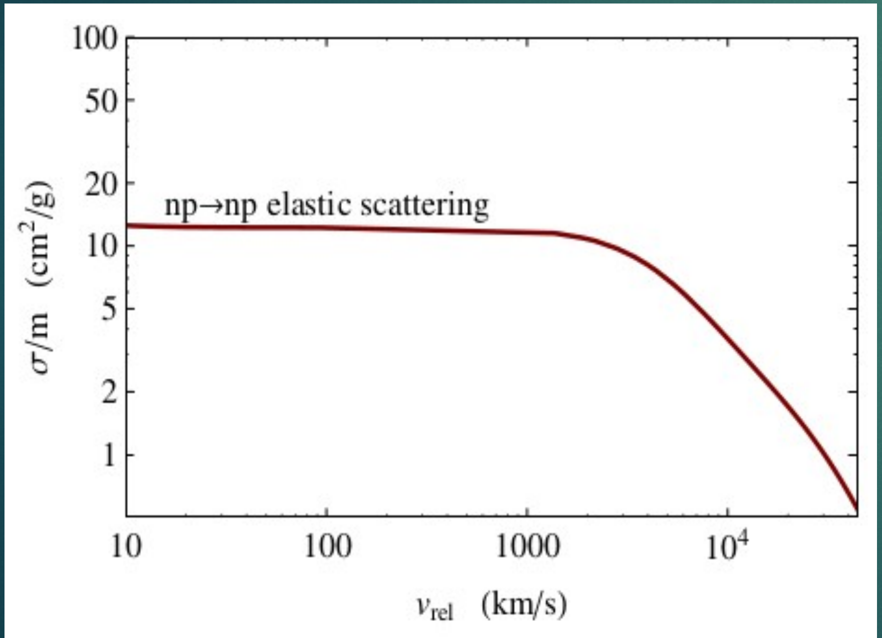


Image Courtesy: S Tulin, Frascati'15 & arXiv:1705.02358

Self-Interacting Dark Matter

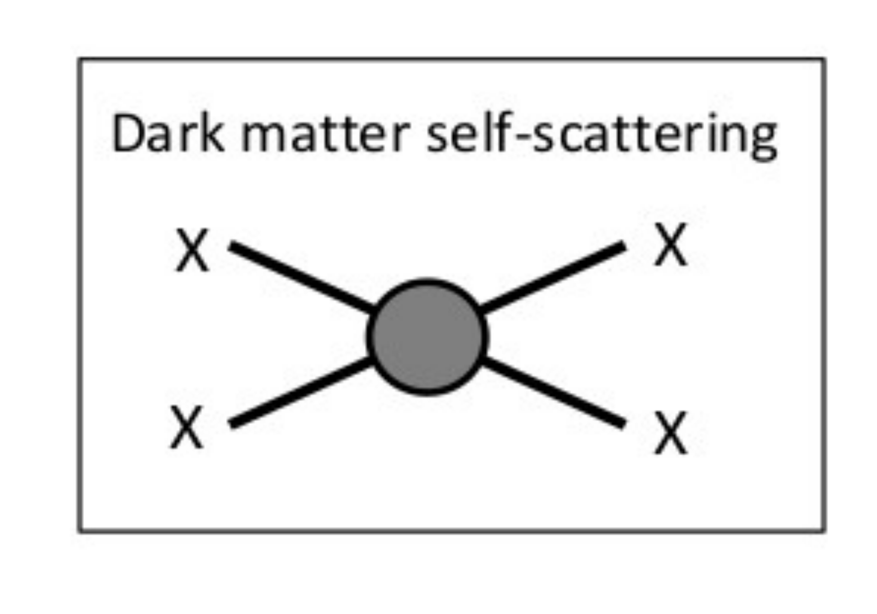
SIDM: $\frac{\sigma}{m}$ = 1 cm^2/g = 10^{-24} cm^2/GeV

WIMP: $\frac{\sigma}{m} = 10^{-38}$ cm^2/GeV



GeV Scale DM
With
MeV scale Mediator

Velocity-dependent Cross-section



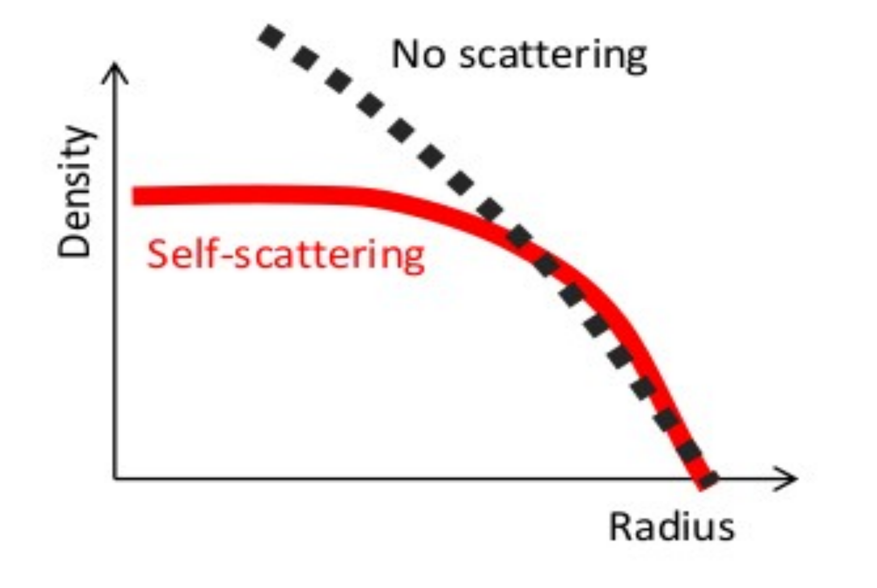
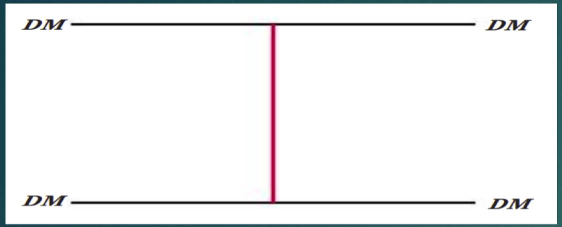
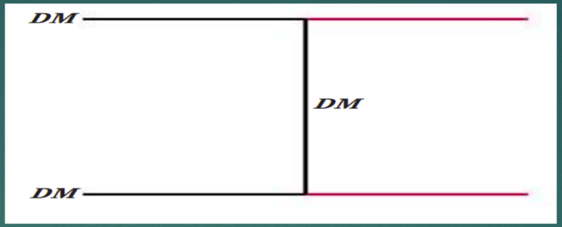


Image Courtesy: S Tulin, Frascati'15 & arXiv:1705.02358

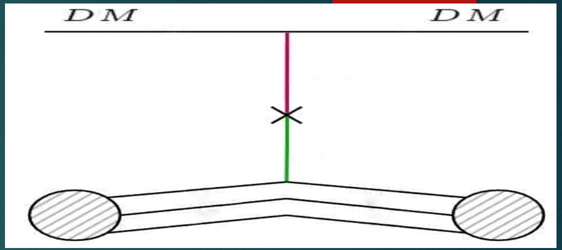
SIDM with Light Mediators



Self-scattering



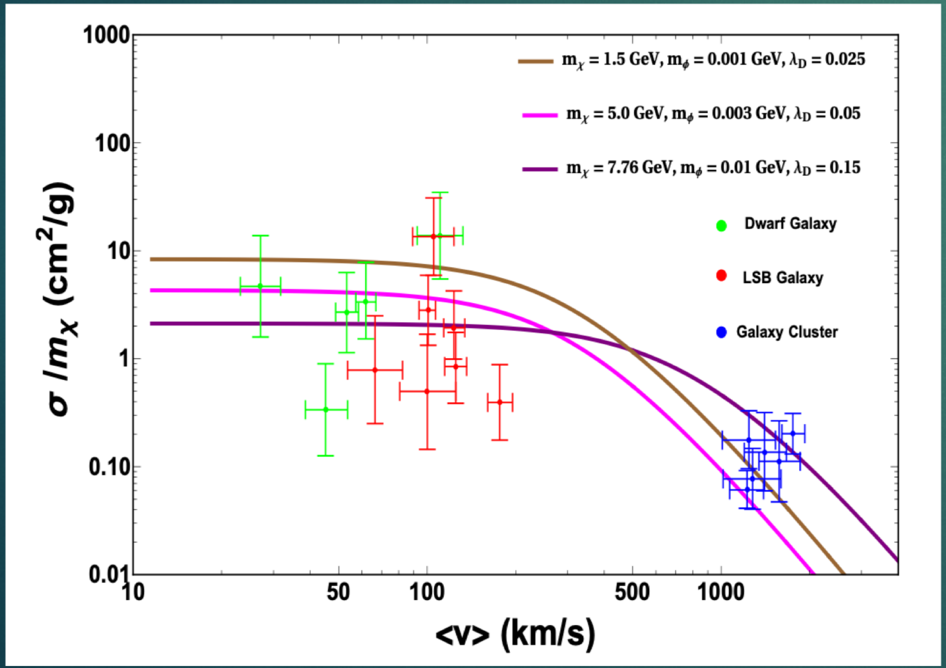
Relic Density

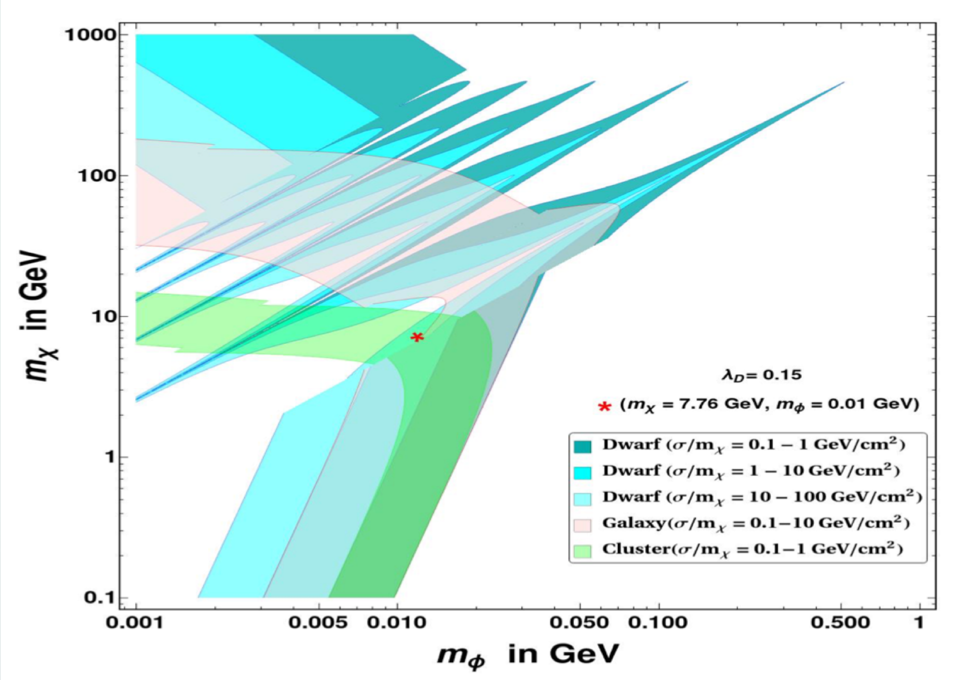


Direct Search

$$\mathcal{L}_{\rm int} = \begin{cases} g_D \bar{\chi}\gamma^\mu \chi \phi_\mu & \text{(vector mediator)} \\ g_D \bar{\chi}\chi\phi & \text{(scalar mediator)} \end{cases}$$

$$V(r) = \pm \frac{\alpha_D}{r} e^{-M_\phi r}$$





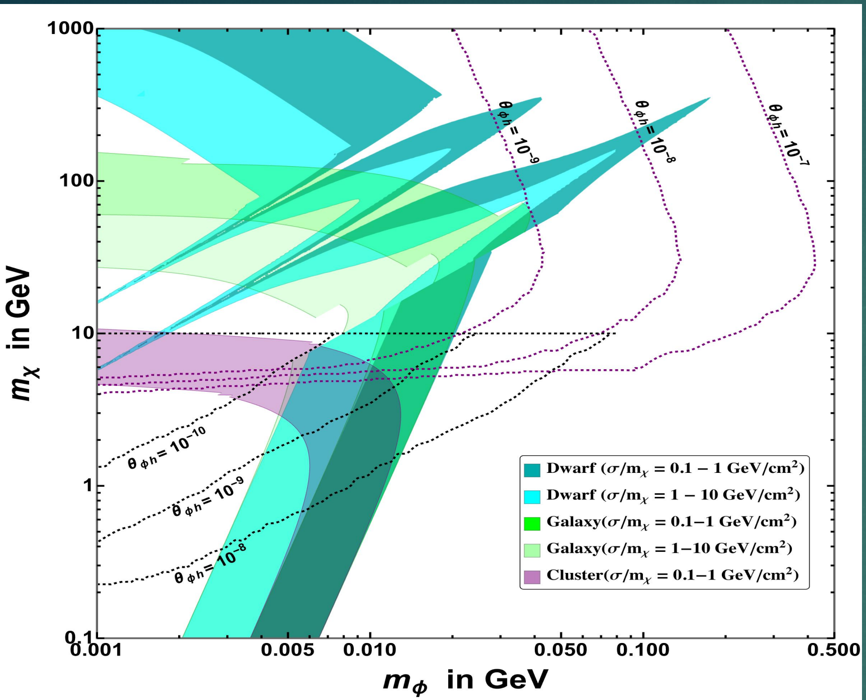
•(*PRD 105 (2022) 1, 015004, PRD 106 (2022) 095017, PRD 105 (2022) 075019, PRD 103 (2021) 9, 095018, NPB 979 (2022) 115787*)

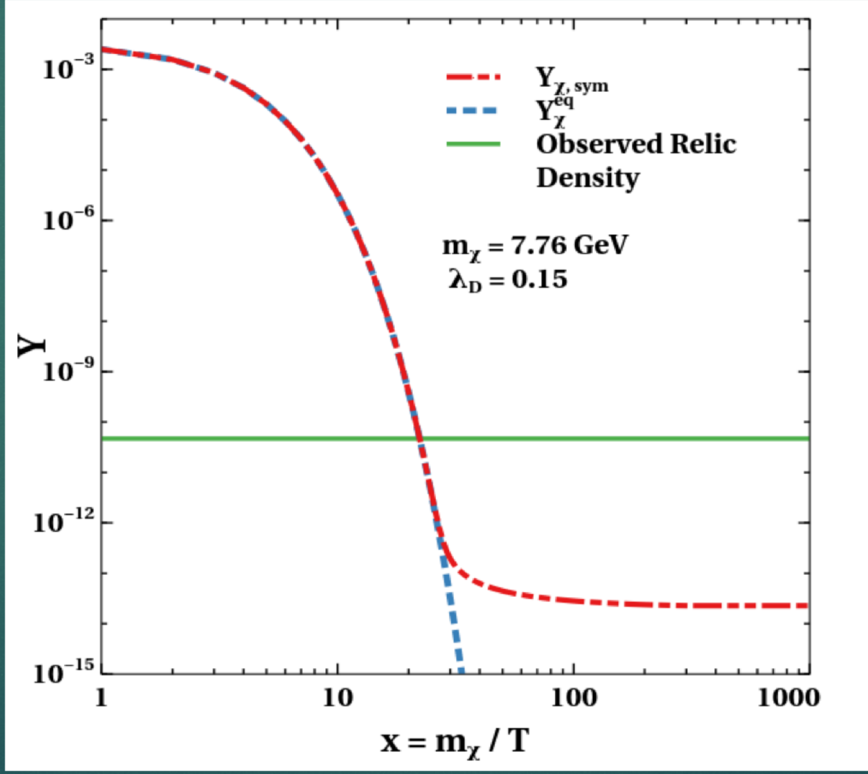
Issues with Symmetric SIDM

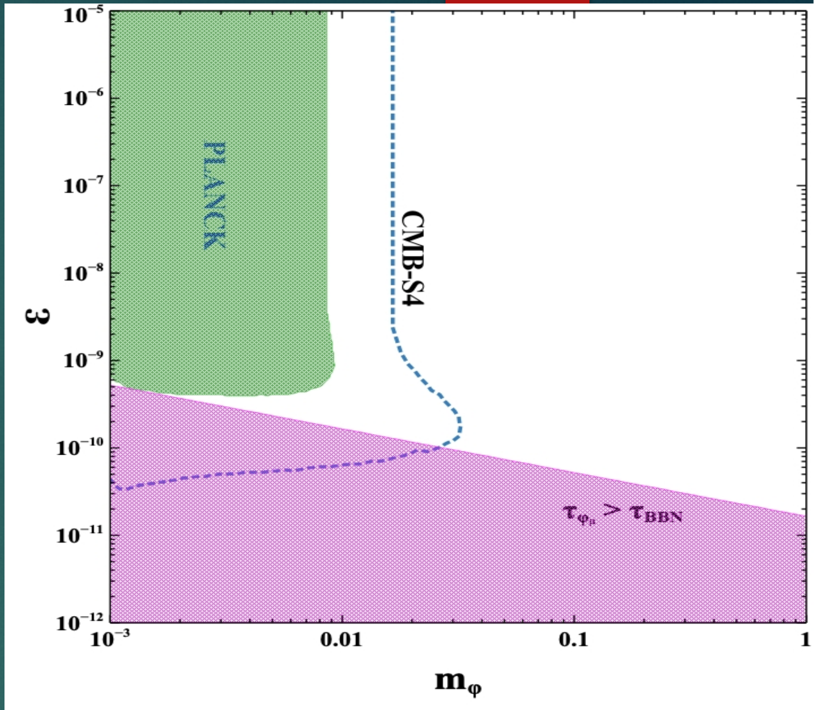
Under-abundant relic

↑

Observed Relic Density







Direct Search

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Tight upper bound on portal mixing

Indirect Search

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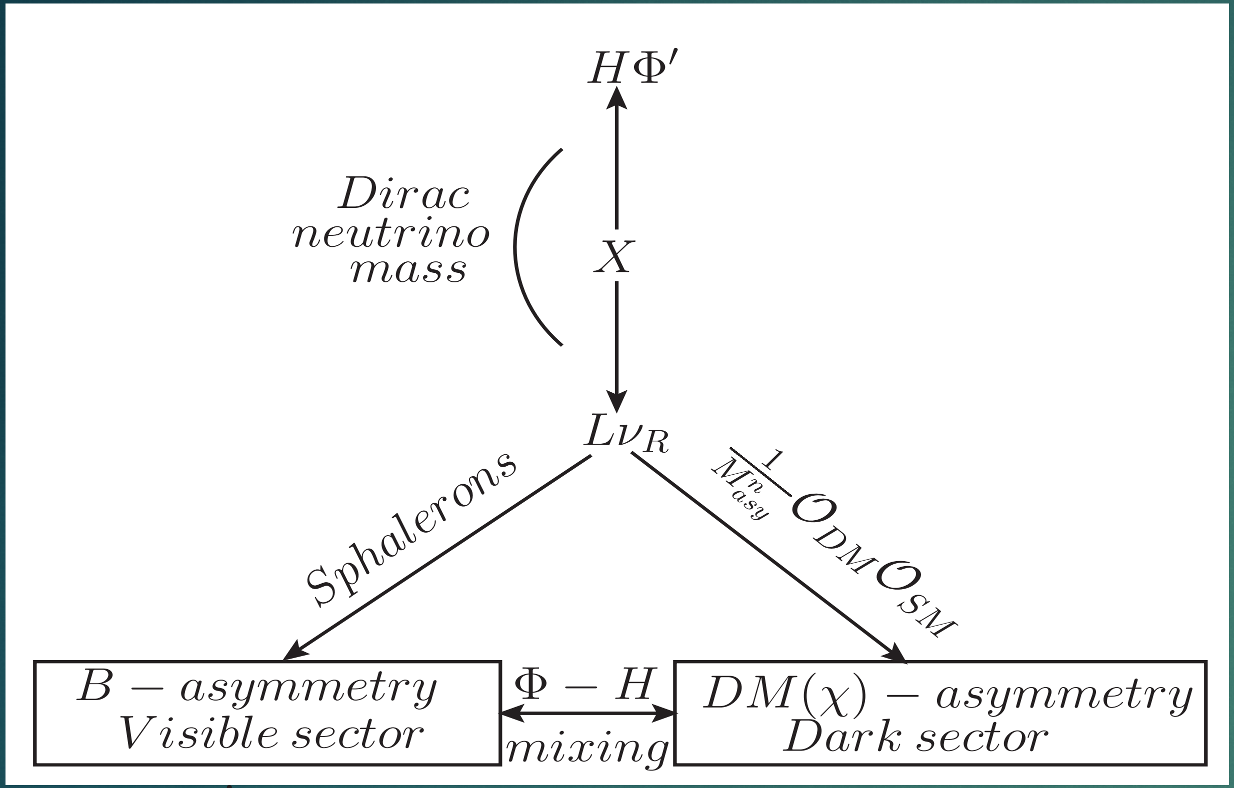
Tight lower bound on portal mixing

(M. Dutta, N. Narendra, N. Sahu, S. Shil, Phys. Rev. D 106 (2022) 9, 095017)

ASIDM via Dirac Leptogenesis



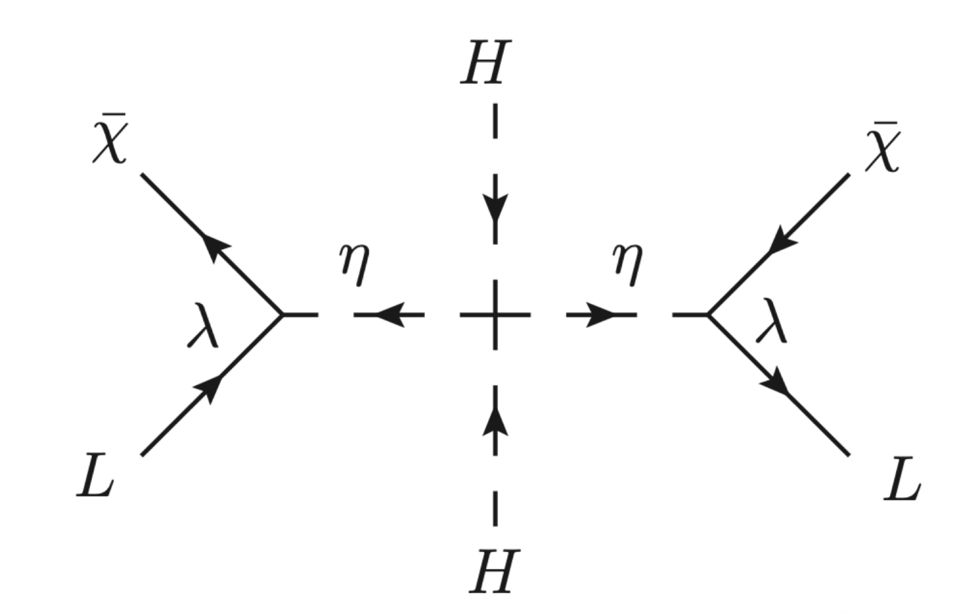
Fields	$SU(2)_L$	$U(1)_Y$	$U(1)_D$	$U(1)_{B-L}$
X_i	2	+1	-1	0
η	2	+1	1/2	0
ν_R	1	0	-1	-1
Φ'	1	0	+1	0
Φ	1	0	0	0
χ	1	0	1/2	-1

$$
\begin{aligned}
-\mathcal{L} \supset\ & m_\chi \overline{\chi}\chi + \lambda_D \overline{\chi}\chi\Phi + y\,\overline{L}\tilde{X}\nu_R + \rho\,\Phi'^* X^\dagger H \\
& + \lambda\,\overline{\chi}L\eta + \text{h.c.} + V(X,\eta,H,\Phi,\Phi'),
\end{aligned}
$$

$$
\begin{aligned}
V(\eta,H,\Phi,\Phi') =\ & M_\eta^2(\eta^\dagger\eta) + \lambda_\eta(\eta^\dagger\eta)^2 + \lambda'_{\eta H}(\eta^\dagger\eta)(H^\dagger H) \\
& + [\lambda_{\eta H}(\eta^\dagger H)^2 + h.c.] \\
& - \mu_H^2 H^\dagger H + \lambda_H(H^\dagger H)^2 + \frac{1}{2}m_\phi^2\Phi^2 + \frac{1}{3}\mu_\Phi\Phi^3 \\
& + \frac{1}{4}\lambda_\Phi\Phi^4 - \mu_{\Phi'}^2(\Phi'^\dagger\Phi') + \lambda_{\Phi'}(\Phi'^\dagger\Phi')^2 \\
& + \frac{\mu_1}{\sqrt{2}}\Phi H^\dagger H + \frac{\mu_2}{\sqrt{2}}\Phi(\Phi'^\dagger\Phi') + \frac{\lambda_{H\Phi}}{2}H^\dagger H\Phi^2 \\
& + \lambda_{H\Phi'}H^\dagger H(\Phi'^\dagger\Phi') + \frac{\lambda_{\Phi\Phi'}}{2}\Phi^2(\Phi'^\dagger\Phi')
\end{aligned}
$$

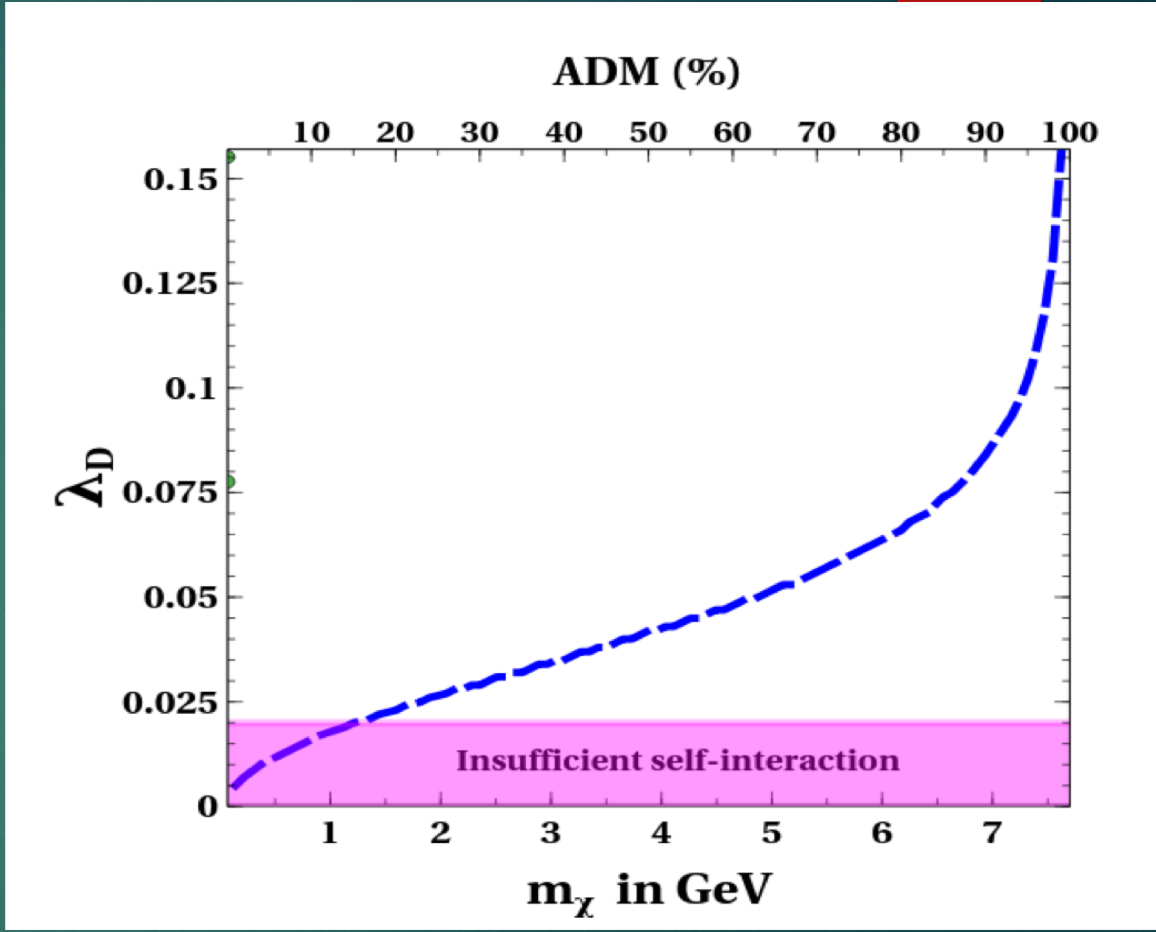
(M. Dutta, N. Narendra, N. Sahu, S. Shil, Phys. Rev. D 106 (2022) 9, 095017)

ASIDM via Dirac Leptogenesis



$$\mathcal{O}_8 = \frac{\lambda^2 \lambda_{\eta H} \overline{\chi} L H H \overline{\chi} L}{M_\eta^4} \equiv \frac{\overline{\chi}^2 (LH)^2}{M_{asy}^4}$$

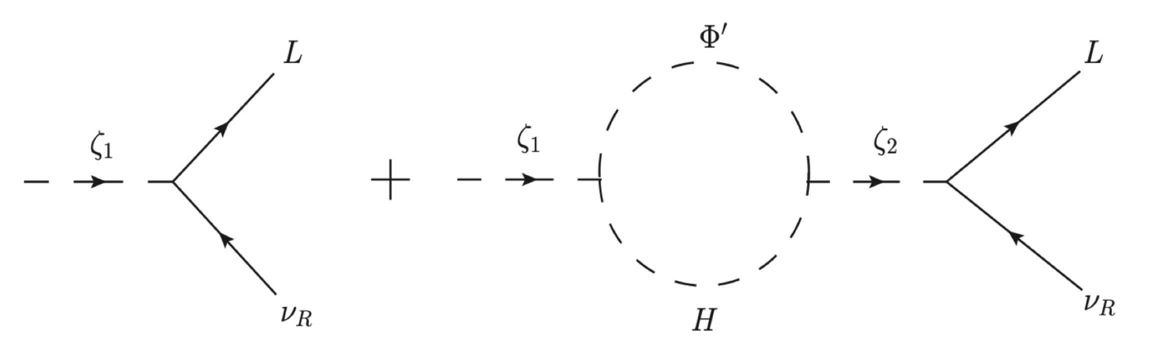
$$n_\chi = (n_{\mathrm{B-L}})_{\mathrm{dark}} = \frac{58}{291} (n_{B-L})_{\mathrm{vis}}$$



$$m_\chi = \frac{90}{58} \times 5 \times \frac{\mathrm{ADM}(\%)}{100}.$$

(M. Dutta, N. Narendra, N. Sahu, S. Shil, Phys. Rev. D 106 (2022) 9, 095017)

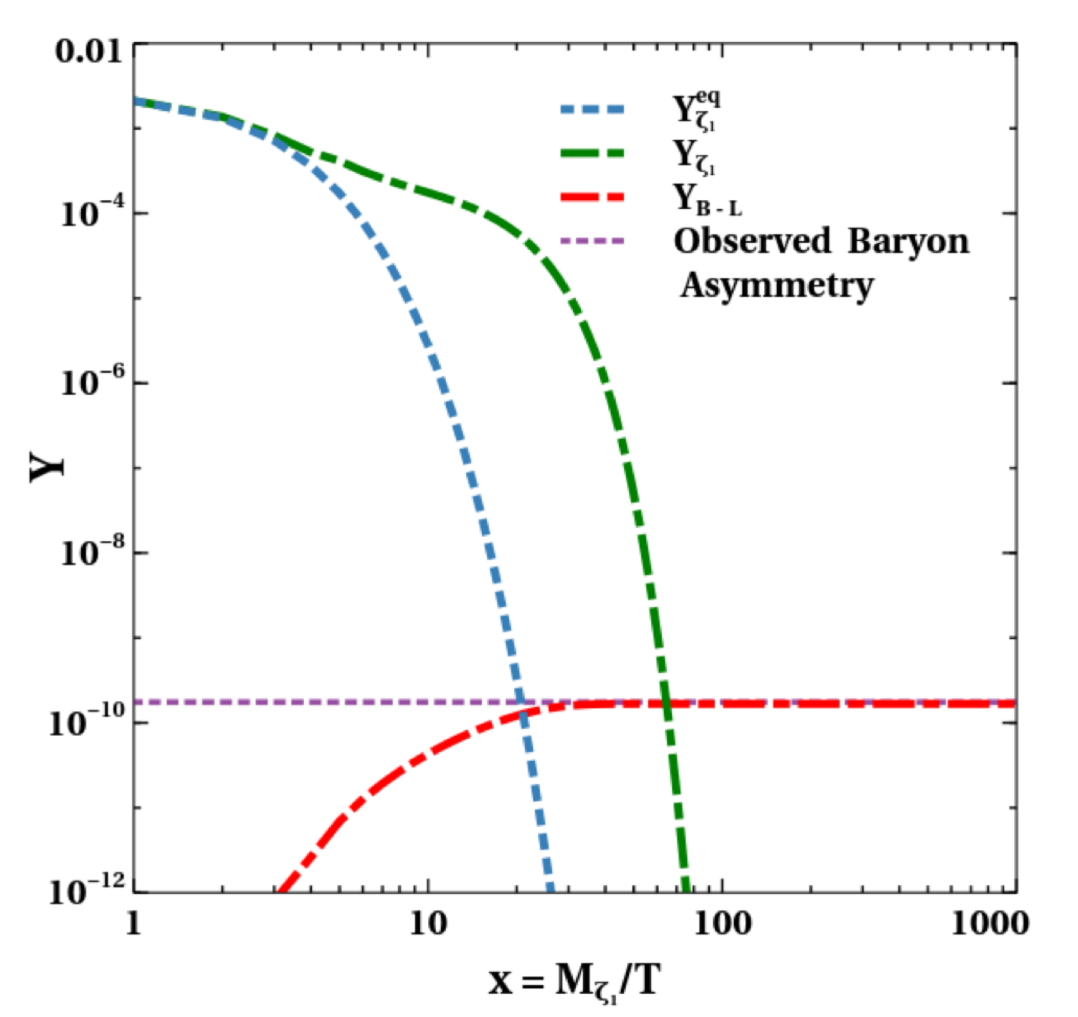
ASIDM via Dirac Leptogenesis



$$\frac{dY_{\zeta_1}}{dx} = -\frac{x}{H(M_{\zeta_1})} s\langle\sigma|v|_{(\zeta_1\zeta_1\to All)}\rangle\left[Y_{\zeta_1}^2 - (Y_{\zeta_1}^{eq})^2\right] - \frac{x}{H(M_{\zeta_1})}\Gamma_{(\zeta_1\to All)}\left[Y_{\zeta_1} - Y_{\zeta_1}^{eq}\right]$$

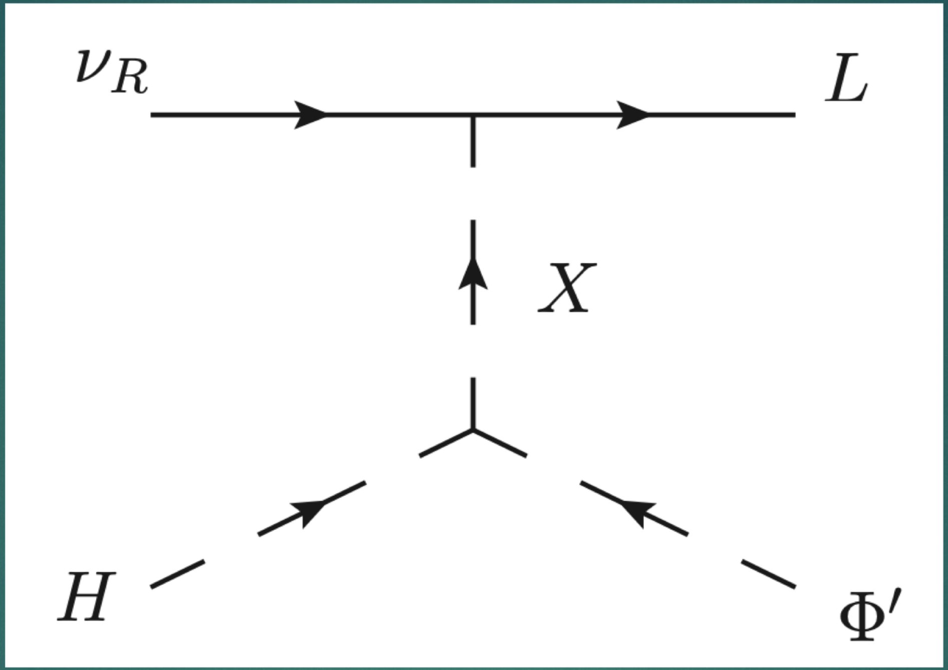
$$\frac{dY_{\mathrm{B-L}}}{dx} = \frac{x}{H(M_{\zeta_1})}\left[\epsilon_L \Gamma_{(\zeta_1\to All)} B_L\left(Y_{\zeta_1} - Y_{\zeta_1}^{eq}\right) - \Gamma_W Y_{\mathrm{B-L}}\right]$$

$$\epsilon_L = [B_L(\zeta_1^- \to l^-\nu_R) - B_L(\zeta_1^+ \to (l^-)^c\nu_R^c)] = -\frac{\mathrm{Im}\left(\rho_1^*\rho_2\sum_{k,l} y_{1kl}^* y_{2kl}\right)}{8\pi^2(M_{\zeta_2}^2 - M_{\zeta_1}^2)}\left[\frac{M_{\zeta_1}}{\Gamma_{\zeta_1}}\right],$$



(M. Dutta, N. Narendra, N. Sahu, S. Shil, Phys. Rev. D 106 (2022) 9, 095017)

ASIDM via Dirac Leptogenesis: Neutrino Mass



$$\mathcal{L}_{Dirac} = -y_1 \frac{\rho_1}{M_{X_1}^2} \overline{L} H \Phi' \nu_R - y_2 \frac{\rho_2}{M_{X_2}^2} \overline{L} H \Phi' \nu_R$$

$$M_\nu \simeq y_1 \frac{\rho_1 v w}{M_{X_1}^2} + y_2 \frac{\rho_2 v w}{M_{X_2}^2}.$$

(M. Dutta, N. Narendra, N. Sahu, S. Shil, Phys. Rev. D 106 (2022) 9, 095017)

Summary

- The inadequacies of symmetric SIDM (relic density, indirect detection) can be alleviated in Asymmetric SIDM Scenario.
- It can naturally explain the cosmic coincidence "$\Omega_{DM} \simeq 5\Omega_B$", while simultaneously alleviating the small scale anomalies of ΛCDM.
- Provides an avenue to explain SIDM, neutrino mass and baryon asymmetry in a common frame-work.
- **$0\nu\beta\beta$** experiment will play the crucial role in deciding nature of neutrinos, and hence the type of leptogenesis.
- Next decade will be a testing time for Self-interacting Dark Matter.

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Thank You

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