Secluded effects on scalar light dark matter

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Simon Fraser University

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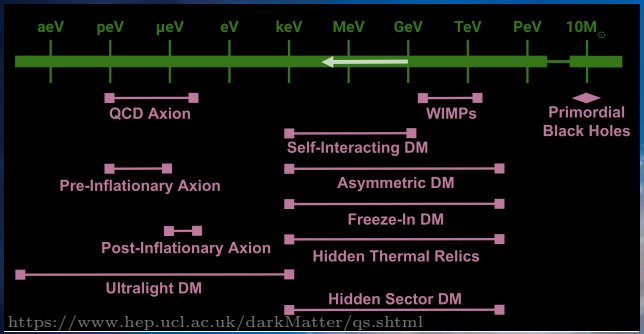
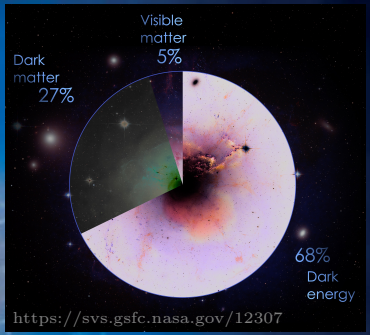
Light Dark Matter (LDM)

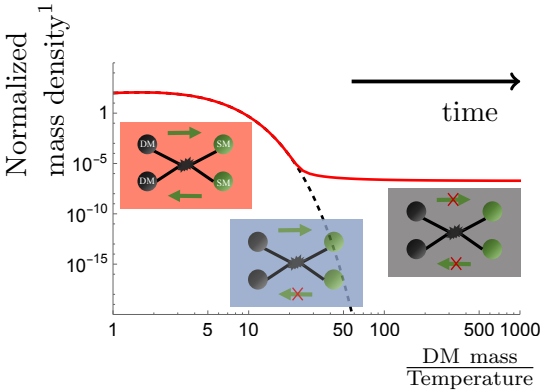




Extending the Standard WIMP Scenario

Weakly Interacting Massive Particle

- Thermal relic, one new fermion



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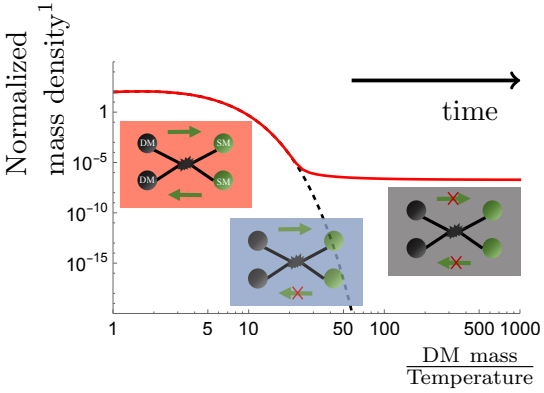

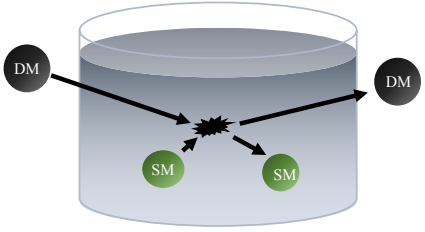

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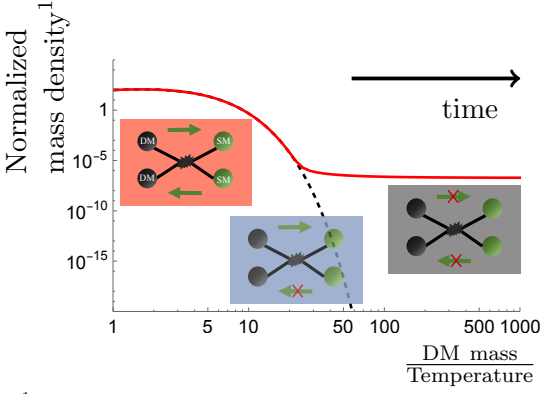
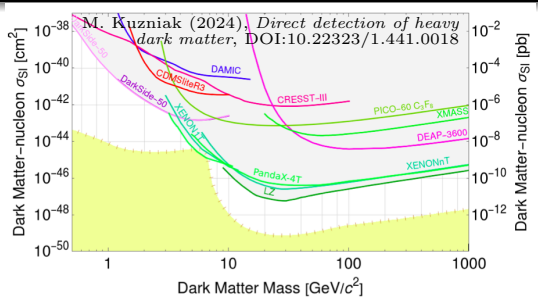
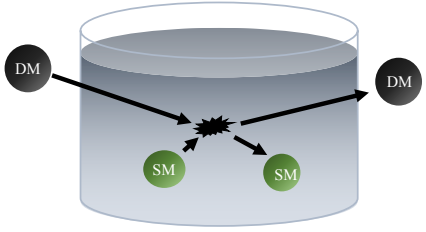
- **Extensively studied**







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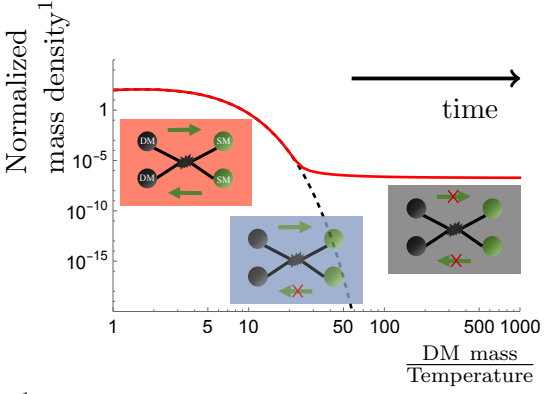

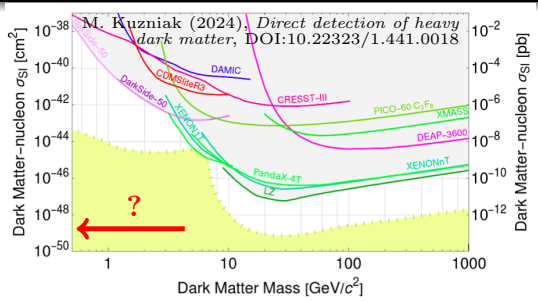

sub-GeV extension (LDM)

- Maintain thermal relic scenario
- New light mediator
- New models & experimental prospects

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A dark sector and light dark matter

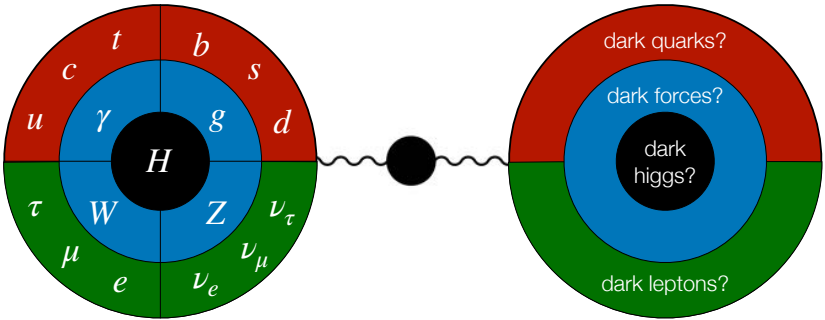

Image adapted from Gori & Williams (2022), *Dark Sector Physics at High Intensity*, arXiv:2209.04671.

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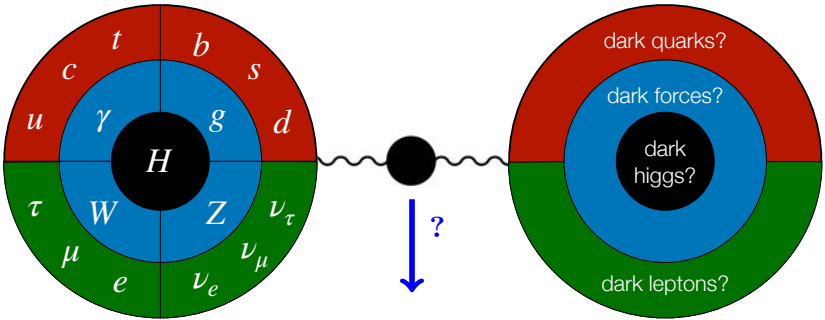
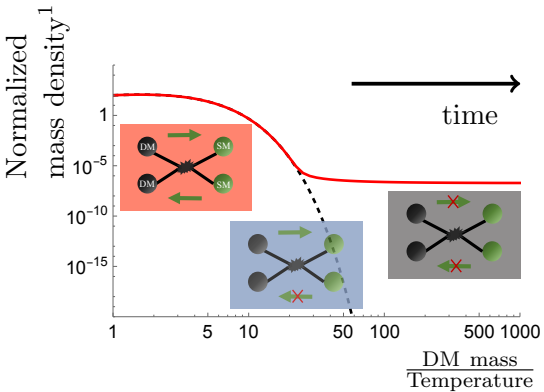


New light mediator ("dark photon")

- Maintain freeze-out: matches observed relic abundance in sub-GeV range
- DM abundance provides experimentally accessible scenarios

Image adapted from Gori & Williams (2022), *Dark Sector Physics at High Intensity*, arXiv:2209.04671.

sub-GeV CMB constraints

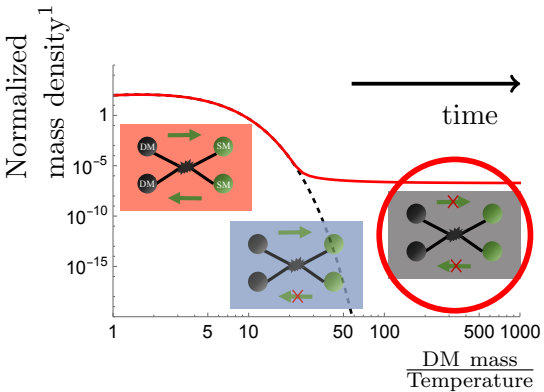


- **DM does not completely stop annihilating at freeze-out**
- sub-GeV Dirac DM $\Longrightarrow$ re-ionization of hydrogen at re-combination

Some viable alternatives

- Late-time asymmetry
- Velocity supression: **Complex scalar** $\langle \sigma_{\rm ann} v \rangle \propto v_{\rm rel}^2$

sub-GeV CMB constraints



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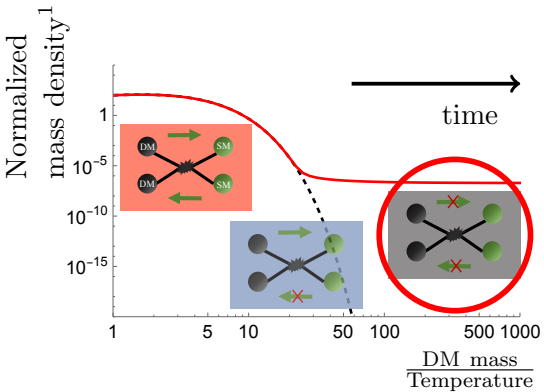

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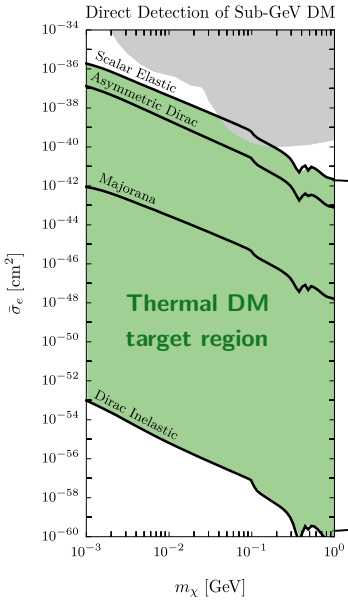
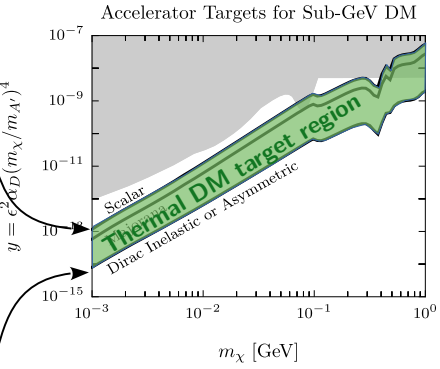
LDM thermal relics: direct detection & accelerator targets



Opportunities identified at Snowmass 2021



Krnjaic et al. (2022), *A snowmass whitepaper: Dark matter production at intensity-frontier experiments.*

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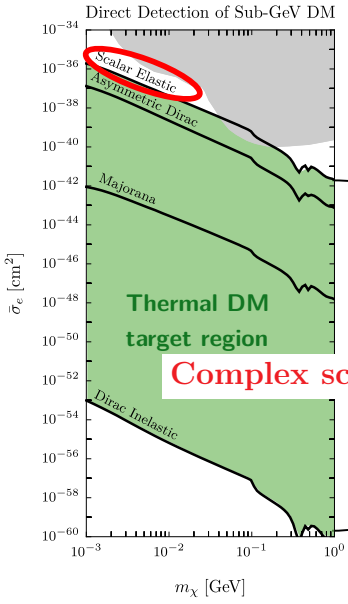

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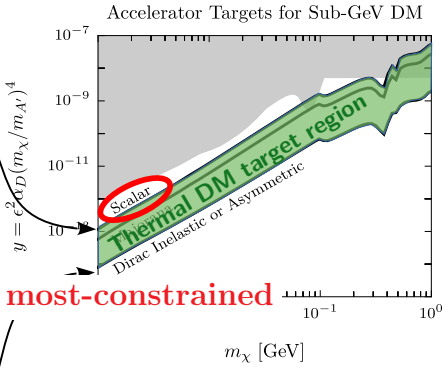

Complex scalars most-constrained

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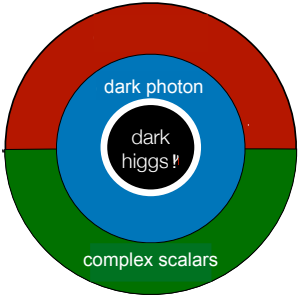
Origin of the dark photon's mass



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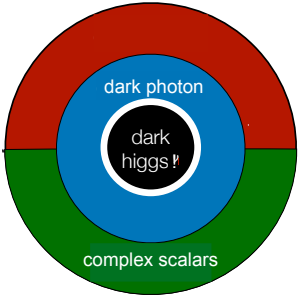
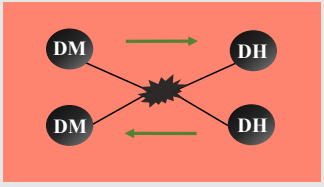


Additional dark sector interactions



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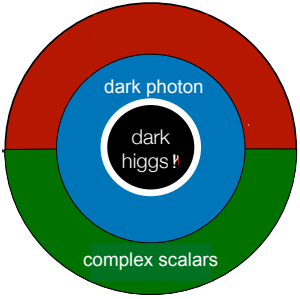

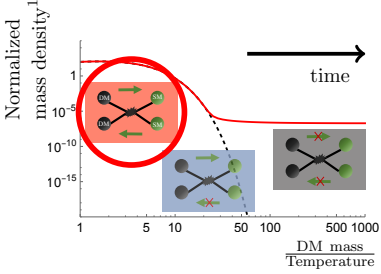

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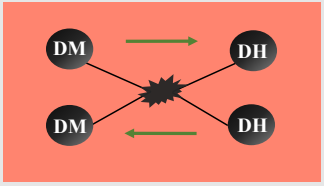

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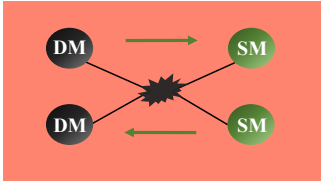
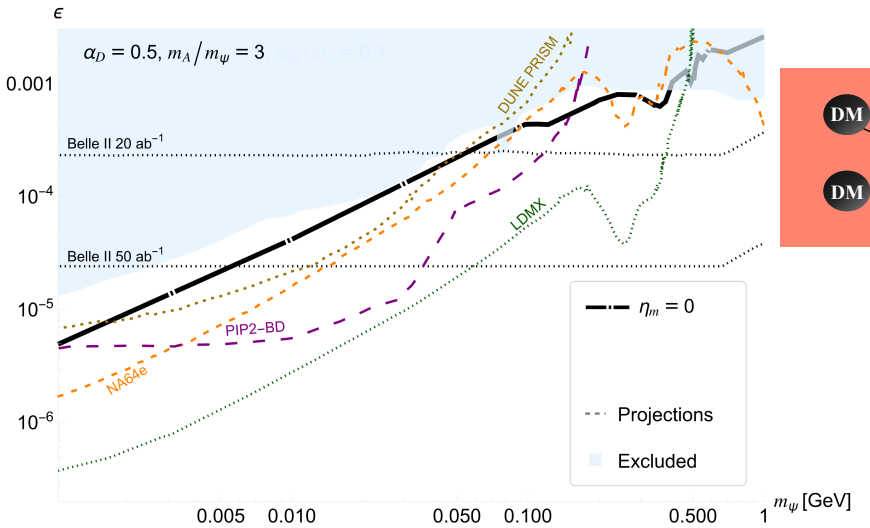
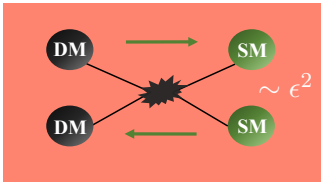


Scalar LDM & a light dark Higgs





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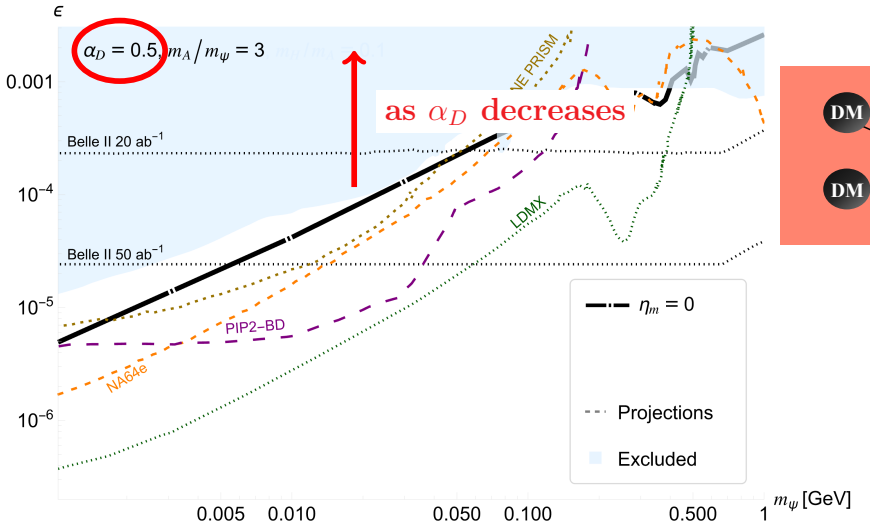

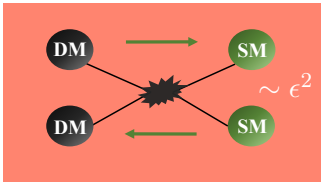

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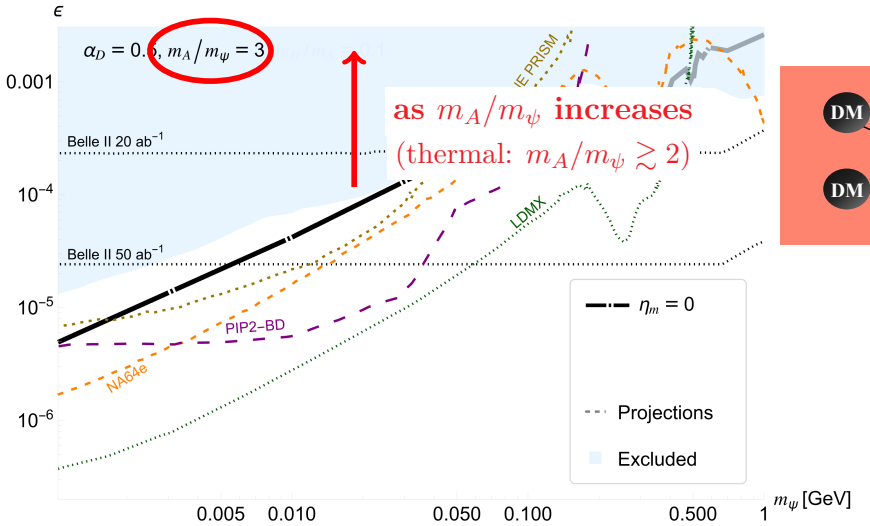

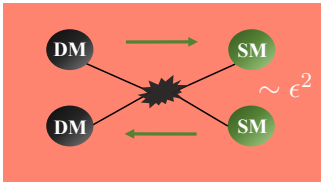

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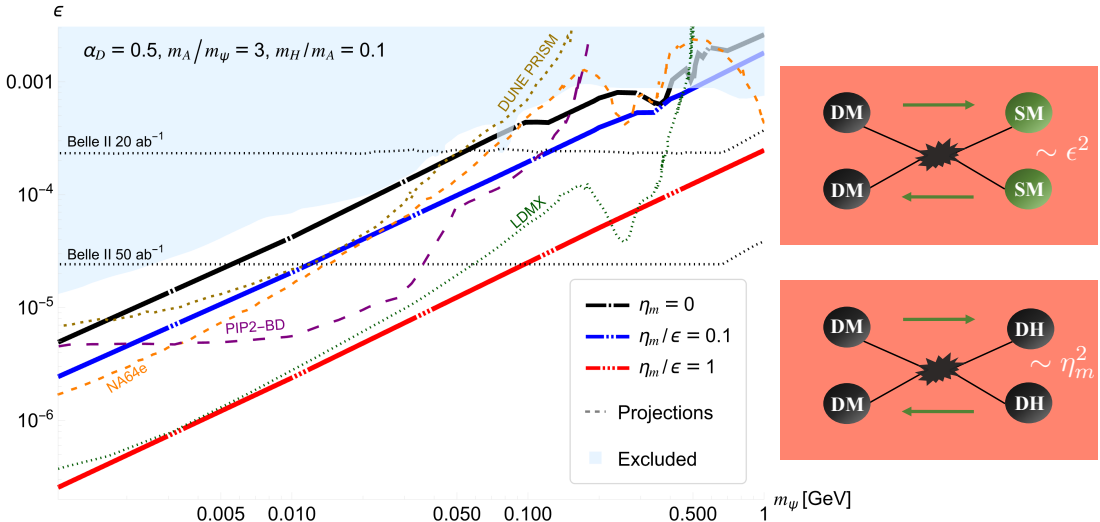

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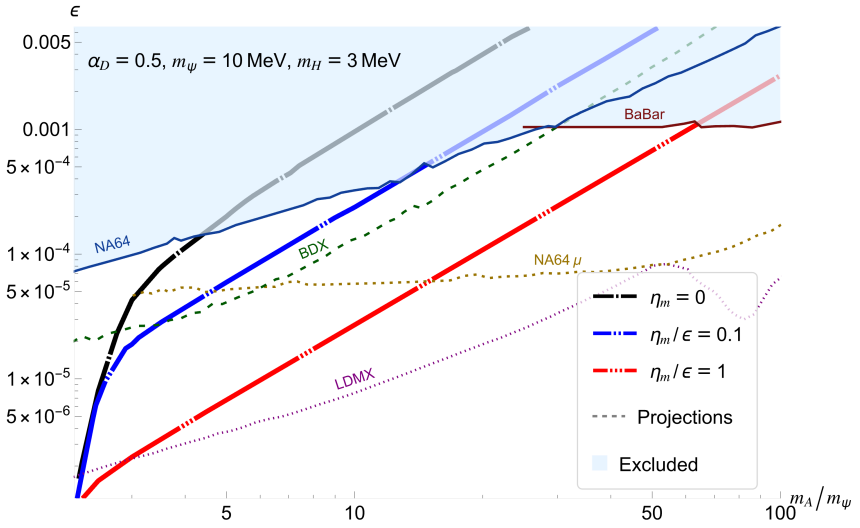
Prospect of a heavy mediator



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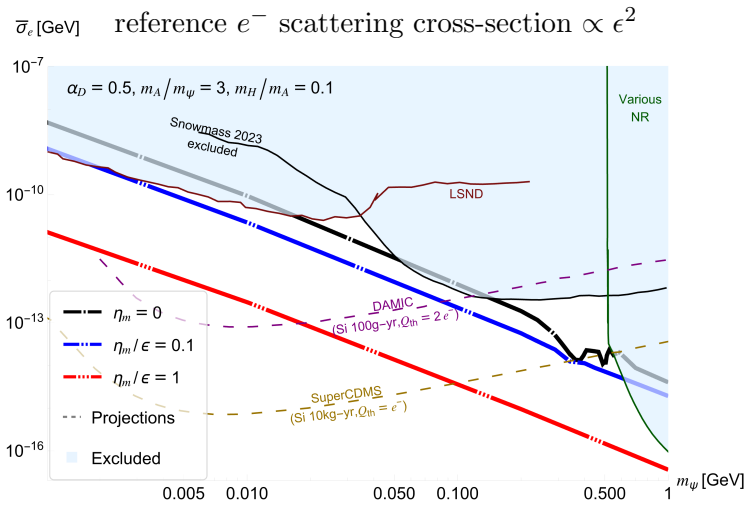
Direct detection



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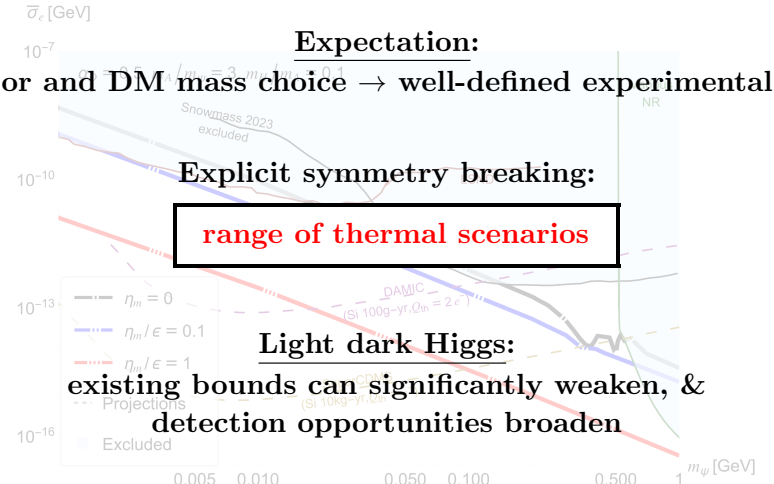
Summary



Expectation:

mediator and DM mass choice → well-defined experimental target

Explicit symmetry breaking:

range of thermal scenarios

Light dark Higgs:

existing bounds can significantly weaken, & detection opportunities broaden

Extra

Model

$$\mathcal{L}_{\text{int}} \approx \varepsilon e \bar{\varphi} \gamma^{\mu} A'_{\mu} \varphi. \tag{1}$$

$$\mathcal{L}_{\text{dark}} \supset |D^a_{\mu} \psi|^2 + |D^a_{\mu} \phi|^2 - V(\psi, \phi), \tag{2}$$

$$V(\psi, \phi) = \mu_{\psi}^2 |\psi|^2 + \lambda_{\psi} |\psi|^4 + (\mu_m \phi^* \psi^2 + \text{c.c.}) + \lambda_m |\phi|^2 |\psi|^2 + \mu_{\phi}^2 |\phi|^2 + \lambda_{\phi} |\phi|^4 \tag{3}$$

Light dark Higgs, some calc details

$$(\dot{n}_\psi + 3Hn_\psi)\left(1 + \frac{1}{3}\frac{d\ln g_s}{d\ln T}\right)^{-1} = -\frac{1}{2}\langle\sigma v\rangle\left[n_\psi^2 - \left(n_\psi^{\rm eq}\right)^2\right] \tag{4}$$

$$\langle\sigma v\rangle_{\rm eff} = \langle\sigma v\rangle_{\psi\psi^*\to f\bar{f}} + \langle\sigma v\rangle_{\psi\psi^*\to 2H_D} \tag{5}$$

$$\langle\sigma v_{\rm M\o ll}\rangle(T) = \frac{1}{8m_\psi^4 T K_2^2\left(\frac{m_\psi}{T}\right)}\int_{4m_\psi^2}^{\infty} ds(s-4m_\psi^2)\sqrt{s}\;\sigma(s)K_1\left(\frac{\sqrt{s}}{T}\right) \tag{6}$$

$$\sigma_{\rm SM} v_{\rm M\o ll} \approx \frac{4\pi\varepsilon^2\alpha_D\alpha_{\rm em}\sqrt{m_\psi^2 - m_f^2}\left(m_f^2 + 2m_\psi^2\right)}{3m_\psi\left(\Gamma_A^2 m_A^2 + \left(m_A^2 - 4m_\psi^2\right)^2\right)} v_{\rm M\o ll}^2 \tag{7}$$