

Probing freeze-in dark matter with gamma ray telescopes

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arXiv:1912.09458 (with Alejandro Ibarra)



The Dark Matter Production Mechanism Program

Dark Matter is...

- long-lived
- charge neutral (“dark”)
- non-relativistic
- dissipationless

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Starting point:

$$\rho_{\text{DM},0} \simeq 1.26 \cdot 10^{-6} \text{ GeV cm}^{-3}$$

→ *Where did it come from?*

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Thermal relic particle dark matter

- stable neutral particles are automatically dark matter candidates
- thermal bath of the early Universe accounts for production

→ *relate production to signatures*



Singlet scalar dark matter

The simplest model, arguably

- add one dof. to the SM, real scalar singlet ϕ , stabilised by a \mathbb{Z}_2

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \frac{1}{2} \partial_\mu \phi \partial^\mu \phi - \frac{1}{2} \textcolor{blue}{m}^2 \phi^2 - \frac{1}{4!} \lambda_\phi \phi^4 - \frac{1}{2} \textcolor{blue}{\lambda_{\phi h}} (H^\dagger H) \phi \phi$$

- production in SM thermal bath

$$\frac{dn_\phi}{dt} + 3Hn_\phi = -\langle \sigma v \rangle_{\phi \phi \rightarrow \text{SM}} \left(n_\phi^2 - n_\phi^{\text{eq2}} \right)$$



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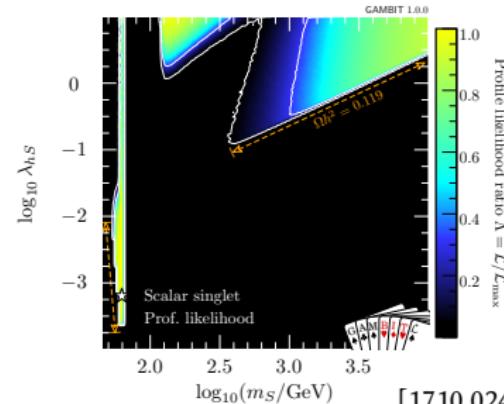
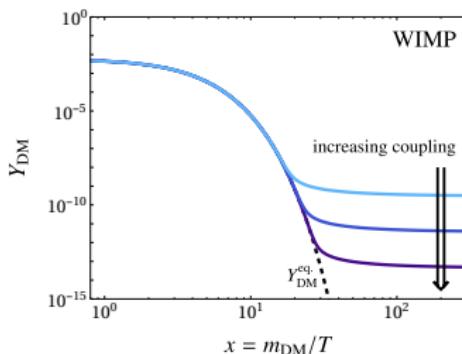
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[1710.02467]

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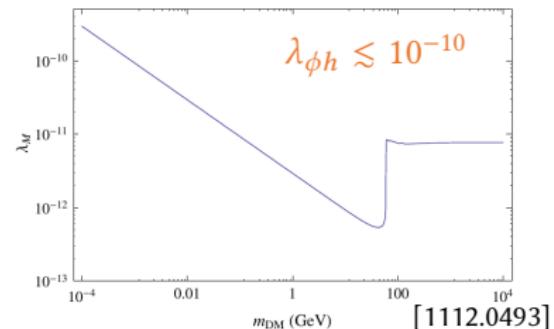
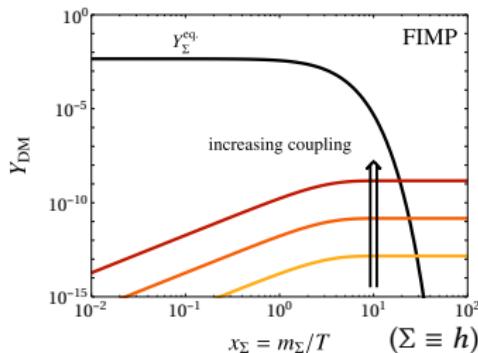
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→ In the simplest case: viable freeze-in DM model, *but no signals.*



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 - what do we do if we find *no* signatures?
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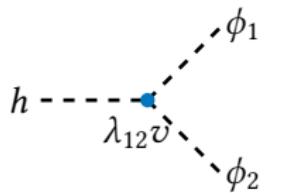
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→ take more detail into account!
- flavour is a detail of the SM; maybe hidden sector fields also come in multiples?

Multi-flavour singlet scalars

Add two real scalars $\phi_{1,2}$ to the SM, stabilised by a \mathbb{Z}_2

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \frac{1}{2} \partial_\mu \phi_i \partial^\mu \phi_i - \frac{1}{2} m_{ij} \phi_i \phi_j - \frac{1}{4!} \lambda'_{ijkl} \phi_i \phi_j \phi_k \phi_l - \frac{1}{2} \lambda'_{ij} \left(H^\dagger H \right) \phi_i \phi_j,$$

FIMP production is governed by the decay


$$\Rightarrow \lambda_{12 \text{ DM}} \simeq 1.2 \cdot 10^{-11} \left(\frac{m_1 + m_2}{\text{GeV}} \right)^{-1/2} \sqrt{\frac{\Omega_{\lambda_{12}}}{\Omega_{\text{DM}}}}$$

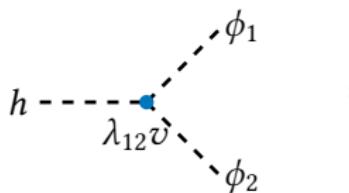


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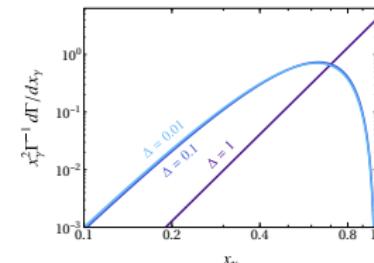
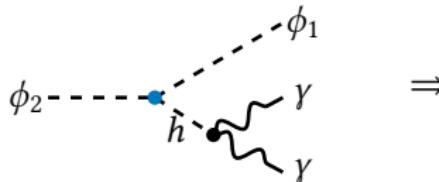
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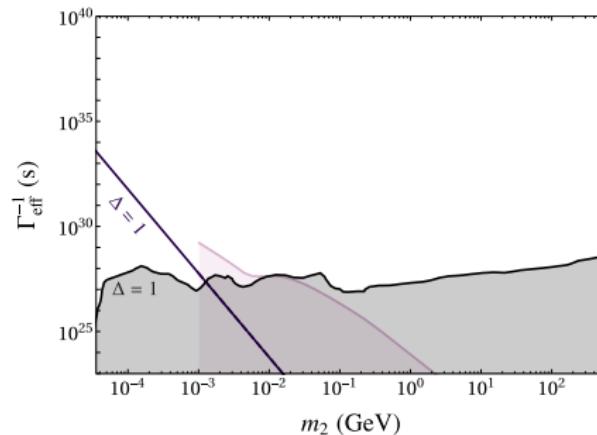
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λ_{12} induces dark matter decay into γ -rays [Ghosh et.al. 1909.13292]



Probing multiflavour FIMP dark matter

⇒ can relate production mechanism to signature!

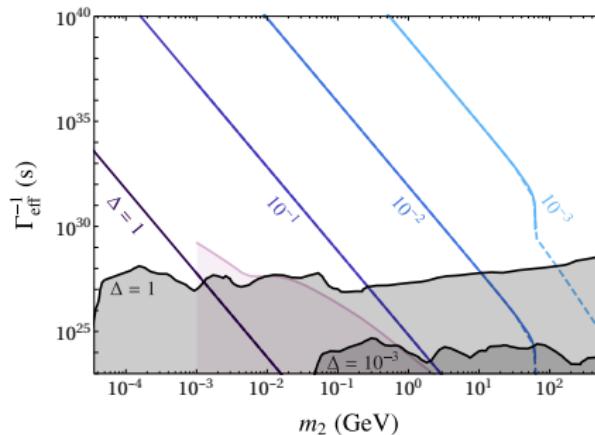


- Gamma ray telescopes probe FIMP masses down to MeV
- Lines show expected signal strength for $\Omega_{\lambda_{12}} = \Omega_{\text{DM}}$
- Limits from [Ghosh et.al. 1909.13292]
- small mass splitting $\Delta \equiv 1 - m_1^2/m_2^2$ suppresses signal
- $\delta m_{ij}^2 \sim \lambda'_{ij} v^2 / 2 \sim \text{MeV}$



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Fermionic multi-flavour Dark Matter

- SM fermions come in 3 generations, 1st generation dominates cosmology and astrophysics
- DM fermions?

DM fermion ψ , odd under \mathbb{Z}_2 → need mediator Σ to couple to SM

$$\begin{aligned}\mathcal{L} \supset & (\mathcal{D}_\mu \Sigma)^\dagger (\mathcal{D}^\mu \Sigma) - m_\Sigma \Sigma^\dagger \Sigma - \lambda_{H\Sigma} |H|^2 |\Sigma|^2 \\ & + \left(\frac{1}{2} \bar{\psi}_i i \not{\partial} \psi_i - \frac{1}{2} m_i \bar{\psi}_i^c \psi_i - g_i \bar{f}_{R,L} \psi_i \Sigma + \text{h.c.} \right)\end{aligned}$$



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- choose *leptophilic* scenario

$$\mathcal{L} \supset -g_i \bar{l}_R \psi_i \Sigma$$

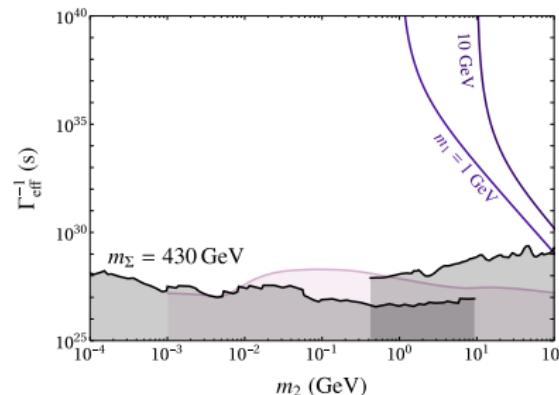
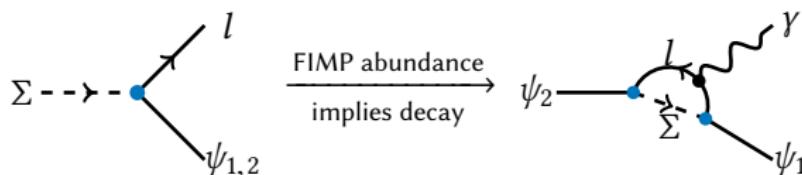
- single component scenario popular model: m_Σ , m_1 , g_1
- multi-flavour scenario:

$$m_\Sigma, m_2, m_1, g_2, g_1$$

→ *qualitatively different signatures?*



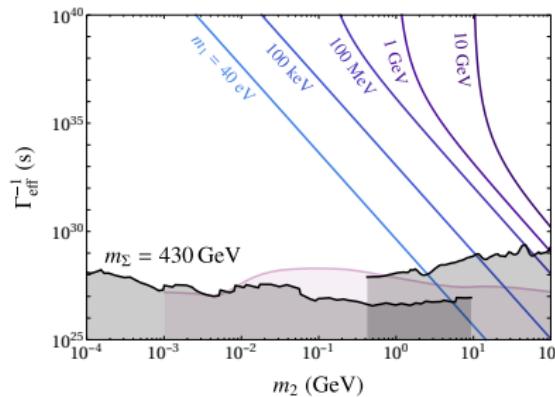
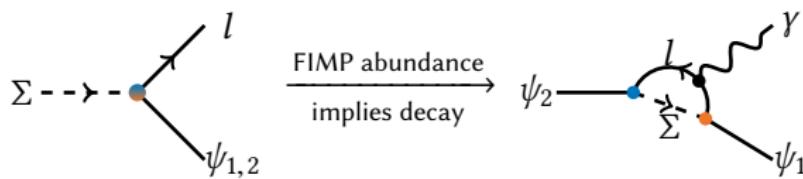
Decaying fermion FIMP DM



- Decay signal suppressed by two small couplings
- γ -ray line limits from [FermiLAT'1506.00013] and [Essig+'1309.4091], CMB limits from [Slatyer+'1610.06933]



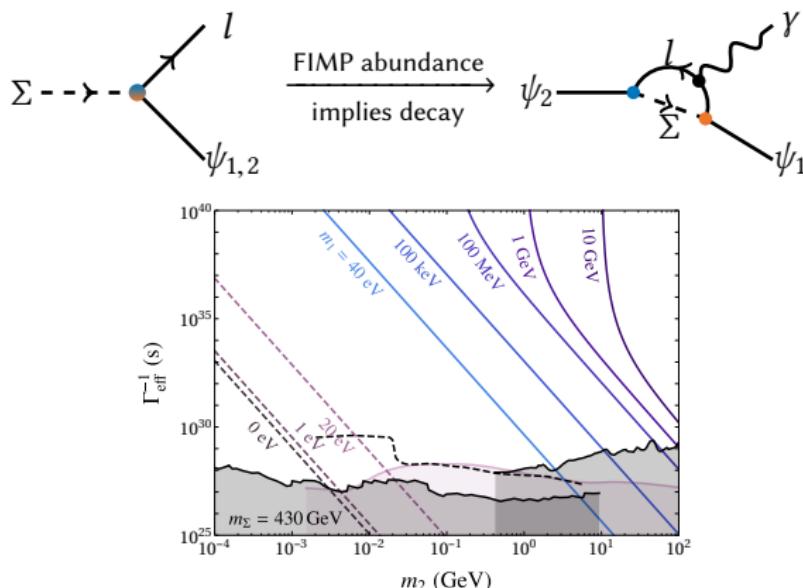
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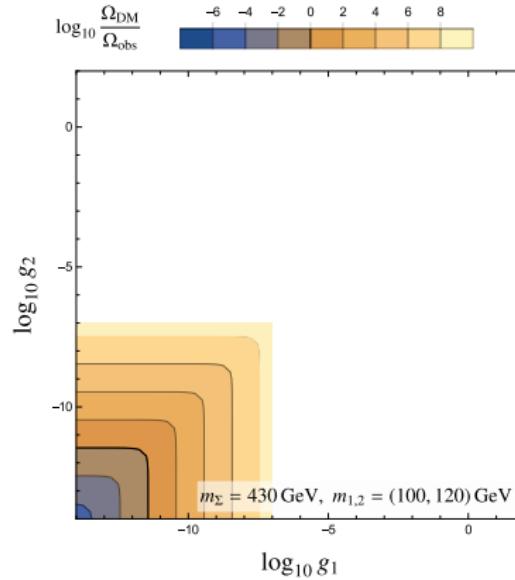


- Decay signal suppressed by two small couplings
- large coupling possible for small m_1
- ψ_1 may thermalise → **mixed FIMP - HDM**
 - g_1 constrained by limits on f_{ncdm} or ρ_{DR}



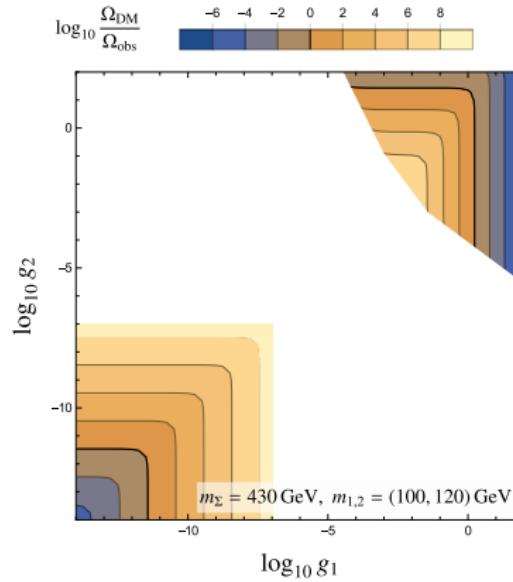
The full range of couplings

- Numerically solve Boltzmann system for particles $i = \Sigma, \psi_2, \psi_1$ in complete coupling parameter space



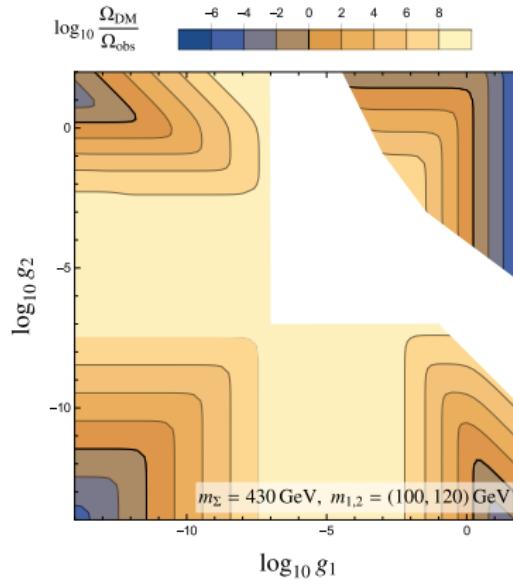
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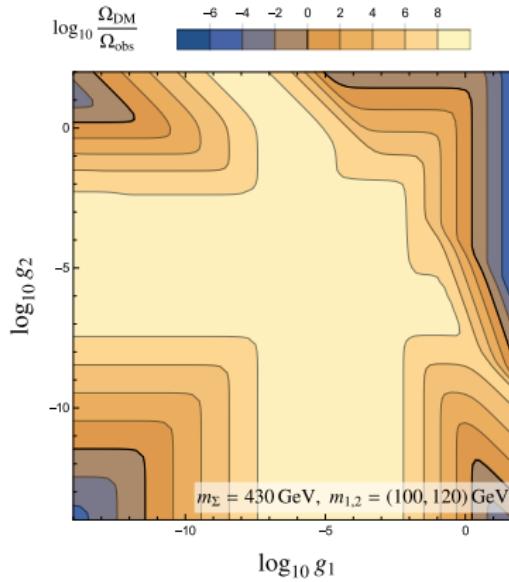
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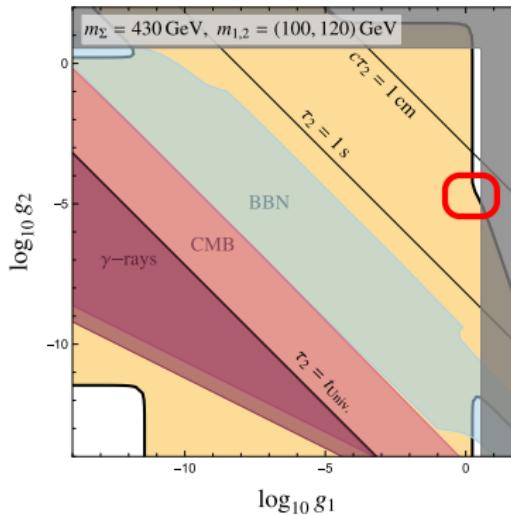
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- most of parameter space ruled out by overabundance
- complex interplay of reactions in WIMP-WIMP region



Conclusions

complications can make life interesting, simple is not generic

- Multicomponent freeze-in dark matter can be probed by DM-decay
- Portal coupling responsible for abundance controls gamma ray signals
- Real scalar singlet
 - (softened) sharp γ -ray spectral feature in the MeV range from decay via off-shell Higgs
- Leptophilic fermion
 - γ -ray lines in MeV to TeV range probe freeze-in
 - heavier flavour may enrich freeze-out options

