

Resonant or asymmetric: The status of sub-GeV dark matter

[2405.17548]

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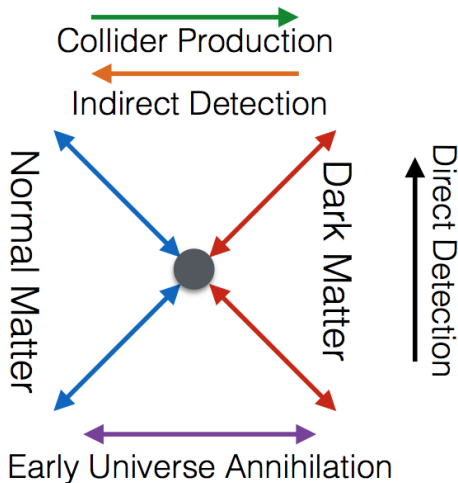
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Background: Dark Matter



- ▶ We assume dark matter (DM) is a particle.
- ▶ If there is weak interaction with the standard model, it can be probed by any/all of:
 - ▶ **Direct detection:** underground detector
 - ▶ **Indirect detection:** telescopes
 - ▶ **Collider searches:** missing energy
 - ▶ **Thermalisation:** cosmological equilibrium
- ▶ Thermalisation: the same thing we search for in the lab would mean DM is in equilibrium with standard model particles at early times, but freezes out at some point.
- ▶ This allows us to link particles physics modelling and cosmology.





Why sub-GeV?

- ▶ If DM is a particle,
 $m_{\text{DM}} \in [10^{-30}, 10^{19}] \text{ GeV}$,
($\lambda < H_0^{-1}$ and $m_{\text{DM}} < m_{\text{p}}$).
- ▶ If DM is thermal, $m > 10 \text{ MeV}$ from CMB
- ▶ Direct detection means $m < 1 \text{ GeV}$.
- ▶ sub-GeV DM was thought ruled out due to Lee-Weinberg bound (known standard model interactions can't produce enough DM).
- ▶ However, Dark Matter + “Dark Photons” ($U(1)'$ gauge group) escapes this bound.

$$[2405.17548] = [\psi, \Phi] \times [\eta_{\text{DM}}, \cdot] \times [f_{\text{DM}}, \cdot]$$

Switches we consider:

- ▶ Fermionic ψ or Scalar Φ
- ▶ Asymmetric $\eta_{\text{DM}} \neq 0$ or symmetric $\eta_{\text{DM}} = 0$
- ▶ Dominant $f_{\text{DM}} = 1$ or sub-dominant $f_{\text{DM}} < 1$



- ▶ Dark photon A' with mass $m_{A'}$ (via Stueckelberg mechanism) with kinetic mixing κ .

$$\mathcal{L} = -\frac{1}{2}m_{A'}^2 A'_\mu A'^\mu - \frac{1}{4}A'_{\mu\nu} A'^{\mu\nu} - \kappa e A'^\mu \sum_{f \in \text{SM}} q_f \bar{f} \gamma_\mu f$$

- ▶ Dark matter candidate χ with mass m_{DM} , with $\chi \in \{\Phi, \psi\}$ complex scalar or Dirac fermion, coupled to the dark photon with g_{DM} .

$$\mathcal{L}_\psi = \bar{\psi}(i\not{\partial} - m_{\text{DM}})\psi + g_{\text{DM}} A'^\mu \bar{\psi} \gamma_\mu \psi$$

$$\mathcal{L}_\Phi = |\partial_\mu \Phi|^2 - m_{\text{DM}}^2 |\Phi|^2 - g_{\text{DM}}^2 A'_\mu A'^\mu |\Phi|^2 + i g_{\text{DM}} A'^\mu [\Phi^* (\partial_\mu \Phi) - (\partial_\mu \Phi^*) \Phi],$$

- ▶ Dark matter different from its anti-particle, there may be an asymmetry η_{DM}
- ▶ Also have local halo DM density ρ_0 , velocity dispersion v_0 and escape velocity v_{esc} as nuisance parameters determined by Gaia data [1901.02016] *et al.*
- ▶ Focus on sub GeV region $\text{MeV} < m_{\text{DM}} < \text{GeV}$.



Cosmological constraints

CMB & BBN

$\Omega_c h^2 \approx 0.120 \pm 0.001$ from *Planck*

$N_{\text{eff}} \approx 2.99 \pm 0.17$ via AlterBBN

Astrophysical constraints

X-rays & Bullet cluster

INTEGRAL, NuStar, XMM-Newton, Suzaku

Bullet cluster gives self-interaction constraints

Accelerator constraints

Beam dumps & electron-positron colliders

beam dump: LSND, MiniBooNE missing

energy searches: NA64, BaBar

Direct detection constraints

searches for electron & nuclear recoils

Xenon1T, SENSEI, DarkSide50, PandaX-4T,

DAMIC-M, SuperCDMS HV

GAMBIT: The Global And Modular BSM Inference Tool

gambit.hepforge.org

github.com/GambitBSM

EPJC 77 (2017) 784

arXiv:1705.07908

- Extensive model database, beyond SUSY
- Fast definition of new datasets, theories
- Extensive observable/data libraries
- Plug&play scanning/physics/likelihood packages
- Various statistical options (frequentist /Bayesian)
- Fast LHC likelihood calculator
- Massively parallel
- Fully open-source



Members of: ATLAS, Belle-II, CLIC, CMS, CTA, Fermi-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

Authors of: BubbleProfiler, Capt'n General, Contur, DarkAges, DarkSUSY, DDCalc, DirectDM, Diver, EasyScanHEP, ExoCLASS, FlexibleSUSY, gamLike, GM2Calc, HEPLike, IsaTools, MARTY, nuLike, PhaseTracer, PolyChord, Rivet, SOFTSUSY, SuperIso, SUSY-AI, xsec, Vevacious, WIMPSim

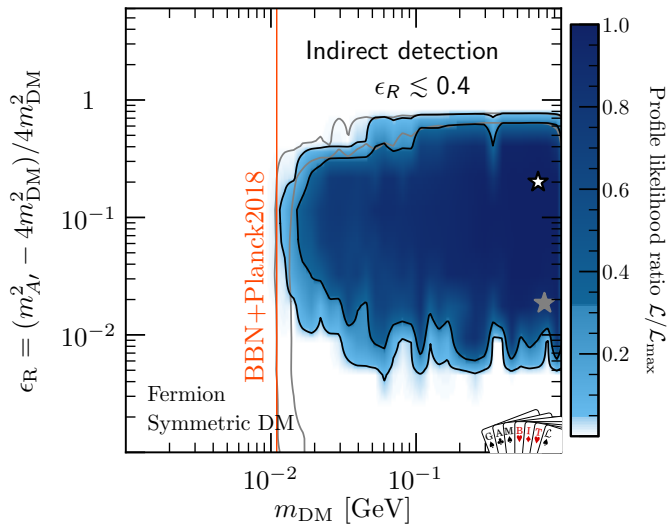
Recent collaborators: V Ananyev, P Athron, N Avis-Kozar, C Balázs, A Beniwal, LL Braseth, T Bringmann, A Buckley, J Butterworth, JE Camargo-Molina, C Chang, J Cornell, M Danninger, A Fowlie, T Gonzalo, W Handley, S Hoof, A Jueid, F Kahlhoefer, A Kvellestad, M Lecroq, C Lin, M Lucente, FN Mahmoudi, DJE Marsh, G Martinez, H Pacey, MT Prim, T Procter, F Rajec, A Raklev, R Ruiz, A Scaffidi, P Scott, W Shorrock, C Sierra, P Stöcker, W Su, J Van den Abeele, A Vincent, M White, A Woodcock, Y Zhang ++

70+ participants in many experiments and numerous major theory codes

Parameter estimation



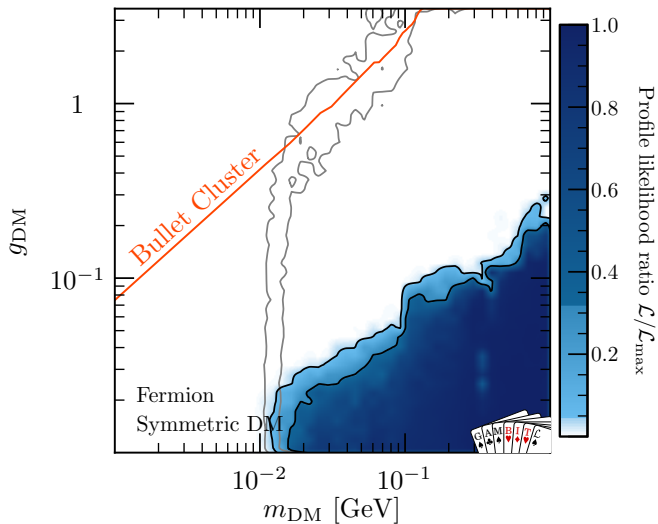
- ▶ Frequentist analysis: Profile likelihood plots optimise unseen parameters
- ▶ Can build intuition for how data constrain parameters
- ▶ Global fit extracts more information than traditional particle physics approach
- ▶ Grey contours have $f_{\text{DM}} \leq 1$.
- ▶ Similar plots for fermions.
- ▶ Asymmetric dark matter less constrained.
- ▶ GAMBIT is flexible enough to also do Bayesian analyses.



Parameter estimation



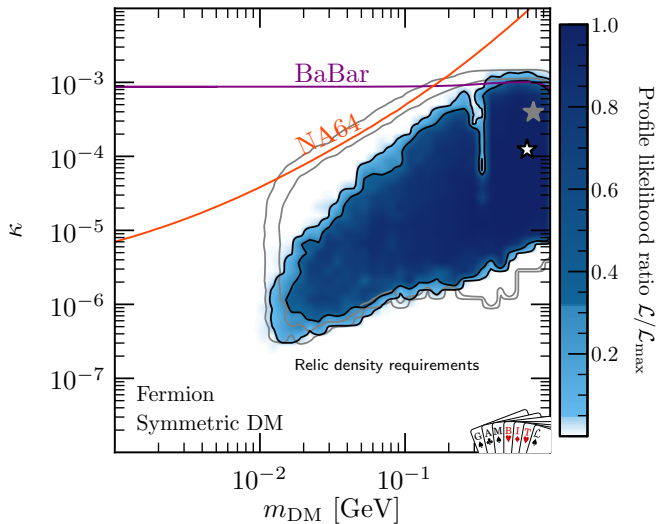
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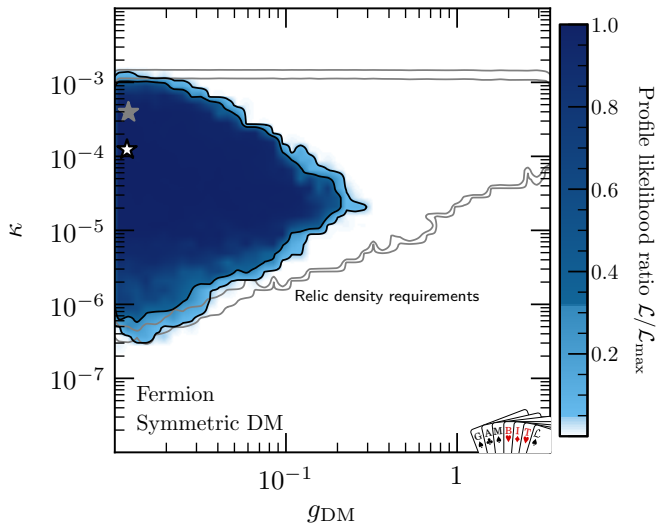
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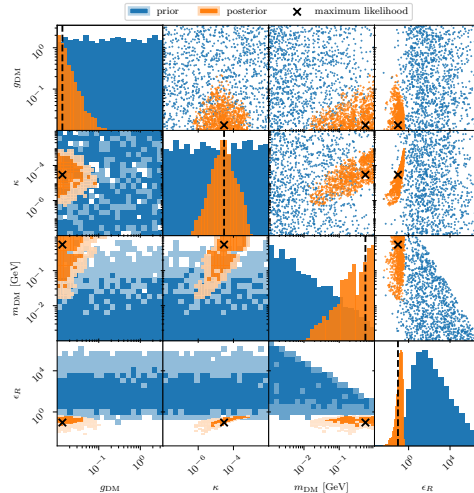
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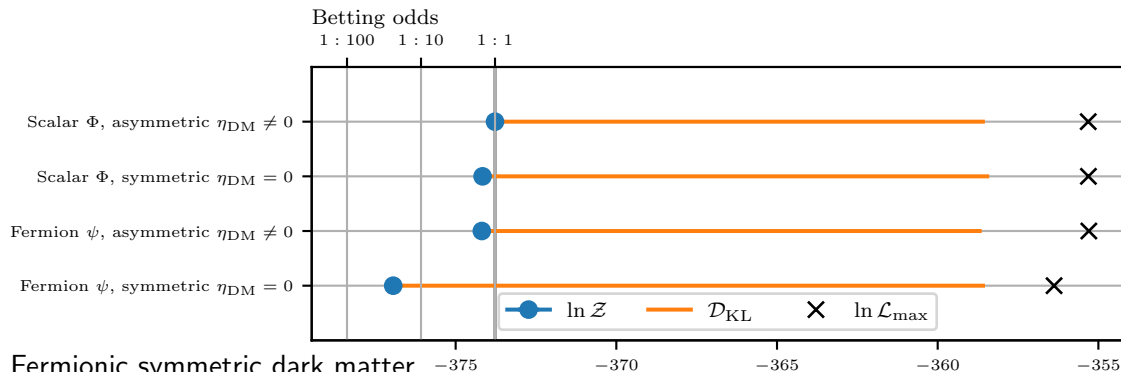


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Fermion ψ , symmetric $m_{\text{DM}} = 0$, $\Omega_{\text{DM}} h^2 \approx 0.12$

Model comparison

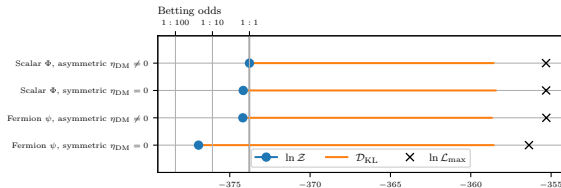


- Fermionic symmetric dark matter disfavoured

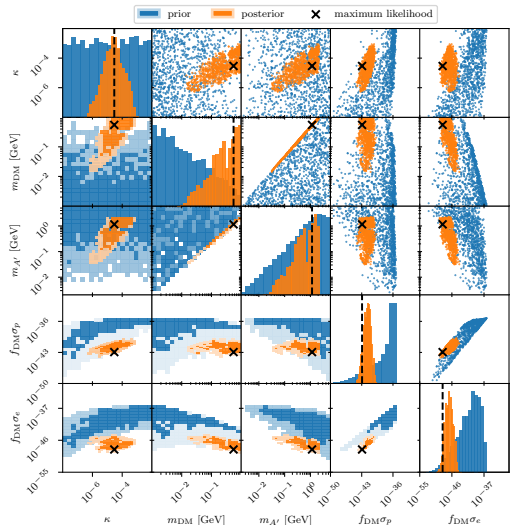
Model comparison



- ▶ Fermionic symmetric dark matter disfavoured



- ▶ This is because the the cross sections with SM need to be more fine-tuned.
- ▶ contrasts with scalar as it's easier to generate dark matter without asymmetry (p -wave suppression of annihilation cross section).

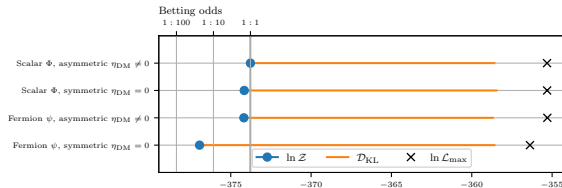


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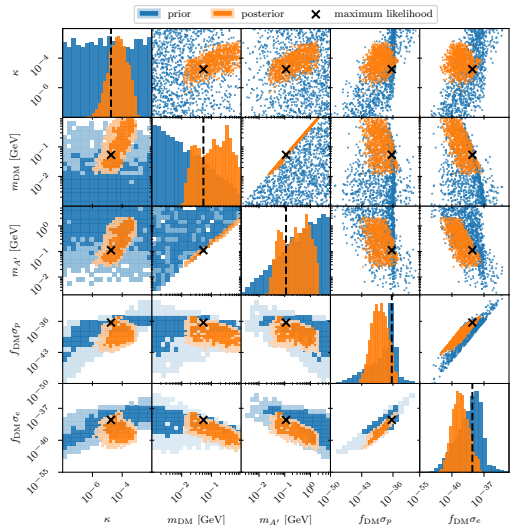
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Fermion ψ , asymmetric $\eta_{DM} \neq 0$, $\Omega_{DM} h^2 \approx 0.12$



- ▶ GAMBIT DarkBit, CosmoBit & ScannerBit modules now mature enough to fit principled dark matter models to a wide variety of data.
- ▶ Unique combination of tools & expertise that can systematically test dark matter models.
- ▶ Looking for other possible contributions to GAMBIT physics-driven global fits