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

[2405.17548]

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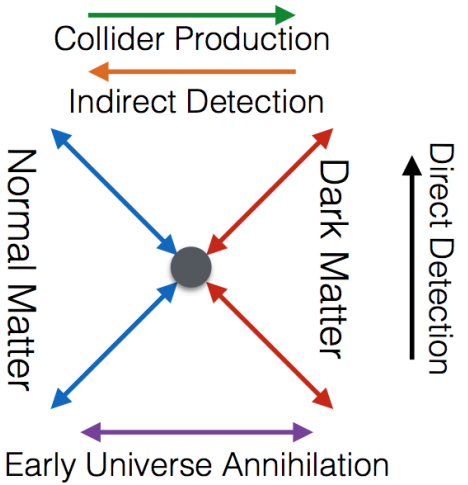
Background: Dark Matter

- 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.



Summary

Why sub-GeV?

- If DM is a particle, $m_{\rm DM} \in [10^{-30}, 10^{19}]$ GeV, ($\lambda < H_0^{-1}$ and $m_{\rm DM} < m_{\rm p}$).
- If DM is thermal, $m > 10$ MeV from CMB
- Direct detection means $m < 1$ 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]$= [\psi, \Phi] \times [\eta_{\rm DM}, \cdot] \times [f_{\rm DM}, \cdot]$

Switches we consider:

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

We find that Fermionic, symmetric, dominant DM is disfavoured.
The other three alternatives separately still allowed in much of the parameter space.

Physics

- Dark photon A' with mass $\boxed{m_{A'}}$ (via Stueckelberg mechanism) with kinetic mixing $\boxed{\kappa}$.

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

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

$$\begin{aligned}\mathcal{L}_\psi &= \bar{\psi}(i\partial\!\!\!/ - m_{\mathrm{DM}})\psi + g_{\mathrm{DM}} A'^\mu \bar{\psi}\gamma_\mu\psi \\ \mathcal{L}_\Phi &= |\partial_\mu \Phi|^2 - m_{\mathrm{DM}}^2|\Phi|^2 - g_{\mathrm{DM}}^2 A'_\mu A'^\mu |\Phi|^2 + i g_{\mathrm{DM}} A'^\mu \left[\Phi^*(\partial_\mu\Phi) - (\partial_\mu\Phi^*)\Phi\right],\end{aligned}$$

- Dark matter different from its anti-particle, there may be an asymmetry $\boxed{\eta_{\mathrm{DM}}}$
- 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 MeV $< m_{\mathrm{DM}} <$ GeV.

Data

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`

Accelerator constraints

Beam dumps & electron-positron colliders

beam dump: LSND, MiniBooNE missing energy searches: NA64, BaBar

Astrophysical constraints

X-rays & Bullet cluster

INTEGRAL, NuStar, XMM-Newton, Suzaku

Bullet cluster gives self-interaction constraints

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 packa
- 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

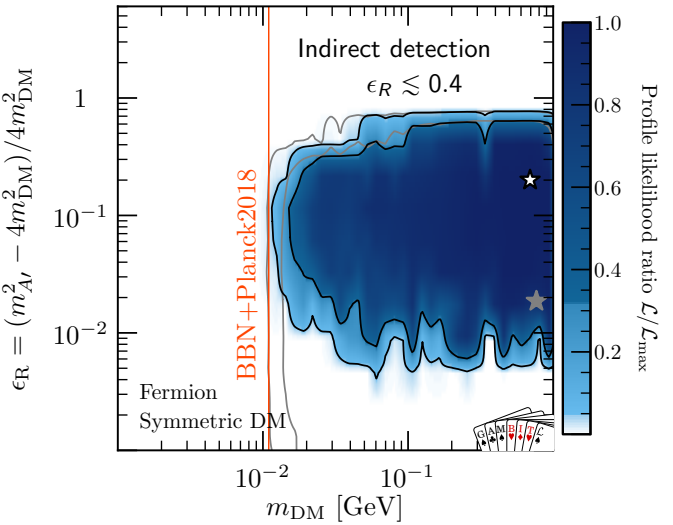
Authors of: BubbleProfiler, Capt'n General, Contur, DarkAges, DarkSUSY, DDCalc, DirectDM, Diver, EasyScanHEP, ExoCLASS, FlexibleSUSY, gamLike, GM2Calc, HEPLike, IsaTools, MARTY, nuLike, PhaseTracer, PolyChord, Rivet, SOFTSUSY, Superlso, SUSY-AI, xsec, Vevacious, WIMPSim

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 $f_{\rm DM} \leqslant 1$.
- Similar plots for fermions.
- Asymmetric dark matter less constrained.
- GAMBIT can do Bayesian & Frequentist analyses.



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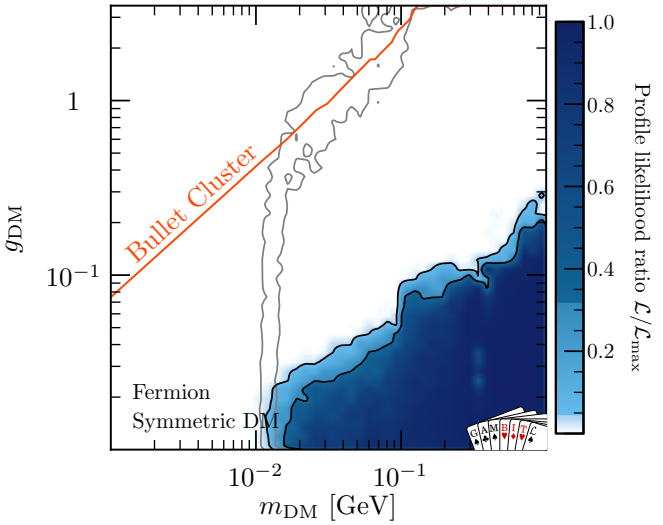

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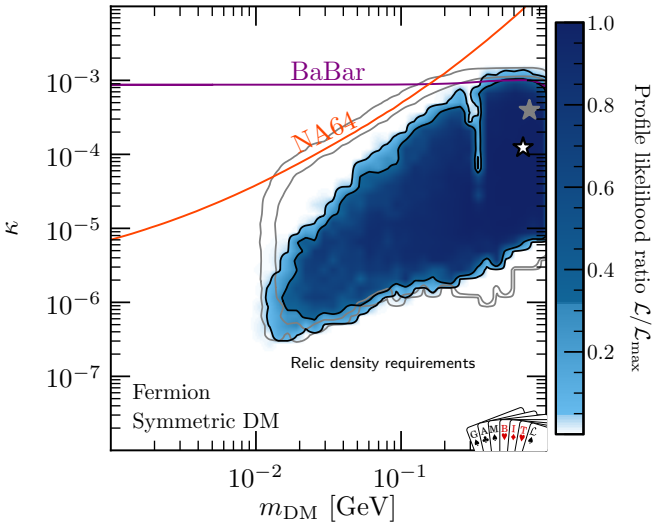

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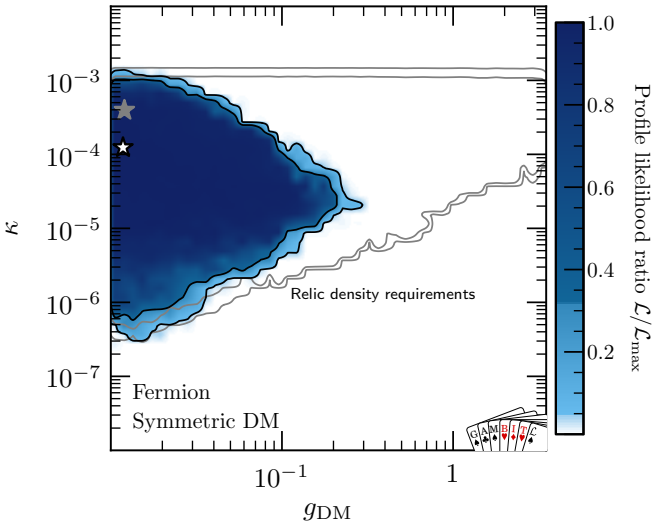

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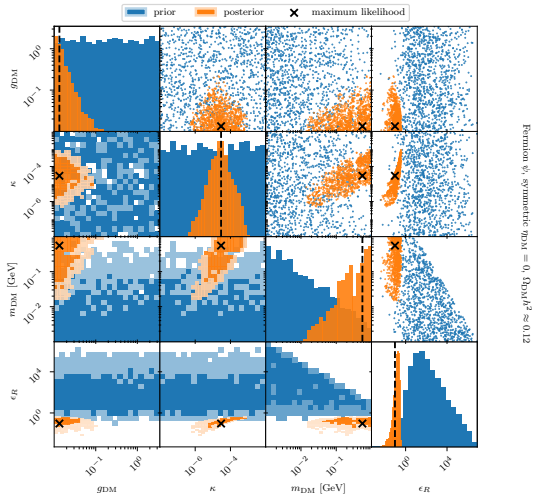
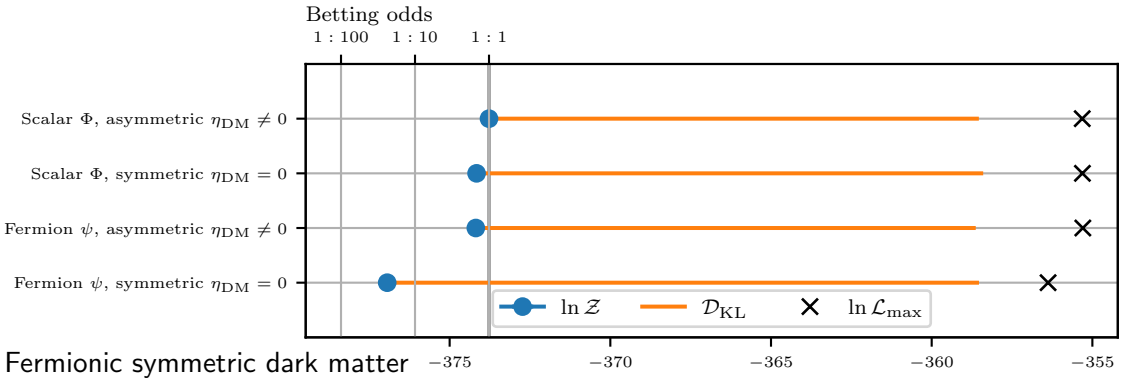


Model comparison



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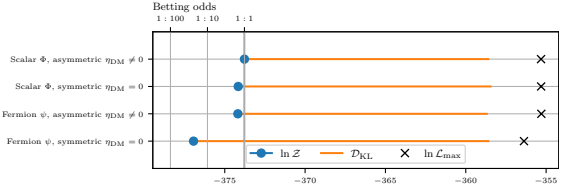
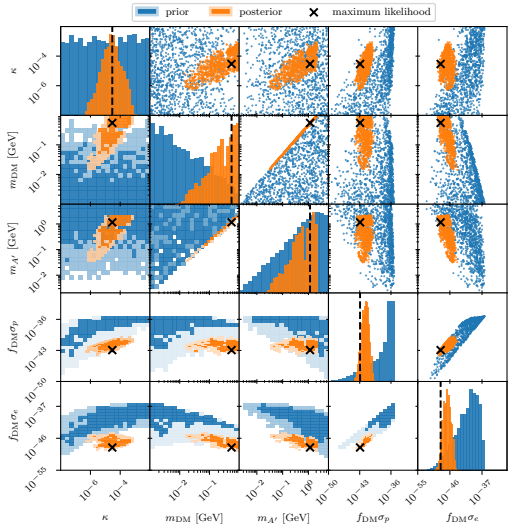


- This is because the the cross sections with SM need to be more fine-tuned.
- contrasts with scalar as it's easier to generate dark matter without asymmetry (p-wave suppression of annihilation cross section).



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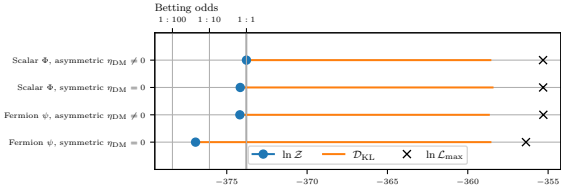

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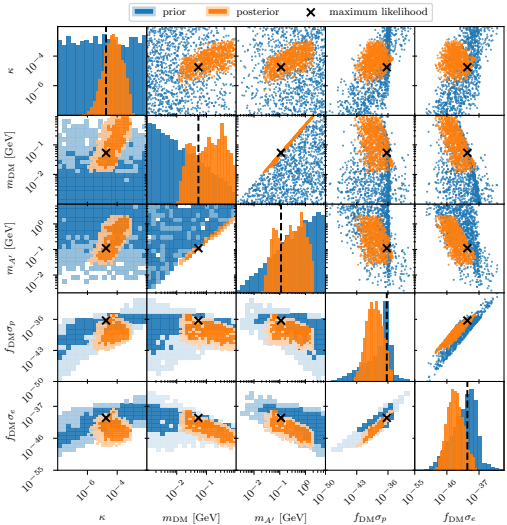

Conclusions

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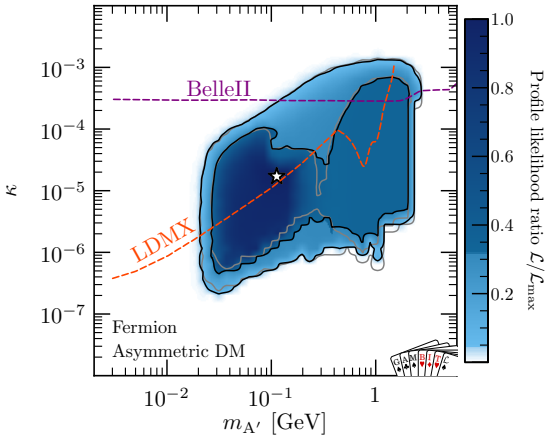
- GAMBIT `DarkBit`, `CosmoBit` & `ScannerBit` modules now mature enough to fit principled dark matter models to a wide variety of data.
- Unique combination of tools & expertise that can systematically test dark matter models.
- Future detectors will constrain these further.
- Looking for other possible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



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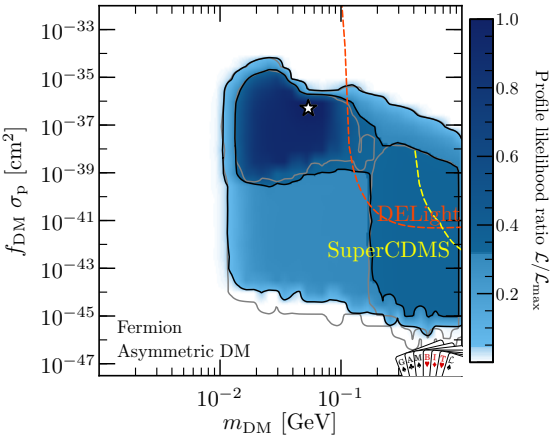

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