

XENON1T excess as a possible signal of sub-GeV DM

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Work done with A. Aboubrahim and P. Nath, JHEP 02 (2021) 229



Graduiertenkolleg 2149
Research Training Group

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Motivation

XENON Coll., Phys. Rev. D 102 (2020) 072004

Low-energy electron recoil excess in XENON1T:

- XENON designed for nuclear recoil, but very low background
- Also sensitive to electron recoil, distinguished by S2/S1 ratio
- Signal should only produce single energy deposition
- Ten background sources: ^{131m}Xe , ^{214}Pb , ^{133}Xe , ^{83m}Kr , ...
- Excess keV electron recoil in SR1 (2/17-2/18, 1042 kg)

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Tested signal hypotheses:

- Solar axions: More energetic than primordials, maybe not DM
- Neutrino μ : $> 10^{-20} \mu_B$ for BSM, $> 10^{-15} \mu_B$ for Majorana ν
- ALPs: Possibly heavier than axions, do not solve CP problem

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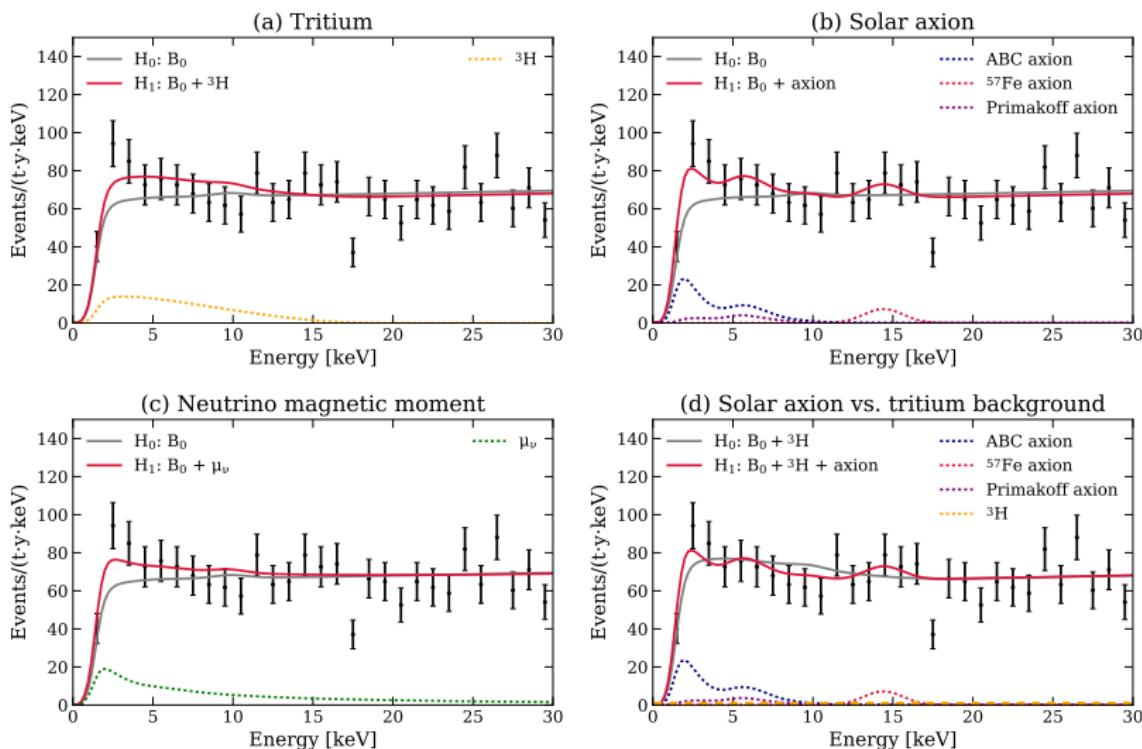
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Alternative background hypothesis: ^3H β -decay in Xe or materials

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Stueckelberg model with dark fermions

A. Aboubrahim, MK, P. Nath, JHEP 02 (2021) 029

Stueckelberg model:

[B. Kors, P. Nath, PLB 586 (2004) 366]

- Extra $U(1)_X$ with C_μ , kinetic mixing with $U(1)_Y$ field B_μ
- Stueckelberg mechanism for mass generation (σ model)

$$\Delta\mathcal{L} \supset -\frac{1}{4}C_{\mu\nu}C^{\mu\nu} - \frac{\delta}{2}C_{\mu\nu}B^{\mu\nu} + g_X J_X^\mu C_\mu - \frac{1}{2}(\partial_\mu\sigma + M_1 C_\mu + M_2 B_\mu)^2$$

- In principle also mass mixing, but here $M_2 = 0$

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Dark sector:

- Dark photon C_μ with small kinetic mixing $\delta \sim 10^{-5}$
- 2 Dirac fermions $D_{1,2}$ with charges $Q_1 = 0.4$, $Q_2 = 0.1$
- Inelastic scattering $eD'_2 \rightarrow eD'_1$ with $\Delta m \sim 2.8$ keV

Model	m_D (GeV)	$m_{\gamma'}$ (MeV)	g_X	δ	Ωh^2	$\bar{\sigma}_e$ (cm 2)
(a)	1.00	55	0.040	4.0×10^{-5}	0.125	2.80×10^{-44}
(b)	0.50	60	0.025	6.0×10^{-5}	0.121	1.75×10^{-44}
(c)	0.30	300	0.055	7.5×10^{-4}	0.116	1.19×10^{-44}

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Can also generate both $m_{\gamma'}$ and Δm from SSB (complex scalar ϕ)

Relic density calculation

A. Aboubrahim, MK, P. Nath, JHEP 02 (2021) 029

Visible sector (VS) and dark sector (DS):

- Feeble interactions of VS and DS → Freeze-in
- Normal interactions of DS and DS → Freeze-out
- Thermalization → Same temperature of VS and DS
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Single Boltzmann equation ($\Delta m \ll m_D$):

$$\frac{dY_D}{dx} \approx -1.32 M_{\text{Pl}} \frac{h_{\text{eff}}(T)}{g_{\text{eff}}^{1/2}(T)} \frac{m_D}{x^2} \left(-\langle \sigma v \rangle_{D\bar{D} \rightarrow i\bar{i}} Y_D^{\text{eq}}{}^2 + \langle \sigma v \rangle_{D\bar{D} \rightarrow \gamma'\bar{\gamma}'} Y_D^2 \right)$$

Equilibrium yield: $Y_D^{\text{eq}}(x) = \frac{45}{4\pi^4} \frac{g_D}{h_{\text{eff}}(T)} x^2 K_2(x)$ with $x = m_D/T$

Relic density: $\Omega h^2 = \frac{m_D Y_\infty s_0 h^2}{\rho_c} = 0.1198 \pm 0.0012$ (Planck)

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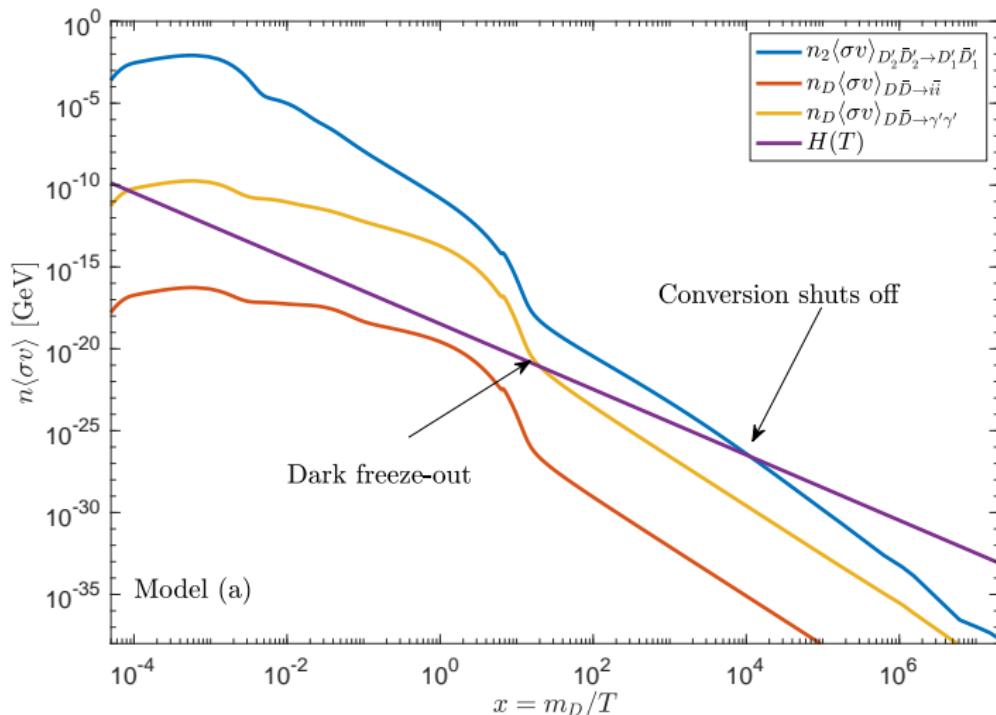
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Decay process: $\Gamma_{D'_2 \rightarrow D'_1 \nu \bar{\nu}} \simeq \frac{x_\nu^2 (\Delta m)^5}{40\pi^3 m_{\gamma'}^4} \rightarrow \tau_{D'_2} \sim 10^{13}$ years

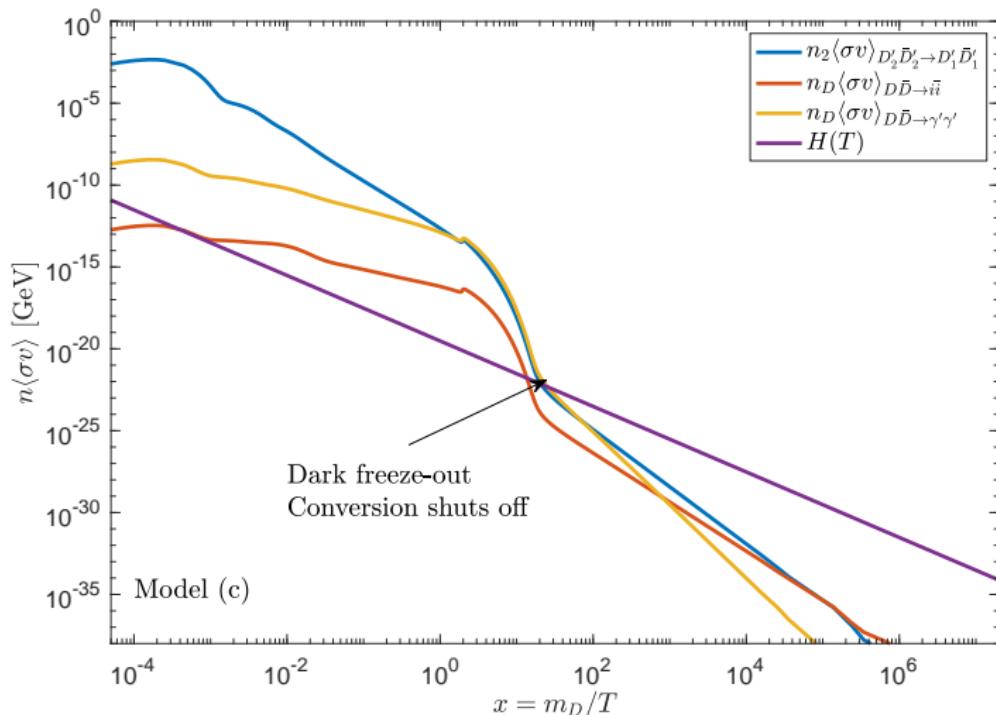
Relic density in Model (a)

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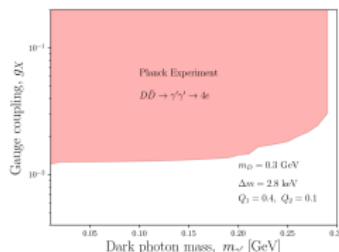
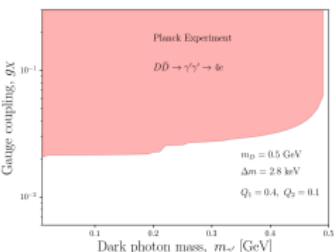
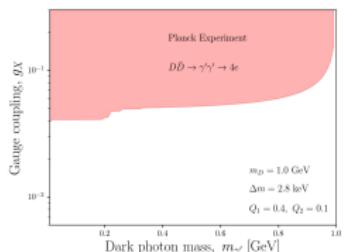
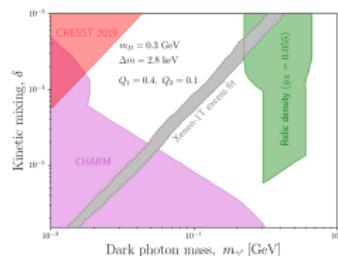
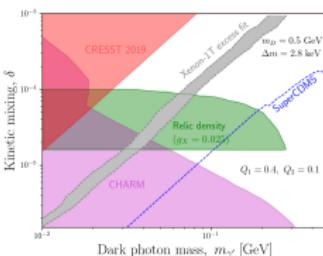
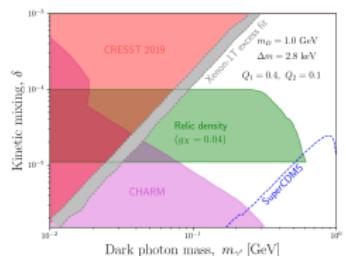
Relic density in Model (c)

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Other constraints

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Nuclear recoil, γ' decays from p beam dumps, energy injection from DM

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DM-electron scattering

Inelastic scattering ($eD'_2 \rightarrow eD'_1$):

$$\overline{|\mathcal{M}|^2} = \frac{2\bar{g}_X^2 g_2^2}{m_{\gamma'}^4 \cos^2 \theta} \left\{ \frac{1}{2} (a_f'^2 - v_f'^2) \left[(m_1 - m_2)^2 - (t + 2m_1 m_2) \right] m_e^2 + \frac{1}{4} (v_f'^2 + a_f'^2) \left[(m_2^2 + m_e^2 - u) \right. \right. \\ \left. \left. (m_1^2 + m_e^2 - u) + (s - m_1^2 - m_e^2)(s - m_2^2 - m_e^2) - 2m_1 m_2 (2m_e^2 - t) \right] \right\} \times |F_{DM}(q)|^2$$

with $\bar{g}_X = \frac{1}{2} g_X (Q_1 - Q_2)$ and $F_{DM}(q) \sim 1$ for small q .

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Total cross section:

$$\bar{\sigma}_e \simeq \frac{\bar{g}_X^2 g_2^2}{16\pi m_{\gamma'}^4 \cos^2 \theta} \left(\frac{4\mu_{De}^2}{1 + \frac{\mu_{De}}{m_2 + m_e} v^2} \right) [v_f'^2 + (a_f'^2 + v_f'^2)v^2]$$

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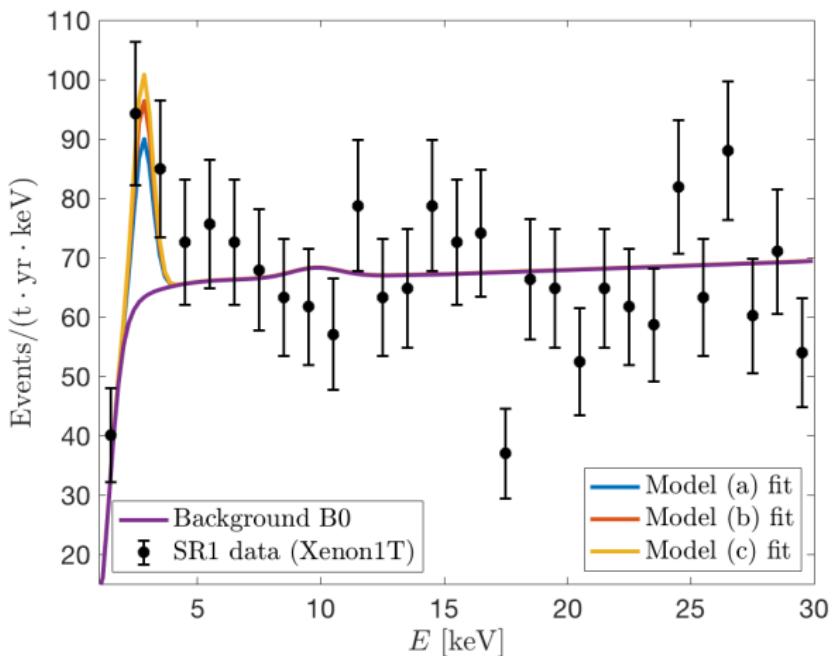
Detection rate:

$$\frac{dR}{dE} = n_{Xe} \rho_2 \sqrt{\frac{2\Delta m}{m_e m_2}} \frac{\bar{\sigma}_e}{K'(\Delta m)} R_S(E, \Delta m)$$

with $n_{Xe} \simeq 4.2 \times 10^{27}/\text{ton}$ and $K'(E_R) \equiv \int_{q_-}^{q_+} dq a_0^2 q K(E_R, q)$.

The XENON1T signal in the dark $U(1)_X$ model

A. Aboubrahim, MK, P. Nath, JHEP 02 (2021) 029



Recoil rate from inelastic scattering: $\frac{dR}{dE} \simeq (1.5 \times 10^{45} \text{ GeV/cm}^2) \frac{\bar{\sigma}_e}{m_2} R_S(E, \Delta m)$

Conclusion

Motivation:

- XENON1T observed keV e^- recoil excess in SR1 (2/17-2/18)
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- Key ingredients: Freeze-in + freeze-out, inelastic scattering
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- 3 models: $m_D = 0.3 \dots 1 \text{ GeV}$, $m_{\gamma'} = 55 \dots 300 \text{ MeV}$, $\Delta m = 2.8 \text{ keV}$
- The last two can also be generated by SSB (complex ϕ)
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Outlook:

- Other models: Solar axions, ν magnetic moment, ALPs, ...
- Distinction crucial: New results coming soon (also nT, LZ)