WIMP direct detection: EFT and phenomenological analysis

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The University of Adelaide

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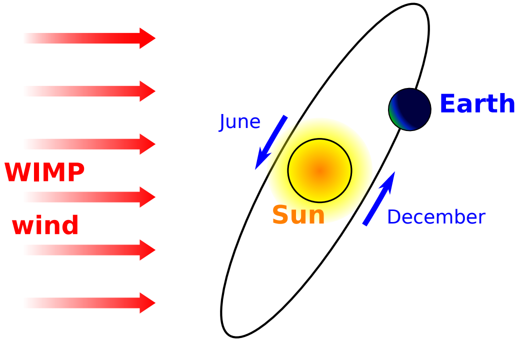
Part I: EFT in WIMP direct detection

Annual modulation of the event rate in direct detection is the key feature for a dark matter signal in direct detection experiments
K. Freese, Rev. Mod. Phys. **85** (2013) 1561

$$\frac{dR}{dE}(E, t) = S_0(E) + S_m(E)\cos\frac{2\pi}{T_0}(t - t_0) \quad (1)$$



DAMA/LIBRA

NaI target

- DAMA
  R. Bernabei *et al.*, Eur. Phys. J. C **56**, 333 (2008)
- DAMA/LIBRA phase-1
  R. Bernabei *et al.*, Eur. Phys. J. C **73**, 2648 (2013)
- DAMA/LIBRA phase-2
  R. Bernabei *et al.*, Universe **4**, 116 (2018).

Null experiments

- XENON100: Xenon
  E. Aprile, Phys. Rev. Lett. **109**, 181301 (2012)
- CDMS: Germanium
  Z. Ahmed, Science **327**, 1619 (2010);
- PICASSO: Fluorine
  E. Behnke, Astropart. Phys. **90**, 85 (2017)
- COUPP, PICO-60: Fluorine-Iodine
  E. Behnke, Phys. Rev. D **86**, 052001 (2012);
  C. Amole, Phys. Rev. D **93**, 052014 (2016)
- CRESST-II: Calcium
  G. Angloher, Eur. Phys. J. C **72**, 1971 (2012).

and more . . .

The differential recoil rate in direct detection is given by

$$\frac{dR_{\chi T}}{dE_R} = \sum_T N_T \frac{\rho_\chi}{m_\chi} \int_{v_{\min}} d^3 v f(\vec{v}, t) v \frac{d\sigma_{\chi T}}{dE_R}, \quad (2)$$

where

$$\frac{d\sigma_{\chi T}}{dE_R} = \frac{2m_T}{4\pi v^2}\left[\frac{1}{2j_\chi + 1}\frac{1}{2j_T + 1}\sum_{spins} |\mathcal{M}|_T^2\right], \quad (3)$$

Calculation of $|\mathcal{M}|_T$ – NR EFT

- WIMP-nucleon operators, $\mathcal{O}_{\chi N} = \sum_i c_i \mathcal{O}_i$
- Embedding $\mathcal{O}_{\chi N}$ in nucleus states

N. Anand *et al.*, Phys. Rev. C **89**, 065501 (2014)

Elastic Effective Operators

For dark matter spin 0 or 1/2,

$$\chi(p) + N(k) \to \chi(p') + N(k')$$

with $\vec{v} = \vec{v}_{\chi,\text{in}} - \vec{v}_{N,\text{in}}$ and $\vec{q} = \vec{p}' - \vec{p}$.

It is convenient to define

$$\vec{v}^{\perp} = \vec{v} + \vec{q}/2\mu_{\chi N}, \tag{4}$$

which satisfies $\vec{v}^{\perp} \cdot \vec{q} = 0$.

NR effective field theory

N. Anand *et al.*, Phys. Rev. C **89**, 065501 (2014)

In non-relativistic limit, the wavefunction of free nucleon,

$$U(p) = \sqrt{\frac{E+m}{2m}} \begin{pmatrix} \xi \\ \frac{\vec{\sigma}\cdot\vec{p}}{E+m}\xi \end{pmatrix} \to \begin{pmatrix} \xi \\ \frac{\vec{\sigma}\cdot\vec{p}}{2m}\xi \end{pmatrix}, \quad (5)$$

- $\mathcal{L} = c_1 \bar{\chi}\chi\bar{N}N \to c_1 \xi_\chi^\dagger \mathbf{1}_\chi \xi_\chi \; \xi_N^\dagger \mathbf{1}_N \xi_N + \mathcal{O}(p/m_N)$
  $\Rightarrow \mathcal{O}_1 = \mathbf{1}_\chi \mathbf{1}_N$
- $\mathcal{L} = c_4 \bar{\chi}\gamma_\mu\gamma_5\chi\bar{N}\gamma^\mu\gamma_5 N \to -4c_4 \xi_\chi^\dagger (S_\chi)_i \xi_\chi \; \xi_N^\dagger (S_N)_i \xi_N$
  $\Rightarrow \mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$

j	$\mathcal{L}^j_{\rm int}$	NR Reduction in medium ($\xi^\dagger \mathcal{O}_{eff} \xi$)	$\sum_i c_i \mathcal{O}_i$
1	$\bar\chi\chi\bar N N$	$1_\chi 1_N$ $\rightarrow$ Standard SI	$\mathcal{O}_1$
2	$i\bar\chi\chi\bar N\gamma^5 N$	$i\frac{\vec q}{m_N}\cdot\vec S_N$	$\mathcal{O}_{10}$
3	$i\bar\chi\gamma^5\chi\bar N N$	$-i\frac{\vec q}{m_\chi}\cdot\vec S_\chi$	$\mathcal{O}_{11}$
4	$\bar\chi\gamma^5\chi\bar N\gamma^5 N$	$-(\frac{\vec q}{m_\chi}\cdot\vec S_\chi)(\frac{\vec q}{m_N}\cdot\vec S_N)$	$\mathcal{O}_6$
5	$\bar\chi\gamma^\mu\chi\bar N\gamma_\mu N$	$1_\chi 1_N$	$\mathcal{O}_1$
6	$\bar\chi\gamma^\mu\chi\bar N i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}N$	$\frac{\vec q^2}{2m_N m_M}1_\chi 1_N + 2(\frac{\vec q}{m_\chi}\times\vec S_\chi + i\vec v^\perp)\cdot(\frac{\vec q}{m_M}\times\vec S_N)$	$\{\mathcal{O}_1,\mathcal{O}_3,\mathcal{O}_4,\mathcal{O}_6\}$
7	$\bar\chi\gamma^\mu\chi\bar N\gamma_\mu\gamma^5 N$	$-2\vec S_N\cdot\vec v^\perp + 2i\vec S_\chi\cdot(\vec S_N\times\frac{\vec q}{m_\chi})$	$\{\mathcal{O}_7,\mathcal{O}_9\}$
8	$\bar\chi i\gamma^\mu\chi\bar N\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}\gamma^5 N$	$2i\frac{\vec q}{m_M}\cdot\vec S_N$	$\mathcal{O}_{10}$
9	$\bar\chi i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\chi\bar N\gamma_\mu N$	$-\frac{\vec q^2}{2m_\chi m_M}1_\chi 1_N - 2(\frac{\vec q}{m_M}\times\vec S_\chi)\cdot(\frac{\vec q}{m_N}\times\vec S_N + i\vec v^\perp)$	$\{\mathcal{O}_1,\mathcal{O}_4,\mathcal{O}_5,\mathcal{O}_6\}$
10	$\bar\chi i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\chi\bar N i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}N$	$4(\frac{\vec q}{m_M}\times\vec S_\chi)\cdot(\frac{\vec q}{m_M}\times\vec S_N)$	$\{\mathcal{O}_4,\mathcal{O}_6\}$

11	$\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\chi\bar{N}\gamma_\mu\gamma_5 N$	$4i(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)\cdot\vec{S}_N$	$\mathcal{O}_9$
12	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\chi\bar{N}i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}\gamma^5 N$	$-[i\frac{\vec{q}^2}{m_\chi m_M}-4\vec{v}^\perp\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)](\frac{\vec{q}}{m_M}\cdot\vec{S}_N)$	$\{\mathcal{O}_{10},\mathcal{O}_{12},\mathcal{O}_{15}\}$
13	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N}\gamma_\mu N$	$2\vec{S}_\chi\cdot v^\perp+2i\vec{S}_\chi\cdot(\vec{S}_N\times\frac{\vec{q}}{m_N})$	$\{\mathcal{O}_8,\mathcal{O}_9\}$
14	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N}i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}N$	$4i\vec{S}_\chi\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_N)$	$\mathcal{O}_9$
15	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N}\gamma^\mu\gamma^5 N$	$-4\vec{S}_\chi\cdot\vec{S}_N$ $\rightarrow$ Standard SD	$\mathcal{O}_4$
16	$i\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N}i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}\gamma^5 N$	$4i(\vec{S}_\chi\cdot\vec{v}^\perp)(\vec{S}_N\cdot\frac{\vec{q}}{m_M})$	$\mathcal{O}_{13}$
17	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\gamma^5\chi\bar{N}\gamma_\mu N$	$2i\frac{\vec{q}}{m_M}\cdot\vec{S}_\chi$	$\mathcal{O}_{11}$
18	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\gamma^5\chi\bar{N}i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}N$	$(\frac{\vec{q}}{m_M}\cdot\vec{S}_\chi)[i\frac{\vec{q}^2}{m_N m_M}-4\vec{v}^\perp\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_N)]$	$\{\mathcal{O}_{11},\mathcal{O}_{15}\}$
19	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\gamma^5\chi\bar{N}\gamma_\mu\gamma^5 N$	$-4i(\vec{S}_\chi\cdot\frac{\vec{q}}{m_M})(\vec{S}_N\cdot\vec{v}^\perp)$	$\mathcal{O}_{14}$
20	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\gamma^5\chi\bar{N}i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}\gamma^5 N$	$4i(\frac{\vec{q}}{m_M}\cdot\vec{S}_\chi)(\frac{\vec{q}}{m_M}\cdot\vec{S}_N)$	$\mathcal{O}_6$

- There are 14 independent effective operators satisfying Galilean invariance, CPT symmetry, Hermitian
- Built out of the following four quantities

$$i\frac{\vec{q}}{m_N}, \quad \vec{v}^{\perp}, \quad \vec{S}_{\chi}, \quad \vec{S}_N. \tag{6}$$

where $\vec{v}^{\perp} = \vec{v} + \vec{q}/2\mu_{\chi N}$, which satisfies $\vec{v}^{\perp} \cdot q = 0$.

- Inelastic scattering of spin 0 and 1/2 dark matter: G. Barello, PRD 90, 094027 (2014)
- Higher dark matter spin: P. Gondolo, arXiv: 2008.05120

Model independent, nucleus independent

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Model independent, nucleus independent

WIMPs interact with bound nucleon in a nucleus

The nuclear dynamics, notably the relativistic mean-fields, may modify these effective operators

M. Bolsterli *et al.*, Phys. Rev. C **10** (1974) 1225.

- model dependent
- nucleus dependent

Part II: Relativistic mean-field corretions

Relativistic mean-field corrections

XGW and A. W. Thomas, arXiv: 2012.10144

In a nuclear medium, we assume that the wave function of a nucleon bound by Lorentz scalar and vector mean-fields satisfies the relativistic Dirac equation

$$\gamma^0\left[-i\vec{\gamma}\cdot\nabla + M + V_s + \gamma^0 V_v\right]\psi(\vec{x}) = E\psi(\vec{x})\,, \qquad (7)$$

where V_s corresponds to an attractive Lorentz scalar potential and V_v the repulsive fourth component of a four-vector.

$$\psi = \left(\begin{array}{c} u \\ v \end{array}\right) \Rightarrow \left\{\begin{array}{l} u = \frac{1}{E-M-V_s-V_v}\vec{\sigma}\cdot\vec{p}v \\ v = \frac{1}{E+M+V_s-V_v}\vec{\sigma}\cdot\vec{p}u \rightarrow \frac{1}{2M[1+(V_s-V_v)/2M]}\vec{\sigma}\cdot\vec{p}u \end{array}\right.$$

j	$\mathcal{L}^j_{\rm int}$	Non-relativistic Reduction in medium ($u^\dagger \mathcal{O}_{eff} u$)
1	$\bar{\chi}\chi\bar{N}N$	$1_\chi 1_N$
2	$i\bar{\chi}\chi\bar{N}\gamma^5 N$	$i\frac{\vec{q}}{m_N}\cdot\vec{S}_N\frac{1}{1+(V_s-V_v)/2m_N}$
3	$i\bar{\chi}\gamma^5\chi\bar{N}N$	$-i\frac{\vec{q}}{m_\chi}\cdot\vec{S}_\chi$
4	$\bar{\chi}\gamma^5\chi\bar{N}\gamma^5 N$	$-(\frac{\vec{q}}{m_\chi}\cdot\vec{S}_\chi)(\frac{\vec{q}}{m_N}\cdot\vec{S}_N)\frac{1}{1+(V_s-V_v)/2m_N}$
5	$\bar{\chi}\gamma^\mu\chi\bar{N}\gamma_\mu N$	$1_\chi 1_N$
6	$\bar{\chi}\gamma^\mu\chi\bar{N}i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}N$	$\frac{\vec{q}^2}{2m_N m_M}1_\chi 1_N + 2(\frac{\vec{q}}{m_\chi}\times\vec{S}_\chi + i\vec{v}^\perp)\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_N)$ $-[\frac{\vec{q}^2}{2m_N m_M}1_\chi 1_N - 2i\frac{\vec{k}'+\vec{k}}{2m_N}\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_N)]\frac{V_s-V_v}{2m_N[1+(V_s-V_v)/2m_N]}$
7	$\bar{\chi}\gamma^\mu\chi\bar{N}\gamma_\mu\gamma^5 N$	$-2\vec{S}_N\cdot\vec{v}^\perp + 2i\vec{S}_\chi\cdot(\vec{S}_N\times\frac{\vec{q}}{m_\chi}) - \vec{S}_N\cdot\frac{\vec{k}'+\vec{k}}{m_N}\frac{V_s-V_v}{2m_N[1+(V_s-V_v)/2m_N]}$
8	$\bar{\chi}i\gamma^\mu\chi\bar{N}\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}\gamma^5 N$	$2i\frac{\vec{q}}{m_M}\cdot\vec{S}_N$
9	$\bar{\chi}i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\chi\bar{N}\gamma_\mu N$	$-\frac{\vec{q}^2}{2m_\chi m_M}1_\chi 1_N - 2(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)\cdot(\frac{\vec{q}}{m_N}\times\vec{S}_N + i\vec{v}^\perp)$ $+2(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)\cdot(\frac{\vec{q}}{m_N}\times\vec{S}_N - i\frac{\vec{k}'+\vec{k}}{2m_N})\frac{V_s-V_v}{2m_N[1+(V_s-V_v)/2m_N]}$
10	$\bar{\chi}i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\chi\bar{N}i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}N$	$4(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_N)$

11	$\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\chi\bar{N}\gamma_\mu\gamma_5 N$	$4i(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)\cdot\vec{S}_N$
12	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\chi\bar{N} i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}\gamma^5 N$	$-[i\frac{\vec{q}^2}{m_\chi m_M}-4\vec{v}^\perp\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)](\frac{\vec{q}}{m_M}\cdot\vec{S}_N)$
		$+4[\frac{\vec{k}'+\vec{k}}{2m_N}\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)(\frac{\vec{q}}{m_M}\cdot\vec{S}_N)-\frac{\vec{k}^2-\vec{k}'^2}{2m_N m_M}(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)\cdot\vec{S}_N]\frac{V_s-V_v}{2m_N[1+(V_s-V_v)/2m_N]}$
13	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N}\gamma_\mu N$	$2\vec{S}_\chi\cdot v^\perp+2i\vec{S}_\chi\cdot(\vec{S}_N\times\frac{\vec{q}}{m_N})+[\vec{S}_\chi\cdot\frac{\vec{k}'+\vec{k}}{m_N}-2i\vec{S}_\chi\cdot(\vec{S}_N\times\frac{\vec{q}}{m_N})]\frac{V_s-V_v}{2m_N[1+(V_s-V_v)/2m_N]}$
14	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N} i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}N$	$4i\vec{S}_\chi\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_N)$
15	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N}\gamma^\mu\gamma^5 N$	$-4\vec{S}_\chi\cdot\vec{S}_N$
16	$i\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N} i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}\gamma^5 N$	$4i(\vec{S}_\chi\cdot\vec{v}^\perp)(\vec{S}_N\cdot\frac{\vec{q}}{m_M})+4i[(\vec{S}_\chi\cdot\frac{\vec{k}'+\vec{k}}{2m_N})(\vec{S}_N\cdot\frac{\vec{q}}{m_M})-\frac{\vec{k}'^2-\vec{k}^2}{2m_N m_M}(\vec{S}_\chi\cdot\vec{S}_N)]\frac{V_s-V_v}{2m_N[1+(V_s-V_v)/2m_N]}$
17	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\gamma^5\chi\bar{N}\gamma_\mu N$	$2i\frac{\vec{q}}{m_M}\cdot\vec{S}_\chi$
18	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\gamma^5\chi\bar{N} i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}N$	$(\frac{\vec{q}}{m_M}\cdot\vec{S}_\chi)[i\frac{\vec{q}^2}{m_N m_M}-4\vec{v}^\perp\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_N)]$
		$-(\frac{\vec{q}}{m_M}\cdot\vec{S}_\chi)[i\frac{\vec{q}^2}{m_N m_M}+4\frac{\vec{k}'+\vec{k}}{2m_N}\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_N)]\frac{V_s-V_v}{2m_N[1+(V_s-V_v)/2m_N]}$
19	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\gamma^5\chi\bar{N}\gamma_\mu\gamma^5 N$	$-4i(\vec{S}_\chi\cdot\frac{\vec{q}}{m_M})(\vec{S}_N\cdot\vec{v}^\perp)-4i(\vec{S}_\chi\cdot\frac{\vec{q}}{m_M})(\vec{S}_N\cdot\frac{\vec{k}'+\vec{k}}{2m_N})\frac{V_s-V_v}{2m_N[1+(V_s-V_v)/2m_N]}$
20	$i\bar{\chi} i\sigma^{\mu\nu}\frac{q_\nu}{m_M}\gamma^5\chi\bar{N} i\sigma_{\mu\alpha}\frac{q^\alpha}{m_M}\gamma^5 N$	$4i(\frac{\vec{q}}{m_M}\cdot\vec{S}_\chi)(\frac{\vec{q}}{m_M}\cdot\vec{S}_N)$

The large component $u(\vec{x})$ of the bound nucleon wave-function satisfies the Schrodinger equation

$$\Big[\frac{1}{2m_N}p^2 + (V_s + V_v) + \frac{1}{2m_N}(V_s^2 - V_v^2) + \frac{B}{m_N}V_v \\ \underbrace{-\frac{1}{4m_N^2}\frac{1}{r}\frac{d(V_s - V_v)}{dr}\vec{\sigma}\cdot\vec{l}}_{\text{spin}-\text{orbital}} \underbrace{-\frac{1}{8m_N^2}\nabla^2(V_s - V_v)}_{\text{Darwin term}}\Big]u(\vec{x}) = Bu(\vec{x}),$$

One can define the effective potential

$$V_{\text{eff}} = V_s + V_v + \frac{V_s^2 - V_v^2}{2m_N} + \frac{B}{m_N}V_v. \tag{8}$$

J. V. Noble, Phys. Rev. C **17** (1978)2151

The correction induced by the RMF potentials involves a factor

$$1/[1 + (V_s - V_v)/2m_N] \tag{9}$$

- Quantum hydrodynamics:
  $V_s \approx -400\ \mathrm{MeV}, \qquad V_v \approx 350\ \mathrm{MeV}$
  J. D. Walecka, Int. J. Mod. Phys. E 6, 515 (1997)

- Quark meson coupling (QMC) model:
  $V_s \approx -190\ \mathrm{MeV}, \qquad V_v \approx 130\ \mathrm{MeV}$
  A. W. Thomas, Prog. Part. Nucl. Phys. 58, 1 (2007)

$\Rightarrow$ a boost for the effective interaction as large as 21-66%

Summary

- The standard SI/SD operators are unchanged
- Certain interactions will receive non-negligible corrections, which may significantly change the sensitivity of WIMP-nucleus cross sections to these operators
- It may help to study the nucleus-dependence of direct detection experiments
- This analysis can also be applied to the case of arbitrary dark matter spin, as well as inelastic scattering

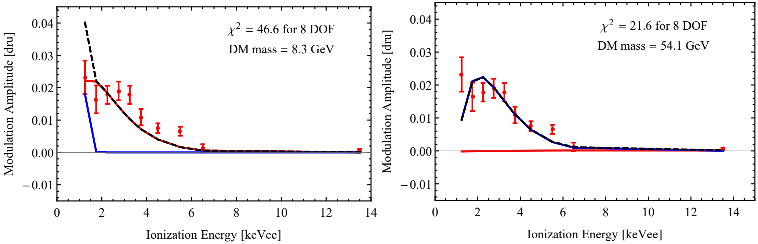
Part III: Phenomenological analysis

Existing models

Either elastic or inelastic, single or two-component dark matter

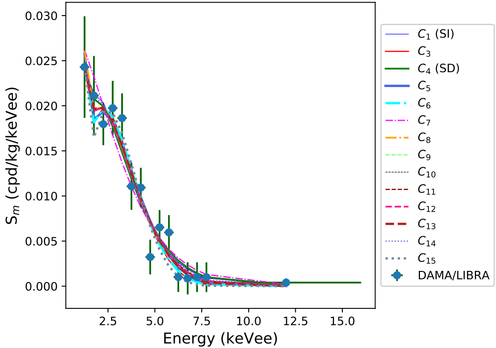
	VDF	DM response	Nuclear response
$\frac{dR_{\chi T}}{dE_R} \propto$	$f(\vec{v}, t)$	$\otimes R_k \left(\vec{v}_T^{\perp 2}, \{c_i^\tau c_j^{\tau'}\} \right)$	$\otimes W_k^{\tau\tau'}(\vec{q}^{\,2} b^2)$
	$\boxed{\text{SHM}}$	spin-1/2	$\boxed{\text{Shell model}}$
	SHM + Stream	SI/SD	RMF
	Gaia Sausage		coupled − cluster
	⋮		⋮

- SI/SD + elastic
  S. Baum, PLB 789, 262 (2019)



- SI + isospin conserving is disfavored
- SI + isospin violating, or, SD ($c_n \neq c_p$) can provide a good fit

- Non-SI/SD + elastic
  S. Kang, JCAP 07, 016 (2018)



- χ^2 ranging from 10.69 to 13.94 with 12 degree of freedom
- m_χ ranging from $7.32 \sim 13.41\ \mathrm{GeV}$
- All the best fit solutions are in tension with XENON1T and PICO60.

- Two-component DM + SI + elastic
  J. Herrero-Garcia, PRD 98, 123007 (2018)

$$\chi_i + N \to \chi_i + N, \quad (i = 1, 2)$$

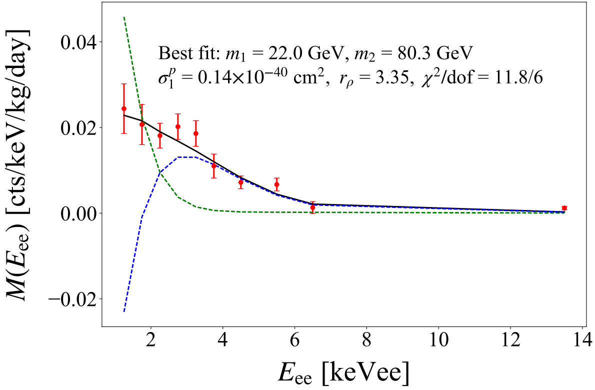


Figure: dotted green: DM 1; dashed blue: DM 2

pSIDM model

Proton-philic + SD + inelastic:
S. Kang, PRD 99, 023017 (2019)

$$\chi_1(m_\chi) + N \to \chi_2(m_\chi + \delta) + N$$

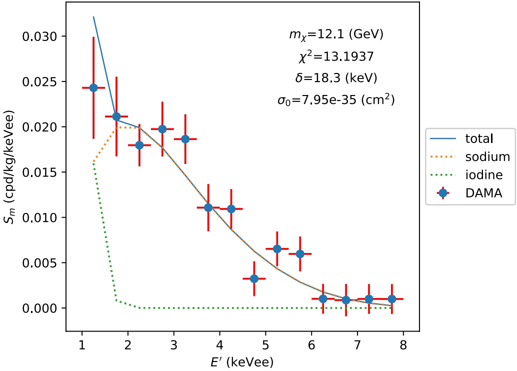


Figure: SHM + Best fit to DAMA/LIBRA

Relax experimental tensions

- tune SI coupling by large suppression
- tune SD couplings $c_n/c_p = -0.028$
  Xe, Ge : unpaired neutron $\rightarrow$ suppressed
  Na, I, F: unpaired proton
- inelastic up-scatter

$$\chi_1(m_\chi)+N \rightarrow \chi_2(m_\chi+\delta)+N$$

$$v^*_{\rm min} = \sqrt{\frac{2\delta}{\mu_{\chi N}}},$$

$$v^{*\rm Na}_{min} < v^{\rm lab}_{\rm esc} < v^{*\rm F}_{\rm min}$$

WIMP-Fluorine scattering is kinematically suppressed

SHM + Best fit to DAMA/LIBRA data do not satisfy this requirement.

SHM + Stream arXiv.org/abs/2005.10404 (Madeleine)

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$$\chi_1(m_\chi) + N \rightarrow \chi_2(m_\chi + \delta) + N$$

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$$v^{*\mathrm{Na}}_{min} < v^{\mathrm{lab}}_{\mathrm{esc}} < v^{*\mathrm{F}}_{\mathrm{min}}$$

WIMP-Fluorine scattering is kinematically suppressed

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SHM + Stream
arXiv.org/abs/2005.10404 (Madeleine)

Phenomenological project

Tony Williams, Andre Scaffidi, Bill Loizos (Honours)

Our plan

- SHM + substructure
- two-component dark matter
- beyond SI interaction

Something else

- inelastic scattering model
- higher spin dark matter

Thanks!

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

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