Dark Matter Effective Field Theory

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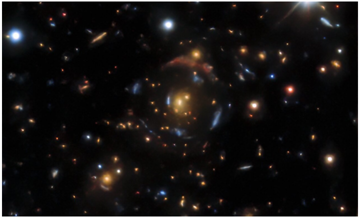
Outline

1. Motivation
2. SM effective field theories
3. DM effective field theories
4. Phenomenological example
5. Summary

based on: 2202.06968, in collaboration with Wolfgang Altmannshofer, Elizabeth Jenkins and Aneesh Manohar

Outline

Dark matter



Outline

SM Effective Theory (SMEFT)

Symmetry

$SU(3)_C \times SU(2)_L \times U(1)_Y$

Fields

$u, d, c, s, b, t, \ell, \nu_\ell, g, W, Z, H$

Poincaré invariance

Dim 6 operators

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}^{(4)} + \frac{1}{\Lambda} C^{(5)} \mathcal{O}^{(5)} + \frac{1}{\Lambda^2} \sum_i C_i^{(6)} \mathcal{O}_i^{(6)} + \mathcal{O}(\frac{1}{\Lambda^3})$$

Weak effective theory (WET)

Symmetry

$SU(3)_C \times U(1)_{em}$

Fields

$u, d, c, s, b, \ell, \nu_\ell, g, \gamma$

Poincaré invariance

Dim 6 operators

Assumptions

SMEFT/WET

No new light degrees of freedom

Fields

SM content

New Physics

Only at higher scales

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New particles

DM fields	ϕ	χ	X_μ
Spin	0	1/2	1
Number	n_ϕ	n_χ	n_X

Table: DM fields: ϕ is a real scalar field, χ is a *right-handed* fermion, and X_μ is a vector field. The DM fields are assumed to be singlets under the SM gauge group, so all DM fields are electrically neutral.

Dark EFT

Dark SMEFT (DSMEFT) & Dark WET (DWET)

SMEFT/WET + singlet scalar ϕ, right-handed fermion χ, vector X

Operators

DM: 26

DSMEFT: 77

DWET: 116

Matching

DSMEFT $\rightarrow$ DWET

Example: Operators

DSMEFT: dimension 6		$\Delta B = \Delta L = 0$	
$(\mathrm{d_{SM}}, \mathrm{d_{DM}})$	Name	Operator	Number
(2,4)	$\mathcal{Q}_{BX^2}$	$B_\mu{}^\nu X_{a\,\nu}{}^\alpha X_{b\,\alpha}{}^\mu$	$\binom{n_X}{2}$
	$\mathcal{Q}_{\widetilde{B}X^2}$	$\widetilde{B}_\mu{}^\nu X_{a\,\nu}{}^\alpha X_{b\,\alpha}{}^\mu$	$\binom{n_X}{2}$
	$\mathcal{Q}_{BX\phi^2}$	$B_{\mu\nu} X_a^{\mu\nu} \phi_b \phi_c$	$\binom{n_\phi+1}{2} n_X$
	$\mathcal{Q}_{\widetilde{B}X\phi^2}$	$\widetilde{B}_{\mu\nu} X_a^{\mu\nu} \phi_b \phi_c$	$\binom{n_\phi+1}{2} n_X$
	$\mathcal{Q}_{HX}$	$(H^\dagger H) X_{a\,\mu\nu} X_b^{\mu\nu}$	$\binom{n_X+1}{2}$
	$\mathcal{Q}_{H\widetilde{X}}$	$(H^\dagger H) \widetilde{X}_{a\,\mu\nu} X_b^{\mu\nu}$	$\binom{n_X+1}{2}$
	$\mathcal{Q}_{H^2\phi^4}$	$(H^\dagger H) \phi_a \phi_b \phi_c \phi_d$	$\binom{n_\phi+3}{4}$
	$\mathcal{Q}_{H\chi\phi}$	$(H^\dagger H)(\chi_a^T C \chi_b)\phi_c + \text{h.c.}$	$n_\phi \binom{n_\chi+1}{2} + \text{h.c.}$
	$\mathcal{Q}_{B\chi\phi}$	$B_{\mu\nu}(\chi_a^T C \sigma^{\mu\nu} \chi_b)\phi_c + \text{h.c.}$	$n_\phi \binom{n_\chi}{2} + \text{h.c.}$

Outline

Example: Two dark vectors $X_{1,2}$

Assumptions

SM & two vectors $X_{1,2}$, dark parity

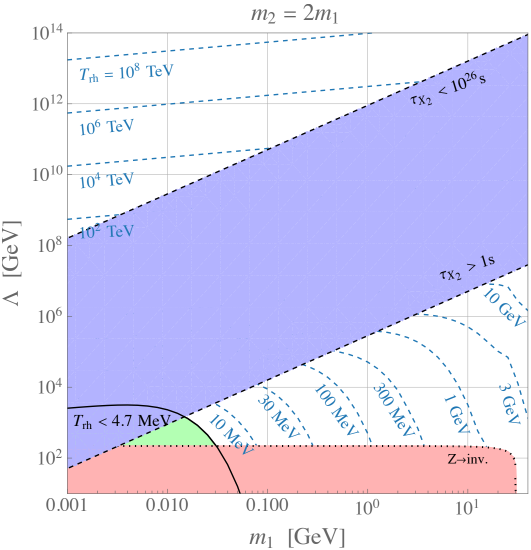
Lagrangian

$$\mathcal{L} = \mathcal{L}_{\text{SM}} - \frac{1}{4} X_1^{\mu\nu} X_{1\,\mu\nu} + \frac{m_1^2}{2} X_1^{\mu} X_{1\,\mu} - \frac{1}{4} X_2^{\mu\nu} X_{2\,\mu\nu} + \frac{m_2^2}{2} X_2^{\mu} X_{2\,\mu}$$
$$+ C_{BX^2} B_{\mu}^{\ \nu} X_{1\,\nu}^{\ \ \alpha} X_{2\,\alpha}^{\ \ \mu} + C_{\widetilde{B}X^2} \widetilde{B}_{\mu}^{\ \nu} X_{1\,\nu}^{\ \ \alpha} X_{2\,\alpha}^{\ \ \mu}$$

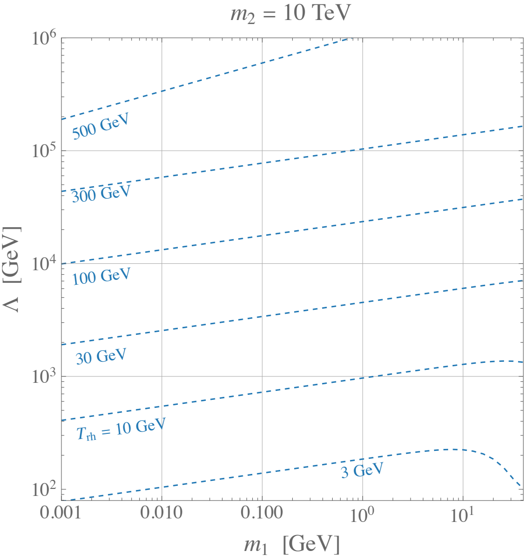
Freeze-in scenario

CMB and BBN, direct searches

Dark vector masses



Dark vector masses



Outline

Summary

DM

Astronomical observations

DSMEFT/DWET

SMEFT/WET + ϕ + χ + X_μ

Example

Two dark vectors $X_{1,2}$