Dark Matter Effective Theory

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based on arXiv:1102.3116v1 [hep-ph] with F. Sannino

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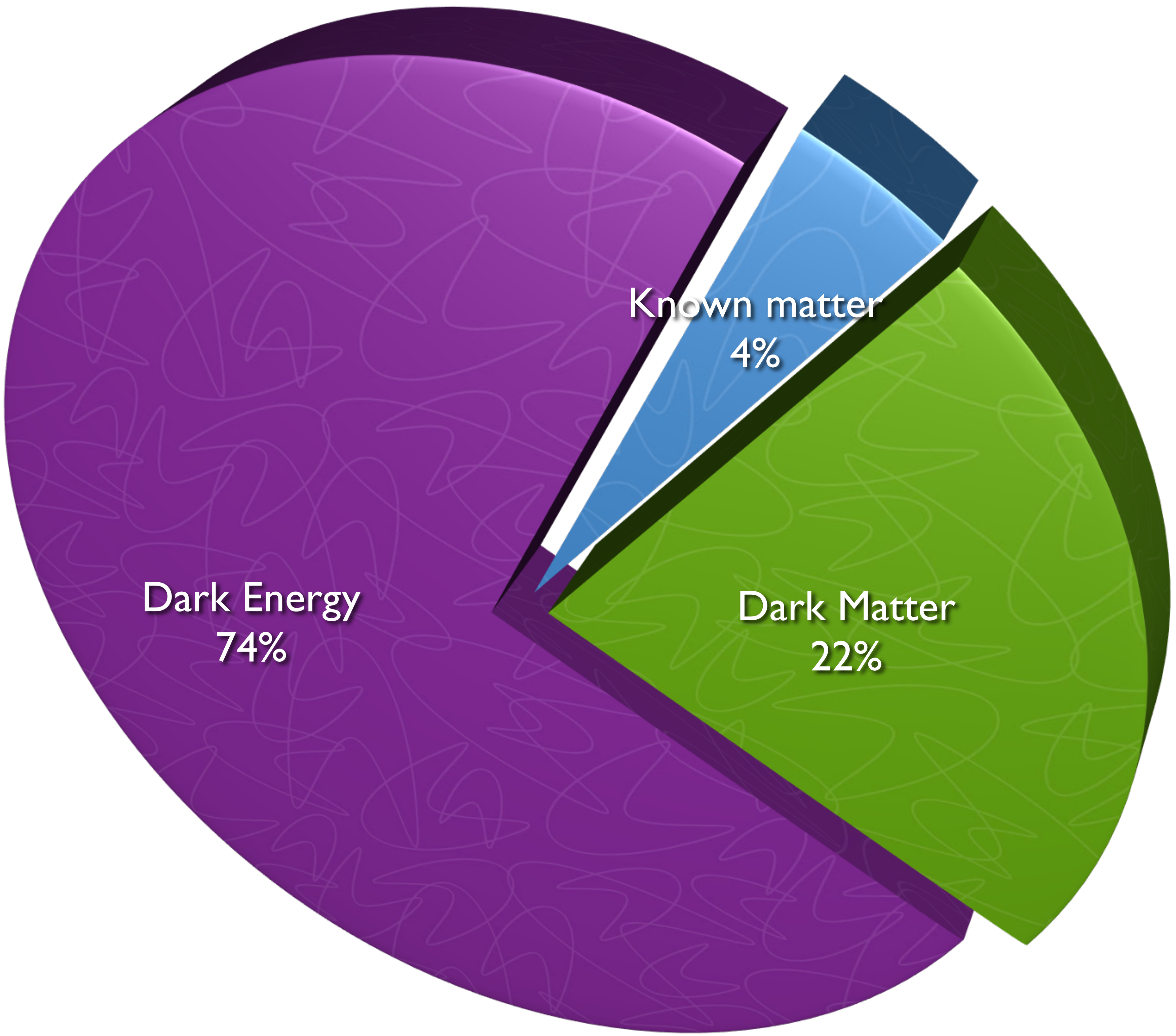
The problem



Do-a-bility

In order to keep things doable,
one usually considers only

- A unique DM candidate
- A few specific interaction terms

But...

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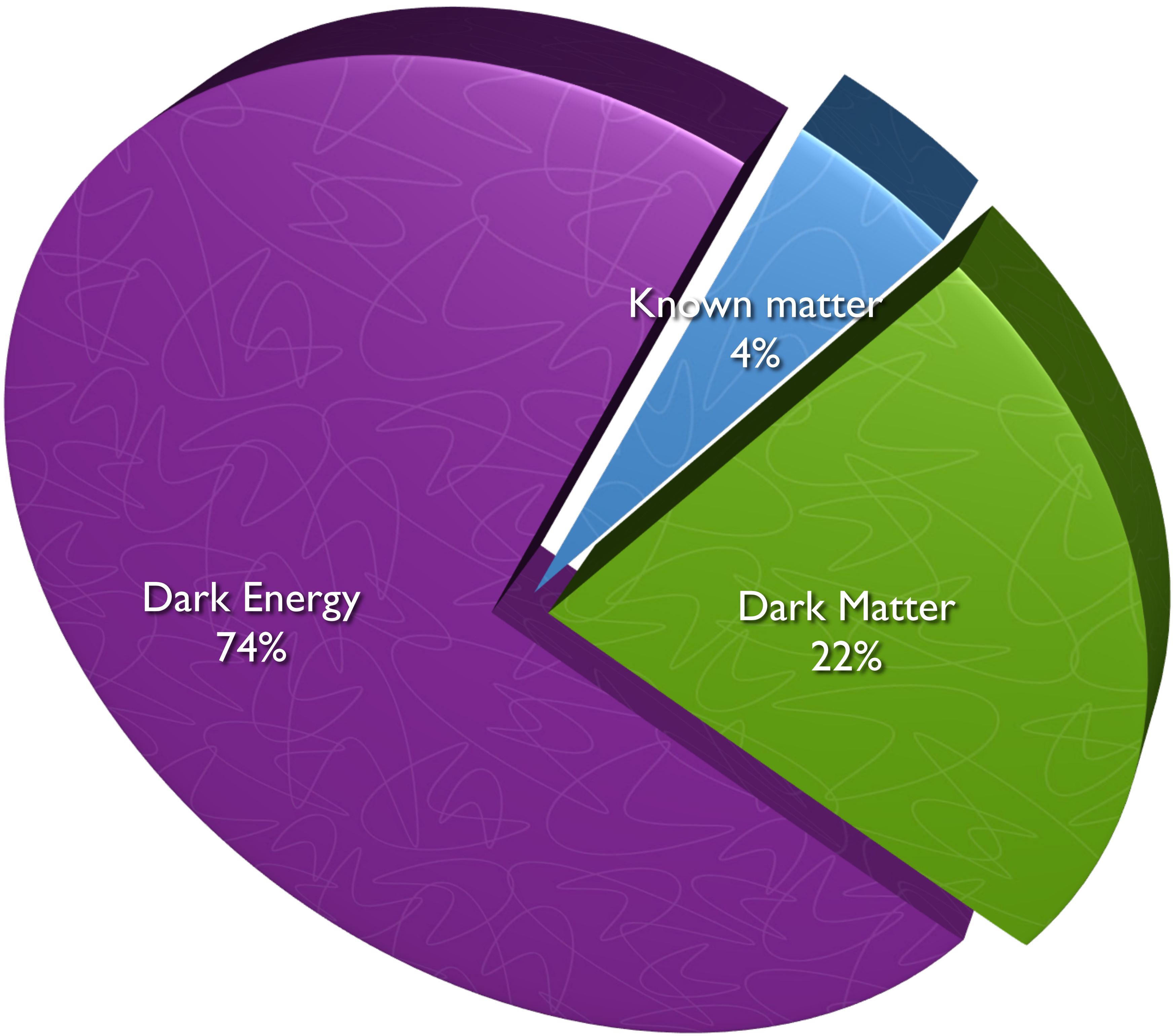
(back to) The problem

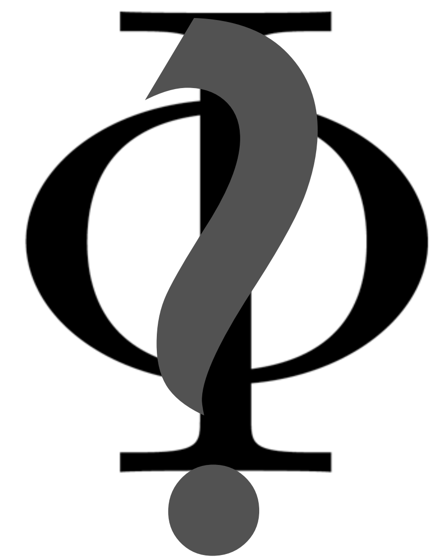


4% vs 22%

The Standard Model

A SU(3)⊗SU(2)⊗U(1) gauge theory with three generations of chiral fermions, namely two quarks, a charged lepton and a neutrino each. A scalar Higgs doublet spontaneously acquires a vacuum expectation value breaking the electroweak symmetry down to U(1)-electromagnetic, providing mass to the heavy gauge bosons and to the fermions, but leaving the photon massless; this also implies a mixing between quarks. The strong sector generates an entire 'zoo' of composite states, and two accidental symmetries enforce the stability of the electron and of the proton. The non-trivial topology of the vacuum enriches the dynamics of the model. The model is renormalizable and gauge anomaly free.

Dark Matter



Effective field theory I

Even remaining in the framework of usual gauge theories, we can face different possibilities:

- New matter multiplets (e.g. Minimal [Dark] Matter)
- A new gauge sector (e.g. Z', W')
- A new composite sector (e.g. Technicolor)
- Grand Unified Theories (GUTs)
- ...

Anyway, whatever new scenario is out there, if it’s possible to decouple “light” physics from “heavy” physics we can undertake an **effective theory** approach

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Effective field theory II

It's a parametrization of our ignorance

- Order the operators in the inverse of the new physics energy scale Λ
- Preserve $SU(3)_{\rm C}$ and $U(1)_{\rm EM}$ symmetries (the EW sector might still seem broken)
- Then, comparison with experimental results can tell us which operators are more important for what (direct & indirect detection & cosmology)

New scalar(s)

Augment the SM with a new (complex) scalar

Singlet	Doublet	Triplet
ϕ	(D^+, D^0) or (D^0, D^-)	(T^+, T^0, T^-)

Assumptions:

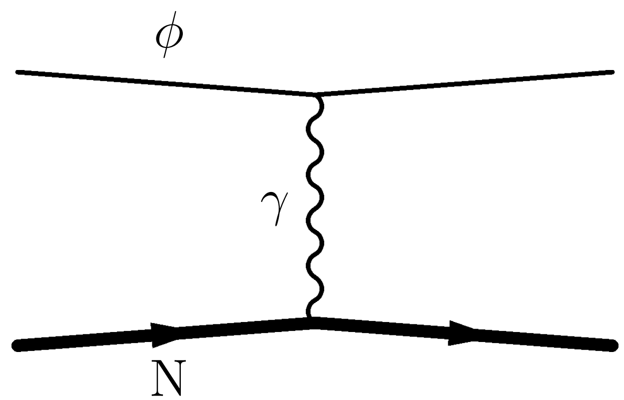
- Electric and color neutral
- Stable due to a new global U(1) symmetry

Gauge invariance

$$J_\mu \frac{\partial_\nu F^{\mu\nu}}{\Lambda^2}$$ charge radius operator

Bagnasco, Dine, Thomas '93; Foadi, Frandsen, Sannino, '08

direct detection:

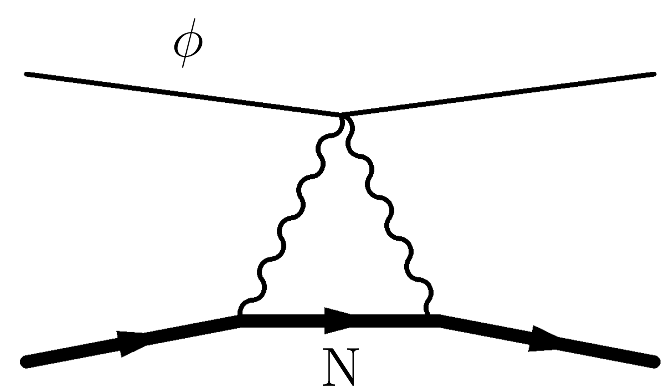


$$\frac{\phi^*\phi}{\Lambda^2} F^{\mu\nu} F_{\mu\nu}$$

$$\frac{\phi^*\phi}{\Lambda^2} F_{\mu\nu} \tilde{F}^{\mu\nu}$$

indirect detection: $\phi\phi \to \gamma\gamma$

direct detection:



Also $\frac{\phi^*\phi}{\Lambda^2} G^a_{\mu\nu} G^{\mu\nu}_a$ and $\frac{\phi^*\phi}{\Lambda^2} G^a_{\mu\nu} \tilde{G}^{\mu\nu}_a$

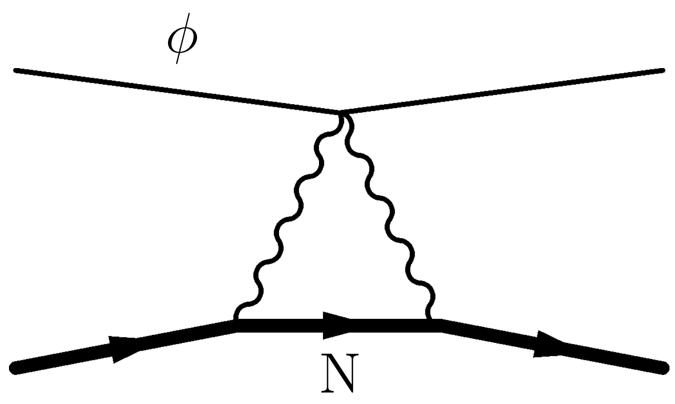
Effective EW interactions

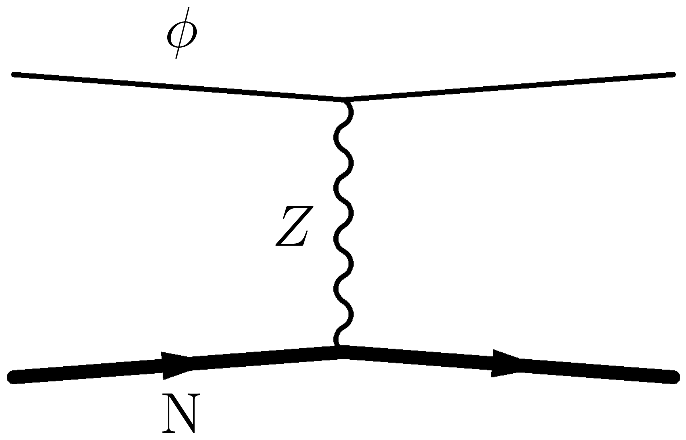
The lowest order terms are

$$\left.\begin{array}{c}\phi^*\phi\, Z^\mu Z_\mu \\ \\ \phi^*\phi\, W^{+\mu} W^-_\mu\end{array}\right\}$$

$$\left.\begin{array}{c}\phi^*\phi\,(\partial_\mu Z^\mu) \\ \\ J_\mu Z^\mu\end{array}\right\}$$

direct detection:





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DM-SM fermions interaction

$$\phi^*\phi\,\bar\psi\psi\ , \qquad \phi^*\phi\,\bar\psi\gamma^5\psi\ ,$$

$$\partial_\mu(\phi^*\phi)\,\bar\psi\gamma^\mu\psi\ , \qquad \partial_\mu(\phi^*\phi)\,\bar\psi\gamma^\mu\gamma^5\psi\ ,$$

$$J_\mu\,\bar\psi\gamma^\mu\psi\ , \qquad J_\mu\,\bar\psi\gamma^\mu\gamma^5\psi\ ,$$

$$\phi^*\phi\,\bar\psi i\not{D}\psi\ , \qquad \phi^*\phi\,\bar\psi i\not{D}\gamma^5\psi$$

ψ and $\bar\psi$ are any two SM fermions such that their combination is colorless and electrically neutral

Examples: $\phi^*\phi\,\bar\mu e$ $\qquad$ $\phi^*\phi\,\bar u\not{D}c$

Flavor changing operators

(suppressed by a power of $1/\Lambda$)

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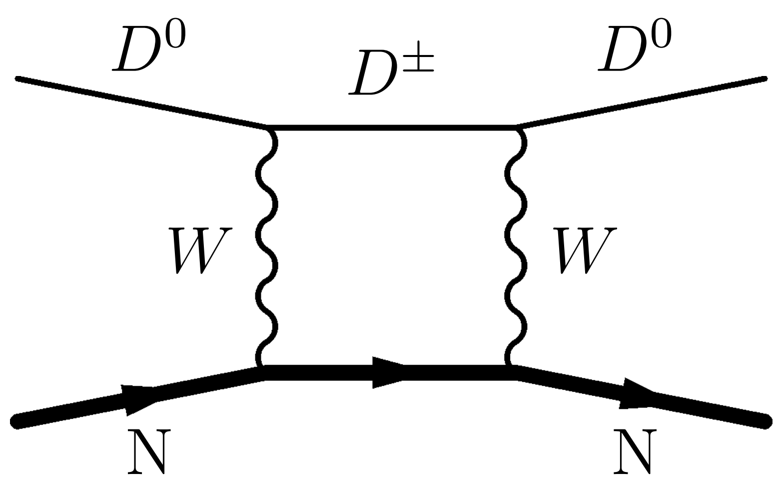
DM-Higgs and self-interaction

$$\mathcal{L}_{\phi h} = \phi^*\phi \sum_{n=1}^{4} a_n \frac{h^n}{\Lambda^{n-2}} + (\phi^*\phi)^2 \sum_{n=1}^{2} b_n \frac{h^n}{\Lambda^n} + (\partial^\mu \phi^*)(\partial_\mu \phi) \sum_{n=1}^{2} c_n \frac{h^n}{\Lambda^n} +$$
$$\partial^\mu(\phi^*\phi)(\partial_\mu h) \sum_{n=0}^{1} d_n \frac{h^n}{\Lambda^{n+1}} + J^\mu(\partial_\mu h) \sum_{n=0}^{1} e_n \frac{h^n}{\Lambda^{n+1}} + f\, \phi^*\phi \frac{(\partial^\mu h)(\partial_\mu h)}{\Lambda^2}$$

$$\mathcal{L}_{\phi\phi} = (\partial^\mu \phi^*)(\partial_\mu \phi) - m_\phi^2 \phi^*\phi + \sum_{n=2}^{3} g_n \frac{(\phi^*\phi)^n}{\Lambda^{2n-4}} + \frac{k}{\Lambda^2} (\partial^\mu \partial_\mu \phi^*)(\partial^\nu \partial_\nu \phi) +$$
$$\frac{1}{\Lambda^2} \left(l_1\, \partial^\mu(\phi^*\phi)\partial_\mu(\phi^*\phi) + l_2\, \partial^\mu(\phi^*\phi) J_\mu + l_3\, J^\mu J_\mu \right)$$

Doublet & Triplet

They contain the **inelastic DM** scenario as special case:



New flavor and lepton number violating operators, e.g.

$$\frac{1}{\Lambda} D^{0*} D^+ \, u^c_{\mathrm{R}i} d_{\mathrm{L}j} \qquad \frac{1}{\Lambda} T^{+*} T^- \, \bar{e}_{\mathrm{L}i} \bar{e}_{\mathrm{L}j}$$

(all left-handed Weyl fermions; i , j flavor indices)

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Conclusions and outlook

- In order to provide a common ground for several possible DM scenarios, we classified all the interaction terms between DM and SM fields up to dimension 6 in Λ in the framework of an effective theory

- Flavor changing operators arise from our analysis

- Now that we have all the operators it is possible to perform a complete study of the relic density