SESAPS'11, October 19-24

Sticky Dark Matter in Effective Field Theory approach

Andriy Badin* (Duke University)
Alexey Petrov (Wayne State University)

Duke University

*presenting author

Outline

- Motivation
- Formalism
- Different scenarios
- Conclusions

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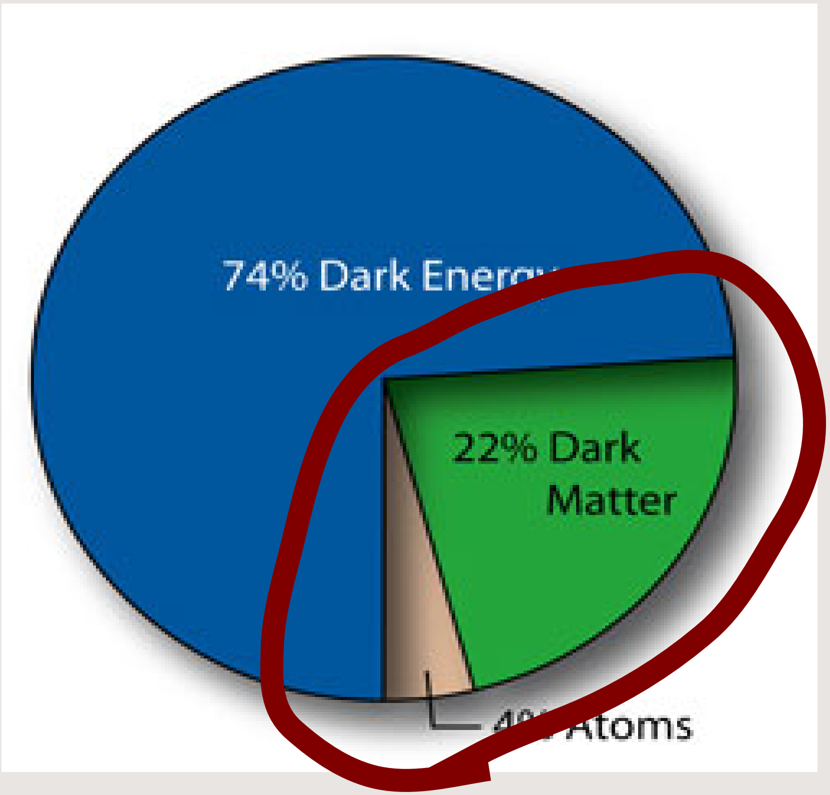
Motivation



- Hard to ignore something like this

- Somewhat controversial evidence from direct detection experiments*

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*http://cdms.berkeley.edu/
http://people.roma2.infn.it/~dama/web/home.html
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Possible solutions

- Models of DM [1,2]
- Alternatives to DM [3]
- Background[4]

Drawbacks

- Rather developed models
- Finely tuned

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Alternative!

- EFT approach
- No up-front assumptions about underlying physics
- Explore classes of models rather than models themselves
- Easier to build new classes of models and explore them

Observed rate

$$\frac{dR}{dE} \sim \int d^3v f(v,t) \frac{d\sigma}{dE}$$

Scattering of nuclei

$$\frac{d\sigma}{dE} \sim \sigma_n \frac{[f_p Z + f_n(A-Z)]^2}{f_n^2} F_N^2(q) F_{DM}^2(q,v)$$

Scattering of nucleon

Type of nuclei

Structure of nuclei

But!

$$M_{DM} \approx M GeV \text{ and } v \approx N \times 100\ km/s$$
$$\text{then wavelength } \lambda_{dB} \approx \frac{36.9}{MN} \times 10^2\ fm$$

Dark matter can not “see” internal details of target nuclei (with certain exceptions)

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How to compute cross-section if we don't know anything about DM?

- Use good-old partial wave expansion (always valid):

$$\mathcal{A} = \sum_l \mathcal{A}_l = \frac{4\pi}{m}\frac{2l+1}{k\cot\delta_l - ik} P_l(\cos\theta)$$

- Then effective range expansion (valid if "mediator is not light"):

$$k^{2l+1}\cot\delta_l = -\frac{1}{a_l} + \frac{r_l}{2}k^2$$

- Compute cross-section and fit to experimental data using three input parameters (mass, scattering length and range)

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Why Sticky?

- Poles in scattering amplitude.
- Possibility of bound (resonant) states formed out of dark and luminous matter.
- Interplay with models already available in the literature [1]

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Preliminary results

- Performed fit to CoGent data using proposed approach.
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S-wave scattering

- 1-st favored region: m~3 GeV, a_0~- few 10^{-8} GeV^{-1}, $r_0\sim$ few 10^{-6} GeV^{-1} .
- 2-nd favored region: m~40 GeV, $a_0 \sim 10^{-7} - 10^{-6}$ GeV^{-1} ,$r_0\sim$ few 10^{-6} GeV^{-1} . - New result! [arXiv:1107.0715 [hep-ph]]
- 3-rd favored region: m~80 GeV, $a_0 \sim 10^{-7} - 10^{-6}$ GeV^{-1} , $r_0\sim$ few 10^{-6} GeV^{-1} .

Sign ambiguity for a_0 and r_0!

P-wave scattering

- Interested in P-wave because it resembles some of the models proposed to resolve DAMA (CoGent) vs CDMS conflict [1].
- Work is in progress, results are not available at the moment.

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Outlook

- Potentially can explain all direct detection experiment.
- Fit CDMS recoil spectrum using our results. Will all fits survive?
- Link between direct detection experiments and interaction of DM with SM fields (quarks, leptons and gauge bosons) at the level of EFT needs to be established. Hints from nuclear physics and experiments with different target nuclei might be useful.
- Cosmological consequences of bound states?
- Can not analyze inelastic Dark Matter models.

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Technical back-up

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S-wave scattering[1]

$$\mathcal{L} = \psi^\dagger[i\partial_0 + \frac{\vec{\nabla}^2}{2m}]\psi + \phi^\dagger[i\partial_0 + \frac{\vec{\nabla}^2}{2M}]\phi + C_2^s(\psi\phi)^\dagger(\psi\phi)$$

- Very similar to deuteron creation in NN EFT
- Pole in scattering amplitude tells us location of bound state. In effective range expansion in reads as:

$$\mathcal{A} = \frac{4\pi}{\mu}\frac{1}{-1/a_0 - ik + \frac{1}{2}r_0k^2}$$

$$\sigma = \frac{4\pi}{k^2}\sin^2\delta_0$$

$$k\cot\delta_0 = -\frac{1}{a_0} + \frac{1}{2}r_0k^2$$

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$$+ \quad (\text{ higher derivatives terms})$$

- ✔ P-wave scattering amplitude has two poles in two lower quadrants
- ✔ Naturally produces narrow resonance behavior used in resonant Dark Matter model[2] to explain difference in signals between DAMA and CDMS.

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$$S_1 = -\frac{k+i\gamma_1}{k-i\gamma_1}\frac{E-E_0-i\Gamma(E)/2}{E-E_0+i\Gamma(E)/2}, \quad \text{where}$$

$$E = \frac{k^2}{2\mu}, \quad E_0 = \frac{\gamma^2+\tilde{\gamma}^2}{2\mu}, \quad \Gamma(E) = -4\gamma\sqrt{\frac{E}{2\mu}}$$

Narrow resonance there!

$$C_2^p = \frac{3\pi a_1(m_\chi + m_N)}{16 m_\chi m_N} = \frac{3\pi}{16}\left(\frac{m_\chi + m_N}{m_\chi m_N}\right)^{5/2}\frac{\Gamma}{(2E_0)^{5/2}}$$

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Matching

- Take heavy particle limit since interacting fields are non-relativistic.

$$\phi(x) = \frac{e^{-imv\cdot x}}{\sqrt{2m}}(\phi_m + \chi_m).$$

$$\psi = \begin{pmatrix} \psi_L \\ \psi_R \end{pmatrix} = \sqrt{\frac{m+E}{4E}} \begin{pmatrix} (1 + i\frac{\vec{\sigma}\cdot\vec{\nabla}}{m+E})\chi \\ (1 - i\frac{\vec{\sigma}\cdot\vec{\nabla}}{m+E})\chi \end{pmatrix}$$

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$$r_1 = \sqrt{\frac{m_\chi m_N}{8E_0(m_\chi + m_N)}}\frac{16E_0^2 - \Gamma^2}{\Gamma}$$

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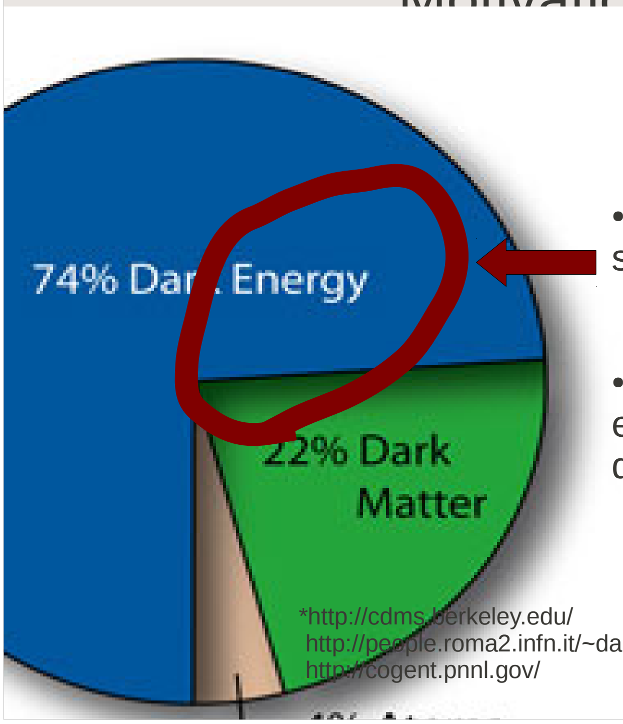

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