Sticky Dark Matter in Effective Field Theory approach (arXiv:1108.xxxx)

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

*presenting author
Outline

• Motivation
• Formalism
• Different scenarios
• Conclusions
Motivation

- Hard to ignore something like this

- Somewhat controversial evidence from direct detection experiments*

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

- IDM [1]
- ResDM [2]
- Alternatives to DM [3]

Drawbacks

- Rather developed models
- Finely tuned

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
Direct detection

- DM – non-relativistic with mass few GeV – 10's GeV
- SM – mass 10's GeV

DM can not see internal structure of target nuclei!
Concept of Sticky DM

- Established formalism
- Element dependent and model independent results
S-wave scattering[1]

\[ \mathcal{L} = \psi^\dagger [i\partial_0 + \frac{\nabla^2}{2m}] \psi + \phi^\dagger [i\partial_0 + \frac{\nabla^2}{2M}] \phi + C^s_2 (\psi\phi)^\dagger (\psi\phi) \]

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

\[
\mathcal{A} = \frac{4\pi}{\mu} \frac{1}{-1/a_0 - ik + \frac{1}{2}r_0 k^2} \\
\sigma = \frac{4\pi}{k^2} \sin^2 \delta_0 \\
k \cot \delta_0 = -\frac{1}{a_0} + \frac{1}{2}r_0 k^2
\]

S-wave scattering – not so optimistic

- Bound state is formed in limit of large scattering length $a_0 \gg 1/\Lambda$
- No current scattering data can be used. Order of magnitude estimates lead to $\Lambda \sim 10^3 \text{TeV}$
- Cosmological consequences are unknown
P-wave \cite{1}

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

+ (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\cite{2} to explain difference in signals between DAMA and CDMS.

\cite{2} Y.Bai and P.J.Fox, JHEP 0911, 052 (2009)
P-wave, ER expansion

\[ T_l = \frac{4\pi}{m} \frac{2l + 1}{k \cot \delta_l - i k} P_l(\cos \theta) \]

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

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

Narrow resonance there!
Matching

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

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

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

\[
\chi_m = e^{imt} \chi
\]

• p-wave-only scattering is possible for scalar-fermion and scalar-scalar pairs of DM-SM particles. Fermion-fermion pair has admixture of s-wave
Results and outlook

Sensitivity of two different direct detection experiments
Results and outlook

- Extensive analysis of ALL direct detection experiments is needed
- Potentially can explain all direct detection experiment
- 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?
- Other types of interaction?
Technical back-up

P-wave

\[
\begin{align*}
k_{\pm} &= i(\gamma + i\tilde{\gamma}) = \sqrt{\frac{2}{a_1 r_1}} \left[ \pm 1 + \frac{i}{r_1} \sqrt{\frac{2}{a_1 r_1}} \right], \\
k_1 &= \frac{i}{6} \left( |r_1| + \frac{|a_1|^{1/3}|r_1|^2}{v} + \frac{v}{|a_1|^{1/3}} \right), \\
v &= \left( 108 + |a_1||r_1|^3 + 108\sqrt{1 + |a_1||r_1|^3/54} \right)^{1/3} \\
r_1 &= \sqrt{\frac{m_\chi m_N}{8E_0(m_\chi + m_N)}} \frac{16E_0^2 - \Gamma^2}{\Gamma} \\
a_1 &= \left( \frac{8E_0(m_\chi + m_N)}{m_\chi m_N} \right)^{3/2} \frac{2\Gamma}{(16E_0^2 - \Gamma^2)^2}
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\[ S_1 = \frac{k + i\gamma_1}{k - i\gamma_1} \frac{E - E_0 - i\Gamma(E)/2}{E - E_0 + i\Gamma(E)/2}, \quad \text{where} \]

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

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