Mili-Charged Strongly Interacting Dark Matter

A Quick Review of Dark Matter

Two Key Properties:

-Dark matter must be stable over more than the lifetime of the universe.

-Dark matter must essentially also both be electrically neutral and effectively neutral with respect to the SM.

Why Strongly Interacting DM?

-**Stability:** The stability of composite dark matter candidates is an automatic consequence of the accidental global flavour symmetries of the underlying theory.

-**Naturalness**: Just like in QCD, once a non-Abelian theory confines, a new scale appears in the theory, allowing for an effective theory description of the low energy theory.

-**Neutrality:** If constituents transform under (part of) the SM gauge symmetries, confinement can lead to colour, weak, and charge-neutral dark hadrons that are idea DM candidates.

-**Suppressed interactions:** The effective theory below the confinement scale can be expressed in terms of higher dimensional operators involving DM fields and SM fields, suppressed by powers of the DM confinement scale.

-Self-interactions: Strongly-coupled theories naturally have strong self-interactions among the Dark mesons and baryons. These interactions may be responsible for addressing the observed galactic structure anomalies and DM abundance.

-New observables: A rich spectrum of dark hadrons from a confined dark non-Abelian theory would provide a plethora of experimental targets.

Many Possible Types of Strongly Interacting Dark Matter

-Meson DM I: Pion-like

-Meson DM II: Quarkonium-like (at least one heavy dark fermion)

-Baryon-like DM

-Dark Glueballs.

How can DM be mili-charged?

Example: DM Candidates with Electromagnetically Charged Constituents.

Coupling to the photon is proportional to:

$$\langle \chi(p') | j^\mu_{\rm EM} | \chi(p) \rangle = F(q^2) q^\mu$$

The form factor ($F(q^2)$) can be described in terms of effective field theory operators:

Magnetic Moment $\quad \mathcal{L} \supset \frac{1}{\Lambda} \bar{\chi} \sigma^{\mu\nu} \chi F_{\mu\nu}$

Charge Radius $\quad \mathcal{L} \supset \frac{1}{\Lambda^2} \bar{\chi} \gamma^\nu \chi \partial^\mu F_{\mu\nu}, \quad \frac{1}{\Lambda^2} \phi^\dagger \phi v^\nu \partial^\mu F_{\mu\nu}$

Electromagnetic Polarizability: $\quad \mathcal{L} \supset \frac{1}{\Lambda^3} \bar{\chi} \chi F_{\mu\nu} F^{\mu\nu}, \quad \frac{1}{\Lambda^3} \phi^\dagger \phi F_{\mu\nu} F^{\mu\nu}$

Where χ is a fermionic DM candidate and ϕ is a spin-zero bosonic candidate.

Example: Pion Like SIMP Model

$$\mathcal{L}_{\text{int}} = -\frac{1}{6f_\pi^2}\ \text{Tr}\left(\pi^2\partial^\mu\pi\partial_\mu\pi - \pi\partial^\mu\pi\pi\partial_\mu\pi\right) + \frac{2N_c}{15\pi^2 f_\pi^5}\epsilon^{\mu\nu\rho\sigma}\ \text{Tr}\left(\pi\partial_\mu\pi\partial_\nu\pi\partial_\rho\pi\partial_\sigma\pi\right) + \mathcal{O}(\pi^6)\,.$$

The 5-point interactions coming from the WZW-action are key to obtaining the correct DM abundances in the model.

Take a $U(1)_D$ gauge field which has kinetic mixing with the $U(1)_Y$ gauge field

$$\mathcal{L}_{\mathcal{A}} = -\frac{1}{4}\mathcal{A}_{\mu\nu}\mathcal{A}^{\mu\nu} - \frac{\sin\chi}{2}B_{\mu\nu}\mathcal{A}^{\mu\nu} + \frac{1}{2}m_V^2\mathcal{A}_\mu\mathcal{A}^\mu\,.$$

$\mathcal{A}_\mu$:$U(1)_D$ gauge field

B_μ:$U(1)_Y$ gauge field

Following the standard field redefinition one obtains:

$$\begin{aligned}\mathcal{L}_D = \; & A_\mu J^\mu_{EM} + Z_\mu\left[c_W s_\zeta t_\chi J^\mu_{EM} + (c_\zeta - s_W t_\chi s_\zeta)J^\mu_Z - \frac{s_\zeta}{c_\chi}J^\mu_D\right] \\ & + V_\mu\left[J^\mu_{EM}(-c_W c_\zeta t_\chi) + J^\mu_Z(s_\zeta + s_W t_\chi c_\zeta) + \frac{c_\zeta}{c_\chi}J^\mu_D\right]\,,\end{aligned}$$

Dark Photon: $V^\mu = -\frac{s_\zeta}{c_\chi}Z^\mu + \frac{c_\zeta}{c_\chi}\mathcal{A}^\mu$

Problem: gauging the WZW term gives rise to the pion's anomalous decay:

$$\pi\pi \to \gamma_D\gamma_D$$

This can be prevented by appropriate $U(1)_D$ charge assignments, but this does not prevent the dark meson self-annihilation:

$$\pi\pi \to \pi\gamma_D$$

A simple solution is to require the dark photon's mass to be larger then the dark pion's