Some manifestations of two-component Dark Matter structure in vectorlike hypercolor model.

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The Mystery of Dark Matter (DM)

Dark Matter candidates:

- Axions
- Sterile neutrinos
- Primordial black holes
- Modifications of gravity
- WIMPs
Simple, one-component WIMP DM

\[ \frac{dn}{dt} + 3Hn = \frac{d(na^3)}{a^3dt} = \langle \sigma v \rangle (n_{eq}^2 - n^2) \]

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\[ m(x) / n_{eq}(x=1) \text{ [GeV]} \]

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Equilibrium

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\[ x = m/T \]
The Quest for Dark Matter

\[
\chi + \chi \rightarrow e^+, \, \bar{p}, \, \gamma, \ldots
\]

scattering (e.g. LUX, DARKSIDE, XENON 100)

\[
\chi + N \leftrightarrow N + \chi
\]

production (LHC)

annihilation (AMS)

\[
p, \, \bar{p}, \, e^-, \, e^+, \, \gamma
\]
The Quest for Dark Matter

Direct experiments (XENON1T)

Indirect experiments (AMS)

E. Aprile et al. (XENON Collaboration)

M. Aguilar et al. (AMS Collaboration)
Phys. Rev. Lett. 117, 091103
The Model

\[ \tilde{Q}_H = \begin{pmatrix} \tilde{U} \\ \tilde{D} \end{pmatrix} \quad Y_Q = 0 \]

Gauge group:
\[ SU(2)^{HC} \otimes SU(2)^W \]

Additional scalar particle (\(\tilde{\sigma}\)) which gives masses to H-quarks

Hypercolor Interaction, form confinement states (\(\Lambda_{HC} \sim 1 \text{TeV}\))

Weak Interaction

Effective Lagrangian is constructed on the violation of the global SO(4) symmetry

\[ B_H = \begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} \quad \text{H-baryon, posses additive conserving quantum number} \]

\[ \tilde{P}_H = \begin{pmatrix} \tilde{\pi}^+ \\ \tilde{\pi}^0 \\ \tilde{\pi}^- \end{pmatrix} \quad \text{H-pion, Nambu–Goldstone bosons, posses multiplicative conserving quantum number} \]

Our model naturally contains at least two stable particles!


Model parameters

\( m_{\tilde{\pi}} \)  - Mass of H-pions and H-baryons at the tree level

\( M_{\tilde{\sigma}} \)  - Mass of H-sigma

\( U \)  - H-sigma and its vacuum expectation value.

\( \theta \)  - Mixing angel between Higgs boson and H-sigma, We define here: \( S_\theta \equiv \sin \theta \)

\[ |S_\theta| \leq 0.1 \]

Mass splitting

\[ B_H = \begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} \]

\[ \tilde{P}_H = \begin{pmatrix} \tilde{\pi}^+ \\ \tilde{\pi}^0 \\ \tilde{\pi}^- \end{pmatrix} \]

\[ m_{\tilde{\pi}^+} - m_{\tilde{\pi}^0} \approx 163 \text{MeV} \]

\[ \frac{|m_{\tilde{\pi}} - M_B|}{m_{\tilde{\pi}}} \lesssim 0.03 \]

\[ \tilde{\pi}^0 \text{-stable particle} \]

\[ \tilde{\pi}^+ \rightarrow \tilde{\pi}^0 + (\pi^+, e^+\nu_e, \mu^+\nu_\mu) \]
Interaction with ordinary matter

$$\sigma_{BN} \approx 3 \times 10^{-43} \left( \frac{S_\theta M_B}{u} \right)^2 \text{cm}^2, \quad M_H^2 \ll M_\sigma^2, M_B^2, \quad C_\theta \approx 1$$
Two-component DM relic

Five Bolzmann equations for five components:

\[ B_H = \begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} \quad \tilde{P}_H = \begin{pmatrix} \tilde{\pi}^+ \\ \tilde{\pi}^0 \\ \tilde{\pi}^- \end{pmatrix} \]

\[ n_B = n_{B^0} + n_{\bar{B}^0} \quad n_{\tilde{\pi}} = n_{\tilde{\pi}^+} + n_{\tilde{\pi}^0} + n_{\tilde{\pi}^-} \]

(Co)annihilation processes:

\[ \tilde{\pi}^0 \tilde{\pi}^0, \tilde{\pi}^+ \tilde{\pi}^-, \tilde{\pi}^{\pm} \tilde{\pi}^0 \rightarrow XY \]

Component mixing:

\[ \tilde{\pi}^+ \tilde{\pi}^-, \tilde{\pi}^0 \tilde{\pi}^0 \rightarrow B^0 \bar{B}^0 \]

\[ \frac{da^3n_{\tilde{\pi}}}{a^3 dt} = \left< \bar{\sigma}v > \tilde{\pi} \left( n_{\tilde{\pi}}^2 - (n_{\tilde{\pi}}^{eq})^2 \right) \right> - \left< \sigma v > \tilde{\pi} \tilde{\pi} \left( n_{\tilde{\pi}}^2 - \frac{9}{4} n_B^2 \right) \right> + \left< \sigma v > BB \left( n_B^2 - \frac{4}{9} n_{\tilde{\pi}}^2 \right) \right> \]

\[ B^0 \bar{B}^0 \rightarrow \tilde{\pi}^+ \tilde{\pi}^-, \tilde{\pi}^0 \tilde{\pi}^0 \]

+ one for B
Diffuse spectrum

Example for: \( B^0 \bar{B}^0 \rightarrow W^+ W^- \gamma, t\bar{t}\gamma \)
Conclusions

The simplest vectorlike hypercolor extension of the SM with one H-quark doublet is considered.

The set of pseudo-goldstone bosons contains two neutral stable particles which can be close in mass.

If these particles are interpreted as the DM carriers, the model does not contradict to the current experimental data on the DM relic abundance.

The model naturally suggests that the Dark Matter has two components; relative concentrations of these components were studied in details.

It is shown that interaction of this DM particles with nucleons satisfies the constraints of LUX and XENON.

Analysis of specific annihilation signals and deep inelastic scattering of high-energy cosmic rays off the DM is in progress.
Thank you for your attention!