Chiral Composite Asymmetric Dark Matter

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Contents

Contents

0. The Introduction of Asymmetric Dark Matter (ADM)

- Baryon asymmetry exists in the Universe.

$$\eta \equiv (n_b - n_{\bar{b}})/n_\gamma \sim 10^{-10}$$

- The ratio of $\Omega_{\mathrm{DM}} : \Omega_{\mathrm{B}}$ is $\mathcal{O}(1)$.

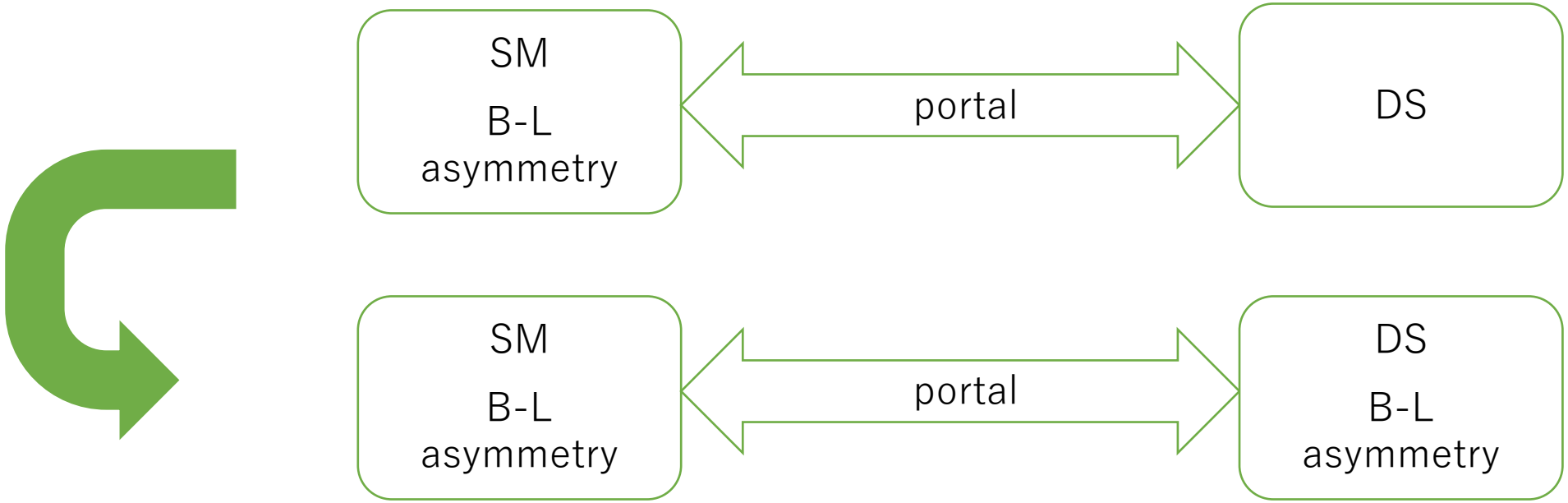
$$\Omega_{\mathrm{DM}}/\Omega_{\mathrm{B}} \simeq 5 \sim \mathcal{O}(1)$$

Do these matters have
a common origin?

ADM

0. The Introduction of Asymmetric Dark Matter (ADM)

$$\mathcal{L}_{B-L\,\mathrm{portal}} = \mathcal{O}_{DS}\,\mathcal{O}_{SM}/M^n$$

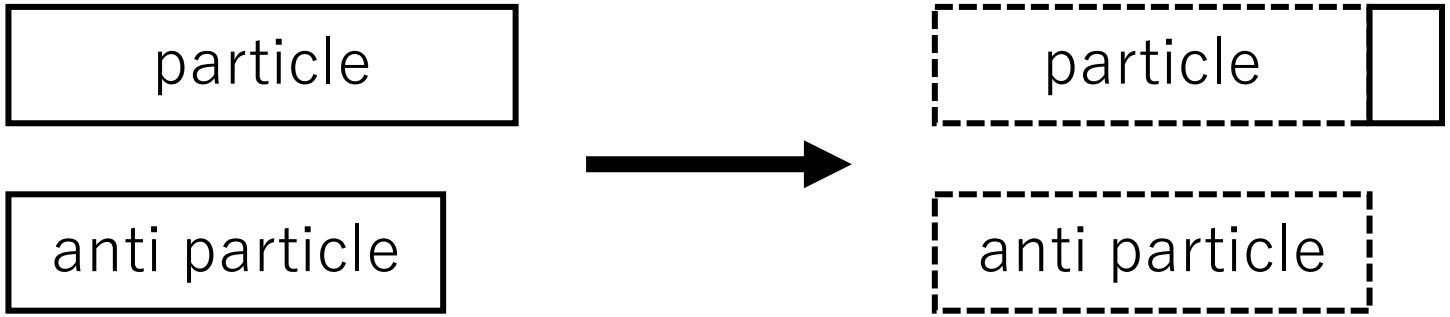


Contents

1. A model of (Non-chiral) Composite ADM [1]

Why was composite model considered ?

- Symmetric component almost vanish like baryons



- Confinement scale determines DM mass ($\mathcal{O}(1)$ GeV)

$$\Lambda_{\mathrm{D}} \sim 10 \times \Lambda_{\mathrm{QCD}}$$

1. A model of (Non-chiral) Composite ADM [1]

	gauge		global
	$\mathrm{SU}(3)_D$	$\mathrm{U}(1)_D$	$\mathrm{U}(1)_{B-L}$
U	$\mathbf{3}$	$2/3$	$1/3$
D	$\mathbf{3}$	$-1/3$	$1/3$
$\bar{U}$	$\bar{\mathbf{3}}$	$-2/3$	$-1/3$
$\bar{D}$	$\bar{\mathbf{3}}$	$1/3$	$-1/3$

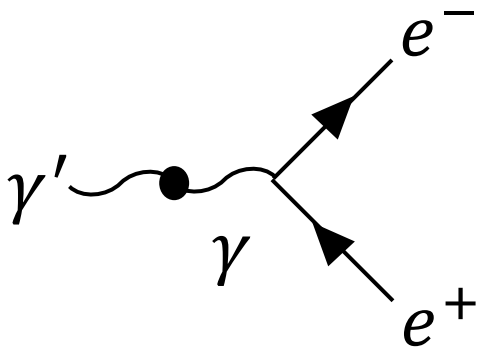
- Dark baryons and dark mesons arise due to the confinement
- dark baryons → dark matter
  e.g. $p' \propto UUD, n' \propto UDD$
- dark mesons → over density
  e.g. $\pi'^0 \propto U\bar{U} - D\bar{D}, \ \pi'^+ \propto U\bar{D}$

Necessity of annihilating or decaying dark mesons into SM particles !

1. A model of (Non-chiral) Composite ADM [1]

dark meson → SM, How ?

→ dark photon (kinetic mixing)



massless → N_{eff} ✗ ⇒ dark photon must be massive ! ($\mathcal{O}(10-100)$ MeV)

$$2 \times m_e < m_{\gamma'} < m_{\pi'} < m_{\mathrm{DM}}$$

1. A model of (Non-chiral) Composite ADM [1]

dark photon mass ($\mathcal{O}(10-100)$ MeV) ← dark Higgs

Problems arise here !

Dark Higgs VEV tuning is needed in addition to Λ_D !

Nothing is said about dark Higgs in [1] !
(e.g. Thermal history, 4-point coupling with SM Higgs)

Contents

2. A Model of Chiral Composite ADM

	gauge		global
	$\mathrm{SU}(3)_D$	$\mathrm{U}(1)_D$	$\mathrm{U}(1)_{B-L}$
U	$\mathbf{3}$	1	$1/3$
D	$\mathbf{3}$	-1	$1/3$
S	$\mathbf{3}$	0	$1/3$
$\bar{U}$	$\bar{\mathbf{3}}$	$-a$	$-1/3$
$\bar{D}$	$\bar{\mathbf{3}}$	a	$-1/3$
$\bar{S}$	$\bar{\mathbf{3}}$	0	$-1/3$

- We assume $0 < a < 1$
- $\mathrm{SU}(3)_L \times \mathrm{SU}(3)_R$ approximate flavor symmetry exists
- U and D can not have the mass

Chiral !

3 flavor $\leftarrow \mathcal{L}_{B-L\,\mathrm{portal}} = \mathcal{O}_{DS}\, LH/M^n$

2. A Model of Chiral Composite ADM

	gauge		global
	$\mathrm{SU}(3)_D$	$\mathrm{U}(1)_D$	$\mathrm{U}(1)_{B-L}$
U	$\mathbf{3}$	1	$1/3$
D	$\mathbf{3}$	-1	$1/3$
S	$\mathbf{3}$	0	$1/3$
$\bar{U}$	$\bar{\mathbf{3}}$	$-a$	$-1/3$
$\bar{D}$	$\bar{\mathbf{3}}$	a	$-1/3$
$\bar{S}$	$\bar{\mathbf{3}}$	0	$-1/3$

Below Λ_D ,

$$\langle U\bar{U} + \mathrm{h.c.}\rangle = \langle D\bar{D} + \mathrm{h.c.}\rangle = \langle S\bar{S} + \mathrm{h.c.}\rangle = \mathcal{O}(\Lambda_D^3)$$

$$\mathrm{SU}(3)_L \times \mathrm{SU}(3)_R \to \mathrm{SU}(3)_V$$

$\mathrm{U}(1)_D$ also breaks due to this condensation

2. A Model of Chiral Composite ADM

SSB of $\mathrm{U}(1)_D \rightarrow$ massive dark photon ! [2]

Chiral Lagrangian

$$\mathcal{L} = \frac{f_\pi'^2}{4} \mathrm{tr}\left[(D_\mu U)(D^\mu U)^\dagger\right]$$

$+$ meson mass term

$$U(x) = \exp\left[\frac{i}{f_\pi'} \sum_{i=1}^{8} \pi_i'(x)\, \lambda_i\right]$$

$$D_\mu U(x) = \partial_\mu U(x) - i e_D A_\mu' \lambda_3 U(x) + i a e_D A_\mu' U(x) \lambda_3$$

2. A Model of Chiral Composite ADM

From chiral Lagrangian,

$$m_{\gamma'} = e_D(1-a)f'_\pi \sim e_D(1-a)\Lambda_D$$ (π'_3 is would-be NG boson)

~~Dark Higgs VEV tuning is needed in addition to Λ_D !~~

~~Nothing is said about dark Higgs in [1] !~~

~~e.g. Thermal history, 4-point coupling with SM Higgs~~

Contents

3. Conclusion

We constructed the new composite ADM model that solves the following problems.

~~Dark Higgs VEV tuning is needed in addition to Λ_D !~~

~~Nothing is said about dark Higgs in [1] !~~

~~e.g. Thermal history, 4-point coupling with SM Higgs~~

References

[1]: M. Ibe, A. Kamada, S. Kobayashi and W. Nakano, JHEP 11 (2018) 203

[2]: K. Harigaya and Y. Nomura, Phys. Rev. D 94 no.3 (2016), 035013

Thank you !

BACK UP

ADM mass

$$m_{\mathrm{DM}} \simeq \frac{\Omega_{\mathrm{DM}}}{\Omega_{\mathrm{B}}} \frac{A_{\mathrm{B}}}{A_{\mathrm{SM}}} \frac{A_{\mathrm{SM}}}{A_{\mathrm{DM}}} \times m_{\mathrm{N}}$$

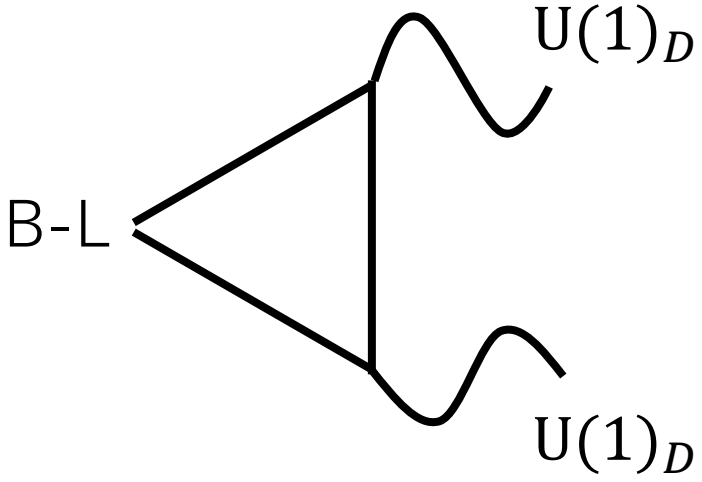
$$A_{\mathrm{B}} \equiv \sum_{i \in \mathrm{SM}} q_{i,B} \left(n_i - \bar{n}_i\right), \qquad A_{\mathrm{SM}} \equiv \sum_{i \in \mathrm{SM}} q_{i,B-L} \left(n_i - \bar{n}_i\right),$$

$$A_{\mathrm{DM}} \equiv \sum_{i \in \mathrm{DM}} q_{i,B-L} \left(n_i - \bar{n}_i\right)$$

Anomaly in Chiral Composite ADM model

	$\mathrm{SU}(3)_D$	$\mathrm{U}(1)_D$	$\mathrm{U}(1)_{B-L}$
U	$\mathbf{3}$	1	$1/3$
D	$\mathbf{3}$	-1	$1/3$
S	$\mathbf{3}$	0	$1/3$
$\bar{U}$	$\bar{\mathbf{3}}$	$-a$	$-1/3$
$\bar{D}$	$\bar{\mathbf{3}}$	a	$-1/3$
$\bar{S}$	$\bar{\mathbf{3}}$	0	$-1/3$

$\mathrm{U}(1)_{B-L} \times [\mathrm{U}(1)_D]^2$ global anomaly exists,



$\propto (1 - a^2)$

This anomaly does not affect the ADM scenario, unless a dark helical magnetic field exists.

Phenomenology of Dark Matter

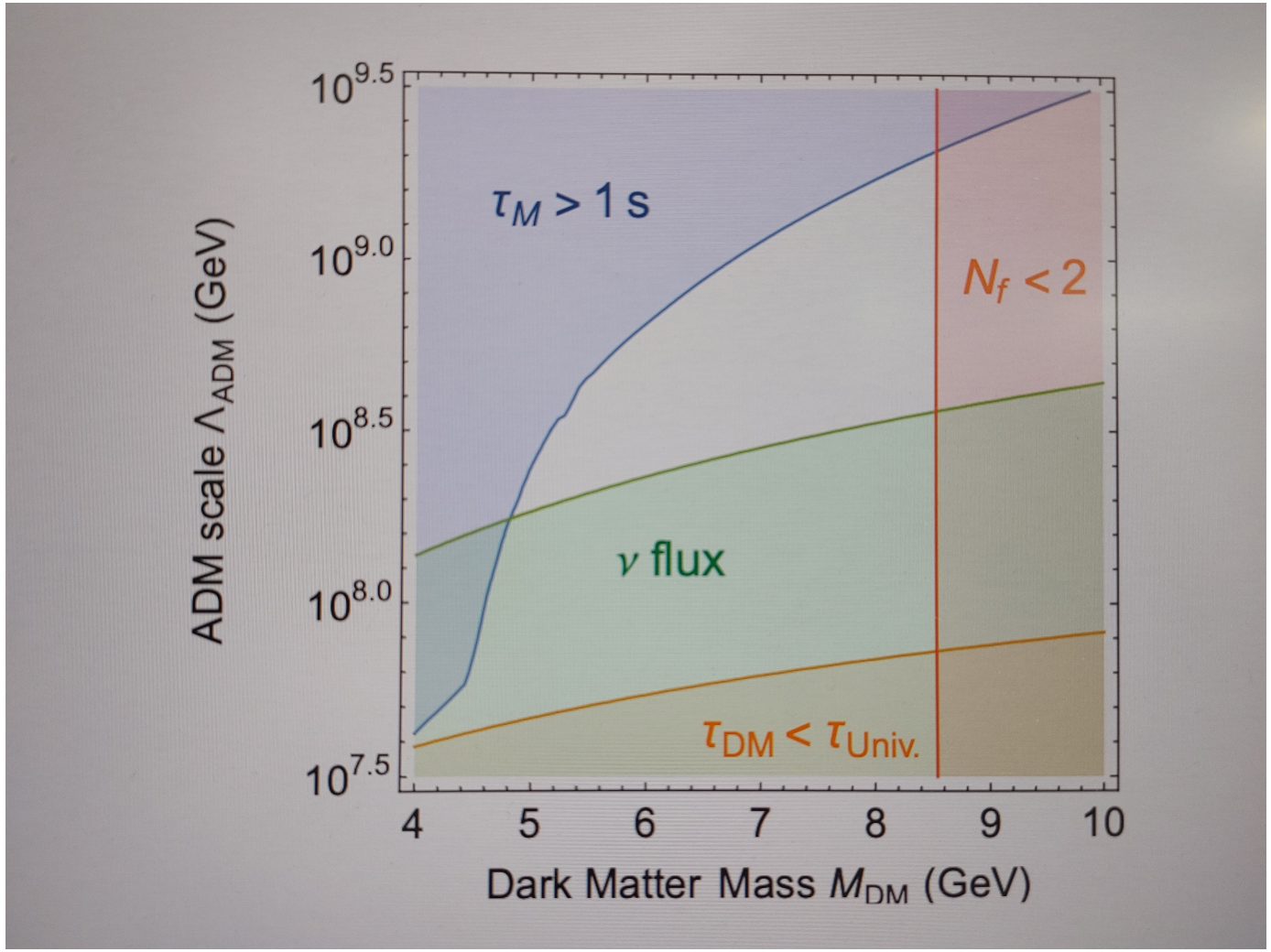
These dark baryons decay due to B-L portal,

$$\mathcal{L}_{B-L\,\mathrm{portal}} = \mathcal{O}_{DS}\, LH/M^3 \qquad \mathcal{O}_{DS} = UDS + \bar{U}^{\dagger}\bar{D}^{\dagger}S$$

but their lifetime is longer than the age of the Universe for $\mathrm{M} \gtrsim 10^{8.2}\ \mathrm{GeV}$,

$$\tau_{\mathrm{DM}} \gtrsim 10^{21}\ \mathrm{sec} = 10^{14}\ \mathrm{year}$$

Lifetime of the DM



Phys. Rev. D 92 (2015) 1, 013008

Formula of the Dark Baryon

	$\mathrm{SU}(3)_D$	$\mathrm{U}(1)_D$	$\mathrm{U}(1)_{B-L}$	$\mathrm{U}(1)_{3D}$	$\mathrm{U}(1)_{8D}$
U	$\mathbf{3}$	1	$1/3$	1	1
D	$\mathbf{3}$	-1	$1/3$	-1	1
S	$\mathbf{3}$	0	$1/3$	0	-2
$\overline{U}$	$\overline{\mathbf{3}}$	$-a$	$-1/3$	-1	-1
$\overline{D}$	$\overline{\mathbf{3}}$	a	$-1/3$	1	-1
$\bar{S}$	$\overline{\mathbf{3}}$	0	$-1/3$	0	2

$$B' = \begin{pmatrix} \Sigma_3' + \Lambda'/\sqrt{3} & \sqrt{2}\,\Sigma_1' & \sqrt{2}\,p' \\ \sqrt{2}\,\Sigma_2' & -\Sigma_3' + \Lambda'/\sqrt{3} & \sqrt{2}\,n' \\ \sqrt{2}\,\Xi_2' & \sqrt{2}\,\Xi_1' & -2\,\Lambda'/\sqrt{3} \end{pmatrix} \quad \left(B_{\mathrm{SM}} = \begin{pmatrix} \Sigma^0 + \Lambda/\sqrt{3} & \sqrt{2}\,\Sigma^+ & \sqrt{2}\,p \\ \sqrt{2}\,\Sigma^- & -\Sigma^0 + \Lambda/\sqrt{3} & \sqrt{2}\,n \\ \sqrt{2}\,\Xi^- & \sqrt{2}\,\Xi^0 & -2\,\Lambda/\sqrt{3} \end{pmatrix} \right)$$

Formula of the Dark Meson

	$\mathrm{SU}(3)_D$	$\mathrm{U}(1)_D$	$\mathrm{U}(1)_{B-L}$	$\mathrm{U}(1)_{3D}$	$\mathrm{U}(1)_{8D}$
U	$\mathbf{3}$	1	$1/3$	1	1
D	$\mathbf{3}$	-1	$1/3$	-1	1
S	$\mathbf{3}$	0	$1/3$	0	-2
$\overline{U}$	$\overline{\mathbf{3}}$	$-a$	$-1/3$	-1	-1
$\overline{D}$	$\overline{\mathbf{3}}$	a	$-1/3$	1	-1
$\bar{S}$	$\overline{\mathbf{3}}$	0	$-1/3$	0	2

$$M' = \begin{pmatrix} \eta'/\sqrt{3} & \sqrt{2}\,\pi' & \sqrt{2}\,K'^{1} \\ \sqrt{2}\pi'^{\dagger} & \eta'/\sqrt{3} & \sqrt{2}\,K'^{2} \\ \sqrt{2}\,K'^{1\dagger} & \sqrt{2}\,K'^{2\dagger} & -2\,\eta'/\sqrt{3} \end{pmatrix} \quad \left(M_{\mathrm{SM}} = \begin{pmatrix} \pi^0 + \eta/\sqrt{3} & \sqrt{2}\,\pi^+ & \sqrt{2}\,K^+ \\ \sqrt{2}\,\pi^- & -\pi^0 + \eta/\sqrt{3} & \sqrt{2}\,K^0 \\ \sqrt{2}\,K^- & \sqrt{2}\,\overline{K^0} & -2\,\eta/\sqrt{3} \end{pmatrix} \right)$$

Dark pion mass

Dark pion also obtains the mass,

$$m_{\pi'}^2 \sim \frac{3a \log 2}{2\pi^2} e_D^2 \Lambda_D^2$$

There is a parameter region (a, e_D) which satisfies the following relation

$$2 \times m_e < m_{\gamma'} < m_{\text{Dark meson}} < m_{\text{DM}},$$