# Chiral Composite Asymmetric Dark Matter

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KEK-PH + KEK-COSMO joint mini-workshop

# What we did

- We constructed a new composite asymmetric dark matter (ADM) model.
- This ADM model is composed of dark quarks with QCD-like SU(3) gauge charge and chiral U(1) gauge charge.
- We refer to this ADM model as chiral composite ADM model.

# About ADM

- Baryon asymmetry exists in the Universe.

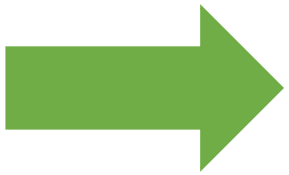
$$\eta \equiv (n_b - n_{\bar{b}})/n_\gamma = \mathcal{O}(10^{-10})$$

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

$$\Omega_{\mathrm{DM}}/\Omega_{\mathrm{B}} \simeq 5 = \mathcal{O}(1) \qquad (\,\Omega_{\mathrm{DM}}/\Omega_{\mathrm{B}}\,(\text{no asymmetry}) = \mathcal{O}(10^{10})\,)$$

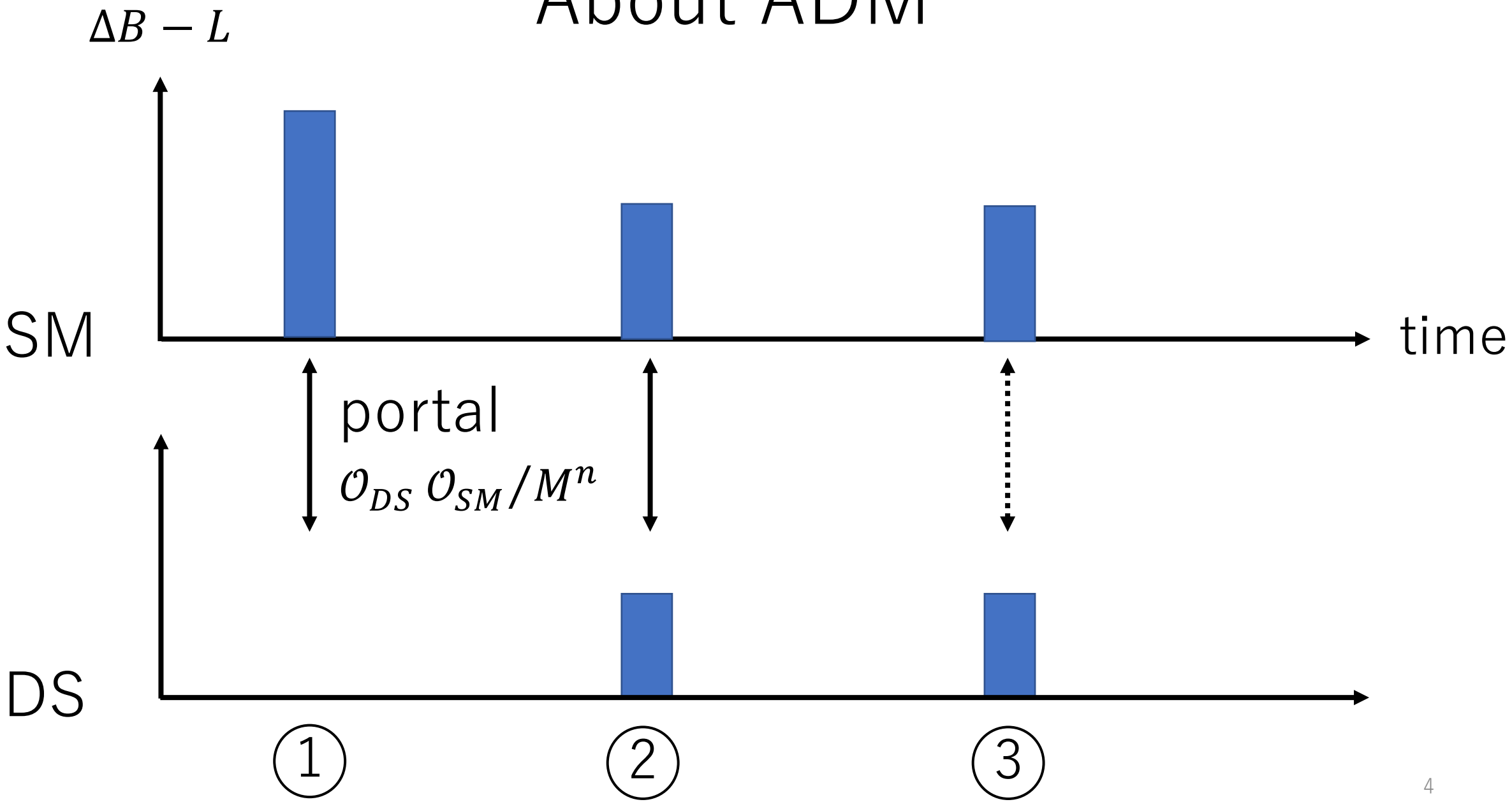
This is miraculous coincidence of Baryon - DM

Do these matters have
a common origin?



ADM

# About ADM



# About ADM

## ADM mass

$$m_{\mathrm{DM}} \simeq \frac{\Omega_{\mathrm{DM}}}{\Omega_{\mathrm{B}}} \frac{A_{\mathrm{B}}}{A_{\mathrm{SM}}} \frac{A_{\mathrm{SM}}}{A_{\mathrm{DM}}} \times m_{\mathrm{N}} \sim \mathcal{O}(1)\ \mathrm{GeV}$$

$A_{\mathrm{B}}$ : baryon asymmetry in the SM $\quad A_{\mathrm{B}} \equiv \sum_{i \in \mathrm{SM}} q_{i,B} \, (n_i - \bar{n}_i)$

$A_{\mathrm{SM}}$ : B-L asymmetry in the SM $\quad A_{\mathrm{SM}} \equiv \sum_{i \in \mathrm{SM}} q_{i,B-L} \, (n_i - \bar{n}_i)$

$A_{\mathrm{DM}}$ : B-L asymmetry in the DS $\quad A_{\mathrm{DM}} \equiv \sum_{i \in \mathrm{DM}} q_{i,B-L} \, (n_i - \bar{n}_i)$

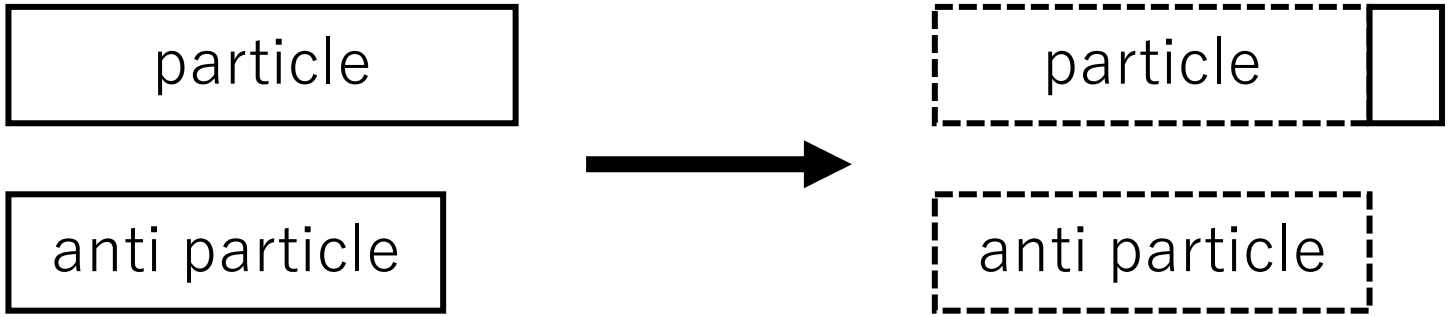
# Contents

# 1. A model of (non-chiral) Composite ADM

M. Ibe et al. JHEP 11 (2018) 203

Two advantages of a composite ADM model

- Symmetric component almost vanish like baryons



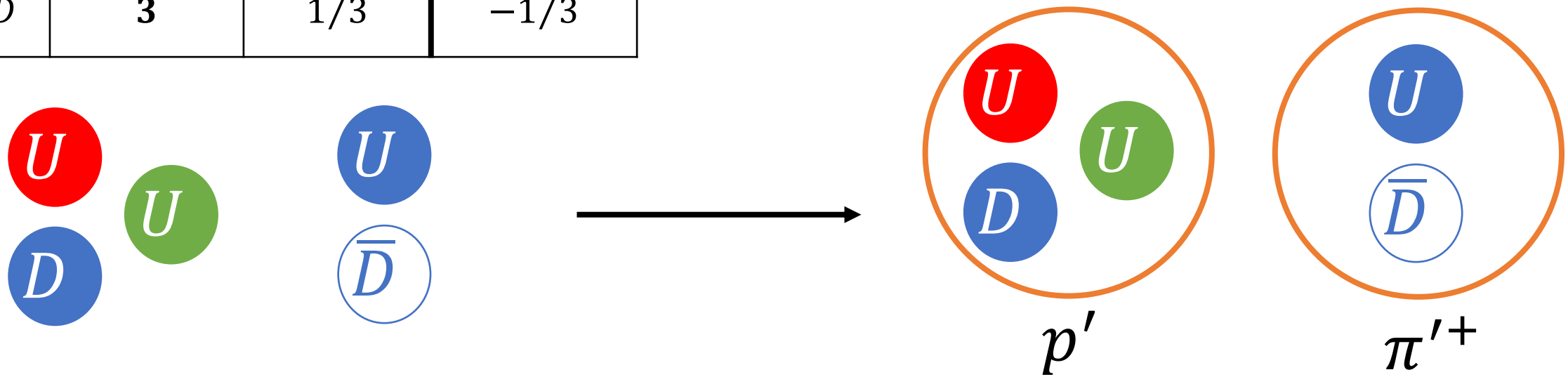

- Confinement scale determines DM mass ($\mathcal{O}(1)$ GeV)

$$\Lambda_D \sim 10 \times \Lambda_{QCD}$$

# 1. A model of (non-chiral) Composite ADM

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

- $\mathcal{L}_{\mathrm{portal}} = (UDD)(LH)/M^3$
- Dark baryons and dark mesons arise due to the confinement



# 1. A model of (non-chiral) Composite ADM

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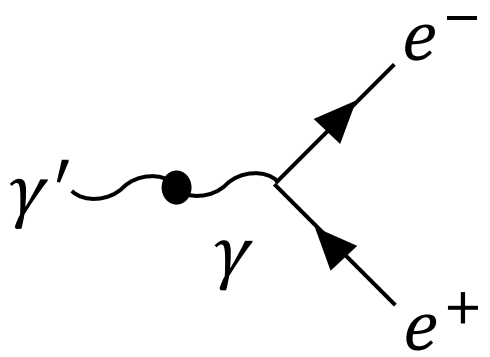
- $\mathcal{L}_{\mathrm{portal}} = (UDD)(LH)/M^3$
- Dark baryons and dark mesons arise due to the confinement
- dark baryons → dark matter
- dark mesons → over abundance

Need to annihilate or decay dark mesons into SM particles !

# 1. A model of (non-chiral) Composite ADM

dark meson → SM

massive dark photon was used(kinetic mixing)




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

$$m_{\gamma'} = \mathcal{O}(10 - 100)\ \text{MeV}$$

# 1. A model of (non-chiral) Composite ADM

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

Problems arise here !

The dark Higgs VEV tuning is needed in addition to $\Lambda_D$ !

Nothing is said about the dark Higgs !
(e.g. thermal history, 4-point coupling with SM Higgs)

# Contents

# 2. A Model of Chiral Composite ADM

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

Chiral !

- $\mathcal{L}_{\mathbf{portal}} = (UDS)(LH)/M^3$
- We assume $0 < a < 1$
- $U$ and $D$ can not have the mass

# 2. A Model of Chiral Composite ADM

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

Below $\Lambda_D$ ,

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

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

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

# 2. A Model of Chiral Composite ADM

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

K. Harigaya and Y. Nomura. PRD 94 (2016) 3, 035013

Chiral Lagrangian

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

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

$$D_\mu U(x) = \partial_\mu U(x) - ie_D A'_\mu \lambda_3 U(x) + iae_D A'_\mu U(x)\lambda_3$$

# 2. A Model of Chiral Composite ADM

From chiral Lagrangian,

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

Dark Higgs VEV tuning is needed in addition to $\Lambda_D$ !

Nothing is said about the dark Higgs !

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

# 2. A Model of Chiral Composite ADM

Dark meson mass

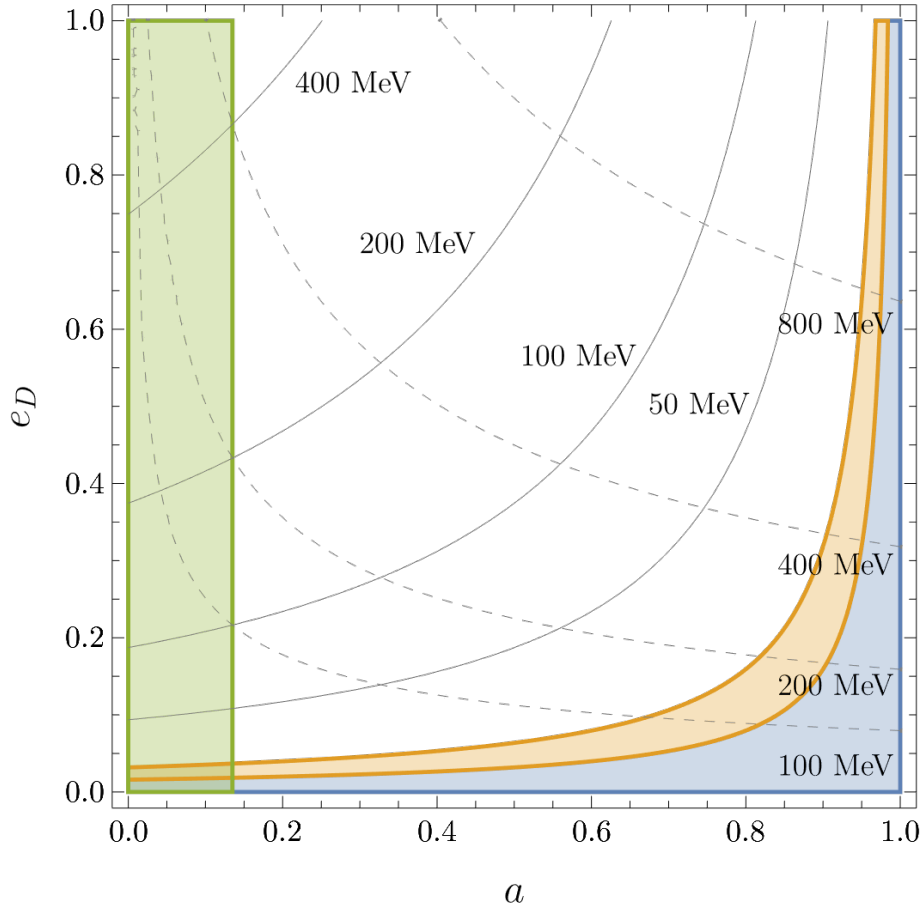
Dark pion : $m_{\pi'}^2 \sim \frac{3a \log 2}{2\pi^2} e_D^2 \Lambda_D^2$

Other dark mesons : $m_{\text{other dark mesons}} \sim \sqrt{m_{S'} \Lambda_{\mathrm{D}}}$

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

There is a parameter region of $(a, e_D)$ which satisfies the above relation

# 2. A Model of Chiral Composite ADM




$m_{\gamma'}$

$m_{\pi'}$

: $m_{\gamma'} > m_{\pi'}$

: $m_{\gamma'} \lesssim 8.5$ MeV

: $m_{\gamma'} \lesssim 17$ MeV

M. Ibe et al. JHEP 04 (2020) 009

# Contents

# 3. Conclusion

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

Dark Higgs VEV tuning is needed in addition to $\Lambda_D$ !

Nothing is said about the dark Higgs !

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

# Thank you !