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UV Completions of Composite Asymmetric Dark Matter with Dark Photon Portal

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in collaboration with

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Baryon-DM Coincidence

$$\Omega_{\rm DM} \simeq 5\,\Omega_{\rm Baryon}$$

Some mechanism behind the coincidence?

Hint of a dark sector!

Composite Asymmetric DM with Dark Photon Portal

Ibe, Kamada, Kobayashi, Nakano (2018)

- DM number = (B-L)
- lightest dark baryon = DM: large annihilation (SM baryons)
- B-L number asymmetry shared via high-energy portal interaction -> $n_{\rm DM} \simeq n_{\rm Baryon}$
- entropy release by dark photon

talk by S. Kobayashi

Coincidence is explained when $m_{\rm DM} \simeq m_{\rm Baryon}$.

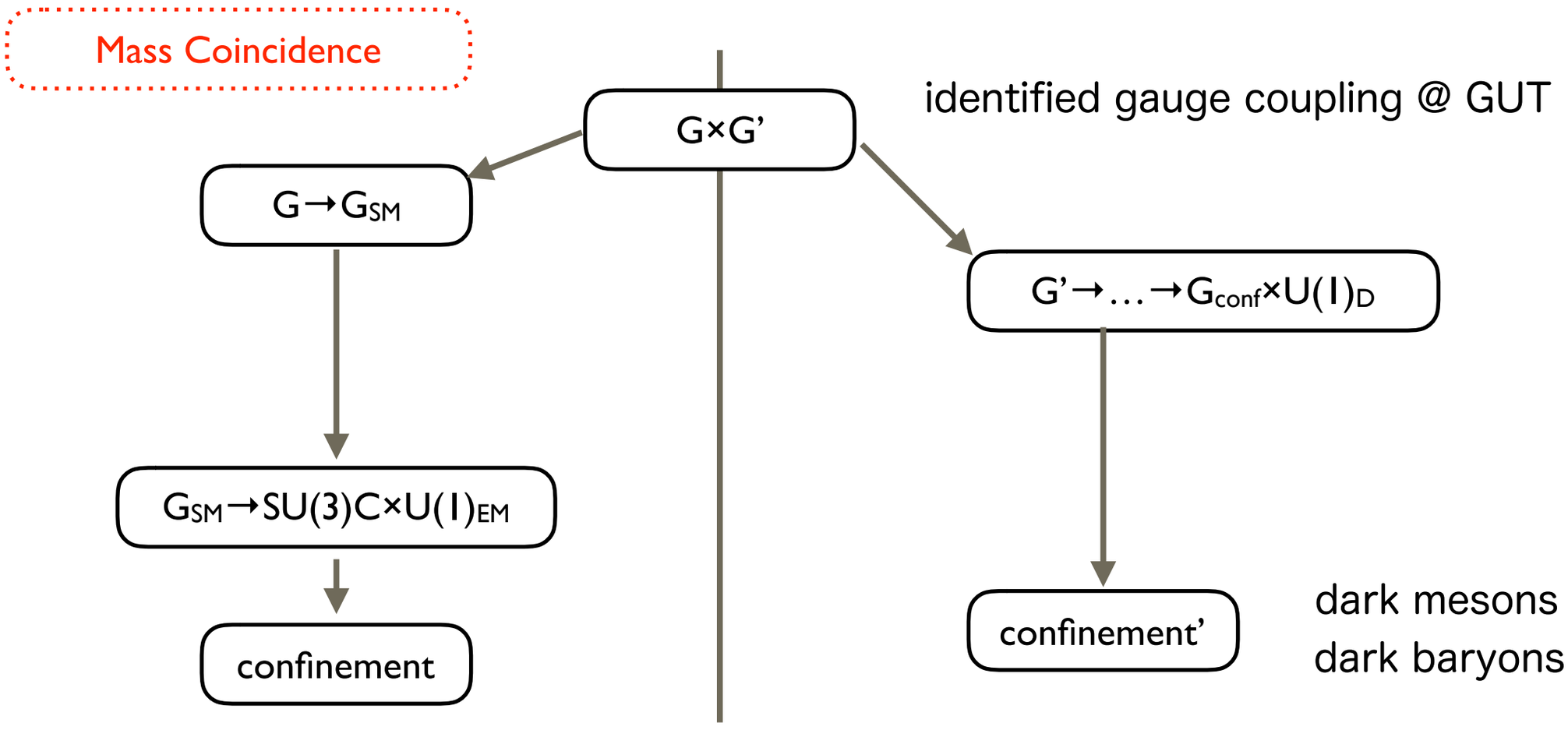
Why confinement scales coincide?

dark sector is mirrored SM?

Our Framework

Based on a $G \times G'/\mathbb{Z}_2$ unification model

- Dark sector consists of a perfect copy of visible sector
- $\mathbb{Z}_2$ breaking by vacuum choices @ unification scale



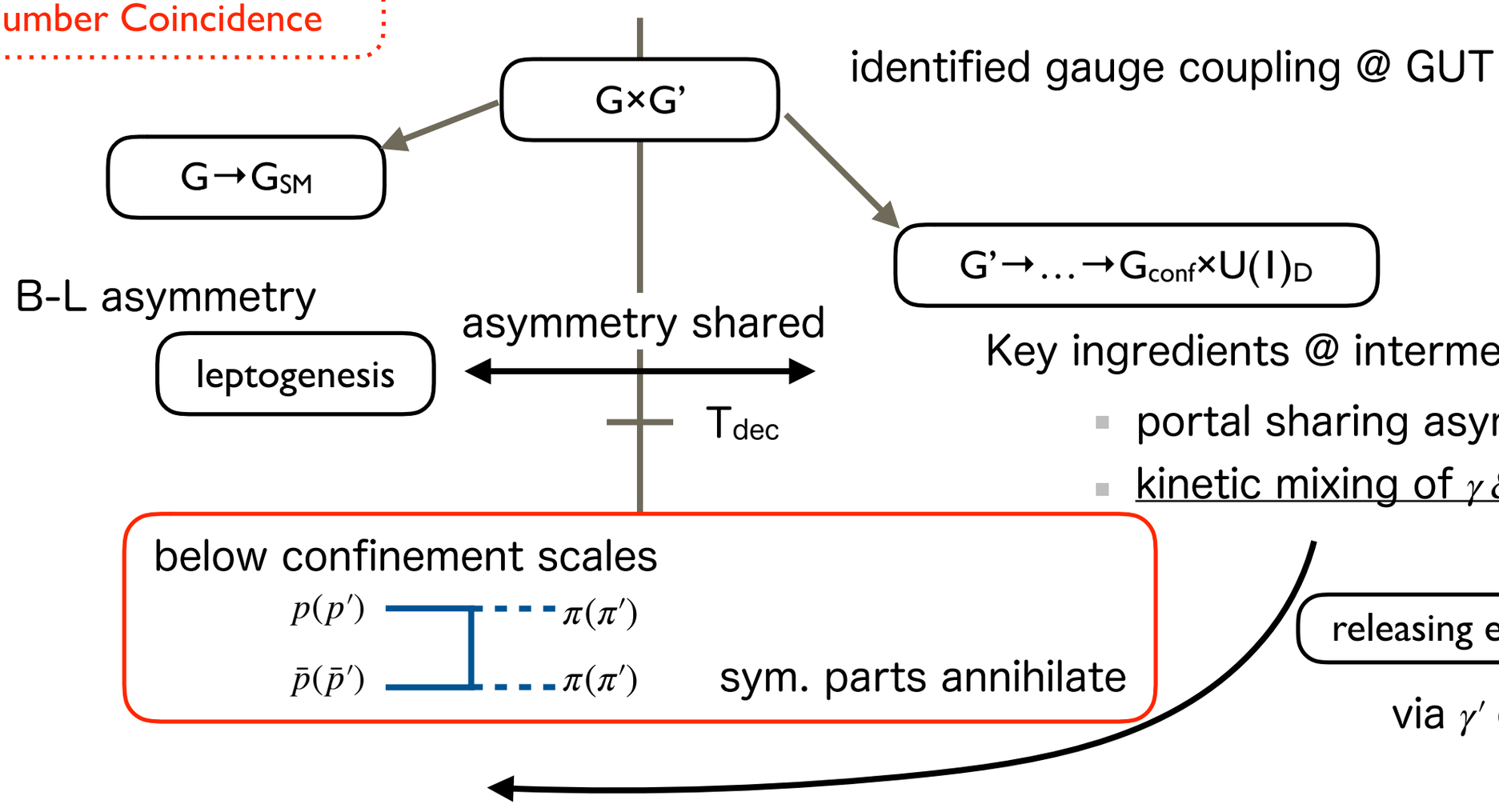
Even if low-energy EFTs are different, $m_{\mathrm{DM}} \simeq m_{\mathrm{Baryon}}$ is realized.

Our Framework

Based on a $G \times G'/\mathbb{Z}_2$ unification model

- Dark sector consists of a perfect copy of visible sector
- $\mathbb{Z}_2$ breaking by vacuum choices @ unification scale
- B-L (= DM #) is approximately conserved separately below T_{dec}

Number Coincidence



☑ Compatible with asymmetric DM ☑ viable cosmology

Key ingredients @ intermediate scale

Ibe, Kamada, Kobayashi, TK, Nakano (2018)

- tiny kinetic mixing via non-renormalizable operator

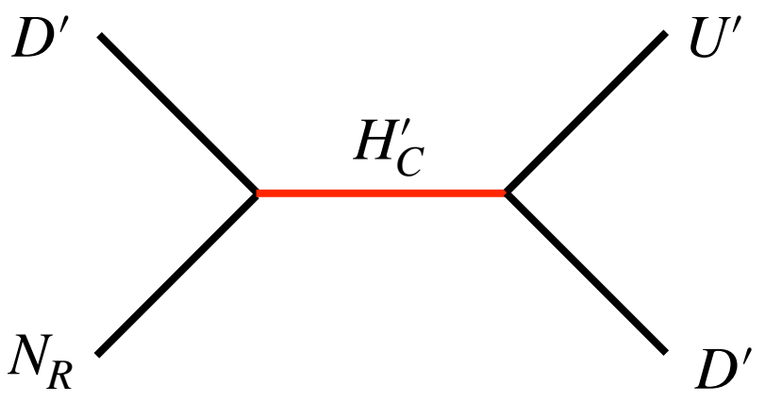
  non-Abelian groups forbid a renormalizable γ-γ' kinetic mixing

  non-renormalizable op. with GUT breaking Higgses

$$\mathcal{L} = \frac{1}{M_{\rm Pl}^2}\mathrm{tr}(F_{G\,\mu\nu}\Sigma_V)\mathrm{Tr}(F_D^{\mu\nu}\Sigma_D)$$

$$\mathcal{L} = \frac{\epsilon}{2}F^{\mu\nu}F'_{\mu\nu}\,, \qquad \epsilon \simeq \frac{v_V v_D}{M_{\rm Pl}^2} \simeq 10^{-9}\left(\frac{v_V}{2\times 10^{16}\ \mathrm{GeV}}\right)\left(\frac{v_D}{5\times 10^{10}\ \mathrm{GeV}}\right)$$

- portal interaction sharing asymmetry



generated asymmetry shared by effective interaction

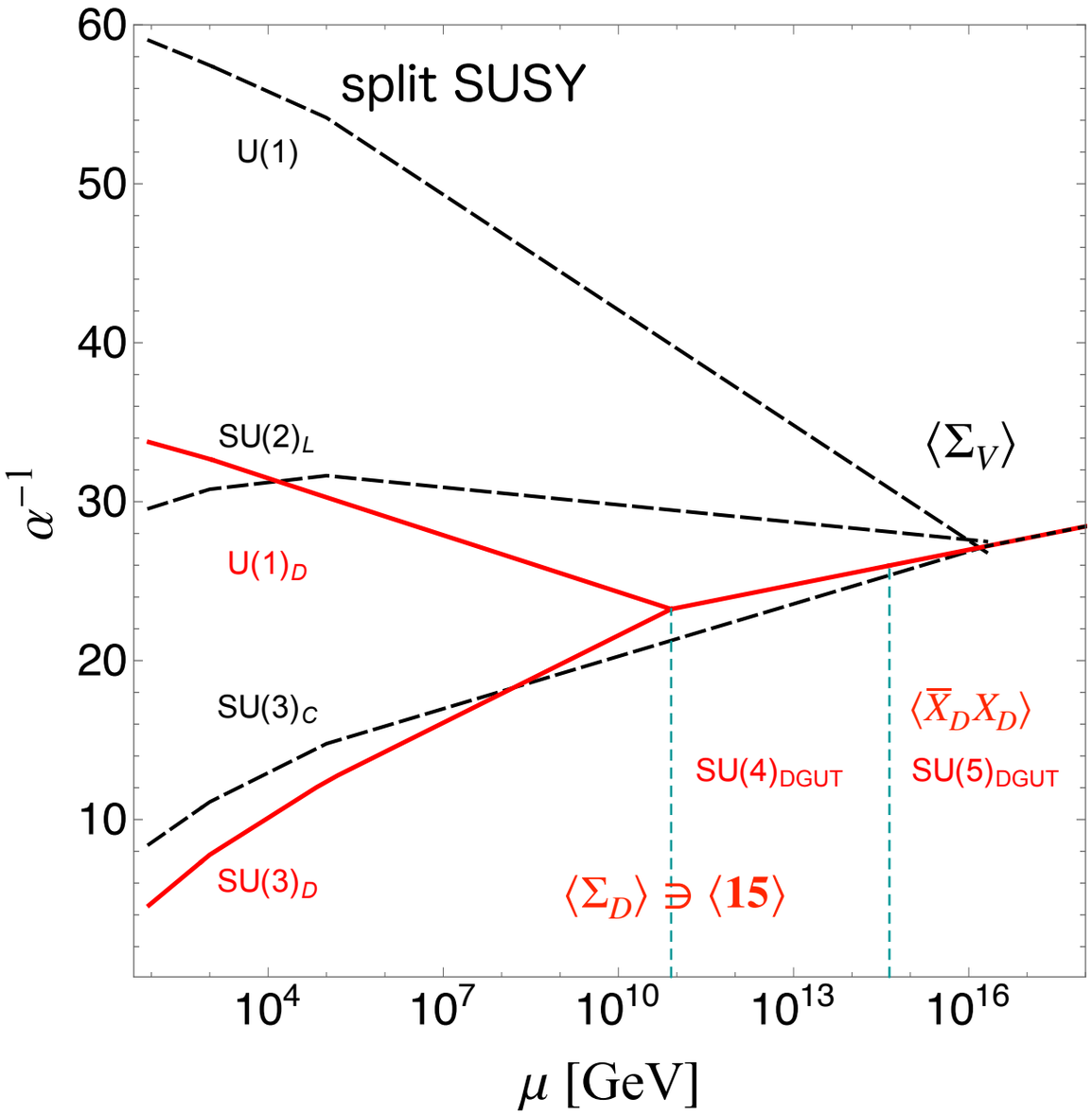
$$\mathcal{L} = \frac{1}{M^3}\overline{U}'\overline{D}'\overline{D}'(LH)$$

(c.f. nucleon decay in GUT)

Intermediate scale dark GUT breaking provides necessaries for composite ADM

A Simple Realization

Ibe, Kamada, Kobayashi, TK, Nakano (2019)



	$SU(5)$	$U(1)_X$
Ψ_{Si}	$\mathbf{10}$	1
Φ_{Si}	$\overline{\mathbf{5}}$	-3
$\overline{N}_i\,,\overline{N}'_i$	$\mathbf{1}$	5
H_S	$\mathbf{5}$	-2
$\overline{H}_S$	$\overline{\mathbf{5}}$	2
X_S	$\mathbf{5}$	-2
$\overline{X}_S$	$\overline{\mathbf{5}}$	2
Σ_S	$\mathbf{24}$	0

$SU(5)_V \times SU(5)_D$ gauge theory

with (softly broken) $\mathbb{Z}_2$

SUSY

- gauge coupling unification
- existence of degenerate vacua

$$SU(5)_V \to SU(3)_C \times SU(2)_L \times U(1)_Y$$
$$SU(5)_D \to SU(4)_D \to SU(3)_D \times U(1)_D$$

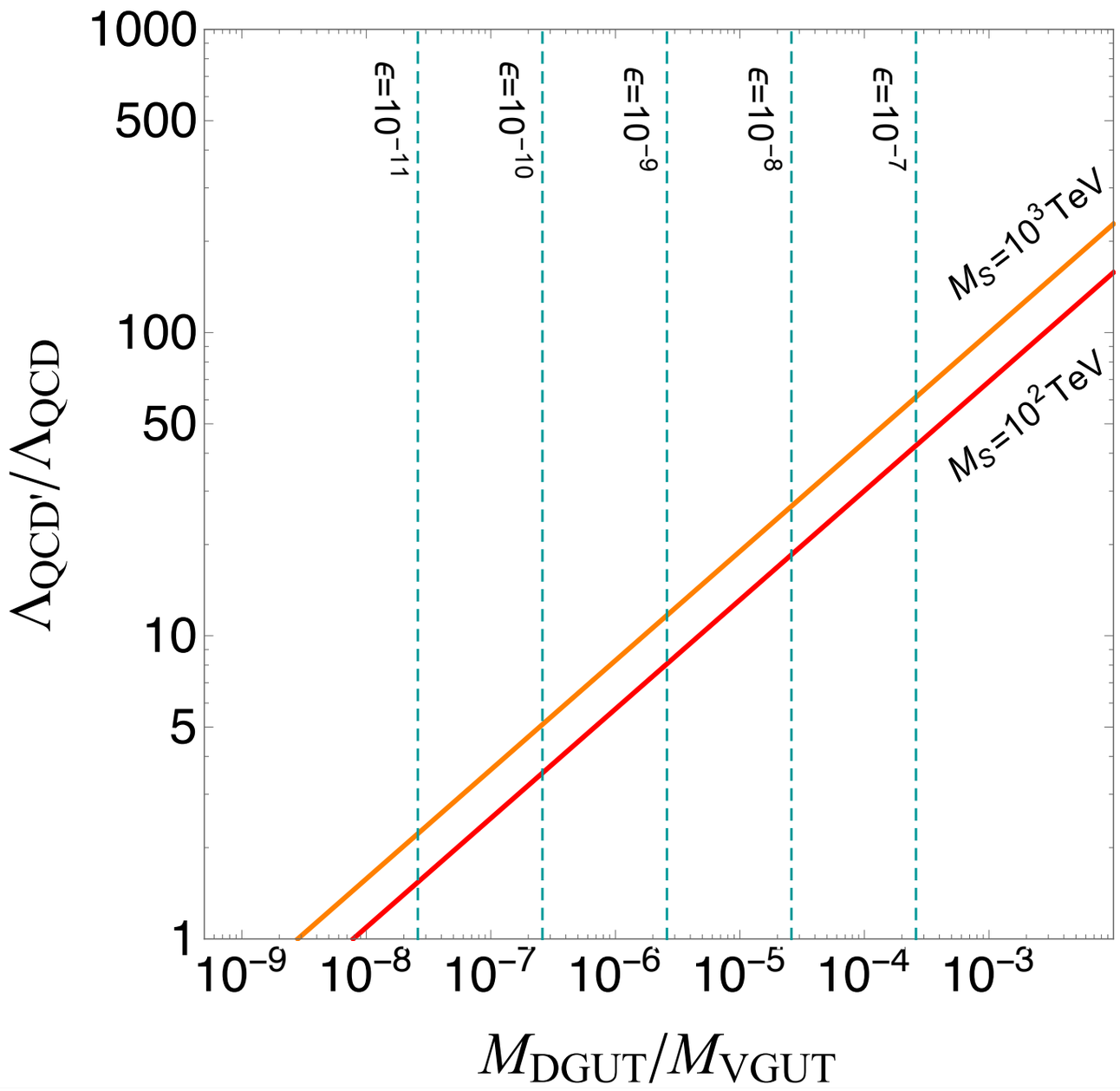
Dark leptons

get their masses via SU(5)$_D$ breaking

dark sector: vector-like theory @ high-scale

Coincidence of Confinement scales

Ibe, Kamada, Kobayashi, TK, Nakano (2019)



Why $\Lambda_{QCD'}/\Lambda_{QCD}$ ~ O(1) ?

Dark GUT scale

~ 7 orders of magnitude

QCD' scale

~ 2 orders of magnitude

$\Lambda_{QCD'}/\Lambda_{QCD}$ is no longer a free parameter!

Summary and Discussion

- ☑ We propose a UV framework for baryon-DM coincidence based on unification
  coincidence of masses: mirror $\mathbb{Z}_2$ @ unification scale
  coincidence of number densities: (composite) ADM scenario

- ☑ Rich phenomenologies
  - DM decay via portal interactions
  - DM annihilation thru dark neutron oscillation
  - etc.

- ☑ Extended models
  a simple realization is presented
  fine-tunings of parameters? chiral gauge model?

Backup

Superpotential in a specific model

Ibe, Kamada, Kobayashi, TK, Nakano (2019)

	$SU(5)$	$U(1)_X$
Ψ_{Si}	$\mathbf{10}$	1
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$\overline{X}_S$	$\overline{\mathbf{5}}$	2
Σ_S	$\mathbf{24}$	0

Superpotential for Yukawa and Higgs sectors

$$
\begin{aligned}
W_S = {} & \Psi_S Y_u \Psi_S H_S + \Psi_S Y_d \Phi_S \overline{H}_S \\
& + H_S(M_S + \lambda\Sigma_S)\overline{H}_S \\
& + \mu_S \mathrm{tr}(\Sigma_S^2) + \lambda_\Sigma \mathrm{tr}(\Sigma_S^3) \\
& + M'_S X_S \overline{X}_S - \xi \frac{(X_S \overline{X}_S)^2}{M_{\rm Pl}}
\end{aligned}
$$

$$\langle \Sigma_S \rangle = 0 \quad \text{or} \quad \mathcal{O}(\mu_S)$$

$$\langle X_S \overline{X}_S \rangle = 0 \quad \text{or} \quad \mathcal{O}(M_{\rm Pl} M'_S)$$

LSPs in a specific model

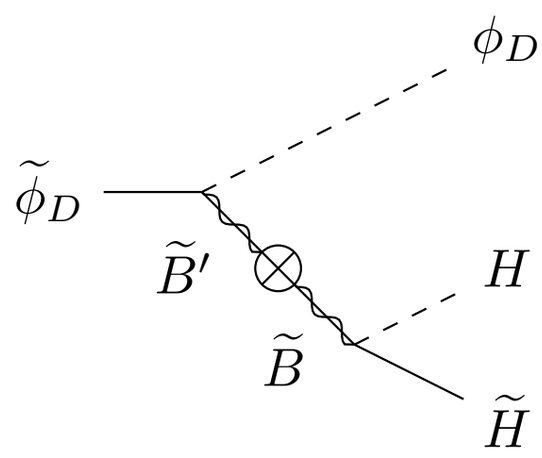
Ibe, Kamada, Kobayashi, TK, Nakano (2018)

Lightest Supersymmetric Particles are also stable in two sectors

- LSPs should be subdominant components of DM
  -> prediction of light sparticles
- feeble connection b/w visible and dark sectors
  -> overclosure of the Universe
  or problematic late-time decay of heavier LSPs?

Higgsinos (MSSM & U(1)$_D$) LSPs help!

heavy higgsino decay via supersymmetric kinetic mixing



$$\tau(\widetilde{\phi}_D \to \phi_D H \widetilde{H}) \sim \frac{8\pi}{\epsilon^2 \alpha_Y \alpha' m_{\widetilde{\phi}_D}}$$

$$\sim 2 \times 10^{-5}\ \mathrm{sec} \left(\frac{10^{-9}}{\epsilon}\right)^2 \left(\frac{8 \times 10^{-2}}{\alpha'}\right) \left(\frac{1\ \mathrm{TeV}}{m_{\widetilde{\phi}_D}}\right)$$