Unification for Darkly Charged Dark Matter

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in collaboration with

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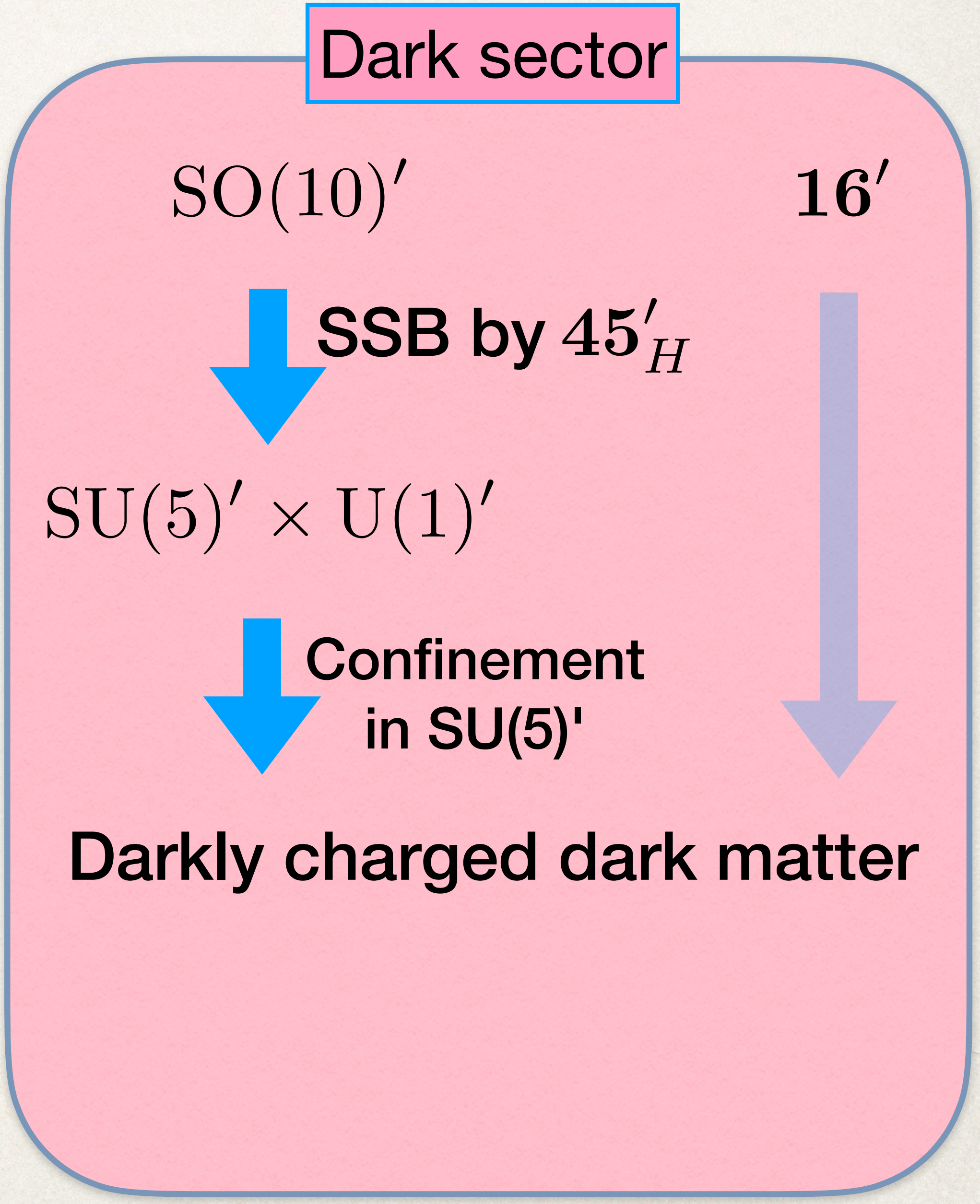
Overview


Dark sector
$\mathrm{SO}(10)'$
$\mathbf{16}'$
SSB by $\mathbf{45}'_H$
$\mathrm{SU}(5)' \times \mathrm{U}(1)'$
Confinement
in SU(5)'
Darkly charged dark matter

Overview

Standard Model sector

$\mathrm{SO}(10)$ $\quad \mathbf{16}^i \ (i=1,2,3)$

↓ **SSB by $\mathbf{45}_H$**

$\mathrm{SU}(5)\times\mathrm{U}(1)$

↓ **SSB**

$G_{\mathrm{SM}}\times\mathrm{U}(1)_{B-L}$ $\quad$ **SM particles + N_R**

↓ **SSB**

G_{SM} $\quad$ **SM particles**

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↓ **Confinement in SU(5)'**

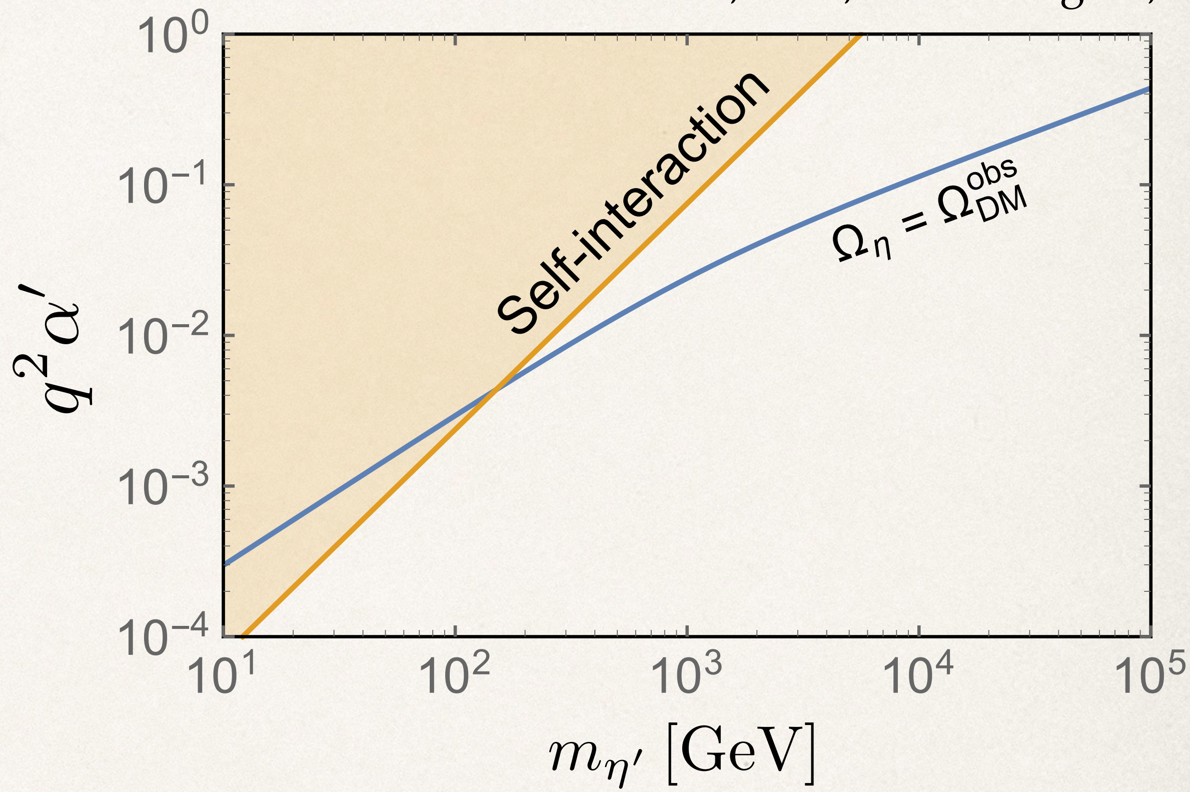
Darkly charged dark matter

Outline

- Motivation of darkly charged DM and its UV theory
- Darkly charged DM from SO(10) gauge theory
  - Gauge coupling constant and DM mass
  - Kinetic mixing and dark radiation
- Summary

Darkly charged DM

A. Kamada, M.Y., T. T. Yanagida, '19



Dark matter is
- stable
- neutral
- cold

Darkly charged DM?

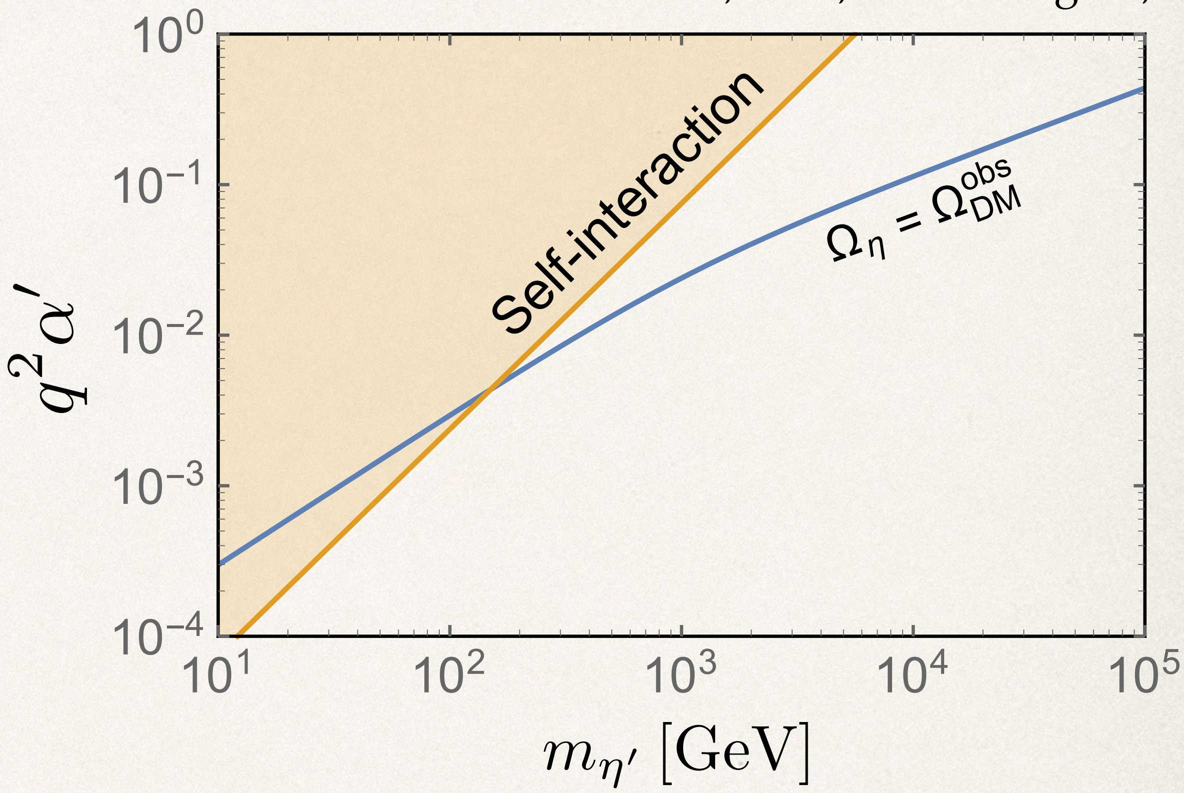
- Thermal relic density: $\Omega_\eta h^2 \simeq 0.13 \left(\frac{m_\eta}{1\ \mathrm{TeV}}\right)^2 \left(\frac{q^2\alpha'}{0.025}\right)^{-2}$

- Self-interaction cross section: $\frac{\sigma_T}{m_\eta} \simeq 0.2\ \mathrm{cm}^2/\mathrm{g} \left(\frac{q^2\alpha'}{0.025}\right)^2 \left(\frac{m_\eta}{1\ \mathrm{TeV}}\right)^{-3} \left(\frac{v}{300\ \mathrm{km/s}}\right)^{-4}$

P. Agrawal, F.Y.Cyr-Racine, L.Randall, J.Scholts 16

Darkly charged DM

A. Kamada, M.Y., T. T. Yanagida, '19



Dark matter is
- stable
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↓

Darkly charged DM?

- Therm

- Self-in

- ✤ Why is the Dirac fermion so light?
- ✤ What is the origin of the U(1)' gauge boson?

$\left(\frac{v}{300\ \mathrm{km/s}}\right)^{-4}$

P. Agrawal, F.Y.Cyr-Racine, L.Randall, J.Scholts '16

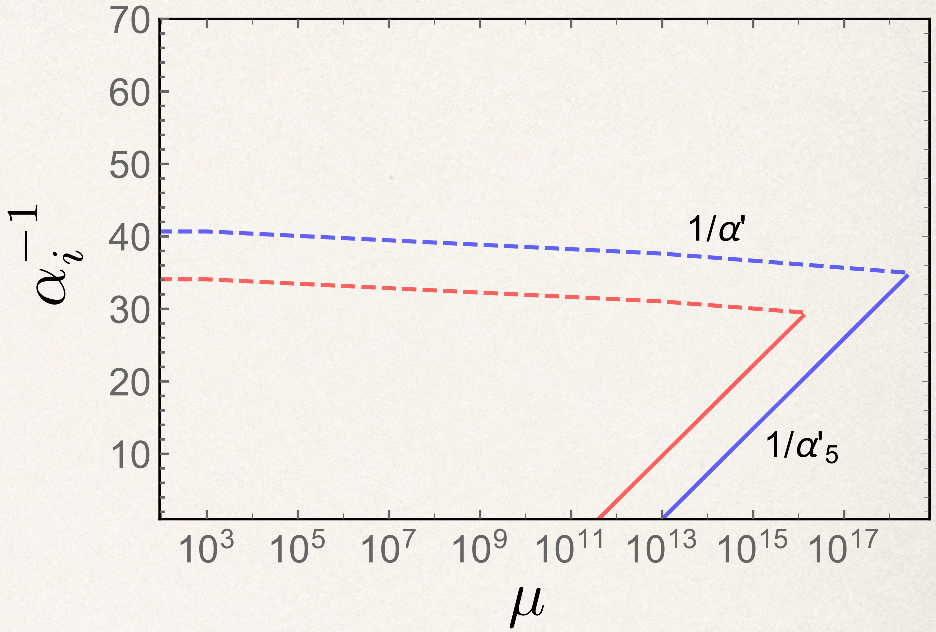
Darkly charged DM from SO(10)' gauge theory

	Ψ'
$\mathrm{SO}(10)'$	$\mathbf{16}$

+ Higgs

SSB at $E \sim 10^{16\text{-}18}$ GeV

	ψ'	χ'	N'
$\mathrm{SU}(5)'$	$\bar{\mathbf{5}}$	$\mathbf{10}$	$\mathbf{1}$
$\mathrm{U}(1)'$	$-3/5$	$1/5$	$\sqrt{10}/4$



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SSB at E ~ $10^{16\text{-}18}$ GeV

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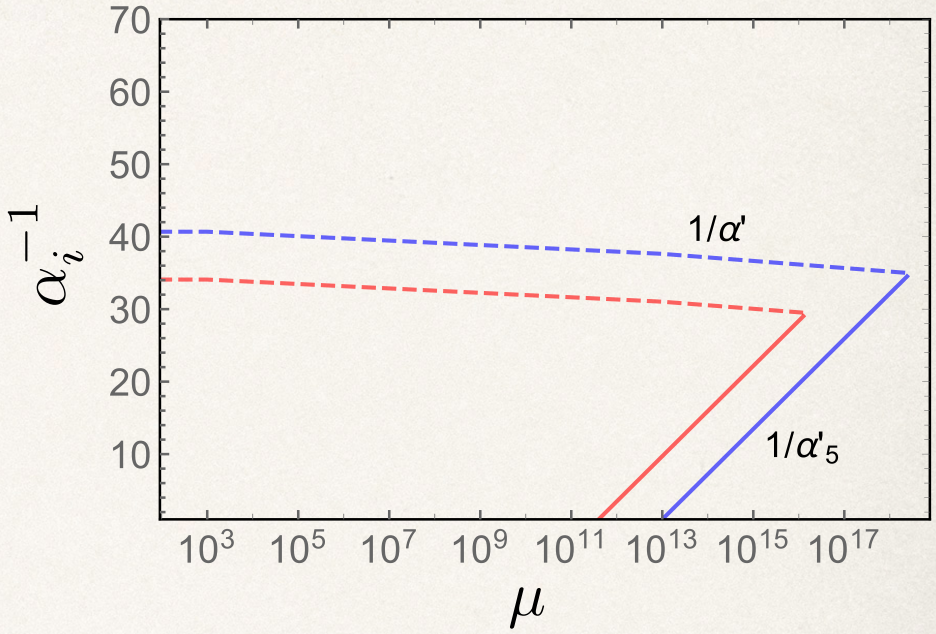

Confinement in SU(5)' at E ~ $10^{12\text{-}13}$ GeV

One linear combination of gauge singlets remains light.

$$\eta' \equiv c_1\psi'\psi'\chi' + c_2\psi'\chi'^\dagger\chi'^\dagger + c_3\chi'^\dagger\chi'^\dagger\chi'^\dagger\chi'^\dagger\chi'^\dagger$$

	η'	N'
$\mathrm{U}(1)'$	$-\sqrt{10}/4$	$\sqrt{10}/4$

S.Dimopoulos, S.Raby, L.Susskind, '80
N.Arkani-Hamed, Y.Grossman, '99

A. Kamada, M.Y., T. T. Yanagida, '19

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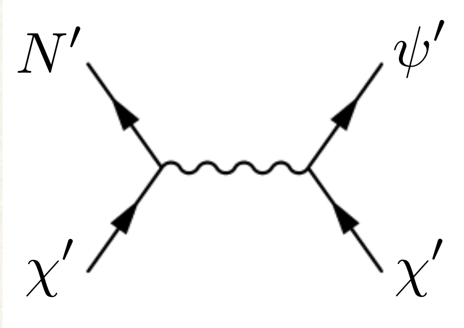
$$\eta' \equiv c_1 \psi' \psi' \chi' + c_2 \psi' \chi'^\dagger \chi'^\dagger + c_3 \chi'^\dagger \chi'^\dagger \chi'^\dagger \chi'^\dagger \chi'^\dagger$$

The exchange of massive SO(10)' gauge boson induces dim-6 operator:

$$\frac{c}{M_{\mathrm{GUT'}}^2} \chi'^\dagger \chi'^\dagger \psi' N' + \mathrm{h.c.}$$



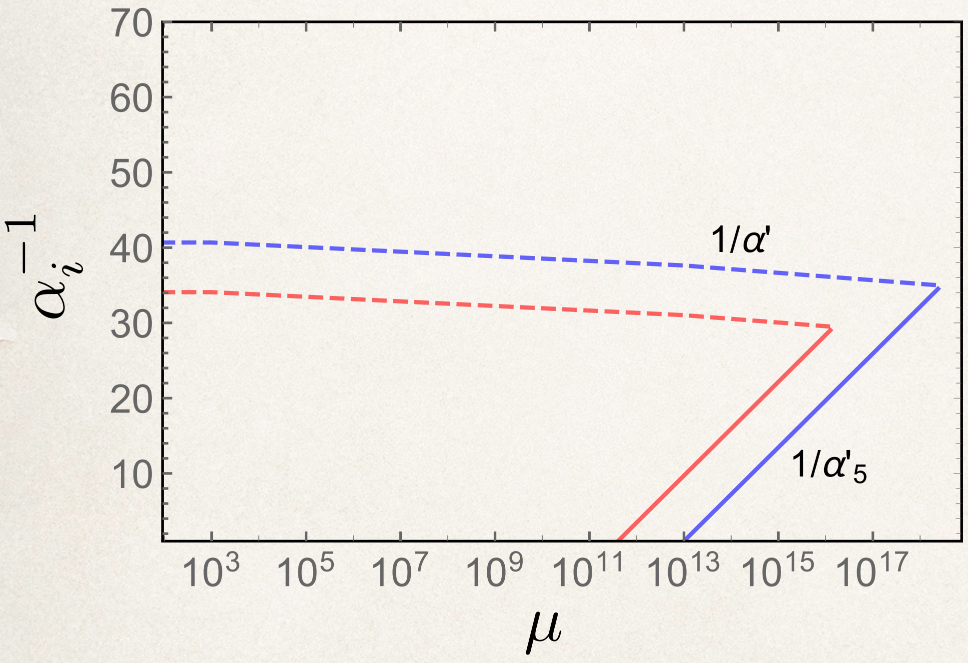
This results in a Dirac mass term for η' and N'.

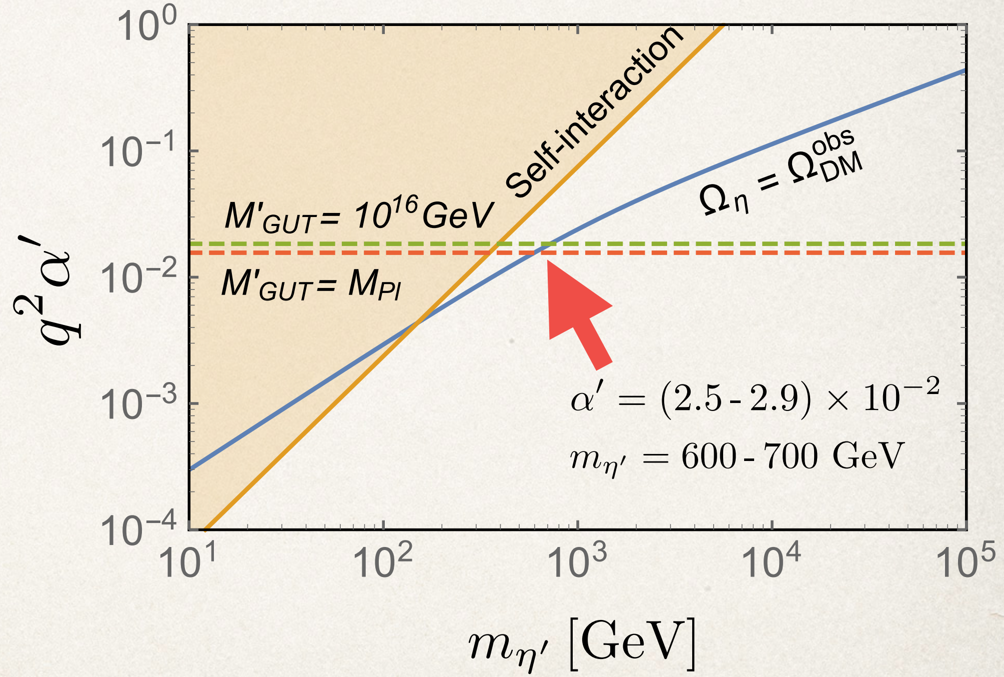
$$m_{\eta'} \eta' N' + \mathrm{h.c.} \quad \text{where} \quad m_{\eta'} \sim c' \frac{(\Lambda_5')^3}{M_{\mathrm{GUT'}}^2}$$

$$\sim 1\ \mathrm{TeV} \left(\frac{\Lambda_5'}{10^{13}\ \mathrm{GeV}} \right)^3 \left(\frac{M_{\mathrm{GUT'}}}{10^{18}\ \mathrm{GeV}} \right)^{-2}$$

Gauge coupling constant and DM mass

Assuming $E_{\mathrm{GUT'}}$ ~ $10^{16\text{-}18}$ GeV,
we can predict α' and $m_{\eta'}$.





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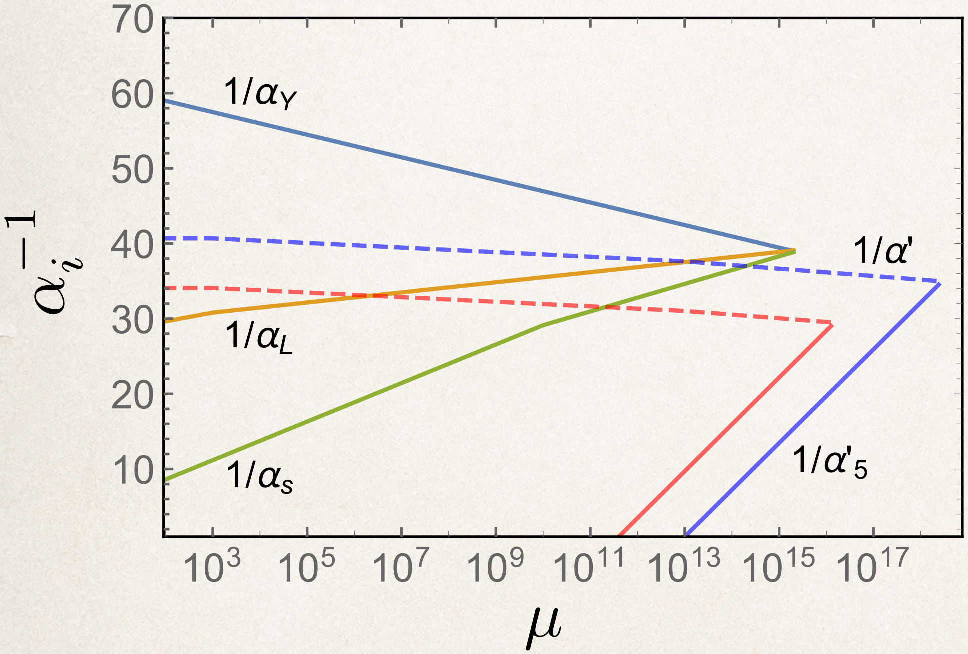

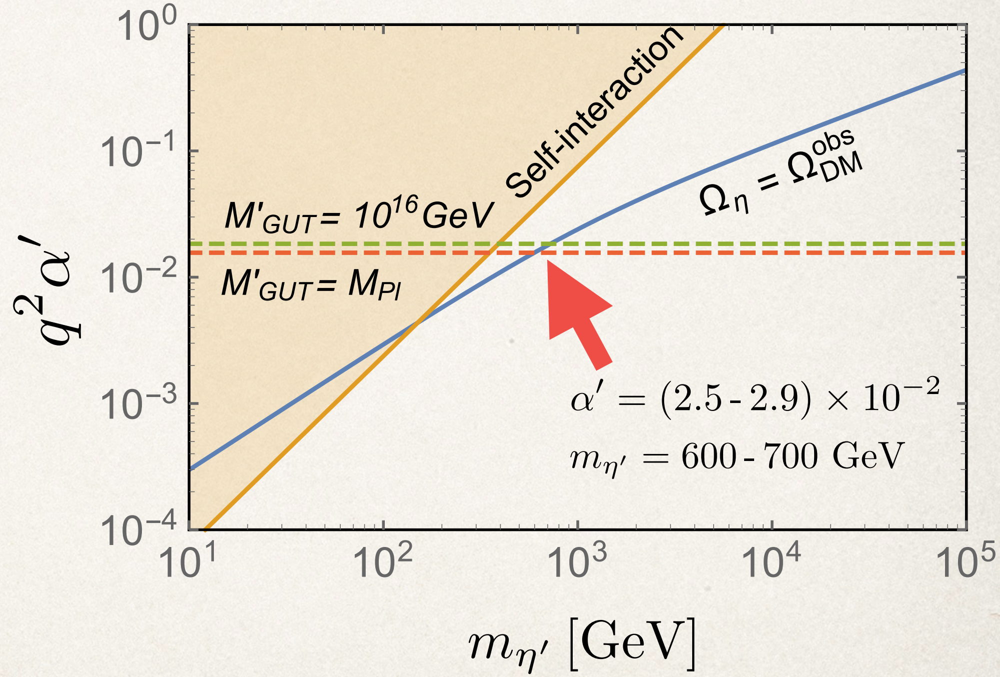

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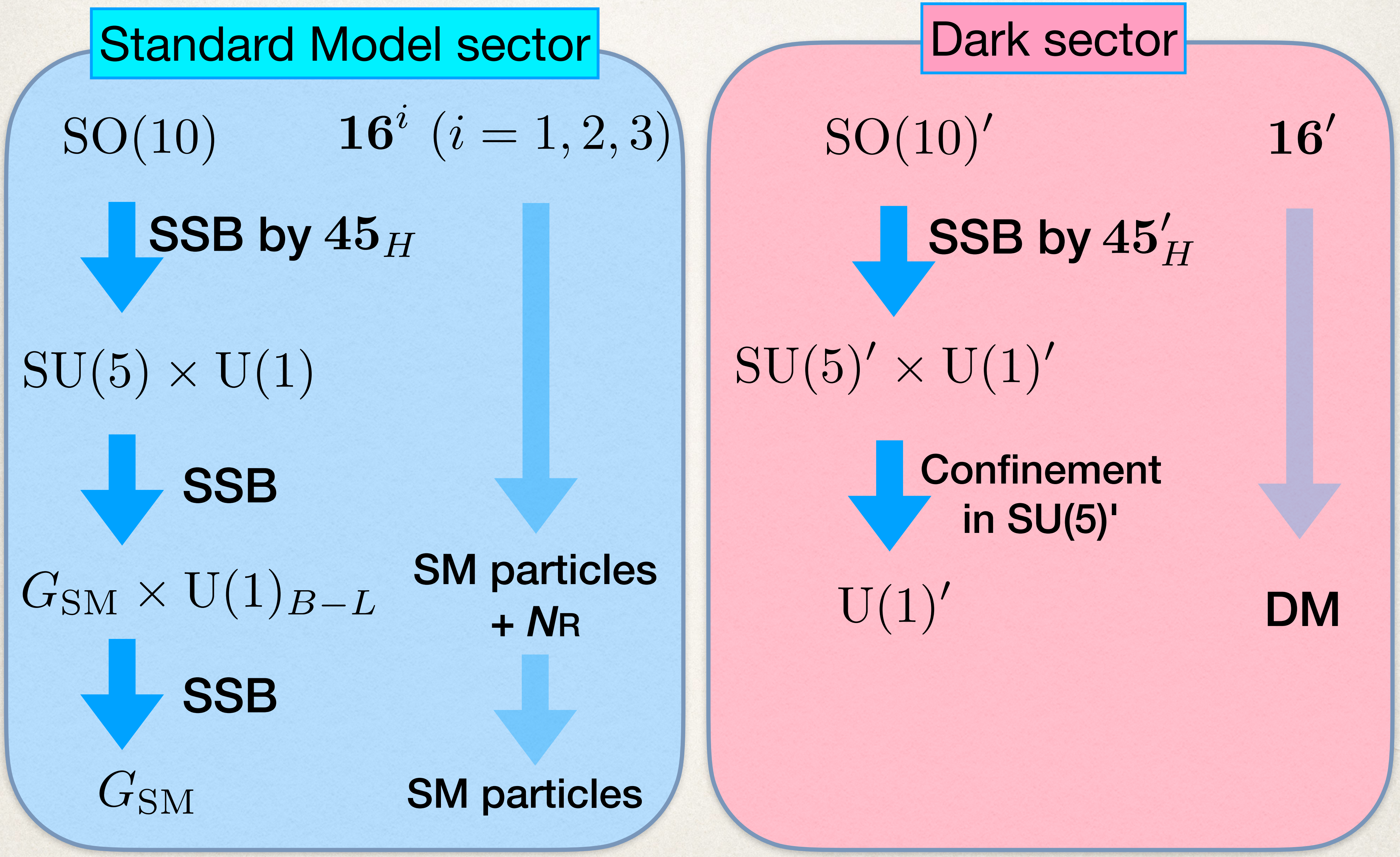
SO(10) GUTs in SM and dark sectors



Kinetic mixing between U(1)Y and U(1)'

Standard Model sector

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Dark sector

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SSB by $\mathbf{45}'_H$

DM

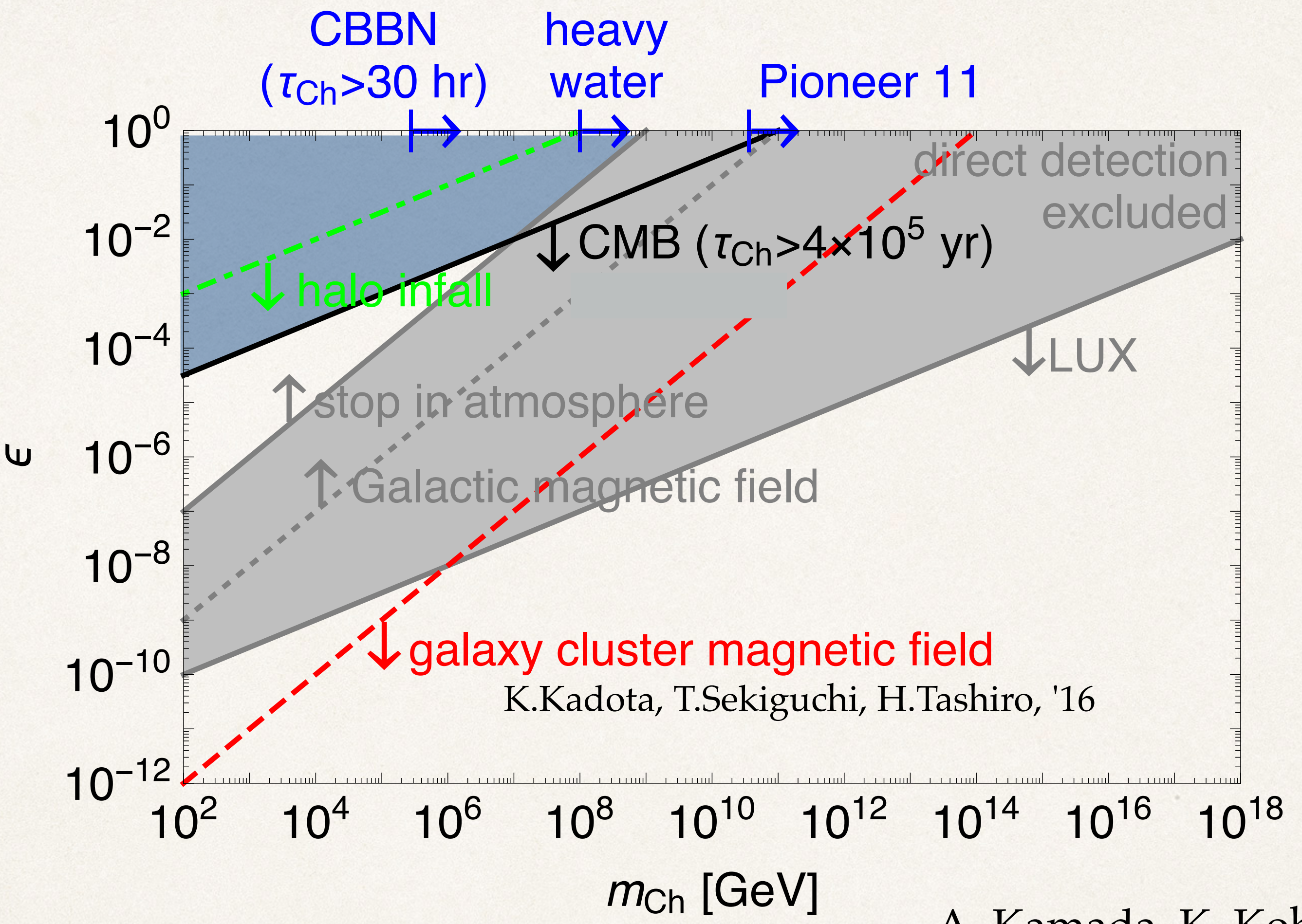
We can write down

$$\frac{c'}{M_{\rm Pl}^2} \mathbf{45}_H \left(F_{10}\right)_{\mu\nu} \mathbf{45}'_H \left(F'_{10'}\right)^{\mu\nu}$$

This gives a kinetic mixing between U(1)Y and U(1)'

$$\epsilon \sim c'(v_{\rm GUT}/M_{\rm Pl})(v'/M_{\rm Pl}) = \mathcal{O}(10^{-(3-6)})$$

Kinetic mixing between U(1)Y and U(1)'



A. Kamada, K. Kohri, T. Takahashi, N. Yoshida, '16

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A. Kamada, M.Y., T. T. Yanagida, '19

Kinetic mixing between U(1)Y and U(1)'

Standard Model sector

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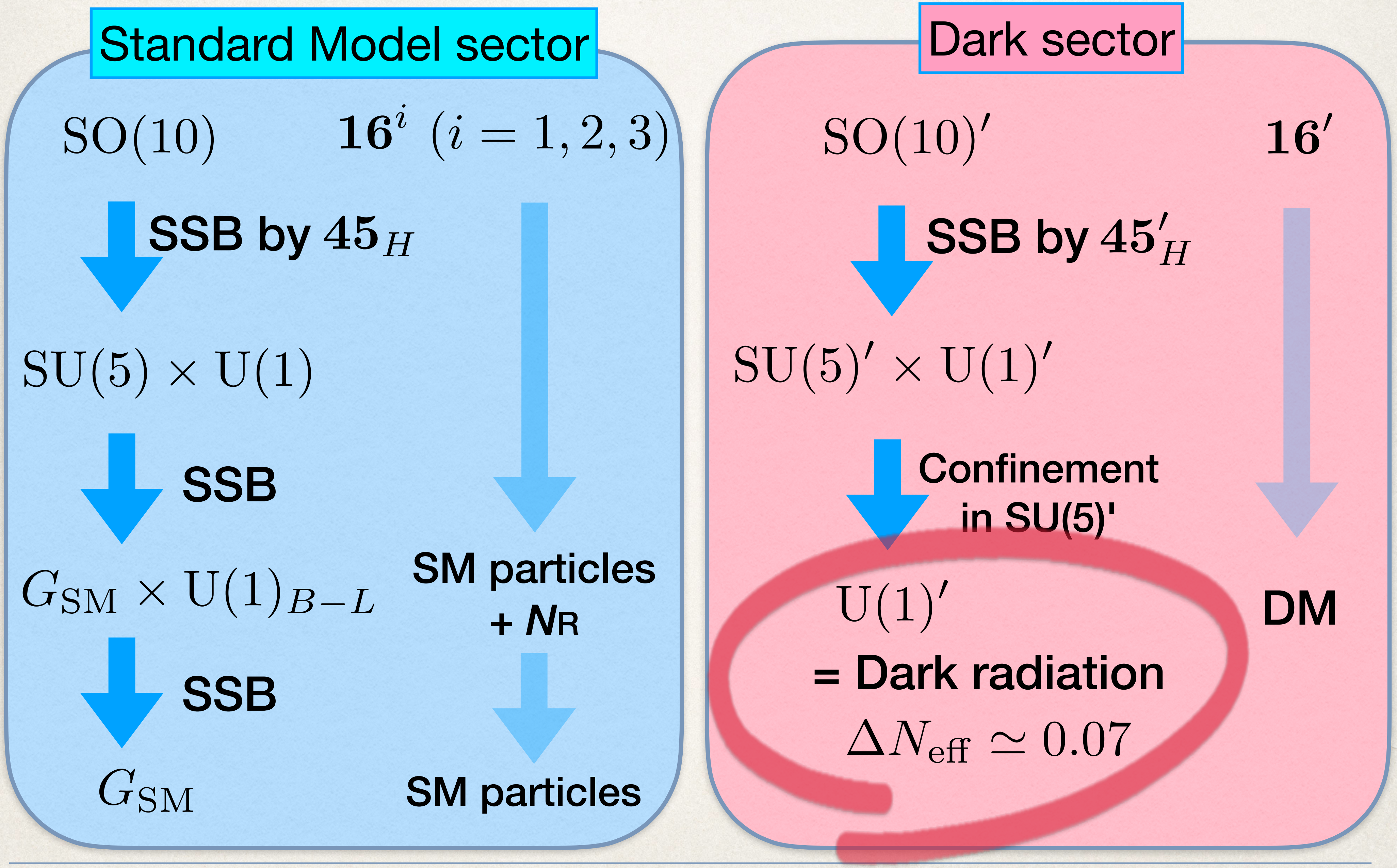
Both sectors have the same temperature because of the interaction via the kinetic mixing.

$G_{\rm SM}$ SM particles

Dark radiation



Dark radiation

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$\mathrm{SU}(5) \times \mathrm{U}(1)$

SSB

$G_{\mathrm{SM}} \times \mathrm{U}(1)_{B-L}$ $\quad$ **SM particles + N_R**

SSB

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Dark sector

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Confinement in SU(5)'

$\mathrm{U}(1)'$ $\quad$ **DM**

= Dark radiation

$\Delta N_{\mathrm{eff}} \simeq 0.07$

CMB-S4: $\delta(N_{\mathrm{eff}}) = 0.016$

W.L.K.Wu, et. al., '14
K.N.Abazajian, et. al., '16

Summary

	Ψ'
$\mathrm{SO}(10)'$	$\mathbf{16}$

+ Higgs

⬇

Darkly charged dark matter with mass of 600-700 GeV

Gauge coupling constant is $\alpha' = (2.5 - 2.9) \times 10^{-2}$.

U(1)' gauge boson is dark radiation with $\Delta N_{\rm eff} \simeq 0.07$.