Coupling unification in an extension of the minimal dark matter model

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Minimal Dark Matter Models (MDMs)

MDMs introduce a single SU(2)$_L$ multiplet to explain Dark Matter(DM)[1].

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \begin{cases} c\overline{\chi}(iD - M)\chi & (\chi\text{:fermion}) \\ c(|D_u\chi|^2 - M^2|\chi|^2) & (\chi\text{:scalar}) \end{cases}$$

$$c = \begin{cases} \frac{1}{2} & \text{(DM is Majorana fermion or real scalar.)} \\ 1 & \text{(DM is Dirac fermion or complex scalar.)} \end{cases}$$

DM candidates : χ_0 (electrically neutral component of χ)

relic density = Ωh²(obs.)

Quantum number :
- SU(3)$_c$ singlet
- SU(2)$_L$ n-plet
- Y is assigned to satisfy $Q = Y + I_3 = 0$.

	Quantum numbers			DM can	DM mass
	$SU(2)_L$	$U(1)_Y$	Spin	decay into	[TeV]
①	3	0	0	HH^*	2.5
②	3	0	1/2	LH	2.7
③	5	0	0	(HHH^*H^*)	9.4
④	5	0	1/2	-	10
⑤	7	0	0	-	25

Questions:
- DM is Unstable?
- Origin of SU(2) multiplet ?

SO(10) grand unified theory (GUT) can answer these questions.

Matter Parity $(P_M : \phi \to \pm\phi)$

$SO(10) \to SU(5) \otimes U(1)_\xi$

$SU(5) \to SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$

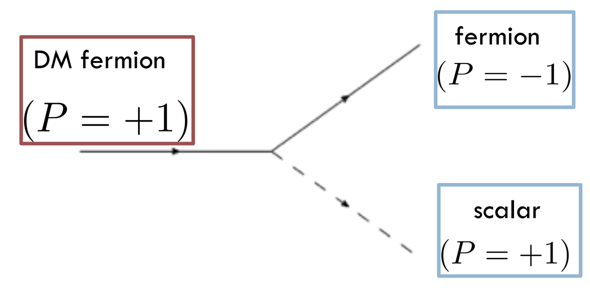
$U(1)_\xi \to Z_2$

- charge:

$$P_M = (-1)^\xi$$

- quark, lepton : $\mathbf{16} = (\mathbf{10}, 1) + (\mathbf{5}^*, -3) + (\mathbf{1}, 5)$ (P$_M$=-1)
- higgs : $\mathbf{10} = (\mathbf{5}^*, -2) + (\mathbf{5}, 2)$ (P$_M$=+1)

ex) Yukawa coupling



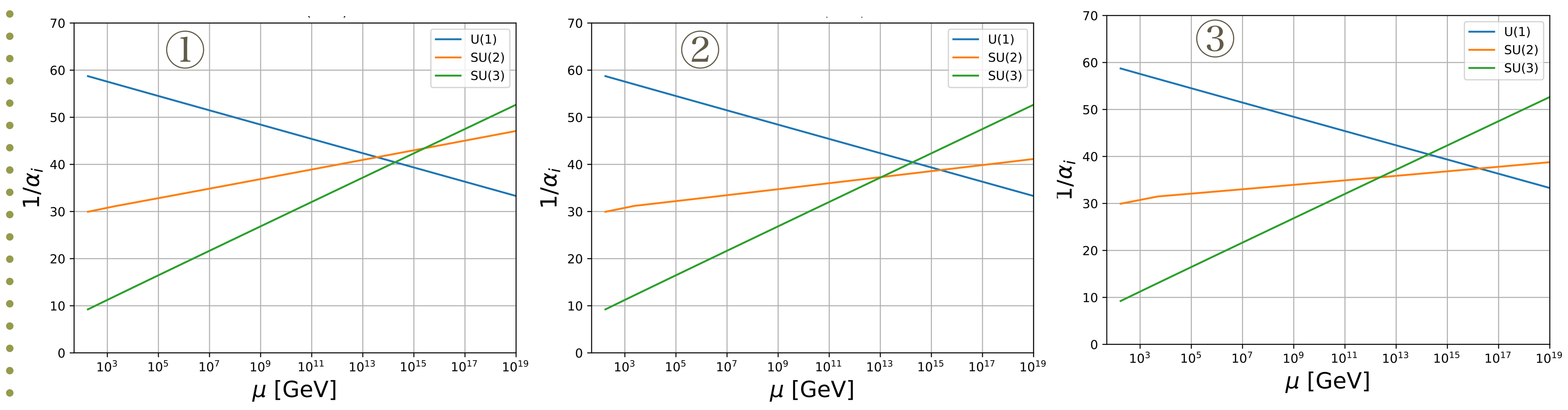
For DM candidates, P$_M$ stabilizes DM after SO(10) breaking.

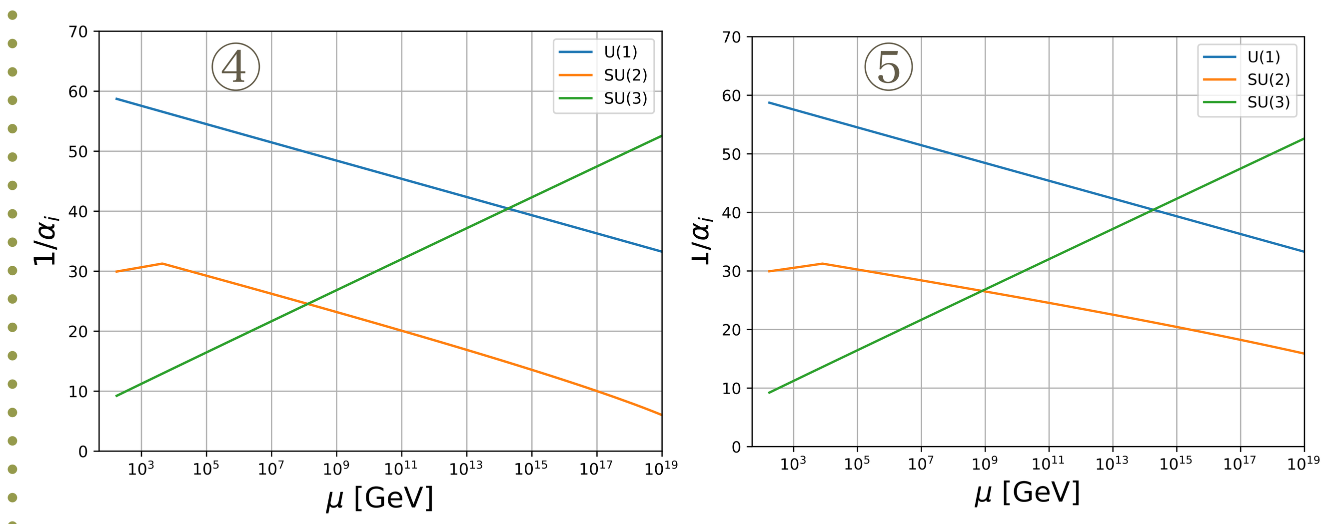
Gauge Coupling Unification

- β function of Renormalization group equation @2-loop :

$$\frac{dg_i}{dt} = \beta_i = \frac{1}{16\pi^2} b_i g_i^3 + \frac{1}{(16\pi^2)^2} b_{ij} g_i^3 g_j^2 \ (t = \ln\mu) \qquad \alpha_i = \frac{g_i^2}{4\pi} \ (i = 1, 2, 3)$$

$$b_i = \begin{pmatrix} \frac{41}{10} \\ -\frac{19}{6} \\ -7 \end{pmatrix} + (\Delta b)_i \qquad b_{ij} = \begin{pmatrix} \frac{199}{50} & \frac{27}{10} & \frac{44}{5} \\ \frac{9}{10} & -\frac{5}{6} & 12 \\ \frac{11}{10} & \frac{9}{2} & -26 \end{pmatrix} + (\Delta b)_{ij}$$





The gauge interactions are not unified by the contribution of only MDM.

We study the positility of the unification by introducing a additional multiplet.

Model(SM+DM+ϕ)

the limit on proton lifetime by Super-Kamiokande exp.[2][3]:

$$\tau(p \to \pi^0 e^+) \simeq (8.2 \times 10^{33}\text{yrs}) \left(\frac{2.3}{A_{SD}}\right)^2 \left(\frac{1/39}{\alpha_X}\right)^2 \left(\frac{M_X}{4.3 \times 10^{15}\text{GeV}}\right)^4$$

α_X : GUT coupling constant
M_X : GUT scale
$A_{SD}(\gtrsim 2.3)$: effects of renormalization

Condition of the GUT models

$M_X \gtrsim 4 \times 10^{15}$[GeV]

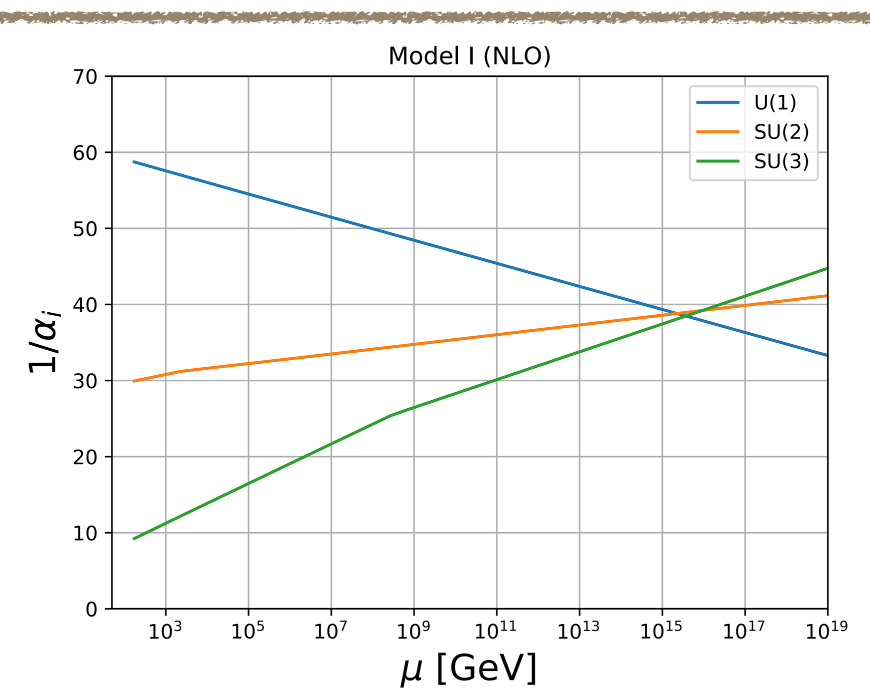
$\alpha_X = \alpha_1 = \alpha_2 = \alpha_3 \lesssim \frac{1}{40}$

To suppose multiplet ϕ between M$_{EW}$ and M$_{GUT}$

- Y=0
- SU(2) singlet
- SU(3) octet

ϕ : ・SO(10) 45 represent
・unstable

Model ② and ③ satisfy conditions.



- Model I

DM : (1, 3, 0) fermion

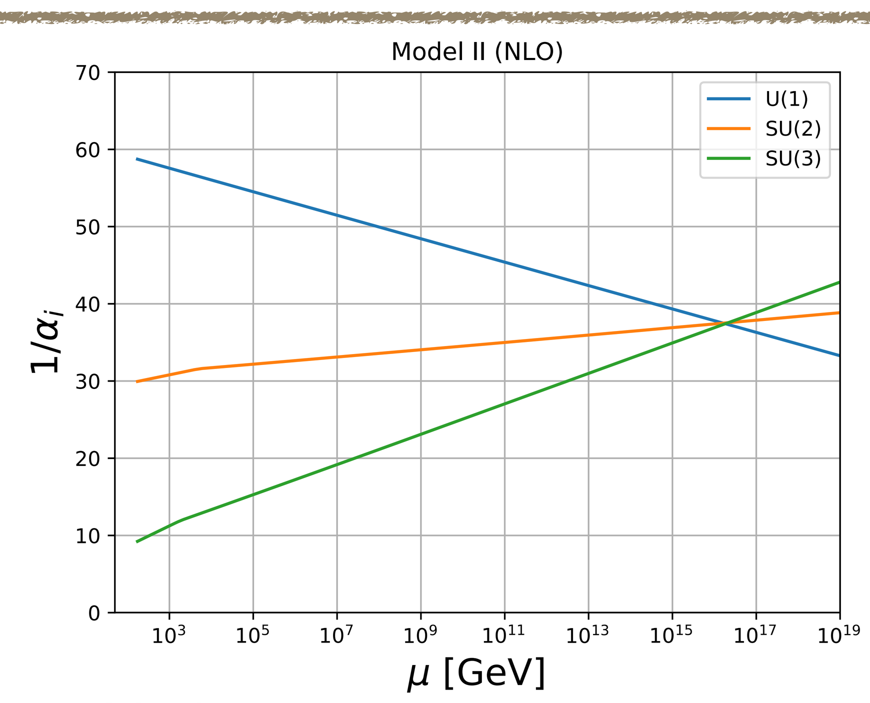
$45 \supset (24, 0) \supset (1, 3, 0)$ (P$_M$=+1)

DM can decay into LH.

Octet mass : 3 × 10^8 [GeV]
- 1 octet fermion
- ϕ can decay into DM.

→ ϕ is fermion.

stable



- Model II

DM : (1, 5, 0) scalar

$\mathbf{2640} \supset (\mathbf{200}, 5) \supset (\mathbf{1}, \mathbf{5}, 0)$ (P$_M$=-1)

DM can decay into HHH^*H^*.

Octets mass : below 2 TeV
- 3 octet scalars
- ϕ can decay into SM.

→ ϕs are scalars.

Summary

- We found 2 models where gauge interactions are unified and DMs are stable.
- Model II predicts color octet scalar particles (~2 TeV).

Tasks

- To study the effects of colored light particles to verify Model II at LHC.
- To consider mechanisms to lower masses of DM and ϕ much below the GUT scale.

reference

- [1] M. Cirelli, N. Fornengo and A. Strumia, Nucl. Phys. B 753 (2006) 178 [hep-ph/0512090].
- [2]M. Frigerio and T. Hambye, Phys. Rev. D 81 (2010) 075002[arXiv:0912.1545 [hep-ph]].
- [3]H. Nishino et al. Phys. Rev. Lett. 102, 141801 (2009) [arXiv:0903.0676 [hep-ex]].