次元6有効相互作用による核子崩壊における世代対称性の影響

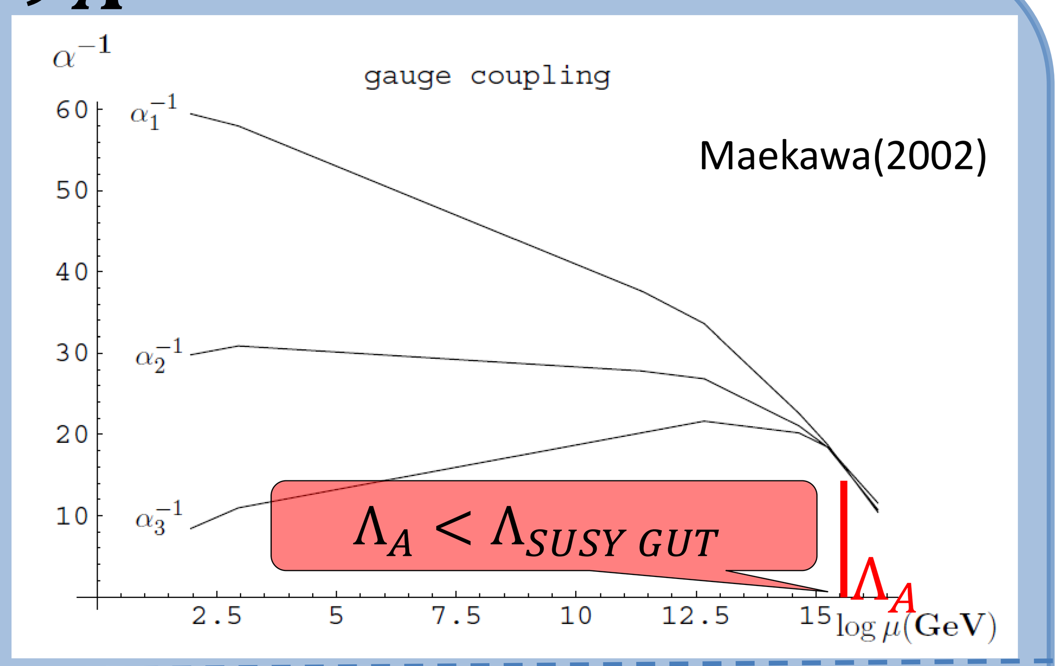
speaker : Yu Muramatsu collaborator : Nobuhiro Maekawa（NAGOYA University） based on arXiv: 1307.7529, and more

核子崩壊を用いて超対称大統一理論の模型を判別できるかを研究した。標準模型に存在しないゲージボソンの媒介によって生じる次元6有効相互作用が主要な場合を考えた。次元6有効相互作用には世代混合からの不定性がある。これまでの研究により、将来複数の核子のdecay modeを観測できた時に模型がSU(5)群による模型かSO(10)群による模型かの判別が期待できることが分かった。しかし、世代混合からの不定性などによって世代構造などを判別するのは困難である。この研究において世代混合行列は各粒子の世代の自由度によって単位行列にできるものを抜かし、unitary性やCKM,MNS行列を満たすなどの条件を課しながら全ての物にorder 1の不定性があるとした。

しかし、超対称大統一理論においては世代対称性を課しても実験結果を満たす世代構造を実現できることが知られている。つまり、世代に制限を掛けた現実的な超対称大統一模型があるということである。これらの模型においては世代に制限が掛かっているため、世代混合行列にも制限が掛かる。つまり、先の研究とは違い全ての世代混合行列の不定性はorder 1ではなく一部の不定性はより小さくなることが期待される。この制限により超対称大統一模型の判別性が向上することが期待される。そのため、世代対称性が核子崩壊に与える影響を考えた。

Anomalous $U(1)_A$ SUSY GUT model

Natural models
- consider all operators which are allowed by symmetries
- consider effects of all higher order operators
- operators' coefficients are order 1



Realization of natural fermion masses and mixing - with 10 *rep.* model

In the minimal SO(10) GUT model, all matters belong to 16 *rep.*

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Mixing matrices for each matter have same order magnitude.

⬇

unnatural fermion masses and mixing

introduce new 10 *rep.* Maekawa(2001)

$\bar{5}_{\Psi_i} \in 16_{\Psi_i} (i = 1\sim3), \bar{5}_T \in 10_T$

$$\begin{pmatrix} \bar{5}_{\Psi_1} \\ \bar{5}_{\Psi_2} \\ \bar{5}_{\Psi_3} \\ \bar{5}_T \end{pmatrix} \xrightarrow{\text{mix}} \begin{pmatrix} \bar{5}_1 \\ \bar{5}_2 \\ \bar{5}_3 \\ \bar{5}_M \end{pmatrix}$$

$\bar{5}_1, \bar{5}_2, \bar{5}_3$: The SM; $\bar{5}_M$: non-SM

⬇

realize natural fermion masses and mixing

E_6 27 dimensional rep. particle

E_6	SO(10)	SU(5)	$SU(3)_C \times SU(2)_L \times U(1)_Y$
27	16	10	$q_{L\alpha}(3,2)_{\frac{1}{6}}$, $u_R^{c\alpha}(\bar{3},1)_{-\frac{2}{3}}$, $e_R^+(1,1)_1$
		$\bar{5}$	$d_R^{c\alpha}(\bar{3},1)_{\frac{1}{3}}$, $l_L(1,2)_{-\frac{1}{2}}$
		1	$\nu_R^c(1,1)_0$
	10	$\bar{5}$	$D_R^{c\alpha}(\bar{3},1)_{\frac{1}{3}}$
		5	$L_L(1,2)_{-\frac{1}{2}}$
	1		

E_6 adjoint rep. gauge particle

E_6	SO(10)	SU(5)
78	adjoint 45	adjoint 24 $\ni \bar{X}_\alpha(3,2)_{-\frac{5}{6}}$
		$10 \ni X'_\alpha(3,2)_{\frac{1}{6}}$
		$\overline{10}$
		1
	$16 \ni X''_\alpha(3,2)_{\frac{1}{6}}$	
	$\overline{16}$	
	1	

$M_X^2 = g_{GUT}^2 x^2$,

$M_{X'}^2 = g_{GUT}^2(x^2 + v_c^2), M_{X''}^2 = g_{GUT}^2(\frac{1}{4}x^2 + v_\phi^2)$

x, v_c, v_ϕ are VEV of Higgs.

E_6 27 *rep.* Higgs has VEV v_c in SU(5) singlet part.

E_6 27 *rep.* Higgs has VEV v_ϕ in SO(10) singlet part.

E_6 78 *rep.* Higgs has VEV x, E_6 78 *rep.* include SO(10) adjoint. SO(10) adjoint Higgs A has DW-form VEV.

$$\langle A \rangle = i\,\sigma_2 \times \begin{pmatrix} x 1_{3\times3} & \\ & 0_{2\times2} \end{pmatrix}$$

$x \sim \lambda^{-a}\Lambda_{SUSY\ GUT}$ in anomalous $U(1)_A$ SUSY GUT

In this work we take these VEVs as

$x = 1\times10^{16}GeV, \quad v_c = 5\times10^{14}GeV, \quad v_\phi = 5\times10^{15}GeV.$

Nucleon decay

Nucleon is stable in the SM. ⟶ bSM, especially GUT

$\tau_{p\to\pi^0+e^c} \geq 1.3\times10^{34}$ **years**

current limit at the Super-Kamiokande

	dim 6 effective int. X type gauge boson mediated $p \to \pi^0 + e^c$	dim 5 effective int. triplet Higgs or Higgsino mediated $p \to K^+ + \nu^c$
GUT	$\Lambda_{GUT}\sim10^{14}$GeV $\to \tau_p\sim10^{30}$ years	none
SUSY GUT	superpartners make GUT scale $\Lambda_{SUSY\ GUT}\sim10^{16}$ GeV $\to \tau_p\sim10^{36}$ years	suppression from mediated particle mass is smaller than dim 6 effective int. dim 5 effective int. is strong
Anomalous $U(1)_A$ SUSY GUT	Anomalous $U(1)_A$ theory's make GUT scale $\Lambda_A\sim\lambda^{-a}\Lambda_{SUSY\ GUT} < 10^{16}$ GeV dim 6 effective int. is strong	natural doublet-triplet splitting realization suppress dim 5 effective int.

Dim 6 effective int. in E_6 GUT

$$\begin{aligned}
\mathcal{L}_{eff} = &- \frac{2\pi\alpha_{GUT}}{M_X^2}\{(\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Li\beta})(\overline{e^+_{Rj}}\gamma_\mu d_{Lj\alpha}) + (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Lj\beta})(\overline{e^+_{Ri}}\gamma_\mu d_{Lj\alpha})\\
&+ (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Li\beta})(\overline{e^+_{Lj}}\gamma_\mu d_{Rj\alpha}) + (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Li\beta})(\overline{E^+_{Lj}}\gamma_\mu D_{Rj\alpha})\\
&- (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu d_{Li\beta})(\overline{\nu^c_{Lj}}\gamma_\mu d_{Rj\alpha}) - (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu d_{Li\beta})(\overline{N^c_{Lj}}\gamma_\mu D_{Rj\alpha})\}\\
&- \frac{2\pi\alpha_{GUT}}{M_{X'}^2}\{(\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Lj\beta})(\overline{e^+_{Li}}\gamma_\mu d_{Rj\alpha}) - (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu d_{Lj\beta})(\overline{\nu^c_{Li}}\gamma_\mu d_{Rj\alpha})\}\\
&- \frac{2\pi\alpha_{GUT}}{M_{X''}^2}\{(\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Lj\beta})(\overline{E^+_{Li}}\gamma_\mu D_{Rj\alpha}) - (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu d_{Lj\beta})(\overline{N^c_{Li}}\gamma_\mu D_{Rj\alpha})\}
\end{aligned}$$

Yukawa Matrix

real Yukawa matrix

$$Y = \begin{pmatrix} y_{11} & y_{12} & y_{13} \\ y_{21} & y_{22} & y_{23} \\ y_{31} & y_{32} & y_{33} \end{pmatrix}$$

9 parameters
- 3 parameters for masses
- \+
- 6 parameters for mixings

R_ψ, L_ψ:diagonalizing matrix

$$\psi_{Li} M_{ij} \psi^c_{Rj} = (L_\psi^\dagger \psi_L)_i (L_\psi^T M R_\psi)_{ij} (R_\psi^\dagger \psi_R^c)_j = \psi'_{Li} M_{diag\,ij} \psi'^c_{Rj}$$

$\psi'_{Li} = (L_\psi^\dagger)_{ij}\psi_{Lj}$, $\psi'^c_{Ri} = (R_\psi^\dagger)_{ij}\psi^c_{Rj}$

mass eigenstate flavor eigenstate

$$\underbrace{R_u, R_d, R_e, L_d, L_e}_{\text{3 parameters for each diagonalizing matrix}}, L_u = L_d U_{CKM}^{exp\,\dagger}, L_\nu = L_e U_{MNS}^{exp\,\dagger}$$

3 parameters for each diagonalizing matrix

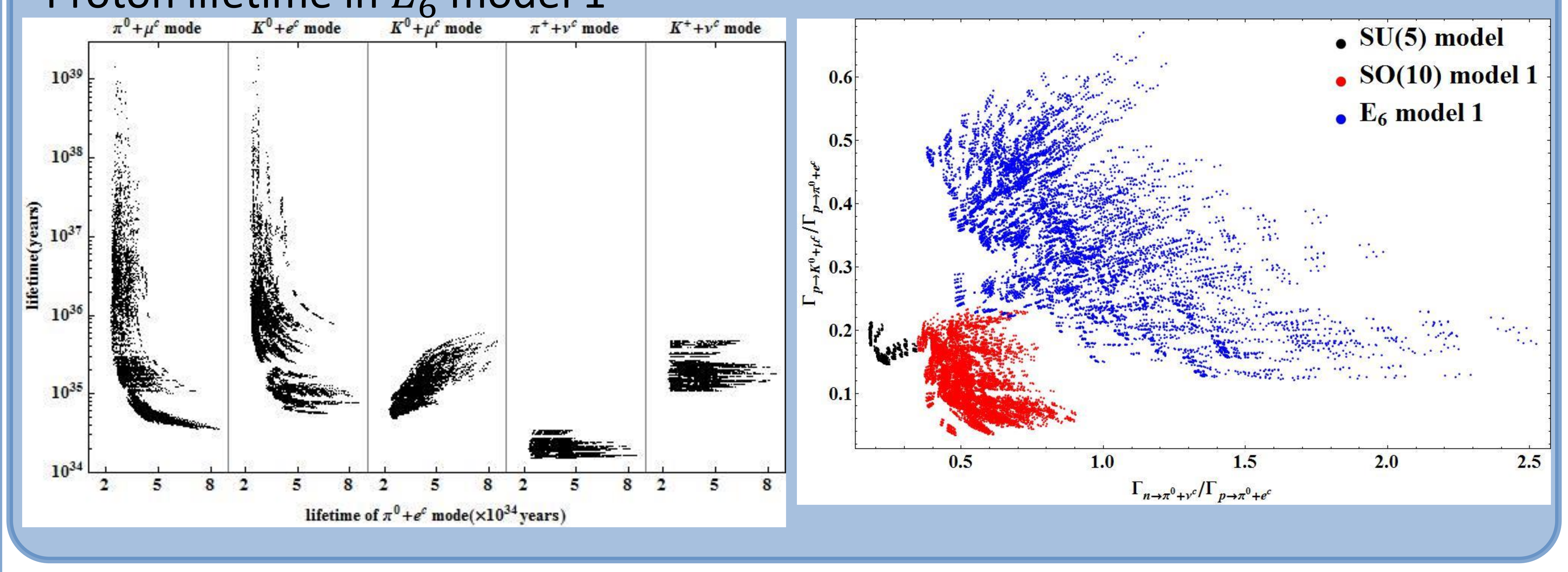
⇒15 parameter

$$L_u \sim L_d \sim R_u \sim R_e \sim U_{CKM} \qquad R_d \sim L_e \sim L_\nu \sim U_{MNS}$$

$$U_{CKM} = \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}, U_{MNS} = \begin{pmatrix} 1 & \lambda^{\frac{1}{2}} & \lambda \\ \lambda^{\frac{1}{2}} & 1 & \lambda^{\frac{1}{2}} \\ \lambda & \lambda^{\frac{1}{2}} & 1 \end{pmatrix}$$

Result 1

Proton lifetime in E_6 model 1



Yukawa Matrix in $E_6 \times SU(2)_F$ model

$$Y_u = \begin{pmatrix} 0 & y_{u12} & 0 \\ -y_{u12} & y_{u22} & y_{u23} \\ 0 & y_{u23} & y_{u33} \end{pmatrix}, Y_d = \begin{pmatrix} y_{d11} & y_{d12} & y_{d13} \\ y_{d21} & y_{d22} & y_{d23} \\ y_{d31} & y_{d32} & y_{d33} \end{pmatrix}$$

$$Y_e = \begin{pmatrix} y_{d11} & y_{e12} & 0 \\ 0 & y_{e22} & y_{e23} \\ -y_{e12} & y_{d23} & y_{d33} \end{pmatrix}$$

10 conditions for masses and mixings @GUT scale

$\theta_{ij}^{\psi L,R}$:mixing angle for diagonalizing matrix of $\psi_{L,R}$

$$\theta_{13}^{uL} = 0 \quad \theta_{13}^{uR} = 0 \quad \theta_{13}^{eL} = 0 \quad \theta_{23}^{dL} = \theta_{23}^{eR}$$

$$|\theta_{12}^{uL}| = |\theta_{12}^{uR}| = \sqrt{m_u/m_c} \quad \theta_{12}^{eR} = \theta_{23}^{eL}\theta_{12}^{eL} \quad \frac{m_\mu}{m_\tau} = -\frac{\theta_{13}^{eR}}{\theta_{12}^{eL}}$$

$$\frac{\theta_{13}^{eL}\theta_{13}^{eR}m_\tau - \theta_{13}^{dL}\theta_{13}^{dR}m_b + \theta_{12}^{eL}\theta_{12}^{eR}m_\mu - \theta_{12}^{dL}\theta_{12}^{dR}m_s}{m_d - m_e} = 1 \qquad m_b = m_\tau$$

We can use 8 conditions for mixings @nucleon mass scale ⇒(15 − 8) = 7 parameter

Result 2

Proton lifetime in $E_6 \times SU(2)_F$ model