Hadronic EDMs in SUSY GUT models

Minoru Nagai

(ICRR, Univ. of Tokyo)

Based on

- J. Hisano, M. Kakizaki, M.N. and Y. Shimizu
- J. Hisano, M. Kakizaki and M.N., in preparation
1. Introduction

GUT models
• Unification of gauge couplings
• Unification of quarks and leptons

\[ \text{SUSY mass terms of squarks and sleptons are correlated} \]

We can investigate SUSY GUT models by considering the correlation between flavor physics in the quark sector and those in the lepton sector.

Recently, it is pointed out that Hadronic electric dipole moments (EDMs) severely constrain the flavor mixing terms in SUSY models. [Hisano & Shimizu (2003, 2004)]

We investigated the effects and constraints of Hadronic EDMs on SUSY GUT models.

✓ SUSY SU(5) GUT with Right-handed neutrino (RN)
✓ 5D Orbifold GUT model - Hall-Nomura model -
Contents of my talk

1. Introduction
2. Hadronic EDM constraints on flavor mixing terms
3. SUSY SU(5) GUT with RN
4. Hall-Nomura model
5. Summary and discussion
2. Hadronic EDM constraints on flavor mixing terms

**EDM**

\[ \mathcal{H}_{eff} = -d_f \vec{S} \cdot \vec{E} \]  \quad \text{T, P violating}

SM have only one CP phase, so induced EDMs are very tiny.

Sensitive to beyond SM physics!

**Hadronic EDM**

- \(^{199}\text{Hg EDM}\)
- Deuteron EDM
- Neutron EDM
- CP violating Hadronic Interaction
- Quark CEDM
- Quark EDM

Though there can be large hadronic uncertainties, we can estimate

\[
\begin{align*}
    d_{\text{Hg}} &= -8.7 \times 10^{-3} \times e(d_u^C - d_d^C + 0.005 \times d_s^C) \\
    d_n &= -1.6 \times e(d_u^C + 0.81 \times d_d^C + 0.16 \times d_s^C)
\end{align*}
\]

\[ \text{ex. } d_n \approx 10^{-32} e \text{ cm} \]

we concentrate on

Current experimental bound
SUSY Contributions to Quark CEDMs

Quark CEDMs

\[ d_{q_i}^C \sim \frac{\alpha_s}{4\pi} m_{\text{SUSY}} \Im \left[ (\delta_{ij}^q)_L (\delta_{ji}^q)_R \right] \]

\[ (\delta_{ij}^f)_{L/R} = \frac{(m_{\tilde{f}_{L/R}}^2)_{ij}}{\tilde{m}_f^2} \]

\[ (\delta_{i}^d)_{LR} = \frac{m_{d_i}(A_i^{(d)} - \mu \tan \beta)}{\tilde{m}_d^2} \]

\[ (\delta_{i}^u)_{LR} = \frac{m_{u_i}(A_i^{(u)} - \mu \cot \beta)}{\tilde{m}_u^2} \]

\[ \tan \beta = \langle H_2 \rangle / \langle H_1 \rangle \]

These diagrams are enhanced by heavier quark masses.

When both Left- and right-handed squark mixing exist and there is relative CP phase between them, large CEDMs are generated.

Stringent constraint on \( \Im \left[ (\delta_{ij}^q)_L (\delta_{ji}^q)_R \right] \)
3. SUSY SU(5) GUT with RN

Unification of (s)quark and (s)lepton

\[ T(U^c, Q, E^c), \quad F(D^c, L) \]

Squark mixing and slepton mixing are correlated

Neutrino yukawa coupling

\[ y_{ij}^\nu = e^{i\phi_i}U^*_{ij}y_{\nu j} \]

GUT CP phase

Left-handed slepton mixing

Right-handed sdown mixing

multiplet F (D^c, L)

LFV, leptonic EDM...

S\( \cdot \)K_s, hadronic EDM...

comparison!
Constraints on neutrino sector by Hadronic EDMs

\[ M_{H_c} = 2 \times 10^{16} \text{GeV}, \ m_{\nu_\tau} = 0.05 \text{eV}, \ U_{\mu 3} = 1/\sqrt{2}, \ m_0 = 500 \text{GeV}, \ A_0 = 0, \ m_g = 500 \text{GeV}, \ \tan \beta = 10 \]

Right-handed tau neutrino mass (GeV)

Current experimental bound \( M_{N_3} \lesssim \mathcal{O}(10^{14}) \text{GeV} \)

Deuteron EDM (future experiment) \( \cdots \ \cdots \ \) We can probe more severely
4. Orbifold GUT model (Hall-Nomura model)

Flavor structure in Orbifold GUT models

Matter configuration + \( \text{SUSY mechanism} \)

Hall-Nomura model

- \( S_1/Z_2 \) orbifold SU(5) GUT
- Zero mode

\[
\begin{align*}
T_3 & \quad T_{1,2}(U^c, E^c) \\
F_{1,2,3} & \quad T'_{1,2}(Q)
\end{align*}
\]

- Colored higgs become massive as KK mode
- Gauge coupling unification
- Dangerous Proton decay can be avoided
- Bottom-tau GUT relation
- FCNC, LFV constraints is cleared
- Hierarchical yukawa coupling

\( \text{SUSY by Scherk Schwarz mech.} \)

- Bulk fields have small yukawa coupling
- Generate soft terms only for bulk fields
Flavor structure in the Hall Nomura model

- 1\textsuperscript{st} and 2\textsuperscript{nd} generation of $U^c$, $E^c$, $Q$ in SM exist as zero mode of two different Bulk fields $T_{1,2}(U^c, E^c)$, $T'_{1,2}(Q)$

- Asymmetric up-type yukawa $y_e \neq y_d^T$

\[
W = \begin{pmatrix}
U_1^c & U_2^c & U_3^c \\
y_{ij} & y_{ij} & y_{i3} \\
y_{3j} & y_{33} & y_{33}
\end{pmatrix} \begin{pmatrix}
Q_1 \\
Q_2 \\
Q_3
\end{pmatrix} H_2 + \ldots
\]

- SUSY terms are generated only for Bulk fields by SS mech.

\[
m_f^2 = \tilde{m}^2 \begin{pmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 0
\end{pmatrix}
\] diagonalize yukawa

\[
(m_f^2)_{ij} = \tilde{m}^2 (\delta_{ij} - (V_f)_{i3}(V_f^*)_{j3})
\]

for $f = q, u^c, e^c$

Flavor violation of $m^2_{e_R}$ $\Rightarrow$ LFV
Flavor violation in $m^2_{u_L} \& m^2_{u_R}$ $\Rightarrow$ up quark CEDM

$Y_u$ is asymmetric, $m^2_{u_L} \& m^2_{u_R}$ are independent (no CP phase cancellation)

cf. Flavor violation of up-type squark by RG eqs is small $\Rightarrow$ bottom yukawa
Hadronic EDM constraints in the Hall Nomura model

$(\mu < 0)$

- Marginal up quark CEDM is induced.
- We can check the consistency of this model.
5. Summary and Discussion

Though Hadronic EDMs are flavor-conserving, they restrict the flavor violation severely.

SUSY GUT models have rich flavor structure, so the hadronic EDMs can be a good probe.

- SUSY SU(5) GUT with RN
  \[ M_{N_3} \lesssim \mathcal{O}(10^{14}) \text{GeV} \implies BR(\tau \rightarrow \mu \gamma, e\gamma) \lesssim 10^{-7\sim8} \]

- Hall-Nomura model
  Marginal up quark CEDM is generated, so we can use hadronic EDMs as a probe

Future experiments of deuteron EDM and LFV process are prospected to probe GUT models in more detailed.
Correlation to other observables in SUSY SU(5) GUT with RN

Hadronic EDMs

- severally constrain right-handed down-type squark mixing

Large contribution in SUSY SU(5) GUT with RN

- We can probe neutrino sector from hadronic sector

Correlation to other observables

We can constrain other observables from EDM experiments, and we can test the SUSY GUT model.

- SUSY contribution to $B \rightarrow \phi K_S$ by right-handed down-type squark mixing must be severely suppressed.

- Constraint on $\tau$ decay $\text{BR}(\tau \rightarrow \mu \gamma, e\gamma) \lesssim 10^{-(7\sim8)}$

( cf experimental bound $\text{Br}(\tau \rightarrow \mu (e)\gamma) < 3.6(3.2) \times 10^{-7}$ )

- Constraint on Muon EDM $d_\mu < \mathcal{O}(10^{-25}) \text{ e cm}$

This phase is same as $d_s^c$
Back Up Slide
Constraints on down-type squark flavor mixing

For left-handed down-type squark (MSSM)

\[
\begin{align*}
(\delta_{12}^d)_L &\sim \lambda^5, \\
(\delta_{13}^d)_L &\sim \lambda^3, \\
(\delta_{23}^d)_L &\sim \lambda^2 \\
& (\lambda \sim 0.2)
\end{align*}
\]

Hadronic EDM experiments

- constraints on right-handed down-type squark mixings

the strongest constraint

\[
\begin{align*}
(\delta_{12}^d)_R &\lesssim 10^{-4} & (\square_K) \\
(\delta_{13}^d)_R &\lesssim 10^{-(2\sim3)} & \text{(neutron, mercury EDM)} \\
(\delta_{23}^d)_R &\lesssim 10^{-(2\sim3)} & \text{(neutron EDM)}
\end{align*}
\]

(m_{SUSY}=500\text{GeV}, \tan\beta = 10)

c.f. \( (\delta_{13}^d)_R \lesssim 0.1 \) \( (\Delta m_{B_d}) \)

If there is O(1) CP phase

Stringent constraints on right-handed down-type squark mixing, especially 1-3 and 2-3 generation mixing.
Constraints on $S_{\Phi K_s}$ by Hadronic EDMs

[Hisanô, Shimizu (2003, 2004)]

SUSY contributions to $S_{\Phi K_s}$ by the right-handed down-type squark mixing is very suppressed.
Combining the experimental results of LFV and Hadronic EDMs, we can test the GUT model.