SUSY CP Problem in Gauge Mediation Model

Norimi Yokozaki (The Univ. of Tokyo)

in collaboration with
Takeo Moroi (The Univ. of Tokyo)

Supersymmetry

- SUSY is motivated by facts that SUSY ...
  - Solves the hierarchy problem
  - Preferred by gauge coupling unification
  - Provide a candidate for dark matter with R-parity
    However ...
SUSY CP Problem

In terms of the CP violation, soft SUSY breaking terms can cause trouble

Dangerous sources for CP violation

- K-K bar mixing, EDM
- squark mass (off-diagonal) \( m_{\tilde{q}_{ij}} \)
- Higgs B-term \( B_\mu \)
- Gaugino masses \( M_A \)

(The phases of A-terms are also relevant)

How to generate soft SUSY breaking parameters is important

this talk
Gauge Mediation

\[ W = (M + F\theta^2)\Psi\bar{\Psi} \]

Gaugino
\[ M_A \approx \frac{g_A^2}{16\pi^2} \frac{F}{M} \]
Sfermion
\[ \tilde{m}_i^2 \approx \frac{1}{(16\pi^2)^2} \left( c_i^A g_A^4 \right) \left| \frac{F}{M} \right|^2 \]

Both F and M can be taken to be real

No CPV in gaugino and sfermion masses
However, even in Gauge Mediation, new CPV phase can be induced

1. The phase of Higgs B-term

2. Small GUT breaking operator (Plank suppressed)

3. SUGRA effects

In this talk, we focus on 2 and 3
Electric Dipole Moment

\[ d_e \propto m_e \tan \beta \frac{\text{Arg}(M_2 B_\mu^*)}{m_{soft}^2} \]

proportional to relative phase between Wino mass and Higgs B-term

exp. constraint

\[ d_e < 2.1 \times 10^{-27} e \text{ cm} \]
(95% C.L.)

The phase should be small as \( O(10^{-3}-10^{-4}) \) with \( O(1) \)
TeV sparticles and \( O(10) \) \( \tan \beta \)

chargino diagram is dominant

(unless higgsino and wino are heavy)
Muon g-2

When sparticles are heavy the constraint on the phase becomes loose, however ....

The EXP value and SM prediction of muon g-2 are deviated more than 3 \sigma level

$$a_{\mu}^{\text{EXP}} - a_{\mu}^{\text{SM}} = (26.1 \pm 8.0) \cdot 10^{-10} \quad 3.3 \sigma \text{ deviation}$$

(Hagiwara, Martin, Nomura, Teubner, 2011)

The other group also reported the discrepancy more than 3 \sigma level

(M. Davier, A. Hoecker, B. Malaescu, Z. Zhang, 2010)

If the SUSY is responsible for the deviation of muon g-2, sleptons can not be heavy
Dominant SUSY contribution to the muon g-2 is essentially same diagram as that of EDM

\[ d_e \simeq \frac{m_e}{2m^2_{\mu}} \text{Arg}(M_2 B_{\mu}^*) a^{\text{SUSY}}_{\mu} \]

(J. L. Feng, T. Moroi, 1999)

To suppress the EDM while explaining the muon g-2 is quite difficult
\( \mu / B_\mu \) have to be induced with the phase smaller than \( O(10^{-3} - 10^{-4}) \)

(e.g.) Only SUSY mass, \( \mu \) is generated above the messenger scale

\[
W = \lambda \frac{X^2}{M_P} H_u H_d
\]

PQ breaking scale \( 10^9 \text{GeV} \lesssim \langle X \rangle \lesssim 10^{12} \text{GeV} \)

However, \( O(10^{-3} - 10^{-4}) \) phase can arise in other ways
The CPV effects from Dim. 5 GUT breaking operator

24 Higgs case

\[
\langle \Sigma \rangle \\
SU(5) \rightarrow SU(3)_C \times SU(2)_L \times U(1)_Y
\]
24 Higgs breaks GUT symmetry

\[ W = \lambda_0 S \bar{\Psi}^\alpha \Psi_\alpha + \frac{\lambda_1}{M_{\text{Pl}}} S \bar{\Psi}^\alpha \Sigma_\alpha^\beta \Psi_\beta + M \bar{\Psi}^\alpha \Psi_\alpha \]

\[ = \lambda_0 \left(1 + \frac{1}{\sqrt{15} \epsilon_{24}}\right) S \bar{\psi}_d \psi_d + \lambda_0 \left(1 - \frac{3}{2\sqrt{15} \epsilon_{24}}\right) S \bar{\psi}_l \psi_l + \cdots \]

complex

\[ \epsilon_{24} = \frac{\lambda_1 v_{24}}{\lambda_0 M_{\text{Pl}}} \sim O(10^{-2}) \]

(The GUT breaking SUSY mass term may also exist)

The messengers of SU(2) doublet and SU(3) triplet have different phases of \( O(10^{-3}) \)
The phases of gauginos are not aligned any more

\[
M_1 = \frac{g_1^2}{16\pi^2} \left(1 - \frac{1}{2\sqrt{15}} \epsilon_{24}\right) \frac{F_S}{M}
\]

\[
M_2 = \frac{g_2^2}{16\pi^2} \left(1 - \frac{3}{2\sqrt{15}} \epsilon_{24}\right) \frac{F_S}{M}
\]

\[
M_3 = \frac{g_2^2}{16\pi^2} \left(1 + \frac{1}{\sqrt{15}} \epsilon_{24}\right) \frac{F_S}{M}
\]

The phases differ by \(O(10^{-3})\)

\[
\epsilon_{24} = \frac{\lambda_1 v_{24}}{\lambda_0 M_{Pl}} \sim O(10^{-2})
\]
The Higgs B-term is also affected by the phase difference of gauginos through RGE

\[
\frac{d B_\mu}{d \ln \mu} = \frac{1}{8 \pi^2} \left[ 3 g_2^2 M_2 + g_1^2 M_1 - 3 \text{tr}(Y_U^\dagger A_U) - 3 \text{tr}(Y_D^\dagger A_D) - \text{tr}(Y_L^\dagger A_L) \right]
\]

\[
d_e \propto m_e \tan \beta \frac{\text{Arg}(M_2 B_\mu^*)}{m_{soft}^2}
\]

The induced CP phase is large enough to be constrained from EDM experiments for numerical calculation \( \epsilon_{24} = i0.01 \)
The dim 5 GUT breaking operator should be suppressed by $O(0.1)$ somehow.

exp. bound $d_e < 2.1 \times 10^{-27} e\, cm$ (95% C.L.).
The CPV effects from Dim. 6 GUT breaking operator

75 Higgs case

\[ \langle \Sigma \rangle \]

\[ SU(5) \to SU(3)_C \times SU(2)_L \times U(1)_Y \]
\[ W = \lambda_0 S \bar{\Psi}^{\alpha} \Psi_{\alpha} + \frac{\lambda_1}{M_{Pl}^2} S \bar{\Psi}^{\alpha} \sum_{\alpha \epsilon} \gamma_{\delta} \Sigma^{\beta \epsilon} \Psi_{\beta} + M \bar{\Psi}^{\alpha} \Psi_{\alpha} \]

\[ \epsilon_{75} = \frac{\lambda_1^{1/2} v_{75}}{\lambda_0^{1/2} M_{Pl}} \]

\[ M_A = \frac{g_A^2}{16\pi^2} (1 + \kappa_A^{(75)} \epsilon_{75}^2) \Lambda, \]

\[ \kappa_1^{(75)} = \frac{11}{60}, \quad \kappa_2^{(75)} = \frac{1}{4}, \quad \kappa_3^{(75)} = \frac{1}{12}. \]

The induced CP phase
\[ d_e \propto m_e \tan \beta \text{ Arg}(M_2 B_{\mu}^*) / m_{soft}^2 \]

for numerical calculation \( \epsilon_{75} = i0.01 \)
The dim 6 GUT breaking operator is consistent with g-2 and EDM

EDM may be seen at the future experiment
The SUGRA effects

- Even in GMSB, the effects from SUGRA exists
- Higgs B-term obtains additional contribution from SUGRA

\[ B_\mu = B^{(0)}_\mu + B^{(\text{SUGRA})}_\mu \]

\[ B^{(\text{SUGRA})}_\mu \sim m_{3/2} \]

For numerical calculation, we take

\[ B^{(\text{SUGRA})}_\mu = i100\text{MeV} \]
$M_{\text{mess}} = 10^6 \text{GeV}$

$M_{\text{mess}} = 10^{12} \text{GeV}$

100 MeV gravitino is marginally consistent with g-2 and EDM.
Higgs mass in minimal GMSB

\[ M_{\text{mess}} = 5 \times 10^5 \text{GeV} \text{ and } N_5 = 1 \]

(M. Endo, K. Hamaguchi, S. Iwamoto, N. Yokozaki, 2011)
Summary

- The effects of the GUT breaking operator is sizable, and may induce large EDM
- The effect of gravity mediation is also sizable when the gravitino mass is large as 100MeV
- EDM may be seen at future experiments