CP Violation and EDMs in an M-theory Motivated New Physics Model

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Introduction

Soft CP violation in MSSM

Gaugino masses

$$-\mathcal{L}_{soft} \supset \frac{1}{2}(M_3\tilde{g}\tilde{g} + M_2\tilde{W}\tilde{W} + M_1\tilde{B}\tilde{B} + h.c.)$$

Trilinear couplings

$$-\mathcal{L}_{soft} \supset \tilde{u}_R^* a_u \tilde{Q} H_u - \tilde{d}_R^* a_d H_d - \tilde{e}_R^* a_e \tilde{L} H_d + h.c.$$

Higgs masses

$$-\mathcal{L}_{soft} \supset M_{H_u}^2 H_u^\dagger H_u + M_{H_d}^2 H_d^\dagger H_d + (B\mu H_u H_d + h.c.)$$

The physical phases are $Arg(M_i\mu)$ and $Arg(a_f\mu)$ (assuming $B\mu$ is real).

Probing CP violation

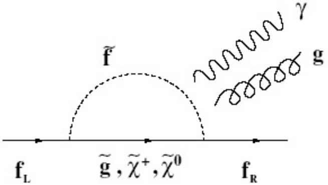
Many ways to probe CP violation:

- B decays (See talks in the CP violation sections)
- Higgs sector - induced at loop level
- Electric Dipole Moments
  Nulll experimental results $\Longrightarrow$ bounds on the EDMs

$$
\begin{aligned}
|d_{Tl}| &< 9 \times 10^{-25}\ e\,\mathrm{cm} \\
|d_n| &< 3 \times 10^{-26}\ e\,\mathrm{cm} \\
|d_{Hg}| &< 3 \times 10^{-29}\ e\,\mathrm{cm}
\end{aligned}
$$

Note: the Hg bound is recently updated [W. C. Griffith et al,arXiv:0901.2328]

SUSY CP problem

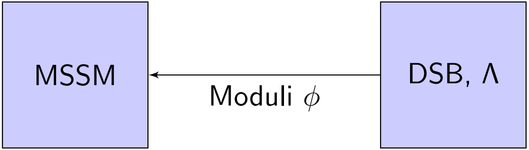


The EDM constraints on the CP violation in new physics is stringent (see Abel and Lebedev, hep-ph/0103320 for a summary):

- Small phases $\lesssim 10^{-3} - 10^{-2}$
- Decoupling $m_{\tilde{f}} \gtrsim 10$ TeV
- Cancellation between different contributions

An M-theory Motivated MSSM

In this talk, we focus on a new physics model which arise from compactification of M-theory (Phys.Rev.D78:065038,2008; Phys.Rev.D76:126010,2007)



- Stabilize Moduli
- Generate TeV scale
- Soft SUSY breaking

LHC search: Quasi-long-lived charginos and Gluino pair production and decay to four-top
Dark matter: Non-thermal Wino Dark matter
Cosmology: No moduli problem
Fine-tuning ? It's probably OK if there is a UV theory

Basic Feature

Soft SUSY breaking parameters:

- sfermion masses $m_{\tilde{f}} \sim m_{3/2}$
- gaugino masses $M_a \ll m_{3/2}$ suppressed at least by a one-loop factor $\Longrightarrow m_{\tilde{f}} \gtrsim 10$ TeV.
- $\mu, B\mu \sim m_{3/2}$

CP violating phases in the soft terms are not generated except the trilinear a_f

- dynamical relaxation of the phases
- Shift symmetry of moduli fields $\phi \to \phi + i\delta$
- Trilinears are not aligned with the Yukawas

CP-violating phases

The trilinear couplings in the gravity mediation is given by

$$a_{ijk} = F_I \partial_I \left[\ln \left(e^{\hat{K}} Y'_{ijk} / \tilde{K}_i \tilde{K}_j \tilde{K}_k \right) \right] Y_{ijk} \equiv A_{ijk} Y_{ijk}$$

- The Yukawas are moduli dependent $\Longrightarrow$ A_f are flavor non-universal and non-diagonal.
- If the trilinear matrices are not proportional to the Yukawa matrices, this leads to non-zero CP-violating phases. [Abel, Khalil and Lebedev, hep-ph/0012145 and hep-ph/0112260]
- Induced CP-violating phases depend on the Yukawa structure

Yukawa Couplings

Explicit construction of realistic Yukawa is difficult and model dependent. Let us focus on the general expectation: a hierarchical Yukawa texture

$$Y^u_{ij} \sim \epsilon^q_i \epsilon^u_i, \quad Y^d_{ij} \sim \epsilon^q_i \epsilon^d_j, \quad Y^e_{ij} \sim \epsilon^l_i \epsilon^e_j$$

- wavefunction localized in ED (the idea of split fermion, Arkani-Hamed and Schmaltz, hep-ph/9903417)
- U(1) symmetry, Froggatt-Nielsen mechanism

Fermion mass relations are given by
$m^{u,d}_i / m^{u,d}_j \sim |\epsilon^q_i \epsilon^{u,d}_i| / |\epsilon^q_j \epsilon^{u,d}_j|$

The Yukawa couplings must contain phases to give CKM phase. To be simply, let us assume the phases in the Yukawa matrices to be $\mathcal{O}(1)$. In the super-CKM bases

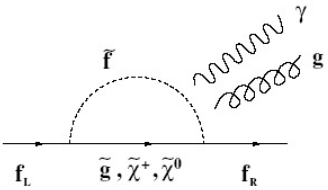
$$\hat{a}_f = (V_L)^\dagger a_f V_R$$

$\Longrightarrow$ Diagonal components

$$\begin{aligned} \mathrm{Im}(\hat{a}_f)_{11} &\sim Y_{11}\, m_{3/2}, \\ \mathrm{Im}(\hat{a}_f)_{22} &\sim Y_{22}\, m_{3/2}, \\ \mathrm{Im}(\hat{a}_f)_{33} &\sim \left(\frac{\epsilon_2}{\epsilon_3}\right)^2 Y_{33}\, m_{3/2} \end{aligned}$$

The CP violating phases are large! except the third generation, suppressed by $\left(\frac{\epsilon_2}{\epsilon_3}\right)^2 \sim 10^{-2}$.

One-loop contribution to EDMs



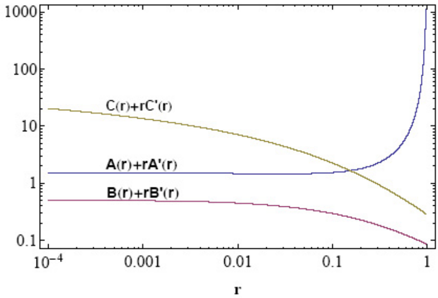
- gaugino mass suppression $\Longrightarrow$ the one-loop contribution can be expanded in terms of small ratio $r \equiv M_a^2/m_{\tilde{q}}^2$.
- large μ term compare to gaugino mass $\Longrightarrow$ small gaugino-higgsino mixing $\Longrightarrow$ Chargino contribution to one-loop diagram is suppressed

- The gluino diagram is the dominant contribution.
  For example, for quark CEDM

$$d_q^C \sim \frac{g_s \alpha}{4\pi} \frac{m_q}{M_a^3} \mathrm{Im}(A_q) r^2 G(r)$$

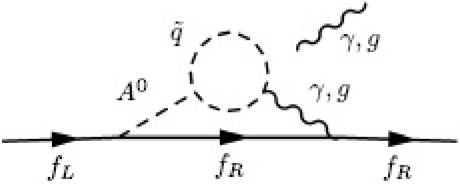
the function $G(r) = C(r) + rC'(r)$ for gluinos and $G(r) = B(r) + rB'(r)$ for neutralinos.

- The electron EDM dominantly comes from the neutralino diagram.



Barr-Zee diagrams

- Generally, Barr-Zee type diagrams involve chargino(or neutralino) in the loop are typically suppressed by the small gaugino-higgsino mixing.
- For Barr-Zee type diagrams with sfermions running in the loop, they are suppressed by the large A^0 mass.

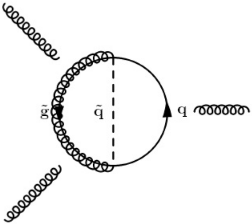


Weinberg Operator

For neutron EDM, there is also a contribution from Weinberg operator.

$$d^G \approx -3\alpha_s \left(\frac{g_s}{4\pi}\right)^3 \frac{1}{m_{\tilde{g}}^3} \sum_{q=t,b} \mathrm{Im}(A_q) z_q H(z_1, z_2, z_q)$$

where $z_i = m_{\tilde{q}_i}^2/m_{\tilde{g}}^2$ for $i = 1, 2$, and $z_q = m_q^2/m_{\tilde{g}}^2$ for $q = t, b$. If the CP-phases for the third generation is large, this contribution could be larger than the one-loop contribution.



Results

- Neutron EDM (expt: $\lesssim 3 \times 10^{-26}$ e cm)

$$d_n^{NDA} \sim \left(\frac{m_{\tilde{g}}}{600\mathrm{GeV}}\right)\left(\frac{20\mathrm{TeV}}{m_{\tilde{q}}}\right)^3 3 \times 10^{-28} e\,\mathrm{cm}$$

- Mercury EDM (expt:$\lesssim 3 \times 10^{-29}$ e cm)

$$|d_{H_g}| \sim \left(\frac{m_{\tilde{g}}}{600\mathrm{GeV}}\right)\left(\frac{20\mathrm{TeV}}{m_{\tilde{q}}}\right)^3 \times 10^{-30}\mathrm{e}\ \ \mathrm{cm}$$

- electron EDM (expt: $\lesssim 2 \times 10^{-27}$ e cm)

$$d_e \sim \left(\frac{m_{\tilde{B}}}{200\mathrm{GeV}}\right)\left(\frac{20\mathrm{TeV}}{m_{\tilde{e}}}\right)^3 \times 10^{-31}\mathrm{e}\ \ \mathrm{cm}$$

Discussion

- Mercury EDM gives the strongest constraints on the squark masses if phases are order one in trilinears: $m_{\tilde{q}} \gtrsim 7$ Tev.
- Neutron EDM can be dominant by Weinberg operator if third generation phases are large. With stop or sbottom mass ~ 5 TeV and $\mathcal{O}(1)$ phases in A_{33}, the neutron EDM bound can be saturated.
- $d_n \gtrsim 10^3 d_e$ – especially large compared to the typical supersymmetric models [Abel and Lebedev, JHEP 0601:133,2006]

Conclusion

- Soft CP-violating phases in an M-theory motivated model can be dominated by the phases of trilinear couplings, since they are typically not proportional to the Yukawas.
- The SUSY breaking scenario with partial sequestering gaugino masses leads to a different EDM pattern, which can be tested in the future.