Anomaly mediation deformed by axion

Kazunori Nakayama (University of Tokyo)

KN, T.T.Yanagida, Phys.Lett.B 722, 107(2013) [arXiv:1302.3332]

2014/2/14 BURI2014 @ Toyama University
Contents

• Pure gravity mediation and Supersymmetric axion model

• Gaugino mass in SUSY axion model in pure gravity mediation
Pure gravity mediation

Ibe, Moroi, Yanagida (2006), Ibe, Yanagida (2011)

- Sfermion mass: Coupling with SUSY breaking field
  \[ K = c \frac{|Q|^2 |Z|^2}{M_P^2} \rightarrow m_{\tilde{Q}} \sim m_{3/2} \sim O(100) \text{TeV} \]

  \( Z \): SUSY breaking field

- Gaugino mass: Anomaly-mediation (AMSB) effect
  \[ m_{\tilde{g}} \sim \frac{g^2}{16\pi^2} m_{3/2} \sim O(100) \text{GeV} \]

Randall, Sundrum (1998), Giudice, Luty, Murayama, Rattazzi (1998)
Figure 2: The contour plot of the lightest Higgs boson mass. The bands for $m_h = 120, 125, 130, 135, 140$ GeV represent the effects of the theoretical uncertainty of the ratio $\mu/H/M_{\text{SUSY}}$ to the lightest Higgs boson mass. We have assumed that $M_{\text{SUSY}}/3 < \mu < 3M_{\text{SUSY}}$. We have used the central values of the uncertainties of the strong coupling constant and the top quark mass.

4 Upper Bound on The Lightest Higgs Boson Mass

As we mentioned above, the lightest superparticle in the pure gravity mediation is the neutral wino which can be a good dark matter candidate. The important feature of the wino dark matter scenario is that the current abundance consists of two contributions. The one is from the thermal relic density of the wino itself, and the other from the late time decay of the gravitino. Notice that the late time decay of the gravitino does not cause the gravitino problem since the gravitino decays before the BBN.

The thermal relic density of the wino is determined by the annihilation cross section of the winos into the $W$ bosons via the weak interaction. The resultant relic density $(T_H)_{h^2 r M^2_{\text{sc a}}}$ agrees with the observed dark matter density $h^2_0$, while it is quickly decreasing for the lighter wino. The non-thermal relic density, on the other hand, is proportional to $\tan^2\beta$. We have not shown the uncertainty due to the $\tan^2\beta$ errors of the strong coupling constant which is smaller than the one from the top mass errors.
Gaugino masses in pure gravity mediation

- **Bino:** 
  \[ M_{\tilde{B}} = \frac{33}{5} \frac{g_1^2}{16\pi^2} m_{3/2} \sim 3 \]

- **Wino:** 
  \[ M_{\tilde{W}} = \frac{g_2^2}{16\pi^2} m_{3/2} \sim 1 \]

- **Gluino:** 
  \[ M_{\tilde{g}} = -\frac{3g_3^2}{16\pi^2} m_{3/2} \sim 8 \]

Wino LSP > 270GeV @ LHC \rightarrow \text{Gluino} > 2.3\text{TeV}

*Is this relation robust?*
SUSY axion model

- Let us consider a SUSY axion model to solve the strong CP problem

\[ \mathcal{L} \sim \int d^2 \theta \frac{\alpha}{8\pi} \frac{\Phi}{f_a} \mathcal{W}^a \mathcal{W}^a \]

- \( \Phi \): PQ scalar
- \( f_a \): PQ scale

- Correction to gaugino mass

\[ \delta m_{\tilde{g}} \sim \frac{\alpha}{8\pi} \frac{F_{\Phi}}{f_a} \]

- Naive expectation:

\[ F_{\Phi} \sim m_{\Phi} f_a \]

\[ \delta m_{\tilde{g}} \sim \frac{\alpha}{8\pi} m_{\Phi} \text{ Same order of AMSB contribution!} \]

- In sequestered AMSB case: Abe, Moroi, Yamaguchi (2001)
Example

- One of the simplest SUSY axion models

\[ W = \lambda X (\Phi_1 \Phi_2 - v^2) + k \Phi Q \bar{Q} + W_0 \]

|            | \( \Phi_1 \) | \( \Phi_2 \) | \( X \) | \( Q \) | \( \bar{Q} \) |
|------------|-------------|-------------|--------|------|-------|
| PQ charge  | +1          | -1          | 0      | -1/2 | -1/2  |
| R charge   | 0           | 0           | +2     | 0    | 0     |

- After including SUSY breaking effect, PQ scalar is stabilized at \( \Phi_1 \sim \Phi_2 \sim v (= f_a) \)

- Need to check: \( F^{\Phi_1} \sim m_{3/2} v \) ?
\[ V_{\text{SUSY}} = \lambda^2 |\Phi_1 \Phi_2| - v^2 |^2 + \lambda^2 |X|^2 (|\Phi_1|^2 + |\Phi_2|^2) \]

\[ V_{\text{SB}} = 2\lambda m_{3/2} (X + X^\dagger) + c_1 m_\phi^2 |\Phi_1|^2 + c_2 m_\phi^2 |\Phi_2|^2 \]

heavy mode mass $\sim v$

flat direction = Saxion mass $\sim m_{3/2}$

$\Phi_1 \Phi_2 = v^2$
F-term of PQ scalar

\[ F^{\Phi_1} \approx W_{\Phi_1} + \frac{K_{\Phi_1} W}{M^2_P} \]
\[ = \lambda v_X v_2 + v_1 m_{3/2} \]
\[ \approx m_{3/2}(v_1 - v_2) \]

\[ (\lambda v_X = -m_{3/2}) \]

In pure gravity mediation,

\[ m_{\Phi_1} \neq m_{\Phi_2} \]

\[ (K \supset (c_1|\Phi_1|^2 + c_2|\Phi_2|^2)\frac{|Z|^2}{M^2_P}) \]

\[ F^{\Phi_1} \sim \mathcal{O}(m_{3/2}v) \]
Without SUSY breaking

flat direction (Saxion)
SUSY breaking (sequester)

Without SUSY breaking

flat direction (Saxion)

SUSY minimum: $F^\Phi = 0 \ (v_1 = v_2)$
Without SUSY breaking (sequester)

SUSY minimum: $F_\Phi = 0 \ (v_1 = v_2)$

+Soft mass

flat direction (Saxion)
**Detailed calculation**

\[ v_X \equiv \langle X \rangle = -\frac{2m_3/2v^2}{\lambda(v_1^2 + v_2^2)} \]

\[ v_1 \equiv \langle |\Phi_1| \rangle = v \left( \frac{c_2m_\phi^2 + \lambda^2v_X^2}{c_1m_\phi^2 + \lambda^2v_X^2} \right)^{1/4} + \mathcal{O} \left( \frac{c_1m_\phi^2}{v} \right) \]

\[ v_2 \equiv \langle |\Phi_2| \rangle = v \left( \frac{c_1m_\phi^2 + \lambda^2v_X^2}{c_2m_\phi^2 + \lambda^2v_X^2} \right)^{1/4} + \mathcal{O} \left( \frac{c_2m_\phi^2}{v} \right) \]

\[ F^\Phi_1 = -\epsilon K/M_P^2 K^\Phi_1 \Phi_1^* \left( W_{\Phi_1} + \frac{K_{\Phi_1} W}{M_P^2} \right)^\dagger = -m_3/2v_1 \epsilon \]

\[ \epsilon = \frac{c_2 - c_1}{c_2 + c_1 + 2\lambda^2v_X^2/m_\phi^2} \cdot \sim \mathcal{O}(1) \]
Effective interaction

\[ -\mathcal{L} = \sum_{i=1}^{3} \frac{C_i \alpha_i}{8\pi} \int d^2 \theta \ln(\Phi_1) \mathcal{W}_i^a \mathcal{W}_i^a + \text{h.c.} \]

\( \mathcal{W}_i \): gaugino superfield

\( C_i \): numerical coefficient depending on PQ quarks

Correction to gaugino mass

\[ \delta M_{\lambda}^i(M_{PQ}) = -C_i \frac{\alpha_i}{4\pi} \frac{F_{\Phi_1}}{v_1} = C_i \frac{\alpha_i}{4\pi} m_{3/2} \epsilon \]

\( C_1 = C_2 = C_3 = N_5 \) for \( N_5 \) pairs of \( Q, \bar{Q} \) with 5, \( \bar{5} \) of SU(5)

**Contribution from PQ scalar ~ AMSB!**
Gaugino mass spectrum

$m_{3/2} = 100$ TeV

$m_{3/2} = 300$ TeV

Gaugino masses are significantly modified
Even the gluino LSP is possible!
Comments

- In sequestered AMSB, gaugino masses are not modified: \((c_1 = c_2 = 0)\) [Abe, Moroi, Yamaguchi (2001)]

- Deflected anomaly-mediation [Pomarol, Rattazzi (1999)]
  AMSB + GMSB (vector-like matter)

  Little motivation to introduce GMSB sector?

- Higgsino threshold correction can modify the relation

- More phenomenological study: Harigaya’s talk [Harigaya, Ibe, Yanagida, 1310.0643]
Summary

- In SUSY axion model, PQ scalar may give gaugino mass comparable to AMSB
- In pure gravity mediation, gaugino masses are significantly modified
- Mass difference between Wino and Gluino may become small

→ Enhanced detection possibility
Another SUSY axion model

\[ W = \frac{\Phi_1^n \Phi_2}{M^{n-2}} + k\Phi_1 Q\bar{Q} + W_0 \]

PQ charge \( \Phi_1 : +1, \Phi_2 : -n \)

\[ \nu_1^{2n-2} \equiv \langle |\Phi_1| \rangle^{2n-2} \approx m_\phi^2 M^{2n-4} \]

\[ \nu_2 \approx \frac{m_{3/2} \nu_1}{m_\phi} \]

\[ F^{\Phi_1} = -\frac{2}{n} m_{3/2} \nu_1 \]

Modification on gaugino masses