Runaway and D term in Gauge-Mediated SUSY Breaking

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and coming soon.

Introduction

Gauge mediation——Mechanism for mediating supersymmetry breaking to the MSSM.

Pseudo-moduli (a flat direction of the vacuum)

Under following conditions,

- Canonical Kahler potential
- Global SUSY
- only a F-term potential
- Vacuum is stable at tree-level

pseudo-moduli exists at the supersymmetry breaking vacuum. [S. Ray, 2006]

Problem in gauge mediation

If the vacuum is stable at the tree-level and has a pseudo-moduli, the gaugino mass is not generated at the leading order $\alpha(\phi_i).$ [Z. Komargodski and D. Shih, 2009]

Sfermion masses

$O\left(\frac{1}{\alpha(\phi_i)}\right)\cdot M_{SUSY} \gg o\left(\left(\frac{1}{\alpha(\phi_i)}\right)^3\cdot M_{SUSY} \gg 1\right)$

It implies heavy sfermions, and the hierarchy problem occurs.

Approach and Preparation

We will construct models without the pseudo-moduli at the vacuum.

We introduce an extra U(1) gauge symmetry.

Set up

Renormalizable superpotential

$W = \sum_i f_i \phi_i + \sum_{i,j} \frac{m_{ij}}{2} \phi_i \phi_j + \sum_i \tilde{\lambda}_{ij} \phi_i \phi_j \phi_k.$

Scalar potential is

$V = V_F + V_D,$
$V_F = \sum_i |F_i|^2 = \sum_{i,j} \frac{\partial W}{\partial \phi_j}$
$V_D = \frac{\phi_i^2}{2} = \frac{\phi_i^2}{2} + \sum_i \xi_i \phi_i^2.$

$\phi_i^0$ : the global minimum of the F-term potential.

$V_F(\phi_i^0) = \sum_{i,j} \frac{\partial W}{\partial \phi_i} \phi_j^0 = \sum_i |W_i|^2.$

The case D=0 at the vacuum, and pseudo-moduli

The stationary conditions are

$\frac{\partial V}{\partial \phi_i} = \sum_j W_j W_i^* + \frac{\phi_i}{2} \frac{\partial D}{\partial \phi_i} = \sum_j W_j W_i^* = 0.$

Same as that of only the F-term potential.

The vacuum has a pseudo-modul.

The pseudo-moduli direction is

$\phi_i = \phi_i^0 + \varepsilon \phi_i^*(0) \quad (\varepsilon \in \mathbb{C}).$

Along the pseudo-moduli direction,

$W_i(\phi_i^0 + \varepsilon \phi_i^*(0)) = \phi_i^0 + \varepsilon \sum_j W_j W_i^* + \frac{\phi_i^0}{2} \sum_j W_j W_i^* W_j W_i^* = 0.$

$D = \sum_i \phi_i^2 + \xi_i = \sum_i \phi_i^2 + (\bar{\phi}_i^2 + \phi_i^2 + h.c.) + \varepsilon \sum_{i,j} |W_i|^2 + \xi = \sum_i |W_i|^2 + \xi = 0.$

We need $V_D \neq 0 \quad (D \neq 0)$ at the vacuum to avoid pseudo-moduli.

Classification by $V_F^0$

(A) $V_F^0$ are finite.
(B) $\phi_i^0 \to \infty$ (runaway or no minimum)

<table>
<thead>
<tr>
<th>(A)(i) $V_F^0 \neq 0$ (F \neq 0)</th>
<th>(A)(ii) $V_F^0 = 0$ (F = 0)</th>
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<tbody>
<tr>
<td>(B) runaway</td>
<td>SUSY breaking</td>
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F-term runaway from U(1) symmetry

If there exists points which satisfy

$W_i = 0, \quad \text{for all } q_i \geq 0.$

$W_i \neq 0, \quad \text{for some } q_i < 0.$

complexified U(1) $\phi_i \to \infty$ or 0 $(\alpha \to \infty)$, for $q_i \geq 0.$

Runaway is uplifted by the D-term.

Along the U(1) runaway direction, $D \to \sum_i q_i e^{a_0 \phi_i^2} + \xi \to \infty (\alpha \to \infty).$

U(1)-type F-term runaway is uplifted by the D-term potential.

Supersymmetry breaking vacuum may appear elsewhere.

Example without FI-term

$W = f X_0 + \lambda_1 \phi_1 + \phi_2 \phi_3 + \lambda_2 \phi_1 \phi_2 + \lambda_3 \phi_1 \phi_3,$

$D = |X_0|^2 + |\phi_2|^2 - |X_0|^2 - |\phi_2|^2.$

$W_{X_0} = f + \lambda_1 \phi_1 + \phi_2 \phi_3 = 0,$

$W_{\phi_2} = \lambda_2 \phi_1 + \phi_2 \phi_3 = 0.$

$D \to |\phi_2|^2 \to \infty (\phi_2 \to \infty).$

F-term runaway is uplifted by D-term. For example, $(m^2 f, \lambda_1, \lambda_2, \alpha) = (0.0, 0.7, 0.5, 0.5),$ the vacuum is $(\phi_+, \phi_-, X_\lambda) \simeq (1.34, -0.252, 1.29) \times m, (F_{\phi_1}, F_{\phi_2}, F_{\phi_3}) \simeq (0.504, 0.527, -0.346, 0.144) \times f.$

Supersymmetry breaking and R-symmetry breaking vacuum

Messenger sector and gaugino mass

$W_{mass} = (m_{\psi} + \phi_0) M \tilde{M}.$ The vacuum is still stable if $m_{\psi}^2 \geq g^2 D.$

The gaugino mass is generated at the leading order.

Summary

- We classify supersymmetry models with F-terms and U(1) D-term.
- We propose a supersymmetry breaking model for gauge mediation.
- Minimum of F-term potential: $V_F + V_D$
- Minimum of non-zero F-term: $V_F + V_D$

(A)(i) $V_F^0 \neq 0$ runaway

(A)(ii) $V_F^0 = 0$ SUSY breaking

(B) runaway SUSY breaking