Runaway and D term in Gauge-Mediated SUSY Breaking

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and coming soon.

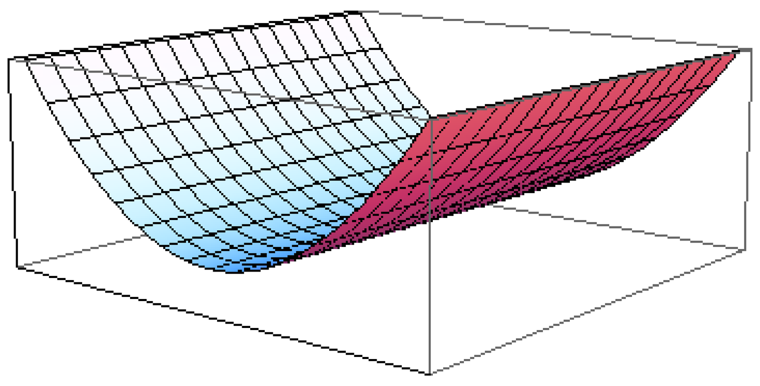
Introduction

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 $O\left(\frac{g^2}{16\pi^2}\right)$.

[Z. Komargodski and D. Shih, 2009]

Sfermion masses $\quad\quad$ Gaugino masses

$$O\left(\frac{g^2}{16\pi^2}\right)\cdot M_{SUSY} \gg O\left(\left(\frac{g^2}{16\pi^2}\right)^3\right)\cdot M_{SUSY} > 1\mathrm{TeV}$$

It implies heavy sfermions, and the hierarchy problem occurs.

Approach and Preparation

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

We get rid of one of the conditions to appear pseudo-moduli.

✓only a F-term potential $\Longrightarrow$ F and D-term potential
Extension

We introduce an extra U(1) gauge symmetry.

Set up

Renormalizable superpotential

$$W=\sum_i f_i\phi_i+\sum_{i,j}\frac{m_{ij}}{2}\phi_i\phi_j+\sum_{i,j,k}\frac{\lambda_{ijk}}{6}\phi_i\phi_j\phi_k \ .$$

Scalar potential is

$$V=V_F+V_D \ ,$$
$$V_F=\sum_i|F_{\phi_i}|^2=\sum_i\left|\frac{\partial W}{\partial\phi_i}\right|^2\equiv\sum_i|W_i|^2 \ ,$$
$$V_D=\frac{g^2}{2}D^2=\frac{g^2}{2}\left(\sum_i q_i|\phi_i|^2+\xi\right)^2 \ .$$

q_i -----U(1) charge

ξ ------FI term

$\phi_i^{(0)}$: the global minimum of the F-tem potential.

$V_F^{(0)}\equiv V_F(\phi_i^{(0)})$, $W^{(0)}\equiv W(\phi_i^{(0)})$ etc...

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

The stationary conditions are

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

Same as that of only the F-term potential.

The vacuum has a pseudo-moduli.

The pseudo-moduli direction is $\phi_i=\phi_i^{(0)}+zW_i^{*(0)} \quad (z\in\mathbb{C})$.

Along the pseudo-moduli direction,

$$W_i(\phi_i^{(0)}+zW_i^{*(0)})=W_i^{(0)}+z\underbrace{\sum_j W_{ij}^{(0)}W_j^{*(0)}}_{0\ \text{(Stationary)}}+\frac{1}{2}z^2\underbrace{\sum_{j,k}W_{ijk}^{(0)}W_j^{*(0)}W_k^{*(0)}}_{0\ \text{(Stable)}}=W_i(\phi_i^{(0)}) \ ,$$

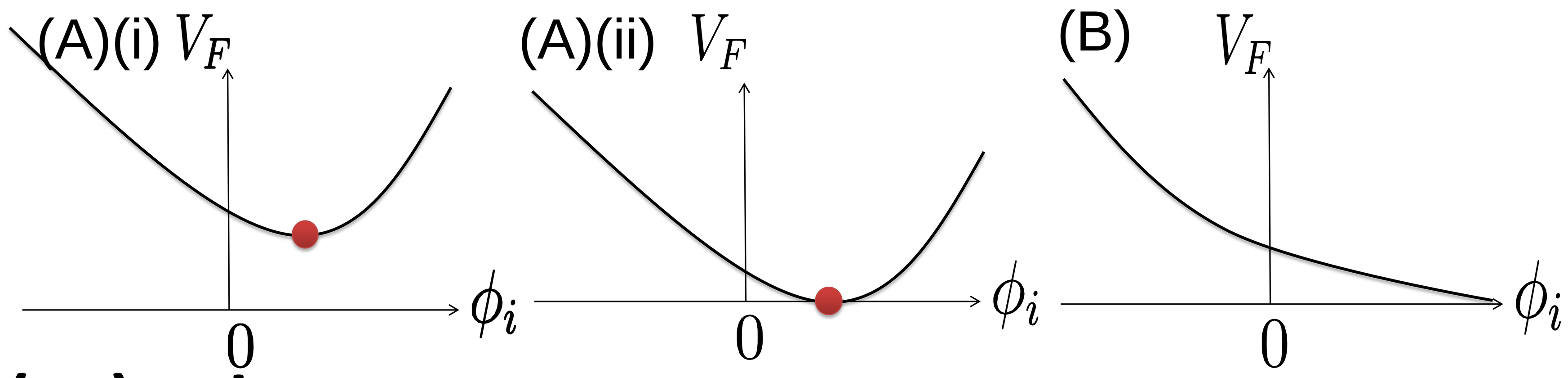
$$D=\sum_i q_i|\phi_i|^2+\xi=\sum_i q_i[|\phi_i^{(0)}|^2+(z\underbrace{\bar{\phi}_i^{(0)}W_i^{(0)}}_{0\ \text{(U(1) sym)}}+h.c.)+z|\underbrace{W_i^{(0)}}_{0\ \text{(U(1) and stationary)}}|^2]+\xi=\sum_i q_i|\phi_i^{(0)}|^2+\xi=0$$

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

Classification by $V_F^{(0)}$

(A) $^\forall\phi_i^{(0)}$ are finite. $\longrightarrow$ (i) $V_F^{(0)}\neq 0 \quad (F\neq 0)$; (ii) $V_F^{(0)}=0 \quad (F=0)$

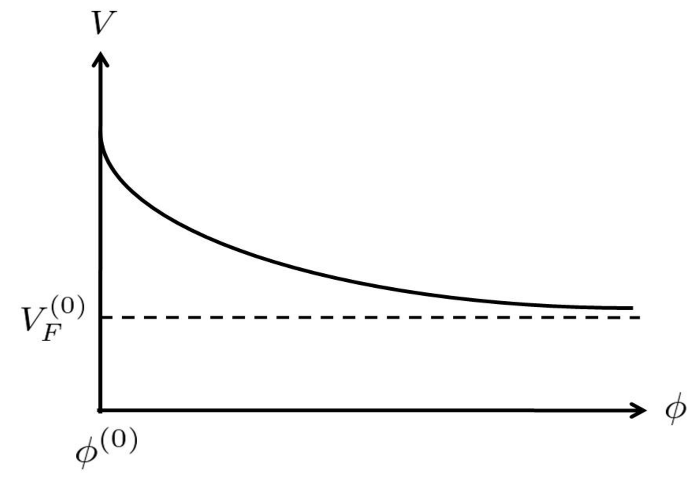
(B) $^\exists\phi_i^{(0)}\to\infty$. (runaway or no minimum)



(A) class

(A)(i) There exist runaway directions as

$$\phi_i=\phi_i^{(0)}+zW_i^{*(0)}+\frac{c_i^{(1)}}{z^*}+\frac{c_i^{(2)}}{z^{*2}} \ ,$$
$$V=V_F+V_D\to V_F^{(0)} \quad (z\to\infty) \ .$$



(A)(ii) If the FI-term is zero, $\xi=0$, supersymmetry preserving.

Under the complexified U(1) transformation,

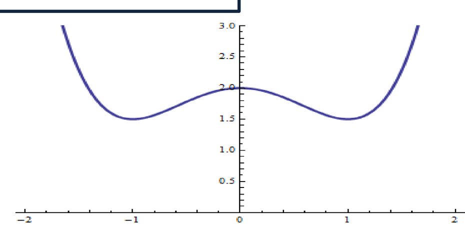
$$\phi_i^{(0)}\to e^{\alpha q_i}\phi_i^{(0)} \ , \quad W_i^{(0)}\to e^{-\alpha q_i}W_i^{(0)}=0 \ ,$$
$$V_D=\frac{1}{2}g^2\left(\sum_i q_i e^{2\alpha q_i}|\phi_i|^2\right)^2=0 \ , \quad V_F^{(0)}=0 \ , \ \text{for a proper value of } \alpha \ .$$

If the FI-term is not zero, $\xi\neq 0$, supersymmetry may break.

Example

$$W=m\phi_+\phi_- \ ,$$

	ϕ_+	ϕ_-
U(1)	1	-1



$$V=m^2|\phi_+|^2+m^2|\phi_-|^2+\frac{1}{2}g'^2(|\phi_+|^2-|\phi_-|^2+\xi)^2 \ . \quad (g^2\xi>|m|^2)$$

[P. Fayet and J. Iliopoulos, 1974]

(B) class

F-term runaway from U(1) symmetry

If there exist points which satisfy

$$\begin{cases} W_i=0 \ , & \text{for all } q_i\geq 0 \ . \\ W_i\neq 0 \ , & \text{for some } q_i<0 \ . \end{cases} \Longrightarrow \begin{cases} e^{-\alpha q_i}W_i=0 \ , & \text{for } q_i\geq 0 \ . \\ e^{-\alpha q_i}W_i\to 0 \ , & \text{for } q_i<0 \ . \end{cases}$$

complexified U(1) $\quad(\alpha\to\infty)$

$\phi_i\to\infty$ or $0 \ (\alpha\to\infty)$, for $q_i\geq 0$. F-term runaway

Runaway is uplifted by the D-term

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

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

Supersymmetry breaking vacuum may appear elsewhere.

Example without FI-term

$$W=fX_0+\lambda_1\varphi_+\varphi_-X_0+m\varphi_-X_++\lambda_2\varphi_0\varphi_+X_- \ ,$$
$$D=|X_+|^2+|\varphi_+|^2-|X_-|^2-|\varphi_-|^2 \ .$$

	X_0	X_+	X_-	φ_+	φ_-	φ_0
U(1)	0	1	-1	1	-1	0
$\mathrm{U(1)}_R$	2	2	2	0	0	0

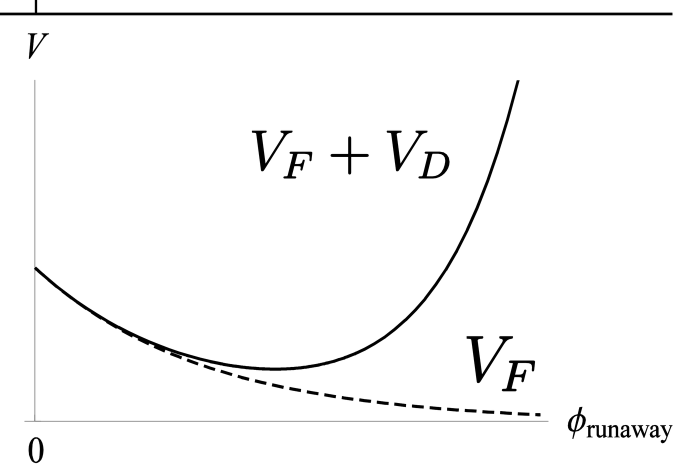
$$\begin{cases} W_{X_0}=f+\lambda_1\varphi_+\varphi_-=0 \ , \\ W_{X_+}=m\varphi_-\to 0 \quad (\varphi_-\to 0) \ , \\ D\to|\varphi_+|^2\to\infty \quad (\varphi_+\to\infty) \ . \end{cases}$$

F-term runaway is uplift by D-term.

For example, $(m^2/f,\ \lambda_1,\ \lambda_2,\ g)=(2,\ 0.7,\ 0.1,\ 0.5)$,

the vacuum is

$$(\varphi_+,\ \varphi_-,\ X_-)\simeq(1.34,\ -0.252,\ 1.29)\times m \ ,$$
$$(F_{X_+},\ F_{X_0},\ F_{\varphi_0},\ D)\simeq(0.504,\ 0.527,\ -0.346,\ 0.144)\times f \ .$$



Supersymmetry breaking and R-symmetry breaking vacuum

Messenger sector and gaugino mass

$W_{mess}=(m_M+\varphi_0)M\tilde{M}$. The vacuum is still stable if $m_M^2\geq g^2D$.

The gaugino mass is generated at the leading order. $M_{\tilde{g}}=\frac{g_{SM}^2}{16\pi^2}T_2(R)\frac{F_{\varphi_0}}{m_M}$.

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 no FI-term	V_F+V_D non-zero FI-term
(A)(i)	$V_F^{(0)}\neq 0$	runaway	runaway
(A)(ii)	$V_F^{(0)}=0$	SUSY	SUSY breaking
(B)	runaway	SUSY breaking	SUSY breaking