The possibility of generating leading order gaugino masses in direct gauge mediation scenario

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Context

- USP of Gauge Mediated SUSY Breaking: universal flavor independent nature of gauge interactions.

- The Ingredients of GMSB: SM gauge singlet X that gets a SUSY breaking vev and ϕ_i messenger fields that communicate this to the visible sector.

- Direct Gauge Mediation: SUSY breaking vev is generated dynamically through potential minimization. Described in terms of O'Raifeartaigh (O'R) models.

- Renewed Interest: The realization that generalized O'R models of direct gauge mediated supersymmetry breaking are low energy description of dynamical supersymmetry breaking scenarios from a strongly coupled sector.

- Typically stubborn problem: leading order gaugino masses vanish (J. Polchinski, 1982).

Though known for some time, it is now understood in terms of Komargodski-Shih (KS) no-go theorem (2009).

KS theorem

A general renormalizable O'R model:

$$W = fX + \frac{1}{2}(\lambda_{ab}X + m_{ab})\phi_a\phi_b + \frac{1}{6}g_{abc}\phi_a\phi_b\phi_c \ , \quad K = \text{canonical}$$

Corresponds to the following messenger mass matrices:

$$\mathcal{M}_{\mathcal{F}} = W_{ab} = \lambda_{ab}X + m_{ab}, \quad \mathcal{M}_B^2 = \begin{pmatrix} \mathcal{M}_{\mathcal{F}}^*\mathcal{M}_{\mathcal{F}} & (f\lambda_{ab})^* \\ f\lambda_{ab} & \mathcal{M}_{\mathcal{F}}\mathcal{M}_{\mathcal{F}}^* \end{pmatrix}$$

Crucially $M_g^a \propto \partial \log det(\mathcal{M}_{\mathcal{F}})/\partial \mathcal{X}$.

Leading order gaugino mass $\Rightarrow det(\lambda_{ab}X + m_{ab}) = \Sigma C_n(\lambda, m)X^n$

$\Rightarrow$ Goldstino direction v such that $(\lambda_{ab}X_0^l + m_{ab})v = 0$ where $\Sigma C_n(\lambda, m)X^n|_{X\to X_0^l} = 0$.

Consider the vector $v_B = (v \quad v^*)^T$ such that

$$v_B^\dagger \mathcal{M}_B^2 v_B = v^T f\lambda_{ab}v + cc.$$

$\Rightarrow$ instability at $X = X_0^l$ or $\lambda_{ab}v = 0 \Rightarrow det(\mathcal{M}_{\mathcal{F}}) = 0$

The condition for local stability of the supersymmetry breaking pseudomoduli direction would prevent gaugino masses from being generated at the leading order for general renormalizable models of direct gauge mediation.

Our Objective

The possibility to evade the KS theorem by introducing non-renormalizable terms to models with stable supersymmetry breaking vacuum. We consider the possibility that these contributions introduce a holomorphic pseudomoduli dependence in the determinant of the fermionic mass matrix for the messengers generating leading order gaugino masses, without disturbing the vacuum configuration.

Models with polynomial correction and flat Kähler metric

We assume $\bar{W}_{\bar{a}}(R_{\bar{b}b})^{a\bar{a}}W_a = 0$, this ensures that $M_g^a \propto \partial \log det(\mathcal{M}_{\mathcal{F}})/\partial\mathcal{X}$.

The most general non-canonical Kähler term that contributes to the fermionic mass matrices of the messenger fields:

$$\Delta K \supset C_{ab}\phi_a\phi_b f(\frac{X}{\Lambda},\frac{\bar{X}}{\Lambda}) + cc.$$

Interestingly in the desired vacuum: $\langle X\rangle \rightarrow$ undetermined, $\{\langle\phi_a\rangle = 0\}\forall a$.

$$\Leftrightarrow \Delta W_{NR} = m\phi_a\phi_b g(\frac{X}{\Lambda}).$$

where $f(\frac{X}{\Lambda},\frac{\bar{X}}{\Lambda}) = \frac{\bar{X}}{\Lambda}g(\frac{X}{\Lambda})$ and $m = \frac{C_{ab}\langle W_X\rangle}{\Lambda}$.

If $f(\frac{X}{\Lambda},\frac{\bar{X}}{\Lambda}) = \sum_{n\bar{n}} C^{n\bar{n}}\frac{X^n\bar{X}^{\bar{n}}}{\Lambda^{n+\bar{n}}} \Rightarrow$ the pseudomoduli direction will in general have an instability at the points where $f(\frac{X}{\Lambda},\frac{\bar{X}}{\Lambda}) = 0$.

Models with polynomial correction and curved Kähler metric

In this case the structure of the bosonic mass matrix is deformed:

$$(\mathcal{M}_B^{NC})^2 = \begin{pmatrix} {\mathcal{M}_\mathcal{F}}^{NC}{\mathcal{M}_\mathcal{F}}^{*NC} - \mathcal{N} & \mathcal{F}^* \\ \mathcal{F} & {\mathcal{M}_\mathcal{F}}^{*NC}{\mathcal{M}_\mathcal{F}}^{NC} - \mathcal{N} \end{pmatrix}$$

where ${\mathcal{M}_\mathcal{F}}^{NC} = {\mathcal{M}_\mathcal{F}}^{C} - \Gamma^d_{ab} W_d$, $\mathcal{N} = \bar{W}_{\bar{a}} W_a (K^{\bar{a}c}\partial_{\bar{b}}\Gamma^a_{bc}) W_a$ and $\mathcal{F}^{NC} = \partial_{bc}(W_a K^{\bar{a}a})\bar{W}_{\bar{a}}$.

In this case one can get new contributions to the gaugino masses $\sim \mathcal{N}\mathcal{F}/m^3$.
In the basis where the fermionic messenger mass matrix is diagonal (m_i)

$$\begin{aligned} M_g^a &= -\frac{g_a^2}{8\pi^2}\left[\sum_k \frac{\mathcal{F}_{kk}}{m_k}\left(1 - \frac{2}{3}\frac{\mathcal{N}_{kk}}{m_k^2}\right)\right. \\ &\left. + \sum_k \sum_{n\neq k} \frac{2Re(\mathcal{N}_{nk}\mathcal{F}_{kn})}{m_k^2 - m_n^2}\left(\frac{2m_n m_k^2}{(m_k^2 - m_n^2)^2}\log\left(\frac{m_k}{m_n}\right) + \frac{1}{m_k}\right)\right] \end{aligned}$$

However the contributions are of higher order, $O(F^3/M^3)$.

Non polynomial corrections

With X (SM singlet) and $(\phi\ \tilde{\phi})$ (vector-like pair of messenger fields), the simplest SUSY breaking sector is:

$$W = -\mu^2 X + f(X)\phi\tilde{\phi}$$

where now $f(X)$ need not be a polynomial function of X.

The bosonic mass matrix is given by,

$$m_B^2 = \begin{pmatrix} |f(X)|^2 & -\left(\mu^2 \frac{\partial f(X)}{\partial X}\right)^* \\ -\mu^2 \frac{\partial f(X)}{\partial X} & |f(X)|^2 \end{pmatrix}$$

m_B^2 is positive semidefinite (local stability condition) implies $\Rightarrow |f(X)|^4 \geq \left|\mu^2 \frac{\partial f(X)}{\partial X}\right|^2$.

The condition that saturates this bound can be solved and yields a unique solution:

$$f(X) = \frac{\mu^2 e^{i\theta}}{X + b}$$

Some salient features of this model: (to simplify assume $\theta = b = 0$)

- For $m^2 > \mu^2$, the eigenvalues are positive for any value of $\langle X \rangle \Rightarrow$ the pseudomoduli direction is locally stable everywhere.
- Curiously the condition $m^2 > \mu^2$ implies that there is only one global minimum.
- Gaugino masses are generated at the leading order $M_a \sim \frac{\alpha_a}{4\pi}\mu^2 \frac{1}{\langle X \rangle}$, unsuppressed by any high scale.
- These models are tantalizingly close to the theories obtained from strongly coupled supersymmetry breaking schemes.

Conclusion

- KS theorem implies that in renormalizable Direct Gauge Mediation models gaugino masses vanish at leading order.
- We find that adding non-renormalizable terms polynomial in fields, to stable SUSY breaking models, cannot evade this road block.
- Non-polynomial corrections can easily evade the bound and lead to interesting phenomenological scenarios.
- Alternatively one can start with renormalizable models that have instabilities in the flat direction and use non-renormalizable operators (Y. Nakai and Y. Ookouchi) or radiative corrections (Dudas, Lavignac, Parmentier) terms to lift instabilities .

THANK YOU!