Models of broken SUSY with Constrained Superfields

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Introduction

Motivations

- SUSY has to be broken.
- When broken, SUSY can be non-linearly realized.
- Constrained Superfields: superfield tool to study models of broken SUSY.

Applications

- Low energy effective theories, with broken SUSY.
  - Mass splitting in the spectrum
  - Massless Goldstino + light degrees of freedom (d.o.f.)
  - fermionic d.o.f. $\neq$ bosonic d.o.f.
- Supergravity and Inflationary models.

The simplest model [Rocek '78; Casalbuoni, De Curtis, Dominici, Feruglio, Gatto '89; Seiberg, Komargodski '09]

- Consider one scalar and one fermion organized in a chiral superfield

$$X = S + \sqrt{2}\,\theta^{\alpha} G_{\alpha} + \theta^2 F\,.$$

- If SUSY is broken by $\langle F \rangle \sim f \neq 0$, G_{α} is the goldstino

$$\delta G_{\alpha} = -f \epsilon_{\alpha} + \cdots\,.$$

- The simplest Lagrangian is

$$\mathcal{L} = \int d^4\theta\, X\overline{X} + f\left(\int d^2\theta\, X + c.c.\right)$$
$$= -\partial_m S \partial^m \overline{S} + i\partial_m \overline{G} \overline{\sigma}^m G - f^2\,.$$

The simplest model [Rocek '78; Casalbuoni, De Curtis, Dominici, Feruglio, Gatto '89; Seiberg, Komargodski '09]

- The scalar S can be (very) heavy

$$\mathcal{L} - \frac{1}{\Lambda^2}\int d^4\theta\, X^2\overline{X}^2 \quad \Longrightarrow \quad m_s^2 \sim \frac{f^2}{\Lambda^2}\,.$$

- At energies $E \ll \frac{f}{\Lambda}$ we can integrate out S and get an effective theory.
- This procedure is **equivalent** to imposing on $\mathcal{L}$ the constraint

$$X^2 = 0 \quad \Longleftrightarrow \quad X = \frac{G^2}{2F} + \sqrt{2}\theta^\alpha G_\alpha + \theta^2 F\,.$$

- In general **imposing constraints on superfields eliminates some of their components.**

The general constraint [Dall'Agata, Dudas, Farakos '16]

- We saw the SUSY breaking sector. How to describe **matter**?
- Given any matter superfield $Q = q + \sqrt{2}\,\theta^\alpha \chi_\alpha + \cdots$,

$$X\overline{X}Q = 0 \qquad\qquad (X^2 = 0).$$

eliminates the lowest component q and expresses it as a function of goldstino G_α

$$q = \frac{G\chi}{2F} + \cdots .$$

- It reproduces all known constraints and generates new ones.
- It can be used as a systematic procedure to reproduce any desired spectrum in the low energy (goldstino + matter).

A model with SUGRA [NC, Dall'Agata, Farakos, Porrati '16]

- Consider Old Minimal SUGRA multiplet $\{e_\mu{}^a, \psi_\mu, M, b_a\}$.
- The auxiliary fields M, b_a are lowest components of superfields R, B_a. They can be eliminated by imposing

$$X\overline{X}R = 0, \qquad X\overline{X}B_a = 0\,.$$

- Gravity auxiliary fields generate the (**negative**) gravity contribution to the scalar potential. If we eliminate them the **scalar potential** will be **positive definite**

$$V = |f|^2 \qquad \text{de Sitter vacuum}\,.$$

- The setup is well suited for studying Inflation.
- The procedure is equivalent to the CCWZ procedure [Delacretaz, Gorbenko, Senatore '16].

Is $X^2 = 0$ general? [NC, Dall'Agata, Farakos '17]

- F-term breaking: parametrize $\Phi = X + \cdots$

$$\mathcal{L} = \int d^4\theta\, \Phi\overline{\Phi} + \left(f \int d^2\theta\, \Phi + c.c.\right)$$
$$= \int d^4\theta\, (X\overline{X} + \cdots) + \left(f \int d^2\theta\, (X + \cdots) + c.c.\right) .$$

- D-term breaking: parametrize $V = \frac{X\overline{X}}{D^2 X} + \frac{X\overline{X}}{\overline{D}^2 \overline{X}} + \cdots$

$$\mathcal{L} = \frac{1}{4}\left(\int d^2\theta\, W^2 + c.c.\right) + \xi \int d^4\theta V$$
$$= \int d^4\theta\, (X\overline{X} + \cdots) - \frac{\sqrt{2}\xi}{4}\left(\int d^2\theta\, (X + \cdots) + c.c.\right) .$$

- The procedure works also in the mixed F-term and D-term case.

Conclusion

- Constrained superfields describe non-linear SUSY.
- In global SUSY $X^2 = 0$ and $X\overline{X}Q = 0$ cover the more general case.
- Systematic procedure to build any desired model with broken SUSY.

Future directions:

- Extended SUSY [NC, Dall'Agata, Farakos '16].
- Matter couplings in SUGRA and Inflationary models. (work in progress)

Thank you for your attention!

Extra

F-term breaking [NC, Dall'Agata, Farakos '17]

- Break SUSY with a chiral superfield Φ and parametrize it in the UV-independent manner

$$\Phi = X + S \,,$$

using the constrained superfields

$$\begin{aligned} X^2 &= 0 \qquad \text{Goldstino,} \\ \overline{X}\, D_\alpha S &= 0 \qquad \text{Sgoldstino.} \end{aligned}$$

- Equivalently in components

$$\begin{aligned} A^\Phi &= \frac{G^2}{2F} + s \,, \\ \chi^\Phi &= G + 2i\,\sigma^m \left(\frac{\overline{G}}{\sqrt{2}\,\overline{F}} \right) \partial_m s \,, \\ F^\Phi &= F + \left(\frac{\overline{G}^2}{2\overline{F}^2} \partial^2 s - 2\partial_n \left(\frac{\overline{G}}{\sqrt{2}\,\overline{F}} \right) \overline{\sigma}^m \sigma^n \frac{\overline{G}}{\sqrt{2}\,\overline{F}} \partial_m s \right) \,. \end{aligned}$$

Example: decoupling the Sgoldstino [NC, Dall'Agata, Farakos '17]

- Consider

$$\mathcal{L} = \int d^4\theta \left(\Phi\overline{\Phi} - \mu\,\Phi^2\overline{\Phi}^2\right) + \left(\int d^2\theta\, f\,\Phi + c.c.\right)$$
$$= \int d^4\theta \left(|X|^2 + |S|^2 - \mu\left[4|X|^2|S|^2 + |S|^4\right]\right)$$
$$+ f\left(\int d^2\theta (X + S) + c.c.\right) .$$

- In the IR the scalar decouples and we find

$$s = 0 \qquad \Longrightarrow \qquad S = 0\,.$$

- For more complicated models, the decoupling of S might be more complicated, but this cannot change the presence of $X^2 = 0$.