Supersymmetry breaking from complex linear superfield

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Overview

Introduction

- supersymmetric theories are one of the most promising candidates for physics beyond the Standard Model
- if supersymmetry exists it must be spontaneously broken
- various mechanisms and ideas have been proposed to achieve this
- mainly using chiral superfield, but that is not the only representation of supersymmetry
- under normal circumstances, complex linear superfield is equivalent to chiral superfield (chiral-complex linear duality)
- but not always! $\Rightarrow$ a new mechanism for SUSY breaking

Definition of chiral superfield

In 4D, $N = 1$ supersymmetry algebra is

$$\{D_\alpha, \bar{D}_{\dot{\alpha}}\} = i\partial_{\alpha\dot{\alpha}}.$$

(see for example [Gates, Grisaru, Roček, Siegel '83])

Chiral superfield Φ: $\bar{D}_\alpha \Phi = 0$.

$$\Phi| = A \qquad\qquad D^2\Phi| = F$$

$$D_\alpha \Phi| = \psi_\alpha$$

$$\Phi = A + \psi\theta + F\theta^2$$

Free Lagrangian reads

$$\begin{aligned} \mathcal{L} &= \int d^4\theta \; \bar{\Phi}\Phi = \\ &= \frac{1}{2} A\,\partial^{\alpha\dot{\alpha}}\partial_{\alpha\dot{\alpha}}\bar{A} + F\bar{F} - i\psi_\alpha \partial^{\alpha\dot{\beta}}\bar{\psi}_{\dot{\beta}}, \end{aligned}$$

where F is an auxiliary field.

Definition of complex linear superfield

Complex linear superfield Σ: $\bar{D}^2\Sigma = 0$.

$$\Sigma| = A \qquad D^2\Sigma| = F$$

$$D_\alpha\Sigma| = \lambda_\alpha \qquad \bar{D}_{\dot\alpha}D_\alpha\Sigma| = P_{\alpha\dot\alpha}$$

$$\bar{D}_{\dot\alpha}\Sigma| = \bar{\psi}_{\dot\alpha} \qquad \frac{1}{2}D^\alpha\bar{D}_{\dot\beta}D_\alpha\Sigma| = \bar{\chi}_{\dot\beta}$$

Free Lagrangian reads

$$\begin{aligned}\mathcal{L} &= -\int d^4\theta\ \bar{\Sigma}\Sigma = \\ &= \frac{1}{2}A\,\partial^{\alpha\dot\alpha}\partial_{\alpha\dot\alpha}\bar{A} - F\bar{F} + P^{\alpha\dot\alpha}\bar{P}_{\alpha\dot\alpha} - i\psi_\alpha\partial^{\alpha\dot\beta}\bar{\psi}_{\dot\beta} + \chi^\alpha\lambda_\alpha + \bar{\chi}^{\dot\alpha}\bar{\lambda}_{\dot\alpha},\end{aligned}$$

where χ, λ, P, F are auxiliary fields.
[Gates, Siegel '81]

Spontaneous SUSY Breaking

- If SUSY is realized in Nature, it must be broken.
- There are several mechanisms for SUSY breaking. [Fayet, Iliopoulos, '74] [Raifeartaigh '75]

When is SUSY broken?

- When $\langle F \rangle = f \neq 0$
  - $\delta\psi_\alpha \sim F\epsilon_\alpha + \cdots \to \delta\psi_\alpha \sim f\epsilon_\alpha$.
  - There exists Goldstone fermion.

SUSY Breaking for chiral superfield

- The simplest example is

$$\begin{aligned}\mathcal{L} &= \int d^4\theta\ \bar{\Phi}\Phi - f\int d^2\theta\ \Phi + \text{c.c.}\\ &= \frac{1}{2}A\,\partial^{\alpha\dot{\alpha}}\partial_{\alpha\dot{\alpha}}\bar{A} + F\bar{F} - f\,F - f\bar{F} - i\psi_\alpha\partial^{\alpha\dot{\beta}}\bar{\psi}_{\dot{\beta}}\end{aligned}$$

- Equation of motion for F: $\bar{F} = f$
- Existence of Goldstone fermion $\psi_\alpha : \delta\psi_\alpha = \epsilon_\alpha f$
- Possitive vacuum energy: $H \sim P^0 \sim |Q|^2 \geq 0$

SUSY breaking for complex linear superfield

Recent work in 4D, $N = 1$ supersymmetry shows that superspace higher derivatives containing complex linear superfield may trigger supersymmetry breaking. For example

$$\mathcal{L} = -\int d^4\theta \ \bar{\Sigma}\Sigma + \frac{1}{8f^2}\int d^4\theta D^\alpha \Sigma D_\alpha \Sigma \bar{D}^{\dot{\beta}} \bar{\Sigma} \bar{D}_{\dot{\beta}} \bar{\Sigma}.$$

[Farakos, Ferrara, Kehagias, Porrati '14]

The main properties of this mechanism:

- it can not be captured by Kähler potential or superpotential
- it does not give rise to any instability (Ostrogradsky)

SUSY Breaking for $(\mathrm{D}\Sigma)^2(\bar{\mathrm{D}}\bar{\Sigma})^2$

- Bosonic part of Lagrangian has a form

$$
\begin{aligned}
\mathcal{L}_{\mathrm{B}} \quad = \quad & \frac{1}{2} A\, \partial^{\alpha\dot{\alpha}} \partial_{\alpha\dot{\alpha}} \bar{A} + P^{\alpha\dot{\alpha}} \bar{P}_{\alpha\dot{\alpha}} - F\bar{F} + \frac{1}{2f^2} F^2 \bar{F}^2 + \frac{1}{2f^2} F\bar{F} P^{\alpha\dot{\alpha}} \bar{P}_{\alpha\dot{\alpha}} \\
& + \frac{1}{8f^2} P^{\alpha\dot{\alpha}} P_{\alpha\dot{\alpha}} \bar{P}^{\beta\dot{\beta}} \bar{P}_{\beta\dot{\beta}}.
\end{aligned}
$$

- Equation of motion for F $(P_{\alpha\dot{\alpha}} = 0)$

$$
\bar{F} - \frac{1}{f^2} F \bar{F}^2 = 0
$$

has two solutions

$$
\begin{aligned}
F &= 0 \text{ (SUSY preserving vacuum)} \\
F\bar{F} &= f^2 \text{ (SUSY breaking vacuum).}
\end{aligned}
$$

- A fermionic (previously auxiliary) field λ becomes propagating in the broken vacuum. It is the Goldstone fermion. The supersymmetry is non-linearly realized.

Summary of recent results

The main results of our work:

- we study supersymmetry breaking also from CNM multiplet ($\bar{D}^2\Sigma = m\Phi$) [Deo, Gates '85]
- we discuss chiral-complex linear duality
- we find supercurrent multiplets and we show that F-Z multiplet in IR-limit has a form [Roček'78] [Komargodski, Seiberg '09]

$$\bar{D}^{\dot{\alpha}}\mathcal{J}_{\alpha\dot{\alpha}} = D_\alpha X$$
$$X \to \frac{1}{3} f\, X_{NL}$$

- we discussed different Goldstino embeddings, namely using Samuel-Wess superfield we propose [Ivanov, Kapustnikov'78,'82] [Samuel, Wess '83]

$$\Sigma_\Lambda = \bar{D}^{\dot{\alpha}}\left(\bar{\Lambda}_{\dot{\alpha}}\Lambda^\alpha\Lambda_\alpha\right)$$

[Farakos, Hulík, Kočí, von Unge '15]

Summary

- superspace higher derivatives containing complex linear superfield may trigger supersymmetry breaking
- it can not be captured by Kähler potential or superpotential
- this new mechanism could open up new directions for constructing realistic models
- how are these results modified by couplings to other fields?

Thank you for your attention!