Aspects of N=2 supersymmetry breaking

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Supersymmetry:

→ Motivated from BSM physics.

→ Motivated from UV complete theories.

In low energy:

→ Supersymmetry is broken (spontaneously) completely.

→ Supergravity on de Sitter background ($\mathcal{V} > 0$).
Plan:

→ Fayet–Iliopoulos terms in N=1.

→ FI terms in N=2 and gauging.

→ FI terms in N=2 without gauging and de Sitter vacua.
Fayet–Iliopoulos terms in N=1
An N=1 gauge multiplet contains the component fields

\[ u_m, \quad \lambda, \quad D. \]

The simplest model with a Fayet–Iliopoulos term is

\[ \mathcal{L} = -\frac{1}{4} F^{mn} F_{mn} - i \lambda \sigma^m \partial_m \overline{\lambda} + \frac{1}{2} D^2 - \sqrt{2} \xi D + \text{interactions}. \]

- The auxiliary field gets a vev: \( \langle D \rangle = \sqrt{2} \xi. \)
- The goldstino is: \( \delta \lambda_\beta = -i \sqrt{2} \xi \epsilon_\beta + \cdots \)
- The vacuum energy is: \( \mathcal{V} = \xi^2. \)

How do we embed \(-\sqrt{2} \xi D\) in supergravity?
Gauging the $U(1)$
Freedman ’77

- The physical fields of N=1 supergravity are

$$g_{mn}, \psi_m.$$ 

- The standard FI term is

$$L_{\text{Standard FI}} = -e^{\sqrt{2}} \xi D + \frac{i}{2} e \xi \epsilon^{klmn} \psi_k \sigma_1 \psi_n u_m + O(\lambda, \bar{\lambda}),$$

and R-symmetry is gauged.

- Simplest supergravity setup gives

$$e^{-1} L \bigg|_{\lambda = 0} = -\frac{1}{2} R + \frac{1}{2} \epsilon^{klmn} (\psi_k \sigma_1 D_m \psi_n - \psi_k \sigma_1 D_m \bar{\psi}_n)$$

$$- \frac{1}{4} F_{mn} F^{mn} + \frac{i}{2} e \xi \epsilon^{klmn} \psi_k \sigma_1 \psi_n u_m - \xi^2.$$
Without gauging the U(1)  
Cribiori, Tournoy, FF, Van Proeyen ’17

- We observe that $\lambda_\alpha / D$ has the property

$$\delta \left( i \frac{\lambda_\alpha}{D} \right) = \epsilon_\alpha + \cdots$$

- We follow a new procedure without R-symmetry gauging

$$\mathcal{L}_{\text{New FI}} = -e \sqrt{2} \xi D + \xi \mathcal{O}(\lambda, \bar{\lambda})$$

- Simplest supergravity setup gives

$$e^{-1} \mathcal{L} \big|_{\lambda=0} = -\frac{1}{2} R + \frac{1}{2} \epsilon^{klmn} (\bar{\psi}_k \bar{\sigma}_l D_m \psi_n - \psi_k \sigma_l D_m \bar{\psi}_n) - \frac{1}{4} F_{mn}F^{mn}$$

$$- (\xi^2 - 3|P_0|^2) - \overline{P}_0 \psi_a \sigma^{ab} \psi_b - P_0 \bar{\psi}_a \bar{\sigma}^{ab} \bar{\psi}_b$$

Further developments in N=1: Antoniadis, Chatrabhuti, Isono, Knoops ’18, Aldabergenov, Ketov, Knoops ’18, Cribiori, Tournoy, FF ’18, ...
FI terms in \( N=2 \) and gaugings
Pure N=2 supergravity

- The supersymmetry parameters are:
  \[ \epsilon^i_\alpha(x), \quad i = 1, 2. \]

- The physical fields are:
  \[ g_{mn}, \quad \psi^i_m, \quad u^{(\text{sugra})}_m. \]

- Bosonic auxiliary fields that contribute to the scalar potential are:
  \[ F, \quad X^{(\text{sugra})}_{ij} \quad \text{(Role similar to D)}. \]

- Bosonic auxiliary fields that contribute to the gauging are:
  \[ B_{mn} \quad \text{(Integrate out)}, \quad \phi^i_m \quad \text{(Gauges SU}(2)_R). \]
Including an abelian $N=2$ vector multiplet

- The physical fields are:
  
  $\phi, \lambda^i_\alpha, u_m$.

- Bosonic auxiliary fields that contribute to the scalar potential are:
  
  $X^{ij}$ (Role similar to D).

- The gaugini transform as
  
  $\delta \lambda^i = 2\epsilon_j X^{ij} + \ldots$,

  and therefore, generically, are the goldstini when $\langle X^{ij} \rangle \neq 0$. 
The gauging and the scalar potential

Consider a theory with Kähler potential

\[ K = - \ln \left( 1 - |\phi|^2 \right) \]

and introduce an FI term for the physical vector multiplet

\[ e^{-1} L^{(bos.)}_{\text{Standard FI}} = -\xi F \phi - \frac{1}{8} \xi \delta^{ij} X_{ij} - \frac{1}{4} \xi \varepsilon^{mnpq} B_{mn} F_{pq} + \text{c.c.} \]

We integrate out the auxiliary fields \((L_{\text{Kin.}} \sim (\text{aux.})^2)\) to find

\[ F = -2 \xi \overline{\phi} , \quad X_{ij} = 4 \xi \delta_{ij} , \quad \delta_{ij} \phi^i_m = -2 \xi u_m \text{ (R-symmetry gauging)} . \]

The scalar potential is

\[ V_{\text{Standard FI}} = \xi^2 \left( 1 - 2 \frac{|\phi|^2}{1 - |\phi|^2} \right) , \]

and has no stable de Sitter vacua.
New FI terms in N=2 Supergravity

Antoniadis, Derendinger, FF, Tartaglino-Mazzucchelli ’19
N=2 Goldstini and new FI terms

- Similar to the N=1 case we observe that for the composite fermion we have
  \[
  \delta \left( \frac{X_{ij}}{2 X^{pq} X_{pq}} \chi^j \right) = \epsilon_i + \ldots
  \]
  and it allows to follow an alternative procedure.
- The construction can be lifted to the full N=2 superspace, and in components we have
  \[
  \mathcal{L}_{\text{New FI}} = e \left\{ -\frac{1}{8} \xi \delta^{ij} X_{ij} + \text{c.c.} \right\} \left[ e^K \right]^n + \xi \mathcal{O} \left( \chi^i, \bar{\chi}_i \right),
  \]
  for an arbitrary constant $n$ (because N=2 supergravity has two compensators).
- We integrate out the auxiliary fields to find
  \[
  F = 0, \quad X_{ij} = 4\xi \delta_{ij} e^n, \quad \delta_{ij} \phi^j_m = 0 \quad \text{(No gauging)}.
  \]
New FI terms and de Sitter

- The scalar potential take the form
  \[ V_{\text{New FI}} = \frac{\xi^2}{(1 - |\phi|^2)^n}. \]

- Three possibilities depending on \( n \):
  \[ V = \frac{\xi^2}{(1 - |\phi|^2)^n} + \xi^2 n|\phi|^2 + \mathcal{O}(n^2|\phi|^4), \]
  delivering stable de Sitter vacua.
  
  \[ V = \xi^2 \]
  delivering de Sitter with a modulus \( \phi \).
  
  \[ V = \xi^2 \]
  for \( n < 0 \) the scalar potential has no critical points within the moduli space (\( |\phi| < 1 \)).
Outlook:

→ New FI terms in N=1 with various applications and possible relation to anti D3-branes.

→ New FI terms in N=2 give new model building directions. Interpretation within string theory not known.

→ What happens for D>4 and N>2?
Thank you!
Backup
Pure new FI D-term in supergravity
Cribiori, Tournoy, FF, Van Proeyen ’17

▶ In superspace we have

\[ \mathcal{L}_{\text{New FI}} = \sqrt{2} 8 \xi \int d^4 \theta E \frac{W^2 \overline{W}^2}{D^2 W^2 \overline{D}^2 \overline{W}^2} D^\alpha W_\alpha \]

\[ = - e \sqrt{2} \xi \mathcal{D} + \xi \mathcal{O}(\lambda, \lambda) . \]

▶ Gravitino not charged under \( U(1)_{FI} \)
\[ \rightarrow \text{No } U(1)_R \text{ gauging.} \]

▶ Simplest superspace supergravity coupling is

\[ \mathcal{L} = -3 \left( \int d^2 \Theta 2 \mathcal{E} \mathcal{R} + \text{c.c.} \right) + \left( \int d^2 \Theta 2 \mathcal{E} P_0 + \text{c.c.} \right) \\
+ \frac{1}{4} \left( \int d^2 \Theta 2 \mathcal{E} W^2(V) + \text{c.c.} \right) + \mathcal{L}_{\text{New FI}} . \]