Aspects of N=2 supersymmetry breaking

Fotis Farakos

KU LEUVEN

HEP 2019, Athens

Supersymmetry:

$\rightarrow$ Motivated from BSM physics.

$\rightarrow$ Motivated from UV complete theories.

In low energy:

$\rightarrow$ Supersymmetry is broken (spontaneously) completely.

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

Plan:

$\rightarrow$ Fayet–Iliopoulos terms in N=1.

$\rightarrow$ FI terms in N=2 and gauging.

$\rightarrow$ FI terms in N=2 without gauging and de Sitter vacua.

Fayet–Iliopoulos terms in N=1

Fayet–Iliopoulos D-term

→ An N=1 gauge multiplet contains the component fields

$$u_m\,, \quad \lambda\,, \quad \mathrm{D}\,.$$

→ The simplest model with a Fayet–Iliopoulos term is

$$\mathcal{L} = -\frac{1}{4}F^{mn}F_{mn} - i\lambda\sigma^m\partial_m\bar{\lambda} + \frac{1}{2}\mathrm{D}^2 - \sqrt{2}\,\xi\,\mathrm{D} + \text{interactions}\,.$$

- The auxiliary field gets a vev: $\langle \mathrm{D} \rangle = \sqrt{2}\,\xi$.
- 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

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

- The standard FI term is

$$\mathcal{L}_{\textit{Standard FI}} = -e\sqrt{2}\,\xi\,\mathrm{D} + \frac{i}{2}e\,\xi\epsilon^{klmn}\overline{\psi}_k\overline{\sigma}_l\psi_n u_m + \mathcal{O}(\lambda,\overline{\lambda})\,,$$

and R-symmetry is gauged.

- Simplest supergravity setup gives

$$\begin{aligned} e^{-1}\mathcal{L}\Big|_{\lambda=0} = & -\frac{1}{2}R + \frac{1}{2}\epsilon^{klmn}\left(\overline{\psi}_k\overline{\sigma}_l\mathcal{D}_m\psi_n - \psi_k\sigma_l\mathcal{D}_m\overline{\psi}_n\right) \\ & -\frac{1}{4}F_{mn}F^{mn} + \frac{i}{2}e\xi\epsilon^{klmn}\overline{\psi}_k\overline{\sigma}_l\psi_n u_m - \xi^2\,. \end{aligned}$$

Without gauging the U(1)

Cribiori, Tournoy, FF, Van Proeyen '17

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

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

- We follow a new procedure without R-symmetry gauging

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

- Simplest supergravity setup gives

$$e^{-1}\mathcal{L}\Big|_{\lambda=0} = -\frac{1}{2}R + \frac{1}{2}\epsilon^{klmn}\left(\overline{\psi}_k\overline{\sigma}_l\mathcal{D}_m\psi_n - \psi_k\sigma_l\mathcal{D}_m\overline{\psi}_n\right) - \frac{1}{4}F_{mn}F^{mn}$$
$$-\left(\xi^2 - 3|P_0|^2\right) - \overline{P}_0\psi_a\sigma^{ab}\psi_b - P_0\overline{\psi}_a\overline{\sigma}^{ab}\overline{\psi}_b\,.$$

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:

$$g_{mn}\,, \quad \psi^i_m\,, \quad u_m^{(\text{sugra})}\,.$$

- Bosonic auxiliary fields that contribute to the scalar potential are:

$$F\,, \quad X_{ij}^{(\text{sugra})} \quad \text{(Role similar to D)}\,.$$

- Bosonic auxiliary fields that contribute to the gauging are:

$$B_{mn}\ \text{(Integrate out)}\,, \quad \phi^{ij}_m\ \text{(Gauges } SU(2)_{\text{R}}\text{)}\,.$$

Including an abelian N=2 vector multiplet

- The physical fields are:

$$\phi\,, \quad \lambda^i_\alpha\,, \quad u_m\,.$$

- Bosonic auxiliary fields that contribute to the scalar potential are:

$$X^{ij} \quad \text{(Role similar to D)}\,.$$

- 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

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

- We integrate out the auxiliary fields ($\mathcal{L}_{Kin.} \sim (\text{aux.})^2$) to find

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

- The scalar potential is

$$\mathcal{V}_{Standard\ FI} = \xi^2\left(1 - 2\frac{|\phi|^2}{1-|\phi|^2}\right)\,,$$

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

$$\delta\left(\frac{X_{ij}}{2\,X^{pq}X_{pq}}\,\lambda^j\right) = \epsilon_i + \dots$$

  and it allows to follow a n alternative procedure.
- The construction can be *lifted* to the full N=2 superspace, and in components we have

$$\mathcal{L}_{New\,FI} = e\left\{-\frac{1}{8}\xi\,\delta^{ij}\,X_{ij} + c.c.\right\}\left[e^K\right]^n + \xi\,\mathcal{O}\left(\lambda^i,\overline{\lambda}_i\right)\,,$$

  for an arbitrary constant n (because N=2 supergravity has two compensators).
- We integrate out the auxiliary fields to find

$$F = 0\,,\quad X_{ij} = 4\xi\,\delta_{ij}\,e^{nK}\,,\quad \delta_{ij}\phi^{ij}_m = 0 \quad \text{(No gauging)}.$$

New FI terms and de Sitter

- The scalar potential take the form

$$\mathcal{V}_{New\ FI} = \frac{\xi^2}{(1-|\phi|^2)^n}\,.$$

- Three possibilities depending on n:

  $\rightarrow$ For $n > 0$ we have $\mathcal{V} = \xi^2 + \xi^2\, n\, |\phi|^2 + \mathcal{O}(n^2|\phi|^4)$, delivering stable de Sitter vacua.

  $\rightarrow$ For $n = 0$ we have a constant $\mathcal{V} = \xi^2$ delivering de Sitter with a modulus ϕ.

  $\rightarrow$ For $n < 0$ the scalar potential has no critical points within the moduli space ($|\phi| < 1$).

Outlook:

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

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

$\rightarrow$ 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

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

$$= -e\sqrt{2}\,\xi\, \mathrm{D} + \xi\, \mathcal{O}(\lambda, \overline{\lambda}) \ .$$

- Gravitino not charged under $U(1)_{FI}$
  $\rightarrow$ No $U(1)_R$ gauging.

- Simplest superspace supergravity coupling is

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