Goldstino condensation and de Sitter uplift instabilities

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Motivation

$\rightarrow$ The actual nature of Dark Energy ($\rho_{DE} > 0$) is still unknown both Theoretically and Phenomenologically.

See e.g. Danielsson, Van Riet '18

$\rightarrow$ We typically investigate this question within super-symmetric String Theory and Supergravity.

$\rightarrow$ If kinetic energy is subdominant

$$\rho_{DE} \sim V_{4D} = f_{SB}^2 - 3m_{3/2}^2 > 0 \implies \underline{\text{Supersymmetry Breaking.}}$$

We will focus on non-linear SUSY because:

1. NL-SUSY underlines many EFTs with broken SUSY.

   See e.g. Dudas, Dall'Agata, FF '16, Dall'Agata, FF, Cribiori '17

2. For "anti-brane uplifts" the supersymmetry breaking is described by sectors with non-linear supersymmetry.

   See e.g. Bergshoeff, Dasgupta, Kallosh, Van Proeyen, Wrase '15, Dasgupta, Emelin and McDonough '16

Plan:

$\rightarrow$ Non-linear supersymmetry

$\rightarrow$ Goldstino condensation

$\rightarrow$ Consequences for uplifts

$\rightarrow$ Outlook

Non-linear supersymmetry

- Break SUSY with a chiral multiplet (X, G, F)

$$\langle F \rangle \neq 0 \,, \quad G_\alpha = \langle F \rangle \xi_\alpha + \dots$$

- The scalar can be removed from the spectrum by imposing the constraint

$$X^2 = 0 \quad \to \quad X = \frac{G^2}{2F} \,,$$

and SUSY becomes NL: $\delta G_\alpha = F \epsilon_\alpha + i \sigma^m_{\alpha\dot\alpha} \bar\epsilon^{\dot\alpha} \partial_m (G^2/2F)$.
Rocek '78, Casalbuoni, De Curtis, Dominici, Feruglio, Gatto '89

- The constraint can be imposed by including a Lagrange multiplier multiplet T.

- The simplest supersymmetric Lagrangian with NL SUSY is the Volkov–Akulov model

$$K = X\overline{X} \,, \quad W = fX + \frac{1}{2}TX^2 \,,$$

  where the variation of T gives $X^2 = 0$.

- In component form integrate out F ($F = -f + \dots$) to get

$$\mathcal{L}_{VA} = -f^2 + i\partial_m \overline{G}\overline{\sigma}^m G + \frac{1}{4f^2}\overline{G}^2 \partial^2 G^2 - \frac{1}{16f^6} G^2 \overline{G}^2 \partial^2 G^2 \partial^2 \overline{G}^2 \,,$$

  and generate the uplift.

- We want to study goldstino condensation due to the higher order fermion terms, and remain at *weak coupling* $\Lambda < \sqrt{f}$.

Goldstino condensation

Fermion condensation:

- E.g. Nambu–Jona-Lasinio at Large N is schematically

$$\overline{\Psi}_i \partial\!\!\!/ \Psi_i - \frac{g}{N}\Psi_i^4 \quad \rightarrow \quad \overline{\Psi}_i \partial\!\!\!/ \Psi_i + \frac{N}{g}\sigma^2 + \sigma\Psi_i^2 \, . \qquad (i = 1, \ldots N)$$

- The fermions are Gaussian and are integrated out to give

$$V_{EFF} = N\left(\frac{1}{g} - \Lambda^2\right)\sigma^2 + \mathcal{O}(\sigma^3)\,,$$

  and make σ propagating and the central point tachyonic when $g^{-1} - \Lambda^2 < 0$.

- Observations:
  1. Strong coupling (i.e. $g\Lambda^2 > 1$) is required only if you want to eventually stabilize the σ nearby the center.
  2. Large N controls the calculation but is not required if one uses Exact RG Flow.

- We use an Exact RG flow (i.e. Polchinski equation) to lower the cut-off Λ to Λ' and uncover the existence of composite states.

- We track only the interactions that can be described by a K and W and ignore HD terms, and the ERG takes the form

$$\frac{d}{dt_{RG}} K \sim (\#) \frac{\partial W}{\partial \Phi^i} \frac{\partial \overline{W}}{\partial \overline{\Phi}^i} + (\#) \frac{\partial^2 K}{\partial \Phi^i \partial \overline{\Phi}^i} ,$$

  when Φ_i is propagating in the UV (i.e. at Λ).

- We apply to the Volkov–Akulov, of which we have the K and the W, and check if T becomes propagating.

- The chiral model for the composite states is

$$K = \alpha|X|^2 + \beta|T|^2 + g|T|^2|X|^2 \,, \quad W = fX + \frac{1}{2}TX^2 \,.$$

- We find for $t_{RG} = \log \Lambda/\Lambda' \ll 1$ that

$$\alpha = 1 \,, \quad \beta \simeq \frac{1}{16\pi^2}t^2 \,, \quad g \simeq \frac{2t}{\Lambda'^2} \,, \quad f > \Lambda^2 \,,$$

  and flows to weak coupling at large RG-time ($g \to const./\Lambda'^2$ and $\beta \sim t_{RG}$).

- Around the "V–A" point $T \sim \langle \partial^2 \overline{G}^2 / f^2 \rangle = 0$ and $X \sim \langle G^2/f \rangle = 0$ we find tachyons

$$V = f^2 \,, \quad V'' < 0 \,.$$

Consequences for uplifts

A new problem for anti-brane uplifts?

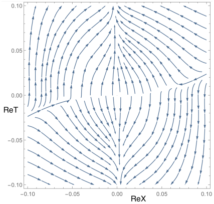
- The V–A model is easily coupled to 4D N=1 supergravity to get de Sitter. *See e.g. Lindstrom, Rocek '79, Bergshoeff, Freedman, Kallosh, Van Proeyen '15*

- Doing the ERG within supergravity is actually beyond the state-of-the-art.

- We simply directly couple the effective theory at Λ' to supergravity.

  1. Tachyons persist in SG.

  2. Similarly due to NL SUSY of $\overline{\text{D3}}$, also in KKLT.



Discussion

Take-away message:

- Non-linear supersymmetry shows an instability towards goldstino condensation. *Dall'Agata, Emelin, FF, Morittu '22*

- This result persists in supergravity and seems related the gravitino condensation instability. *See e.g. Jasinschi, Smith '83,'84, Alexandre, Ellis, Houston, Mavromatos '13-'15*

- Our results resonate with de Sitter skepticism. *See e.g. Danielsson, Van Riet '18, Obied, Ooguri, Spodyneiko, Vafa '18, Andriot '18*

What next?

- What about HD terms? - better control over the ERG results.
- Where do the tachyons stop? - Some other stable vacuum? - Supersymmetric vacuum?
- We need to go beyond the state-of-the-art in ERG to include quantum effects from supergravity.
- We would like to identify these tachyons with some open or closed string sector. (What happens within 10D BSB?)
- What happens for N $>$ 1 or matter couplings?

Thank you