Goldstino Condensation

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Plan:

$\rightarrow$ Motivation

$\rightarrow$ Methods for fermionic condensation

$\rightarrow$ Goldstino condensation at large N

$\rightarrow$ Outlook

Motivation

Dark Energy in String Theory/Supergravity means

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

We will focus on non-linear SUSY because:

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

   See e.g. Wess, Bagger '92, Dudas, Dall'Agata, FF '16, Dall'Agata, FF, Cribiori '17

2. In specific "anti-brane" setups the supersymmetry breaking is described by sectors with NL-SUSY.

   See e.g. Kallosh, Wrase '14, Bergshoeff, Dasgupta, Kallosh, Van Proeyen, Wrase '15, Dasgupta, Emelin and McDonough '16

Goldstino: An indispensable part of uplifts

Salient features of NL-SUSY in Volkov–Akulov model *('73)*

- The (N=1) goldstino Lagrangian

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

  and generates the uplift when coupled to SG.

- The non-linear SUSY is

$$\delta G_\alpha = -f\xi_\alpha - (i/2f)\partial\!\!\!/_{\alpha\dot{\alpha}}\, G^2\,\overline{\xi}^{\dot{\alpha}} + \ldots$$

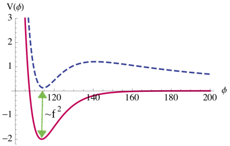
We want to understand if the non-linear terms are spectators or they have any physical significance/impact.

Goldstino condensation: A threat to uplifts

- If there is a condensate of the form

$$\langle i\overline{G}\,\partial\!\!\!/\, G\rangle \neq 0\,,$$

then this may potentially ruin uplifts.



(uplift Kachru, Kallosh, Linde, Trivedi '03)

- Due to the non-linear terms, the goldstini may produce such condensates.

- We will discuss the simplest model where goldstino condensation can be studied convincingly.

Methods for fermionic condensation

see e.g. Gross, Neveu ’74

- We can work with N copies of 2D Dirac fermions

$$\mathcal{L} = i\overline{\psi}^a \partial\!\!\!/ \psi^a + \frac{g_0}{\mathrm{N}} \left(\overline{\psi}^a \psi^a\right)^2 ,$$

with $a = 1, \ldots, \mathrm{N}$, with cut-off Λ.

- The theory can be written as

$$\mathcal{L} = i\overline{\psi}^a \partial\!\!\!/ \psi^a - \frac{\mathrm{N}}{2g_0}\sigma^2 + \sigma \overline{\psi}^a \psi^a ,$$

making the path integral Gaussian in the fermions.

- Once we integrate out the scalar, we recover the starting Lagrangian and that

$$\sigma = \frac{g_0}{\mathrm{N}} \overline{\psi}^a \psi^a .$$

- Integration instead over the Gaussian fermions gives

$$Z \sim \int D[\sigma]\ (\det[i\partial\!\!\!/ + \sigma])^{\mathrm{N}}\ e^{i\int d^2x\left(-\frac{\mathrm{N}}{2g_0}\sigma^2\right)}\ ,$$

  because we had N copies.

- Then bring the determinant on the exponent to get

$$S(\sigma) = \mathrm{N} \times \left[\int d^2x \left(-\frac{1}{2g_0}\sigma^2\right) - i \log\det[i\partial\!\!\!/ + \sigma]\right]\ .$$

- We restore momentarily $\hbar$ (i.e. we have $S/\hbar$) to notice that now we have an "effective" $\hbar$ as

$$\hbar_{eff} = \frac{\hbar}{\mathrm{N}}\ ,$$

  which is infinitesimal at large N and the theory behaves "classically".

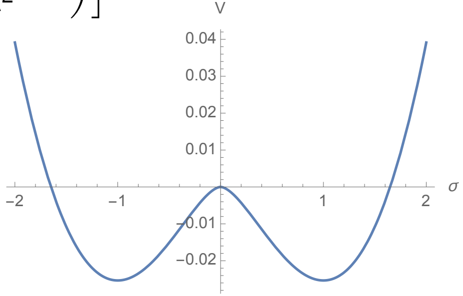
- The scalar potential takes the form

$$V(\sigma) = \mathrm{N}\left[\frac{\sigma^2}{2g_0} + \frac{\sigma^2}{4\pi}\left(\log\frac{\sigma^2}{\Lambda^2} - 1\right)\right] .$$

- The new critical point at

$$\sigma = \Lambda \exp[-\pi/g_0] ,$$

corresponds to the fermion condensate.



We want to apply the same logic to the goldstino.

Goldstino condensation at large N

FF, Matteo Morittu '22

- We can work with N copies of 4D Dirac goldstini

$$\mathcal{L} = -\mathrm{N}f^2 \det[\mathcal{A}_m{}^a] = -\mathrm{N}f^2 + i\overline{G}^A \partial\!\!\!/ G^A + \ldots$$

with $A = 1, \ldots, \mathrm{N}$, with cut-off $\Lambda \ll \sqrt{f}$, where

$$\mathcal{A}_m{}^a = \delta_m^a + \frac{i}{2\mathrm{N}f^2}\left(\overline{G}^A \gamma^a \partial_m G^A - \partial_m \overline{G}^A \gamma^a G^A\right) .$$

- The theory can be written as

$$\mathcal{L} = -\mathrm{N}f^2 \det[e_m{}^a] + \mathrm{N}f^2 C_a{}^m (e_m{}^a - \mathcal{A}_m{}^a) ,$$

making the path integral Gaussian in the fermions.

- We can perform the Gaussian integral over the fermions, to find formally

$$Z_F \sim \left(\det[iC_a{}^m \gamma^a \partial_m]\right)^{\mathrm{N}} ,$$

and then the action for the bosons reads

$$S = \mathrm{N} \times \Big\{ -f^2 \int d^4x \left[\det[e_n{}^b] - C_a{}^m (e_m{}^a - \delta_m{}^a)\right] -i \,\mathrm{tr} \log \left[iC_a{}^m \gamma^a \partial_m\right] \Big\} .$$

- We can invoke the large N once more and trust the critical points of the classical potential.

- We want to find new stationary points therefore we can focus on

$$C_a{}^m = (1+h)\,\delta_a{}^m\,, \quad e_m{}^a = (1-\phi)\,\delta_m{}^a\,.$$

- The potential reads

$$V(h,\phi) = \mathrm{N}\left\{ f^2\left[(1-\phi)^4 + 4(1+h)\phi\right] - \frac{\Lambda^4}{16\pi^2}\log\left[(1+h)^2\right]\right\}.$$

- We can readily eliminate h to get an effective $V(\phi)$; an "effective potential" for the condensate to search for critical points.

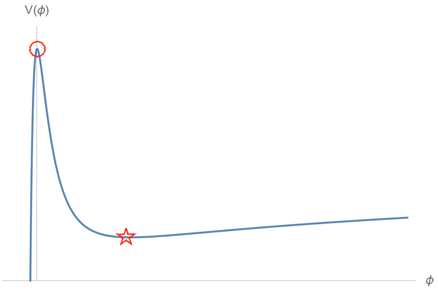
- The potential has a new stationary point at

$$\phi_{GC} \simeq 1\,,$$

with

$$V(\phi_{GC}) \ll \mathrm{N}\, f^2\,,$$

thus ruining uplifts.



- We interpret this as a goldstino condensate because classically

$$\phi = -\frac{i}{8\mathrm{N}f^2}\left(\overline{G}^A\gamma^m\partial_m G^A - \partial_m\overline{G}^A\gamma^m G^A\right)\,.$$

Outlook

- → Large N: GC quite robust under higher derivative goldstino self-couplings / typical matter coupling of NL-SUSY.

- → Using “exact RG flow”, we are studying the 4D goldstino condensate also at N=1, which is physically more relevant. *Dall’Agata, Emelin, FF, Morittu ’22, work in progress*

- → Our results resonate with gravitino condensation. *E.g. Jasinschi, Smith ’83, Alexandre, Houston, Mavromatos ’13-’15*

- → String theory interpretation? Decay time? Tachyon mass? Other dimensions? *Emelin, FF, Morittu, work in progress*

Thank you