Weak gravity, supergravity and de Sitter vacua

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Motivation

- Our universe is expanding due to positive background energy density of order $\Lambda \sim 10^{-122} M_P^4$.

- A lot of effort in finding de Sitter vacua within flux compactifcations of supersymmetric string theory.

- Turns out, it is extremely hard to find stable de Sitter in string theory, if possible at all.
  See e.g. Danielsson, Van Riet '18

Can we uncover such problem directly within 4D supergravity?

$\rightarrow$ For 4D EFTs derived from string theory

$$V = f^2 - 3m_{3/2}^2 > 0 \implies \underline{\text{Supersymmetry Breaking.}}$$

$\rightarrow$ Supersymmetry breaking in 4D supergravity typically from:

- Superpotentials. *(fluxes)*
- Gaugings. *(fluxes)*
- Non-linear realizations. *(anti-branes)*

Can we restrict these ingredients? - what lessons do we learn?

Plan:

$\rightarrow$ Swampland and gaugings

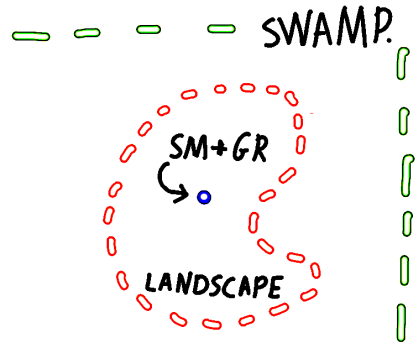
$\rightarrow$ Non-linear supersymmetry and condensates

$\rightarrow$ Outlook

Swampland and gaugings

✗ Swampland: EFTs that do not arise from S.T.

✓ Landscape: EFTs that do arise from S.T.



We distinguish swamp from landscape with so-called conjectures: General properties that we guess and test on compactifications, black holes, quantum gravity etc., e.g.:

Weak gravity conjecture (WGC) postulates that in EFTs with electromagnetism there is a UV cut-off

$$\Lambda_{UV} < qg\, M_P\,.$$

Arkani-Hamed, Motl, Nicolis, Vafa '06

The 4D N=1 Lagrangian of supergravity + FI term *(Freedman '77)* is

$$e^{-1}\mathcal{L} = -\frac{1}{2}M_P^2 R + \frac{1}{2}\epsilon^{\kappa\lambda\mu\nu}\left(\overline{\psi}_\kappa\overline{\sigma}_\lambda D_\mu\psi_\nu - \psi_\kappa\sigma_\lambda D_\mu\overline{\psi}_\nu\right)$$
$$-\frac{1}{4g^2}F_{\mu\nu}F^{\mu\nu} + i\xi\,\epsilon^{\kappa\lambda\mu\nu}\overline{\psi}_\kappa\overline{\sigma}_\lambda\psi_\mu A_\nu - 4g^2\xi^2 M_P^4\,.$$

- Because ξ is the gravitino charge, the WGC gives

$$\Lambda_{UV} \sim g\,\xi\,M_P\,.$$

- The vacuum energy is $4g^2\xi^2M_P^2$ and so the Hubble is

$$H \sim g\xi M_P \sim \Lambda_{UV}\,,$$

therefore such genuine 4D de Sitter vacuum cannot arise from string theory. *Cribiori, FF, Tringas '20*

Why is $H \sim \Lambda_{UV}$ problematic? *See e.g. Cribiori, Dall'Agata, FF '20*

- From an EFT perspective we have

$$e^{-1}\mathcal{L}_{grav.} = M_P^2\left(\frac{1}{2}R + \frac{\mathcal{O}(1)}{\Lambda_{\rm UV}^2}R^2 + \cdots\right) .$$

- On a spatially flat de Sitter background one has

$$R = 12H^2 ,$$

therefore to be able to trust the 2-derivative EFT we need

$$H \ll \Lambda_{\rm UV} .$$

- Supported by further arguments related to scalar fluctuations in de Sitter but also by the interpretation of H as an IR cut-off.

Further results:

- We have shown that all known stable de Sitter vacua of N=2 *(e.g. Fre, Trigiante, Van Proeyen '02)* have the same issue and massless gravitini. *Cribiori, Dall'Agata, FF '20, Dall'Agata, Emelin, FF, Morittu '21*
- N=2 dS by Catino, Scrucca, Smyth '13: no explicit model.
- We have deemed it as a conjecture that:

  Supergravity de Sitter vacua with vanishing gravitino mass belong to the swampland.

  Cribiori, Dall'Agata, FF '20
- All known stable de Sitter N=2 vacua have $m_{3/2} = 0$, $q_{3/2} \neq 0$, so violate also the festina lente bound. *Montero, Van Riet, Venken '19, Montero, Vafa, Van Riet, Venken '21*

Non-linear supersymmetry and condensates

Dall'Agata, Emelin, FF, Morittu '22

- The Volkov–Akulov model is

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

- This EFT is defined with a cut-off $\Lambda \leq \sqrt{f}$, and we want to lower it to uncover the existence of composite states à la Nambu–Jona-Lasinio.

- In terms of *linear SUSY* it is described by

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

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

$$X = G^2/2F \implies \text{NL SUSY.}$$

Check M. Morittu's poster for details!

- Using the Functional RG Flow (with some approx.) we find

$$K = \alpha|X|^2 + \beta|T|^2 + g|T|^2|X|^2 + \frac{1}{4}q|X|^4, \quad W = fX + \frac{1}{2}TX^2.$$

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

$$\alpha \simeq 1\,, \ \beta \simeq \frac{1}{16\pi^2}t^2\,, \ g \simeq \frac{2t}{\Lambda'^2}\,, \ q \simeq \frac{2t}{\Lambda'^2}\,, \ f \gtrsim \Lambda^2\,.$$

- Around the "V–A" point $T = X = 0$ we find tachyons

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

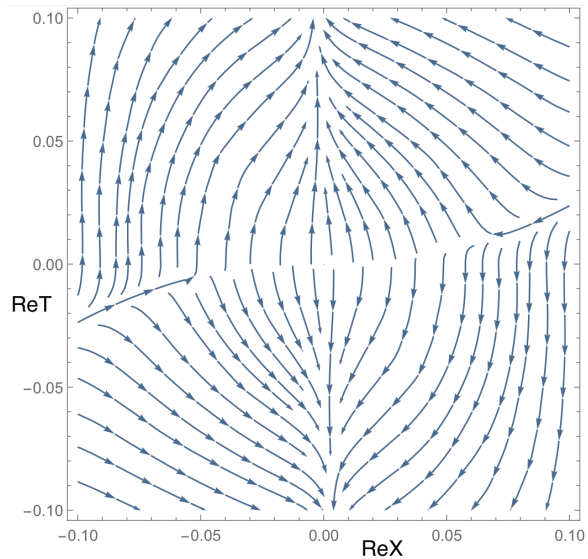
- You can imagine the composite states to have the form

$$X \sim G^2/f\,, \quad T \sim \partial^2\overline{G}^2/f^2\,.$$

What happens with de Sitter?

- 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.
3. Agreement with gravitino condensates bibliography. *E.g. Alexandre, Houston, Mavromatos '13-'15*



Outlook

4D supergravity can give us a very strong handle on de Sitter:

- Break SUSY and uplift with gaugings $\rightarrow$ Clash with WGC or festina lente bound.
- Anti-brane uplift with NL SUSY $\rightarrow$ New tachyonic instability towards goldstino condensates.
  - New stable vacua / Matter couplings?
  - We need to understand ERG in supergravity.
  - Revisit anti-brane uplifts.
- What about the superpotential?
  (Maybe using p-forms? See e.g. Martucci, Sorokin, et al.)

Thank you