De Sitter vacua in gauged Supergravity and the Swampland

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Πανεπιστήμιο Ιωαννίνων

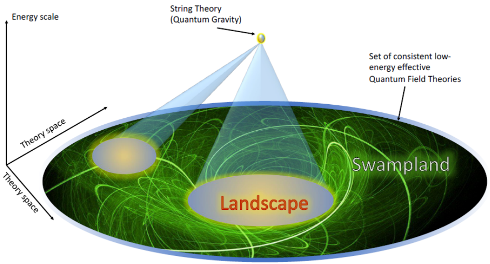
The Swampland program at our hands

Our Universe is experiencing a phase of **accelerated expansion** [S. Perlmutter et alii, 1998; PLANCK, 2018].

One way to account for it is via a **positive cosmological constant** [Einstein, 1915; Weinberg, 1989].

Can we uncover the difficulty of finding **de Sitter vacua** in String Theory [H. Danielsson and T. Van Riet, 2018; G. Obied et alii, 2018] when adopting the perspective of **four-dimensional Supergravity** in combination with the **Swampland program** [C. Vafa, 2005]?

The **Landscape** and the **Swampland**:



[E. Palti, 2019]

Distilling out the Swampland from the Landscape via conjectures,

Magnetic WGC

[N. Arkani-Hamed, L. Motl, A. Nicolis, C. Vafa, 2006]

In the presence of a $U(1)$ gauge symmetry, with gauge coupling g, the quantum gravity induced cut-off of a consistent EFT is bounded by

$$\Lambda_{UV} \lesssim g q M_P \text{ for every charged object.}$$

Our main result

[N. Cribriori, G. Dall'Agata and F. Farakos, 2020;
G. Dall'Agata, F. Farakos, M. Emelin and M. M., 2021]

All known stable de Sitter critical points of $N = 2$ supergravity theories, where the gravitini are $U(1)$-charged and massless, have

$$H \sim \Lambda_{UV}$$

and thus belong to the Swampland.

Note: Our findings agree with the *Festina Lente* bound [M. Montero et alii, 2019], the Gravitino Mass Conjecture [M. Cribriori et alii, 2021] and the results of arXiv/hep-th: 2201.04512 [D. Andriot et alii, 2022].

The plan

i. The $N = 2$ setup and our main result;

ii. An illustrative new example;

iii. Conclusions.

$N = 2$ supergravity ingredients and fundamental quantities

The multiplets and the manifolds

Gravity multiplet: $g_{\mu\nu}$, $\{\Psi^i_\mu\}_{i=1,2}$, A^0_μ ;

Vector multiplets: z^I, $\{\lambda^I_i\}_{i=1,2}$, A^I_μ for $I = 1, ..., n_V$;

Hypermultiplets: q^u, $\{\chi_i\}^a$ with $u = 1, ..., 4n_H$ and $a = 1, ..., 2n_H$.

For $\{z^I\}_I$, **special-Kähler manifold**:

$$Z^M = \begin{pmatrix} X^\Lambda(z) \\ F_\Lambda(z) \end{pmatrix} = e^{-\frac{K}{2}} \begin{pmatrix} L^\Lambda(z) \\ M_\Lambda(z) \end{pmatrix} \text{ for } \Lambda = 0, I \,,$$

with $K = -\log[-i\langle Z, \overline{Z}\rangle]$, and correpondingly $g_{I\overline{J}} = \partial_I \partial_{\overline{J}} K$.

For $\{q^u\}_u$, **quaternionic-Kähler manifold**:

$$h_{uv}\,, (J^x)_u^{\ v} \text{ with } x = 1, 2, 3\,.$$

The gaugings, the prepotentials and the couplings

Gaugings: k^I_Λ, k^u_Λ.

Prepotentials: P^0_Λ, P^x_Λ, deduced thanks to

$$\partial_I P^0_\Lambda = g_{I\bar{J}} k^{\bar{J}}_\Lambda \text{ and } \nabla_u P^x_\Lambda = -2(J^x)_{uv} k^v_\Lambda \,.$$

Couplings: $\mathcal{I}_{\Lambda\Sigma}$ being the gauge kinetic matrix,

$$U^{\Lambda\Sigma} = g^{I\bar{J}} \nabla_I L^\Lambda \nabla_{\bar{J}} \overline{L}^\Sigma = -\frac{1}{2}\mathcal{I}^{-1|\Lambda\Sigma} - \overline{L}^\Lambda L^\Sigma \,.$$

The gravitino mass and charge

Gravitino mass: $S_{ij} = i P^x_\Lambda L^\Lambda (\sigma_x)_i^k \epsilon_{jk}$.

Gravitino charge: $(Q_A)_i^j = \frac{1}{2}\mathcal{E}^\Lambda_A \left(P^0_\Lambda \delta_i^j + P^x_\Lambda (\sigma_x)_i^j \right)$.

Given a $U(1)$ symmetry, exploiting the $SO(n_V+1)$ freedom in defining $\mathcal{E}^\Lambda_A$: $(Q_1)_i^j$.

The general proof

$$\mathbf{V}\Big|_{S_{ij}=0} = -\frac{1}{2}\mathcal{I}^{-1|\Lambda\Sigma}[P^0_\Lambda P^0_\Sigma + P^x_\Lambda P^x_\Sigma] + 4h_{uv}k^u_\Lambda k^v_\Sigma \overline{L}^\Lambda L^\Sigma \,.$$

Then,

$$V\Big|_{S_{ij}=0} \geq \frac{1}{4}\delta^{AB}[\delta^j_i P^0_A + (\sigma^x)^j_i P^x_A][\delta^i_j P^0_B + (\sigma^y)^i_j P^y_B] \geq$$

$$\geq \frac{1}{4}[\delta^j_i P^0_1 + (\sigma^x)^j_i P^x_1]^2 = \mathrm{Tr}[Q_1 Q_1] = q_1^2 + q_2^2 \,.$$

The cut-off being bounded by the gravitino charges,

$$V \geq q_1^2 \;\text{ and }\; V \geq q_2^2 \;:\; V \geq \Lambda_{UV}^2 \;\text{ or }\; H \geq \frac{\Lambda_{UV}}{\sqrt{3}} \,.$$

However, in de Sitter spaces, one generally expects

$$H \ll \Lambda_{UV} \,,$$

because of:

1. Thermal fluctuations of a scalar in a dS background;

2. Bounds on investigable distances within a two-derivative supergravity EFT;

3. Irrelevance of higher curvature corrections, e.g. $\mathcal{R}^2$ corrections, on a spatially flat dS background.

If $H \sim \Lambda_{UV}$, the Dine–Seiberg problem manifests!

A new illustrative example

Content: 5 vector multiplets and 2 hypermultiplets.

Special-Kähler manifold:

$$\mathcal{M}_{\mathsf{SK}} = \frac{SU(1,1)}{U(1)} \times \frac{SO(2,4)}{SO(2)\times SO(4)} \;\text{ with }\; z^I = \{S, y^0, \{y^x\}_{x=1,2,3}\}$$

and

$$X^\Lambda = \begin{pmatrix} \frac{1}{2}(1+y^a y^a) \\ \frac{1}{2}(1-y^a y^a) \\ y^0 \\ y^x(\cos\varphi - S\sin\varphi) \end{pmatrix} \;\text{ and }\; F_\Lambda = \begin{pmatrix} \frac{1}{2}S(1+y^a y^a) \\ \frac{1}{2}S(1-y^a y^a) \\ -Sy^0 \\ -y^x(S\cos\varphi + \sin\varphi) \end{pmatrix}.$$

Quaternionic-Kähler manifold:

$$\mathcal{M}_{\mathsf{QK}} = \frac{SO(4,2)}{SO(4)\times SO(2)} \;\text{ with }\; q^u \;\text{ for }\; u = 1, \ldots, 8\,.$$

Gauging $SO(2,1)$ **in** $SO(2,4)$: $k^I_\Lambda = e_0(k^I_0, k^I_1, k^I_2, 0, 0, 0)$ with

$$k^I_0 = \left(0, -\frac{i}{2}\left[1 + y_0^2 - \sum_x (y_x)^2\right], -iy_0y_1, -iy_0y_2, -iy_0y_3\right) \; ;$$
$$k^I_1 = \left(0, \frac{1}{2}\left[1 - y_0^2 + \sum_x (y_x)^2\right], -y_0y_1, -y_0y_2, -y_0y_3\right) \; ;$$
$$k^I_2 = (0, iy_0, iy_1, iy_2, iy_3)\,,$$

and

Gauging $U(1)^3$ in $SO(4,2)$: $k^u_\Lambda = (0, 0, 0, e_4 k^u_{T_{\underline{12}}}, e_5 k^u_{T_{\underline{34}}}, e_6 k^u_{T_{\underline{56}}})$, $(T_{\underline{ab}})_{\underline{c}}^{\underline{d}} = \eta_{\underline{c}|\underline{a}}\delta^{\underline{d}}_{\underline{b}}$ (for $\underline{a} = 1, ..., 6$) being the generators of $SO(4,2)$ in the fundamental representation of $so(4,2)$.

Scalar potential critical points:

$$y^0 = y^x = 0 \;\text{ and }\; S = \cot\varphi - i\left|\frac{e_0}{\sqrt{e_4^2+e_5^2}\sin\varphi}\right|$$

and

$$q^1 = q^5 = 1 \;\text{ and }\; q^2 = q^3 = q^4 = q^6 = q^7 = q^8 = 0$$

with

$$V = \sqrt{e_4^2+e_5^2}\,|e_0 \sin\varphi|\,.$$

Interestingly,

$$m^2_{(\text{multiplicity})} = \left(0_{(2)}, 1_{(6)}, 2_{(2)}, \frac{e_4^2}{e_4^2+e_5^2}_{(4)}, \frac{e_5^2}{e_4^2+e_5^2}_{(4)}\right) \times V$$

and

$$S_{ij} = 0\,.$$

Moreover,

$$q_{\text{phys.}} = e_0 \sqrt{\sqrt{e_4^2+e_5^2}\left|\frac{\sin\varphi}{e_0}\right|} \text{ under } U(1) \longleftarrow SO(2,1)\,.$$

Note: $k_\Lambda^u = 0$ and $P^x_{0,1,2,3} = \begin{pmatrix}0\\0\\0\end{pmatrix}$, $P^x_3 = \begin{pmatrix}-e_4\\0\\0\end{pmatrix}$, $P^x_4 = \begin{pmatrix}-e_5\\0\\0\end{pmatrix}$.

Because

$$V = q^2_{\text{phys.}}$$

and for any charged field

$$\Lambda_{\text{UV}} \lesssim q_{\text{phys.}} \, ,$$

then

$$V > \Lambda^2_{\text{UV}} \;\text{ so that }\; H{\sim}\Lambda_{\text{UV}} \, ,$$

this vacuum being thus in the **Swampland**!

Conclusions

The **magnetic WGC** can be used to constrain de Sitter critical configurations, in combination with the adoption of a **four-dimensional supergravity** perspective.

Main result: *All known stable de Sitter critical points of $N = 2$ supergravity with charged massless (or parametrically light) gravitini have*

$$H \sim \Lambda_{\mathrm{UV}} \,,$$

thus being in the Swampland.

There are **examples** supporting the criterion.

There are also **loopholes** (but no explicit models!) to it, related (for instance) to massive gravitini, complete symmetry breaking.

Thank you for your interest and attention!