Microscopic constraints for de Sitter uplifts in String Theory

Ander Retolaza

DESY, Hamburg

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Constructing String Theory Vacua

Compactify (Type IIB) String Theory to 4d:

Many scalars/moduli $\Rightarrow$ stabilize them. Usual steps:

1. Complex structure + τ get masses $\quad m_{CS}$
2. Kähler/volume modulus ρ with mass $\quad m_{CS} \gg m_\rho$
   $\Rightarrow$ Anti de Sitter (or Minkowski) vacuum $\quad V_0 \leq 0$
3. Uplift to de Sitter (~~SUSY~~) $\quad \Delta V \Rightarrow \quad V_0 + \Delta V \geq 0$

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To which extent can we decouple steps 2 & 3 ?

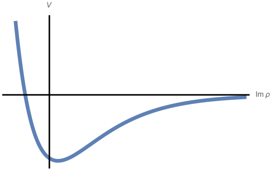
We cannot always do so, but the way out is rather simple.

KKLT vacua

[Kachru, Kallosh, Linde, Trivedi '03]

Consider that $h^{1,1} = 1$. Volume modulus ρ stabilized by gaugino condensate

$$K = -3\log[-i(\rho - \overline{\rho})] \qquad ; \qquad W = W_0 + Ae^{ia\rho}$$



- Vacuum is SUSY AdS with $V_0 \simeq -m_\rho^2 M_P^2$
- To end up on de Sitter one needs $\Delta V \sim |V_0|$, $\Delta\rho$ not small

Do we know 4d EFT for ρ well enough when uplifting?

We need higher dimensional picture to answer this question.

A toy model example

Consider a 6d theory on $\mathcal{M}_4 \times S^2$ [Freund, Rubin '80]

$$\mathcal{S}_6 = \frac{1}{2}\int \left(*R_6 - \frac{1}{2} F_2 \wedge *F_2 \right)$$

- Stabilize S^2 radius by taking $\int_{S^2} F_2 \simeq N$. Then

$$L_0^2 = \frac{3N^2}{32} \qquad \& \qquad \frac{V_0}{M_P^4} = -\frac{256}{27\pi N^4} \quad \text{so} \quad \mathcal{M}_4 = AdS_4$$

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- Now we add N_3 3-branes of tension T_3.
- S^2 backreacts: it grows $\quad L_0^2 \to L_0^2 \left(1 - \frac{N_3 T_3}{4\pi}\right)^{-1}$
- This results in a 4d vacuum energy change

$$\frac{V_0}{M_P^4} \to \frac{V_0}{M_P^4}\left(1 - \frac{N_3 T_3}{4\pi}\right)^3 = \frac{V_0}{M_P^4} + \frac{N_3 T_3}{M_P^4} + \mathcal{O}\left(\left(\frac{N_3 T_3}{m_{KK}^2 M_P^2}\right)^2\right)$$

We can add energy, but the uplift flattens out leaving V $\leq$ 0

The String Theory case I: setup

A generalization of [Giddings, Kachru, Polchinski '01] vacua: Type IIB on

$$ds^2 = e^{2A(y)}\tilde{g}_{\mu\nu}dx^\mu dx^\nu + \underbrace{e^{-2A(y)}\tilde{g}^6_{mn}}_{=g^6_{mn}}dy^m dy^n \quad ; \quad F_5 = (1+\star_{10})d\alpha \wedge dx^4$$

- 10d *trace reversed* Einstein's eq.s & EoM of F_5

$$\tilde{R}_{4D} = \tilde{\nabla}^2(e^{4A}-\alpha) - e^{-6A}|\partial(e^{4A}-\alpha)|^2 - e^{2A}\left(\frac{|G_3^-|^2}{6\mathrm{Im}(\tau)} + \frac{\Delta^{loc}}{2\pi}\right)$$

where $\star_6 G_3^- = -iG_3^-$ & $\Delta^{loc} \equiv \frac{1}{4}\left(T^m_m - T^\mu_\mu\right)^{\mathrm{loc}} - T_3\rho_3^{\mathrm{loc}}$

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$$\tilde{R}_{4D} = \tilde{\nabla}^2(e^{4A} - \alpha) - e^{-6A}|\partial(e^{4A} - \alpha)|^2 - e^{2A}\left(\frac{|G_3^-|^2}{6\mathrm{Im}(\tau)} + \frac{\Delta^{loc}}{2\pi}\right)$$

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- From here $\left(V = M_P^2 \tilde{R}_{4D}/4 \,;\; \mathcal{V} = \int \sqrt{g^6} e^{2A} d^6y ;\; \tilde{\mathcal{V}} = \int \sqrt{g^6} e^{6A} d^6 y \right)$

$$\frac{V}{M_P^4} = -\frac{1}{16\pi\mathcal{V}\tilde{\mathcal{V}}} \int d^6y \sqrt{g^6}\left[|\partial(e^{4A} - \alpha)|^2 + e^{8A}\left(\frac{|G_3^-|^2}{6\mathrm{Im}(\tau)} + \frac{\Delta^{loc}}{2\pi}\right)\right]$$

- We can use this expression when stabilizing all moduli, including ρ.

The String Theory case II: moduli stabilization

$$\frac{V}{M_P^4} = -\frac{1}{16\pi\mathcal{V}\tilde{\mathcal{V}}}\int d^6y\sqrt{g^6}\left[|\partial(e^{4A}-\alpha)|^2 + e^{8A}\left(\frac{|G_3^-|^2}{6\mathrm{Im}(\tau)} + \frac{\Delta^{loc}}{2\pi}\right)\right]$$

- CS moduli & dilaton: via G_3^+ fluxes & with $(e^{4A}-\alpha)=0$.
- Kähler: via $\langle\lambda\lambda\rangle$ from a stack of D7-branes: [Dymarsky, Martucci '10]
    - Local: $e^{8A}\,\dfrac{\Delta^{loc}}{2\pi} = -3\dfrac{|\lambda\lambda|^2|\Omega|^2}{(4\pi)^4}|g^{m\bar{n}}\nabla_m\nabla_{\bar{n}}F(z)|^2 \leq 0$
    - Bulk: $e^{8A}\,\dfrac{|G_3^-|^2}{6\mathrm{Im}(\tau)} = 4\dfrac{|\lambda\lambda|^2|\Omega|^2}{(4\pi)^4}|\nabla_p\nabla_q F(z)|^2 \geq 0$

      [Baumann, Dymarsky, Kachru, Klebanov, McAllister '10]
- $\dfrac{V_{\lambda\lambda}}{M_P^4} = -\dfrac{|\lambda\lambda|^2}{(4\pi)^6\mathcal{V}\tilde{\mathcal{V}}}\displaystyle\int d^6y\sqrt{g^6}\left[|\Omega|^2|g^{m\bar{n}}\nabla_m\nabla_{\bar{n}}F(z)|^2\right] \leq 0$
    - In agreement with the 4d EFT we have an AdS vacuum.

The String Theory case III: the uplift

$$\frac{V}{M_P^4} = -\frac{1}{16\pi\mathcal{V}\tilde{\mathcal{V}}}\int d^6y\sqrt{g^6}\left[|\partial(e^{4A}-\alpha)|^2 + e^{8A}\left(\frac{|G_3^-|^2}{6\mathrm{Im}(\tau)} + \frac{\Delta^{loc}}{2\pi}\right)\right]$$

- Add $\overline{\textbf{D3}}$**-brane** (+ G_3^+ fluxes for tadpoles) on warped throat ($e_{IR}^{4A} \ll 1$).
- In 10d picture, we don't know details of $\overline{D3}$ backreaction down the throat.
  (**Don't worry!!!** We assume there exists a stable solution :)

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- Approach: check how an IR perturbation $\delta\phi_{IR}$ affects bulk physics.
  - Using tools from [Gandhi, McAllister, Sjors '11] $\delta\phi_{UV} \sim e_{IR}^{4A}\,\delta\phi_{IR}$
  - In particular, for the Kähler modulus $\delta\rho \sim \dfrac{e_{IR}^{4A}T_3}{m_\rho^2 M_P^2}$
  - Such that we recover $V_{\lambda\lambda}(\rho_0+\delta\rho) = V_0 + \mathcal{O}(T_3 e^{4A}) + \ldots$
  - Recall from EFT $V_0 = -m_\rho^2 M_P^2$

For $V_0 + \Delta V_{\overline{D3}} \overset{!}{>} 0 \quad \Rightarrow \quad \delta\rho \sim 1$ Uplift flattens ($V < 0$)

It seems that we can uplift, but not uplift to de Sitter (in this setup)

The way out

$$\frac{V}{M_P^4} = -\frac{1}{16\pi\mathcal{V}\tilde{\mathcal{V}}}\int d^6y\sqrt{g^6}\left[|\partial(e^{4A}-\alpha)|^2 + e^{8A}\left(\frac{|G_3^-|^2}{6\mathrm{Im}(\tau)} + \frac{\Delta^{loc}}{2\pi}\right)\right]$$

- From the EFT perspective, for being safe we need $|V_0| \lesssim \Delta V \ll m_i^2 M_P^2$
- Decouple the AdS scale L_{AdS} from m_ρ, such that $m_\rho L_{AdS} \gg 1$

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- From 10d, we need $\Delta^{loc} < 0$. **Gaugino condensate*S***
  (There was already a 4d proposal by [Kallosh, Linde '04])
- After Kähler moduli stabization one may find $V_0 = 0$ due to

$$\frac{|G_3^-|^2}{6\mathrm{Im}(\tau)}+\frac{\Delta^{loc}}{2\pi} \sim 4\left|\sum_a \langle\lambda\lambda\rangle_a \nabla_p\nabla_q F_a(z)\right|^2 - \sum_a 3\left|\langle\lambda\lambda\rangle_a g^{m\bar{n}}\nabla_m\nabla_{\bar{n}}F_a(z)\right|^2$$

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- Inclusion of an $\overline{D}3$-brane: $\Delta V_{\overline{D3}} = e^{4A}(2T_3) + \ldots \Rightarrow V_0 + \Delta V_{\overline{D3}} > 0$ **!!!**
  - 2^{nd} term contributes more on the integral when including the $\overline{D}3$-brane

Thank you!