The (anti-brane uplifted) LVS Parametric Tadpole Constraint

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Based on

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Can we get (controlled) de Sitter in string theory?

Much discussion whether possible [Danielsson, Van Riet ‘18] overview

Two main proposals to realize 4D de Sitter in string theory

-KKLT: Singular bulk problem [Gao, Hebecker, Junghans ‘20]: deadly warping

-Large Volume Scenario (LVS) <- This talk: are there warping corrections that are deadly?

see also [Junghans ‘22]

(Not to say these are the only ones, but have received most attention)

Outline

-Review LVS basics

-Warping correction that leads to Parametric Tadpole Constraint (PTC)

-Implications of needing to satisfy PTC

LVS review

IIB string theory compactified to 4D on warped CY3 orientifold with 2 Kahler moduli

Steps:

(0: assume Complex Structure moduli have been stabilized by flux at high mass)

1: Stabilize 2 Kahler moduli at an AdS minimum with exponentially large internal volume

2: Provide uplift energy to raise potential minimum to de Sitter (Usually via anti-D3 brane in warped throat)

LVS step 1: AdS

Compactify IIB on CY3 orientifold

Big 4-cycle τ_b and small 4-cycle τ_s, volume $\mathcal{V} = \tau_b^{3/2} - \kappa_s \tau_s^{3/2}$

$$K = -2\ln\left(\mathcal{V} + \frac{\xi}{2g_s^{3/2}}\right) = -2\ln\left(\tau_b^{3/2} - \kappa_s \tau_s^{3/2} - \frac{\chi\,\zeta(3)}{2(2\pi)^3 g_s^{3/2}}\right)$$

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$$W = W_0 + A_s \mathrm{e}^{-a_s T_s}$$

Nonpert. From e.g. D7s wrapping τ_s
gaugino condensation or ED3 branes

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These K and W lead to a 3-term scalar potential
with an AdS Minimum

LVS step 1: AdS

AdS minimum at exponentially large volume

$$V_{\text{AdS}} = -\frac{3\kappa_s g_s \sqrt{\tau_s} |W_0|^2}{8 a_s \mathcal{V}^3}$$

LVS step 1: AdS

AdS minimum at exponentially large volume

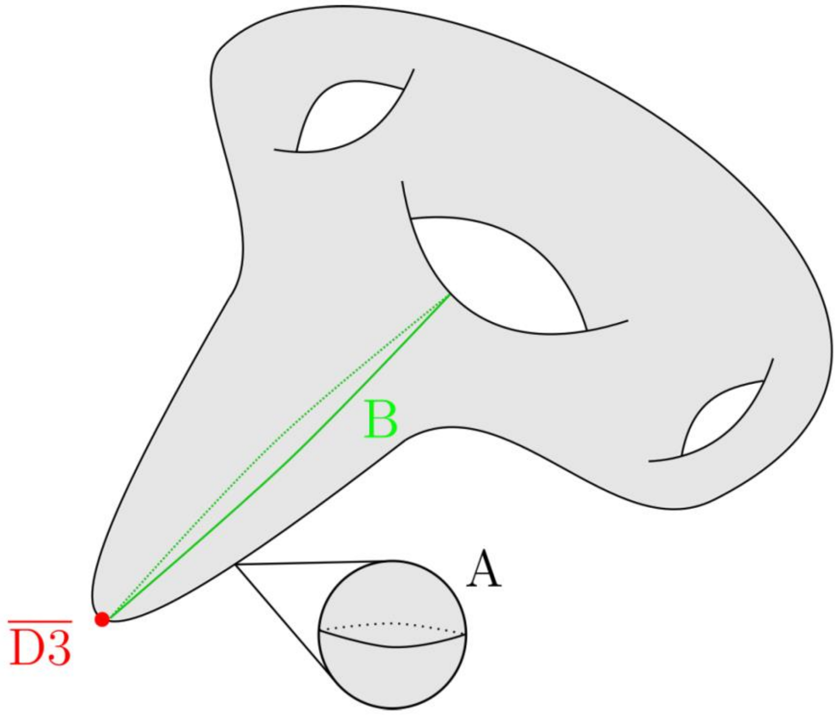
$$V_{\rm AdS} = -\frac{3\kappa_s g_s \sqrt{\tau_s}|W_0|^2}{8a_s \mathcal{V}^3}$$

$$\mathcal{V} = \frac{3\kappa_s |W_0| \sqrt{\tau_s}}{4a_s |A_s|} \boxed{e^{a_s \tau_s}}$$

$$\tau_s = \frac{\xi^{2/3}}{(2\kappa_s)^{2/3} g_s}$$

LVS step 2: de Sitter uplift

Need warped throat with fluxes



$$V_{\text{uplift}} = V_{\overline{D3}} = 2T_{D3}e^{4A(0)}$$

$$V_{\text{uplift}} = \frac{\left(3^2\,\pi^3\,2^{22/3}\right)^{1/5}\,g_s^{1/2}}{(g_sM^2)^{3/2}\mathcal{V}^{4/3}}\boxed{e^{-\frac{8\pi K}{3g_sM}}}$$

A(y) warping

y=0 tip of throat

M units of F_3 flux on A-cycle

K units of H_3 flux on B-cycle

N=KM contribution to D3 tadpole

LVS step 2: de Sitter uplift

Small cc de Sitter vacuum rather than destabilize means
$|V_{uplift}| \approx |V_{AdS}|$

This relates parameters warped throat to parameters bulk CY

In particular:

$$a_s \tau_s = \frac{16\pi N}{9 g_s M^2} + \ln(\mathcal{O}(1))$$

LVS: Corrections

If V_{AdS} minimum shallow, easy for corrections to the potential to destroy it

We focus on one warping correction which:

-We think is one of the main difficulties

-Has clear interpretation and clear what work one should do to evade

Further corrections analysed in [Junghans 01/’22, Junghans 05/’22].

(Note: Our constraint in spirit equivalent to a combination of constraints from [Junghans 01/’22])

Warping correction to Euler number

$$K = -2\ln\left(\mathcal{V} + \frac{\xi}{2g_s^{3/2}}\right) = -2\ln\left(\tau_b^{3/2} - \kappa_s\tau_s^{3/2} - \frac{\chi\,\zeta(3)}{2(2\pi)^3 g_s^{3/2}}\right)$$

Comes from R^4 term in 10D

$$\frac{1}{g_s^{3/2}}\int_{\mathcal{M}_{10}} \qquad R\wedge R\wedge R\wedge R\wedge e\wedge e$$

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Comes from R^4 term in 10D

$$\frac{1}{g_s^{3/2}}\int_{\mathcal{M}_{10}} R\wedge R\wedge R\wedge R\wedge e\wedge e$$

But our geometry is warped:

New correction

$$\frac{1}{g_s^{3/2}}\int_{\mathcal{M}_{10}} e^{2A(y)} R\wedge R\wedge R\wedge R\wedge e\wedge e \approx \frac{1}{g_s^{3/2}}\int d^4x R_4\left(\chi(X) + \frac{\chi(X)N}{\mathcal{V}^{2/3}}\right)$$

Correction to potential

$$\delta V = \frac{\xi\, N\, |W_0|^2}{\sqrt{g_s}\, \mathcal{V}^{11/3}}\, \mathcal{O}(1)$$

Demand that this correction is significantly smaller than $|V_{AdS}|$ to be in controlled regime:

Correction to potential

$$\delta V = \frac{\xi\, N\, |W_0|^2}{\sqrt{g_s}\, \mathcal{V}^{11/3}}\, \mathcal{O}(1)$$

Demand that this correction is significantly smaller than $|V_{AdS}|$ to be in controlled regime:

$$c_N = \frac{(2\kappa_s)^{2/3} g_s}{10\, a_s\, \xi^{2/3}} \frac{\mathcal{V}^{2/3}}{N}$$

With c_N control parameter:
$c_N = 1 \;\rightarrow |\delta V| = |V_{AdS}|$
$c_N \gg 1 \;\rightarrow |\delta V| \ll |V_{AdS}|$

Constraining W_0

W_0 is bounded from above by:

-$m_{gravitino} \ll m_{KK}$ for 4D SuGra to be valid

-Imposing higher F-terms in potential controlled

- $-Q_3 \geq 2\pi g_s |W_0|^2$ [Denef, Douglas '04]

Parametric Tadpole Constraint

1. Start from LVS AdS.
2. Uplift to small cc de Sitter $|V_{uplift}| \approx |V_{AdS}|$ imposes $a_s \tau_s = \frac{16\pi N}{9 g_s M^2}$
3. Demand warping is weak enough and W_0 small enough to be in control

Putting these constraints together one can obtain a constraint on the flux $N = KM$ required in the warped throat

Parametric Tadpole Constraint

Can give analytic expression constraining N in terms of Lambert W-functions. Leading behaviour:

The LVS parametric tadpole constraint:
The D3 tadpole contribution Q_3 of O3/O7-planes and D7-branes must fulfil

$$-Q_3 > N = N_* \left(\frac{1}{3} \ln N_* + \frac{5}{3} \ln c_N + \ln a_s - \frac{2}{3} \ln \kappa_s + 8.2 + \mathcal{O}(\ln(\ln)) \right), \qquad (3.16)$$

where we defined $\quad N_* = 9 g_s M^2/(16\pi)$.

This bound is stronger than in v1 (Thanks to Daniel Junghans and Erik Plauschinn!)

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Two control parameters:

C_N (only log dependence)

$g_s M^2$ most important:

$g_s M^2 > 12$ KPV [Kachru, Pearson, Verlinde '02]

$g_s M^2 > 46$ Conifold stability [Bena, Dudas, Grana, Lust '18][Blumenhagen, Klawer, Schlechter '19] Is this bound valid? [Lust, Randall '22]

$g_s M^2$ even bigger [Junghans 01/'22, Junghans 05/'22] .

Our constraint doesn't tell you how big these parameters should be, only how big the required tadpole is given them

Filling in the numbers

Set $\kappa_s \sim 1$

N	$c_N = 5$	$c_N = 100$
$g_s M^2 = 46; a_s = \pi/3$ (gaugino condensation D7)	133	180
$g_s M^2 = 90; a_s = 2\pi$ (ED3)	298	388

For $h^{1,1} = 2$ can get $-Q_3 = 149$ [Crino, Quevedo, Valandro '20]

For $h^{1,1} \leq 12$, $-Q_3 = 251 \ldots 3332$ possible [Crino, Quevedo, Schachner, Valandro '22]

LVS review

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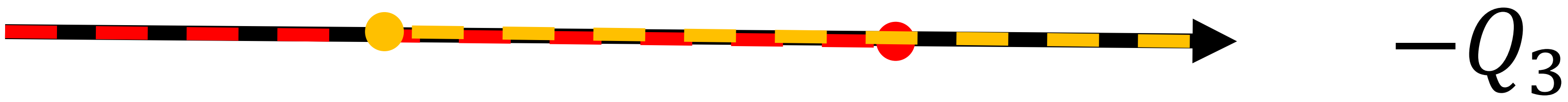
Interplay with Tadpole Conjecture

Not enough to allow sufficient N for PTC

Too much to be able to stabilize CS moduli



But tadpole conjecture only applies to smooth geometries! Was possible to stabilize CS singular geometries. Embrace singular geometries and use nonabelian gauge symmetries on singularities for pheno?

How to satisfy Parametric Tadpole Constraint?

Constraint comes from warped throat + anti-D3 uplift.

Study alternative uplifts? e.g.

- Winding uplift [Hebecker, Leonhardt ‘20] [Carta, Mininno, Righi, Westphal ’21]
- T-branes [Cicoli, Fernando Quevedo, Roberto Valandro ‘15]
- D-term uplift [Achucarro, de Carlos, Casas, Doplicher ‘06] [Cremades, Garcia del Moral, Quevedo, Suruliz ‘07]

Want to uplift with anti-D3? Need suitable geometry

Find models with large enough $-Q_3$

- Non-local D7 tadpole cancellation
- D7 wrapping divisor with large Euler number
- Models with more O3 planes
- Consider CYs with $h^{1,1} > 2$? -> Other params then also larger values?
- F-theory?

Of course easy to say ‘find me a better CY’ but hard to do

In general trade-off more complicated geometry may provide larger tadpole but may also introduce new difficulties

So what is the way forward?

Realizing large tadpole may be difficult but situation LVS is very different from situation KKLT:

KKLT: Singular bulk problem dangerous independent of concrete topological parameters CY

LVS: Road to parametric control is clear, but need to find if geometries with the right tadpole exist

Conclusion

In LVS it seems to us that the main challenge right now is being able to realize a large enough $-Q_3$ such that N and $g_s M$ can be sent into a regime with sufficient control over warping corrections

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The D3 tadpole contribution Q_3 of O3/O7-planes and D7-branes must fulfil

$$-Q_3 > N = N_* \left(\frac{1}{3} \ln N_* + \frac{5}{3} \ln c_N + \ln a_s - \frac{2}{3} \ln \kappa_s + 8.2 + \mathcal{O}(\ln(\ln)) \right), \qquad (3.16)$$

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