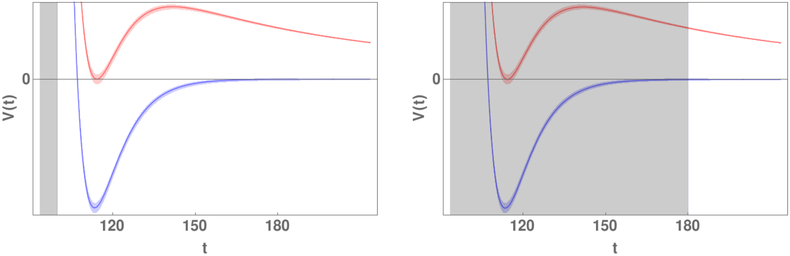
(GAUGINO CONDENSATION AND)

SMALL UPLIFTS IN KKLT



based on 1902.01412 with Federico Carta and Alexander Westphal

Jakob Moritz (DESY)

THE PROBLEM

$$\Lambda_{cc} > 0$$

Can we do it in string theory?

[Obied,Ooguri,Spodyneiko,Vafa'18] conjectures the answer to be "no".

(why shouldn't we?)

DE SITTER IN STRING THEORY?

Common (and useful) construction scheme:

tree-level starting point: O3/O7 CY orientifolds of type IIB string theory with fluxes. [Giddings,Kachru,Polchinski'01]

complex structure moduli & axio-dilaton obtain a scalar potential from generic fluxes at tree level

$$W(z^i, \tau) = \int (F_3 - \tau H_3) \wedge \Omega(z^i)$$ [Gukov,Vafa,Witten'99]

After integrating out z^i & τ, for $h^{1,1}_+ = 1$,

$$W(T) = W_0 = const.,\ K(T, \bar{T}) = -3 \log(T + \bar{T})$$

Kähler moduli remain massless at tree level

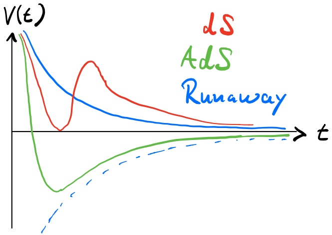
THE DINE SEIBERG PROBLEM

SUSY is broken by the constant flux superpotential

$$W = W_0 = const\,,$$ [Gukov,Vafa,Witten'99]

$\longrightarrow$ the flatness of the scalar potential is a "tree-level accident".

What happens to them?



[Dine,Seiberg'85]

KKLT

[Kachru,Kallosh,Linde,Trivedi'03]

KKLT solved this problem at the price of a tuning, $|W_0| \ll 1$.

Incorporating the leading non-perturbative corrections to the superpotential,

$$W = W_0 + \underbrace{e^{-2\pi T/N}}_{\text{from gaugino condensation on D7s}} + \ldots$$

there exist supersymmetric stabilized *AdS* vacua at 'large' volume

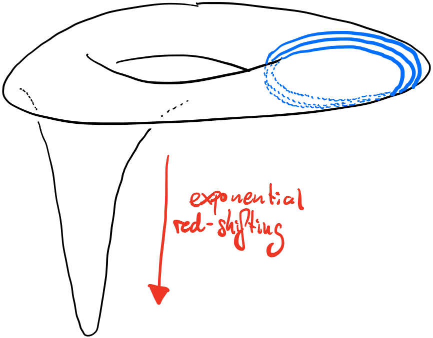
$$(R_{CY})^4 \equiv \mathrm{Re}(T) \sim N \log(|W_0|^{-1})$$

THE UPLIFT

Important fact: Generic flux compactification possess warped throats. [Klebanov,Strassler'00]
These are exponentially red-shifted regions of space, really a $10d$ realization of the Randall-Sundrum idea.

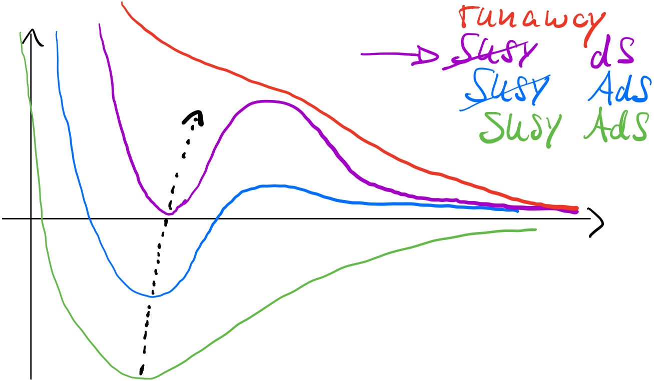
[Randall,Sundrum'99],[GKP]

So a typical compactification will look like this:



THE UPLIFT (continued)

KKLT have argued that SUSY breaking objects such as the famous $\overline{D3}$ branes placed at the bottom of the throat can lead to de Sitter vacua:



But do these solutions lift to consistent 10d ones?

CONSISTENCY CHECKS

Useful questions:

I: Does the 4d SUGRA model of KKLT correctly reflect the 10d physics? What is the correct 10d lift of the 4d model?

$\longrightarrow$ [Baumann,Dymarsky,Klebanov,Maldacena,McAllister,Murugan'06], [Baumann,Dymarsky,Kachru,Klebanov'10],[Dymarsky,Martucci'10],[J,Retolaza,Westphal'17], [Gautason,Van Hemelryck,Van Riet'18],[Hamada,Hebecker,Shiu,Soler'18],[Kallosh'18], [Hamada,Hebecker,Shiu,Soler'19],[Carta,J,Westphal'19],[Gautason,Van Hemelryck,Van Riet,Venken'19]

cf Arthur's, Liam's, Pablo's and Thomas' talks

II: If so, what is its regime of validity? $\longrightarrow$ this talk

cf Mariana's and Severin's talks

SCALES OF THE THROAT

Two properties of these throats will be important:

1. The strongest gravitational red-shifting occurs at the "tip" where

$$a_{redshift} \sim \exp\left(-\frac{K}{g_s M}\right) ,$$

2. The transverse size of the throat is

$$R \sim (M \cdot K)^{1/4} .$$

10D KKLT: a parametric control problem [Carta,J,Westphal'19]

We have *assumed* the existence of arbitrarily strongly warped throats.

But the *size* and redshift of these is set by the same pair of integers (M, K),

$$(R_{\text{throat}})^4 \sim MK \,, \quad \log(a_{redshift}) \sim -\frac{K}{g_s M} \,.$$

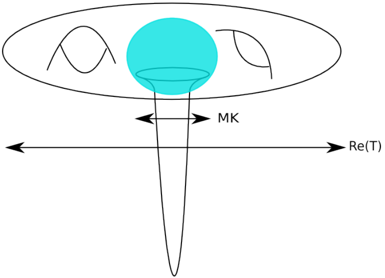
The size of the CY is set by $|W_0|$:

$$(R_{CY})^4 \sim N_{D7} \log(|W_0|^{-1})$$

10D KKLT: a parametric control problem [Carta,J,Westphal'19]

For a parametrically controlled setup, we need [Freivogel,Lippert'08]

$$\mathrm{Re}(T) \sim (R_{CY})^4 > (R_{\mathrm{throat}})^4 \sim MK$$



$\texttt{10D KKLT}$: a parametric control problem [Carta,J,Westphal'19]

We also want the uplift to not overshoot into a run-away solution,

$$(a_{\text{red-shift}})^4 \lesssim |W_0|^2$$

This gives us

$$1 < \frac{\log(a_{\text{red-shift}}^{-4})}{\log(|W_0|^{-2})} \overset{\text{at minimum}}{\sim} \frac{K/g_s M}{\text{Re}(T)/N_{D7}} \sim \frac{N_{D7}}{g_s M^2}\left(\frac{R_{\text{throat}}}{R_{CY}}\right)^4$$

So N_{D7} must be (somewhat) large,

$$N_{D7} > \frac{(g_s M)^2}{g_s}\left(\frac{R_{CY}}{R_{\text{throat}}}\right)^4$$

Can this be done?

10D KKLT: a parametric control problem [Carta,J,Westphal'19]

How large is large?

In $10d$ supergravity regime, (where local stability of anti-brane has been tested) [Kachru,Pearson,Verlinde'01],... $\longrightarrow$ Thomas' talk

$g_s M \alpha' =$ size of tip region of throat [KS'00]

so we need $(g_s M) \gg 1$. Also $g_s \ll 1$.

and N_{D7} really needs to be parametrically large.

But with single size modulus it is hard (impossible?) to have $N_{D7} > \mathcal{O}(10)$.

[Louis,Rummel,Valandro,Westphal'12]

`10D KKLT` a parametric control problem [Carta,J,Westphal'19]

The situation might not be so bad: What if the uplift also exists in the gauge theory regime $g_s M \ll 1$?

Independently of the value of $g_s M$ we can write the bound as

$$N_{D7} > \left(\frac{R_{\text{IR-region}}}{R_{\text{uplift}}}\right)^4 \left(\frac{R_{CY}}{R_{\text{throat}}}\right)^4$$

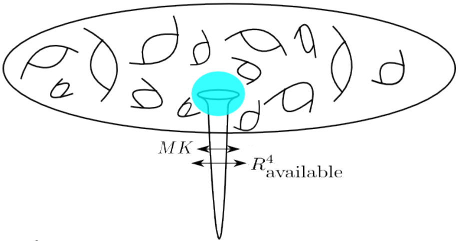
If we are lucky, $N_{D7} = \mathcal{O}(10)$ might be enough to bring everything under marginal control...

A WAY OUT? $h^{1,1} \gg 1$ [Carta,J,Westphal'19]

Large $N_{D7} \sim$ large $h^{1,1}$. [Louis,Rummel,Valandro,Westphal'12]

(Naive) expectation: Increasing $h^{1,1}$ at fixed $\mathcal{V}$ decreases 'freely available volume' that can host warped throats

pessimistic illustration:



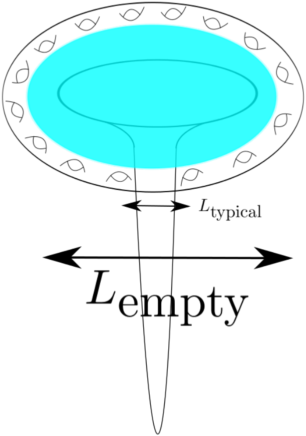
$$\frac{R^4_{\text{available}}}{\mathcal{V}^{2/3}} \sim (h^{1,1})^{-p}, \text{ with } p = \mathcal{O}(1)?$$

$$\longrightarrow N_{D7}/h^{1,1} > \left(\frac{R_{\text{IR-region}}}{R_{\text{uplift}}}\right)^4 \left(\frac{R_{CY}}{R_{\text{throat}}}\right)^4 (h^{1,1})^{p-1}$$

tentative interpretation of [Demirtas,Long,McAllister,Stillman'18]: $p > 1$.

A WAY OUT? $h^{1,1} \gg 1$ [Carta,J,Westphal'19]

optimistic illustration:



Can CY's be tuned into such a regime?

CONCLUSIONS

- In my opinion the "de Sitter problem" in string theory is a fascinating issue that remains an open one:
- On the one hand KKLT is remarkably consistent with the ten-dimensional equations of motion.
- On the other hand KKLT seems to suffer from a parametric control issue. I am cautiously optimistic that this issue can be resolved...
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THANK YOU!