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Uplifting Runaways

with I. Bena, E. Dudas, and M. Graña [arXiv:1809.06861]

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de Sitter vacua in string theory

Three-step procedure [Kachru, Kallosh, Linde, Trivedi '03]:

1. warped IIB with CS-moduli stabilized by three-form fluxes including a region with strong warping [Giddings, Kachru, Polchinski '01] described by the Klebanov Strassler throat [Klebanov, Strassler '00]
   $\rightarrow$ large hierarchy of scales

2. Stabilize Kähler moduli by non-perturbative effects
   $\rightarrow$ supersymmetric AdS-vacuum

3. Supersymmetry breaking by an $\overline{D3}$-brane at the bottom of the throat
   $\rightarrow$ exponentially suppressed uplift to dS due to strong warping

(See also many other talks during this conference.)

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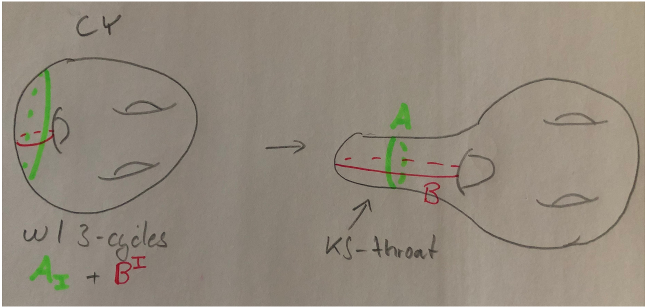
Warped CY

- Metric: $\mathrm{d}s_{10}^2 = e^{2A}\mathrm{d}s_4^2 + e^{-2A}\mathrm{d}s_{CY_3}^2$
- Fluxes fix the sizes of the 3-cycles: $\int_{A_I} F_3 = M^I, \int_{B^I} H_3 = K_I$



- Choose a configuration such that one cycle is exponentially large.

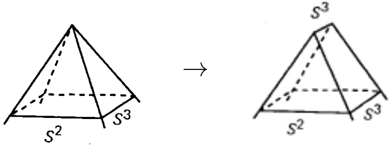
→ Klebanov-Strassler throat.

Deformed conifold

- In the region of high warping, the six-dimensional geometry is given by the deformed conifold.
- embedding of the deformed conifold into $\mathbb{C}^4$:

$$\sum_{a=1}^{4} z_a^4 = S\,.$$

- Replace the singularity of the conifold ($S = 0$) by a S^3 of size $|S|$

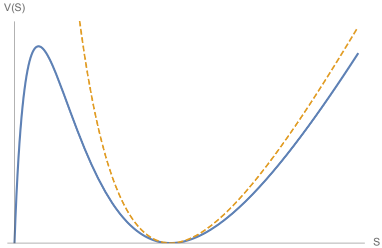


[Candelas, Ossa '89]

- S is a complex structure modulus of the deformed conifold.

Potential for S

- Fluxes M and K along the two three-cycles of the conifold generate a potential $V_{KS}(S)$ [Douglas, Shelton, Torroba '07, '08]:



(dotted without warping effects)

- (Supersymmetric) minimum at $s_{KS} = \Lambda_0^3 \exp\left(-\frac{2\pi K}{g_s M}\right)$.
- Relative warp factor: $\Lambda_0/\Lambda_{IR} \sim |s_{KS}|^{\frac{1}{3}}$.

$\rightarrow$ Large hierarchy for suitable values of K, M, and g_S [Giddings et al. '01].

Mass of S

- The mass of S at the minimum s_{KS} can be computed by

$$m_S^2 \equiv \frac{1}{M_{pl}^2} G^{S\bar{S}} \partial_S \partial_{\bar{S}} V \Big|_{S=s_{KS}}$$

- Including the effects of the warping we find:

$$m_S^2 \sim \frac{s_{KS}^{2/3}}{\alpha'^2}$$

(c.f. [Blumenhagen, Herschmann, Wolf '16] for m_S^2 without warping)

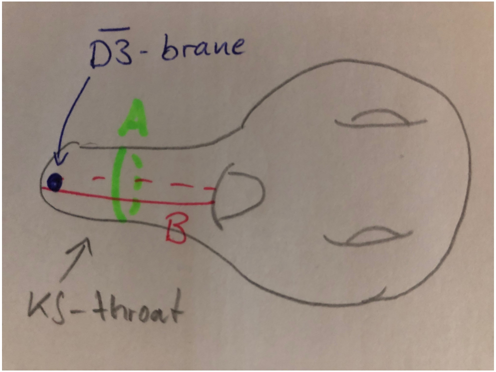
→ If s_{KS} is exponentially small, S becomes exponentially light.

→ S cannot be integrated out before uplifting with an anti-brane.

Comparison with Kähler moduli masses: [Blumenhagen, Kläwer, Schlechter '19]

$\overline{D3}$-brane in the KS throat

- Place an anti-D3 brane at the bottom of the throat



- Positive contribution to the energy $\rightarrow$ uplift to de Sitter

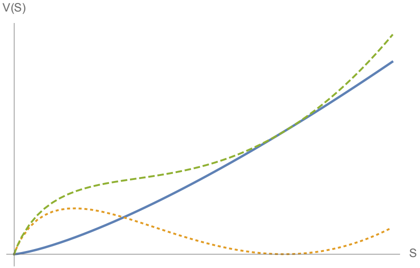
$\overline{D3}$-brane in the KS throat

- The $\overline{D3}$-brane gives a contribution to the potential:

$$V_{\overline{D3}}(S) \propto e^{4A} \propto \frac{|S|^{4/3}}{(\alpha' g_s M)^2}$$

with e^{4A} the warp factor of the Klebanov-Strassler solution.

- Plot of the potential:



(dotted lines represent the KS potential and their superposition)

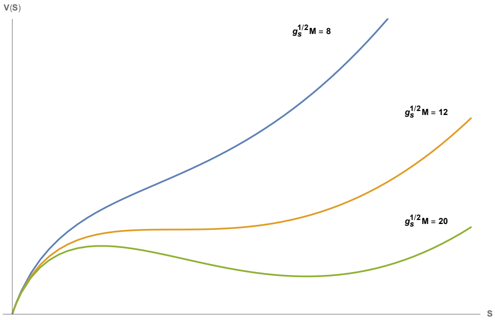
Stability with one $\overline{D3}$-brane

- A stable minimum of $V_{KS} + V_{\overline{D3}}$ with $S > 0$ exists iff

$$g_s M^2 > M_{min}^2 \quad \text{with} \quad M_{min} \approx 12\,.$$

(see also [Blumenhagen, Kläwer, Schlechter '19])

- Superposition of the potentials:



Implications on the maximal hierarchy

- Warping creates a hierarchy of scales

$$h = 3 \ln \frac{\Lambda_0}{\Lambda_{IR}} = \frac{2\pi K}{g_S M}$$

- Tadpole cancellation:

$$M^I K_I + Q_3^{loc} = 0 \,,$$

where Q_3^{loc} is the D3-charge of localized sources.

- Stability of the KS throat + tadpole cancellation:

$$h = 2\pi \frac{MK}{g_s M^2} < 2\pi \frac{\left|Q_3^{loc}\right|}{M_{min}^2} \approx \frac{\left|Q_3^{loc}\right|}{23}$$

Tadpole cancellation in IIB

- For CY orientifolds with O3-planes and D3-branes:

$$Q_3^{loc} = N_{D3} - \frac{1}{4} N_{03}$$

  - Largest number of O3-planes: $T^6/\mathbb{Z}_2$: $Q_3^{loc} \leq 32$

  $\rightarrow$ No large hierarchy possible.

- O7-planes and D7-branes:

$$Q_3^{loc} = \frac{1}{24}\chi(D7) + \frac{1}{6}\chi(O7) - (\text{gauge})$$

  - χ : Euler number of the 4-cycles wrapped by the D7s/O7s.

  $\rightarrow$ Large tadpole possible, but D7-moduli need to be stabilized.

Tadpole cancellation in F-theory

- Tadpole cancelation for F-theory on a Calabi-Yau four-fold CY_4 with four-form flux G:

$$N_{D3} + \frac{1}{2} \int G \wedge G = \frac{\chi(CY_4)}{24}$$

- $\chi(CY_4)$: Euler number of the CY $\rightarrow$ can be very large (largest know example [Klemm et al. '97]: $\chi = 1\,820\,448 = 24 \cdot 75\,852$)

- But: Large χ implies a lot of moduli:

$$\chi(CY_4) = 6(8 + h^{1,1} + h^{3,1} - h^{2,1})$$

- $h^{3,1}$: complex structure of CY_4 $\rightarrow$ must be stabilized by flux:

$$\int G \wedge G = \mathcal{O}(h^{3,1}) \; ?$$

Conclusions

- With a large hierarchy the KS-modulus becomes exponentially light.
- One $\overline{D3}$ makes a Klebanov-Strassler throat unstable unless $g_s^{1/2}M > 12$.
- Due to tadpole-cancellation: Constraints on the hierarchy.

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Thank You!