UNIVERSITY OF LIVERPOOL

XIV International Conference on Interconnections
between Particle Physics and Cosmology

DE SITTER VACUA IN STRING THEORY
WITH FLUXES AND ANTI-BRANES

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In collaboration with

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WHAT

de Sitter solution in the 4d EFT of Type IIB flux compactifications.

WHY

Cosmological observations show evidence of Dark Energy.
String Theory has difficulty in finding de Sitter vacua (e.g. Tadpole problem).

HOW

Using fluxes, warped throats, perturbative and non-perturbative corrections, anti-D3 branes…

UV

String Theory (type IIB)

Low-energy ⇩ Effective Field Theory

Less UV

$E \ll M_s$

10d Supergravity (type IIB)

$$S_{IIB}^{boson} = \frac{1}{2\kappa^2}\int d^{10}x\sqrt{-g_{10}}\left\{R_{10} - \frac{\partial_M\tau\partial^N\tau}{2(\mathrm{Im}\tau)^2} - \frac{g_s|G_3|^2}{2(\mathrm{Im}\tau)} - \frac{g_s^2|F_5|^2}{4}\right\} - \frac{ig_s^2}{8\kappa^2}\int\frac{C_4^+\wedge G_3\wedge\bar{G}_3}{\mathrm{Im}\tau}$$

g_{MN} ϕ, C_0 B_2, C_2 C_4^+

Compactification

4d Supergravity ($N = 1$)

IR

$E \ll M_{KK}$

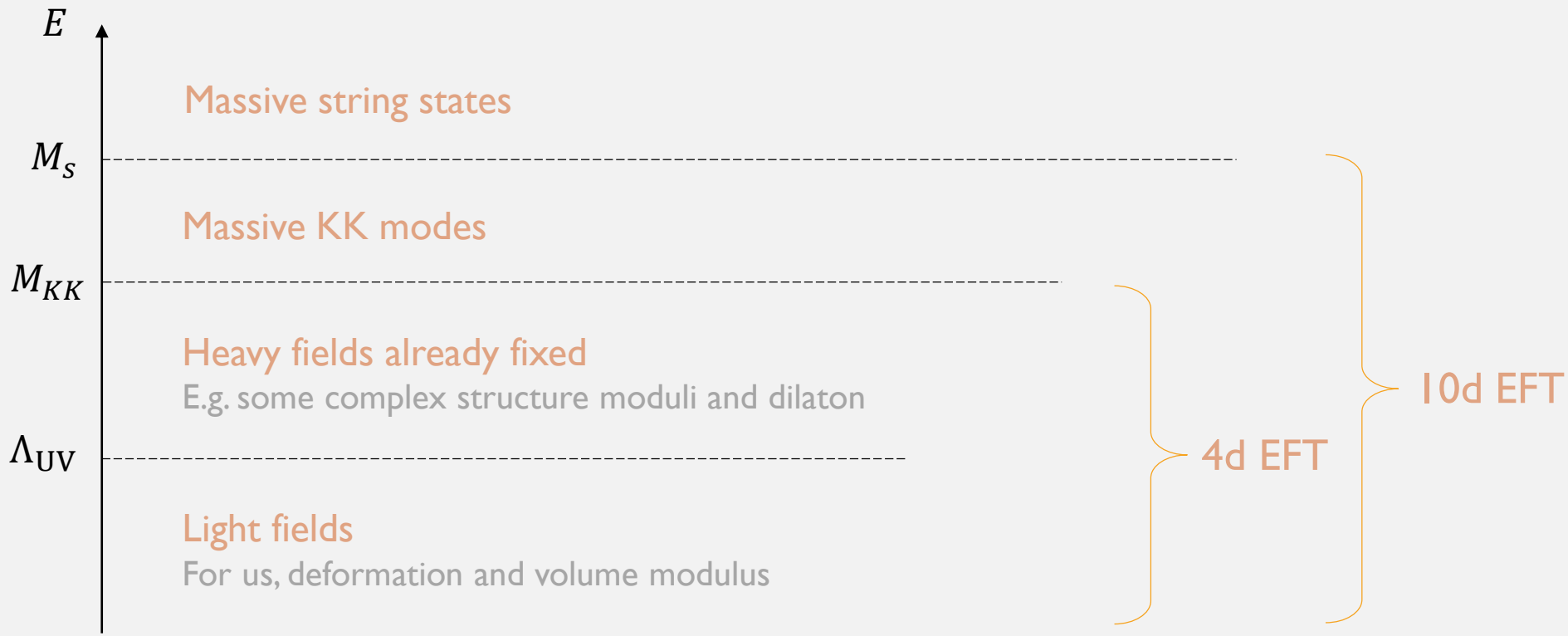
$g_{\mu\nu}$ + many moduli describing the geometry of the compact space

ϕ, C_0 + fields coming from B_2, C_2, C_4^+

4d Effective Field Theory

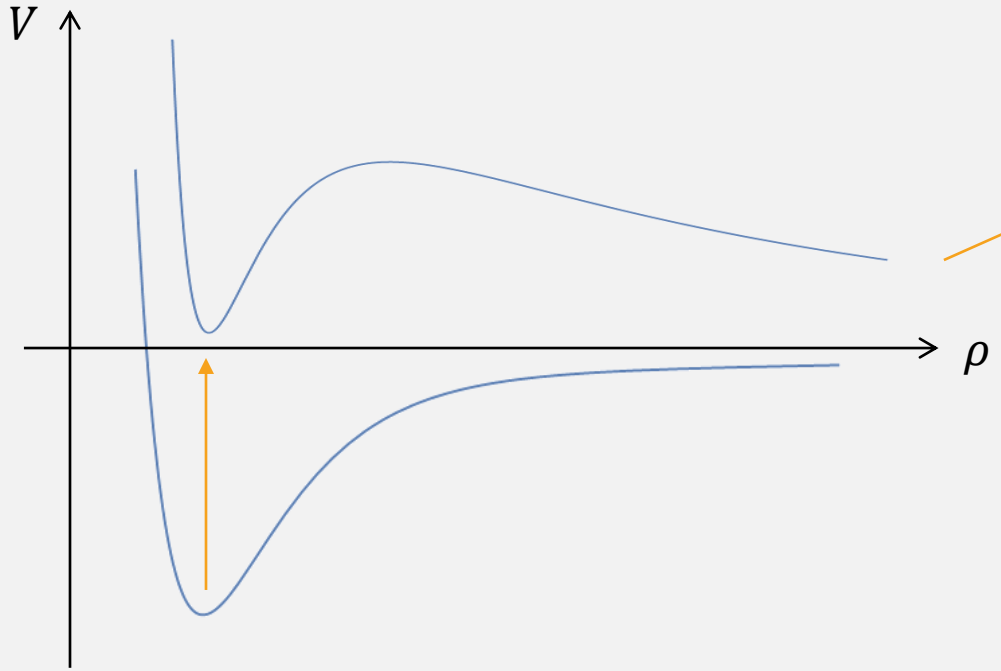
Large number of scalar fields to fix HARD

⇒ Focus on some: fix them and integrate them out if they are heavy

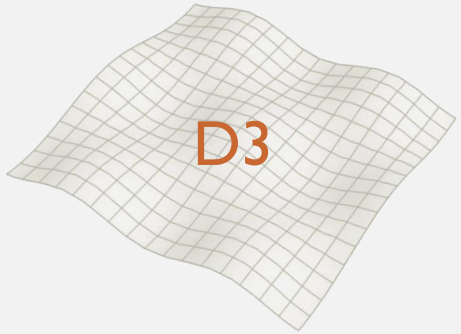


4d Effective Field Theory

Potentials for the volume modulus will usually be negative at the minimum



Use some source with positive energy to uplift the minimum



But not too much!

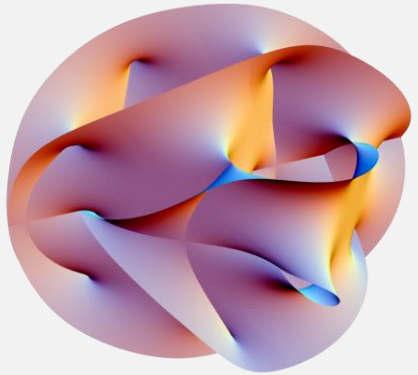
Warped solutions

$g_{\mu\nu}$

$$ds^2 = e^{2A} e^{2\Omega(x)} g_{\mu\nu} dx^\mu dx^\nu + e^{-2A} g_{mn} dy^m dy^n$$

4d Mink, AdS or dS
(maximal symmetry)

Warp factor
Can be used to suppress large scales



Giddings, Kachru, Polchinski [hep-th/0105097]

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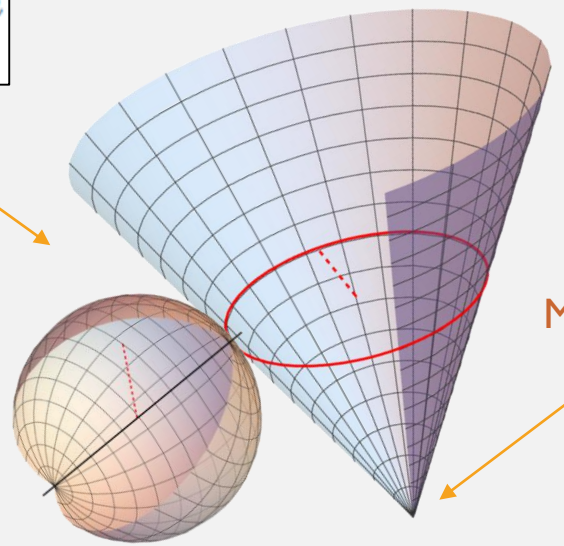
Deformed Conifold
Klebanov-Strassler



Most suppressed point

Giddings, Kachru, Polchinski [hep-th/0105097]

4d Effective Field Theory

Scalar potential in the 4d EFT involving the deformation modulus $z(x^\mu)$

$$V_{KS} = \frac{g_s^3}{8}\frac{g_s}{\mathcal{V}^2}\left(\log\frac{\Lambda_0^3}{|z|} + \frac{1}{(2\pi)^4}\frac{c'(g_sM)^2}{\mathcal{V}^{2/3}|z|^{4/3}}\right)^{-1}\left|\frac{M}{2\pi}\log\frac{\Lambda_0^3}{z} - \frac{K}{g_s}\right|^2 M_p^4$$

Comes from the warping
Mixes the volume and deformation moduli

$$\frac{1}{(2\pi)^2\alpha'}\int_{S^3} F_3 = M$$

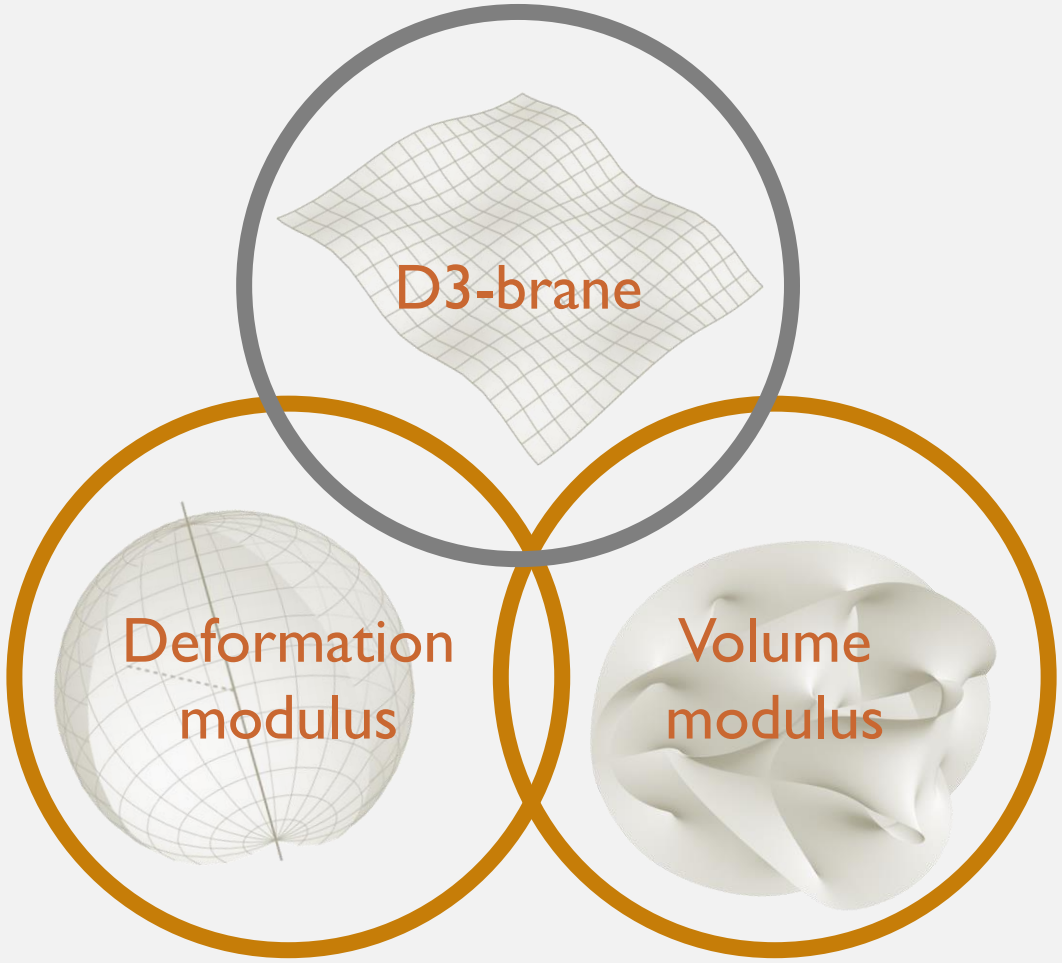
$$\frac{1}{(2\pi)^2\alpha'}\int_{\eta<\eta_\Lambda}\int_{S^2} H_3 = K$$

+ the potential for the volume modulus (e.g. KKLT, LVS)

$$V_{\overline{\text{D3}}} = \left(\frac{g_s^3}{8\pi}\right)\frac{(2\pi)^4}{\mathcal{V}^{4/3}}c''\frac{|z|^{4/3}}{(g_sM)^2}M_p^4 \,.$$

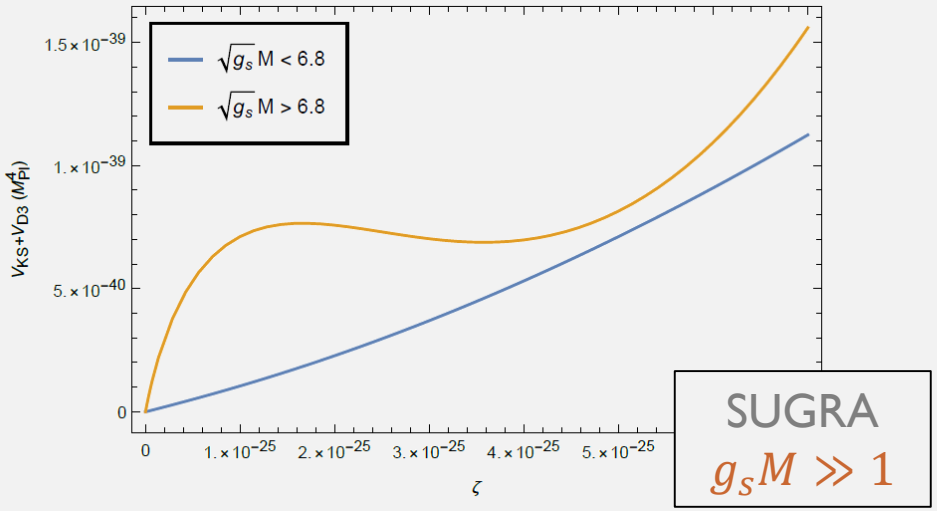
Controlled by deformation modulus, appearing through the warp factor

4d Effective Field Theory



Runaways or tadpoles?

Deformation modulus



SUGRA
$g_s M \gg 1$

I. Bena, E. Dudas, M. Graña, and S. Lüst [1809.06861]
R. Blumenhagen, D. Kläwer, and L. Schlechter [1902.07724]
I. Bena, A. Buchel, and S. Lüst [1910.08094]
E. Dudas and S. Lüst [1912.09948]

Volume modulus

Needs strong enough suppression (warping) to avoid runaway, controlled by

$$|z|^{4/3} \sim e^{-\frac{8\pi(MK)}{3g_s M^2}} \Rightarrow MK \gg g_s M^2 \gtrsim 46$$

$$\mathrm{d}\tilde{F}_5 = H_3 \wedge F_3 + 2\kappa_{10}^2 T_3 \rho_3^{loc}$$

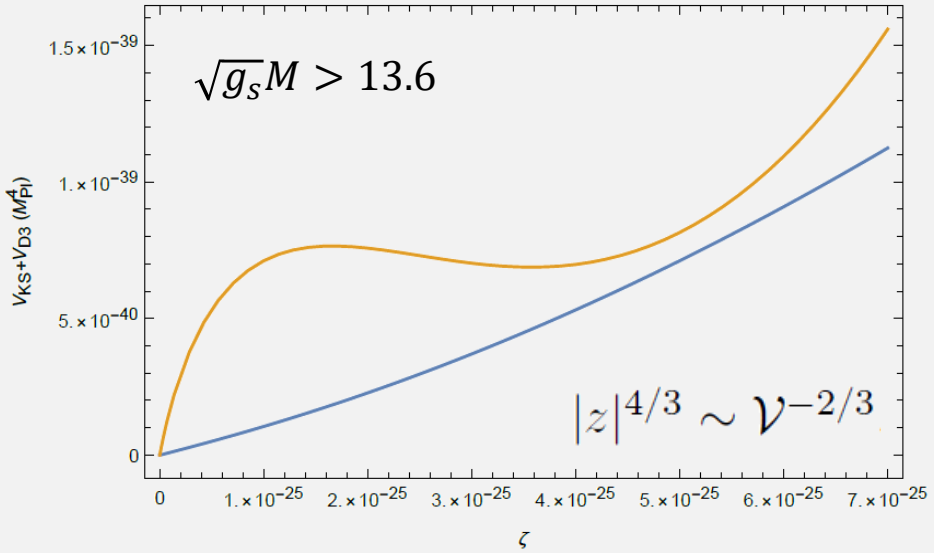
$$\frac{1}{2\kappa_{10}{}^2 T_3} \int_{\mathcal{M}_6} H_{(3)} \wedge F_{(3)} + Q_3^{\mathrm{loc}} = 0$$

L. Randall [1912.06693]
R. Blumenhagen, M. Brinkmann, D. Klaewer, A. Makridou, and L. Schlechter [1902.07724]

New dS solution

$$V_{KS} = \frac{g_s^3}{8}\frac{g_s}{\mathcal{V}^2}\left(\log\frac{\Lambda_0^3}{|z|} + \frac{1}{(2\pi)^4}\frac{c'(g_sM)^2}{\mathcal{V}^{2/3}|z|^{4/3}}\right)^{-1}\left|\frac{M}{2\pi}\log\frac{\Lambda_0^3}{z} - \frac{K}{g_s}\right|^2 M_p^4$$

What if this is NOT dominant?



- New (but similar) bound on M
- Exponentially small z does not depend on $MK \gg 1$
- Large volumes will suppress the brane contribution
- It is natural to try Large Volume scenario (perturbative and non-perturbative corrections)

BB, D. Chakraborty, S. Parameswaran, I. Zavala [2105.03370]

Conclusions

Swampland vs Landscape

- New dS solution in the 4d EFT in a weakly-warped regime
- Uses fluxes, warped throats, perturbative and non-perturbative corrections, branes
- Several ingredients introduced in 4d. Can we get this solution in 10d?
- Tadpole similar to strongly-warped LVS (but also bulk contributions)

  C. Crinò, F. Quevedo, and R. Valandro [2010.15903]
  I. Bena, J. Blåbäck, M. Graña, and S. Lüst [2010.10519]
- Weak warping puts us close to the boundaries of control (e.g. $M_{3/2} \sim M_{KK}$)

THANK YOU