A *New* dS Solution in a *Weakly* Warped Deformed Conifold

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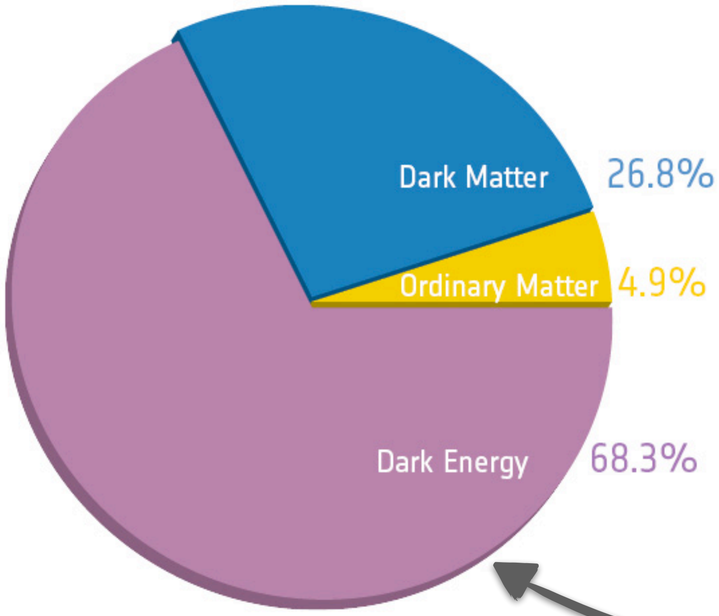
State of the art

dS Vacua
In String
Theory

State of the art



Energy budget of the Universe

dS Vacua
In String
Theory

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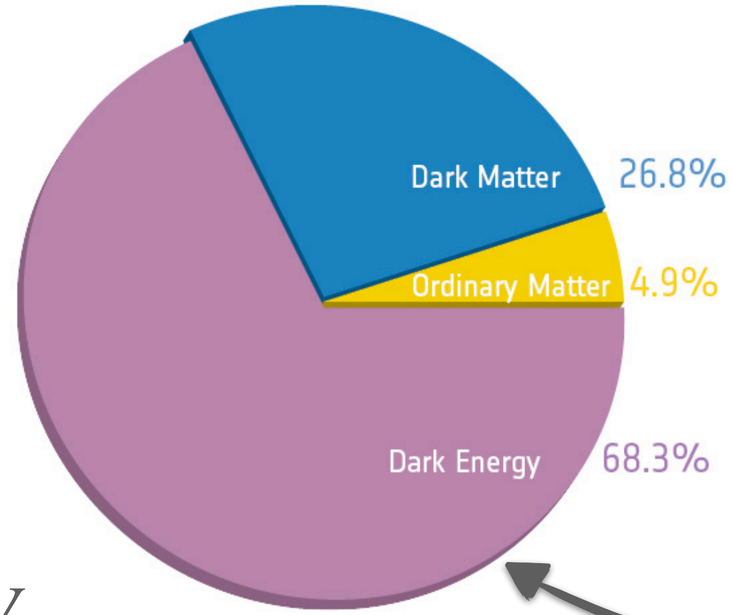
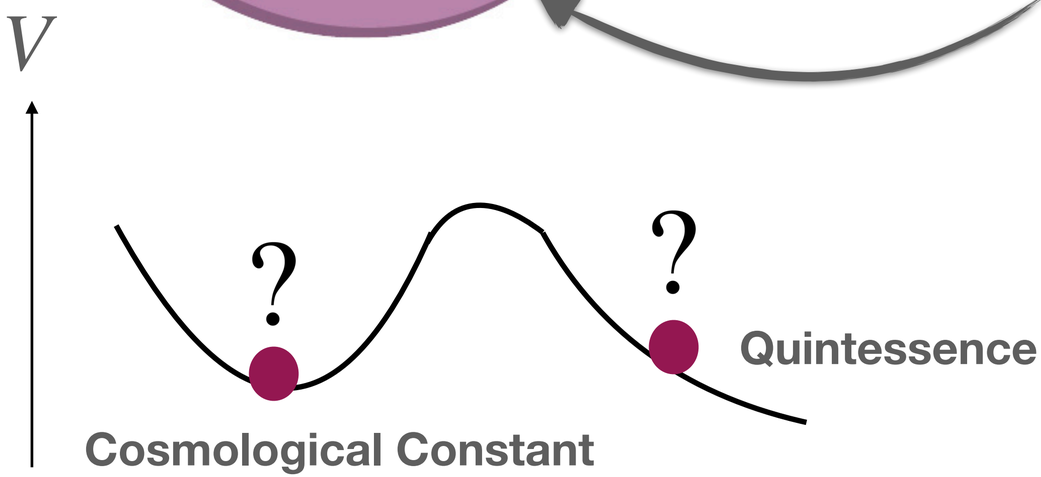


dS Vacua In String Theory



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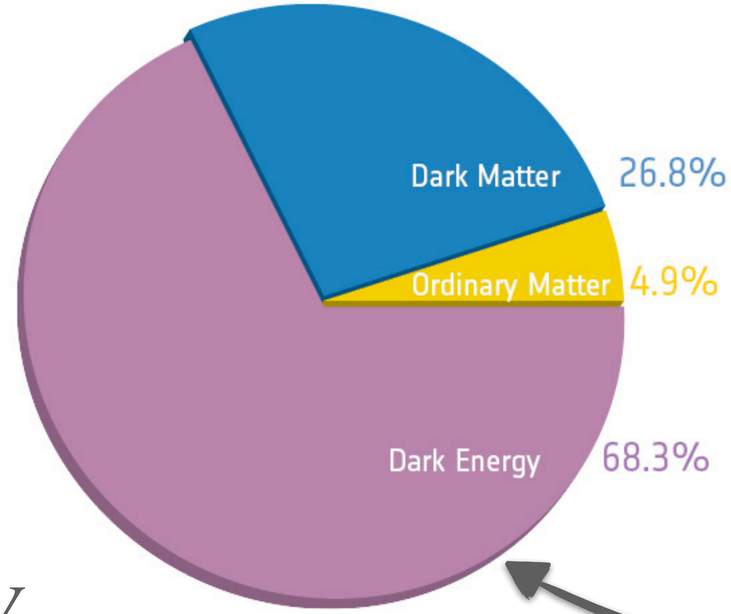
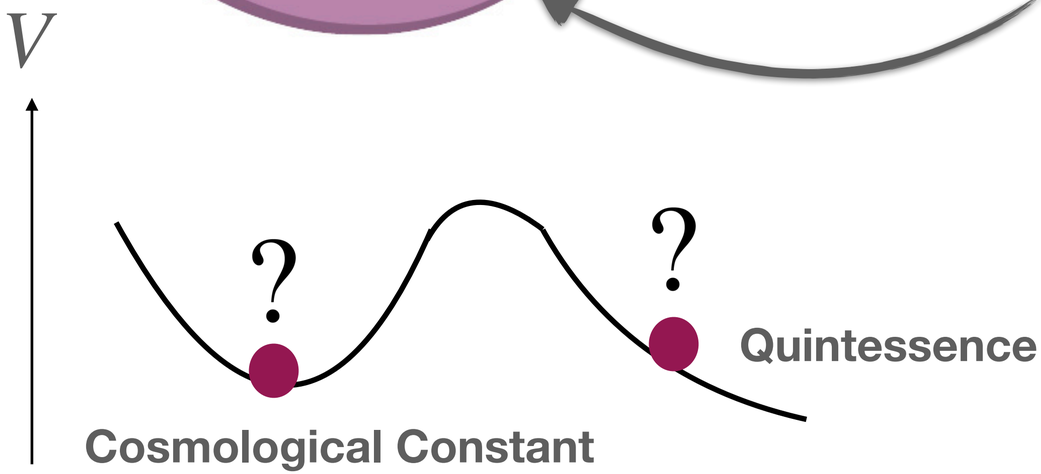
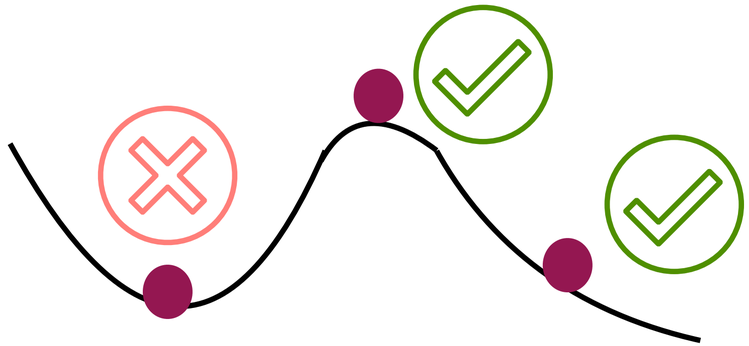


dS Vacua In String Theory

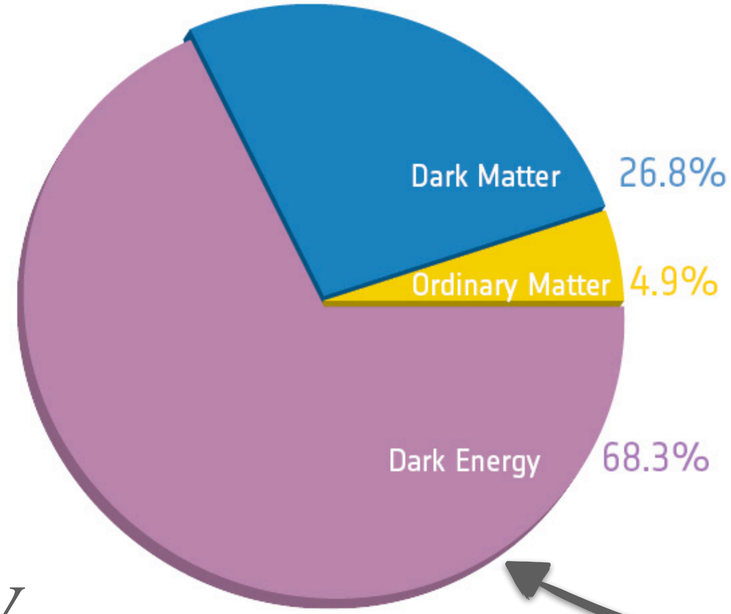
Swampland





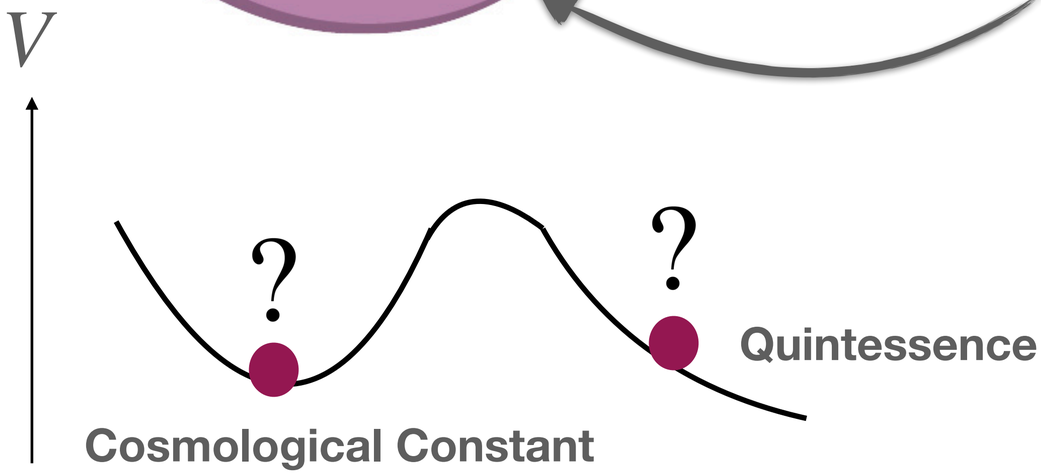
[Danielsson, Van-Riet'18; Obied, Ooguri, Spodyneiko, Rafa'18; Gang, Krishnan'18; Ooguri, Palti, Shiu, Vafa'18]

State of the art



dS Vacua In String Theory

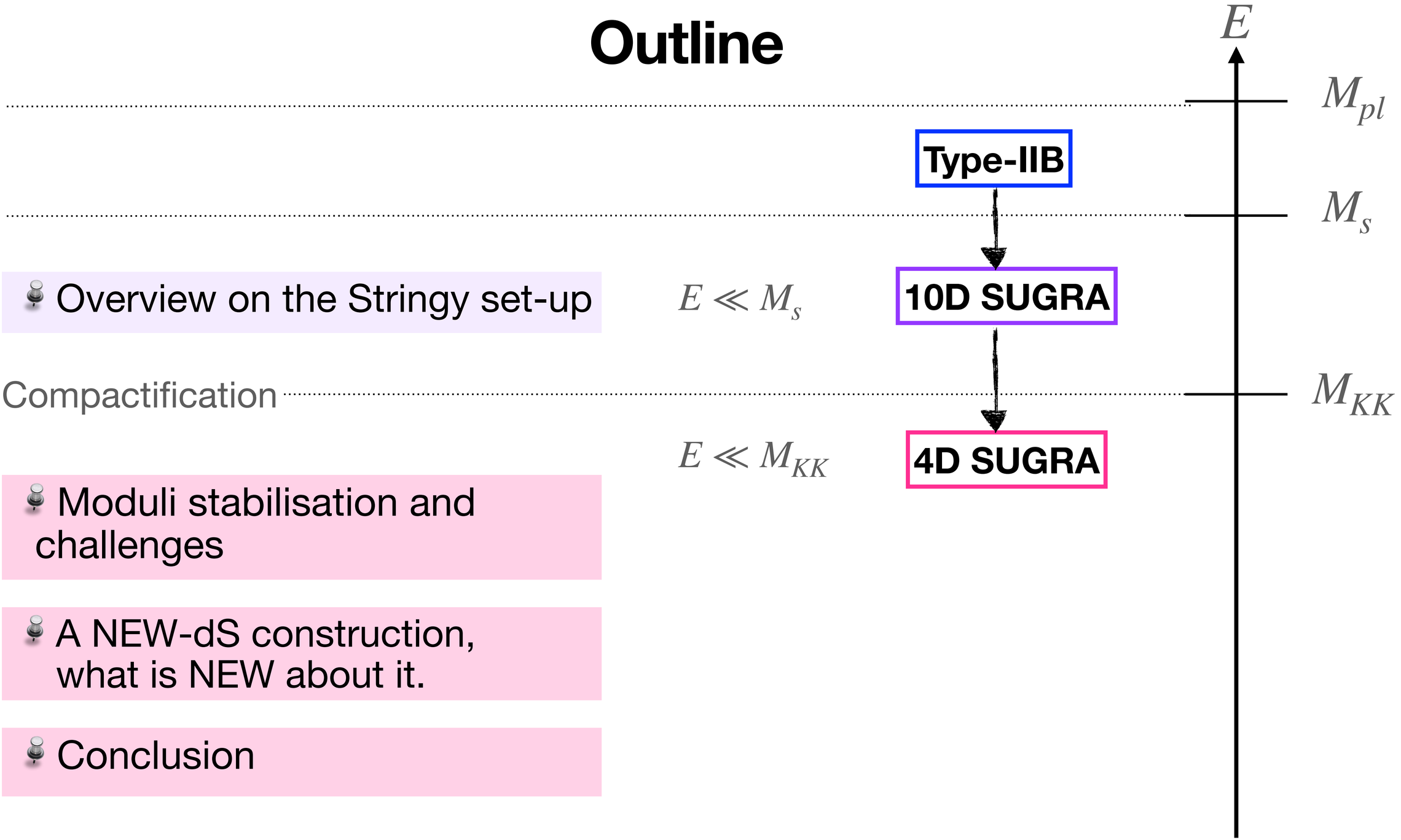
Swampland



- [x] Tadpole problem
- [x] Moduli de-stabilisation

Outline

- Overview on the Stringy set-up
- Moduli stabilisation and challenges
- A NEW-dS construction, what is NEW about it.
- Conclusion



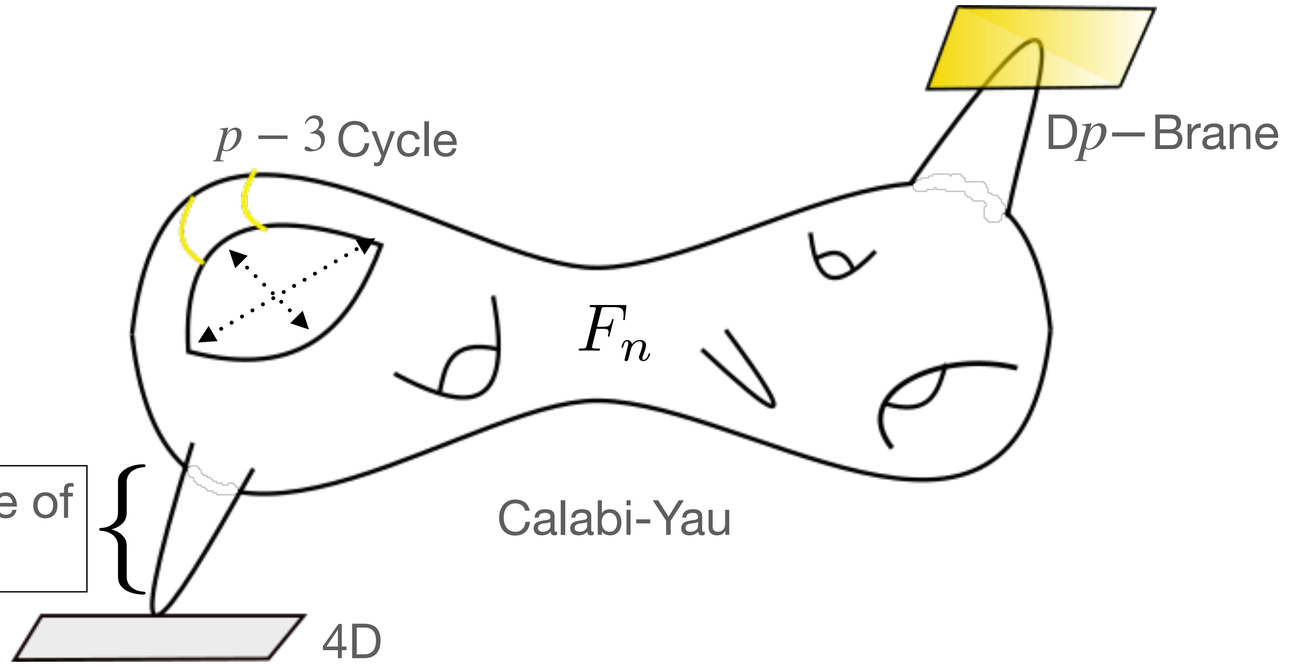
Type-IIB flux compactifications

$$S_{IIB} = \frac{1}{2k^2}\int d^{10}x\sqrt{-g^E}\left[R_E - \frac{1}{2(\mathrm{Im}\tau)^2}g^{E,MN}\partial_M\tau\partial_N\bar{\tau} - \frac{g_s}{2\mathrm{Im}\tau}|G_3|^2 - \frac{1}{4}g_s^2|\tilde{F}_5|^2\right]$$
$$+\frac{ig_s^2}{8k^2}\int\frac{1}{\mathrm{Im}\tau}C_4\wedge G_3\wedge\bar{G}_3 + S_{loc},$$

Gravitational Coupling: $k^2 = g_s^2 k_{10}^2$

axio-dilaton: $\tau = C_0 + ie^{-\phi}$

Three-form fluxes: $G_3 = F_3 - \tau H_3$



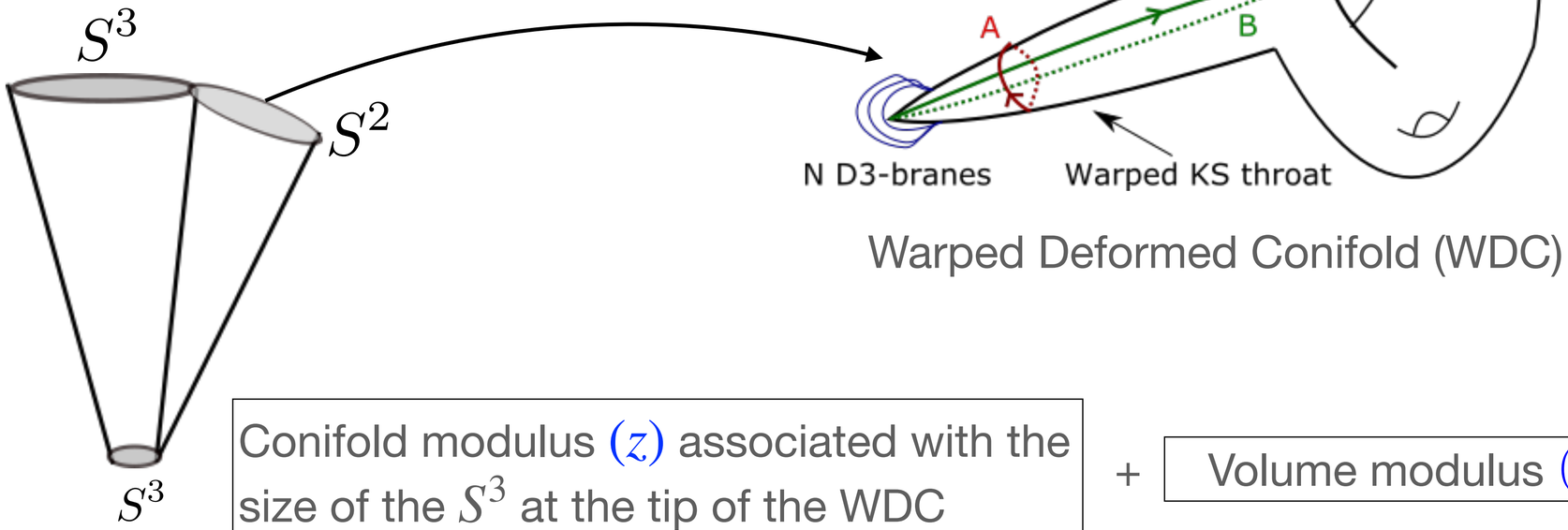
Warped throat in presence of fluxes/branes

[Giddings, Kachru, Polchinski ’01]

Type-IIB flux compactifications

$$ds^2 = h^{-1/2} e^{2\Omega(x)} g_{\mu\nu} dx^\mu dx^\nu + h^{1/2} g_{mn} dy^m dy^n$$

In presence of fluxes or D-branes



Warped Deformed Conifold (WDC)

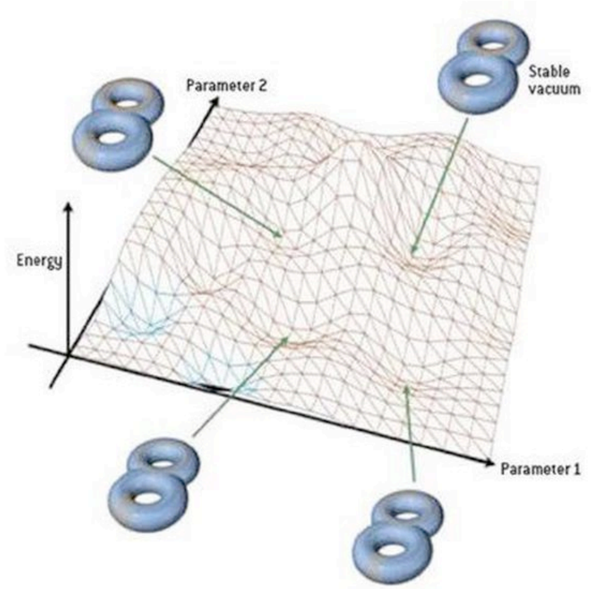
Conifold modulus (z) associated with the size of the S^3 at the tip of the WDC

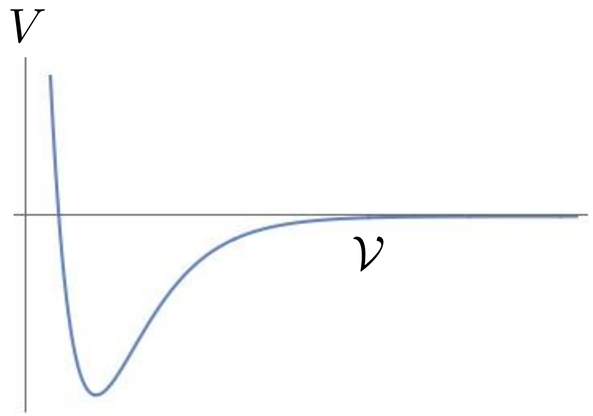
\+ Volume modulus $(\mathcal{V})$

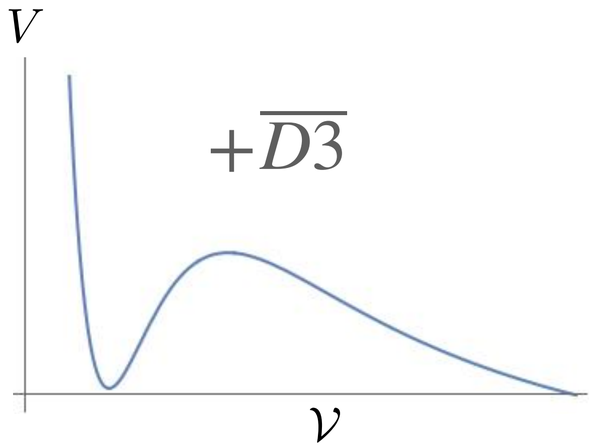
[Klebanov, Strassler '00; Giddings, Kachru, Polchinski '01]

Moduli Stabilisation-KKLT/LVS

$$V_F^{\text{tot}} = V_{F_n} + V_{\text{P/NP}} + V_{\text{uplift}}$$







Stabilize → **Complex structure** moduli, **axio-dilaton** ⊕ **Kähler** Moduli- AdS Vacuum SUSY/~~SUSY~~ ⊕ Uplift to ~~SUSY~~ dS Vacuum

[Kachru, Kallosh, Linde, Trivedi ’03; Balasubhramanian, Burglund, Conlon, Quevedo ’05]

The Tadpole Problem

$$ds^2 = h^{-1/2} e^{2\Omega(x)} g_{\mu\nu} dx^\mu dx^\nu + h^{1/2} g_{mn} dy^m dy^n$$

The **total charge** in the internal CY manifold needs to be **cancelled** in presence of **D-branes, O-planes and fluxes** (F_3, H_3) in Orientifold compactification.

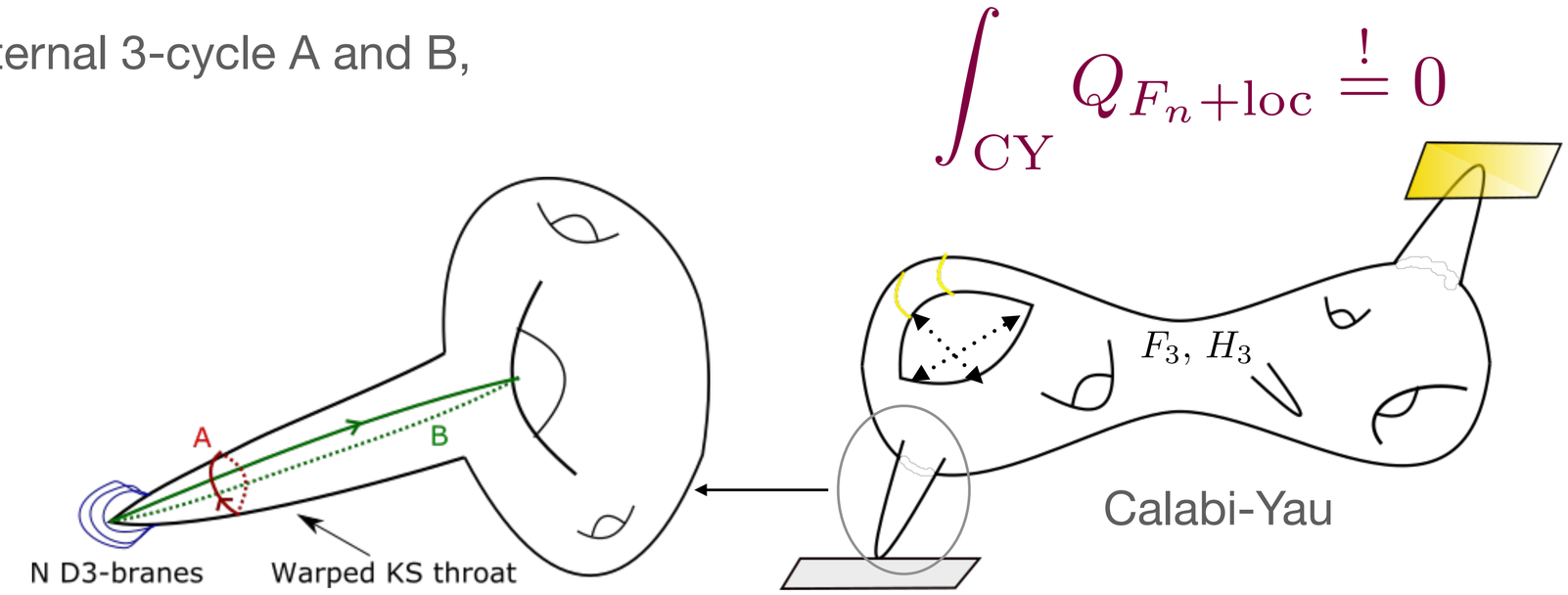
RR and NS-NS fluxes wrap internal 3-cycle A and B,

$$\frac{1}{(2\pi)^2 \alpha'} \int_A F_3 = M,$$

$$\frac{1}{(2\pi)^2 \alpha'} \int_B H_3 = K,$$

$$h \sim e^{\frac{8\pi K}{3 g_s M}}$$

$$\int_{\mathrm{CY}} Q_{F_n + \mathrm{loc}} \stackrel{!}{=} 0$$



Moduli de-stabilisation and the Tadpole problem

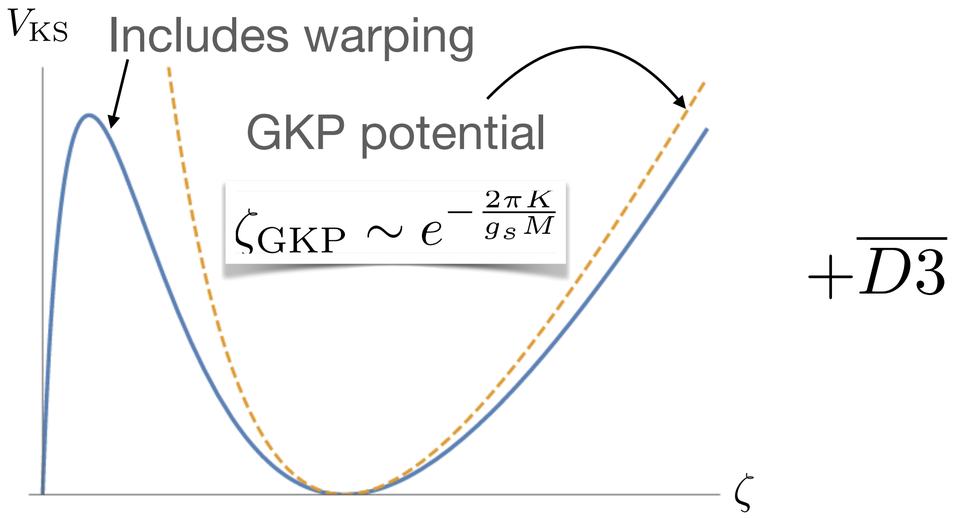
$$V_{KS} = \frac{g_s^3}{8}\frac{g_s}{\mathcal{V}^2}\left(\log\frac{\Lambda_0^3}{|z|} + \frac{1}{(2\pi)^4}\frac{c'(g_sM)^2}{\mathcal{V}^{2/3}|z|^{4/3}}\right)^{-1}\left|\frac{M}{2\pi}\log\frac{\Lambda_0^3}{z} - \frac{K}{g_s}\right|^2 M_p^4$$

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

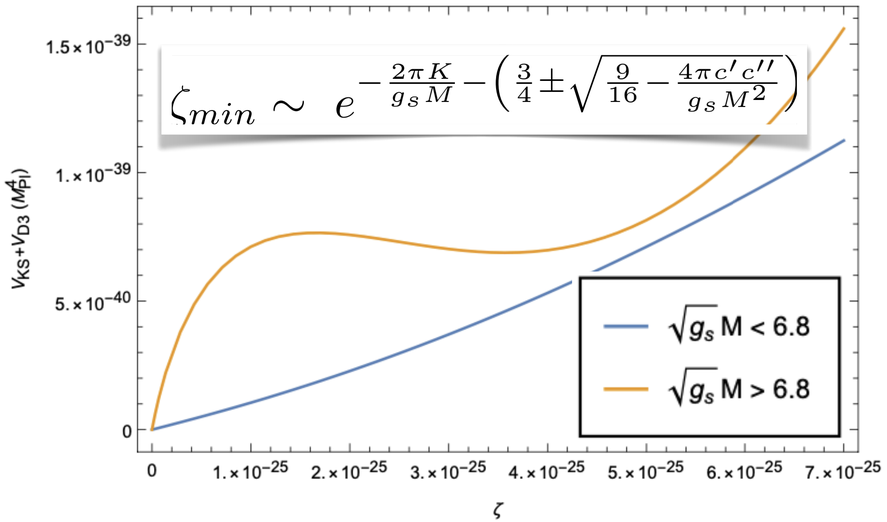
Warping term which mixes volume and deformation modulus is **dominant**

Suppressed by deformation modulus via warping

- ☑ Deformation conifold **modulus** gets **destabilised** by the uplifting mechanism
- ☑ Stability requires **large fluxes**, **threatening tadpole** cancellation

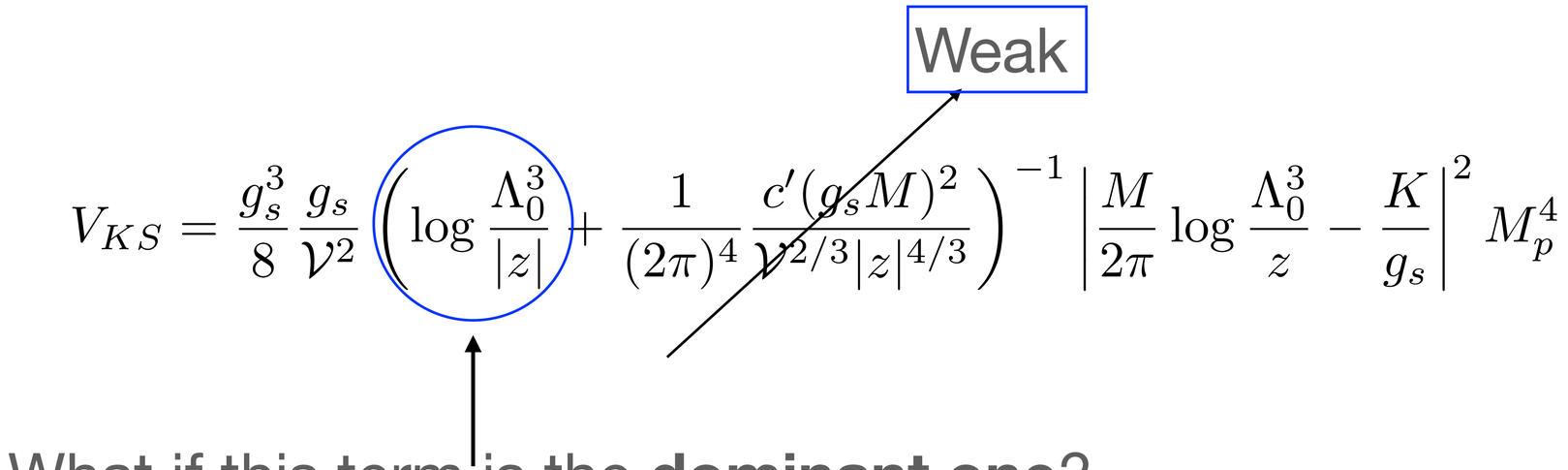


$+\overline{D3}$



[Bena, Dudas, Graña, Lüst '18; Blumenhagen, Kläwer, Schlechter '19; Bena, Buchel, Lüst '19; Randall '19; Crino, Quevedo, Valandro '20, Braun, Valandro '20; Bena, Blabäck, Graña, Lüst '20-21]

A New-dS solution



[Bento, **DC**, Parameswaran, Zavala ’21]

A New-dS solution

Weakly warped regime: new dS solution, exists only in presence of $\overline{D3}$- brane:

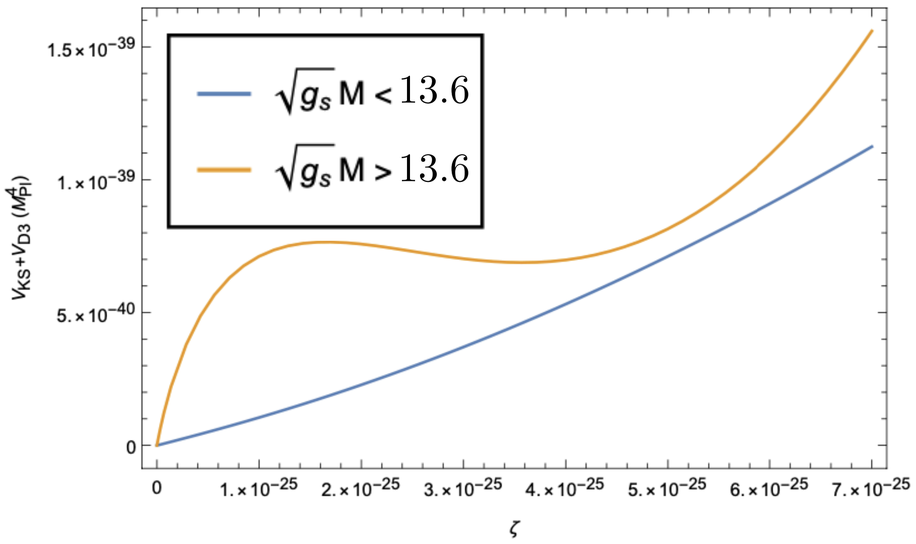
$$V = V_{\rm KS} + V_{\overline{D3}} = \frac{\delta_1 C \Lambda_0^4}{\mathcal{V}^{4/3}} e^{-\frac{4}{3}x} \left[(1+\beta)^{-1} (1-\epsilon x)^2 + \delta_2 \right]$$

$$\beta \simeq \frac{\mathcal{V}^{2/3}}{h^{1/4}} \log \frac{\Lambda_0^3}{\zeta}$$

$\beta \ll 1$ Strongly warped regime (no need for LV)

$\beta \gg 1$ **Weakly warped regime (need for LV)**

☑ Volume can be stabilised using Large Volume Scenario.



The **New-dS solution** is located at-

$$\frac{(2\pi)^4}{c'} \frac{\zeta^{4/3}}{(g_s M)^2} = \frac{g_s M^2}{4\pi c' c'' \mathcal{V}^{2/3}} \left(\frac{3}{8} \pm \sqrt{\frac{9}{64} - \frac{4\pi c' c''}{g_s M^2}} \right),$$

$$\zeta^{4/3} \sim \mathcal{V}^{-2/3}$$

[Bento, **DC**, Parameswaran, Zavala '21]

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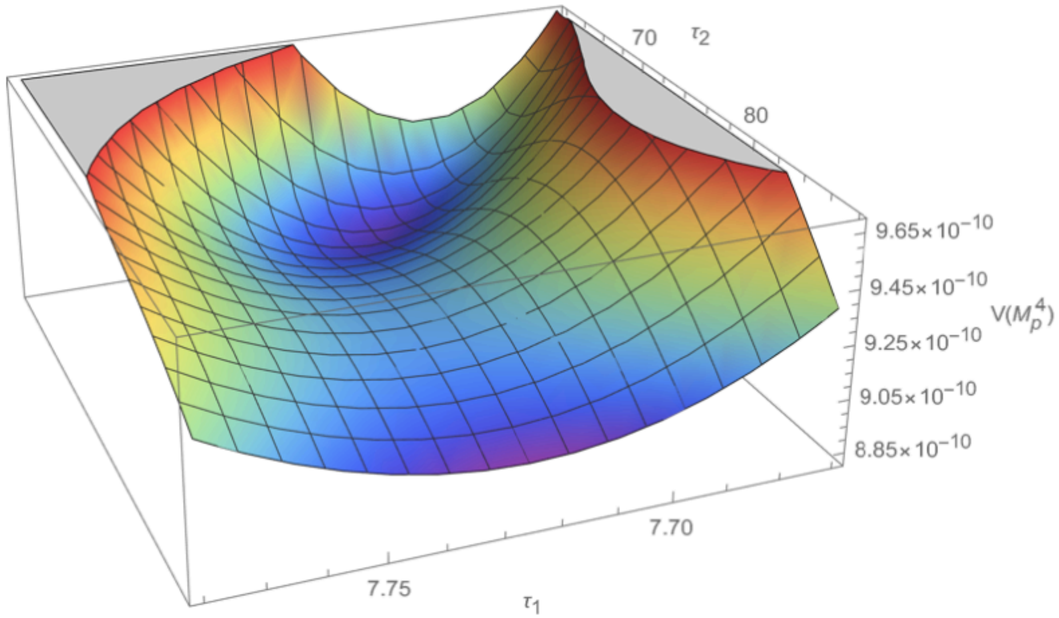

W_0	σ	g_s	M	K	Λ_0	κ_s	χ	a	A
700	0	0.14	39	3	1.1	$\frac{\sqrt{2}}{9}$	-150	$\frac{\pi}{3}$	4300

τ_s	τ_b	ζ	$m_1^2 \sim m_\zeta^2$	$m_2^2 \sim m_{\tau_s}^2$	$m_3^2 \sim m_{\tau_b}^2$
8.79	62.8	0.0062	1.56×10^{-4}	5.77×10^{-4}	3.11×10^{-9}
9.09	78.5	0.0054	1.05×10^{-4}	3.14×10^{-4}	-1.30×10^{-10}

$\mathcal{V}$	M_s	m_{KK}	$m_{3/2}$	M_s^w	m_{KK}^w
498	1.11×10^{-2}	3.95×10^{-3}	1.95×10^{-3}	10.4×10^{-3}	4.76×10^{-3}
696	9.41×10^{-3}	3.16×10^{-3}	1.39×10^{-3}	8.82×10^{-3}	4.03×10^{-3}

[Bento, **DC**, Parameswaran, Zavala '21]

What is NEW

- *Not a small* shift from the GKP minimum. $\zeta^{4/3} \sim \mathcal{V}^{-2/3}$ $\zeta_{\rm GKP} \sim e^{-\frac{2\pi K}{g_s M}}$
- New bound on the units of flux numbers. $\sqrt{g_s} M > 13.6$
- Small value of the deformation modulus and exponential suppression of anti-D3 brane are guaranteed by the *large volume* and *not* by $MK \gg 1$.
- Interesting for cosmological models like inflation and dark energy.

Conclusion

- A new dS solution arises in a WEAKLY warped deformed conifold at the level of 4D EFT.
- dS vacua at the limit of theoretical control.
- Tadpole numbers similar to Strongly warped LVS scenario $MK \sim \mathcal{O}(100)$
  [Crino, Quevedo, Valandro '20]
- Is the solution in the *landscape* or *swampland*?

Thanks!