‘Anti-brane, do you even lift?’

Thomas Van Riet, KU Leuven, Belgium

Saclay, 2019

Based on

Anti-brane singularities as red herrings (1907.05295)
with J. Blåbäck, F. F Gautason, A. Ruipérez

Meta-stable non-extremal anti-branes (1812.01067)
with Jay Armas, Nam Nguyen, Vasilis Niarchos, Niels A. Obers

"Open string" issues.
Non-compact limit
($M_{pl} = \infty$)

A 10d view on the KKLT AdS vacuum and uplifting (1902.01415)
with F. F. Gautason, V. Van Hemelryck, G. Venken

The tension between 10D supergravity and dS uplifts (1810.08518)
with F. F. Gautason, V. Van Hemelryck

"Closed string" issues.
Compactifications
($M_{pl} < \infty$)

1.General comments

2.Open string issues & non-compactifications

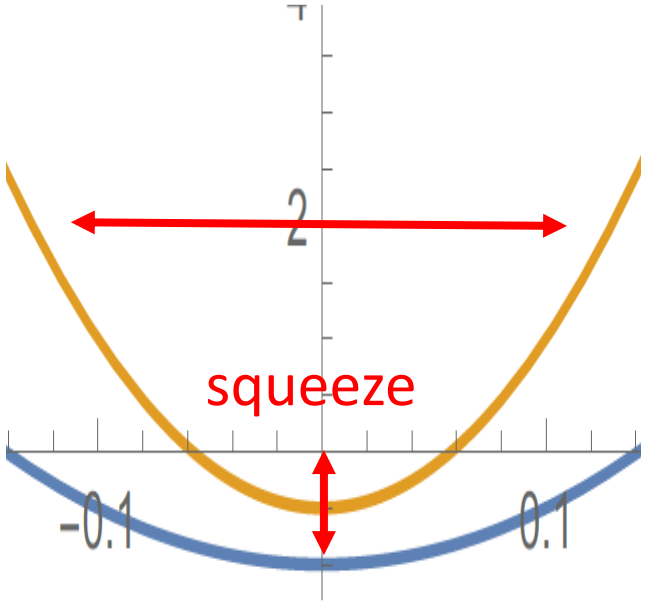
3.Closed string issues& compactifications.

4.Conclusions

If there exist SUSY AdS vacua for which

$$mR = \kappa \gg 1$$

m is mass of lightest modulus,
R adS length



Then any form of SUSY breaking leads to controlled dS vacua!

Conjecture: *such AdS vacua are in the Swampland:*

[1810.08518, F. Gautason, V. Van Hemelryck, VR]

→ Is conjecture on **SUSY AdS vacua** motivated from the more speculative dS conjecture.

→ A stronger version was motivated differently in [Lust, Palti, Vafa 2019]

→ Is conjecture on 3D N=1 CFTs. They have not a single low-lying operator!

$$\Delta = \frac{3}{2} + \frac{1}{2}\sqrt{9 + 4\kappa^2} \gg 1$$

"Dead End CFTs". Do we know such CFTs?

(See also Alday&Perlmutter 2019, Ooguri et al 2019, Conlon&Quevedo 2019)

$$\boxed{mR = \kappa \gg 1}$$???

- Some class of moduli stabilization scenarios try to achieve this: KKLT, LVS and the like.

  → Indeed succesfull dS uplifts are claimed to exist here (THIS TALK).

  Neither KKLT, neither LVS achieve this *parametrically* AND none of them have both *parametric* weak coupling, large volume such that they are under *parametric* control.

- Others do not achieve it, but claim to have parametric control over coupling and volume instead [DeWolfe et al 2005].

  → No succesfull dS uplift known in such classical IIA settings in my opinion. [Andriot 2019, Junghans 2018, Banlaki& Chowdury&Roupec&Wrase 2018, Danielsson&Shiu&Wrase&VR 2012, ….]

- Then there is **racetrack finetuning** [Kallosh, Linde, 2004] and achieves this infinitely well:

$$W = W_0 + \mathcal{A}\exp(ia\rho) + \mathcal{B}\exp(ib\rho)$$

$$W_0 = -\mathcal{A}\left(\frac{a\mathcal{A}}{b\mathcal{B}}\right)^{a/(b-a)} - \mathcal{B}\left(\frac{a\mathcal{A}}{b\mathcal{B}}\right)^{b/(b-a)}$$

→ This is not string theory, but EFT. Finetuning W_0 unclear (& one-loop determinants cannot be ``chosen at will"). There is no string theory description of this.

- **Non-geometric flux configurations** , that can achieve this infinitely well [Micu&Palti&Tasinato 2007, Palti 2007, De Carlos&Guarino&Moreno 2009]. E*xplains* the "wealth" of examples of meta-stable dS solutions with non-geo fluxes [De Carlos&Guarino&Moreno 2009, Blaback&Danielsson&Dibitetto 2013, many more.]

→ Trustworthy? Most likely not.

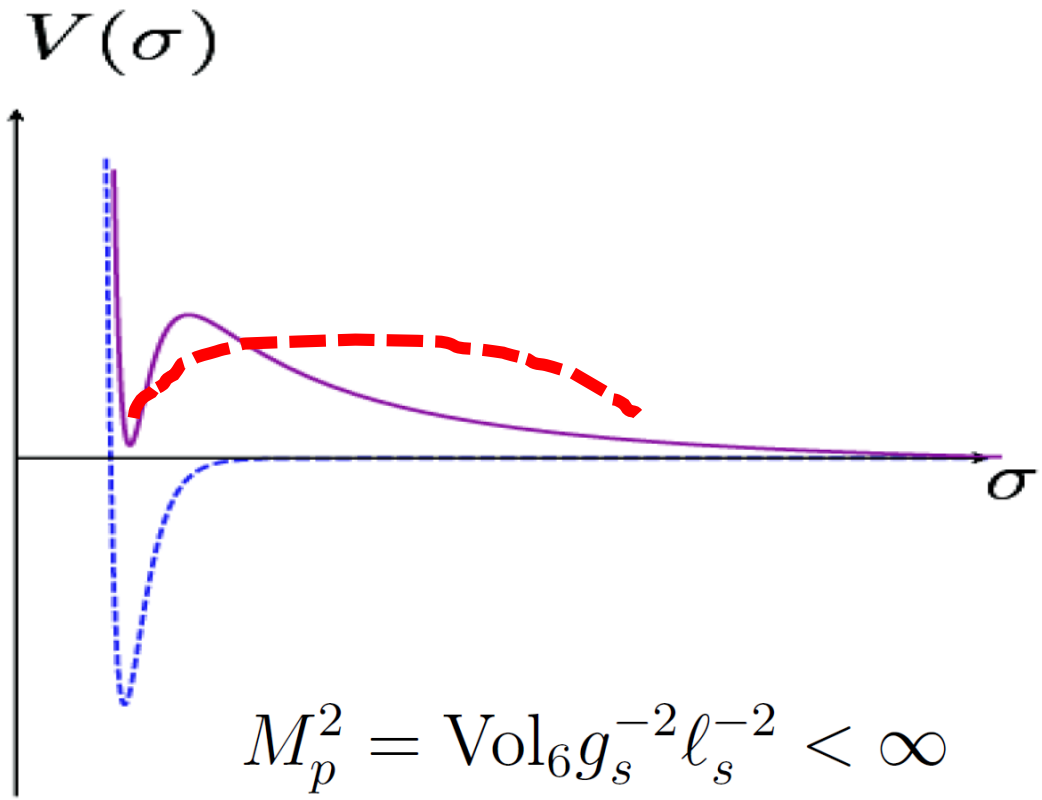
Food for discussions.

- **The cc problem is by definition NOT solvable in EFT.**

- If achieving dS landscape is a matter of writing “stringy inspired superpotentials”, we would have been done 20 years ago. This conference would not be necessary.

(Tunneling) instabilities

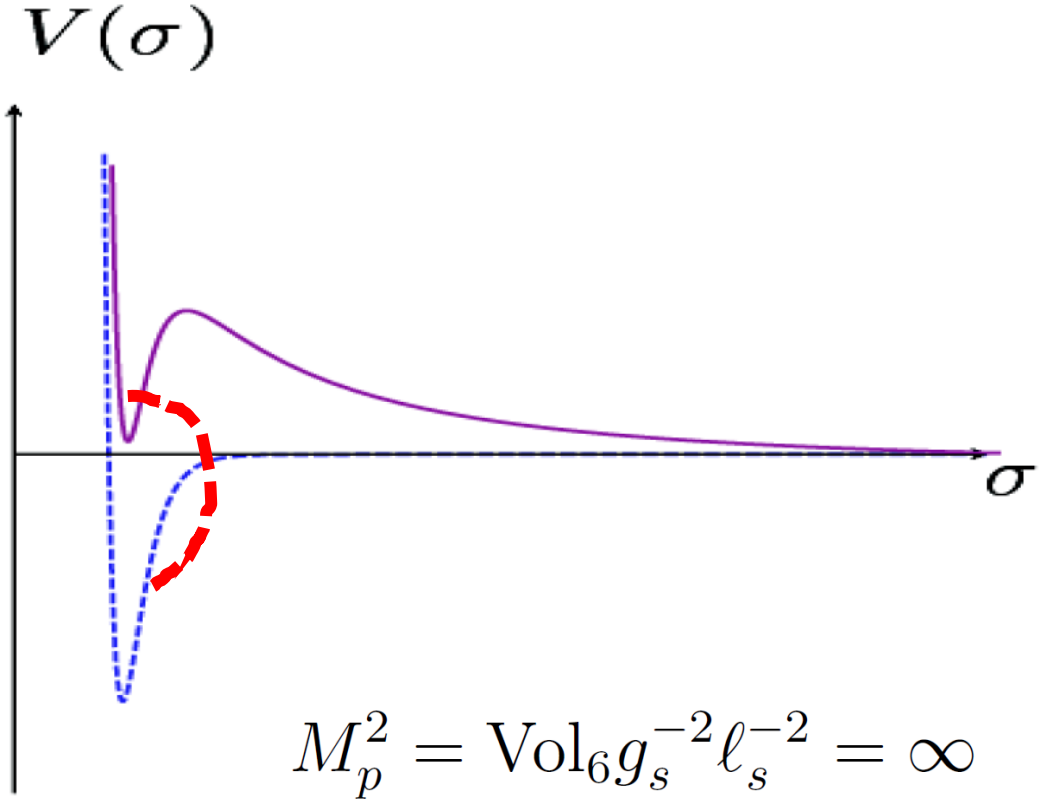
Move towards 10D.



$$M_p^2 = \mathrm{Vol}_6 g_s^{-2} \ell_s^{-2} < \infty$$

Worried!

Move towards AdS.



$$M_p^2 = \mathrm{Vol}_6 g_s^{-2} \ell_s^{-2} = \infty$$

Seems ok?

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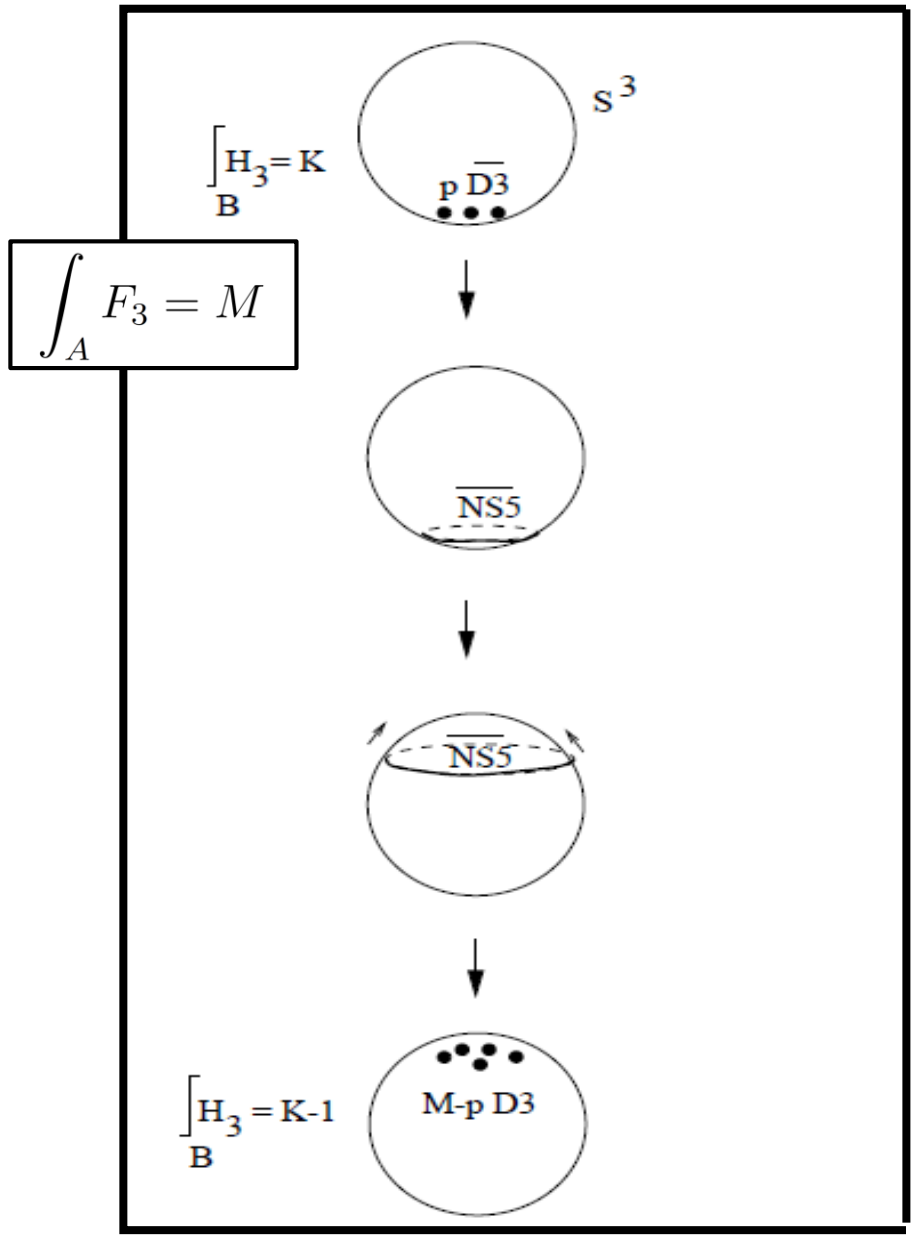
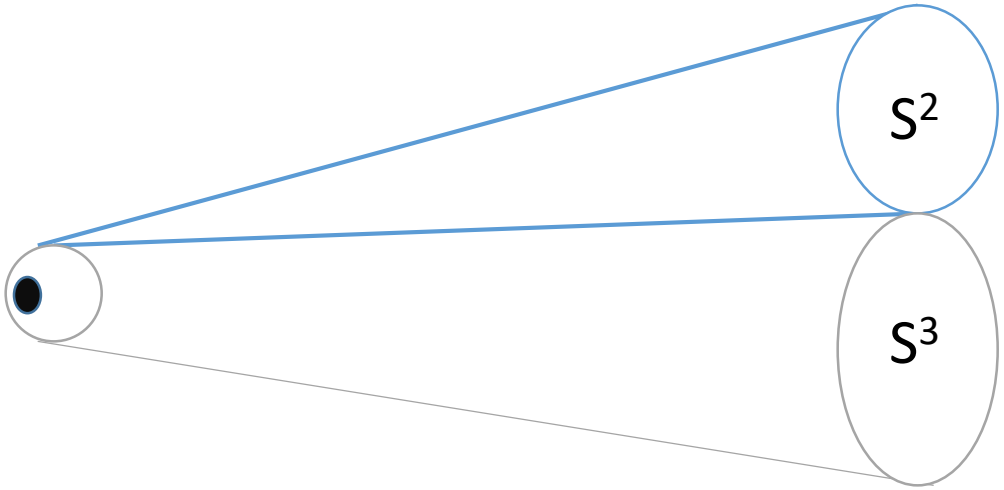
Kachru, Pearson, Verlinde (KPV) 2001

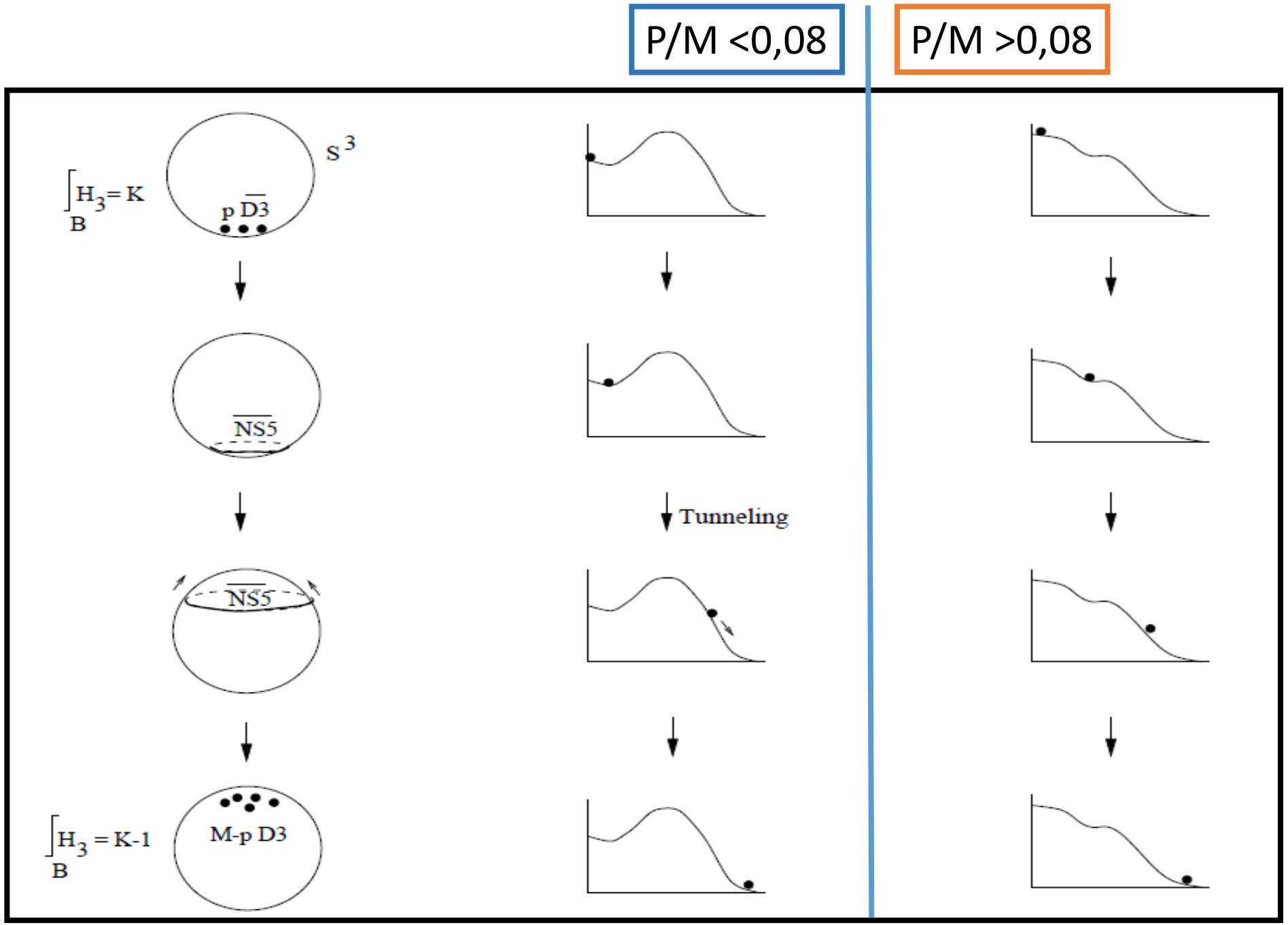




Holographic dual to dynamical SUSY breaking in the KS gauge theory

Locally confined backreaction & meta-stability if :

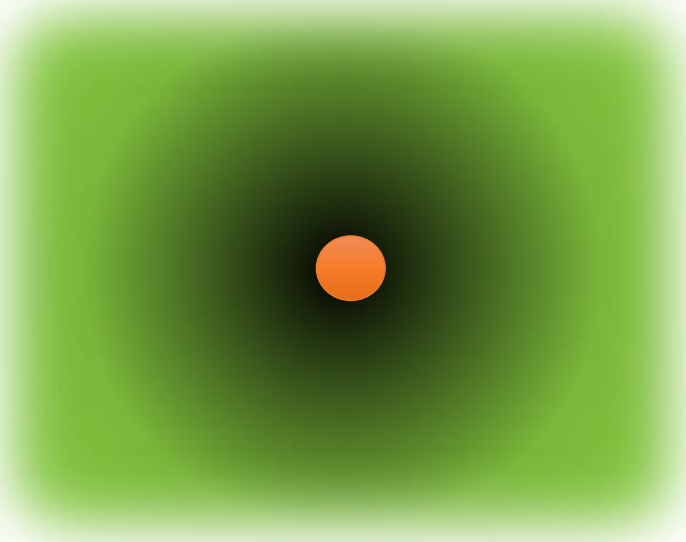
$$p/M << 1$$


P/M <0,08
P/M >0,08
$\int_B H_3 = K$
S^3
p D3
NS5
NS5
Tunneling
$\int_B H_3 = K-1$
M-p D3

KPV computation: no backreaction

Flux attracted towards anti-branes gravitationally *and* magnetically

With backreaction



Can a probe approximation fail (in the probe limit) ?

6D backreaction = infinite fluxclumping

$$e^{-\phi} H^2 \to \infty$$

If correct, direct brane-flux decay [Blaback, Danielsson, VR, 2012].

(**Bena**, Blaback, **Grana**, Giecold, Puhm, Orsi, Massai, Kuperstein, Zagermann, Junghans, Wrase, Danielsson, Gautason, Vercnocke, Diaz, Truijen, Cohen-Maldonado, Hashimoto, Cottrell, VR, Vargas, **Halmagyi**, Kutasov, Wisanji, McGuirk, Massai, Shiu, Sumitomo, Galante, Buchel, Hartnett, Dymarsky, Polchinski, Saad, Mintun, Michel, …….)

With backreaction

How, from a computation? Based on work by [Blaback, Danielsson, Junghans, VR, Wrase, Zagermann 2010-2012, Gautason, Junghans, Zagermann 2013], Blaback, Danielsson, Junghans, Vargas, VR 2014]

$$\mathrm{d}s_{10}^2 = \mathrm{e}^{2A}\left(-e^{2f}\,\mathrm{d}t^2 + \delta_{ij}\mathrm{d}x^i\mathrm{d}x^j\right) + \mathrm{d}s_6^2\,,$$

$$C_4 = \tilde{\star}_4\alpha,$$

$$H_3 = -\mathrm{e}^{\phi-4A-f}\star_6\left((\alpha+\alpha_0)F_3 + X_3\right)\,.$$

$$\mathrm{e}^{-\phi}|H_3|^2 = e^{\phi-8A-2f}|\alpha F_3 + X_3|^2$$

- At zero T: absence of infinite flux clumping implies α=0 at the anti-D3 source.
- At finite T: less obvious [Hartnett 2015]. But not for ***smeared*** anti-Dp's with p<6 or **localized** anti-D6's. [Bena, Blaback, Danielsson, VR 2013]

So can we take α=0 at the source?

[C.-Maldonado, Diaz, VR, Vercnocke 1507.01022]

- Define charges: $Q_3 = \int_{S^5} F_5 \,, \qquad Q_5 = \int_{S^3} H_3$

and the gauge potentials near the source: $C_4 = \alpha_H \tilde{\star}_4 1 \,, \qquad B_6 = b_H \tilde{\star}_4 1 \wedge \epsilon_2$

Then the "**Smarr** relation" constraints UV →IR:

$$M_{ADM} = \mathrm{Vol}_4 \left(\alpha_H Q_3 + b_H Q_5 \mathrm{Vol}_2 \right)$$

- *Only when Ansatz allows spherical NS5 branes one can take $\alpha_{H=0}$. All claims of singularities in the literature can be explained this way: a too restrictive Ansatz (conflicting KPV).*

See [C.-Maldonado, Diaz, Gautason, 1603.05678] for a significant extension and formalization of this.

- Similar story holds at finite temperature, however one extra possible boundary condition which has no NS5 polarization… [C.-Maldonado, Diaz, VR, Vercnocke 1507.01022, Hartnett 2015]

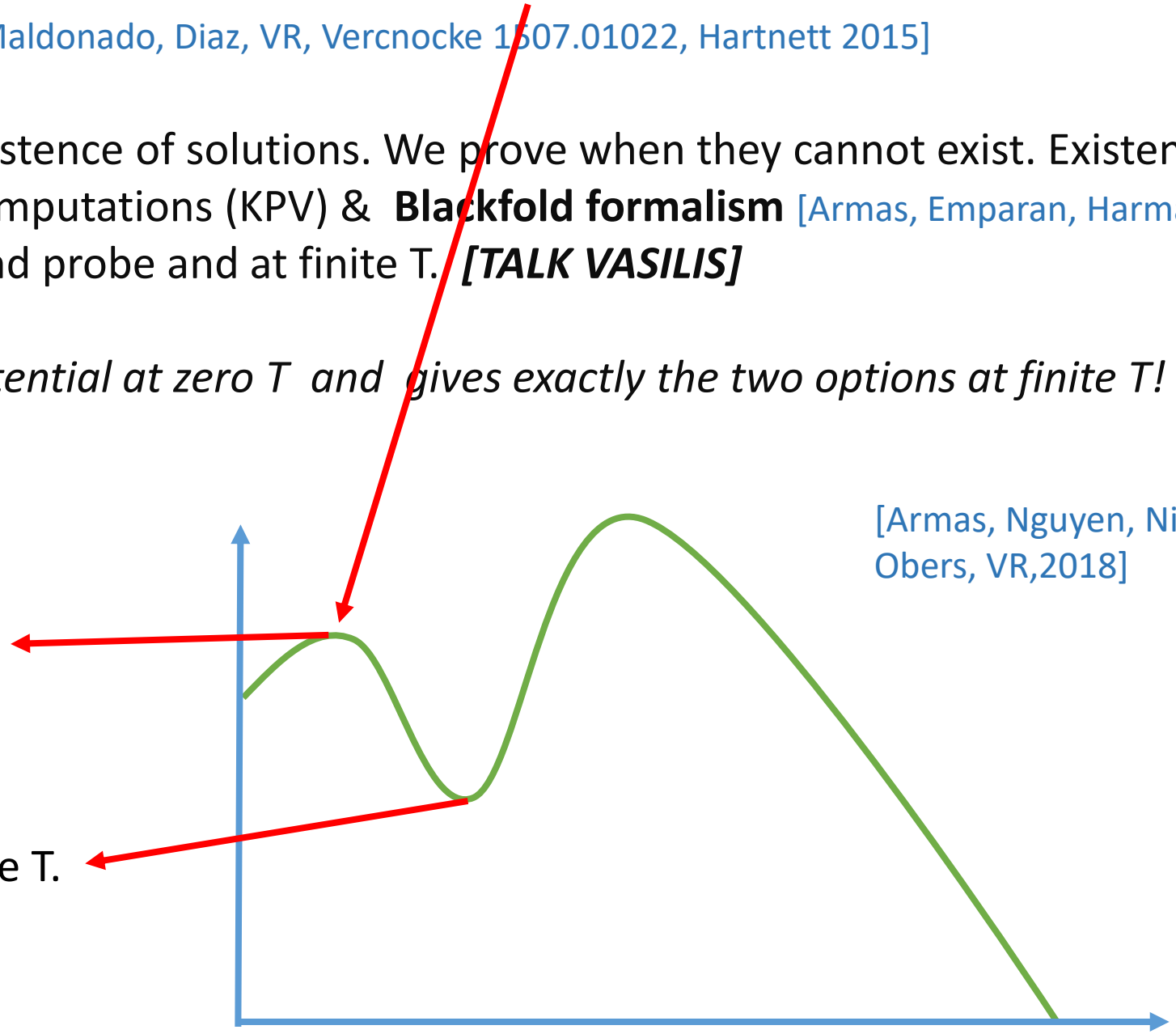
- Note that we do not prove existence of solutions. We prove when they cannot exist. Existence is instead argued from probe computations (KPV) & **Blackfold formalism** [Armas, Emparan, Harmark, Niarchos,…]. allows study beyond probe and at finite T. ***[TALK VASILIS]***

Amazingly reproduces KPV potential at zero T and gives exactly the two options at finite T!

[Armas, Nguyen, Niarchos, Obers, VR,2018]

New &unstable critical point.
Corresponds to “black anti-D3”

Meta-stable KPV vacuum at finite T.
Corresponds to “black NS5”



- “Increasing temperature” makes meta-stable vacuum disappear. This happens exactly when the black NS5 horizon eats its own “ring structure” and becomes black anti-D3.

META-STABLE

HEAT UP

UNSTABLE

[Armas, Nguyen, Niarchos, Obers, VR, 2018]

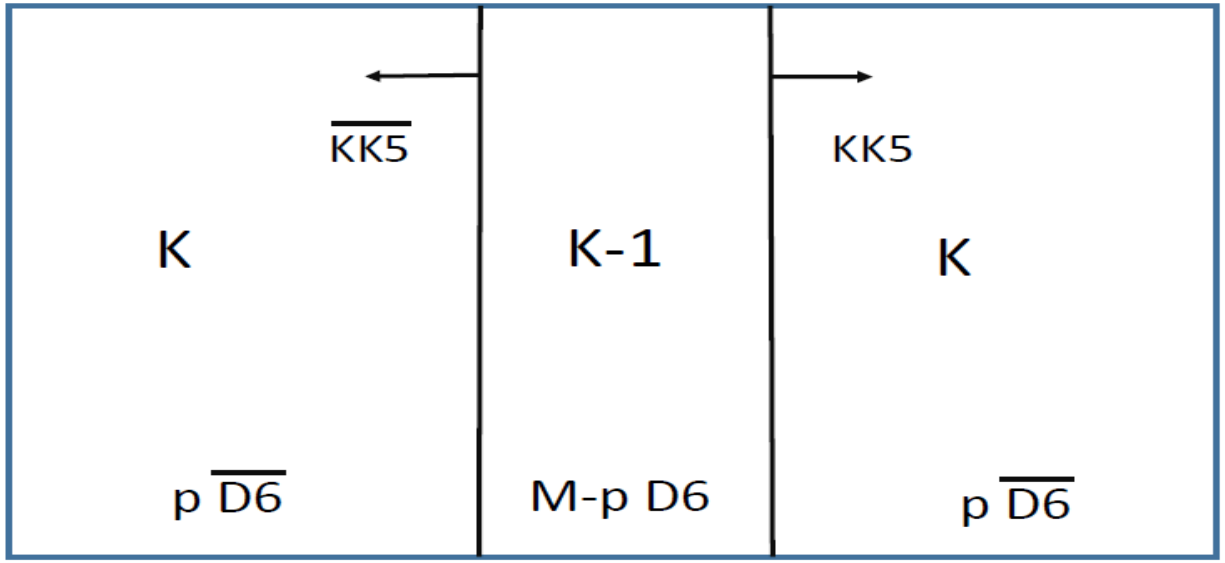
- Also good test of meta-stability: gapped state.
- Not all issues resolved: still instabilities? [Bena, Grana, Massai, Kuperstein, Turton, Blaback 2014, 2015, 2016]

No clash between SUGRA and probe actions? → **Anti-D6 branes** in massive IIA an exception [Danielsson, Gautason, VR 2016] ? Need p=1 stringy regime [Michel, Mintun, Polchinski, Pum, Saad 2014]

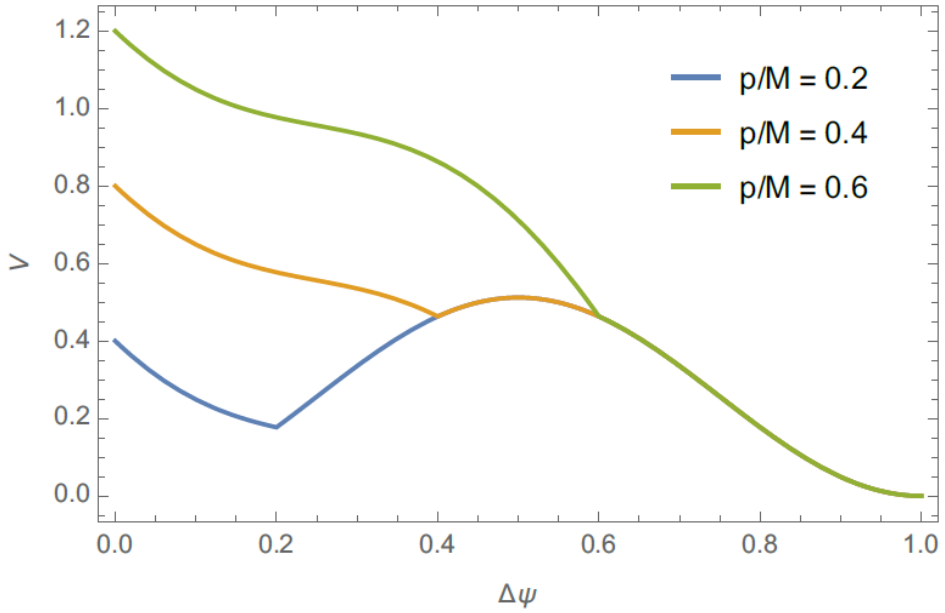
→ This is the only case for which numerical solutions for localized branes are rather "easy" [Blaback, Danielsson, Junghans, VR, Wrase, Zagermann 2011-2012]

→No well behaved solutions for negative D6 charges [Blaback, Danielsson, Junghans, VR, Wrase, Zagermann 2011-2012, Bena, Blaback, Danielsson, VR 2013]

→Direct brane flux decay happens via KK5 dipoles [Danielsson, Gautason, VR 2016]



.....BUT [J. Blåbäck, F. F Gautason, A. Ruipérez , VR 1907.05295]



→ Brane polarization, when done properly, happens exactly at Q=0! (Need tachyon condensation details) **Only way out of nogo theorems for fully backreacted solutions**

→ We find numerical well behaved SUGRA solutions for anti-D6 branes!

Very striking example of how non-SUSY probes can evade problems of backreaction.

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3.Closed string issues& compactifications.

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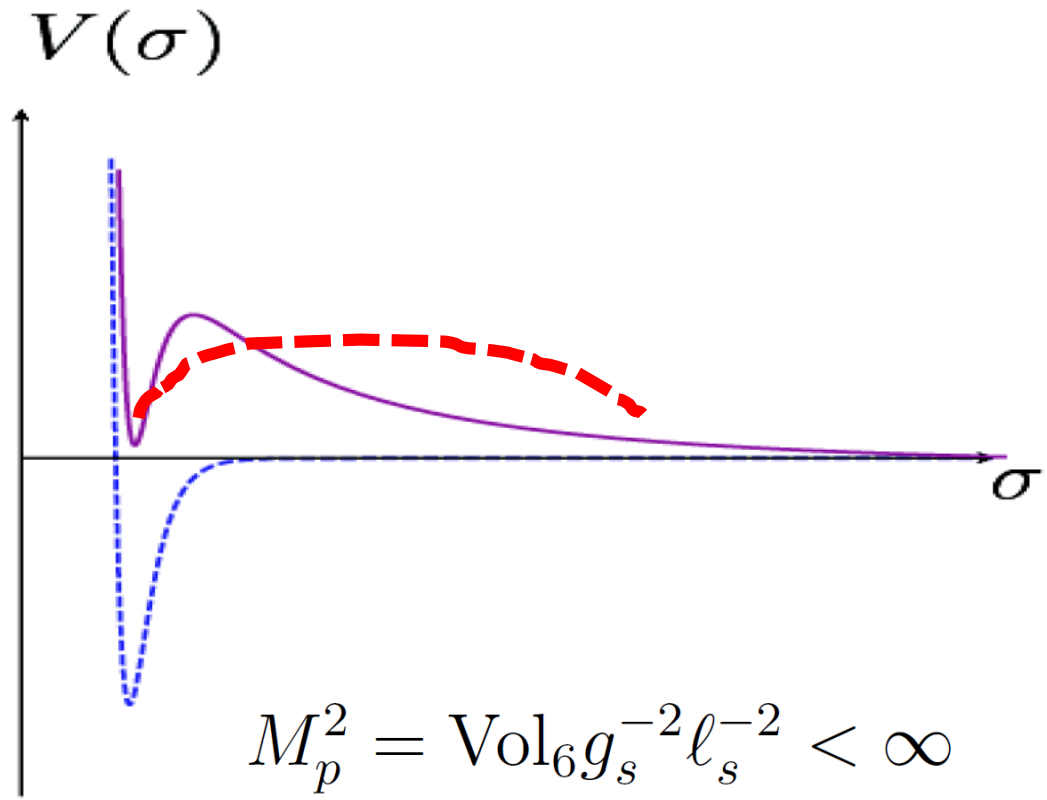
(Tunneling) instabilities

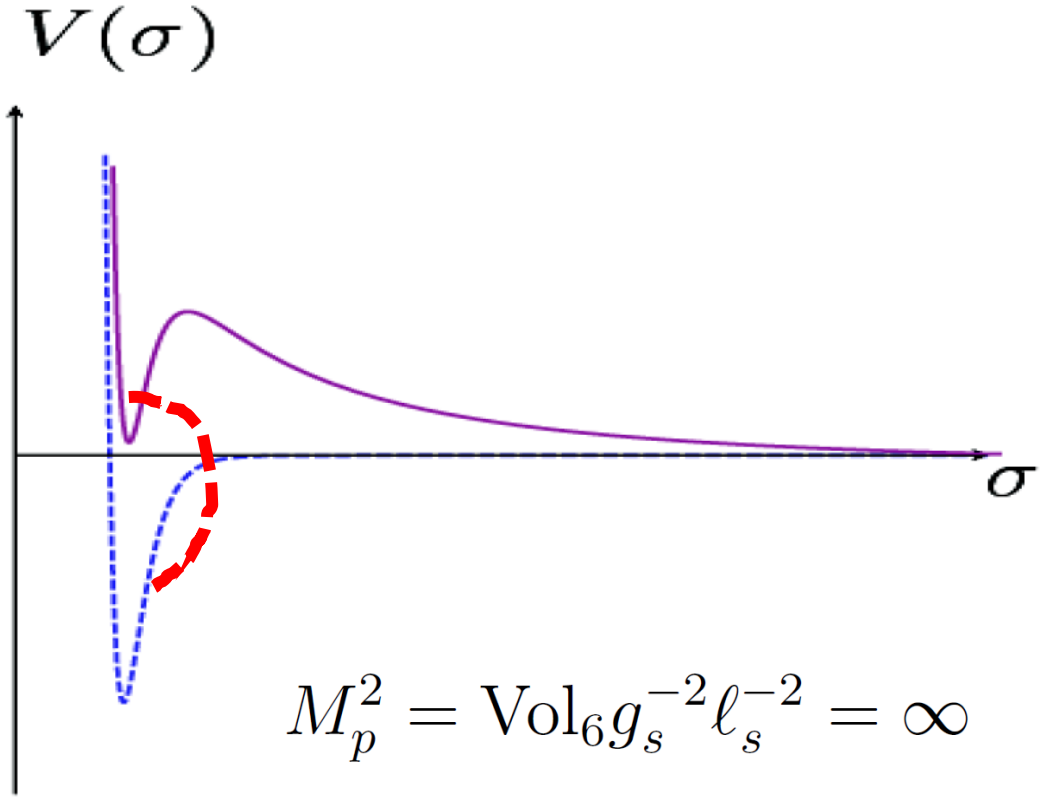
Move towards 10D.



$$M_p^2 = \mathrm{Vol}_6 g_s^{-2} \ell_s^{-2} < \infty$$

Worried!

Move towards AdS.



$$M_p^2 = \mathrm{Vol}_6 g_s^{-2} \ell_s^{-2} = \infty$$

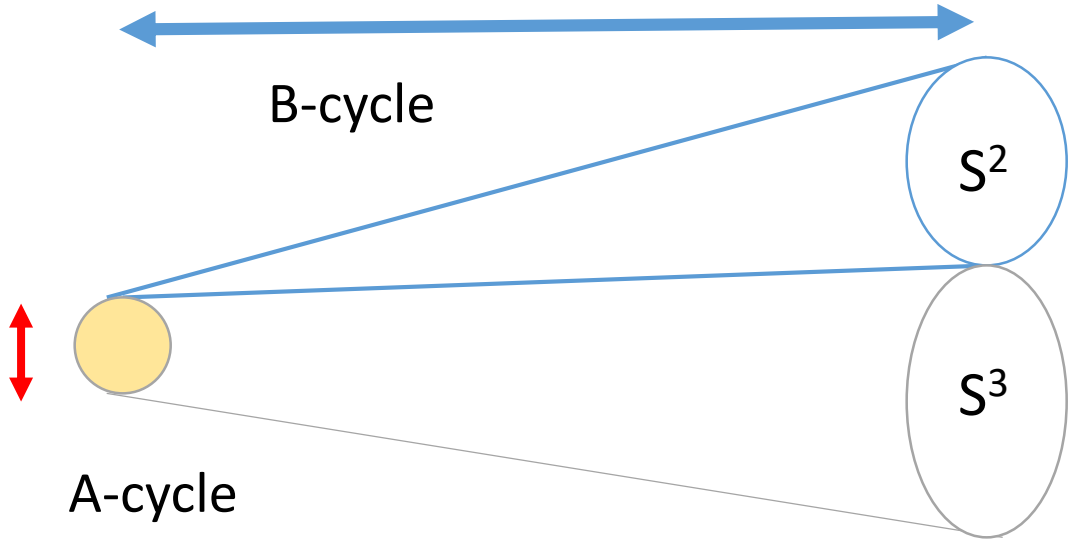
Seems ok?

Whack a mole: problems in dS model building

A very simple illustrative problem.

Fluxes on A-cycle of local throat

$$\int_A F_3 = M \qquad \int_B H_3 = K$$



SUGRA control: small coupling, and large enough A-cycle: $R_A \sim gM >> 1 \quad g << 1$

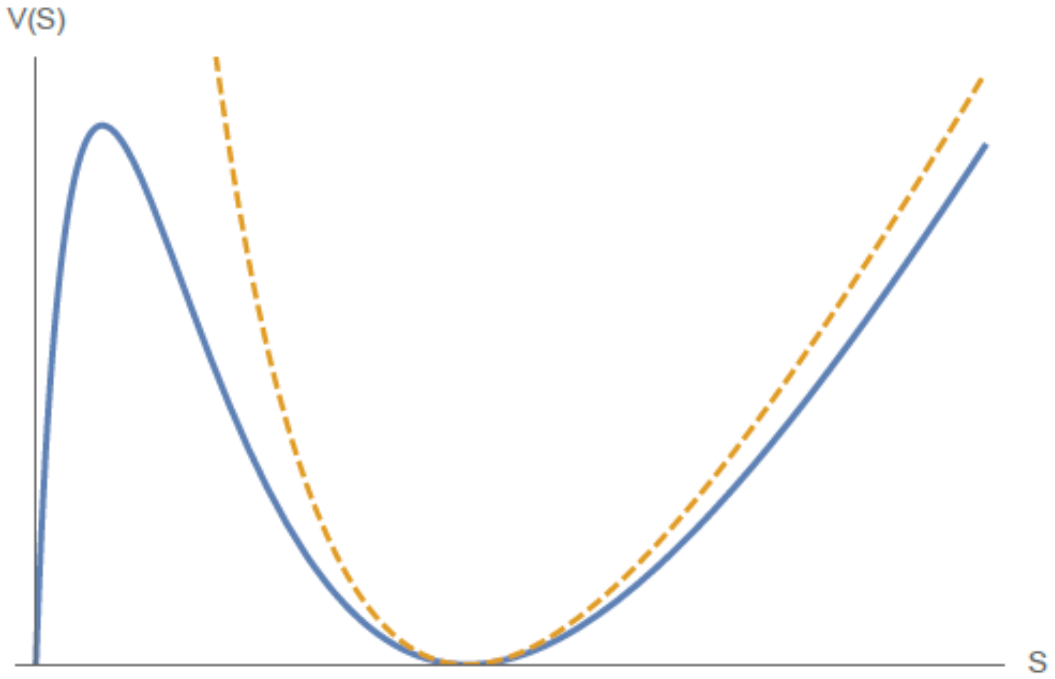
But in perturbative IIB (with single Kahler CY): $32 \geq KM$

Or written differently: $32 \geq K(Mg)(\frac{1}{g})$

Not possible to have KS throats embedded in compact CY's in controllable regime?

But throat is crucial for redshifting anti-brane energy to get control when uplifting to dS!!

Similar problem: “Uplifting runaways”. [Bena, Dudas, Graña, Lüst, 1809.06861]



The conifold modulus is not parametrically heavy. Anti-branes can destabilize it unless KM>>32

- F-theory is final resort. Is this understood? → discussion sessions.
- The conifold modulus is as light as the open string moduli (NS5, D5 brane flux decay channels)…possible issue if there is non-trivial moduli mixing [Scalisi, Soler, Van Hemelryck, VR, in progress]

Moles everywhere!

1. Unclear if we will ever find an example where W_0 can be finetuned to be small. However see [Blumenhagen, Kläwer, Schlechter, 2019] for an interesting suggestion.

2. [Carta, Moritz, Westphal 2019]. “Standard” numbers used in KKLT models imply volume warped throat > total volume! Unavoidable for single Kahler CY’s. Multi-Kahler makes it worse?

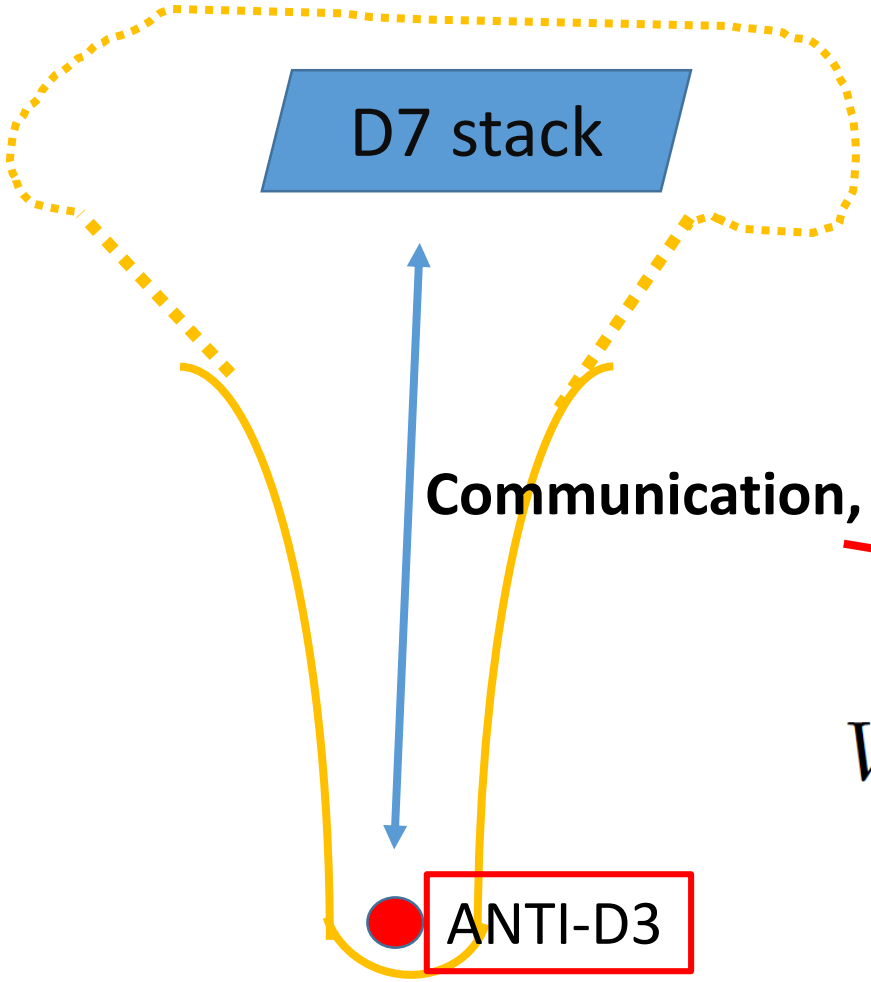
3. [Blumenhagen, Kläwer, Schlechter, 2019]. KK modes in throat redshift to become as light as Kahler and conifold modulus. 4D EFT is unclear. Maybe these KK modes have suppressed couplings and only modify kinetic terms at one loop?

4. Sethi,….,

With F. Gautason, V. Van Hemelryck, G. Venken

‘Anti-brane, do you even lift?’

Interplay gaugino condensation, SUSY-breaking → big corrections to KKLT potential?



- Option A) "red-shift" of anti-brane towards UV.
- Option B) "Blue-shift" of gaugino-condensate towards tip of throat. [Moritz, Retolaza, Westphal 2017 & follow-ups].

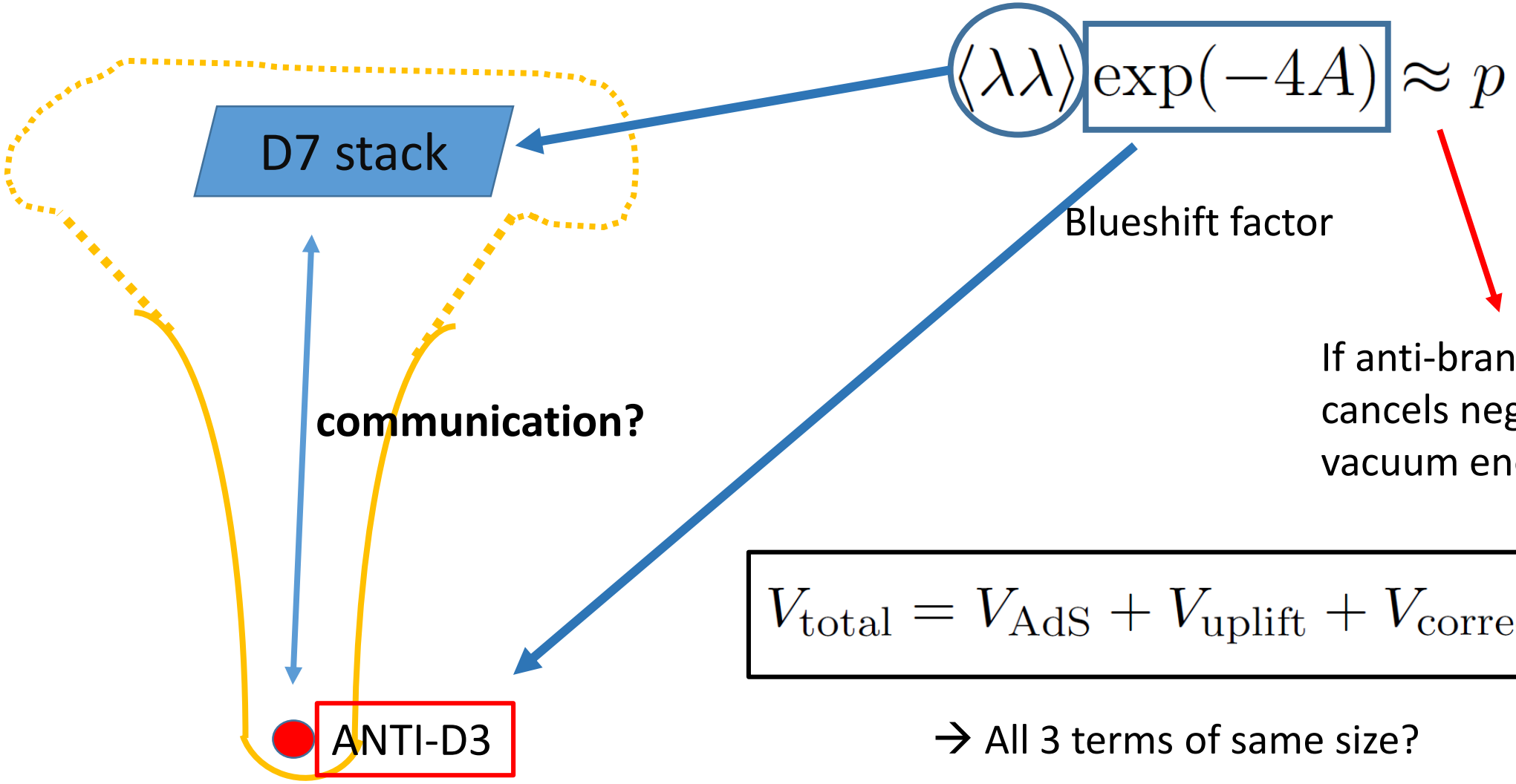
Communication, no decoupling ?

$$V_{\text{total}} = V_{\text{AdS}} + V_{\text{uplift}} + V_{\text{corrections}}$$

Sufficiently warped down?

Back of the envelope argument [Moritz, Retolaza, Westphal, 2017]:

→ UV correction (gaugino condensation) is order 1 effect in IR.



$$V_{\text{total}} = V_{\text{AdS}} + V_{\text{uplift}} + V_{\text{corrections}} \,.$$

→ All 3 terms of same size?

KKLT from a 10D point of view:

[Baumann, Dymarsky, Kachru, Klebanov, McAllister, 2010, Koerber, Martucci, 2008, Dymarsky, Martucci,2010]

$$S_{D7} \supset \int_{\mathcal{M}_{10}} \delta_D^{(0)} e^{\phi/2} e^{-4A} \frac{\bar{\lambda}\bar{\lambda}}{16\pi^2} G_3 \wedge \star_{10}\Omega + c.c.\,,$$

- Before uplift:

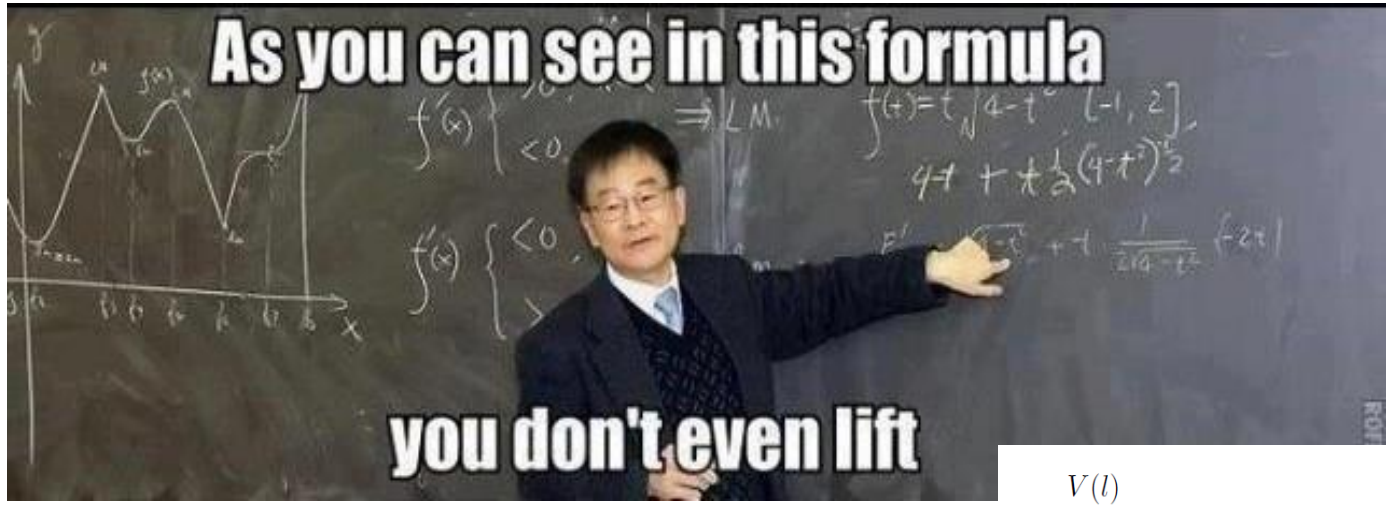
$$\nabla^2\Phi^- = R_4 + e^{-6A}\left|\mathrm{d}\Phi^-\right|^2 + \frac{e^{2A}}{\mathrm{Im}(\tau)}\left|G_3^-\right|^2 + \Delta_{\mathrm{gaugino}}$$

0 when integrated

Should be positive when integrated

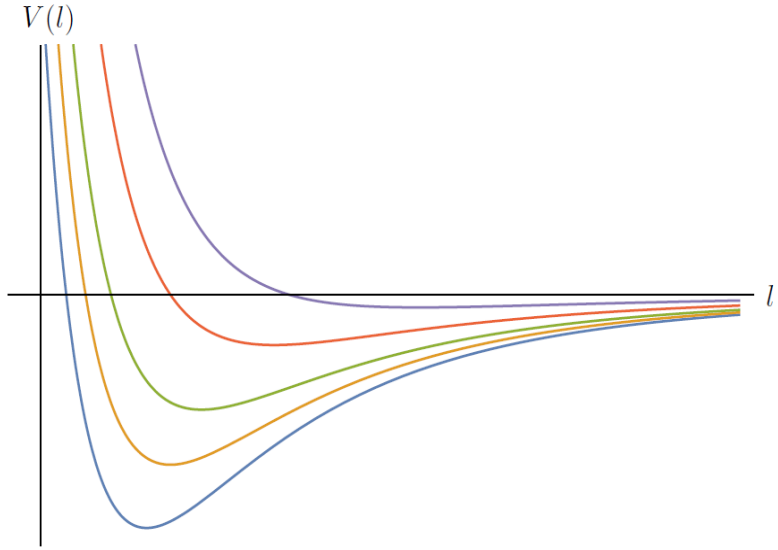
- After uplift: extra term on RHS $e^{4A}(T^\mu_\mu - T^m_m)$ Same sign as other terms !

$$\nabla^2\Phi^- = R_4 + e^{-6A}\left|\mathrm{d}\Phi^-\right|^2 + \frac{e^{2A}}{\mathrm{Im}(\tau)}\left|G_3^-\right|^2 + \Delta_{\mathrm{gaugino}} + e^{4A}(T_\mu^\mu - T_m^m)$$

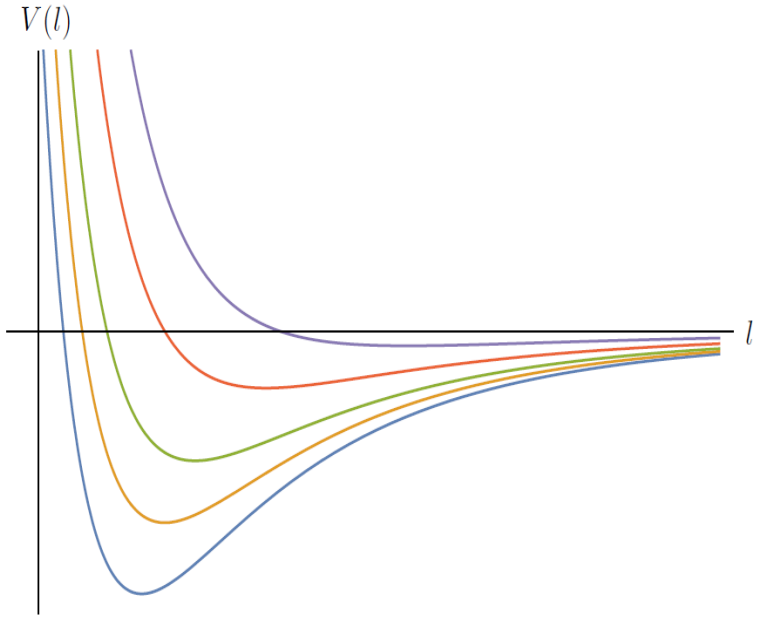


Not true. You lift, but not to positive vacuum energy.

Flattening effects never get you to de Sitter? [Moritz, Retolaza, Westphal 2017]: **volume modulus shifts to larger values→ bigger suppression of negative terms.**



Flattening effects → you never get to de Sitter [Moritz, Retolaza, Westphal 2017]



- Not quite [Gautason, Van Hemelryck, VR, 2018]
- Singular expressions, you need quartic fermion term [Hamada, Hebecker, Shiu, Soler 2018] → <u>one should redo computation.</u>

1. "All expressions manifest finite and negative. No de Sitter!" [Gautason, Van Hemelryck, VR, Venken 2019] (Some correction needed, result probably robust). Thanks @ Pablo Soler
2. "We get KKLT on the nose, no corrections" [Hamada, Hebecker, Shiu, Soler 2019] → **Talk Gary**
3. Similar (but less detailed) to [Hamada, Hebecker, Shiu, Soler 2019] to [Carta, Moritz, Westphal 2019]

Difference in approaches? → definition of semi-classical limit

$$G_{ab} = \langle T_{ab} \rangle$$

[Gautason, Van Hemelryck, VR, Venken 2019] : T-tensor obtained from varying 10D action wrt to metric keeping all other fields fixed. THEN we add fermion condensate vev in T.

[Hamada, Hebecker, Shiu, Soler 2019] : Reverse order.

→ It matters since $\langle \lambda\lambda \rangle = -\frac{32\pi^2}{N}\mathcal{A}\exp\left(\frac{2\pi i}{N}\rho\right)$

- It also means Hamada et al have no local 10D action. But do they need so?
- We reduced the EOM with local 10D sources, whereas Hamada et al reduced the action.

→ Off-shell approach versus on-shell.

A praise for the on-shell method! …with a trivial example: Freund Rubin.

Consider: $S = \int \sqrt{|g|}\left(R - \frac{1}{2}F_p^2\right)$ with magnetic flux $F_p = Q\epsilon_p$

- Imagine humanity did not realise that the Einstein equations inside the extra dimensions imply the internal geometry is Einstein with positive curvature proportional to Q^{-2}
- Hence humanity decides to leave the metric on extra dimensions arbitrary and to look at the ***external traced reversed*** Einstein equations:

$$R_{\mu\nu} = -\frac{(p-1)}{p!2(D-2)} g_{\mu\nu} F_p^2$$

- Humanity realizes the vacuum must be AdS, but is left confused since reducing the action tells them that fluxes contribute positively to the vacuum energy:

$$V_{eff} \subset \int_{internal} \sqrt{g} F_p^2$$

What happened? → backreaction of fluxes curve extra dimensions positively. Extra term in effective potential is induced of similar size but negative contribution

$$V_{eff} \subset \int_{internal} \sqrt{g} \left(\frac{1}{2} F_p^2 - R_{internal} \right)$$

And it overshoots the positive energy:

$$R_{internal} > \frac{1}{2} F_p^2$$

→ *Lesson in life: the trace reversed Einstein equation is the on-shell potential. It knows EVERYTHING, but at a big price: you loose on-shell information….*

- When it comes to anti-branes we are only humans….we are humanity.
- We do not know the internal manifold, we do not know the effective potential. Our light in the darkness is the traced-reversed Einstein equation = on-shell potential!
- That is why we do not demand consistency with SUSY KKLT & do not reduce action, because we then switch off potential flattening!

Further Remarks

- Related work I: [Bena, Graña, Kovensky, Retolaza 2019]. Different method altogether. No anti-branes yet. AdS vacuum energy matches KKLT up to a constant that could not be determined.→ **Talk Nicolas . Is this undetermined constant, the one that measures flattening?**

- Related work II: [McAllister, Kachru, Kim, Zimet 2019]. Exact match with KKLT, no corrections! Similar in spirit to Hamada et al work → **Talk Manki**

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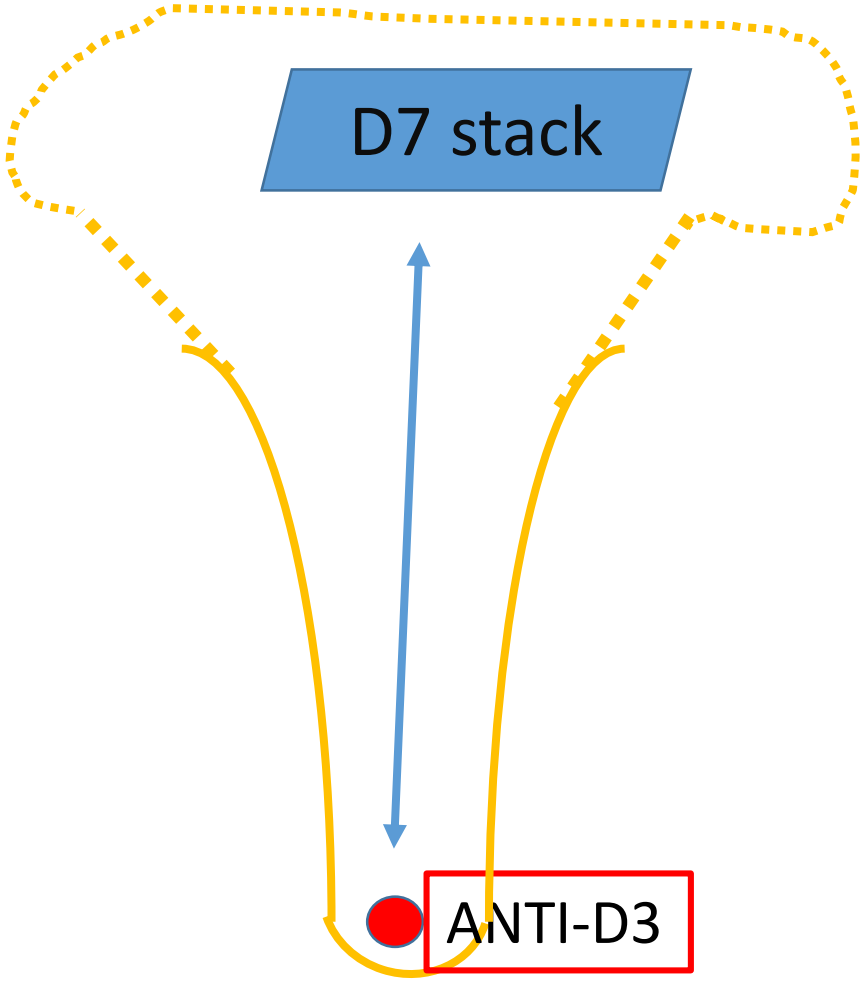
Conclusion I

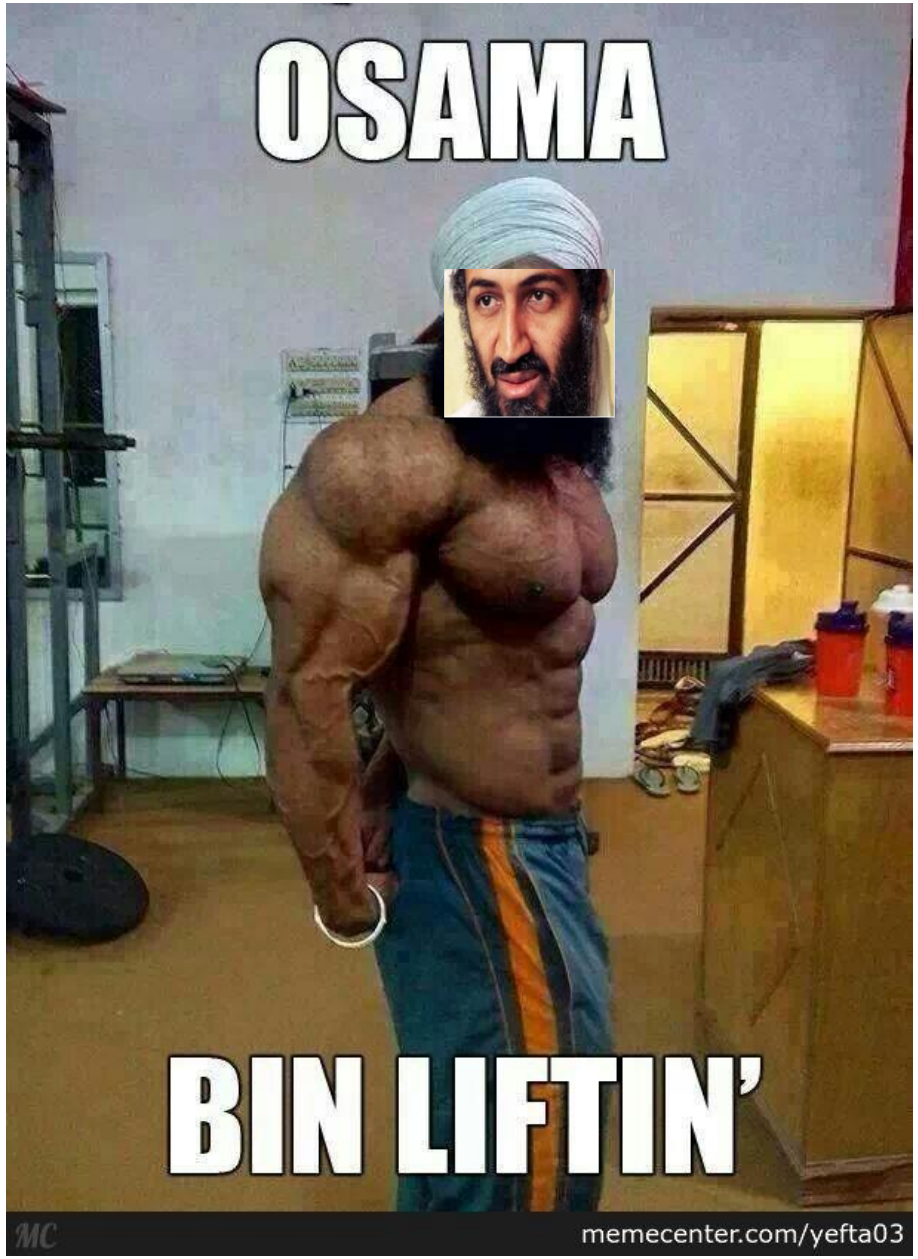


- In *non-compact* settings it seems we can trust probe arguments for stability of anti-branes against brane-flux decay.

- To study possible flattening effects is tough. Reducing the action and assuming SUSY KKLT is correct will not reveal them. One ***should*** find corrections to KKLT that induce flattening. The question is whether they are small or not.

- A concrete way is to directly study UV-IR communication through modes switched on by the D7's . *But do we need to assume a local action for D7 branes? (→ discussion session)*

[64] S. Gandhi, L. McAllister and S. Sjors, *to appear.* When??



Unclear whether anti-branes are "evil" or whether they can lift

Conclusion II: general remarks & emotions.

- The cc problem is by definition NOT solvable in EFT.
- The difficulties with getting dS are not explained by “its ugly because we break SUSY” -argument. Something deeper is going on.
- From scrutinizing KKLT it is clear we cannot claim we have achieved dS vacua. We *have suggestive mechanisms* at best.
- The opposite statement ‘*no-dS*’ is neither proven.