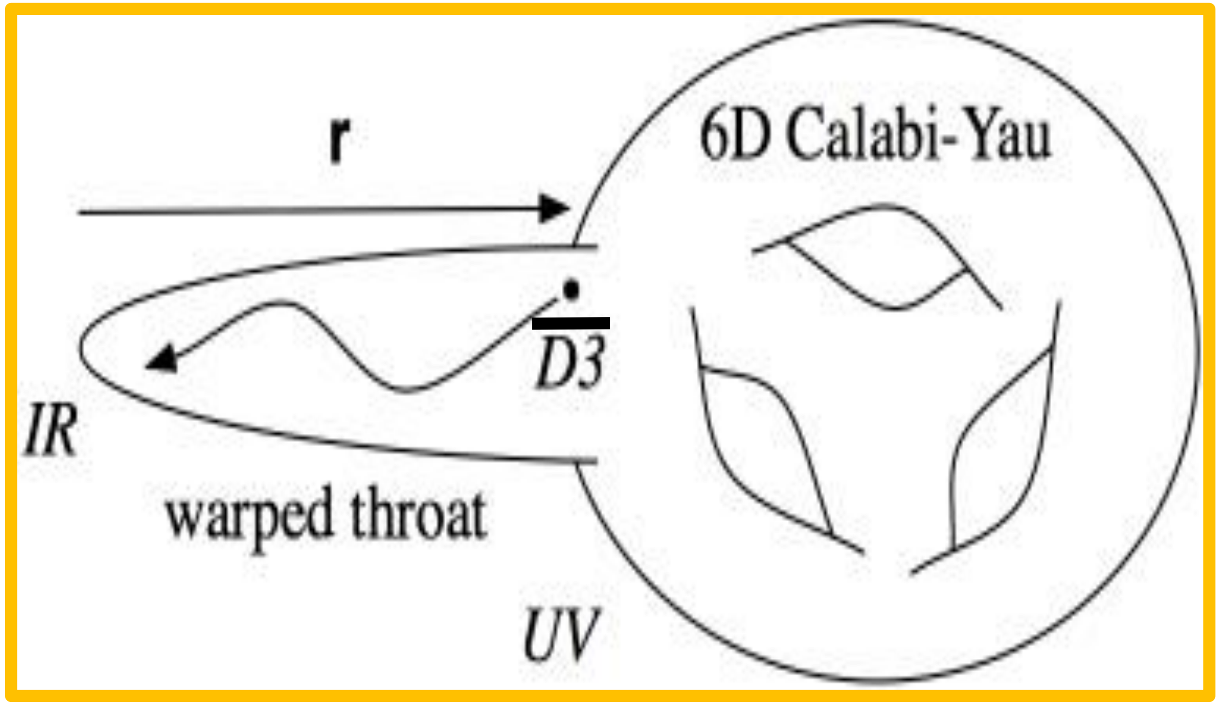
The pros and cons of anti-brane SUSY-breaking (La jodida anti-brane)



Thomas Van Riet – K.U.Leuven

String phenomenology 2015, Madrid

1. Motivation & background

2. Brane-flux annihilation

3. Backreaction

4. [Finite temperature]

5. Conclusions

(politically incorrect) referencing

KKLT, KKLMMT, KPV, Dymarsky, Hartnett, Michel, Mintun, Puhm, Polchinski, Saad,…

<u>Cohen-Maldonado</u>, Cottrell, Halmagyi, Kutasov, Wisanji, McGuirk, Massai, Shiu, Sumitomo, Puhm, <u>Vercnocke</u>, Wrase,…

Bena, Blaback, Buchel, <u>Danielsson,</u> Dias, <u>Diaz</u>, Galante, <u>Gautason</u>, Grana, Giecold, Kuperstein, Junghans, Orsi, VR, Vargas, <u>Truijen</u>, Zagermann, …

Motivation & background

Anti-branes?

$$\mathrm{d}F_{8-p} = H \wedge F_{6-p} + Q_p \delta$$

Opposite orientation

Anti-branes?

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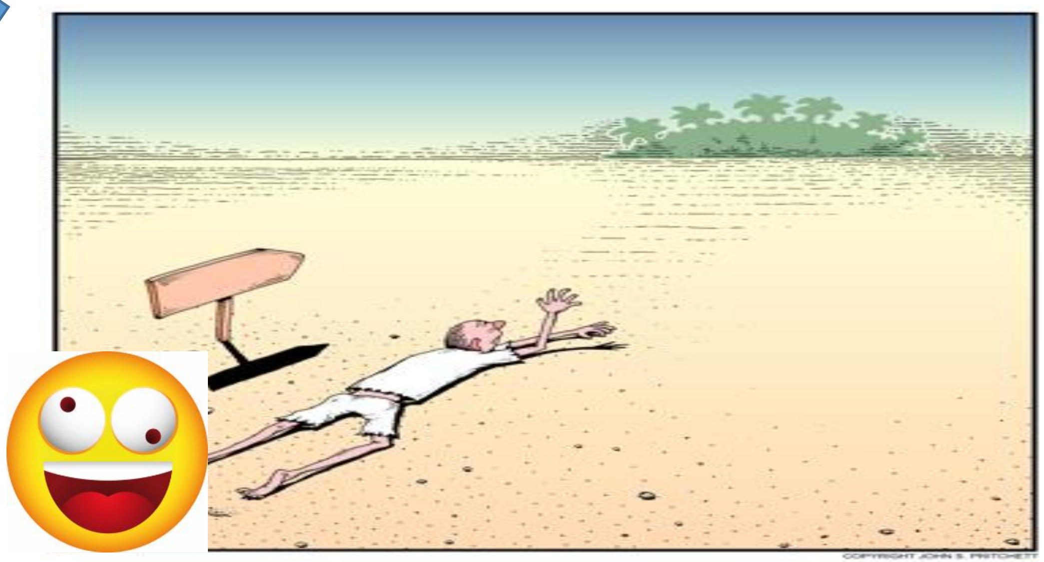
Opposite orientation

Why care? (Why all the fuzz?)

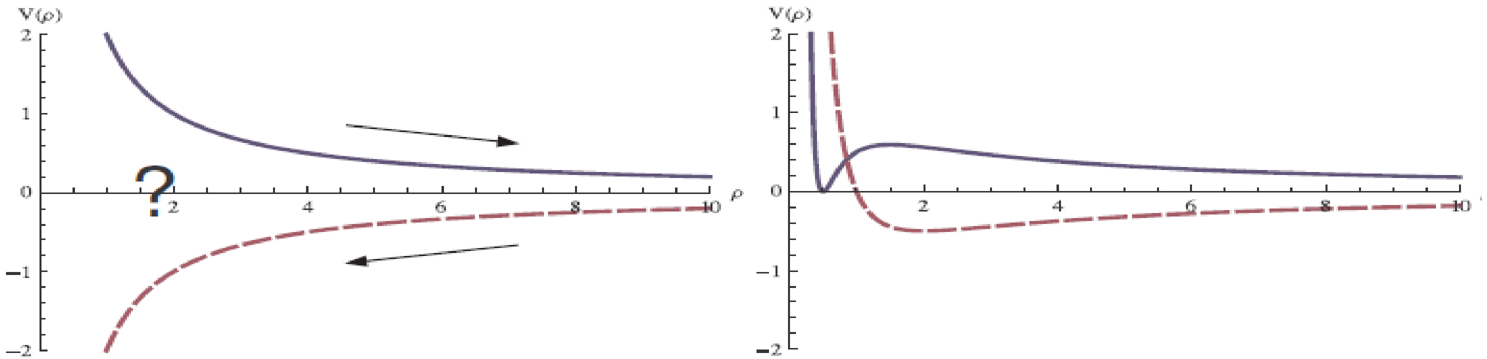
1. dS vacua (KKLT)
2. Inflation (KKLMMT)
3. Holographic models of dynamical SUSY breaking (Maldacena & Nastase, KPV, …)
4. Microscopic description of near extremal black holes

De Sitter vacua in string theory?




'CONSPIRACY THEORISTS' THINK
EVERYTHING IS A COVER-UP
FALSE
WE QUESTION EVERYTHING, DO OUR RESEARCH,
AND COME TO CONCLUSIONS THAT SCARE YOU
/Awaken the mind

- Dine-Seiberg problem. Vacua are typically **not calculable:**



- Fluxes are a way out. *Aim of flux compactification program is to construct **calculable vacua.*** Solutions “under control”. [small curvatures, small string coupling, etc.]

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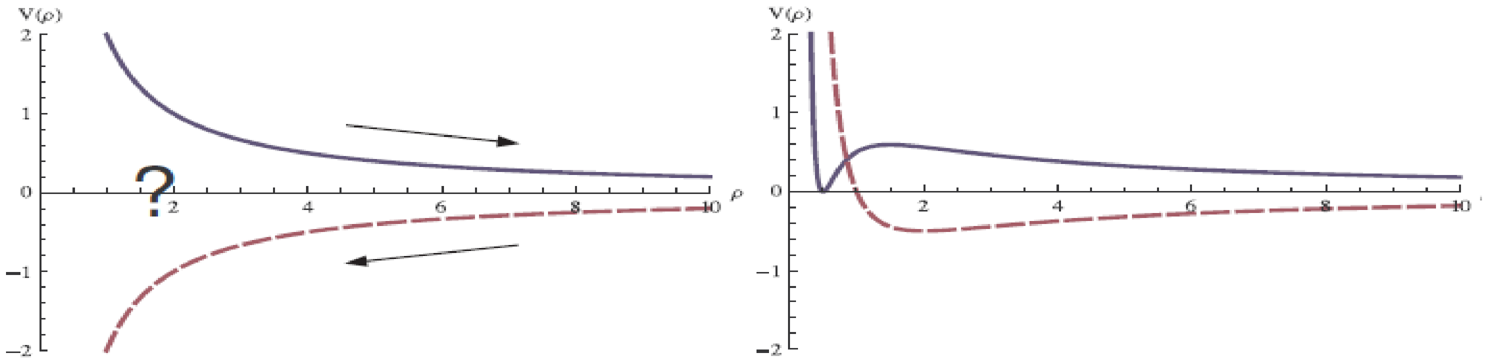

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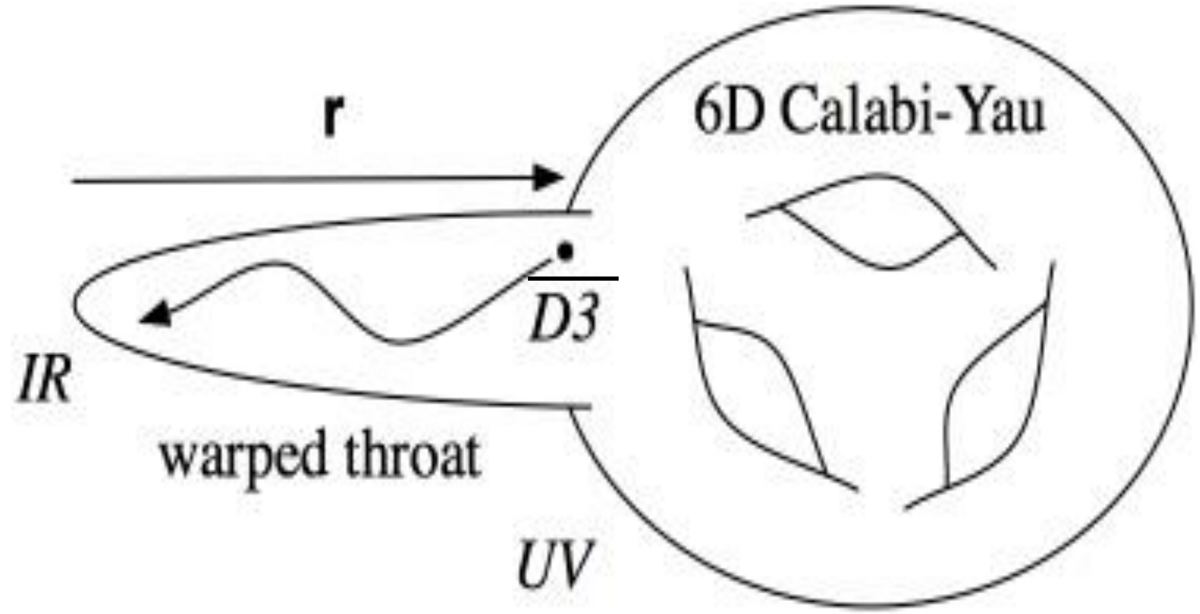
- Relation to anti-branes?

Lets decide stability of anti-branes within SUGRA.

KKLT (anti-D3 uplifting)



$$\delta E = 2T_3 e^{4A}$$

1. SUSY-breaking & uplifting from a ‘natural’ source.
2. SUSY-breaking is in principle entirely 10D, entirely within SUGRA

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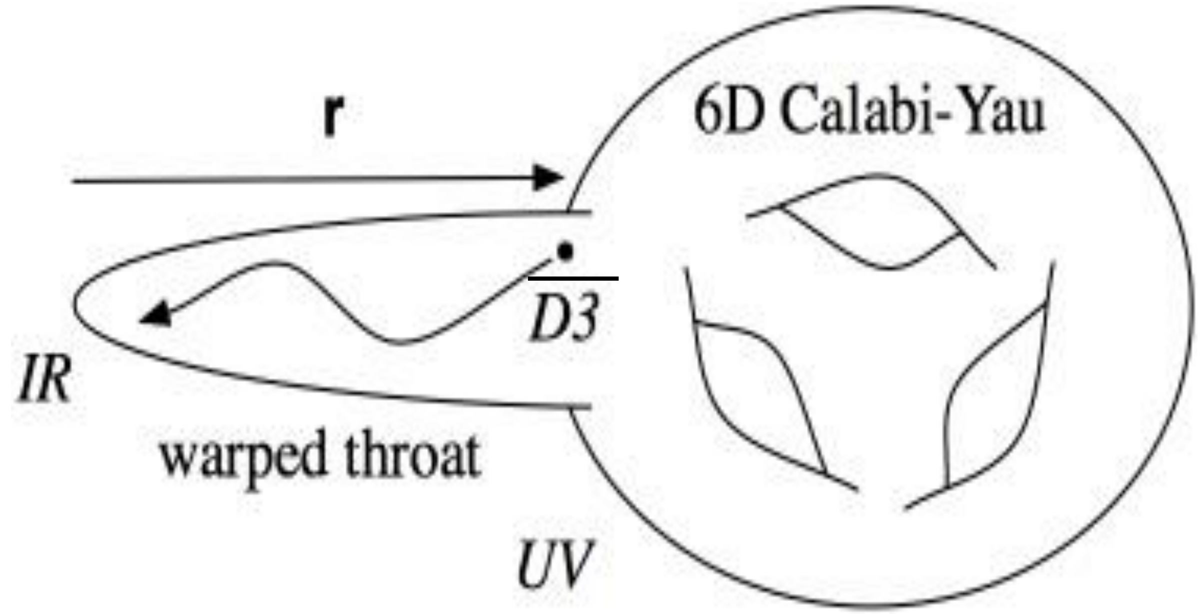

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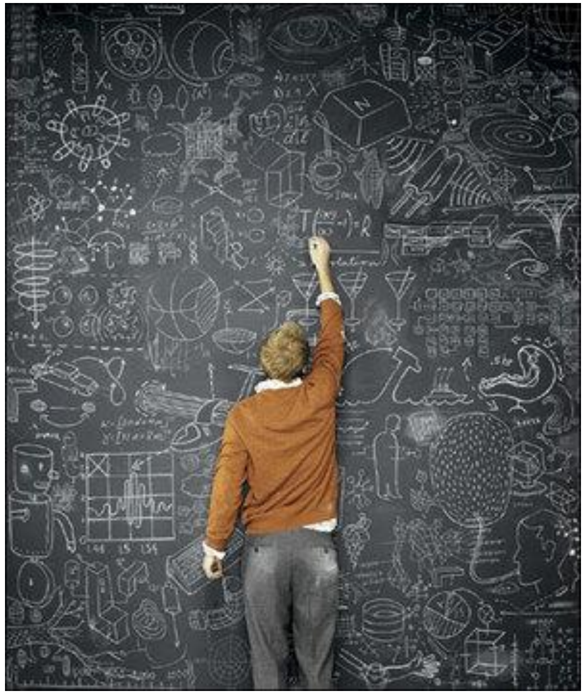
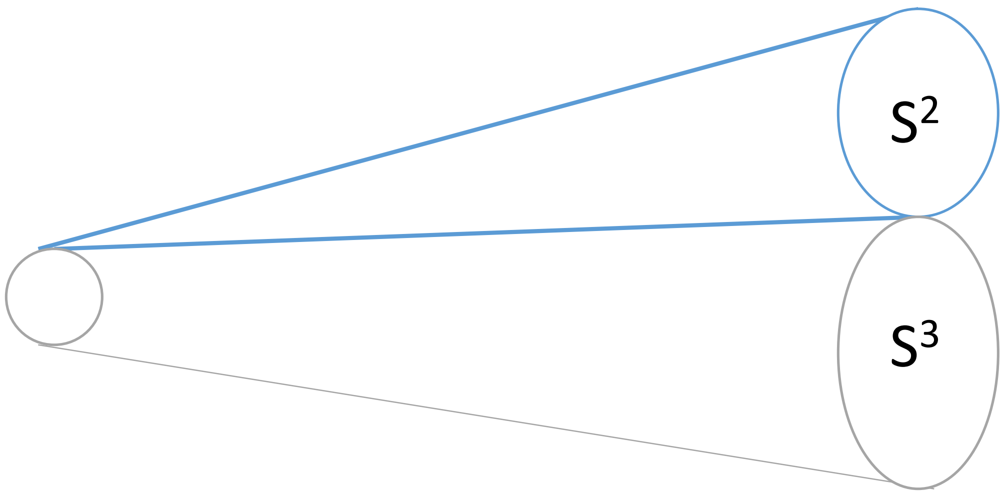


1. SUSY-breaking & uplifting from a ‘natural’ source.
2. SUSY-breaking is in principle entirely 10D, entirely within SUGRA

→ *a unique model to study in all its complex glory*.

A study from supergravity?

1. Pick a local model: Klebanov—Strassler (holographic viewpoint).
2. Enforce consistent SUGRA limit



- Flux: $\int_A F_3 = M$
- Number of anti-branes: p

Size of tip: $R_{\text{tip}} \sim g_s M$

Size of anti-branes: $R_{\overline{D3}} \sim g_s p$

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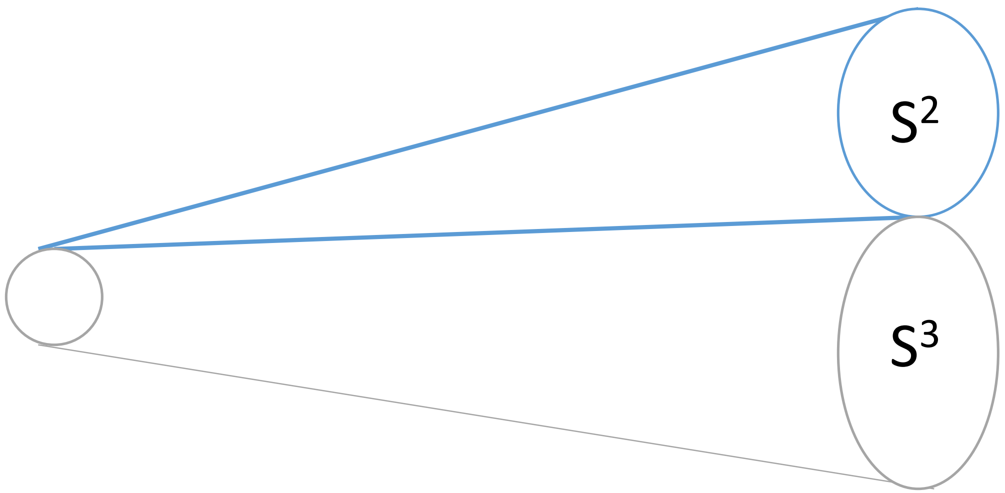

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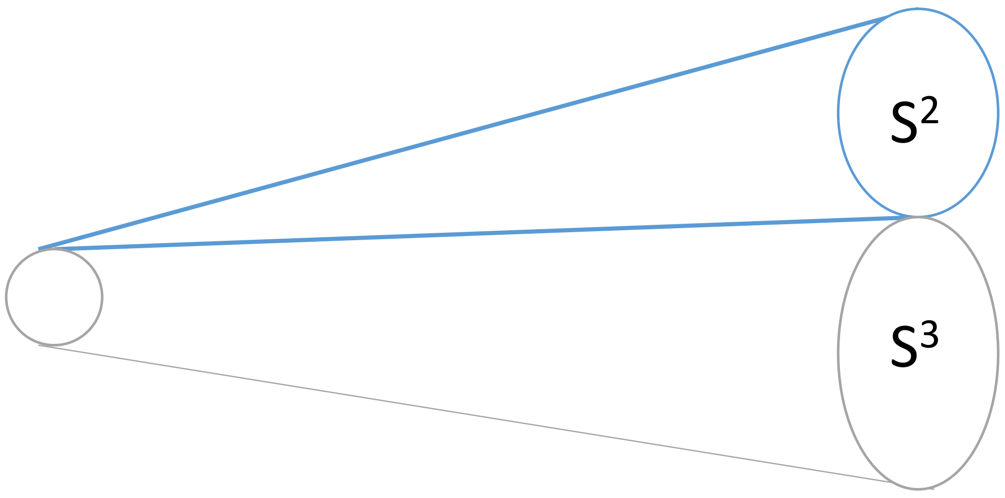

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- SUGRA :

$$g_s << 1\,, \quad g_s p >> 1\,, \quad g_s M >> 1$$

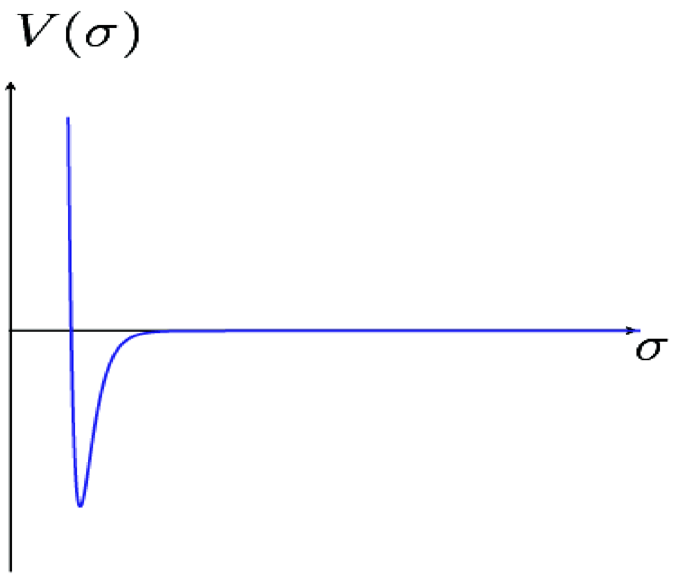
- Local confined backreaction :

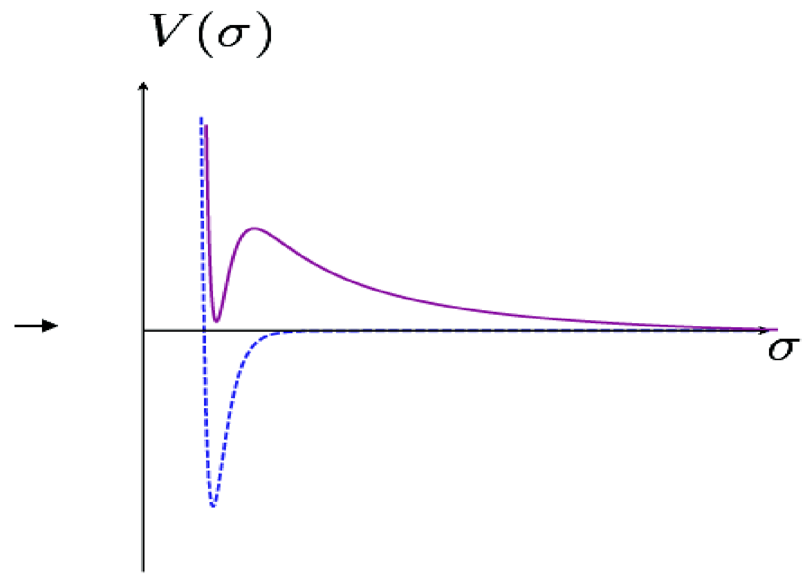
$$p/M << 1$$

Equals condition for stability! [Kachru & Pearson & Verlinde 2001]

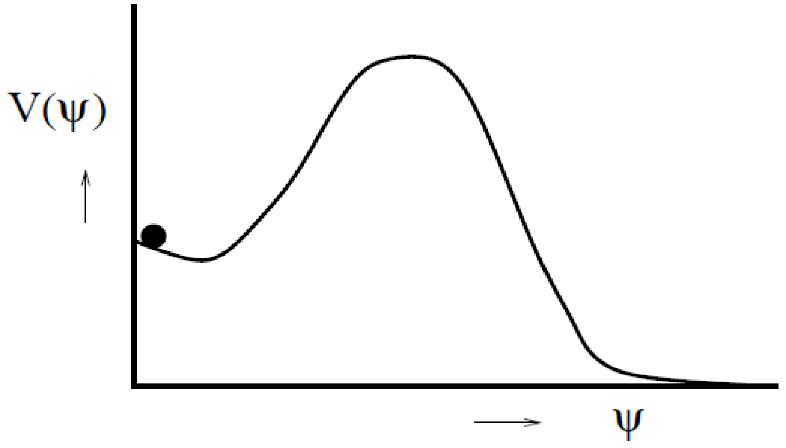
2 decay channels

1. In compact space: "closed string" stability = KKLT (2003)





2. In compact/non-compact space: "open string" stability = KPV (2001)



BRANE-FLUX DECAY

Debate since 2009
[Bena, Grana, Halmagyi & McGuirk, Shiu, Sumitomo]

BRANE-FLUX DECAY

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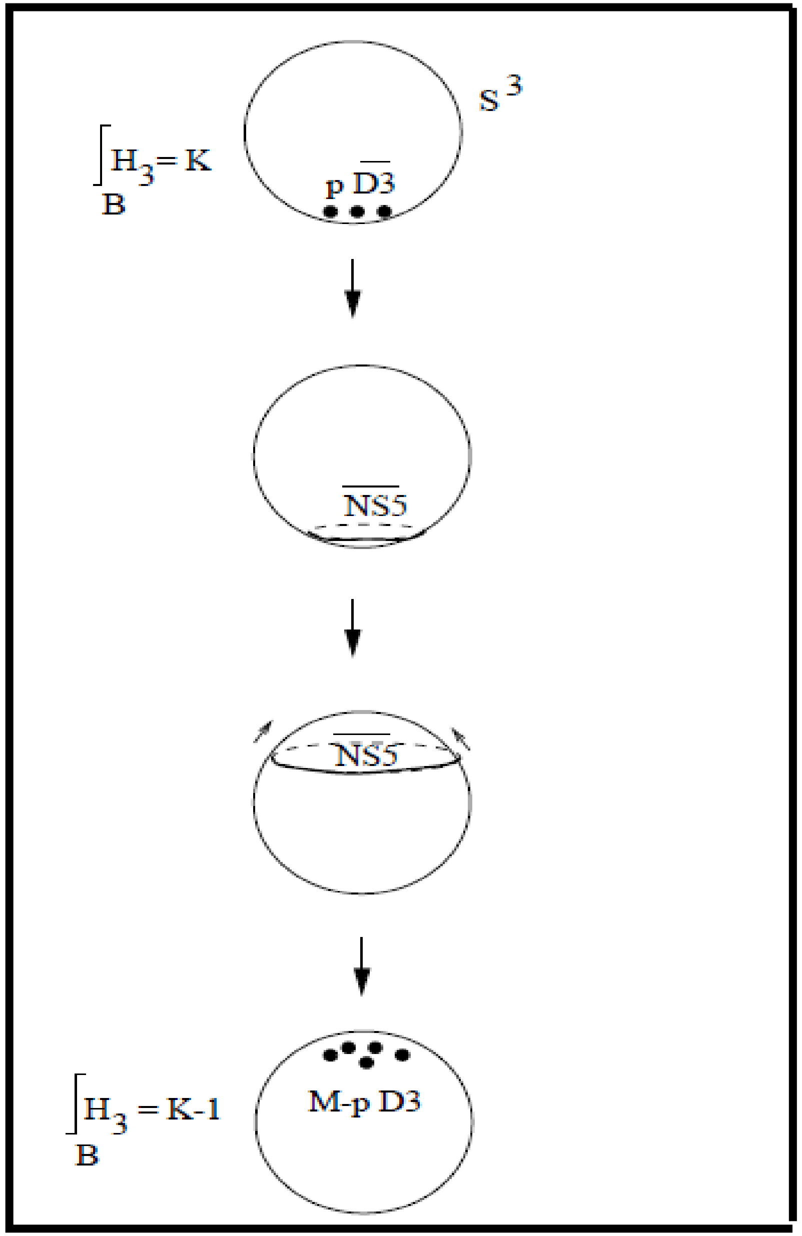
Flux materializes into M D3 branes (Myers)

p D3 branes annihilate with the anti-branes

- Key processes: Brane polarisation (Myers) + bubble nucleation (Brown-Teitelboim)

Kachru, Pearson, Verlinde



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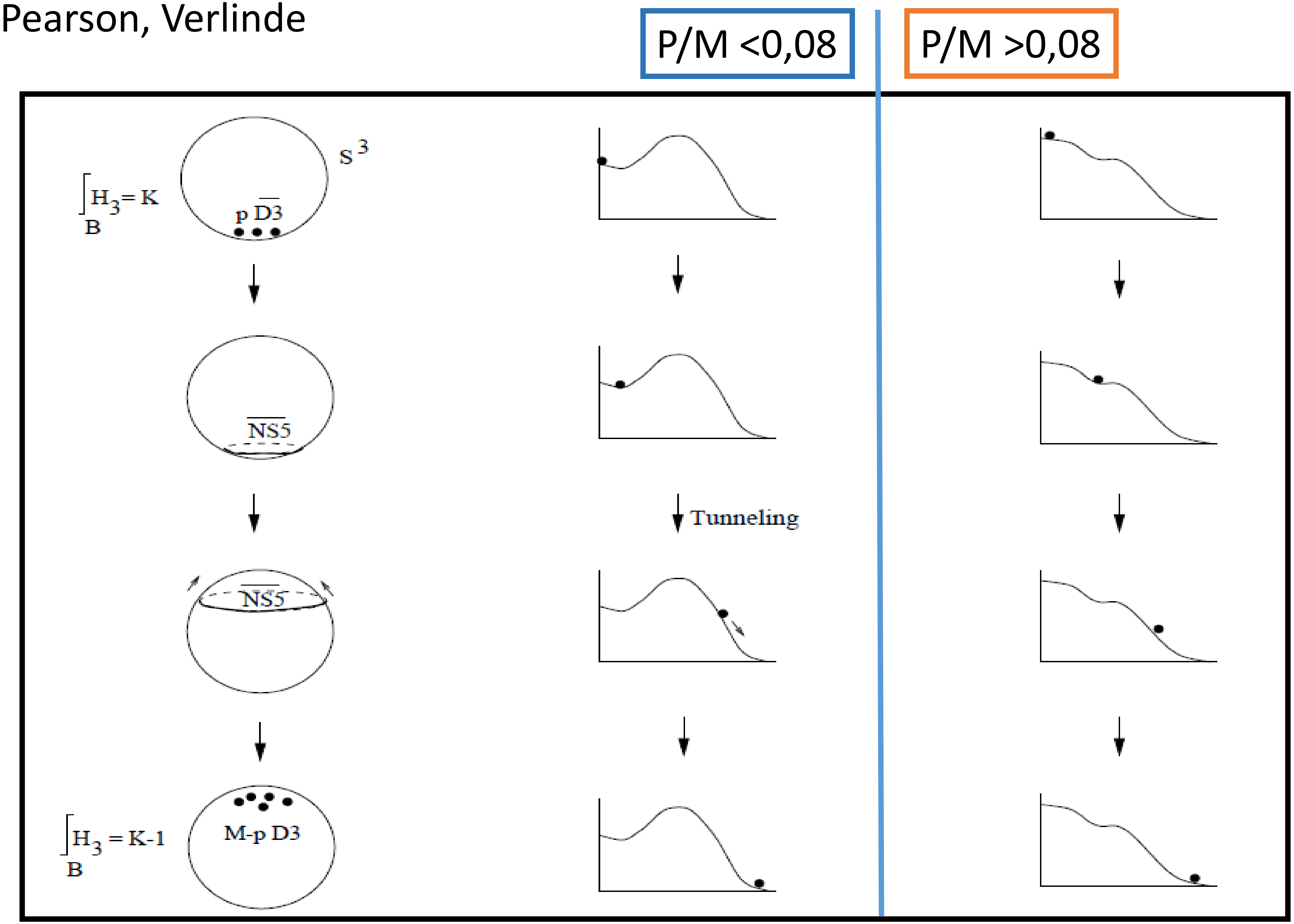
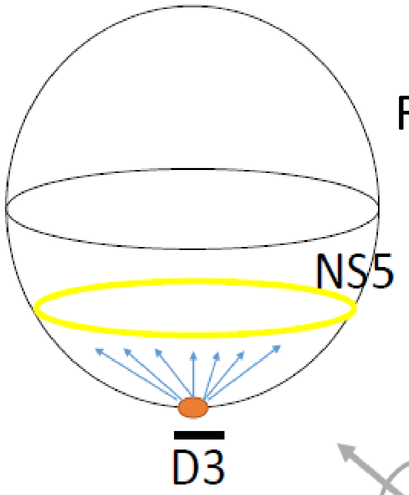
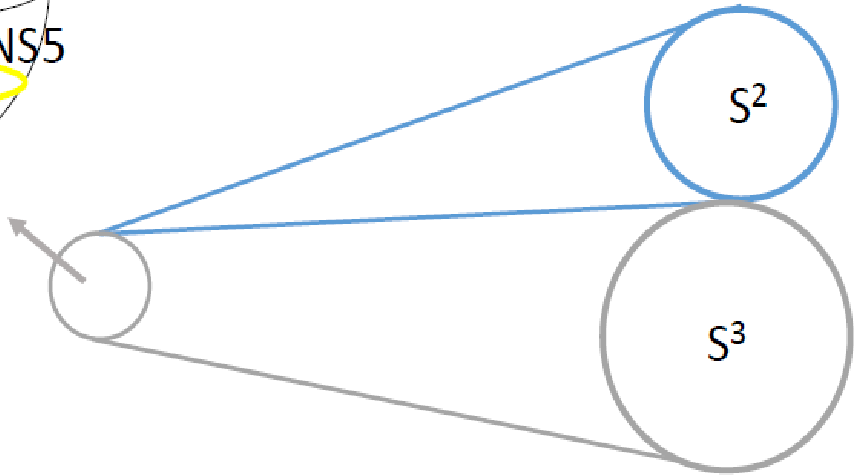


HOW?



Radius = third Euler angle ψ.



At ψ=0 the NS5 induces p anti-D3 charges and at ψ= π it induces M-p D3 charges

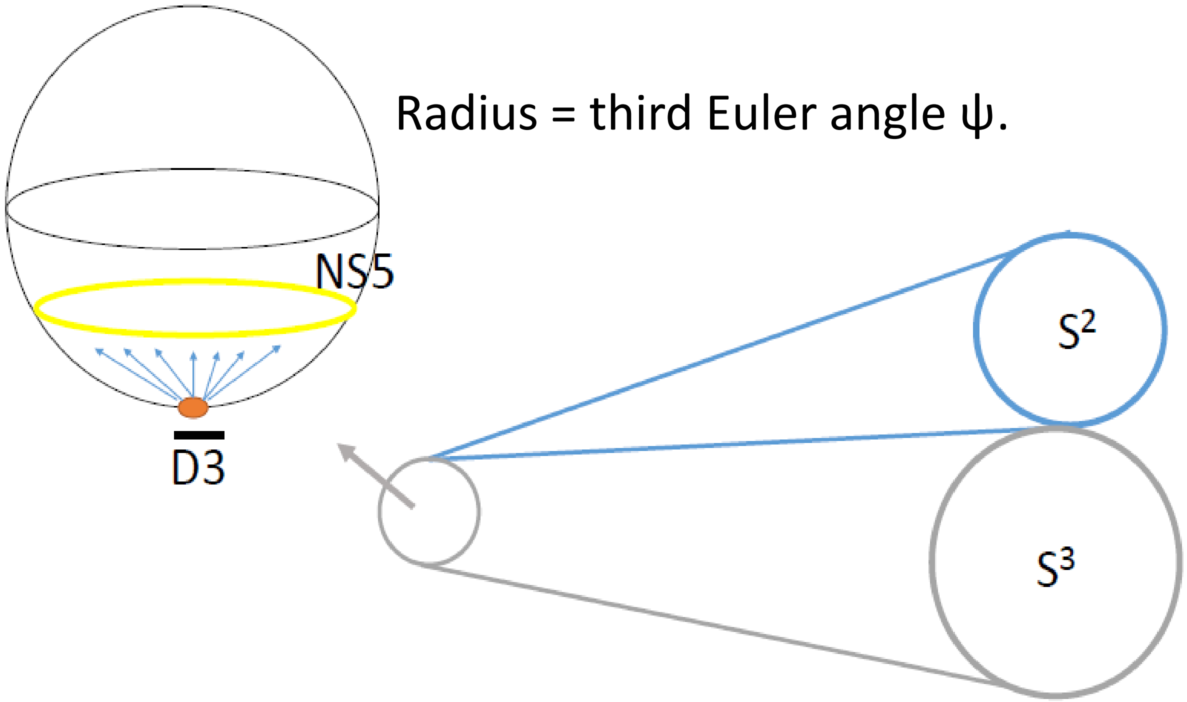
HOW?

WZ action NS5: $$\mu_5 \int B_6 + 2\pi \mathcal{F}_2 \wedge C_4$$

where: $$2\pi\mathcal{F}_2 = 2\pi F_2 - C_2$$

$$\int_{S^2} C_2 = 4\pi M(\psi - \tfrac{1}{2}\sin(2\psi))$$

$$2\pi \int_{S^2} F_2 = 4\pi^2 p\,.$$



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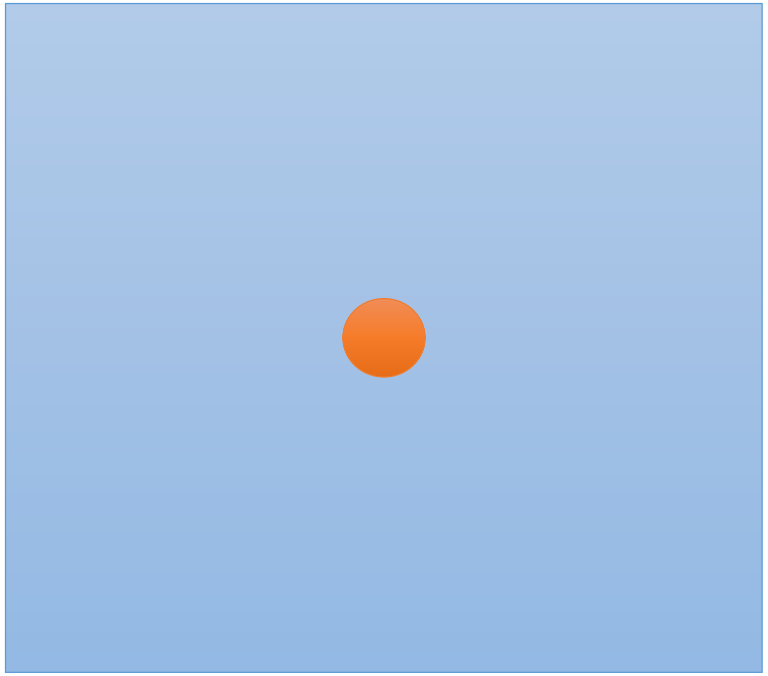
Back-reaction

Back-reacted solutions near the sources: $e^{-\phi} H^2 \to \infty$

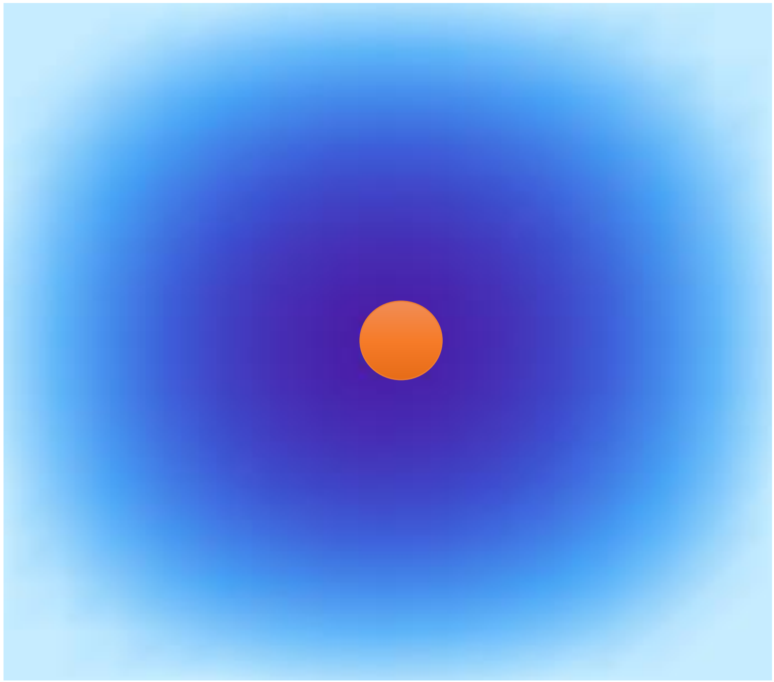
Due to ``flux-clumping'' or ``screening'':

KPV computation: no backreaction



Flux is attracted towards anti-branes both gravitationally and electromagnetically

With backreaction



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Indeed (Blaback, Danielsson, TVR 2012, Danielsson, VR 2014)

$$H = \lambda g_s \star_6 F_3$$

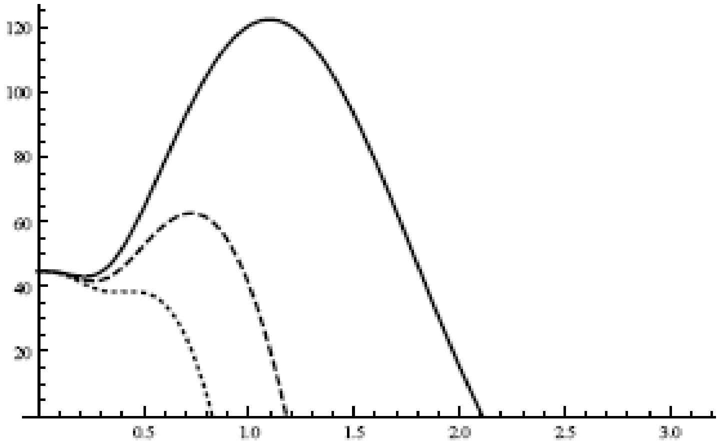

Figure 2: *The effective potential relevant for the NS5-motion, plotted for different values of λ.*

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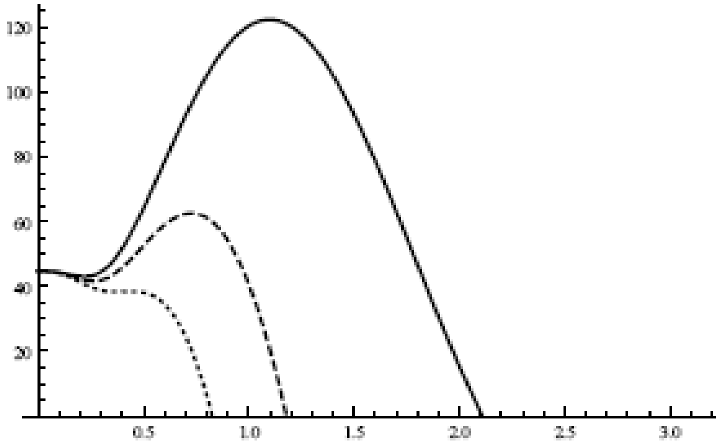

Figure 2: *The effective potential relevant for the NS5-motion, plotted for different values of* λ.

Resolution of singularity due to **time-dependence**

1. Singularity around antiD3 represents singular pile up of *charge dissolved in flux*

2. If too much D3 charge dissolved in flux near anti-D3: direct annihilation.

3. Hence no vacuum but "side of the hill" .

Arguments beyond heuristic approach

1. <u>Backreaction corrections to a probe computation:</u> Both methods are free of infinities

- Method 1: EFT approach a la Goldberger & Wise: Mintun, Michel, Polchinski, Puhm, Saad. Applicable most easily for p=1. Outside of SUGRA regime. See talk A. Puhm.

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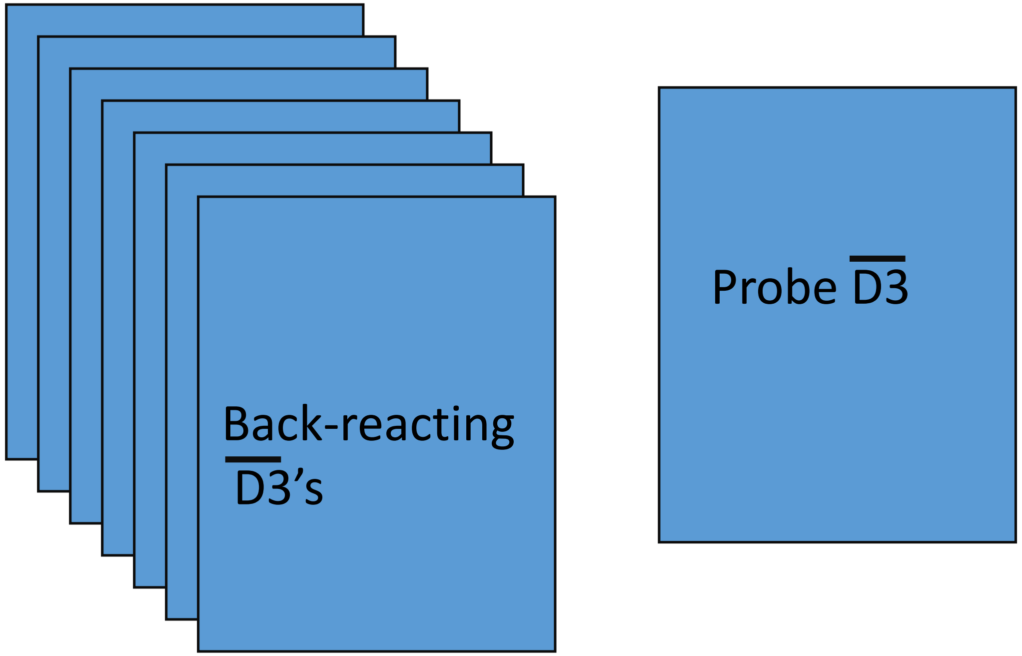

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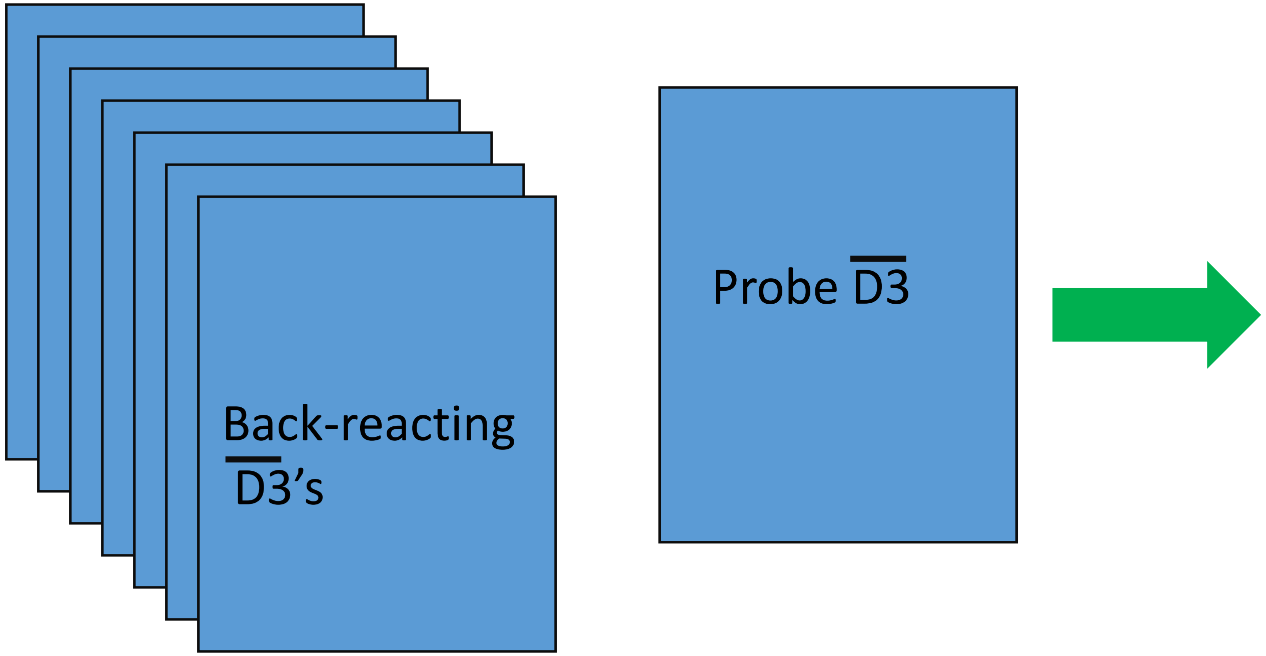

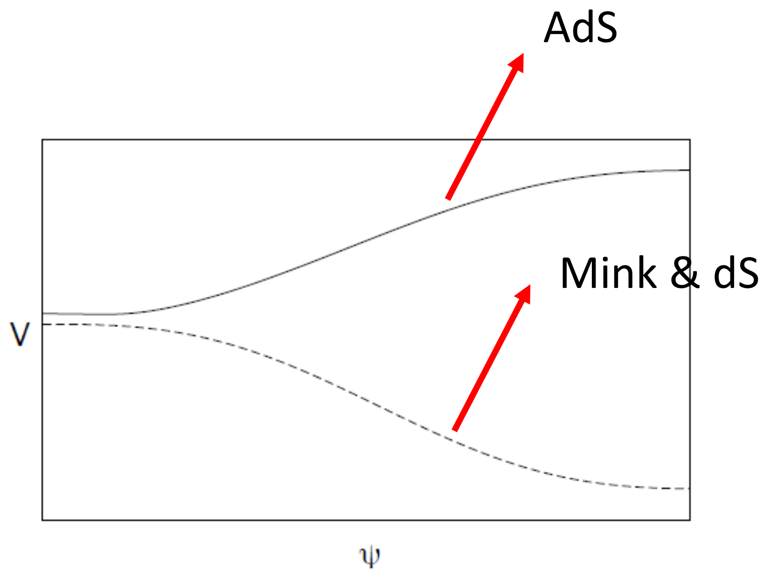

[Gautason, Truijen, VR 2015]
[Danielsson, Gautason, Truijen, VR , in progress]

Arguments beyond heuristic approach

[Cohen-Maldonado, Diaz, VR, Vercnocke, in progress]

2. Full SUGRA solution of backreacting NS5 branes?

- Singular flux clumping is NOT replaced by ordinary singular 3-form flux of NS5 branes

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

→ Natural singularity sourced by NS5

→ But also singular flux clumping!

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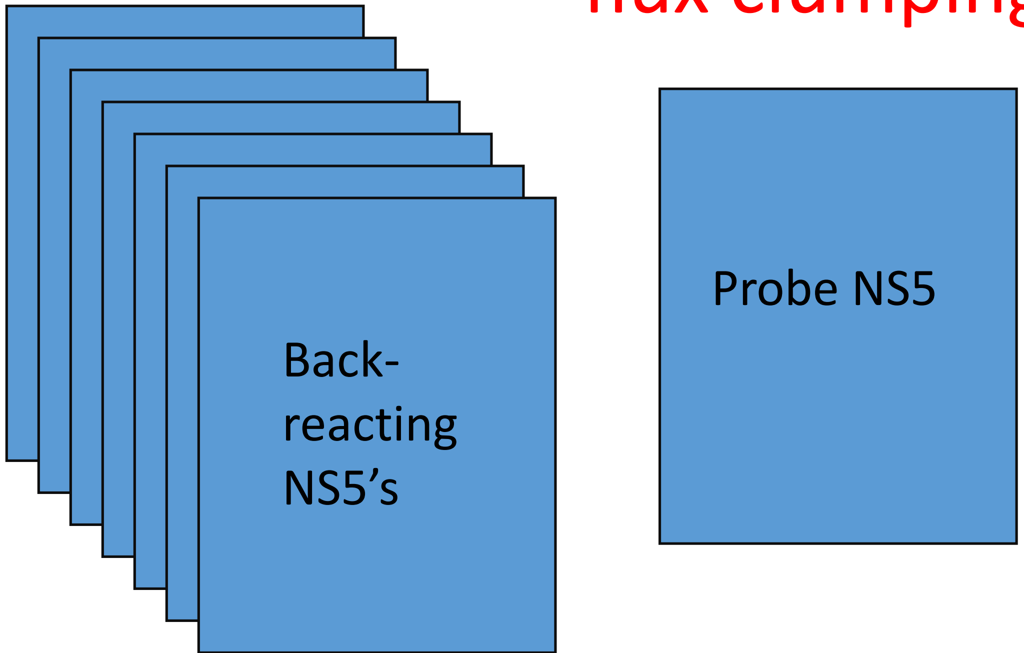
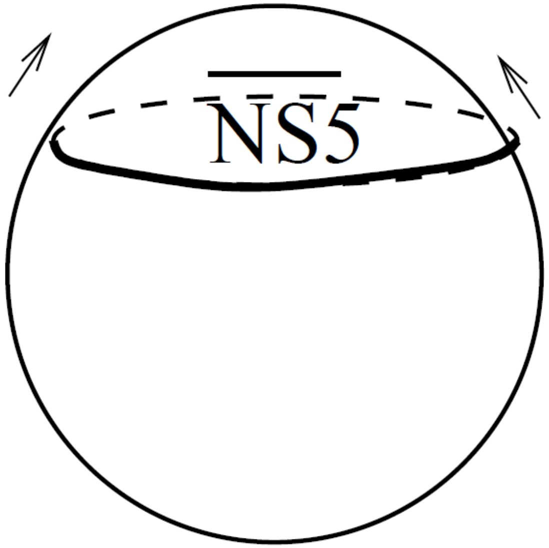


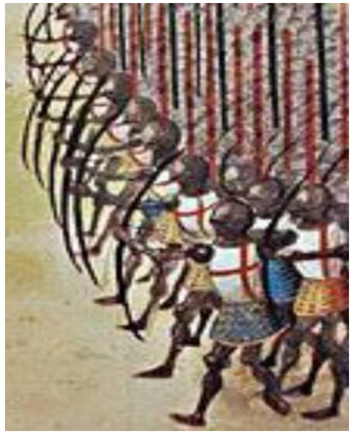


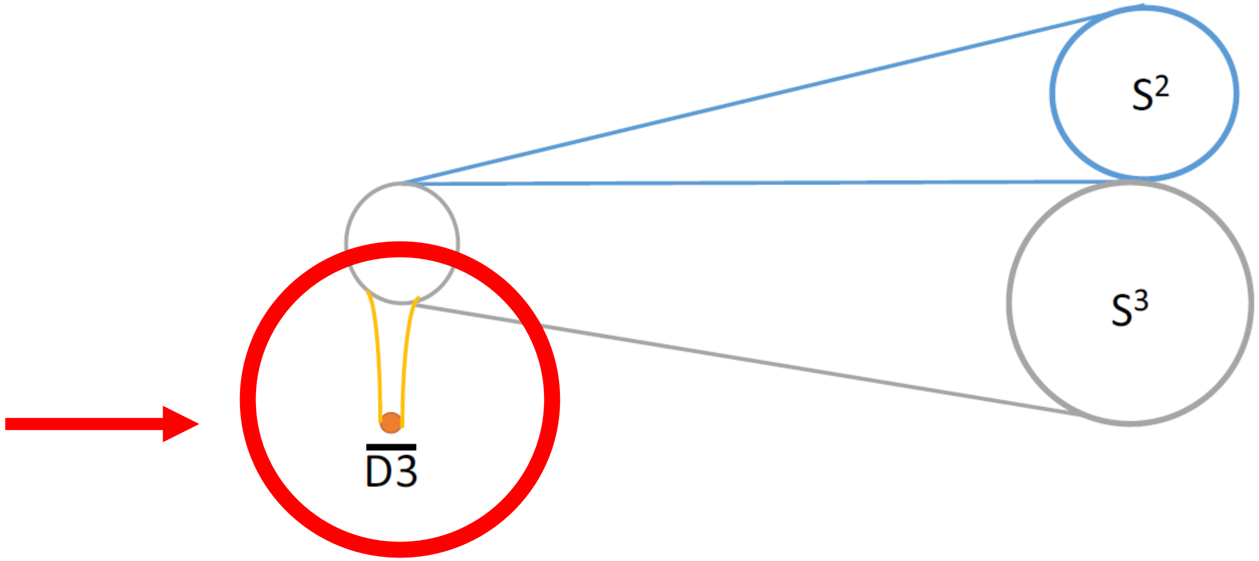
Probe is pushed away: stack is unstable. NS5's want to Move upward towards the North Pole = SUSY vacuum!

What others think:

See talk S. Massai

- Bena, Grana, Kuperstein, Massai:





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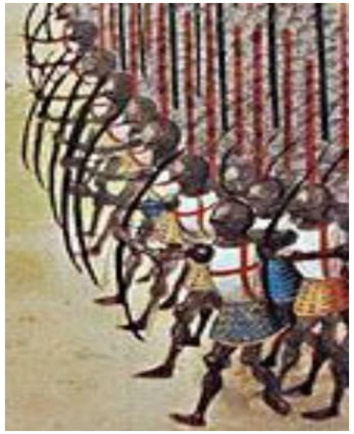

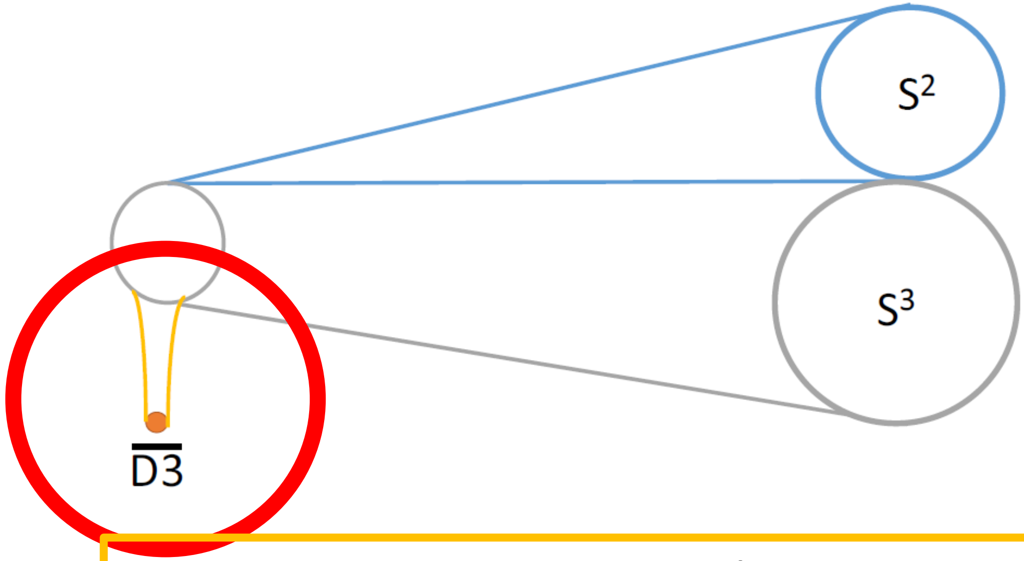

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My speculations:

- Branes can never be pushed out of KS throat.
- BUT can be pushed out of local PS throat. Towards....moving over the compact A-cycle!
- End point: brane flux decay.

→ Consistent with our probe NS5 being pushed away.

What others think:

See talk A. Puhm

- Mintun, Michel, Polchinski, Puhm, Saad:

→ Leave SUGRA and go to p=1.

→ Myers picture not relevant anymore. Stringy regime.

→ Argue using EFT, singularity is ‘renormalized’ : *very mild clumping after cut of at string scale…* No instability.

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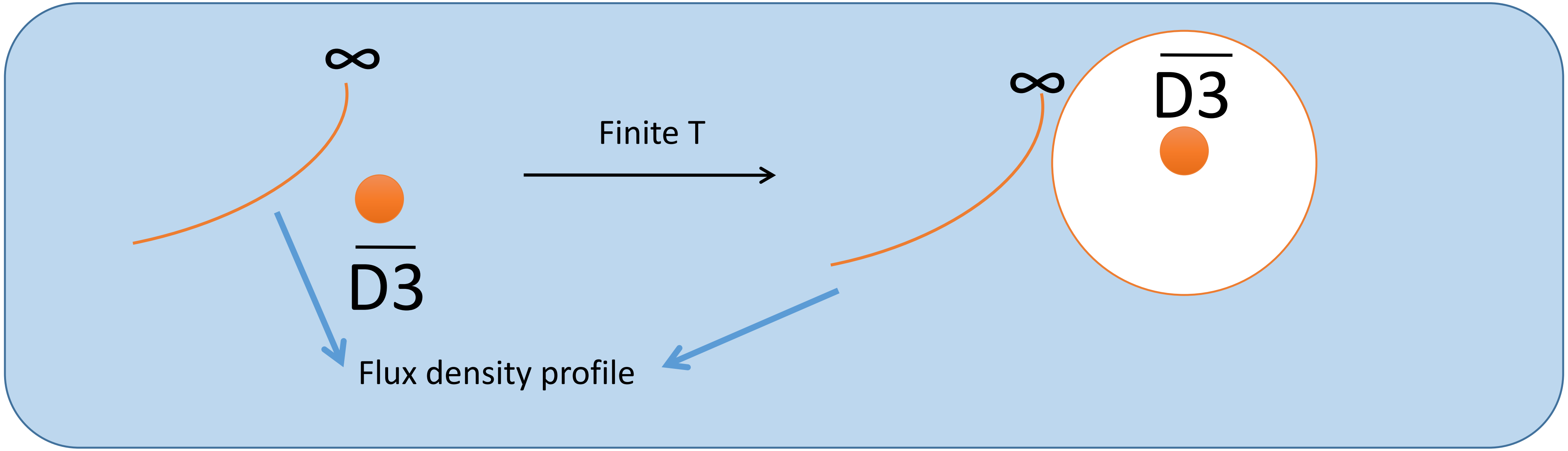
My speculations:

- If stable then also in SUGRA regime, as long as p/M <<1.
- What is decay mechanism when p=1?
- Aim of flux vacua is to construct vacua as explicit as possible. Within SUGRA regime.

Finite temperature

A “good” singularity can be cloaked behind finite T horizon? [Gubser 2000]

- *Does not work* for <u>smeared</u> anti-Dp with p<6 & anti-D6 *[Buchel, Bena, Dias, 2012, Bena, Blaback, Danielsson, VR, 2013]*
- Does not work for <u>localized</u> anti-Dp *[Blaback, Danielsson, Junghans, Vargas, TVR 2014]*



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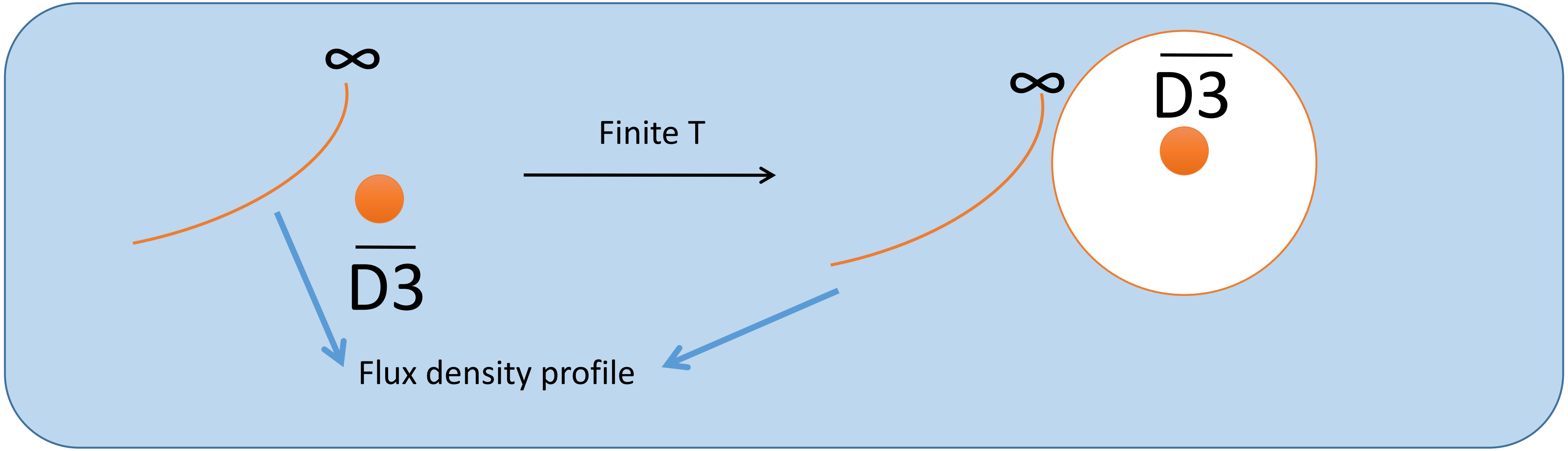

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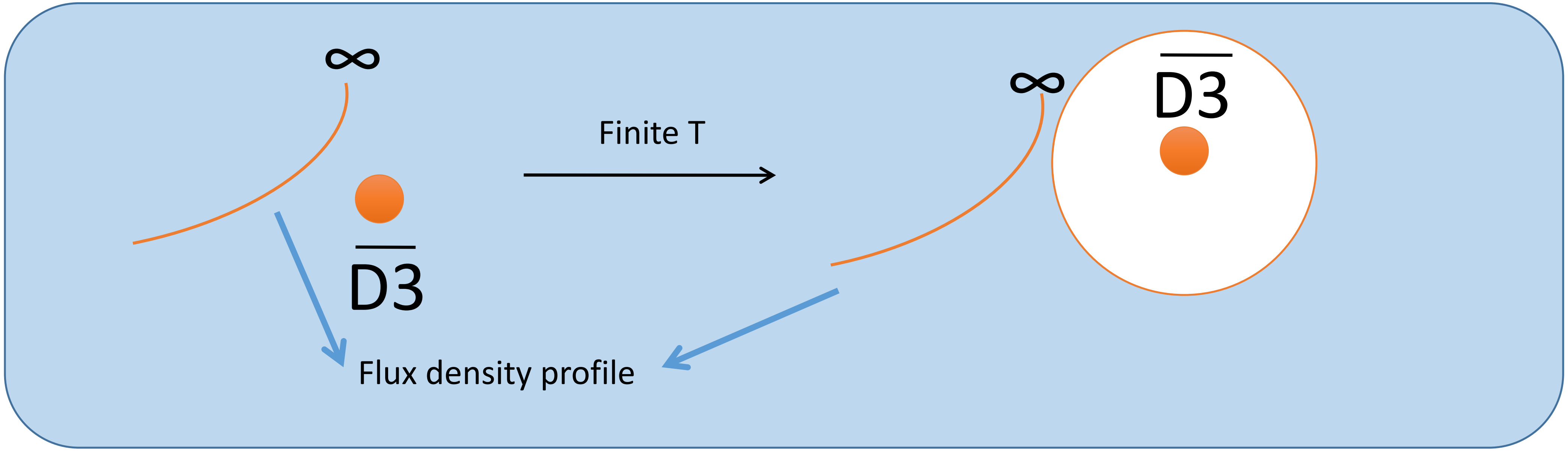

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- *Could work [Cohen-Maldonado, Diaz, VR, Vercnocke]* for p<6, but unclear if it will.

Conclusions

The pros

1. Very natural & 10D way of breaking SUSY by tunable amount.

The cons

1. 10d back-reaction obscures things. Dine-Seiberg again?

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4. Good finite T solutions for anti-D3 still lacking.

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5. Tachyons disappear after brane reshuffling?

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3. Does not seem to happen.
4. Good finite T solutions for anti-D3 still lacking.
5. Tachyon means push over A-cycle, brane flux decay?

The pros		The cons
1. Very natural & 10D way of breaking SUSY by tunable amount.	⟺	1. 10d back-reaction obscures things. Dine-Seiberg again?
2. Singularity is not that unexpected (Polchinski-Strassler)	⟺	2. Singularity is such that we have a local increase in Dp charge dissolved in flux around anti-Dp
3. Flux clumping instability might be circumvented due to blow-up of anti-D3 charge	⟺	3. Does not seem to happen.
4. The nogo theorems for absence of finite T solutions are not exclusive unless for anti-D6.	⟺	4. Good finite T solutions for anti-D3 still lacking.
5. Tachyons disappear after brane reshuffling?	⟺	5. Tachyon means push over A-cycle, brane flux decay?
6. For p=1 the instability dangers are absent?	⟺	6. Are we 100% certain we understand p=1? Why then possible failure for larger p?

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Singularities & related instabilities do not appear for anti-brane SUSY breaking in black holes microstates if one works with **horizonless** "anti-branes" [*Cohen-Maldonado, Diaz, VR, Vercnocke, in progress*].

Thanks!

BACK UP SLIDES

General process/principle [Gautason, Truijen, VR (2015)]

- RR tadpole $$\int_M H_3 \wedge F_{6-p} = 2\kappa_{10}^2 Q_p$$

- $$\int_B H_3 \sim K$$
- $$\int_A F_{6-p} \sim M$$
- $$Q \sim N_p$$

→ $$N_p = KM$$

- Hence

$$\begin{aligned} \text{NSNS decay} &: \quad K \to K-1 \quad , \quad N_p \to N_p - M\,, \\ \text{RR decay} &: \quad M \to M-1 \quad , \quad N_p \to N_p - K\,. \end{aligned}$$

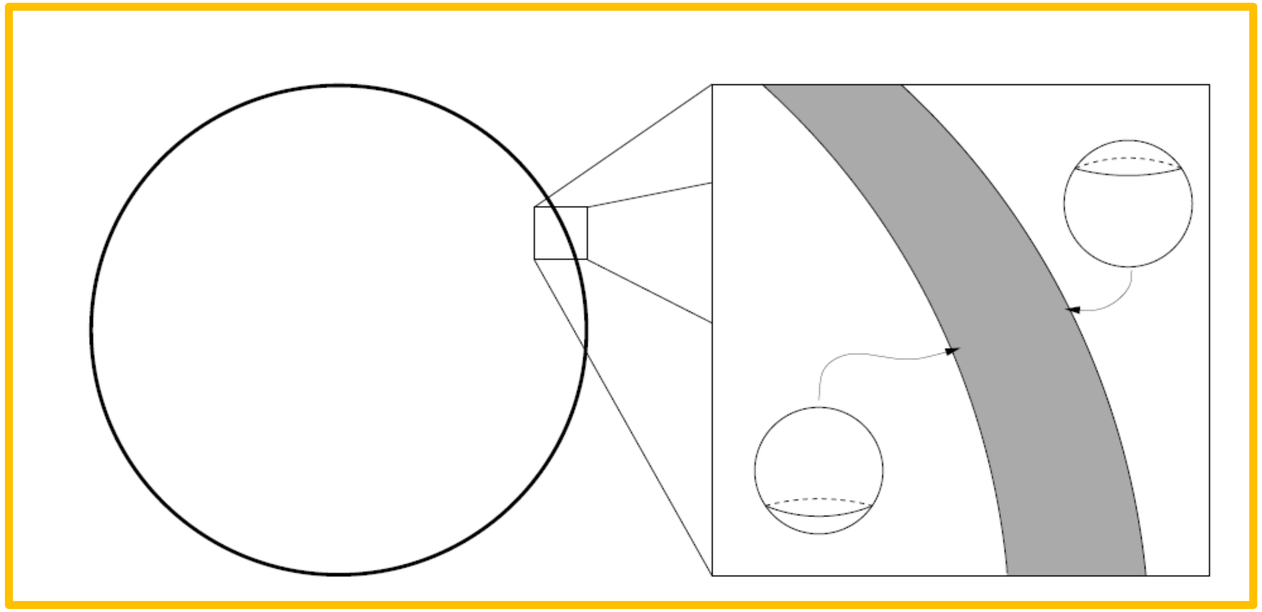
- For p<6:

	Thin wall	$p+1$			A-cycle			B-cycle		
	Op/Dp	$\times$	...	$\times$	$-$	...	$-$	$-$	...	$-$
NSNS decay:	NS5	$\times$	...	$\uparrow$	$\times$	...	$\times$	$-$	...	$-$
RR decay:	D$(p+2)$	$\times$	...	$\uparrow$	$-$	...	$-$	$\times$	...	$\times$

	Thick wall	$p+1$			A-cycle			B-cycle		
	Op/Dp	$\times$	...	$\times$	$-$	...	$-$	$-$	...	$-$
NSNS decay:	NS5	$\times$	...	$\times$	$\times$	...	$\uparrow$	$-$	...	$-$
RR decay:	D$(p+2)$	$\times$	...	$\times$	$-$	...	$-$	$\times$	...	$\uparrow$

- For p=6 : NSNS thick wall, via KK5 branes inside D6 branes.

WZ couplings for thick wall process (brane decay/nucleation):



$$\mu_{\mathrm{NS5}} \int (\mathrm{d}a_{4-p} - C_{5-p}) \wedge \sigma(C_{p+1}) \ ,$$

$$Q(x) = (2\pi)^{\frac{p-5}{2}} \int_{\Sigma_{5-p}(x)} (\mathrm{d}a_{4-p} - C_{5-p}) \, ,$$

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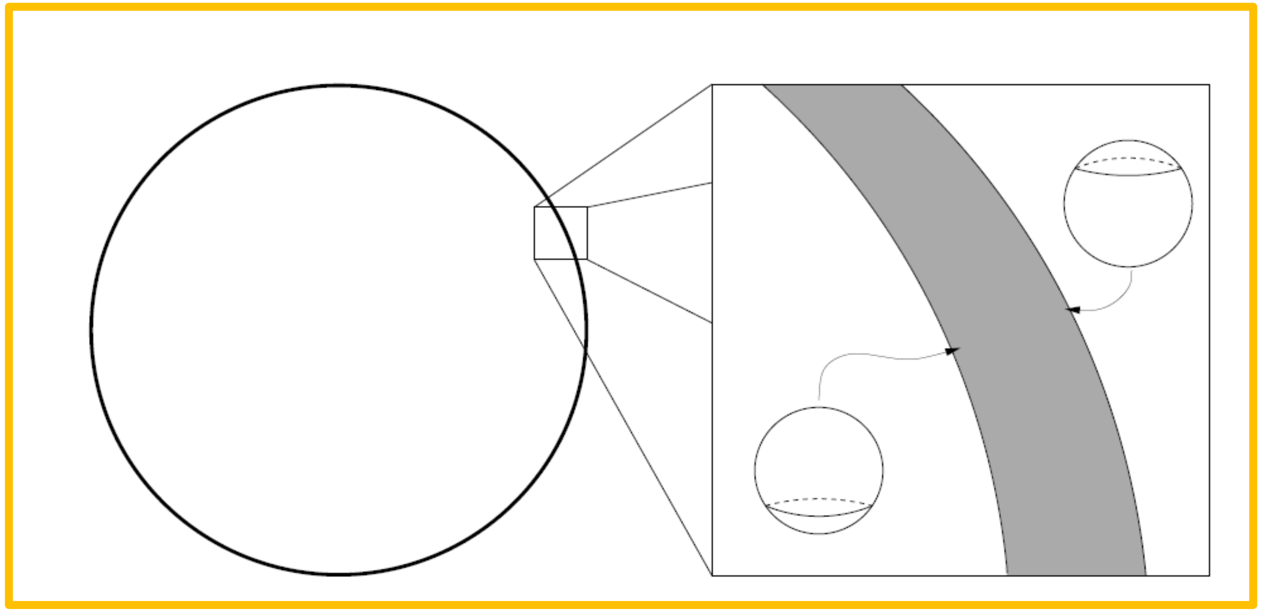

- Quantised worldvolume flux:

$$\int_{\Sigma_{5-p}(x)} \mathrm{d}a_{4-p} = (2\pi)^{\frac{5-p}{2}} n \, .$$

- Stokes theorem:

$$\int_{x\to 1} C_{5-p} - \int_{x\to 0} C_{5-p} = \int_A F_{6-p} = (2\pi)^{\frac{5-p}{2}} M \ .$$

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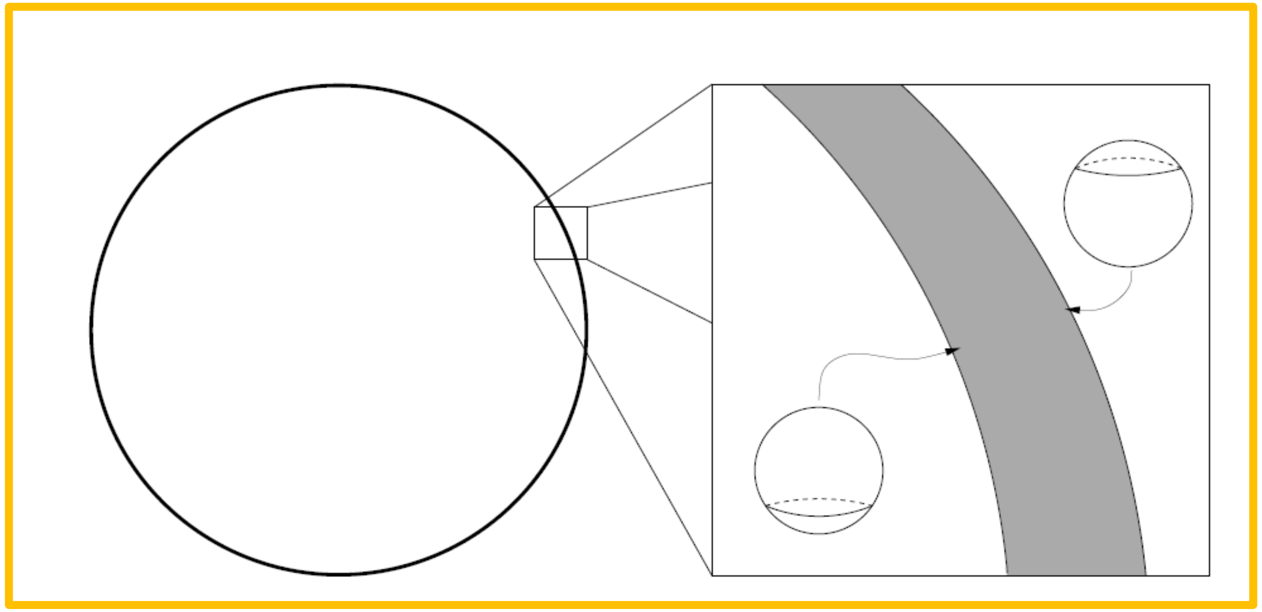

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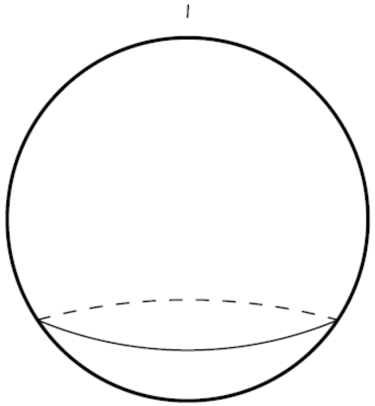
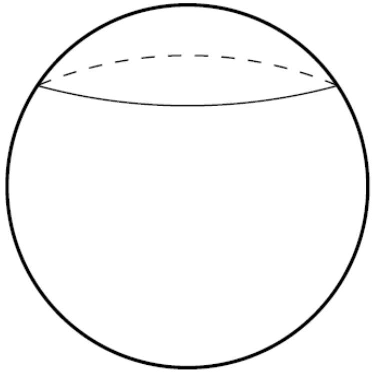


$$Q(1) = n - M \, .$$



Consistency conditions for gluing UV KS throat to IR anti-D3 throat.

[Blaback, Danielsson, Junghans, VR, Vargas, 2014]
based on [Gautason, Junghans, Zagermann 2013]

Ansatz:

$$ds_{10}^2 = e^{2A} g_{\mu\nu} dx^\mu dx^\nu + ds_6^2 \,,$$
$$C_4 = \tilde{\star}_4 \alpha,$$
$$H_3 = e^{\phi - 4A} \star_6 \left([\alpha + \alpha_0] F_3 + X_3 \right)$$

Where

$$F_3 = M \epsilon_A + \hat{F}_3$$

$$g_{\mu\nu} dx^\mu dx^\nu = -e^{2f} dt^2 + \delta_{ij} dx^i dx^j$$

Horizon: $e^{2f} = 0$

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Horizon: $e^{2f} = 0$

$$e^{-\phi} |H_3|^2 \sim e^{-2f} |\alpha F_3 + X_3|^2$$

When non-zero?

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

Argue from a conserved current!

- The following 9-form:

$$\mathcal{B} = -C_4 \wedge F_5 - \tilde{\star}_4 1 \wedge B_2 \wedge X_3 + \star_{10} \mathrm{d}\Big(\phi - 4A - f\Big)$$

obeys:

$$0 = \oint_{\partial \mathcal{M}_{\mathrm{empty}}} \mathcal{B} = \oint_{\mathrm{IR}} \mathcal{B} - \oint_{\mathrm{UV}} \mathcal{B}\,.$$

[Blaback, Danielsson, Junghans, Vargas, TVR 2014]

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- *This is enough info about the fluxes in the IR to see whether singularity is absent or not.*

[Blaback, Danielsson, Junghans, Vargas, TVR 2014]