Who likes de Sitter?

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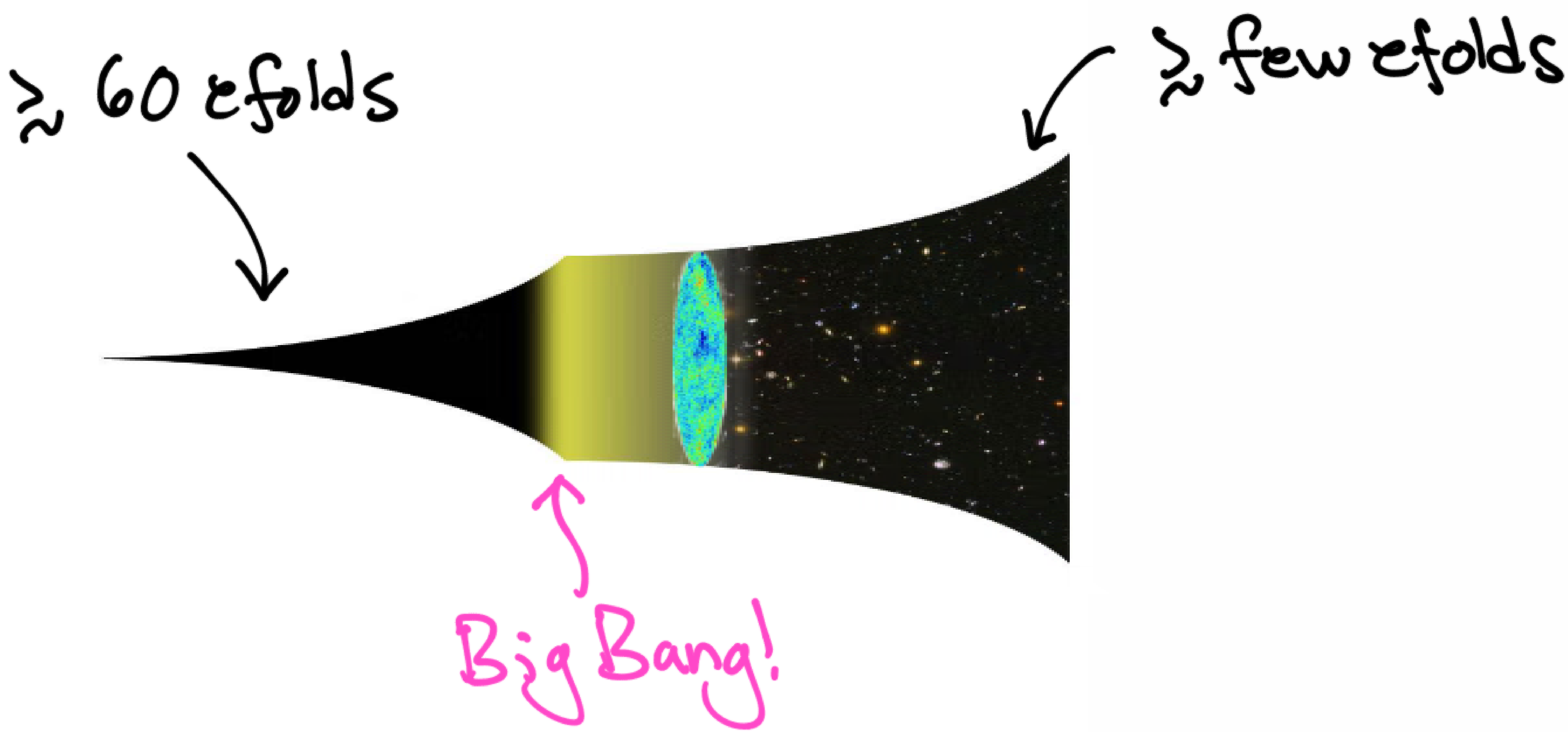
History

$\lesssim 1998$; String theory $\Rightarrow$ $\cancel{\text{dS}}$

$1998 \sim 2003$; ?

$\gtrsim 2003$; String theory $\Rightarrow$ lots of dS!

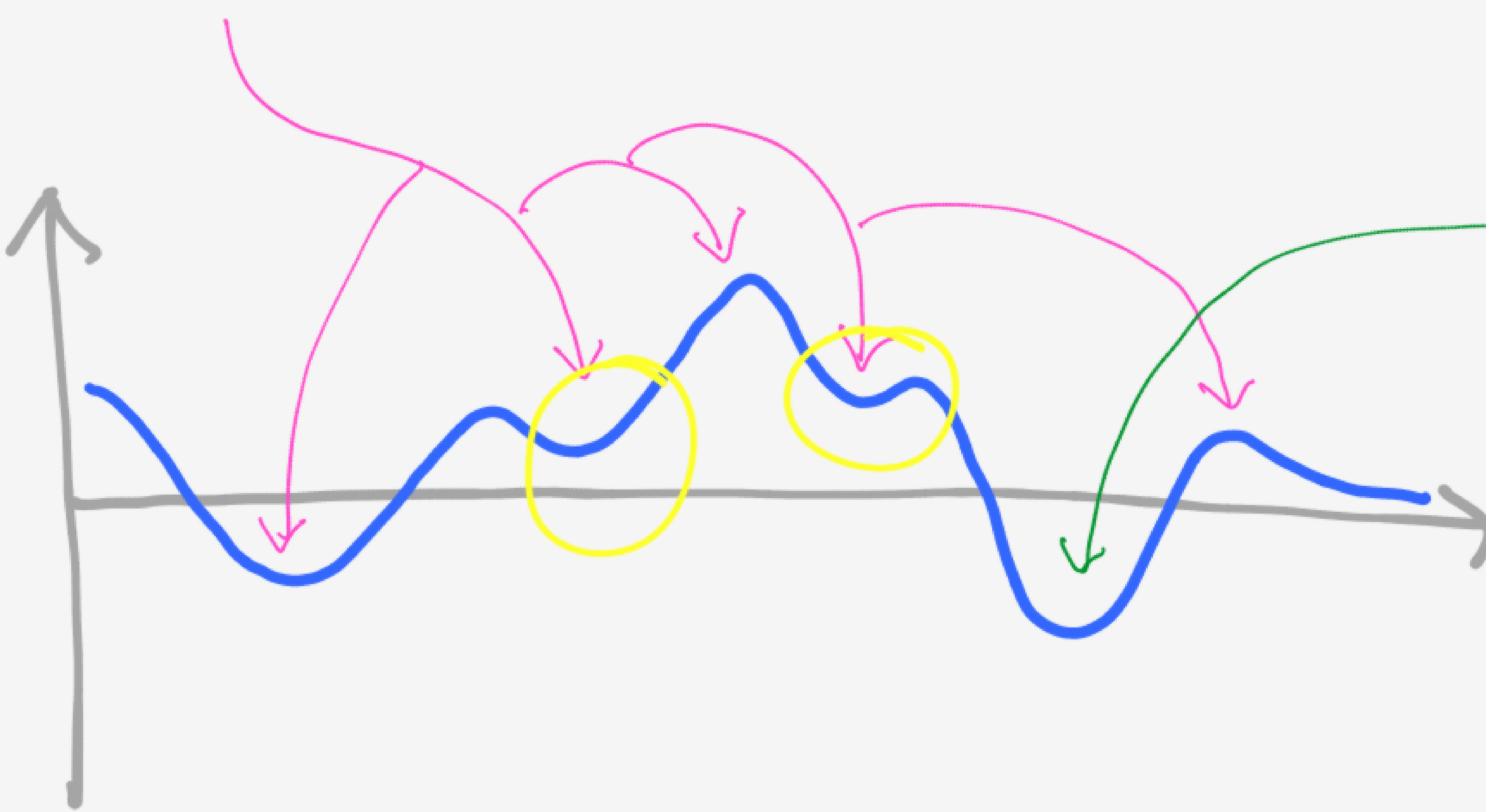

$\gtrsim$ 60 efolds
$\gtrsim$ few efolds
Big Bang!

Explicit ~~SUSY~~... (through uplift)

Add $\bar{D}$ (actually $D+\bar{D}$) to stabilized SUSY AdS...

Spontaneous ~~SUSY~~... (at tree level)

Consider ~~SUSY~~ vacua in potential with SUSY vacua...



Rest of talk

* String theory on $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$
* Uplifting and a generic problem
* Conclusions...

String theory on $T^6/\mathbb{Z}_2\times\mathbb{Z}_2$

Orbifolding $\rightarrow$ $\mathcal{N}=2$

... and the orientifold $\rightarrow$ $\mathcal{N}=1$

Can be interpreted as

IIA with O6 or IIB with O3/O7

We will focus on IIA ...

Orbifold:

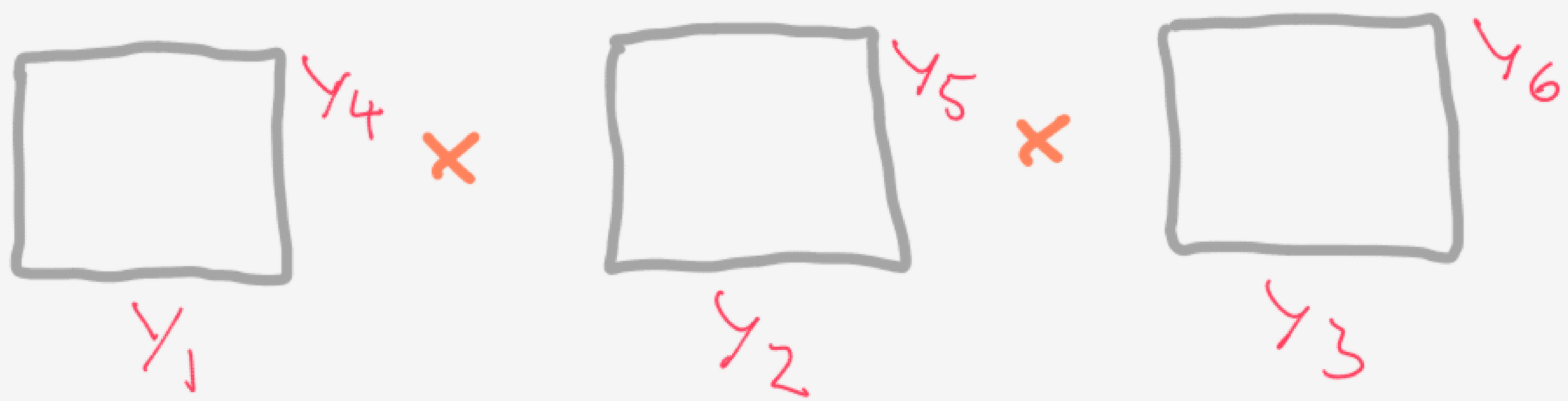
$$\theta_1 : (y^1, y^2, y^3, y^4, y^5, y^6) \to (-y^1, -y^2, y^3, -y^4, -y^5, y^6)$$

$$\theta_2 : (y^1, y^2, y^3, y^4, y^5, y^6) \to (-y^1, y^2, -y^3, -y^4, y^5, -y^6)$$

$$\theta_1\theta_2 : (y^1, y^2, y^3, y^4, y^5, y^6) \to (y^1, -y^2, -y^3, y^4, -y^5, -y^6)$$

... which splits:

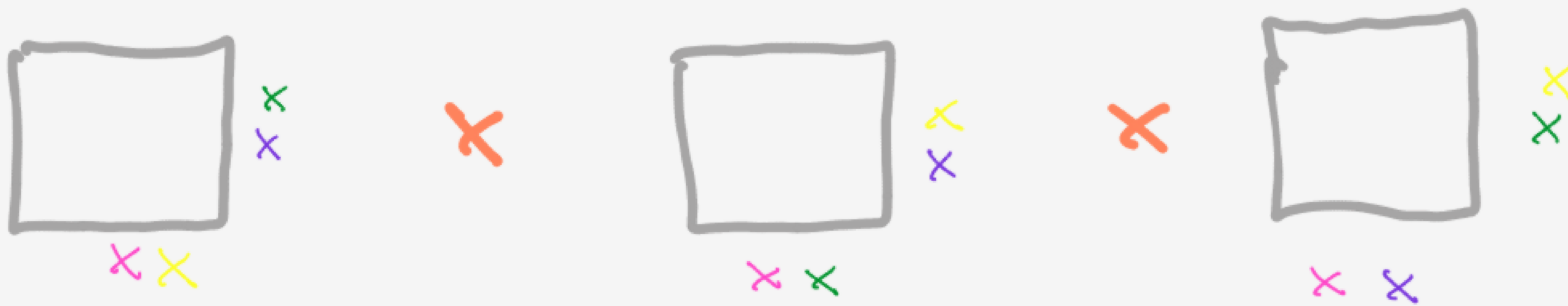
$T^6 =$



Orientifold at fixed point of

$$\sigma : (y^1, y^2, y^3, y^4, y^5, y^6) \to (y^1, y^2, y^3, -y^4, -y^5, -y^6)$$

... and at $\sigma\theta_1$, $\sigma\theta_2$, $\sigma\theta_1\theta_2$

$T^6 =$ 

Consider compactification on:

$$ds^2_{10} = \tau^{-2} ds^2_4 + \rho\, ds^2_6$$

with $\tau = \rho^{3/2} e^{-\phi}$ for Einstein frame...

We get $V = V_R + V_H + \sum V_q + V_{O/D}$ $\quad (q = 0, 2, 4, 6)$

where $V_R \sim -R_6 \sim \rho^{-1} \tau^{-2}$ $\quad V_H \sim \rho^{-3} \tau^{-2}$

$V_q \sim F_q^2 \sim \tau^{-4} \rho^{3-q}$ $\quad V_{O/D} \sim \tau^{-3}$

Basic result: $\boxed{\text{dS requires } V_R > 0 \quad V_{O/D} < 0}$

Are there (meta)-stable solutions without tachyons?

Not enough to consider just ρ and τ ...

For instance:

$$ds_6^2 = \rho\left(\sigma^3 ds_3^{2\,\parallel} + \sigma^{-3} ds_3^{2\,\perp}\right)$$

... with respect to σ-plane.

Tachyons will in general turn up when σ involved...

To be more explicit one can make use of

SU(3)-structures

Decompose: $SO(6) \supset SU(3)$

Globally defined (singlets under $SU(3)$):

Real 2-form: J

Holomorphic 3-form: Ω

For us:

$$dJ = \frac{3}{2}\,\mathrm{Im}(\overline{W_1}\,\Omega) + W_3$$

$$d\Omega = W_1\, J \wedge J + W_2 \wedge J$$

Torsion-classes!

J and Ω specify metric and:

$$R_6 = -\frac{15}{2}|W_1|^2 + \frac{1}{2}|W_2|^2 + \frac{1}{2}|W_3|^2$$

Ansatz for 10D (not completely general) can be written:

$$F_0 \sim f_0 \,, \quad F_2 \sim f_1 J + f_2 W_2 \,, \quad F_4 \sim f_3 J\wedge J + f_4 W_2 \wedge J$$

$$F_6 \sim f_5 \, \mathrm{vol}_6 \,, \quad H \sim f_6 \Omega_R + f_7 W_3 \,, \quad j \sim f_8 \Omega_R + f_9 W_3$$

source

U.D., S. Haque, G. Shiu, T. v. Riet 0907.2041

U.D., P. Koerber, T. v. Riet, 1003.3590

U.D., S. Haque, P. Koerber, G. Shiu, T. v. Riet, T. Wrase

Solve equations of motion and find...

Always at least one tachyon!

To be more systematic...

Unified description for IIA/B in $D=4$, $N=1$, SUGR

with S, T^I, U^I $I=1,2,3$, i.e., $2\times 7=14$ moduli.

We have;

$$K = -\ln(-i(S-\bar{S})) - \sum_{I=1}^{3} \ln(-i(T_I - \bar{T}_I)) - \sum_{I=1}^{3} \ln(-i(U_I - \bar{U}_I))$$

$$W = W(S, T^I, U^I)$$

With isotropy, $T_1 = T_2 = T_3 = T$, $U_1 = U_2 = U_3 = U$

we have: $S = i z \sigma^{-9/2} + c_1$ $\quad T = i z \sigma^{9/2} + c_2$

$U = i \rho + b$

axions

All contributions to potential V come

from particular terms in superpotential W...

In IIA: $1 \sim F_6$, $U \sim F_4$, $U^2 \sim F_2$, $U^3 \sim F_0$

$\Rightarrow 1+3+3+1 = 8$ fluxes

$S, T \sim H_3 \Rightarrow 1+3 = 4$ fluxes

$SU, TU \sim \omega$ (metric) $\Rightarrow 3+9 = 12$

$\omega^2 = 0$ (Jacobi constraint) to get twisted tori $\Rightarrow 12 \to 6$

$\omega^2 \neq 0$ corresponds to having KK-monopole

To appear (U. D., J.-P. Derendinger, G. Dibitetto, A. Guarino)

$$\boxed{V_{STU} = V_{SU(3)} \quad \text{(even when } \omega^2 \neq 0\text{)}}$$

... using

$$W^{(\omega)} = b_1{}^I S U_I + c_1{}^{JI} T_I U_J$$

$$3 \quad + \quad 9 \quad = 12$$

Can be extended to G_2-structures in M-theory, which also includes some non-geometric fluxes...

Key question:

Are there metastable dS?

It is convenient to use SUSY-breaking variables as parameters...

$$D_\alpha W = A_\alpha + i B_\alpha$$

with $\alpha = 1, \dots, N/2$ and N as # of real fields

We have: $S, T, U \to N = 2 \times 3 = 6$

$S, T^I, U^J \to N = 2 \times 7 = 14$

Replace N of M fluxes...

N SUSY-breaking + (M-N) fluxes

quadratic in eq. of motion

linear in eq. of motion

Schematically:

$$\boxed{(DW)^2 + F\,DW = 0}$$

$DW = 0 \Rightarrow$ solution

Move candidate solution to origin of moduli space...

$$S_0 = T_0 = U_0 = i$$

Adjust N parameters for solution...

$M-N$ left to adjust to assure no tachyons...

Must have $M-N-N = \boxed{M-2N \geq 0}$

Isotropic: $N=6$, $M=8$

Non-isotropic: $N=14$, $M=24\,(18)$

Not enough!

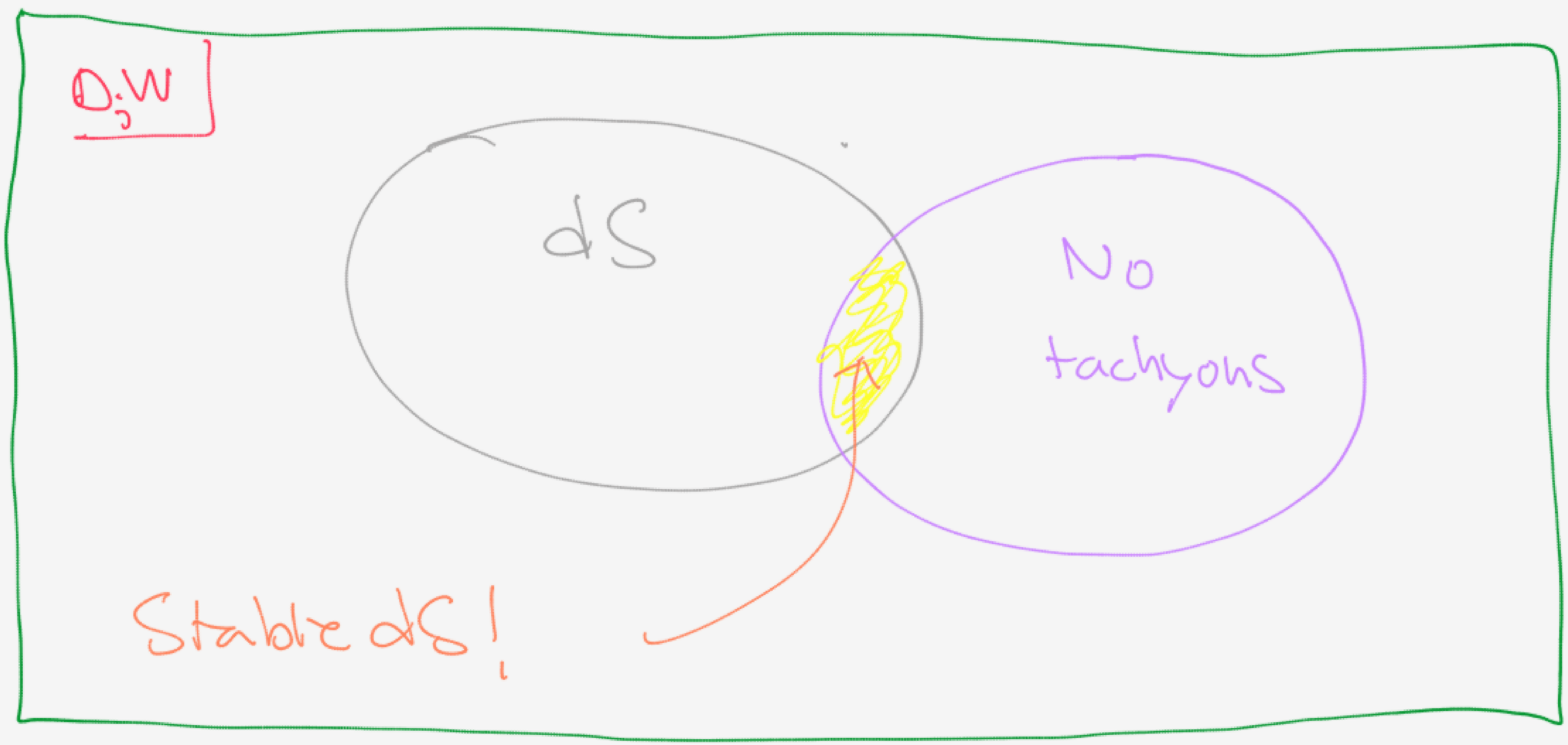
Need more fluxes!

	IIB	IIA	Iso	Non-iso
1	F_3	F_6	1	1
U		F_4	1	3
U^2		F_2	1	3
U^3		F_0	1	1
S	H_3	H_3	1	1
SU		ω	1	3
SU^2		Q	1	3
SU^3		R	1	1
T	Q	H_3	1	3
TU		ω	1	9
TU^2		Q	1	9
TU^3		R	1	3

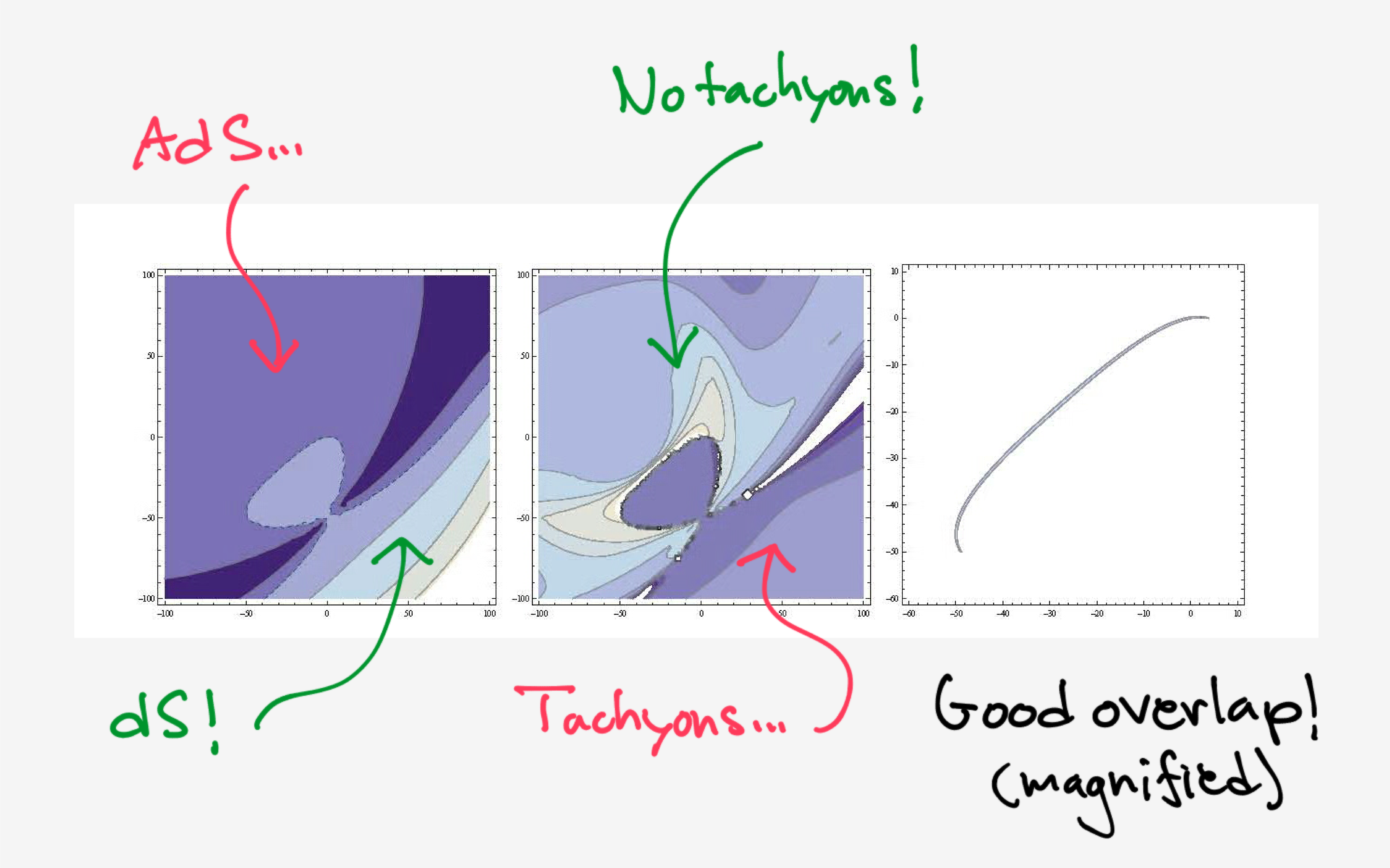
In 1212,4984 (G, Dibitetto, U.D.)

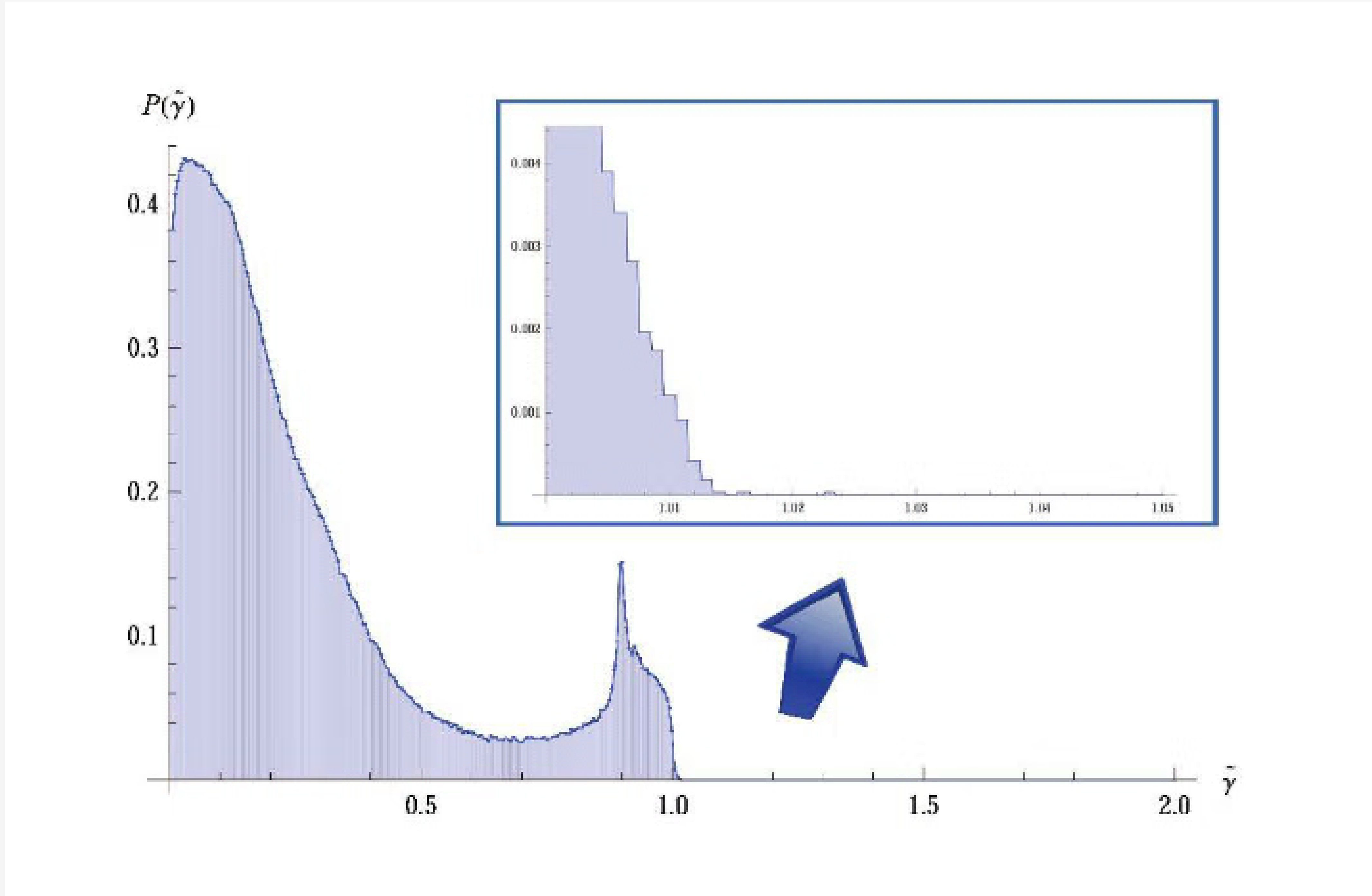
IIB with Q = IIA with Q and R

was studied with M = 12 and solutions found...



6 fluxes fixed for solution...


AdS...
No tachyons!
dS!
Tachyons...
Good overlap!
(magnified)



... much fewer dS with large energy than expected from RMT ...

$\boxed{\Rightarrow \text{ conspiracy?}}$

In 1301.7073 (J. Blåbäck, G. Dibitetto, U.D)

The full nonisotropic case was studied for

$$\mathrm{IIB} + T, TU = \mathrm{IIA} + SU^2, SU^3$$

$$N = 16 + 3 + 9 = 24 + 3 + 1 = 28 = 2 \times 14$$

... again solutions were found. Fully stable in all 14 directions. Genetic algorithm used, but see 1406.4866 (Kallosh, Linde, Vercnocke, Wrase)

	Sol. 1		Sol. 2	
$V_0 \equiv V(\Phi_0)$	8.85×10^{-6}		1.58×10^{-5}	
$\tilde{\gamma} \equiv \frac{\lvert DW\rvert^2}{3\lvert W\rvert^2}$	1.00008		1.00012	
Normalised masses (m^2/V_0)	1.85148×10^6	1.78128×10^6	262778	25970
	1.31064×10^6	1.27212×10^6	160140	15360
	113890	94187.9	24219.8	11296.
	23907.3	11397.5	9273.53	7282.9
	5290.32	1478.37	4155.21	1745.3
	1353.35	607.799	1306.57	343.39
	17.9045	2.85612×10^{-3}	24.7202	11.45

The real values...

A_{U_1} B_{U_1}	0.437796	−0.223916		−0.41	
A_{U_2} B_{U_2}	−0.10521	−0.716205		−0.07453	
A_{U_3} B_{U_3}	−0.110376	−0.952221		−0.597945	
a_0 b_0	0.249727	1.26278		−0.0809612	
$a_1^{(i)}$ $b_1^{(i)}$	−0.385558	−1.00688		0.763615	
	3.24742	3.23091		−0.129007	
	−3.42277	−1.65416		−0.258342	
$a_2^{(i)}$ $b_2^{(i)}$	−0.678952	0.269654		−1.69969	
	4.77196	−2.82032		0.141055	
	−4.74382	3.85504		2.04863	
a_3 b_3	−0.626634	0.244097		−0.0281293	
$c_0^{(i)}$	0.210031				0.22
	0.680146				−0.
	−0.154349				0.28
$c_1^{(ij)}$	0.934579	0.932678	0.134729	1.00141	−1.
	1.3931	0.978188	0.351523	−0.335711	−0.
	−1.12313	−0.707561	−0.313208	−0.628606	[illegible]

Is it OK to have nongeo fluxes?

(At least some can be understood in M ...

To appear (U. D., J.-P. Derendinger, G. Dibitetto, A. Guarino)

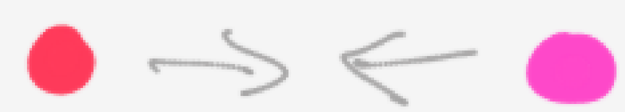
... and work in progress.

Uplifting and a generic problem

So far all branes and orientifolds are smeared...
OK if SUSY... No forces, does not matter how you put things on top of eachother. But when non-SUSY?

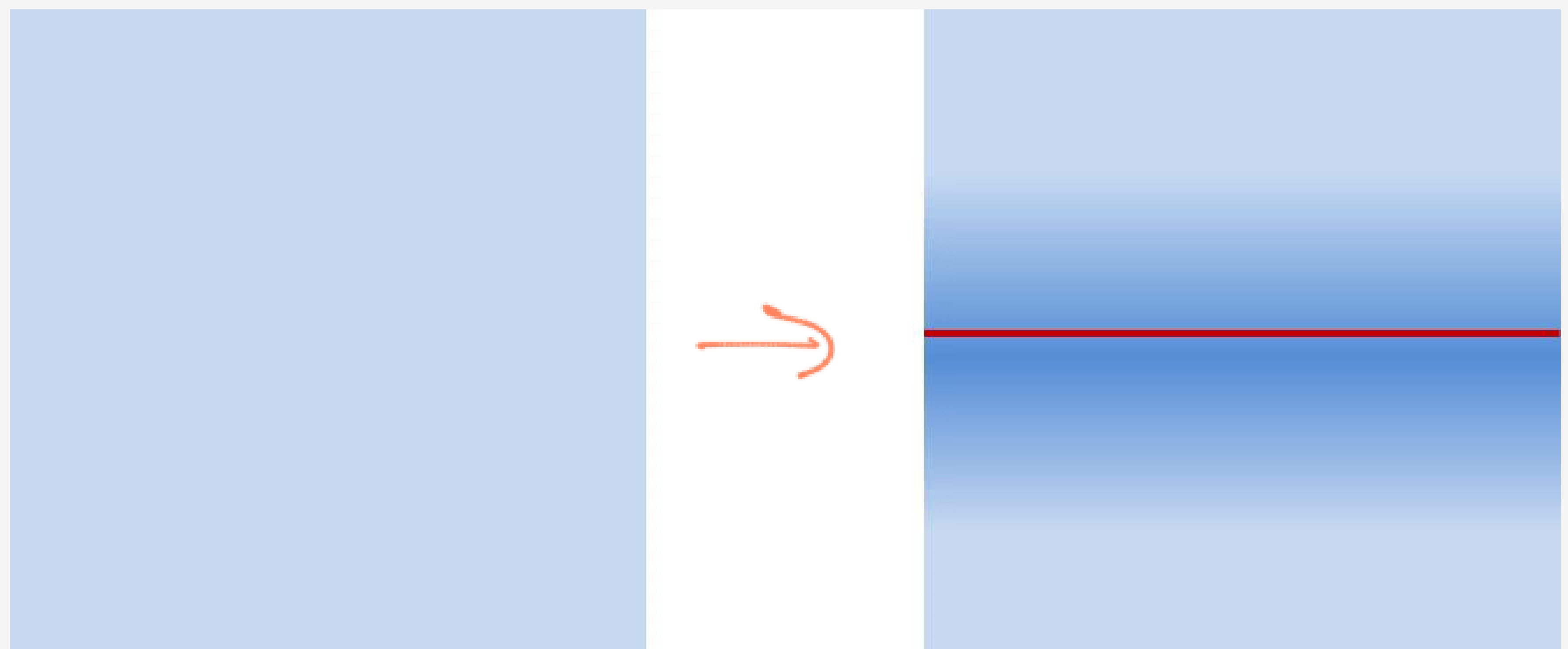
No force!

Force...



Lift to dS by adding antibrane to SUSY-flux configuration...

Surprisingly what happens...



... flux attracted to antibrane and piles up!

Selection of papers...

McGuirk, Shiu, Sumitomo 0910.4581

Bena, Grana, Halmagyi 0912.3519

Dymarsky 1102.1734

Bena, Giecold, Grana, Halmagyi, Massai 1106.6165

Bena, Junghans, Kuperstein, van Riet, Wrase 1205.1798

Bena, Grana, Kuperstein, Massai 1206.6369

Bena, Grana, Kuperstein, Massai 1212.4828

Dymarsky, Massai 1310.0015

...

$\boxed{\text{Get singularity in } H^2 \ldots}$

For $\overline{D6}$ in $\overline{\text{II}}$A this can be proved using...

$$dF_2 = F_0 H_3 + Q\,\delta$$

... sources F_2, which tells H_3 how to move...

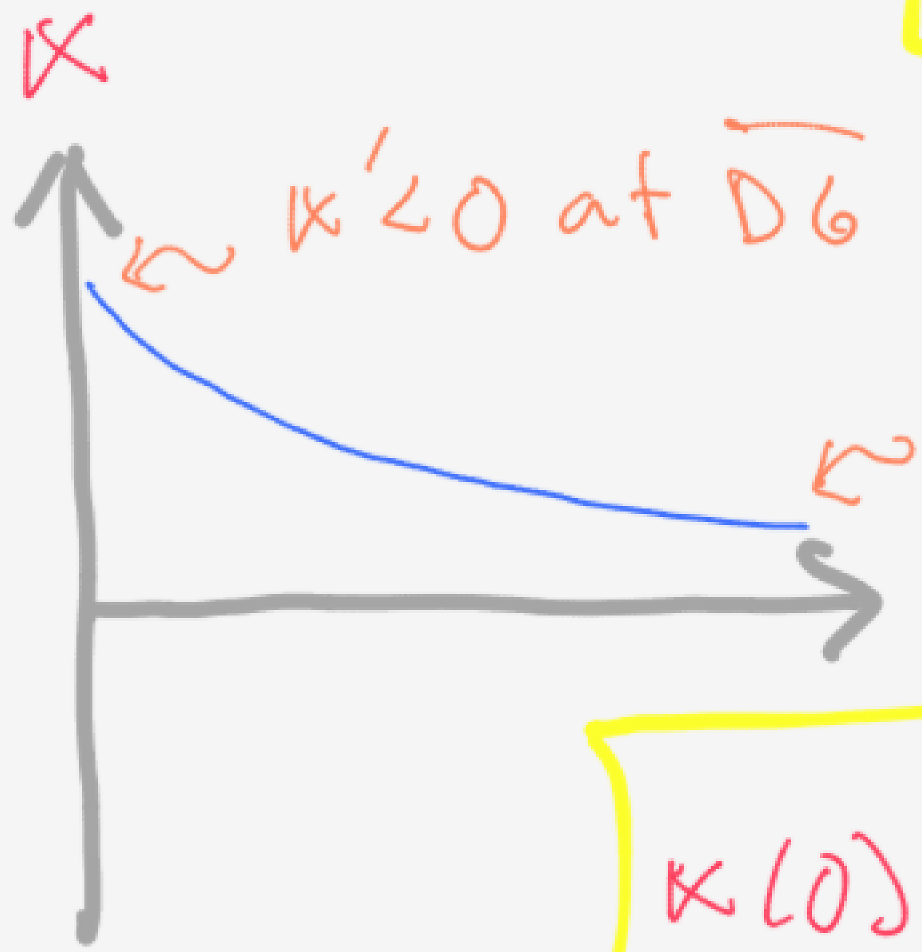
$$d * H_3 = - * F_2 F_0$$

Using $H_3 = \partial F_0 *_3 \Pi$ and $F_2 = *_3\, d\kappa$

one gets at $\kappa' = 0$!

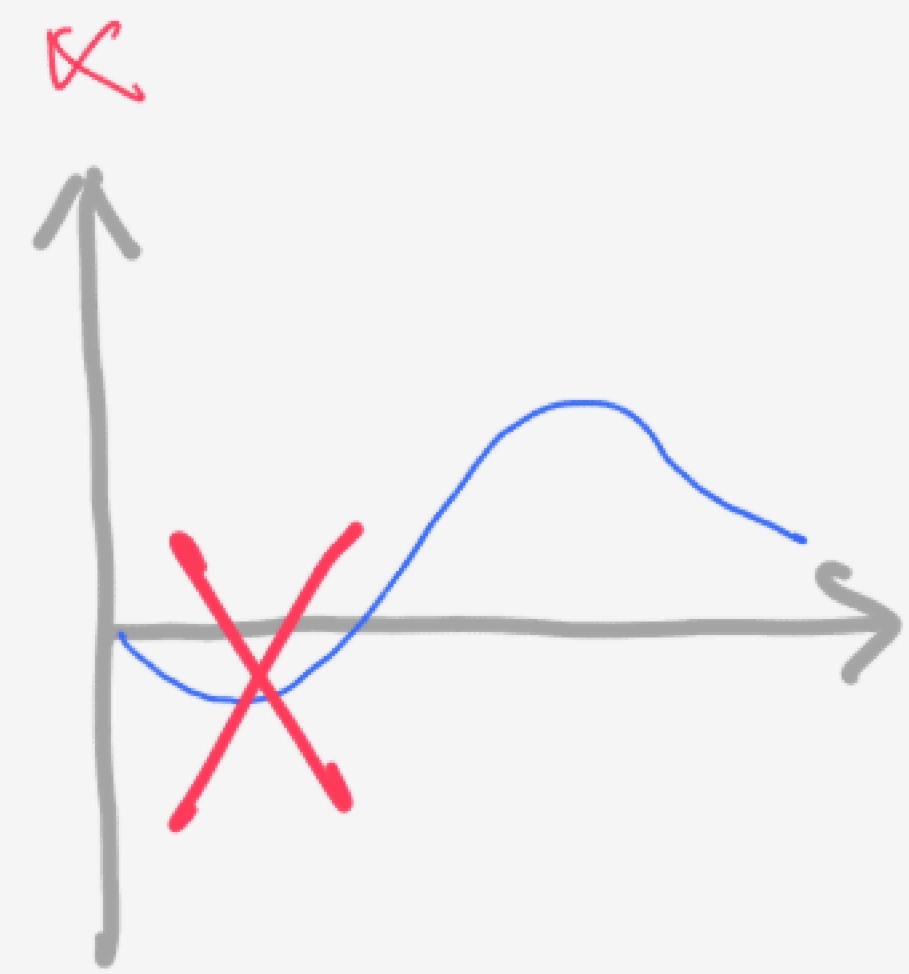
Blåbäck, U.D., Junghans, van Riet, Wrase, Zagerman 1105.4879, 1111.2605

$$\boxed{\operatorname{sign} \kappa'' = \operatorname{sign} \kappa}$$



$\kappa' < 0$ at $\overline{D6}$

$F_0 H_3 > 0 \sim$ BPS-flux



$$\boxed{\kappa(0) \neq 0 \Rightarrow \text{singularity!}}$$

... in case of $\overline{D3}$ in KS you can use the results of 1301.5647 (F. Gautason, D. Junghans, M. Zagermann) further developed in to appear (J. Blåbäck, U. D., D. Junghans, T. van Riet, S. C. Vargas) to the form:

$$\boxed{0 = \cancelto{0}{S_{DBI}} + S_{WZ} + \oint_r \mathcal{B}}$$

independent of r

lives on source

$$\boxed{M_{ADM} \neq 0 \Rightarrow \oint_r \mathcal{B} \neq 0 \Rightarrow S_{WZ} \neq 0 \Rightarrow \kappa(0) \neq 0 \Rightarrow \text{singularity!}}$$

Note!

Not singularity in field at its source.

Rather, singularity in fluid attracted by source!

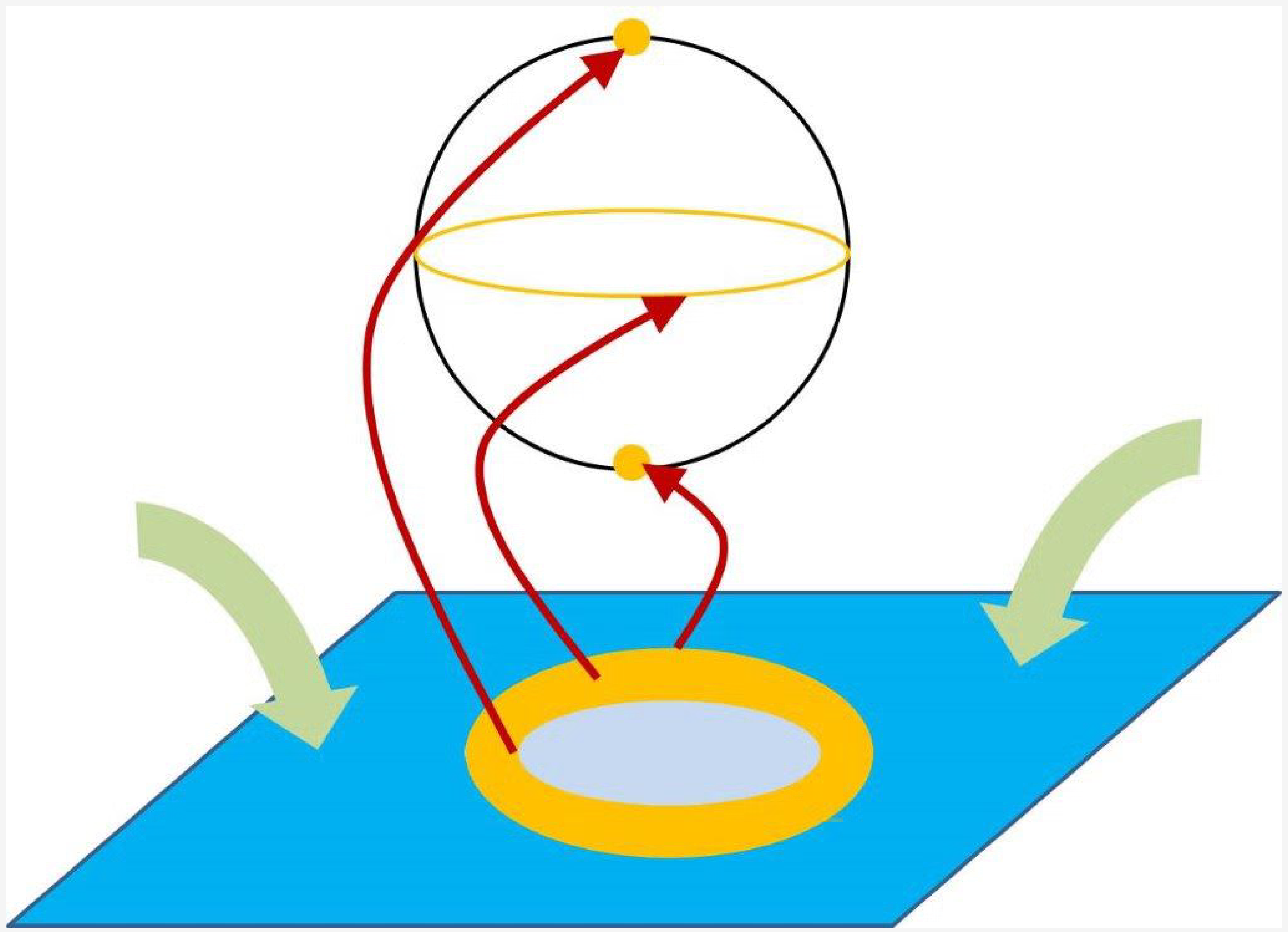
The dS-vacua is always unstable: 

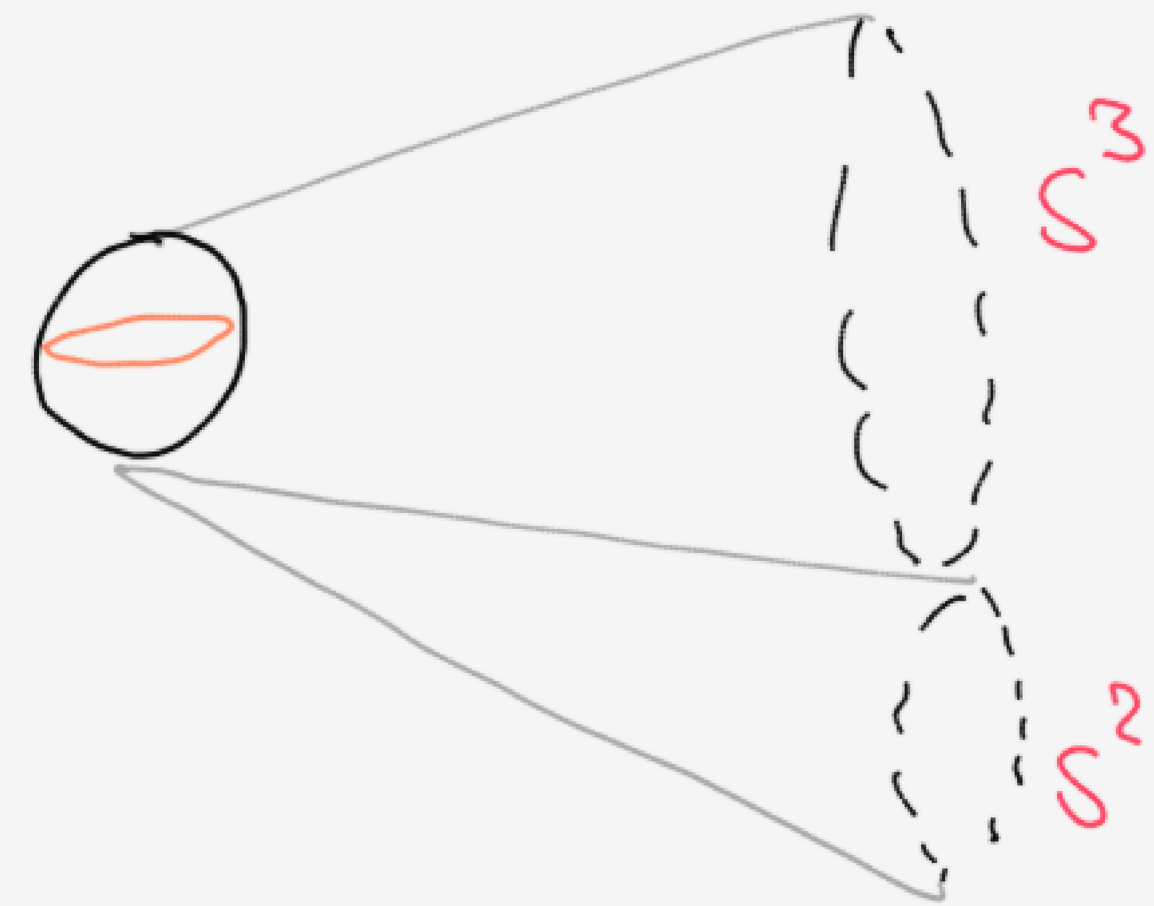
KPV 0112197: barrier against $F_3 \wedge H_3$ annihilating with antibrane.

Claim: barrier lowered when flux piled up on top of antibrane.

1202.1132 (J. Blåbäck, U.D., T. van Riet)

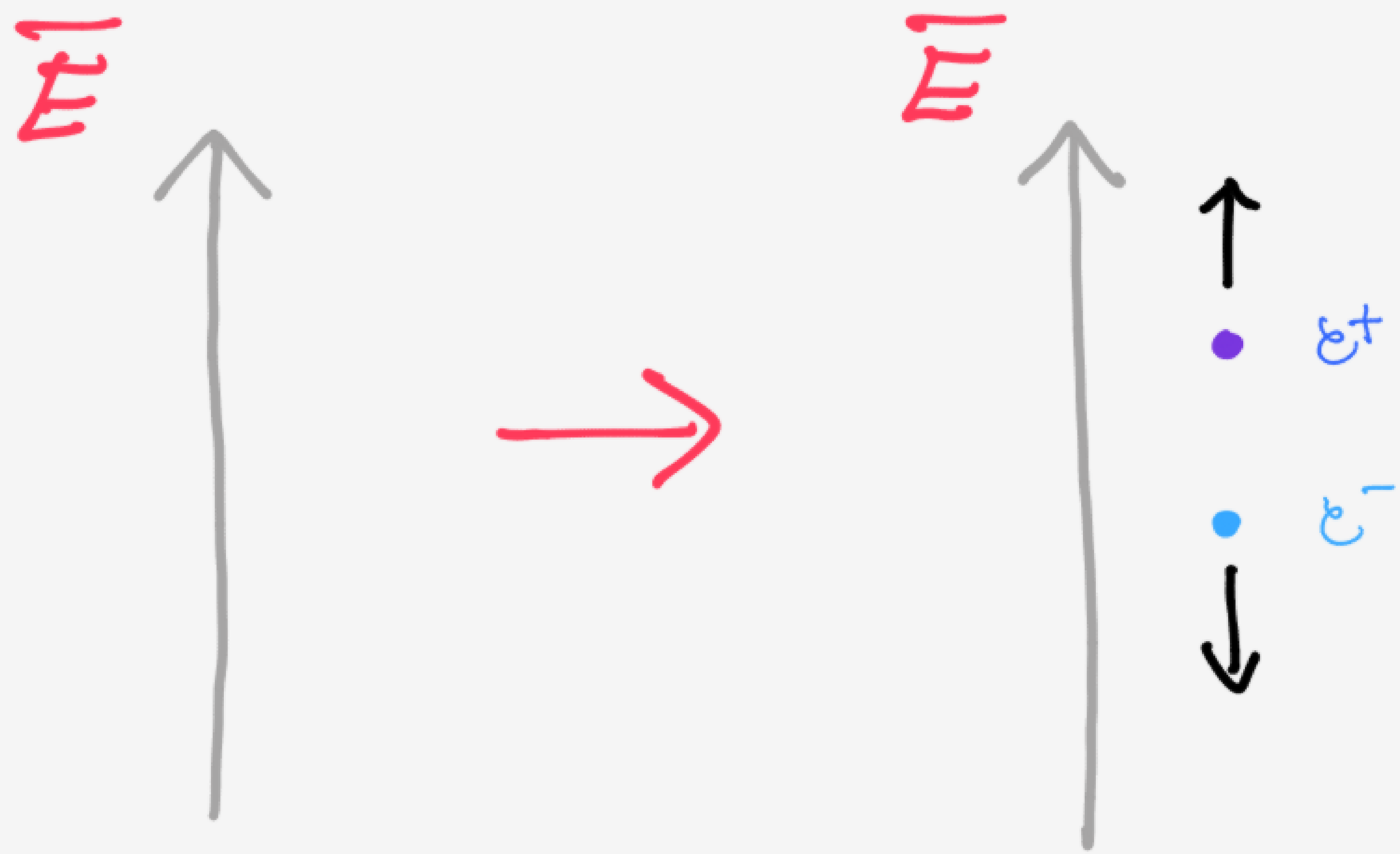
$\overline{D3}$ can end on NS5. Formation of NS5-bubbles annihilate the $\overline{D3}$ ...





Klebanov-Strassler

Just like Schwinger effect...



Gain energy through tunneling. Barrier lowered by higher E.

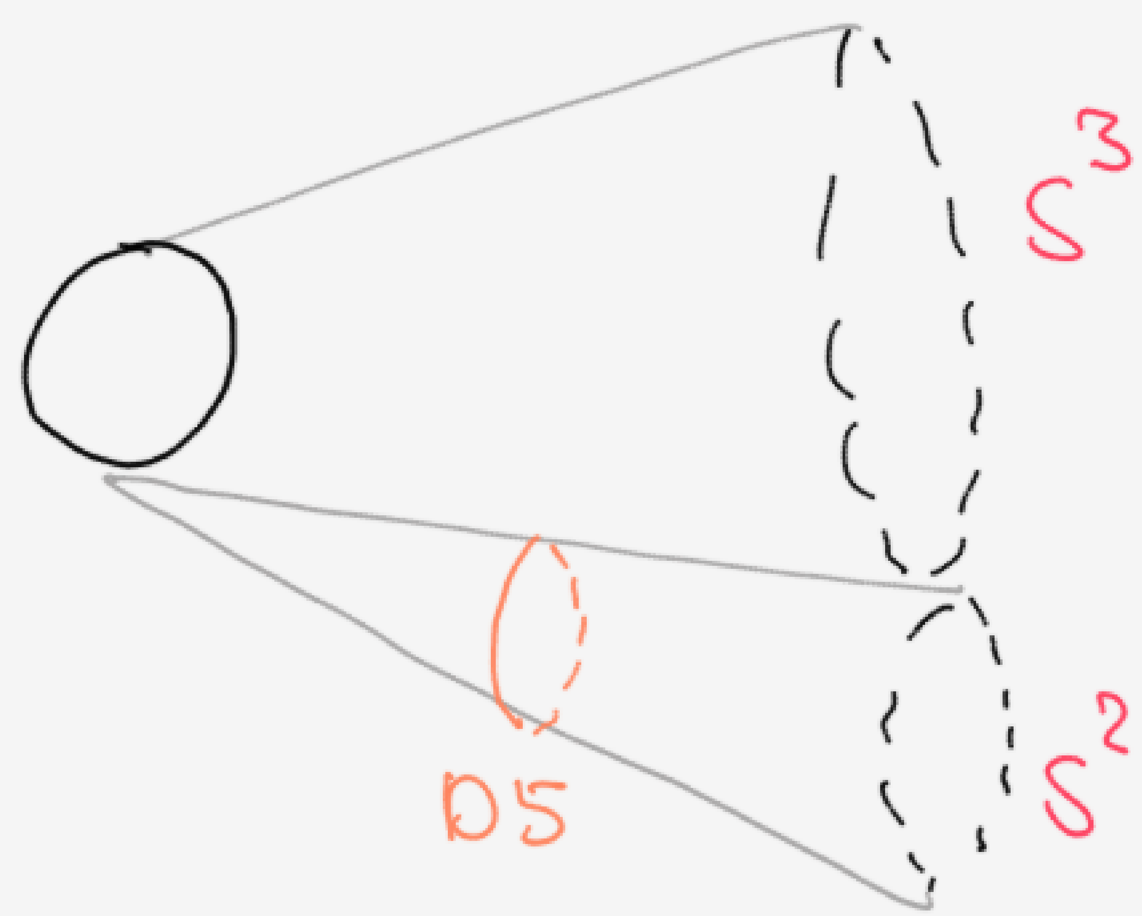
Action for NS5:

$$S = \frac{\mu_5}{g_s^2} \oint d^6\xi \sqrt{-G_{\parallel}(G_{\perp}+F)} - \mu_5 \oint B_6$$

Barrier lowered, goes away, when $H \sim * dB_6$ grows...

Could polarization of $\overline{D3} \to D5$ prevent build up?

Calculations suggest this does not happen...



Singularity resolved by time dependence?

Flux annihilated as it is piled up...

$\boxed{\text{Time scale?}}$

Conclusion: It remains a challenge to prove existence of longlived dS with anti-brane uplift.

Conclusions

Spontaneous ~~SUSY~~ (smeared)

... difficult without non-geo...

Explicit ~~SUSY~~

... instabilities against annihilation

(A smaller landscape ...?

... string theory is more predictive!

(A different landscape ...?

... do not focus on (meta)-stable dS, but consider instead $\boxed{\text{Quintessence}}$

Proof of principle...

In 1310.8300 (J. Blåbäck, U.D., and G. Dibitetto)

The presence of accelerated (unstable) solutions in geometric IIA is investigated...

$\sim$ 2-3 efoldings

$\boxed{\text{Can one do better?}}$