Non-supersymmetric D-branes

Timm Wrase

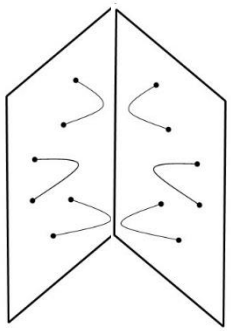
StringPheno, CERN June 25th, 2019

FWF
Der Wissenschaftsfonds.

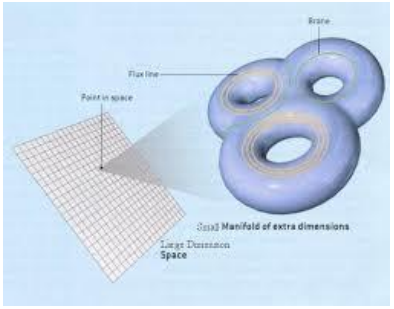
Outline

- Introduction and motivation

- D-branes and non-linear SUSY



- D-branes in flux compactifications



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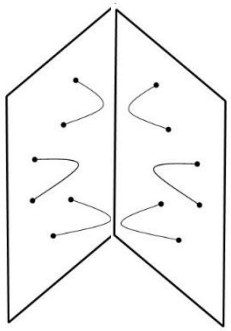

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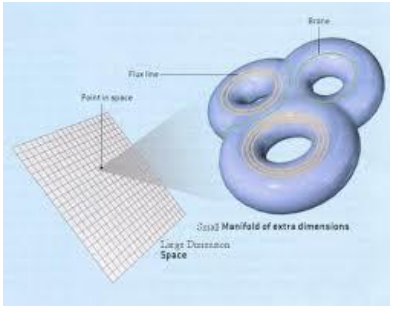

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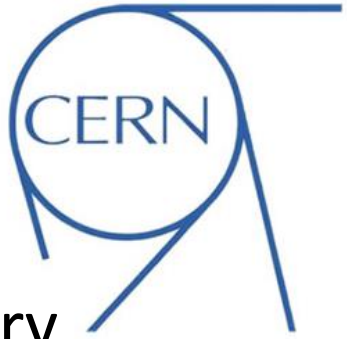
No SUSY discovery

- The LHC has done a spectacular job at confirming the SM of particle physics
- Unfortunately no discovery of supersymmetry



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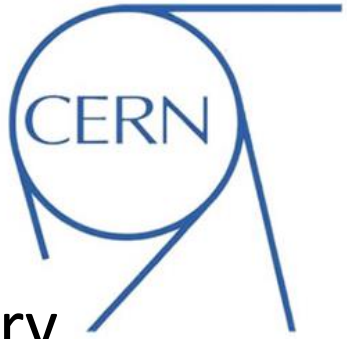

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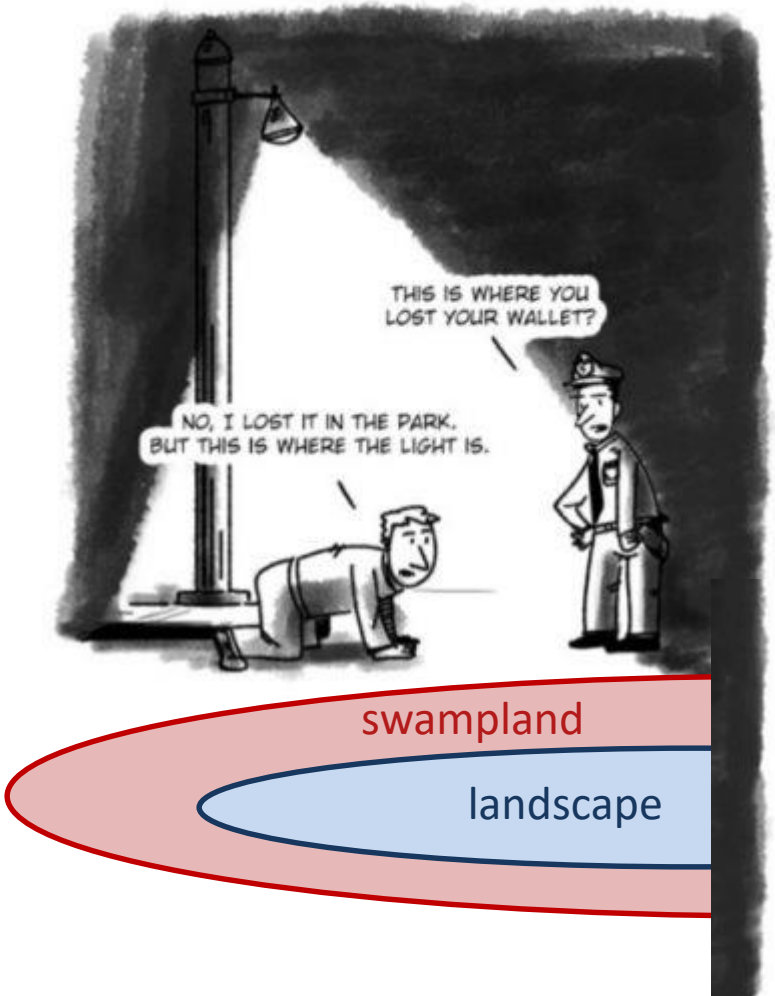
- Unfortunately no discovery of supersymmetry
- We are now faced with two problems:
  1. The cosmological constant problem
  2. The hierarchy problem

SUSY cannot really explain either

Non SUSY string theories

- Without SUSY things are substantially more complicated

- However, it appears that we need to understand the non-SUSY landscape vs. swampland in order to describe our universe



Non SUSY string theories

- There are non supersymmetric string theories
- One can compactify the superstrings on spaces that do not preserve supersymmetry

Acharya 1906.06886

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- One can compactify the superstrings on spaces that do not preserve supersymmetry

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- One can study supersymmetric flux compactifications and search for SUSY breaking vacua
  1. Non-SUSY minima in standard linear SUGRA
  2. Non-supersymmetric branes break SUSY

Non SUSY string theory solutions

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   We can consider string compactifications with ingredients that all preserve some supersymmetry, e.g. standard CY flux compactifications that give rise to $4d, N = 1$ SUGRA theories

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2. Non-supersymmetric branes break SUSY

   We can use stringy ingredients that break supersymmetry, like anti-Dp-branes, e.g. the above plus anti-D3-brane uplift a la KKLT and LVS

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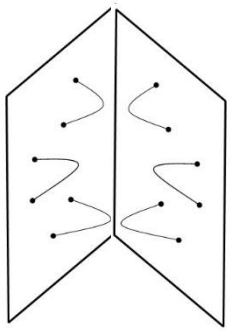

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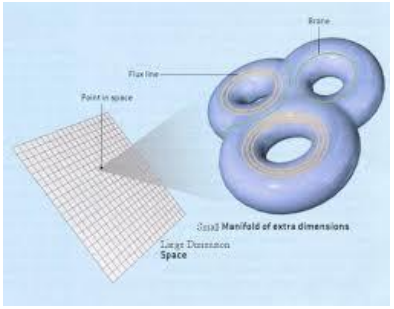

- Conclusion

The Volkov-Akulov model

- Consider a theory with a single massless fermion λ

$$S_{VA} = -\int d^4x(1 + \bar{\lambda}\gamma^\mu \partial_\mu \lambda + \cdots)$$

- For appropriately higher order terms, the above action is invariant under a fermionic symmetry:

$$\delta_\epsilon \lambda = \epsilon + (\bar{\lambda}\gamma^\mu \epsilon)\partial_\mu \lambda$$

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- The above symmetry is supersymmetry!

$$\{\delta_{\epsilon_1}, \delta_{\epsilon_2}\}\lambda = (\bar{\epsilon}_1\gamma^\mu\epsilon_2 + \bar{\epsilon}_2\gamma^\mu\epsilon_1)\partial_\mu\lambda$$

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- We have a supersymmetric theory with a single fermion!

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- In any standard theory with spontaneously broken SUSY we have a Goldstino and all other fields are generically massive, so at low energies we have the above

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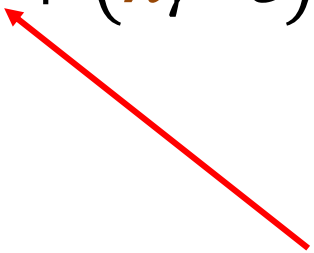
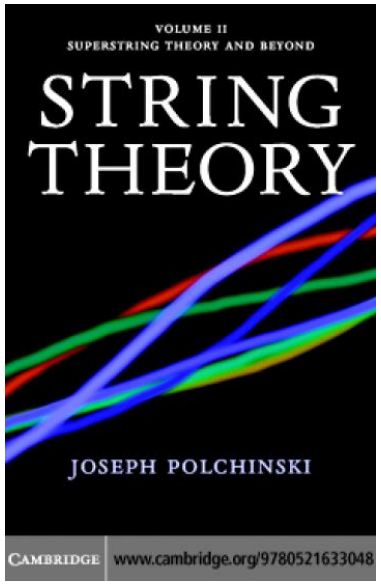


- Note, however, that SUSY is *non-linear realized* and mismatch between bosons and fermions

D-branes in string theory



momentum is measured by the integral of the corresponding current over the world-sheet boundary,

$$\frac{1}{2\pi\alpha'}\int_{\partial M} ds\,\partial_n X'^9 \,, \tag{13.2.3}$$

which up to normalization is just the (0 picture) vertex operator for the collective coordinate, with zero momentum in the Neumann directions.

We conclude by analogy that the D-brane also spontaneously breaks 16 of the 32 spacetime supersymmetries, the ones that are explicitly broken by the open string boundary conditions. The integrals

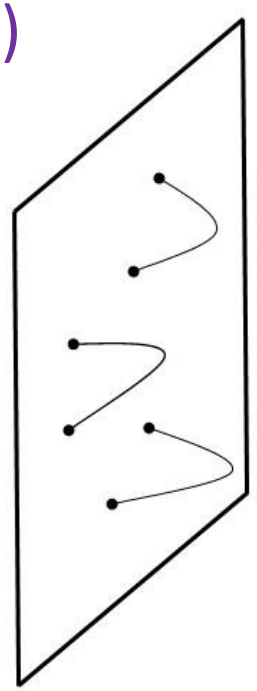
$$\int_{\partial M} ds\,\mathscr{V}'_\alpha = -\int_{\partial M} ds\,(\beta^9\tilde{\mathscr{V}}')_\alpha \,, \tag{13.2.4}$$

which measure the breaking of supersymmetry, are just the vertex op-

D-branes in string theory

Let us recall some facts about D-branes *in flat space*:

- The D-brane breaks half of the supersymmetry *spontaneously* and the other half is linearly realized
- Example: a D3-brane (or an anti-D3-brane)



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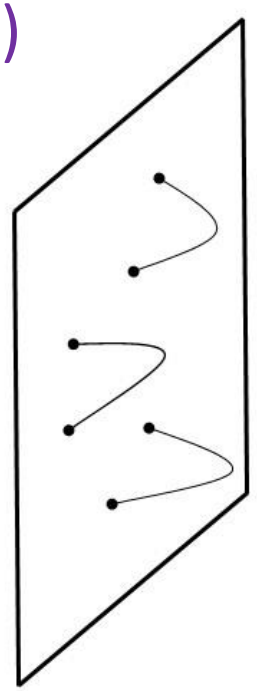
- It preserve 16 linearly realized supercharges, i.e. $N = 4$ in 4d
- The worldvolume fields $A_\mu, \lambda^0, \phi^i, \lambda^i, i = 1, 2, 3$ can be package into an $N = 4$ multiplet



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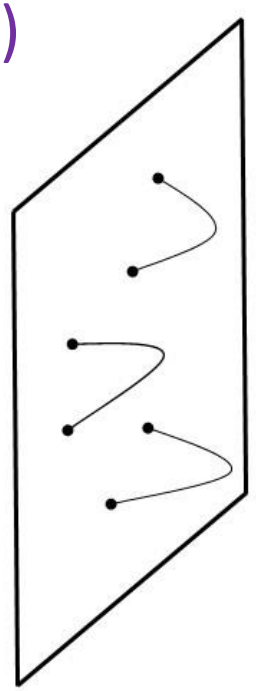
- 16 supercharges are spontaneously broken at the string scale $\mathcal{O}(\alpha')$
- The Goldstone fermions aka Goldstinos are λ^0 and $\lambda^i, i = 1, 2, 3$



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- Example: An anti-D3-brane on top of an O3

Kallosh, Wrase 1411.1121

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$$S = -d^4x \int \left(1 + \bar{\lambda}^A \gamma^\mu \partial_\mu \lambda^A + \cdots\right), \qquad A, B = 0,1,2,3$$

$$\delta_{\epsilon^A} \lambda^B = \epsilon^A \delta_A{}^B + \left(\bar{\lambda}^A \gamma^\mu \epsilon^A\right) \partial_\mu \lambda^B$$

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Exactly as Volkov-Akulov above!

D-brane SUSY breaking

- Consider a standard 4d $N = 1$ SUGRA theory:

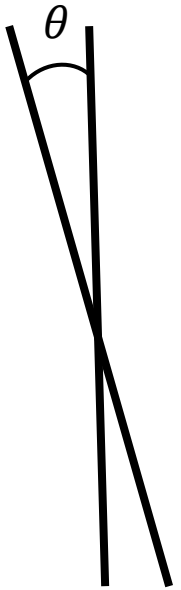
  1. All fields come in standard $N = 1$ multiplets, i.e. boson-fermion pairs

  2. We can break SUSY via D-terms or F-terms but the theory still is invariant under linear SUSY

SUSY breaking via branes is different!

D-brane SUSY breaking

- Consider a standard 4d $N = 1$ SUGRA theory
- Add a SUSY breaking brane that is not exactly but almost calibrated
- For small angles θ SUSY breaking is small



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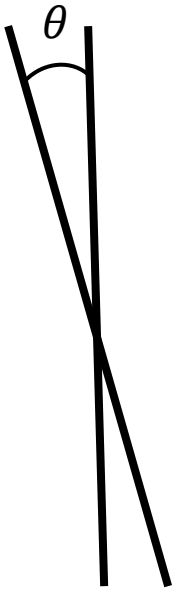
- We can write the action in terms of a standard F-term and a D-term, schematically

$$V = V_F + V_D \cdot (1 + \sin\theta)$$

- For $\theta \ll 1$ this looks like standard SUGRA



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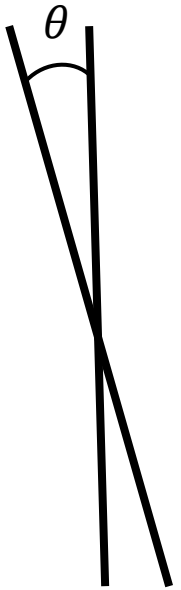

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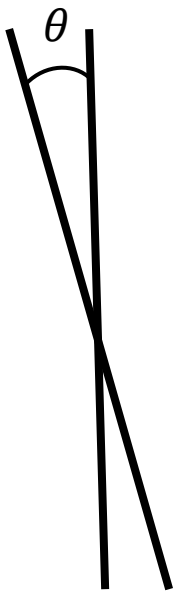

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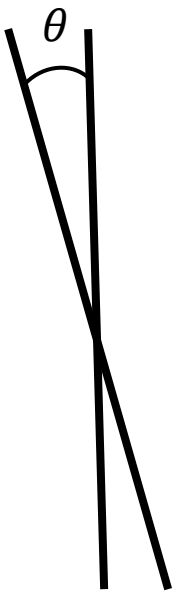
- For $\theta = 0$ this looks like standard SUGRA but otherwise it *does not*
- One can show that there is no field redefinition that leads to standard linear SUSY
- Trivial for $\theta = \pi$, i.e. brane-anti-brane or anti-brane on top of O-plane



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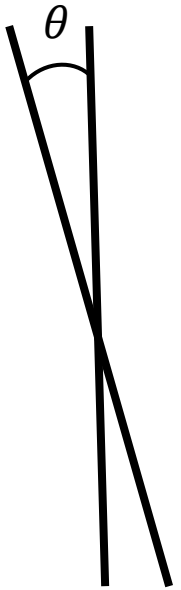
- This setup and all others can be written using standard SUSY with constrained multiplets
- Non-linear SUSY is constraining, and there exist non-renormalization theorems



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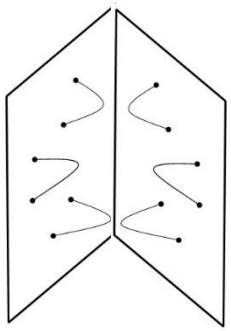

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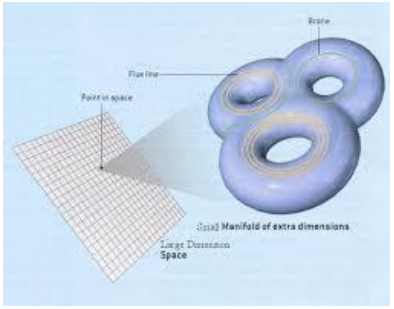


- Conclusion

dS vacua in string theory

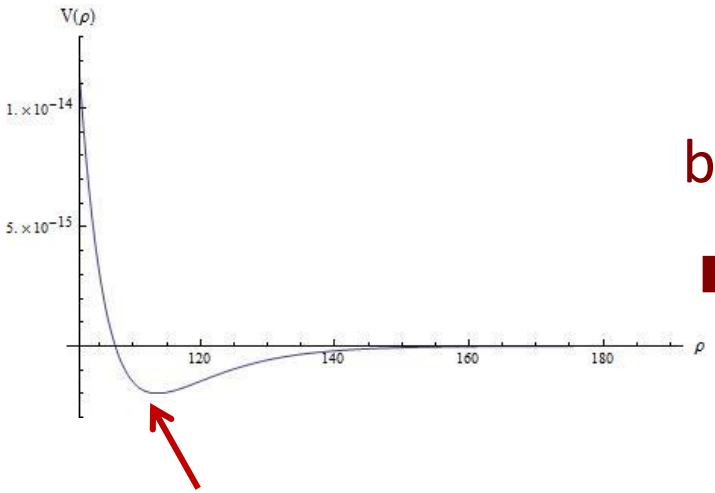
- The first dS vacua in string theory were constructed over a decade ago

Kachru, Kallosh, Linde, Trivedi hep-th/0301240

Balasubramanian, Berglund, Conlon, Quevedo hep-th/0502058

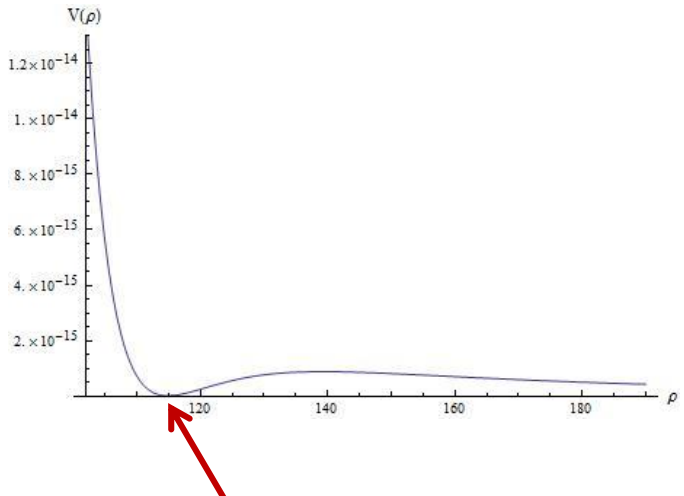
Conlon, Quevedo, Suruliz hep-th/0505076

- They were obtained via a two step procedure:



AdS vacuum

Adding an anti-D3-brane "uplift"



dS vacuum

dS vacua in string theory

- The uplifting term *seems* to explicitly break supersymmetry

$$V = e^{K}\left(K^{I\bar{J}} D_I W \overline{D_J W} - 3|W|^2\right) + \frac{\mu^4}{(T+\bar{T})^2}$$

$$K = -3\log(T+\bar{T})$$
$$W = W_0 - A\, e^{-aT}$$

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- Can we package the uplift term into K, W or D?

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- Can we package the uplift term into K, W or D? YES

Talk by Niccolo Cribiori: Full SUGRA description of anti-D3-brane

Classical dS vacua in type IIA

- Stable dS vacua have been searched for but only *critical points* have been found (until recently)

Flauger, Robbins, Paban, TW 0812.3886
Caviezel, Koerber, Körs, Lüst, TW, Zagermann 0812.3551
Danielsson, Haque, Shiu, Van Riet 0907.2041
Caviezel, TW, Zagermann 0912.3287
Danielsson, Koerber, Van Riet 1003.3590

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Caviezel, TW, Zagermann 0912.3287
Danielsson, Koerber, Van Riet 1003.3590

- The above is a standard 4d $N = 1$ SUGRA where it is notoriously difficult to stabilize the sGoldstino

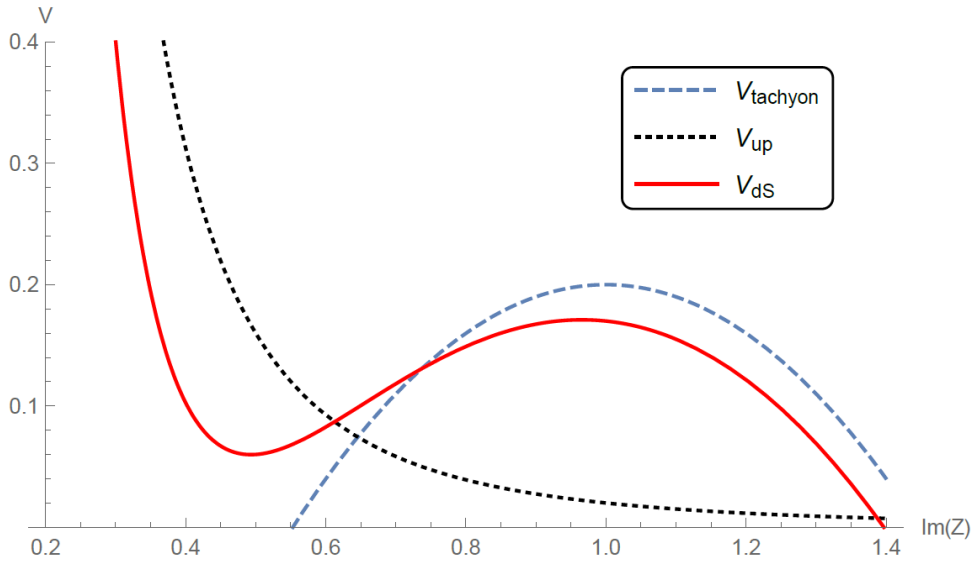
Covi, Gomez-Reino, Gross, Louis, Palma, Scrucca 0804.1073
Jungshans 1603.08939
Junghans, Zagermann 1612.06847

Classical dS vacua in type IIA

- Tachyon always along 3-cycle moduli
- These 3-cycles can be wrapped by anti-D6-branes

Kallosh, Wrase 1808.09427

$$V_{dS} = -m^2(Im(Z) - 1)^2 + \frac{N_{\overline{D6}}}{Im(Z)^3}$$



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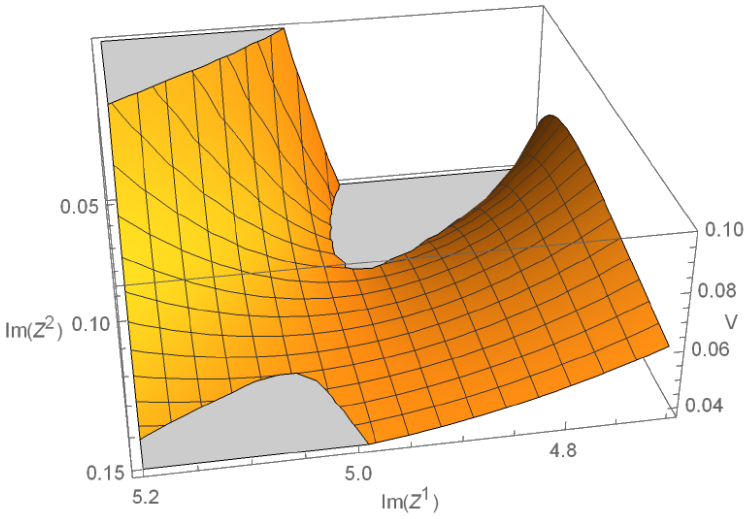

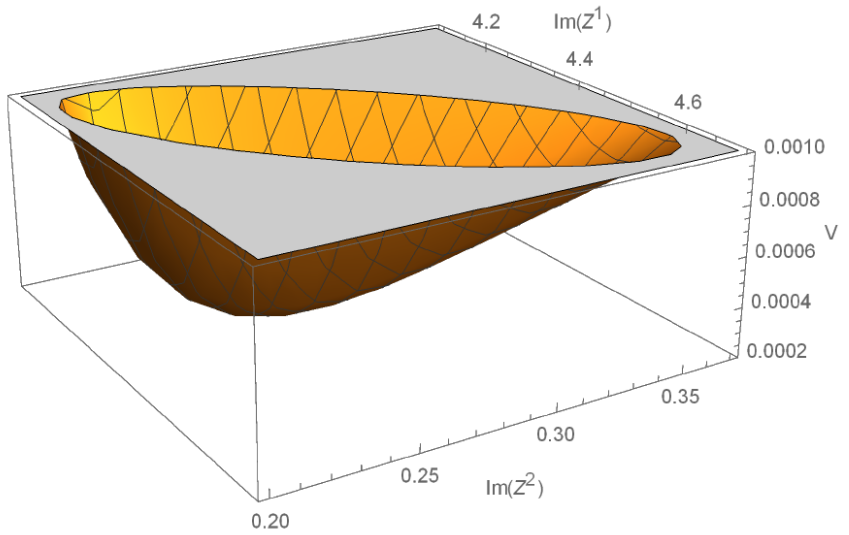

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- The one tachyonic direction is now stable

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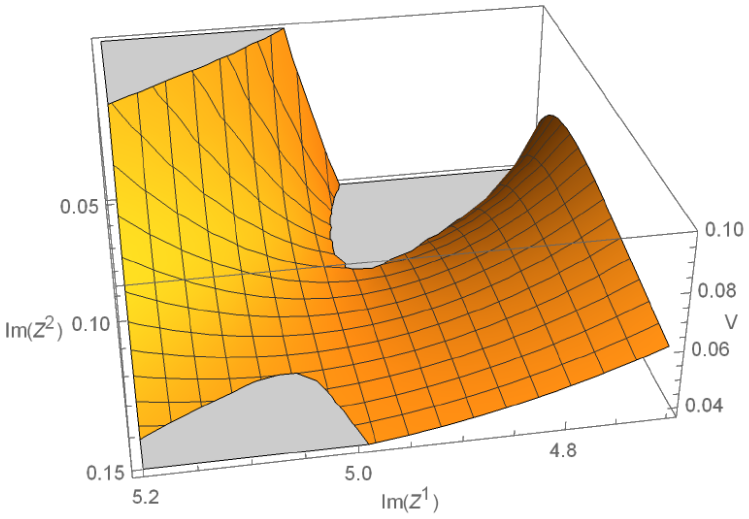

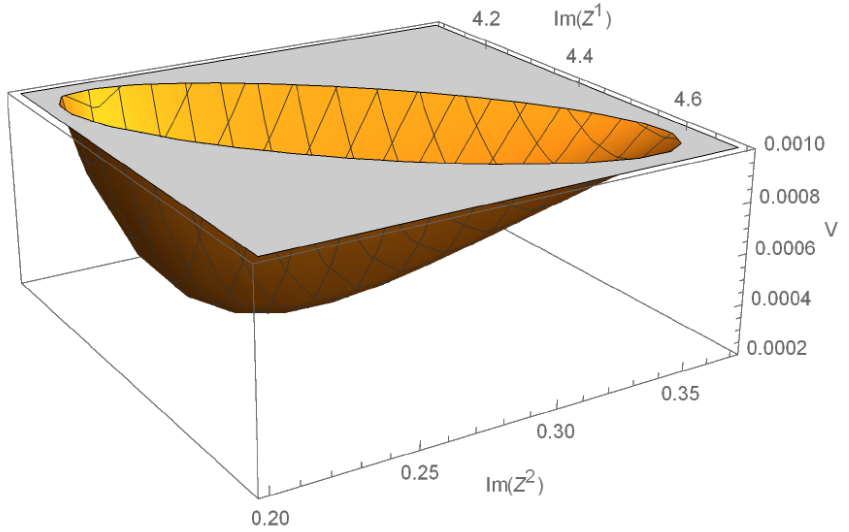

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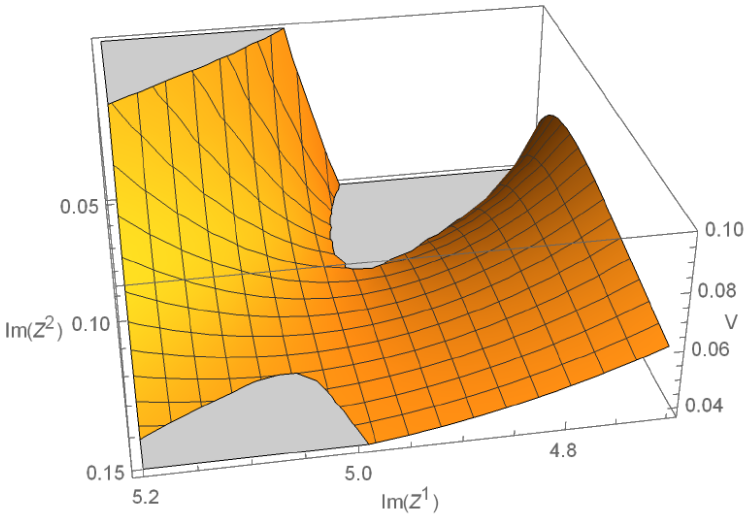
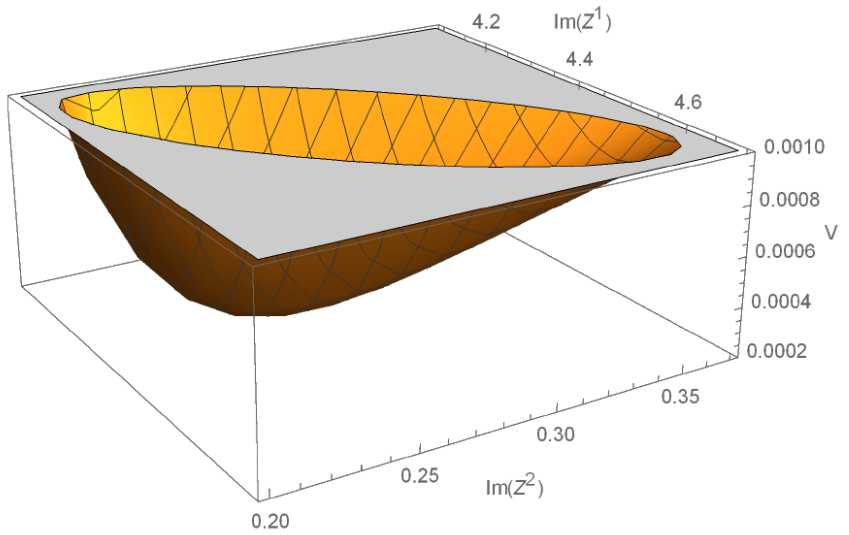
- The one tachyonic direction is now stable
- dS solutions at slightly shifted values, *do not seem to be trustworthy* in this example (small volume, large coupling)

Kallosh, Wrase 1808.09427

Classical dS vacua in type IIA





- Checked explicitly in the simplest example $S^3 \times S^3/Z_2 \times Z_2$
- The one tachyonic direction is now stable
- dS solutions at slightly shifted values, *do not seem to be trustworthy* in this example (small volume, large coupling)

Talk by Christoph Roupec

Kallosh, Wrase 1808.09427
Banlaki, Chowdhury, Roupec, Wrase 1811.07880

Anti-branes instabilites

- Brane with anti-branes can lead to instabilities
- Anti-D3-brane at the bottom of KS throat can annihilate against fluxes, but no problem

Michel, Mintun, Polchinski, Puhm, Saad 1412.5702
C.-Maldonado, Diaz, VR, Vercnocke 1507.01022
C.-Maldonado, Diaz, Gautason 1603.05678

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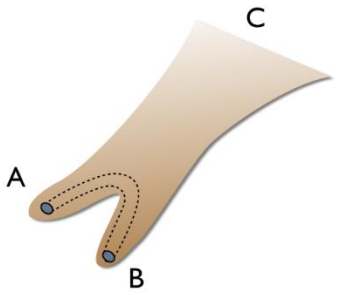
  Michel, Mintun, Polchinski, Puhm, Saad 1412.5702
  C.-Maldonado, Diaz, VR, Vercnocke 1507.01022
  C.-Maldonado, Diaz, Gautason 1603.05678

- Anti-D6-brane in type IIA not necessarily problematic

  Danielsson, Gautason, Van Riet 1609.06529
  Van Riet et al. 19xx.xxxxx

- Bifid throats for axion monodromy inflation

  Retolaza, Uranga, Westphal 1504.02103



SUSY breaking

- We break supersymmetry at the string scale:

$$m_{4d} \ll m_{KK} \ll m_{string} = \cancel{m_{SUSY}} \ll m_{Pl}$$

- In KKLT or LVS we reduce these scales via warping

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Does it make sense to use or do we even have

4d $N = 1$ supergravity theory?

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- SUSY makes life simple and constrains the action
- We want almost vanishing cosmological constant

$$V_F = \cancel{m_{SUSY}^4} - 3m_{\frac{3}{2}}^2 m_{Pl}^2 \approx 0$$

$$m_{\frac{3}{2}} \sim \frac{m_{string}^2}{m_{Pl}} \ll m_{string}$$

- So we can have a 4d SUSY theory with gravitino

Conclusion

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- Non-linear SUSY plus stringy insights lead still to fairly constrained and controlled actions
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THANK YOU!