Anti-branes in flux backgrounds

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Based on:

1409.0534	Blåbäck, Danielsson, DJ, Van Riet, Vargas
1402.6040	DJ, Schmidt, Zagermann
1402.4571	DJ
1301.5647	Gautason, DJ, Zagermann

Outline

Introduction

Flux singularities in supergravity

Resolution in string theory?

Conclusions

Introduction

Anti-branes in Flux Backgrounds

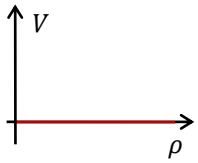
Main motivation:

SUSY breaking in string theory → dS vacua, inflation

Kachru, Pearson, Verlinde 02
Kachru, Kallosh, Linde, Trivedi 03
Kachru, Kallosh, Linde, Maldacena, McAllister, Trivedi 03

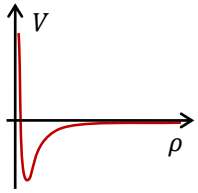
Example: KKLT scenario

- type IIB flux compactification with strongly warped throat (Klebanov-Strassler), scalar potential is no-scale at tree-level



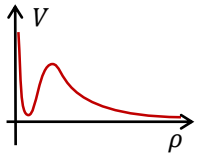
Klebanov, Strassler 00
Giddings, Kachru, Polchinski 01

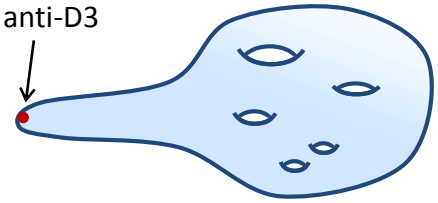
- non-perturbative corrections to scalar potential: stabilize all moduli in SUSY AdS vacuum



Witten 96
Kachru, Kallosh, Linde, Trivedi 03

- add anti-D3-branes at the tip of the throat: positive contribution to vacuum energy, tension redshifted due to warping





Flux singularities

Caveat:

anti-branes considered in probe approximation, 4D EFT description

Backreaction on flux background in internal space?

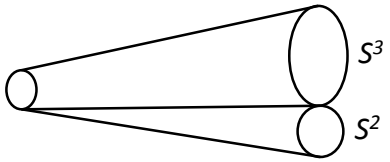
How does the „microscopic“ (10D) solution for the throat region look like?

Before anti-D3: „warped deformed conifold“

roughly a cone over S^2 x S^3, but finite S^3 at the tip

+ non-trivial 3-form fluxes H, F_3

Klebanov, Strassler 00

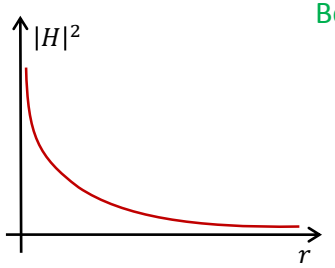


Explicit studies of anti-D3‘s in Klebanov-Strassler:

→ singularities in 3-form fluxes

McGuirk, Shiu, Sumitomo 09
Bena, Graña, Halmagyi 09

$$e^{-\phi}|H|^2 \to \infty, \qquad e^{\phi}|F_3|^2 \to \infty$$



Why bother?

Several mechanisms for (quasi-)dS uplifts in string theory:
anti-D3, D-term, Kähler uplifting, non-perturbative effects, non-geometric fluxes, …

Burgess, Kallosh, Quevedo 03
Cicoli, Klevers, Krippendorf, Mayrhofer, Quevedo, Valandro 13

Louis, Rummel, Valandro, Westphal 12

Burgess , Cicoli, Maharana, Quevedo 12
Blåbäck, Roest, Zavala 14
Danielsson, Dibitetto 14
Rummel, Sumitomo 14

→ Why care about anti-branes?

Status quo:
many plausible 4D scenarios and semi-explicit examples
no fully explicit „microscopic“ 10D/11D example

De Carlos, Guarino, Moreno 09
Blåbäck, Danielsson, Dibitetto 13
Hassler, Lüst, Massai 14
…

Only class studied at the 10D level so far:
classical dS vacua in type IIA/B (all unstable)

Caviezel, Danielsson, Flauger, Haque, Koerber, Körs, Paban, Lüst, Robbins, Shiu, Silverstein, Underwood, Van Riet, Wrase, Zagermann, …

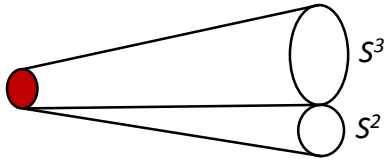
Goal: understand (at least) 1 meta-stable dS vacuum in full explicitness

Could be feasible for anti-branes: already a lot of progress!
→ Try to understand flux singularities!

Flux Singularities in Supergravity

Flux singularities

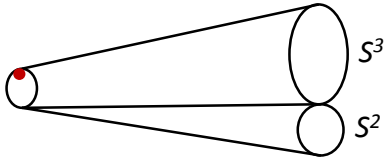
- Initial results limited to linearized backreaction & partially smeared branes



McGuirk, Shiu, Sumitomo 09
Bena, Graña, Halmagyi 09

Later:
confirmed for non-linear backreaction & fully localized (unpolarized) branes

Blåbäck, Danielsson, DJ, Van Riet, Wrase, Zagermann 11
Bena, Graña, Kuperstein, Massai 12
Gautason, DJ, Zagermann 13
Blåbäck, Danielsson, DJ, Van Riet, Vargas 14



- analogous results in many other setups:
anti-D2, anti-M2, anti-D6 in
various different flux backgrounds

Bena, Giecold, Halmagyi 10
Massai 11
Giecold, Goi, Orsi 11
Blåbäck, Danielsson, DJ, Van Riet, Wrase, Zagermann 11
Giecold, Orsi, Puhm 13
Cottrell, Gaillard, Hashimoto 13
Blåbäck 13

→ Universal behavior, largely model-independent!

Master equation

Linear comb. of eoms relates integrand of on-shell brane action to total derivative:

$$\left.\begin{aligned} &\nabla^2\phi = \dots \\ &\mathrm{d}\left(e^{-\phi} *_{10} H\right) = \dots \\ &R_{\mu\nu} = \dots \end{aligned}\right\} \quad \mathcal{L}_{\mathrm{DBI}}\delta(r) + \mathcal{L}_{\mathrm{WZ}}\delta(r) = \partial^M(\dots)$$

Burgess, Maharana, van Nierop, Nizami, Quevedo 11
Gautason, DJ, Zagermann 13
Blåbäck, Danielsson, DJ, Van Riet, Vargas 14

(almost) completely model-independent, follows from how branes and fluxes break scale invariance of type II supergravity

Integrate:

$$S_{\mathrm{DBI}} + S_{\mathrm{WZ}} = \oint \mathfrak{B}$$

on-shell brane action
flux singular if $S_{\mathrm{DBI}} + S_{\mathrm{WZ}} \neq 0$

boundary term at infinity
equals ADM mass
$\oint \mathfrak{B} \propto M = 2e^{4A}N\mu_3$

Master equation relates BC at anti-brane to BC at the end of the throat
enforces singular flux at the tip whenever anti-D3 number is non-zero

Resolution in String Theory?

Evidence for Resolution

Backreacted solution passes several non-trivial tests

- brane/anti-brane force — Bena, Giecold, Graña, Halmagyi 10
- correct ADM mass — Dymarsky 11
- dual field theory tests — Dymarsky, Massai 13
- dimensional reduction to 4D EFT yields correct uplift term — DJ 14

Main proposals for resolution of flux singularity:

- brane polarization → meta-stable
- perturbative decay to SUSY ground state → unstable — Blåbäck, Danielsson, Van Riet 12; Danielsson, Van Riet 14
- something else

Brane polarization

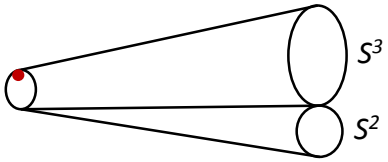
N (anti-)Dp-branes in a flux background: Myers 99

worldvolume scalars can acquire non-commutative vevs $\left[X^i, X^j\right] \neq 0$

$N \gg 1$: effective description in terms of „fuzzy“ higher-dim. brane

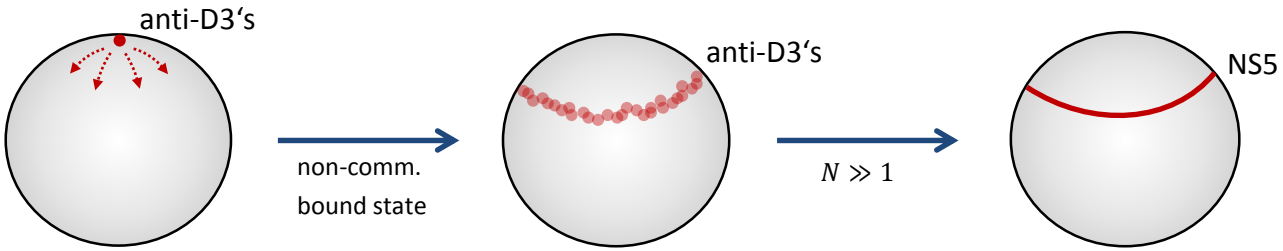
Polarization lowers co-dimension → can cure „naive“ singularities Polchinski, Strassler 00

Does this happen for anti-D3-branes in Klebanov-Strassler?



Probe approximation:

anti-D3‘s polarize into NS5-brane wrapping S^2 inside of S^3 at the tip Kachru, Pearson, Verlinde 02



Brane polarization

Do anti-branes also polarize in backreacted solutions?

- Anti-D*p*-branes in AdS flux backgrounds polarize into D(*p*+2)-branes
  polarization triggered by negative CC
  resolves flux singularities

  DJ, Schmidt, Zagermann 14
  Apruzzi, Fazzi, Rosa, Tomasiello 14
  Gautason, Truijen, Van Riet 15

- Anti-D3-branes in Klebanov-Strassler do not polarize into D5-branes

  Bena, DJ, Kuperstein, Van Riet, Wrase, Zagermann 12
  Bena, Graña, Kuperstein, Massai 12

- Anti-D3-branes in Klebanov-Strassler do polarize into NS5-branes and (*p*,*q*) 5-branes
  But: repulsive force between anti-D3's, endpoint not understood
  Polarized solution meta-stable or unstable itself?

  Bena, Graña, Kuperstein, Massai 14

What is the right answer?

How does the near-tip resolution of the flux singularity look like?

Brane polarization

Distribution of anti-D3‘s

String-size resolution

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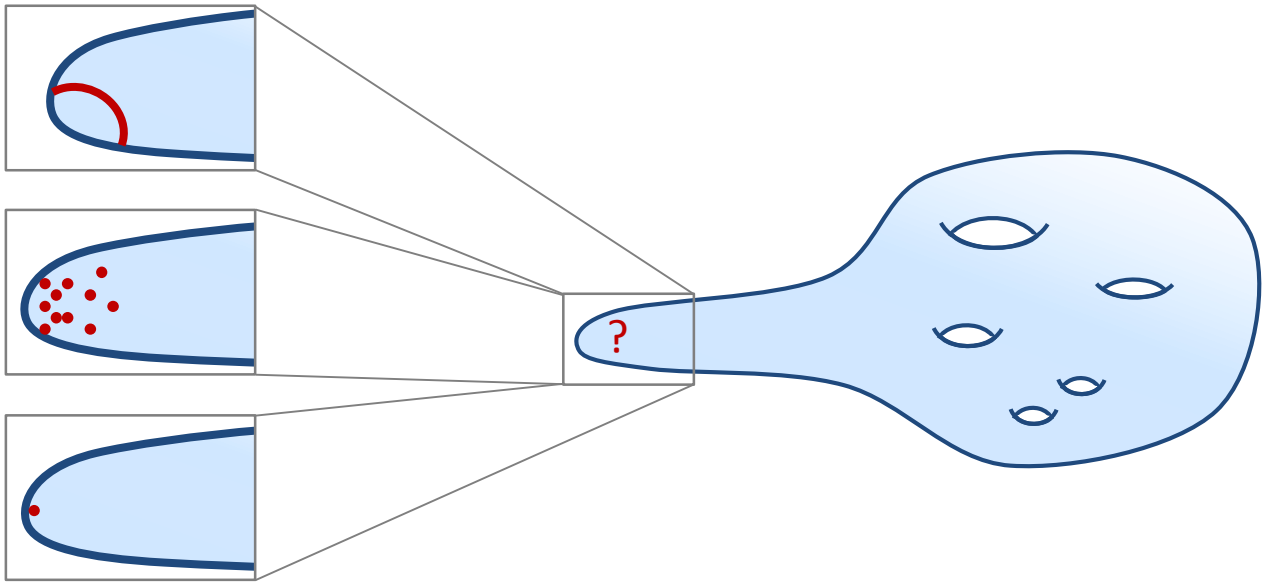


Complicated dynamics, little symmetry

Checking for resolution directly is difficult!

Resolution in string theory?

Indirect argument (Gubser criterion):

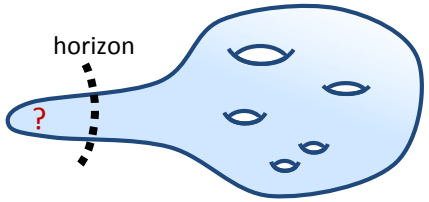
Gubser 00

If singularity is cloaked at finite *T* by regular black brane horizon, it is resolved in string theory

Idea: Skip direct search for resolution mechanism

Whatever the near-tip solution looks like, heat it up!

→ should yield regular black brane in Klebanov-Strassler with anti-D3 charge



Goal: check for existence of such solutions to see whether singularity is benign

Earlier explicit checks negative:

Bena, Buchel, Dias 12
Bena, Blåbäck, Danielsson, Van Riet 13

- analytic result for anti-D6 in H, F_0 background
- numerical search for anti-D3 in Klebanov-Tseytlin/Klebanov-Strassler

Resolution in string theory?

Finite temperature version of master equation:

Blåbäck, Danielsson, DJ, Van Riet, Vargas 14

eoms relate BC at horizon to BC at the end of the throat

$$\oint_{\text{hor}} \mathfrak{B} = \oint_{\text{end}} \mathfrak{B}$$

boundary term at horizon

singular term is generated

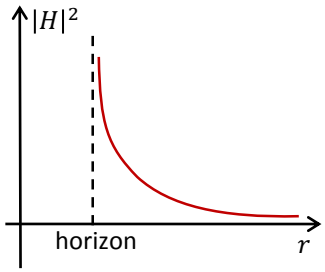
in the flux density if $\oint_{\text{hor}} \mathfrak{B} \neq 0$

boundary term at infinity

depends on T and M

non-zero if anti-D3 charge

→ singular fluxes at horizon if black brane has anti-D3 charge



explains negative searches for regular anti-D*p* charged black branes

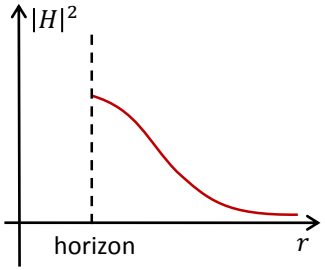
Glimmer of hope: no-go theorem can be evaded if two singular terms conspire to cancel each other out

Recent updates

- Resolution of singularity for many anti-branes? Hartnett 15

  Linearized anti-D3 backreaction in toy geometry:
  regular black brane solutions making use of our loophole exist

  Open questions: Does it also work in KS? Non-linear backreaction?
  Fate of singularity in other setups?



- Resolution of singularity for single anti-brane? Michel, Mintun, Polchinski, Puhm, Saad 14
  Polarization not possible, SUGRA approximation not valid

  Proposal: singularities resolved in EFT
  Explicit check?

- New perturbative decay channel? Danielsson 15
  Proposal: instability against clumping of charge density in 4D spacetime
  (similar to Gregory-Laflamme)

Conclusions

Conclusions

- Anti-branes in flux backgrounds are an important ingredient for dS vacua in string theory
- Anti-brane backreaction leads to singularities in the supergravity approximation

  Universal behavior in many different models
- If regular black brane exists at finite *T,* singularities should be acceptable in string theory

  No-go theorem: black brane with anti-brane charge → singular flux at horizon unless intricate cancellation of several singular terms

  Recent hints that solutions with such cancellations do exist, more work necessary
- Interesting insights expected, independent of outcome:

  How big is the dS landscape? How does string theory resolve singularities? …

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Thank you!