Brane/antibrane dynamics and KKLT stability

Joseph Polchinski
Kavli Institute for Theoretical Physics
UC Santa Barbara

SUSY 2015
Lake Tahoe, Aug. 28

• Virtually all non-supersymmetric string vacua (including de Sitter vacua) are ultimately unstable.

• We live with metastability all the time (ordinary matter), but it makes things harder.

• There are now a variety of constructions:

Supercritical models (Silverstein, hep-th/0106209)

KKLT models (Kachru, Kallosh, Linde, Trivedi, hep-th/0301240)

Large volume models (Balasubramanian, Berglund, Conlon, Quevedo, hep-th/0502058)

Negative curvature compactifications (Silverstein, 0712.1196)

…

• Virtually all non-supersymmetric string vacua (including de Sitter vacua) are ultimately unstable.

• We live with metastability all the time (ordinary matter), but it makes things harder.

• There are now a variety of constructions:

Supercritical models (Silverstein, hep-th/0106209)

KKLT models (Kachru, Kallosh, Linde, Trivedi, hep-th/0301240)

Large volume models (Balasubramanian, Berglund, Conlon, Quevedo, hep-th/0502058)

Negative curvature compactifications (Silverstein, 0712.1196)

…

I will focus on the KKLT models.

The KKLT models have been a subject of controversy: various instabilities and other problems have been claimed by various groups.

These models are intricate, but as with many problems, things become simpler if one uses the right effective field theory.

Outline

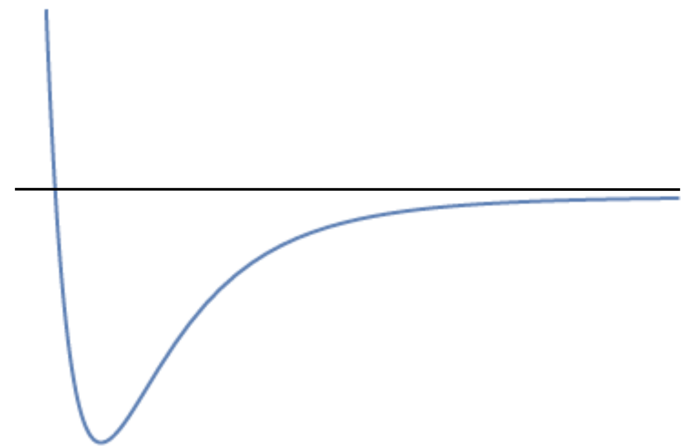
- Overview of KKLT models
- Antibrane issues
- From 10 to 4 dimensions
- Conclusions

I. KKLT Overview

Focus on a single degree of freedom, the radius r of the compact space.

Warmup: simple $AdS_4 \times S^7$ compactification of M theory. The effective 4-dimensional potential is

$$V(r) \sim N^2/r^{21} - 1/r^9$$



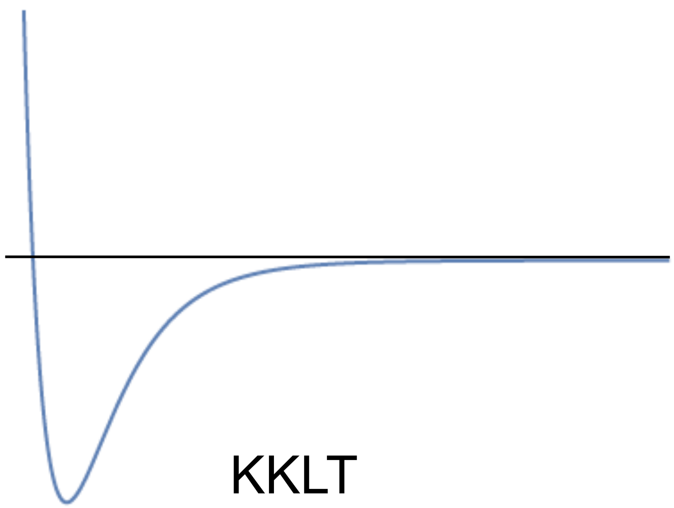
Positive term from flux on S^7, negative term from curvature of S^7.

AdS minimum, supersymmetric, absolutely stable.

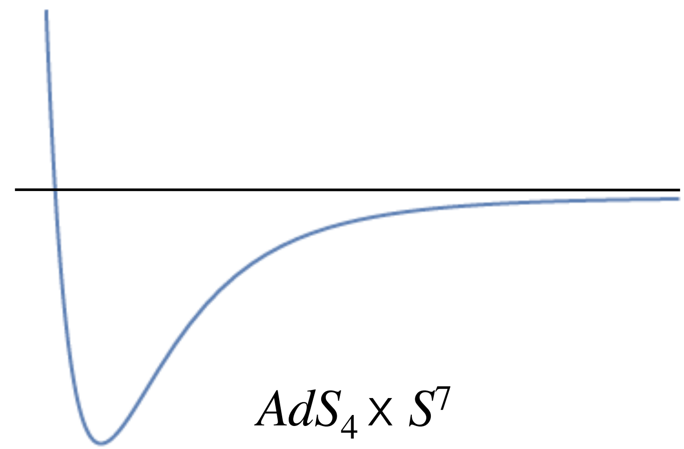
For KKLT, the positive term is still from flux (partly offset by O-planes), but the negative term is from instantons.

$$K = -3\ \ln(\rho + \bar{\rho}), \qquad W = W_0 + Ae^{-\rho}, \qquad \rho = r^4 + i\chi$$

Stable SUSY AdS vacuum, similar to previous, but potential goes to zero more rapidly at large r.

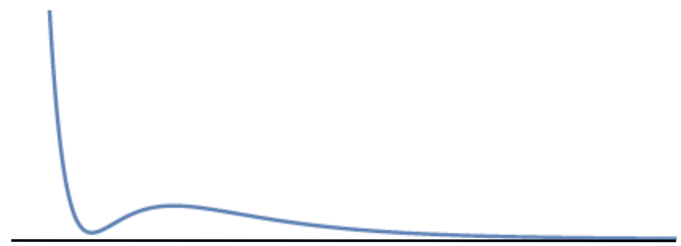


KKLT



$AdS_4 \times S^7$

Next step: excite SUSY vacuum to get long-lived non-SUSY vacuum. Simple mechanism: add anti-D3 brane:



KKLT, uplifted

KKLT argue that anti-D3 brane is long-lived.

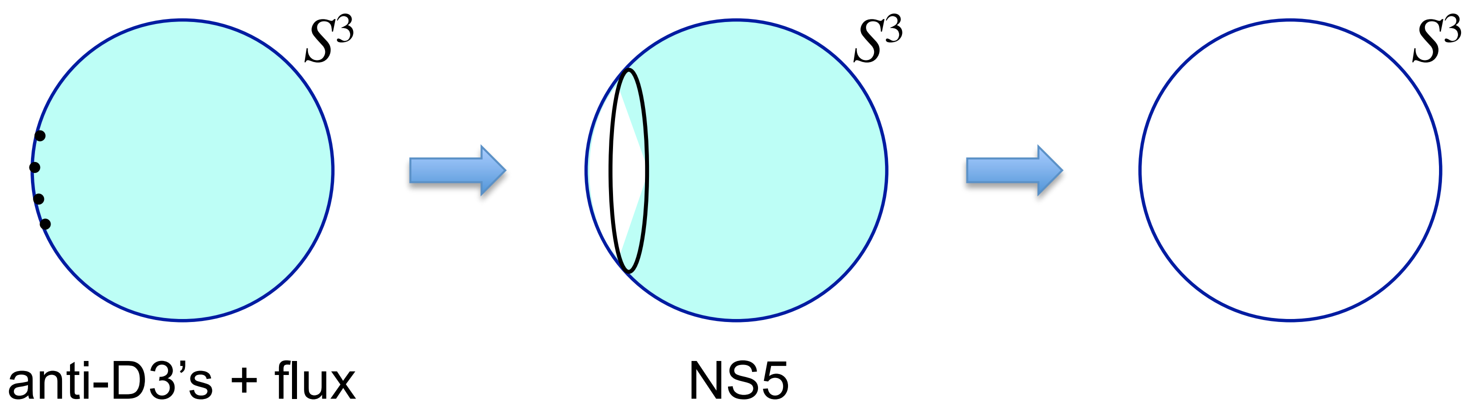
Small final c.c. due to tuning (via landscape).

Obvious instability: decompactification ($r \to \infty$). This can be parametrically slow.

II. Antibrane issues

The `anti' means that the anti-D3 has opposite SUSY, and opposite charge, from other elements of the compactification. In particular, it is immersed in a flux background $H_3 F_3$ that carries the opposite D3 charge.

These can annihilate via the Kachru-Pearson-Verlinde process,



This is nonperturbative, because the NS5 must stretch over the S^3, and it can be parametrically slow.

Bianchi identities for 3-form and 5-form flux seem to forbid any more rapid process.

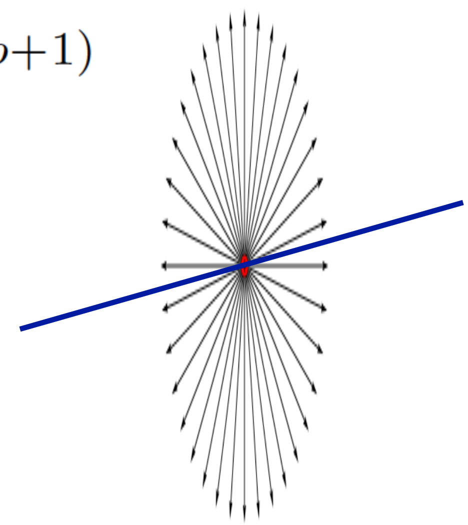
First challenge: sugra backreaction of antibranes seems to lead to unphysical singularities (Bena, Grana, Halmagyi, 0912.3519; McGuirk, Shiu, Sumitomo, 0910.4581).

Consider D-brane action:

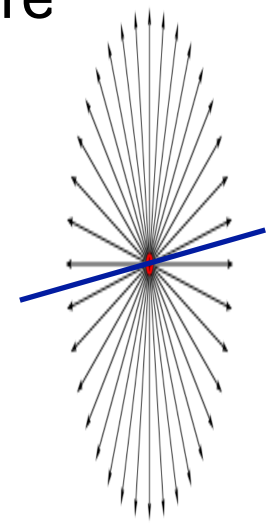
$$-T_p \int d^{p+1}\xi \, e^{-\phi} \det{}^{1/2}\left(G_{ab} + B_{ab} + 2\pi\alpha' F_{ab}\right) + i\mu_p \int_{p-\mathrm{brane}} \mathrm{Tr}\left(e^{2\pi\alpha' F + B}\right) \textstyle\sum_p C_{(p+1)}$$

Bulk fields G, B, C, ϕ; brane fields X, F.

The brane sources the bulk fields, which blow up nonlinearly at the brane – how do we deal with this?



Common approach: use probe approximation, ignore self-field.

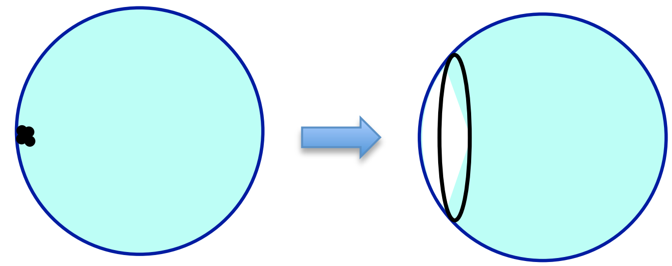


Better: treat brane action as low-energy effective action, even for classical divergences (Damour, 1975; Goldberger, Wise, hep-th/0104170). Even get classical beta functions from classical logs.

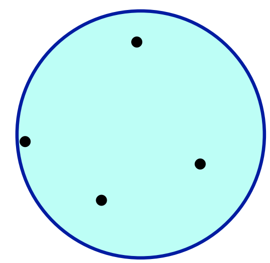
Renormalize by matching onto UV theory. For small numbers of antibranes (which are sufficient), the correct effective theory is perturbative string theory, *not* sugra, and there is manifestly no problem (Michel, Mintun, JP, Puhm, Saad, 1412.5702). The only degree of freedom is the antibrane position, which moves to a minimum (confined near tip of KS throat by warping).

Additional points:

For large numbers of coincident antibranes, the sugra description is good. In this case, the singularity is resolved by brane polarization (JP,Strassler, hep-th/0003136).*



Recent claim (Bena, Grana, Kuperstein, Massai,1410.7776): antibranes want to separate rather than polarizing. No problem if true, because we already know that the single antibrane is fine.



Another claim: there are lower paths through KPV barrier (Danielsson, van Riet, etc., 1202.1132, 1410.8476, 1502.01234). But these paths violate Gauss's law or Bianchi identity.

*Cohen-Maldonado, Diaz, Van Riet , Vercnocke 1507.01022?

III. From 10 dimensions to 4

The KKLT construction is an intricate mix of 10-d physics (fluxes, antibranes, brane instantons wrapped on cycles) and 4-d physics (sugra potential). There are various claims that these have not been correctly joined, and in particular that antibranes cannot actually produce the necessary uplift (Brustein, de Alwis, hep-th/0402088 ; Sethi, unpublished).

To deduce the 4d action, let us first note that the KKLT construction is driven by two small parameters, the constant W_0 in the superpotential, and the warp factor e^A at the bottom of the Klebanov-Strassler throat where the D3 sits.

In the limit that both parameters go to zero, there are two sets of light fields, besides supergravity:

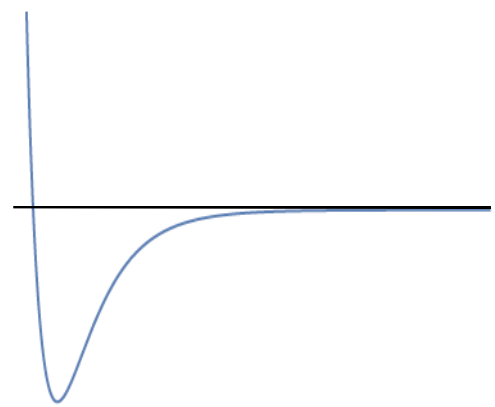
W_0 small: Kahler moduli for the compactification

e^A small: fields at the bottom of the KS throat.

The latter are 10-dimensional, but conveniently can be described by an AdS/CFT dual 4d KS gauge theory. So the 4d action is

sugra + Kahler moduli + KS gauge theory.

The moduli again have $K = -3 \ln(\rho + \bar{\rho})$, $W = W_0 + Ae^{-\rho}$. If the gauge vacuum is supersymmetric, sugra + Kahler give a stable supersymmetric AdS_4 vacuum.



The KS gauge theory has a metastable SUSY-breaking vacuum, described in the AdS dual by adding antibrane(s) (as in part II).

To analyze the coupling to sugra, go below the scale of SUSY-breaking: the only degree of freedom remaining from the gauge theory is the goldstino, describe by the nipotent superfield S ($S^2 = 0$), (Komargodski, Seiberg, 0907.2441, etc.). Low energy theory is sugra + Kahler + S, with

$$W = W_0 + Ae^{-\rho} + fS.$$

This has metastable de Sitter vacua, depending on the tunable ratio W_0/S. (Kallosh, Wrase, 1411.1121; Bergshoeff, Dasgupta, Kallosh, Van Proeyen, Wrase, 1502.07627; Kallosh, Quevedo, Uranga, 1507.07556).

Objections?

“Hard to get the 4d theory from the 10d theory explicitly.”

Yes, effective field theory makes things much easier.

“No-go theorems.” (de Wit, Smit, Hari Dass ’86, …, Maldacena, Nunez hep-th/0007018 …, Kutasov, Maxfield, Melnikov, Sethi 1504.00056).

These all hold under narrow conditions, e.g. the classical limit. None apply to KKLT and the other constructions.

IV. Conclusions

The KKLT construction has been thoroughly vetted, and it seems to me has survived robustly.

The de Sitter vacua are still there, as is the landscape.