SUSY Breaking in the Klebanov-Strassler Background by Anti-D3 Branes

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based on arxiv:0912.3519
Iosif Bena, Mariana Graña, N.H.
and work in progress...
Review of meta-stable vacua, flux

compactifications and the Klebanov-Strassler (KS) Background

KPV proposal for spontaneous susy breaking in the KS background

Our computation of the spectrum around KS

The anti-D3 brane in the Klebanov-Strassler background
Meta-Stable Vacua in Field Theory

$V(\phi)$

non-SUSY vacuum

SUSY vacuum, can be found using an index

$\phi$

scalar potential $\rightarrow$ spontaneous SUSY breaking
Non-SUSY vacua are difficult to identify. In general, strongly coupled QFT is hard to calculate $V(\phi)$.

Strategies to study the scalar potential:
- Limit oneself to the holomorphic sector
- Use a field theory duality
- Use gauge/gravity duality
- Perhaps perturbation theory in simple examples
Flux Compactifications in String Theory

six dimensional internal geometry gives the 4d UV completion by gravity

+ moduli stabilization (hard problem)

Infra-Red

warped throat region, here we can utilize the power of gauge/gravity duality
Flux Compactifications in String Theory

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how is SUSY broken?
Flux Compactifications in String Theory

six dimensional internal geometry gives the 4d UV completion by gravity

+ moduli stabilization (hard problem)

Infra-Red

warped throat region, here we can utilize the power of gauge/gravity duality

how is SUSY broken?

at what scale is SUSY broken?
Warped Throat Region: The Klebanov-Strassler Background

The Deformed Conifold $R_{ij}^{(6)} = 0$

Klebanov-Strassler '99

despite the branes dissolved in flux, this is a smooth sugra solution
Kachru/Pearson/Verlinde '01

A stack of $P$ anti-D3 branes in the IR breaks SUSY

We will preserve the symmetries of the sphere by smearing the anti-D3 branes
KPV proposal for spontaneous SUSY breaking

$V(\phi)$

SUSY vacuum $q_b = 0$

KPV Vacuum

$-\bar{N} < q_b < 0$

$q_b = \int_{T_0^{11}} F^{(5)}$

$q_f = \int_{X_6} H^{(3)} \wedge F^{(3)}$

$Q_{D3}^{Max} = q_b + q_f$

$= -\bar{N}$

$= (\int_{T_\infty^{11}} - \int_{T_0^{11}}) F^{(5)}$
Our Goal: find the supergravity solution for the backreacted anti-D3 branes

This exact supergravity solution would determine unambiguously whether the SUSY breaking by anti-D3 branes is explicit or spontaneous.

If it is spontaneous, this solution would be very useful for model building, explicit SUSY breaking is less useful.

We work in perturbation theory around the KS background in $\frac{\bar{N}}{M}$
In AdS space, the wave equation for a scalar field has two possible behaviours near the boundary.

\[ \phi \sim r^{d-\Delta} \]

\[ \phi \sim r^{-\Delta} \]

**Deformation by**

\[ \delta S = \int d^d x \mathcal{O}(x) \quad \langle \mathcal{O}(x) \rangle \]

**dim(\mathcal{O}) = \Delta**

In the UV the KS solution is almost AdS, up to logarithm terms.

The physical modes in the UV can only be determined by fixing the IR b.c.'s.
SU(2) × SU(2) × \mathbb{Z}_2 invariant KS scalar spectrum

UV Behavior of the spectrum

<table>
<thead>
<tr>
<th>dim \Delta</th>
<th>non-norm/norm</th>
<th>int. constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>( r^4/r^{-8} )</td>
<td>( Y_4/X_1 )</td>
</tr>
<tr>
<td>7</td>
<td>( r^3/r^{-7} )</td>
<td>( Y_5/X_6 )</td>
</tr>
<tr>
<td>6</td>
<td>( r^2/r^{-6} )</td>
<td>( X_3/Y_3 )</td>
</tr>
<tr>
<td>5</td>
<td>( r/r^{-5} )</td>
<td>( ___ )</td>
</tr>
<tr>
<td>4</td>
<td>( r^0/r^{-4} )</td>
<td>( Y_7, Y_8, Y_1/X_5, X_4, X_8 )</td>
</tr>
<tr>
<td>3</td>
<td>( r^{-1}/r^{-3} )</td>
<td>( X_2, X_7/Y_6, Y_2 )</td>
</tr>
<tr>
<td>2</td>
<td>( r^{-2}/r^{-2} )</td>
<td>( ___ )</td>
</tr>
</tbody>
</table>

- The \( X_i \) break SUSY
- The \( Y_j \) preserve SUSY
Universal asymptotic UV falloff for the force on a probe D3 brane in perturbed KS background:

\[ F \sim \frac{X_1}{r^5} + \mathcal{O}(r^{-11}) \]

- \( X_1 \) is solely responsible for a force on a probe D3 brane!
First enforce UV boundary conditions of the SUSY vacuum

- Examine IR boundary conditions and allow for physical singularities

If no such IR boundary conditions can be found, we would then conclude that the UV boundary conditions must be changed
We find various singularities in the IR

- warp factor $\sim \tau^{-1}$
  and thus $R \sim F_{(5)}^{2} \sim \tau^{-4}$

perfectly physical, due to the smeared anti-D3 branes

However, we also find a highly unusual singularity

$$H_{(3)}^{2} \sim F_{(3)}^{2} \sim \tau^{-2}$$

which has no physical interpretation.
Despite having finite action, this singularity **alone** in the energy density from the three-forms should be considered an unacceptable singularity.

However, it could be an artifact of the singularity in the energy density of the curvature and five form due to the smearing.
The superpotential approach is a nice organizing principle for non-SUSY backgrounds which are first order perturbations around a SUSY background.

We have two sets of eight coupled first order O.D.E.'s. The bulk mass of these modes is known numerically but we need the actual modes.
Numerically integrating the field equations will allow us to relate IR and UV integration constants.

\[ Q_{D3}^{Max} = q_b + q_f = -\overline{N} \]

We will compute \((q_b, q_f)\) in terms of \(\overline{N}\).

We will also compute \(X_1^{UV}\) the coefficient of the force on a probe D3, in terms of \(\overline{N}\).
Breaking supersymmetry by adding anti-D3 branes has been common practice and thus understanding the UV behaviour is a vital problem.

Supergravity is our best tool since the field theory is strongly coupled everywhere.

The IR singularities in our linear order analysis around KS suggest that the UV boundary conditions cannot be that of KS.

This seems to imply that the supersymmetry breaking is explicit. However more work needs to be done:

**Future Directions**

- Unsmearing the brane
- Beyond perturbation theory
- Examine stability of our solution