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Non-supersymmetric infrared perturbations to the warped deformed conifold

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Abstract

We analyze properties of non-supersymmetric, isometry-preserving perturbations to the infrared region of the warped deformed conifold, i.e. the Klebanov–Strassler solution. We discuss both perturbations that “squash” the geometry, so that the internal space is no longer conformally Calabi–Yau, and perturbations that do not squash the geometry. Among the perturbations that we discuss is the solution that describes the linearized near-tip backreaction of a smeared collection of $\overline{\text{D3}}$-branes positioned in the deep infrared. Such a configuration is a candidate gravity dual of a non-supersymmetric state in a large-rank cascading gauge theory. Although $\overline{\text{D3}}$-branes do not directly couple to the 3-form flux, we argue that, due to the presence of the background imaginary self-dual flux, $\overline{\text{D3}}$-branes in the Klebanov–Strassler geometry necessarily produce singular non-imaginary self-dual flux. Moreover, since conformally Calabi–Yau geometries cannot be supported by non-imaginary self-dual flux, the $\overline{\text{D3}}$-branes squash the geometry as our explicit solution shows. We also briefly discuss supersymmetry-breaking perturbations at large radii and the effect of the non-supersymmetric perturbations on the gravitino mass.

Keywords: D-branes; Supergravity; Supersymmetry breaking

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1. Introduction

Among the challenges in connecting string theory to our observable universe is the difficulty in constructing controllable supersymmetry-breaking backgrounds. While supersymmetry (SUSY) breaking is a prerequisite in any phenomenological study of four-dimensional supersymmetric theories, the myriad of string theory moduli makes this a formidable task. Unless all moduli are stabilized at a hierarchically higher scale than the scale of SUSY breaking, one generically finds runaway directions that destabilize the vacuum, taking us away from the controllable background which describes the original supersymmetric state.

On top of this challenge, the observational evidence of an accelerating universe adds yet another layer of complication: in addition to the requirement that the SUSY-breaking background be (meta)stable, viable vacua must also have positive energy density. Motivated by this cosmological consideration, several mechanisms to "uplift" the vacuum energy of string vacua have since been suggested, e.g., by adding $\overline{\text{D3}}$-branes [1], by introducing D-terms from gauge fluxes [2], or by considering negatively curved internal spaces [3–6] (see also [7–9]). Though these mechanisms are often discussed in terms of 4D effective field theories, it is of interest for a variety of reasons discussed below to find backreacted supergravity solutions including such uplifting sources as full 10D backgrounds.

In this paper, we report on some properties of non-supersymmetric perturbations to the Klebanov–Strassler (KS) solution [10], a prototypical warped supersymmetric background which is dual to a cascading $SU(N+M) \times SU(N)$ gauge theory in the strong 't Hooft limit, and is ubiquitous in flux compactifications and in describing moduli stabilization. The backreaction of a collection of $\overline{\text{D3}}$-branes placed at the tip of the deformed conifold, should be described by such perturbations. Such a configuration is known to be metastable against brane/flux annihilation provided that the number of $\overline{\text{D3}}$-branes is sufficiently small in comparison to the background flux [11]. Though further instabilities generically arise upon compactification when the closed string degrees of freedom become dynamical and further stabilization mechanisms (e.g., fluxes, non-perturbative effects, etc.) are needed, this *local* construction represents progress towards a genuine metastable SUSY breaking background. Other than being an essential feature in [1] for vacuum uplifting to de Sitter space, the warped $\overline{\text{D3}}$ tension introduces an exponentially small supersymmetry breaking scale which can be useful for describing hidden sector dynamics (both in dimensionally reduced theories and in their holographic descriptions).

Although we are interested especially in modes related to $\overline{\text{D3}}$-branes, the analysis with more general modes brings us interesting features for the classification of near-tip perturbations. We analyze perturbations that are either singular or regular and those that either do or do not "squash" the geometry (i.e. those that do or do not leave the internal geometry as conformally the deformed conifold) in accordance with the equations of motion. We also identify which modes can break supersymmetry. The mode related to $\overline{\text{D3}}$s at the tip should have singular behavior, at least in the warp factor, in order to capture the localized tension. We show below however that the only singular, non-squashed, non-SUSY mode corresponds to a point source for the dilaton, and thus cannot be identified as an $\overline{\text{D3}}$-brane. Furthermore, the squashed backreaction of an $\overline{\text{D3}}$-brane is supported by a 3-form flux that is no longer imaginary self-dual (ISD). The fact that an $\overline{\text{D3}}$-brane squashes the geometry was observed in [12] where the $\overline{\text{D3}}$-brane backreaction was studied in the Klebanov–Tseytlin (KT) region [13]. However, due to the decreased complexity of the geometry, the squashing of the geometry in [12] is less dramatic than the squashing in the near-tip region. Likewise, the resulting non-ISD flux near the tip is more complex than the non-ISD flux supporting the solution of [12]. We also discuss these issues in the KT region.