Dynamical Tadpoles and Weak Gravity Constraints

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Motivations

1. One of the most difficult challenges in string theory has always been **supersymmetry breaking**.
2. In particular, supersymmetry breaking often produce **tadpole sources** for dynamical fields which **unstabilize** the vacuum.[1]
3. Contrary to tadpoles for non-dynamical fields, e.g. RR tadpoles, **dynamical tadpoles** do not indicate an inconsistency of the theory.
4. Instead, the equations of motions are **not** obeyed in the proposed configuration, which should be **modified** to a spacetime dependent solution, e.g. rolling down the slope of the potential.[2]
5. Usually, they are treated lightly, or even **ignored**.

[1] W. Fischler, L. Susskind, *Phys. Lett. B* **171**, 383–389 (1986); W. Fischler, L. Susskind, *Phys. Lett. B* **173**, 262–264 (1986).

[2] E. Dudas *et al.*, *Nucl. Phys. B* **708**, 3–44 (2005); J. Mourad, A. Sagnotti, *Phys. Lett. B* **768**, 92–96 (2017).

What about Swampland constraints?

1. A mistreatment of dynamical tadpoles has a **dramatic** impact on the consistency of the background.
2. We found contradictions with Quantum Gravity, via a **violation** of some swampland constraints.[3]
3. In our work we focused on the **Weak Gravity Conjecture** (WGC).[4]

[3] C. Vafa, arXiv: hep-th/0509212 (hep-th) (2005); H. Ooguri, C. Vafa, *Nucl. Phys.* **B766**, 21–33 (2007); T. D. Brennan *et al.*, *PoS* **TASI2017**, 015 (2017); E. Palti, *Fortsch. Phys.* **67**, 1900037 (2019).

[4] N. Arkani-Hamed *et al.*, *JHEP* **06**, 060 (2007).

Introduction

1. Considering toroidal models, the D7-branes have position *moduli* that are stabilized by the fluxes.[5]
2. We move the D7-branes slightly off the minimum of the potential arising by axion monodromy, with the axion played by the periodic D7-brane position.[6]
3. We have a **controlled** supersymmetry breaking, due to flux-induced extra tension of the D7-brane worldvolume and we generate **dynamical tadpoles**.[7]
4. Such extra energy density stored on the D7-brane worldvolume sources corrections to the geometry, encoded in a corrected **internal** warp factor.[8]

[5] L. Gorlich *et al.*, *JHEP* **12**, 074 (2004); P. G. Camara *et al.*, *Nucl. Phys. B* **708**, 268–316 (2005); J. Gomis *et al.*, *JHEP* **11**, 021 (2005); S. Bielleman *et al.*, arXiv: 1505.00221 (hep-th) (2015).

[6] E. Silverstein, A. Westphal, *Phys. Rev.* **D78**, 106003 (2008); N. Kaloper, L. Sorbo, *Phys. Rev. Lett.* **102**, 121301 (2009); F. Marchesano *et al.*, *JHEP* **09**, 184 (2014); A. Hebecker *et al.*, *Phys. Lett.* **B737**, 16–22 (2014).

[7] A. Hebecker *et al.*, *Phys. Lett.* **B737**, 16–22 (2014); L. E. Ibáñez *et al.*, *JHEP* **01**, 128 (2015).

[8] D. Baumann *et al.*, *JHEP* **11**, 031 (2006); M. Kim, L. McAllister, arXiv: 1812.03532 (hep-th) (2018).

Introduction

We show that this procedure implies **brooming** a dynamical tadpole under the rug, and that it leads to a **contradiction** with Quantum Gravity, via a **violation** of the axion WGC.

1. The problem lies in the assumption that the backreaction of the supersymmetry breaking source is fully encoded in an **internal** warp factor, with no effect on the **non-compact** spacetime configuration.
2. We are **ignoring** the dynamical tadpole sourced by supersymmetry breaking.
3. Quantum Gravity is thus reminding us that consistent configurations **must** necessarily include spacetime dependence to account the dynamical tadpole.

Backreaction away from the minimum

1. Consider type IIB theory on a $\mathbf{T}^6/(\mathbf{Z}_2 \times \mathbf{Z}_2)$ orbifold and orientifold.[9]
2. Let us introduce coordinates $0 \leq x^i, y^i \leq 1$, for each $\mathbf{T}^2$, and complexify them as $z^i = x^i + \tau_i y^i$.
3. Consider the $D7_1$-brane at the origin and a ED3-brane at position z.
4. Move it by a factor
$$\mathrm{Re}\, z^1 = \pm\epsilon \in \mathbf{R}\,.$$
5. We are moving off the **minimum** of the potential $\Longrightarrow$ Non-trivial B-field on the $D7_1$-brane worldvolume.
6. We have a $D3/\overline{D3}$-brane tension which backreacts on the metric:
$$Z \simeq 1 - \frac{N^2|\epsilon|^2}{2\pi}\left[\ln\left|\frac{z-\epsilon}{L}\right| + \ln\left|\frac{z+\epsilon}{L}\right|\right] + \ldots$$
7. We have a $D5/\overline{D5}$-brane density which backreacts on the dilaton:
$$g_s^{-1} \simeq 1 - \frac{N|\epsilon|}{4\pi}\left[\ln\left|\frac{z-\epsilon}{L}\right| + \ln\left|\frac{z+\epsilon}{L}\right|\right] + \ldots$$

[9] R. Blumenhagen *et al.*, *Nucl. Phys. B* **663**, 319–342 (2003); J. F. Cascales, A. M. Uranga, 1048–1067 (Nov. 2003); J. Gomis *et al.*, *JHEP* **11**, 021 (2005).

The dynamical tadpole problem

1. We want to promote the logarithmic backreaction to a solution of the Laplace equation with a delta function source:

$$-\triangle Z \sim \delta_2(z,\overline{z})$$

2. However, this leads to a problem of integrability of the equation, as the LHS integrates to zero in a compact space, and the RHS does not. **Dynamical tadpole problem**.

3. The solution is usually the introduction of a constant distribution of background source compensating the delta function:[10]

$$\triangle G_2(z-z') = \delta_2(z-z') - \frac{\mathbf{1}}{\boldsymbol{L^2 \mathrm{Im}\,\tau}}$$

so that ($L=1$)

$$G_2(z) = \frac{1}{2\pi}\ln\left|\frac{\vartheta_1(z|\tau)}{\eta(\tau)}\right| - \frac{\boldsymbol{(\mathrm{Im}\,z)^2}}{\boldsymbol{2\mathrm{Im}\,\tau}}\,.$$

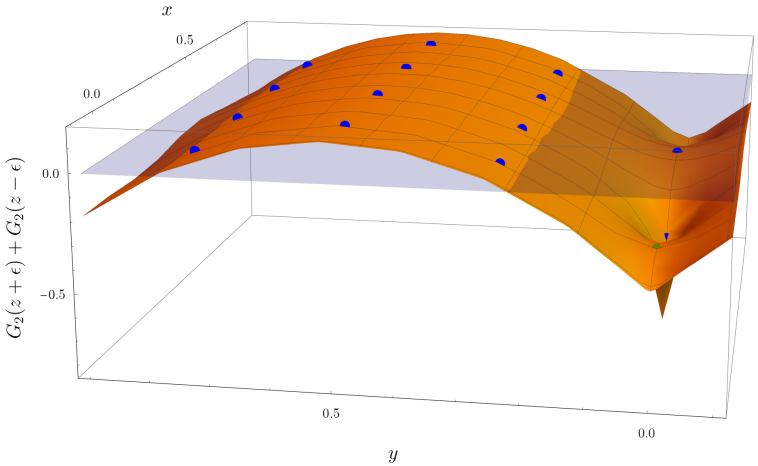
[10] D. Baumann *et al.*, *JHEP* **11**, 031 (2006); M. Kim, L. McAllister, arXiv: 1812.03532 (hep-th) (2018).

The dynamical tadpole problem

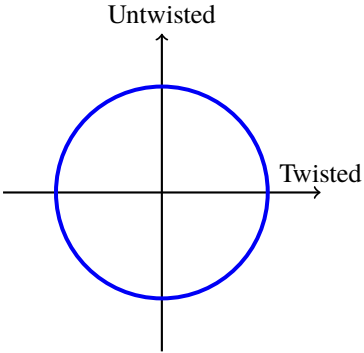
4. Despite being a well-defined mathematical procedure, its **physical** meaning is **questionable**.
5. We are introducing **by hand** a negative constant tension background in the internal geometry.
6. We are **ignoring** the dynamical tadpole (potential for the D7-brane position off its minimum) and insist that the configuration still admits a solution with distortion only in the internal space, keeping the external 4d **Minkowski** spacetime.

The regular ED3

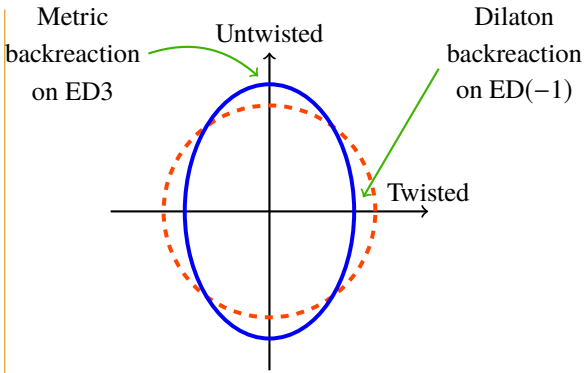
$$\Delta S > 0 \Longrightarrow G_2(z+\epsilon) + G_2(z-\epsilon) < 0$$



The fractional ED3/ED(−1) sector



The 2-axion convex hull WGC for the BPS case. The solid line describes the set of BPS states, **saturating** the WGC for any rational direction.



After including backreaction, the curve of former BPS states is deformed away from the unit circle. In the purely untwisted charge direction, the WGC is satisfied, but it is **violated** in the purely twisted charge direction.

Conclusions

1. We have considered the backreaction of supersymmetry breaking effects, and the corresponding dynamical tadpole, in explicit examples of type IIB toroidal orientifolds.
2. The resulting configurations seem to **violate** the WGC for certain axions.
3. The underlying problem is due to the unphysical assumption of **ignoring** the effects of the **dynamical tadpoles** on the 4d spacetime configuration, restricting the backreaction to the internal manifold.
4. These are examples of theories in which dynamical tadpoles manifest as **direct incompatibility** with quantum gravity, via swampland constraints.
5. **Inverse logic**: the condition to satisfy the WGC in its familiar formulation can be **equivalent** to the condition to sit at a vacuum, i.e. minimizing the corresponding scalar potential.

Outlook

1. It would be nice to carry out the arguments in the paper in a genuinely **non-supersymmetric** model.
2. It would be interesting to find models where the spacetime dependence sourced by the dynamical tadpole can be solved, and to address the formulation of the WGC in those backgrounds. It may be possible that the WGC does **not** hold in its **usual** formulation.
3. It would be interesting to explore if the examples where the dynamical tadpole does not seem to lead to violation of the WGC, instead they violate some **other** swampland constraints.

Thank you!