Dynamical Tadpoles and Weak Gravity Constraints

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arXiv: 2011.00051 (hep-th) (2020)

Seminar Series

on

String Phenomenology

10th November 2020

A.M. received funding from "la Caixa" Foundation (ID 100010434) with fellowship code LCF/BQ/IN18/11660045 and from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 713673

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**.

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[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, arXiv: hep-th/0410101 (2005); J. Mourad, A. Sagnotti, *Phys. Lett. B* **768**, 92–96, arXiv: 1612.08566 (hep-th) (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, arXiv: hep-th/0605264 (hep-th) (2007); T. D. Brennan *et al.*, *PoS* **TASI2017**, 015, arXiv: 1711.00864 (hep-th) (2017); E. Palti, *Fortsch. Phys.* **67**, 1900037, arXiv: 1903.06239 (hep-th) (2019).

[4] N. Arkani-Hamed *et al.*, *JHEP* **06**, 060, arXiv: hep-th/0601001 (hep-th) (2007).

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Introduction

1. Dynamical tadpoles coming from supersymmetry breaking can be found in type II compactifications with orientifolds and anti-branes.[5]
2. We studied an explicit example of type IIB orientifold compactification with NSNS and RR 3-forms fluxes,[6] with D7-branes, admitting a supersymmetric minimum.
3. We focus on supersymmetric instantons given by euclidean D-branes saturating the axion WGC.[7]

[5] S. Sugimoto, *Prog. Theor. Phys.* **102**, 685–699, arXiv: hep-th/9905159 (hep-th) (1999); I. Antoniadis *et al.*, *Phys. Lett.* **B464**, 38–45, arXiv: hep-th/9908023 (hep-th) (1999); G. Aldazabal, A. M. Uranga, *JHEP* **10**, 024, arXiv: hep-th/9908072 (hep-th) (1999).

[6] K. Dasgupta *et al.*, *JHEP* **08**, 023, arXiv: hep-th/9908088 (hep-th) (1999); S. B. Giddings *et al.*, *Phys. Rev.* **D66**, 106006, arXiv: hep-th/0105097 (hep-th) (2002).

[7] N. Arkani-Hamed *et al.*, *JHEP* **06**, 060, arXiv: hep-th/0601001 (hep-th) (2007); H. Ooguri, C. Vafa, *Adv. Theor. Math. Phys.* **21**, 1787–1801, arXiv: 1610.01533 (hep-th) (2017).

Introduction

4. Considering toroidal models, the D7-branes have position *moduli* that are stabilized by the fluxes.[8]
5. 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.[9]
6. We have a **controlled** supersymmetry breaking, due to flux-induced extra tension of the D7-brane worldvolume and we generate **dynamical tadpoles**.[10]
7. Such extra energy density stored on the D7-brane worldvolume sources corrections to the geometry, encoded in a corrected **internal** warp factor.[11]

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[8] L. Gorlich *et al.*, *JHEP* **12**, 074, arXiv: hep-th/0407130 (2004); P. G. Camara *et al.*, *Nucl. Phys. B* **708**, 268–316, arXiv: hep-th/0408036 (2005); J. Gomis *et al.*, *JHEP* **11**, 021, arXiv: hep-th/0506179 (2005); S. Bielleman *et al.*, arXiv: 1505.00221 (hep-th) (2015).

[9] E. Silverstein, A. Westphal, *Phys. Rev.* **D78**, 106003, arXiv: 0803.3085 (hep-th) (2008); N. Kaloper, L. Sorbo, *Phys. Rev. Lett.* **102**, 121301, arXiv: 0811.1989 (hep-th) (2009); F. Marchesano *et al.*, *JHEP* **09**, 184, arXiv: 1404.3040 (hep-th) (2014); A. Hebecker *et al.*, *Phys. Lett.* **B737**, 16–22, arXiv: 1404.3711 (hep-th) (2014).

[10] A. Hebecker *et al.*, *Phys. Lett.* **B737**, 16–22, arXiv: 1404.3711 (hep-th) (2014); L. E. Ibáñez *et al.*, *JHEP* **01**, 128, arXiv: 1411.5380 (hep-th) (2015).

[11] D. Baumann *et al.*, *JHEP* **11**, 031, arXiv: hep-th/0607050 (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.

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Axion Weak Gravity Conjecture

The **Axion Weak Gravity Conjecture** is formulated as follows:[12]

> An axion with decay constant f must couple to instantons with action S, such that
> $$fS \leq M_P \, .$$

The generalization to multiple axions is done introducing[13]

$$z_i \equiv \sum_j \frac{M_P}{f_{ij} S_i} \boldsymbol{e}_i$$

whose convex hull should include the unit ball.

[12] N. Arkani-Hamed *et al.*, *JHEP* **06**, 060, arXiv: hep-th/0601001 (hep-th) (2007); E. Palti, *Fortsch. Phys.* **67**, 1900037, arXiv: 1903.06239 (hep-th) (2019).

[13] C. Cheung, G. N. Remmen, *Phys. Rev. Lett.* **113**, 051601, arXiv: 1402.2287 (hep-ph) (2014); T. Rudelius, *JCAP* **1509**, 020, arXiv: 1503.00795 (hep-th) (2015); M. Montero *et al.*, *JHEP* **08**, 032, arXiv: 1503.03886 (hep-th) (2015); E. Palti, *Fortsch. Phys.* **67**, 1900037, arXiv: 1903.06239 (hep-th) (2019).

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D7-branes on ED3-branes

Consider type IIB theory on $M_4 \times \mathbf{X}_4 \times \mathbf{R}^2$ and N_{D7} D7-branes and a BPS instanton given by an ED3-brane spanning $\mathbf{X}_4$:

IIB	0	1	2	3	4	5	6	7	8	9
D7	×	×	×	×	×	×	×	×	–	–
ED3	–	–	–	–	×	×	×	×	–	–

D7-branes on ED3-branes

Consider the background created by the D7-branes:

$$ds^2 = Z(r)^{-1/2}\eta_{\mu\nu}dx^\mu dx^\nu + Z(r)^{-1/2}ds^2_{\mathbf{X}_4} + Z(r)^{1/2}dzd\overline{z}\,,$$

where we have defined $z = re^{i\theta}$ the complex plane in 89.

$$Z(r) = -\frac{N_{\mathrm{D7}}}{2\pi}\ln\left(\frac{r}{L}\right) + \ldots \text{ contributing also to } e^{-\phi} = Z(r) \Longrightarrow \tau = C_0 + ie^{-\phi} = \frac{N_{\mathrm{D7}}}{2\pi i}\ln\left(\frac{z}{L}\right) + \ldots$$

The action of the ED3-brane in probe approximation, and check it is **independent** of its position:

$$S_{ED3} = \frac{\left(Z(r)^{-1/4}\right)^4 \mathrm{Vol}(\mathbf{X}_4)}{Z(r)^{-1}g_s} = S^0_{ED3}\,.$$

D3-branes on ED3-branes

Consider type IIB theory on $M_4 \times \mathbf{X}_4 \times \mathbf{R}^2$ and N_{D3} D3-branes on M_4 and a BPS instanton given by an ED3-brane spanning $\mathbf{X}_4$:

IIB	0	1	2	3	4	5	6	7	8	9
D3	×	×	×	×	–	–	–	–	–	–
ED3	–	–	–	–	×	×	×	×	–	–

D3-branes on ED3-branes

Consider the background created by the D3-branes:

$$ds^2 = Z(r)^{-1/2}\eta_{\mu\nu}dx^\mu dx^\nu + Z(r)^{1/2}ds^2_{\mathbf{X}_4} + Z(r)^{1/2}dz d\bar{z}\,,$$

where we have defined $z = re^{i\theta}$ the complex plane in 89.

$$Z(r) = -\frac{g_s N_{\mathrm{D3}}}{2\pi}\ln\left(\frac{r}{L}\right) + \ldots$$

The D3-branes source the RR 4-form C_4

$$\varphi = \int_{\mathbf{X}_4} C_4 = \frac{N_{\mathrm{D3}}}{2\pi}\theta + \ldots$$

D3-branes on ED3-branes

We can now compute the action of the ED3-brane that feels the effect of the backreaction.

1. The ED3 feels the warping in the metric and couples with the axion φ.
2. The DBI and WZ action of the ED3 picks up a factor
$$\frac{1}{g_s}\left(-\frac{g_s N_{\mathrm{D3}}}{2\pi}\ln\left(\frac{r}{L}\right)\right)-i\frac{N_{\mathrm{D3}}}{2\pi}\mathrm{Im}\,\ln z+\ldots=-\frac{N_{\mathrm{D3}}}{2\pi}\ln z+\ldots$$
3. The holomorphy of the result encodes the BPS nature of the ED3.
4. In the case of $N_{\mathrm{D3}}=1$, we obtain the 4d non-perturbative contribution to the superpotential[14]

$$W = z e^{-S^0_{ED3}}\,.$$

[14] O. J. Ganor, *Nucl. Phys. B* **499**, 55–66, arXiv: hep-th/9612077 (1997); D. Baumann *et al.*, *JHEP* **11**, 031, arXiv: hep-th/0607050 (2006); R. Blumenhagen *et al.*, *Nucl. Phys.* **B771**, 113–142, arXiv: hep-th/0609191 (hep-th) (2007); B. Florea *et al.*, *JHEP* **05**, 024, arXiv: hep-th/0610003 (hep-th) (2007); L. E. Ibáñez *et al.*, *JHEP* **06**, 011, arXiv: 0704.1079 (hep-th) (2007).

D7/D3-branes on ED3-branes

We can study the gravitational backreaction of BPS bound states of D7- and D3-branes:[15]

$$ds^2 = Z_{\mathrm{D7}}^{-1/2} Z_{\mathrm{D3}}^{-1/2} \eta_{\mu\nu} dx^\mu dx^\nu + Z_{\mathrm{D7}}^{-1/2} Z_{\mathrm{D3}}^{1/2} ds^2_{\mathbf{X}_4} + Z_{\mathrm{D7}}^{1/2} Z_{\mathrm{D3}}^{1/2} dz d\bar{z}\,,$$

with

$$Z_{\mathrm{D7}} = -\frac{N_{\mathrm{D7}}}{2\pi} \ln\left(\frac{r}{L}\right) \quad \text{and} \quad \tau = \frac{N_{\mathrm{D7}}}{2\pi i} \ln\left(\frac{z}{L}\right) \text{ but also } Z_{\mathrm{D3}} = -\frac{g_s N_{\mathrm{D3}}}{2\pi} \ln\left(\frac{r}{L}\right) \quad \text{and} \quad \varphi = \frac{N_{\mathrm{D3}}}{2\pi} \mathrm{Im}\, \ln(z)\,.$$

On the ED3-brane action:

1. The dilaton background **cancels** with the D7-brane metric backreaction.
2. The effect comes **only** from the D3-branes.

[15] T. Ortin, *Gravity and Strings*, (Cambridge University Press, 2nd ed. 2015).

D7/D3/$\overline{\text{D3}}$-branes on ED3-branes

We consider type IIB theory on $M_4 \times \mathbf{X}_4 \times \mathbf{R}^2$ with a D7-brane wrapped on $\mathbf{X}_4$ in the presence of a worldvolume gauge background with field strength F_2 and/or pullbacked NSNS 2-form background B_2:[16]

$$\mathcal{F}_2 = 2\pi\alpha' F_2 + B_2 \,.$$

We have a smeared D3/$\overline{\text{D3}}$-brane charge distributions that locally cancel if

$$\mathcal{F}_2 \wedge \mathcal{F}_2 = 0 \,.$$

However, individually we have D3- and $\overline{\text{D3}}$-brane contributions defined by

$$N_{\mathrm{D3}} = \int_{\mathbf{X}_4} \mathcal{F}_{2,+} \wedge \mathcal{F}_{2,+} \quad \text{and} \quad N_{\overline{\mathrm{D3}}} = \int_{\mathbf{X}_4} \mathcal{F}_{2,-} \wedge \mathcal{F}_{2,-} \,, \text{ where } \mathcal{F}_{2,\pm} = \frac{1}{2}\left(\mathcal{F}_2 \pm \star_{\mathbf{X}_4} \mathcal{F}_2\right) \,.$$

[16] J. Gomis *et al.*, *JHEP* **11**, 021, arXiv: hep-th/0506179 (2005); M. Kim, L. McAllister, arXiv: 1812.03532 (hep-th) (2018).

D7/D3/$\overline{\text{D3}}$-branes on ED3-branes

1. The D7-brane backreaction on the dilaton and the metric cancel out.
2. The effect comes only from the D3-branes and $\overline{\text{D3}}$-brane distribution.
   - The backreaction on C_4 is the same with opposite sign. It **cancels**.
   - The backreaction on the metric is the same with the same sign. It **adds up**.

The ED3 action is then controlled by a factor

$$-\frac{N_3}{2\pi}\ln\left(\frac{r}{L}\right) \text{ where } N_3 = \int_{\mathbf{X}_4} |\mathcal{F}_2|^2 = N_{\mathrm{D3}} + N_{\overline{\mathrm{D3}}} = 2N_{\mathrm{D3}}\,,$$

that specialized to $\mathbf{X}_4 = \mathbf{T}^4$ is of the form

$$S_{ED3} = S^0_{ED3}\left[1 - \frac{1}{2\pi}|\mathcal{F}_2|^2 \ln\left(\frac{r}{L}\right) + \dots\right].$$

D5/$\overline{\text{D5}}$-branes on ED3-branes

In the presence of $\mathcal{F}_2$, there is an induced D5- or $\overline{\text{D5}}$-brane density, which also backreacts on the geometry. The supergravity background created by a D5-brane is

$$\begin{aligned} ds^2 &= Z_{\text{D5}}^{-1/2}\eta_{\mu\nu}dx^\mu dx^\nu + Z_{\text{D5}}^{-1/2}ds^2_{45} + Z_{\text{D5}}^{1/2}ds^2_{67} + Z_{\text{D5}}^{1/2}dz d\bar{z} \\ e^{-2\phi} &= Z_{\text{D5}}\,, \end{aligned}$$

with

$$Z_{\text{D5}} = -\frac{g_s N_{\text{D5}}}{2\pi}\ln\left(\frac{r}{L}\right) + \ldots$$

1. No correction coming from the backreacted metric, since they **cancel** off.
2. There is a **contribution** to the action coming from the dilaton:

$$S_{ED3} = S^0_{ED3}\left[1 - \frac{1}{4\pi}|\mathcal{F}_2|\ln\left(\frac{r}{L}\right) + \ldots\right].$$

Contents

Set up

1. Consider type IIB theory on a $\mathbf{T}^6/(\mathbf{Z}_2 \times \mathbf{Z}_2)$ orbifold.[17]
2. Let us introduce coordinates $0 \leq x^i, y^i \leq 1$, $i = 1, 2, 3$, for each $\mathbf{T}^2$, and complexify them as $z^i = x^i + \tau_i y^i$.
3. We mod out by $\Omega\mathcal{R}(-1)^F_L$, where $\mathcal{R}$ flips all $\mathbf{T}^6$ coordinates, $z^i \longrightarrow -z^i$.
4. We have then 64 O3-planes[18] and 4 O7_i-planes (localized on the i^{th} $\mathbf{T}^2$).
5. Finally, we introduce D7_i-branes, transverse to the i^{th} $\mathbf{T}^2$ at arbitrary positions.

[17] R. Blumenhagen *et al.*, *Nucl. Phys. B* **663**, 319–342, arXiv: hep-th/0303016 (2003); J. F. Cascales, A. M. Uranga, 1048–1067, arXiv: hep-th/0311250 (Nov. 2003); J. Gomis *et al.*, *JHEP* **11**, 021, arXiv: hep-th/0506179 (2005).

[18] A. R. Frey, J. Polchinski, *Phys. Rev. D* **65**, 126009, arXiv: hep-th/0201029 (2002).

Set up

6. Introducing NSNS and RR 3-form fluxes:

$$F_3 = 4\pi^2\alpha' N \left(dx^1 \wedge dx^2 \wedge dy^3 + dy^1 \wedge dy^2 \wedge dy^3\right)$$

$$H_3 = 4\pi^2\alpha' N \left(dx^1 \wedge dx^2 \wedge dx^3 + dy^1 \wedge dy^2 \wedge dx^3\right) .$$

7. For $D7_1$-brane at position (x^1, y^1), there is a non-zero pullback of the NSNS 2-form on the D7-branes

$$B_2|_{D7_1} = 4\pi^2\alpha' N \left(x^1 dx^2 \wedge dx^3 + y^1 dy^2 \wedge dx^3\right) .$$

8. Supersymmetry condition $\mathcal{F}_2$ to be $(1,1)$ and primitive.[19]

9. **Satisfied** at the origin, as well as at any position (x^1, y^1) if $Nx^1, Ny^1 \in \mathbf{Z}$, compensating with suitably quantized worldvolume gauge fluxes,[20]

$$F_2 = -\left(n_1 dx^2 \wedge dx^3 + n_2 dy^2 \wedge dx^3\right) .$$

[19] M. Marino *et al.*, *JHEP* **01**, 005, arXiv: hep-th/9911206 (2000).

[20] J. Gomis *et al.*, *JHEP* **11**, 021, arXiv: hep-th/0506179 (2005).

Backreaction away from the minimum

1. Consider the $D7_1$-brane at the origin.
2. Move it by a factor

$$\mathrm{Re}\, z^1 = \pm\epsilon \in \mathbf{R}\,.$$

3. We are moving off the **minimum** of the potential $\Longrightarrow$ Non-trivial B-field on the $D7_1$-brane worldvolume.
4. We have a D3/$\overline{\text{D3}}$-brane tension which backreacts on the metric:

$$Z \simeq 1 - \frac{N^2|\epsilon|^2}{2\pi}\left[\ln\left|\frac{z-\epsilon}{L}\right| + \ln\left|\frac{z+\epsilon}{L}\right|\right] + \dots$$

5. We have a D5/$\overline{\text{D5}}$-brane density which backreacts on the dilaton:

$$g_s^{-1} \simeq 1 - \frac{N|\epsilon|}{4\pi}\left[\ln\left|\frac{z-\epsilon}{L}\right| + \ln\left|\frac{z+\epsilon}{L}\right|\right] + \dots$$

The dynamical tadpole problem

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

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

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:[21]

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

so that ($L = 1$)

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

[21] D. Baumann *et al.*, *JHEP* **11**, 031, arXiv: hep-th/0607050 (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

1. Consider a regular ED3-brane at position z^1. If there are **no** fluxes, the action for the BPS ED3-brane instanton at the minimum is
$$S_0 = \mathrm{Im}\, T \text{ where } T \text{ is the 4-cycle modulus of the underlying } \mathbf{T}^6.$$
2. Introducing fluxes, the ED3-brane picks up a B-field when $z^1 \neq 0$ which contributes to **increase** its action.
3. When we move the D7-brane off the origin, the correction to the ED3 action at $z = 0$ is
$$\Delta S \sim -\left(\frac{N_{\mathrm{D5}}|\epsilon|}{2\pi} + \frac{N_{\mathrm{D3}}^2|\epsilon|^2}{\pi}\right)(\log|\epsilon|)\,\mathrm{Im}\, T \Longrightarrow \Delta S \sim -\left(\frac{N_{\mathrm{D5}}|\epsilon|}{2\pi} + \frac{N_{\mathrm{D3}}^2|\epsilon|^2}{\pi}\right) G_2(|\epsilon|)\mathrm{Im}\, T\,.$$
4. Since ϵ is small, the action of the instanton **increases**. **Violation** of the axion WGC?

The regular ED3

Violation of the axion WGC? Not quite yet...

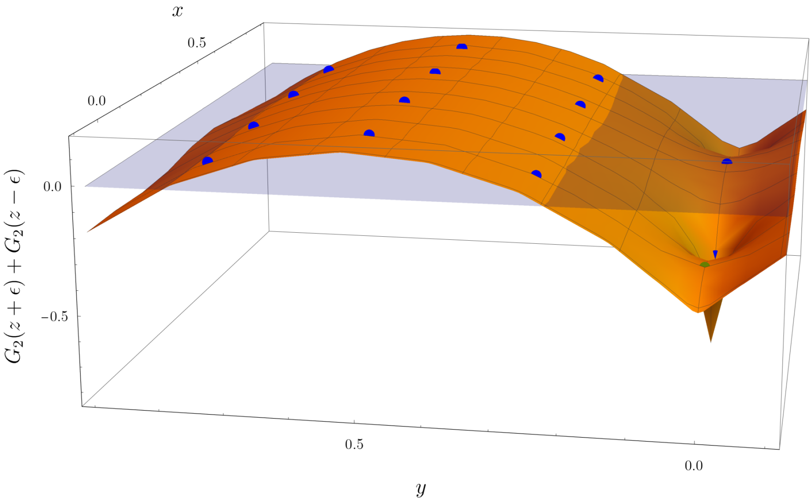
5. Remember that away from $z = 0$ there are places where B-field induced on the volume of the ED3-brane can be **canceled** choosing a suitable worldvolume magnetic flux, F_2
6. A violation of the WGC would be that the backreacted ED3 action increases for **all** points of the ED3 open string landscape.[22] Namely:

$$G_2(z+\epsilon) + G_2(z-\epsilon) < 0$$

   for **all** the ED3 open string landscape points.
7. For different values of ϵ and τ and have always found that there is at least **one** of the open string landscape points where the correction is positive and the axion WGC is satisfied.

[22] J. Gomis *et al.*, *JHEP* **11**, 021, arXiv: hep-th/0506179 (2005).

The regular ED3

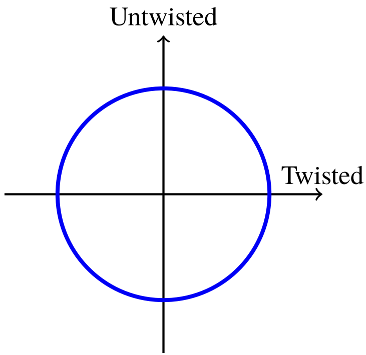


The fractional ED3/ED(-1) sector

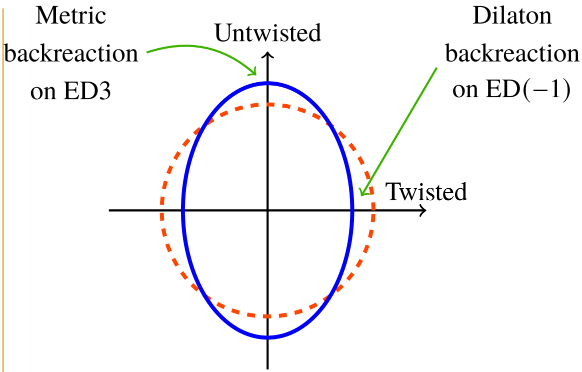
1. Consider a compactification with orientifolds of toroidal orbifolds.
2. There may be **fractional** ED3-branes, **stuck** at the orbifold fixed points.
3. We gave an example of a model in which D7-branes can be **mobile**, while admitting fractional ED3-branes stuck at the orbifold points.
4. Flux quantization in orbifolds ensures that the orbifold points lie at possible ED3 open string landscape positions.
5. The fractional branes cannot move off the fixed points: they can be regarded as ED3/ED(-1)-brane **bound states**.
6. We need to apply the **multi-axion** version of the WGC, described in terms of the convex hull WGC.[23]

[23] C. Cheung, G. N. Remmen, *Phys. Rev. Lett.* **113**, 051601, arXiv: 1402.2287 (hep-ph) (2014); T. Rudelius, *JCAP* **1509**, 020, arXiv: 1503.00795 (hep-th) (2015); M. Montero *et al.*, *JHEP* **08**, 032, arXiv: 1503.03886 (hep-th) (2015); E. Palti, *Fortsch. Phys.* **67**, 1900037, arXiv: 1903.06239 (hep-th) (2019).

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.

Contents

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.

sWGC Z-min/WGC

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.

sWGC **Z-min/WGC**

Thank you!

Holographic set up

D3-branes at a toric CY 3-fold singularity $\mathbf{Y}_6 = C(\mathbf{X}_5) \overset{\text{AdS/CFT}}{\Longleftrightarrow}$ type IIB string theory on $\text{AdS}_5 \times \mathbf{X}_5$.

1. We introduce the Reeb vector:
$$\xi = J\left(r\frac{\partial}{\partial r}\right) .$$
2. We can write:
$$\mathcal{R}_{mn} = 4g_{mn} \Longrightarrow S[g] = \int_{\mathbf{X}_5} d^5x\sqrt{g}\left(\mathcal{R}_{\mathbf{X}_5} - 12\right) = 8\text{Vol}(\mathbf{X}_5) .$$
3. The volume is only a function of ξ.[24]
4. The problem of finding the metric for the Sasaki-Einstein manifold reduces to the **minimization** of the volume with respect to the Reeb vector.

[24]D. Martelli *et al.*, *Commun. Math. Phys.* **268**, 39–65, arXiv: hep-th/0503183 (2006); D. Martelli *et al.*, *Commun. Math. Phys.* **280**, 611–673, arXiv: hep-th/0603021 (2008).

Z-minimization from WGC

1. Consider D3-branes wrapped on 3-cycles Σ_i of $\mathbf{X}_5$:[25]
$$\frac{m_i}{m_{i;0}} = \frac{\mathrm{Vol}(\Sigma_i)}{\mathrm{Vol}_{\min}(\Sigma_i)}\,.$$
2. Consider the gauge couplings of the $\mathrm{U}(1)_R$ symmetry under which they are charged and the 5d Planck mass:
$$g^{-2} = M_s^8 g_s^{-2}\mathrm{Vol}(\mathbf{X}_5)R^2\,,\quad M_{P,5}^3 = M_s^8 g_s^{-2}\mathrm{Vol}(\mathbf{X}_5) \Longrightarrow g M_{P,5}^{3/2} = R^{-1}\,.$$
3. At the minimum we know that the wrapped D3-branes are BPS states, so they saturate the WGC
$$m_{i;0} \;=\; g\,Q\,M_{P,\,5}^{\frac{3}{2}}\,.$$
4. The configuration **away** from the vacuum is
$$m_i \;=\; g\,Q\,M_{P,\,5}^{3/2}\,\frac{\mathrm{Vol}(\Sigma_i)}{\mathrm{Vol}_{\min}(\Sigma_i)}\,.$$

Conclusions Outlook

[25] D. Martelli *et al.*, *Commun. Math. Phys.* **268**, 39–65, arXiv: hep-th/0503183 (2006); A. Butti, A. Zaffaroni, *JHEP* **11**, 019, arXiv: hep-th/0506232 (2005); D. Martelli *et al.*, *Commun. Math. Phys.* **280**, 611–673, arXiv: hep-th/0603021 (2008); A. Butti *et al.*, *JHEP* **11**, 092, arXiv: 0705.2771 (hep-th) (2007).

Scalar WGC

1. We worked in the effective theory of the supersymmetric vacuum: the axion decay constants remain **fixed**.
2. Any change in the axion decay constant should be encoded in a **dependence** on the **scalars**.
3. This would lead to a discussion in terms of the **scalar WGC**:[26]
$$f^2 S^2 + f^2 (\partial_\phi S)^2 M_P^2 \leq M_P^2 \,.$$
4. The scalar contribution is **positive definite** and adds to the gravitational contribution.

Conclusions **Outlook**

[26] E. Palti, *JHEP* **08**, 034, arXiv: 1705.04328 (hep-th) (2017); E. Palti, *Fortsch. Phys.* **67**, 1900037, arXiv: 1903.06239 (hep-th) (2019); E. Gonzalo, L. E. Ibáñez, *JHEP* **08**, 118, arXiv: 1903.08878 (hep-th) (2019); E. Gonzalo, L. E. Ibáñez, arXiv: 2005.07720 (hep-th) (May 2020).