Non-supersymmetric closed strings on AdS_4

(Based on 2604.xxxxx)

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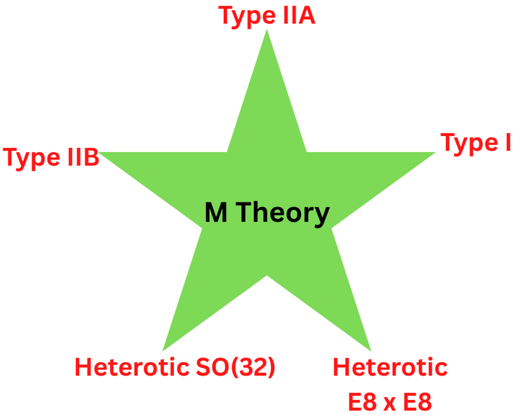
1. Non supersymmetric strings
2. Uplift to deSitter
3. Stability analysis
4. Non-perturbative stability
5. Future directions

Super string theories

- 5 superstring theories (without tachyons)



Tachyons

- Tachyons are particles with negative mass squared

$$m^2_{\text{tachyon}} < 0$$

- These particles signal instability of the vacuum
- Most non supersymmetric string theories have tachyons

Non supersymmetric strings

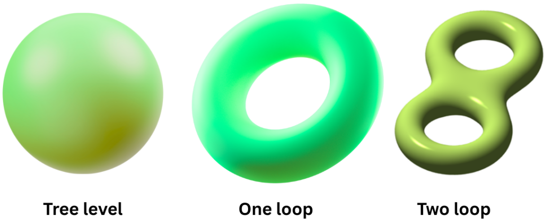
- Three 10-dimensional string theories don't have tachyons

  (i) Heterotic $O(16) \times O(16)$ theory

  (ii) Sugimoto $USp(32)$ model

  (iii) Sagnotti $U(32)$ model (also called $0'B$ model)

- We can have one loop corrections to the string theory action that can give rise to a cosmological constant



- In superstring theories, the loops corrections to the cosmological constant vanish

Uplift to deSitter

- Loop corrections are present in non supersymmetric string theories
- Can you uplift *AdS* spacetime to deSitter spacetime by these loop corrections?

Stability

- Are non-supersymmetric backgrounds stable? or at least metastable?
  - Perturbative stability

$$\begin{cases} m^2 \geq 0 \text{ (Minkowski)} \\ \begin{cases} m^2_{\text{scalars}} \geq \underbrace{-L^{-2}\frac{d^2}{4}}_{\text{scalar BF bound}} \\ m^2_{\text{p-form}} \geq \underbrace{-L^{-2}\frac{(d-2p)^2}{4}}_{\text{p-form BF bound}} \end{cases} \quad (\text{AdS}_{d+1} \text{ spacetime}) \end{cases}$$

  - Non-perturbative stability: Stability under bubbles of true vacuum engulfing the false vacuum [Coleman;1977] [Coleman & Callan ;1977] [Coleman & deLuccia; 1979]

A No-go theorem

- A Maldacena-Nunez style no-go theorem exists [Basile & Lanza; 2020] for compactifying the following action

$$S = \frac{1}{16\pi G_D} \int d^D x \sqrt{-g} \left(R - \frac{4}{D-2} (\partial\phi)^2 - T e^{\gamma\phi} - \frac{e^{\alpha\phi}}{2(p+2)!} |H_{p+2}|^2 \right)$$

on a closed manifold Y with $\dim(Y) = q \geq p+2$ where H_{p+2} threads a $p+2$ cycle in Y. deSitter and Minkowski vacuua are forbidden if

$$\frac{\alpha}{\gamma} + (p+1) > 0$$

- It doesn't apply directly if we have electric and magnetic fluxes.

- $AdS_3 \times S^3 \times S^3$ vacuua have been studied for $O(16) \times O(16)$ heterotic theory on a string scale S^1 [Baykara, Robbins, Sethi; 2022],[Fraiman, Grana, Parra de Freitas, Sethi; 2023]
  - Three H_3 fluxes: n_1 on AdS_3, n_5 on S_3 and $\hat{n}_5$ on $\hat{S}_3$
  - The uplift to deSitter doesn't happen
  - Perturbative stability of scalars in AdS_3 is checked (scalars above the BF bound)
  - Quantum stability still not checked

- $AdS_3 \times S^3$ vacuua have been studied for $O(16) \times O(16)$ heterotic theory on a string scale T^4 [Robbins, HS; 2025]
  - Two H_3 fluxes: n_1 on AdS_3, and n_5 on S_3
  - The uplift to deSitter doesn't happen
  - Perturbative stability of scalars in AdS_3 is checked (scalars above the BF bound)
  - Quantum stability still not checked (torus moduli)

- We will study perturbative/non-perturbative stability for $AdS_4 \times S^3 \times S^3$ vacuua of $O(16) \times O(16)$ theory [Work in progress with Basile and Robbins]
  - No torus moduli
  - Non-perturbative stability is easier to study
  - Has inverse scale separation

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Tree level analysis

The $O(16) \times O(16)$ heterotic theory has the following tree level action

$$S = \frac{1}{2\kappa_{10}^2} \int d^{10}x \, e^{-2\phi} \sqrt{-g} \left(R + 4\,(\partial\phi)^2 - \frac{1}{12}|H_3|^2 - \frac{1}{4}|F_2|^2 \right)$$

where H_3 is the NS 3-form field and F_2 is the heterotic gauge field strength

- The metric on $AdS_4 \times S^3 \times S^3$ is as follows

$$ds_{10}^2 = ds_{AdS_4}^2 + e^{2\chi} d\Omega_3^2 + e^{2\widetilde{\chi}} d\widetilde{\Omega}_3^2$$

where χ and $\widetilde{\chi}$ are the volume moduli of S^3 and $\widetilde{S}^3$.

- $d\Omega_3^2$ and $d\tilde{\Omega}_3^2$ are the metrics on S^3 and $\widetilde{S}^3$ with radius L and $\widetilde{L}$ respectively.

- The potential term in ten-dimensional Einstein frame is

$$-\frac{1}{2\kappa_3^{10}}\int d^{10}x\sqrt{-\hat{g}}\,V_{\text{tree}}(\phi,\chi)$$

where

$$V_{\text{tree}}(\phi,\chi,\tilde{\chi}) = \mathcal{V}^{-1}\left[6\left(\frac{e^{-2\chi}}{L^2}+\frac{e^{-2\widetilde{\chi}}}{\widetilde{L}^2}\right) - 2\alpha'^2\left(\frac{n^2}{L^6}e^{-6\chi}+\frac{\widetilde{n}^2}{\widetilde{L}^6}e^{-6\widetilde{\chi}}\right)\right]$$

with

$$\mathcal{V} = e^{-2\phi+3(\chi+\widetilde{\chi})}$$

where n and $\widetilde{n}$ are the fluxes on S^3 and $\widetilde{S}^3$ repsectively.

- Setting the derivatives of V_{tree} w.r.t ϕ, χ, and $\widetilde{\chi}$ to zero gives equations for $L, \tilde{L}$, and g_s

- These equations are inconsistent

- No tree-level solution exists

One loop correction

- The loop one correction to the potential is

$$V_{1-\text{loop}} = 2\lambda \mathcal{V}^{-2} e^{3(\chi+\widetilde{\chi})} \frac{g_s^2}{\alpha'},$$

where

$$\lambda = -\frac{1}{4(2\pi)^3} \int_{\mathcal{F}} \frac{d^2\tau}{\tau_2^2} Z(\tau)$$

with $Z(\tau)$ being the partition function of the 10D theory (approximated by $\mathbb{R}^{1,9}$)

- The total potential now is $V = V_{\text{tree}} + V_{\text{one-loop}}$

- Set the derivatives to zero

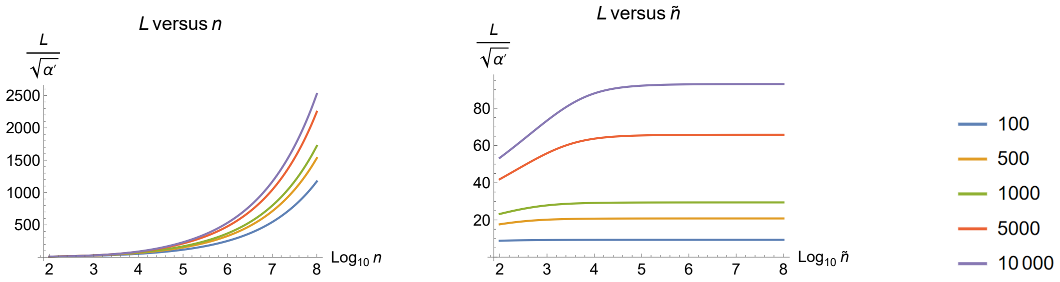
$$\partial_\phi V|_{\phi,\chi,\widetilde{\chi}=0} = 0 \Rightarrow 3\left(\frac{1}{L^2} + \frac{1}{\widetilde{L}^2}\right) - \alpha'^2\left(\frac{n^2}{L^6} + \frac{\widetilde{n}^2}{\widetilde{L}^6}\right) - \frac{2g_s^2\lambda}{\alpha'} = 0$$

$$\partial_\chi V|_{\phi,\chi,\widetilde{\chi}=0} = 0 \Rightarrow \frac{5}{L^2} + \frac{3}{\widetilde{L}^2} - \alpha'^2\left(\frac{3n^2}{L^6} + \frac{\widetilde{n}^2}{\widetilde{L}^6}\right) - \frac{g_s^2\lambda}{\alpha'} = 0$$

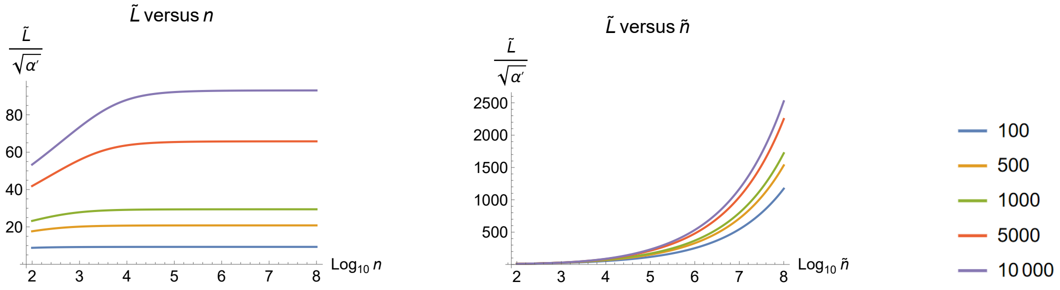
$$\partial_{\widetilde{\chi}} V|_{\phi,\chi,\widetilde{\chi}=0} = 0 \Rightarrow \frac{3}{L^2} + \frac{5}{\widetilde{L}^2} - \alpha'^2\left(\frac{n^2}{L^6} + \frac{3\widetilde{n}^2}{\widetilde{L}^6}\right) - \frac{g_s^2\lambda}{\alpha'} = 0$$

- No analytic solutions exist. We have to use numerics.

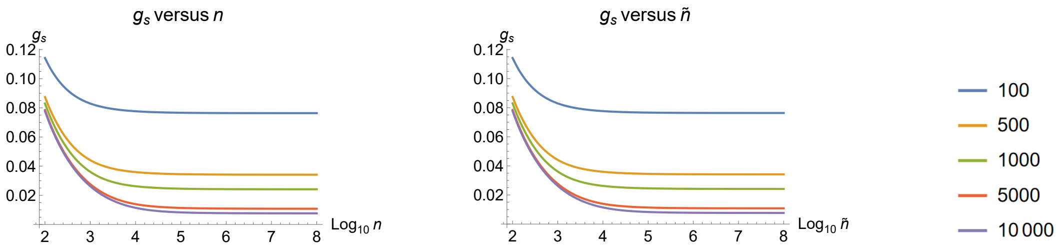
L vs. n and $\tilde{n}$



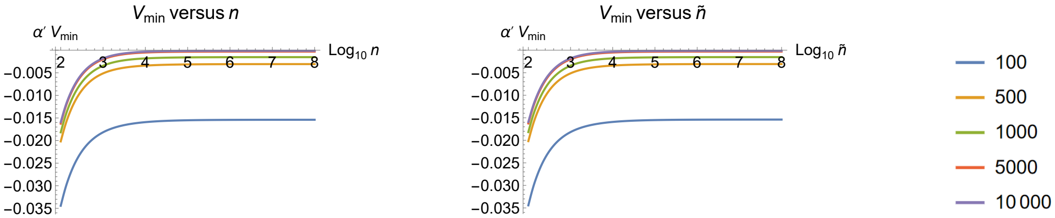
$\widetilde{L}$ vs. n and $\widetilde{n}$



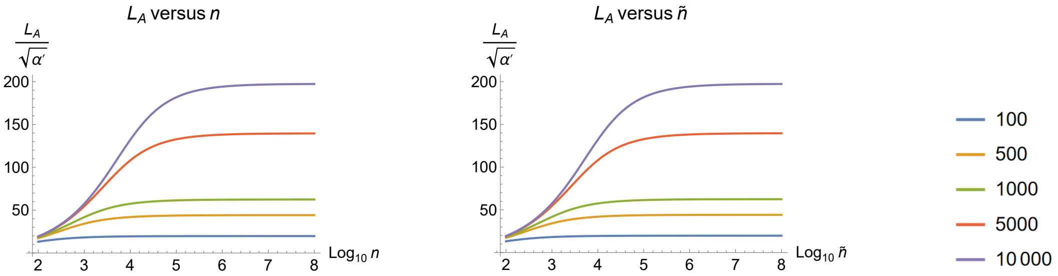
g_s vs. n and $\widetilde{n}$



V_{min} vs. n and $\widetilde{n}$



L_A vs. n and $\tilde{n}$



Some analytic results

- The one-loop equations are invariant under the following rescaling

$$\begin{pmatrix} n \\ \widetilde{n} \end{pmatrix} \to \zeta \begin{pmatrix} n \\ \widetilde{n} \end{pmatrix} \qquad \begin{pmatrix} L \\ \widetilde{L} \end{pmatrix} \to \sqrt{\zeta} \begin{pmatrix} L \\ \widetilde{L} \end{pmatrix} \qquad g_s \to \frac{g_s}{\zeta}$$

- The expression for the AdS radius can be written

$$\frac{1}{L_A^2} = \frac{2}{9}\left(\frac{1}{L^2} + \frac{1}{\widetilde{L}^2}\right)$$

- The analytic solution for equal fluxes $n = \widetilde{n}$ can be written

$$L = \widetilde{L} = \left(\alpha' n \sqrt{\frac{3}{5}}\right)^{1/2} \qquad g_s = \left(\frac{4}{3\lambda n}\sqrt{\frac{5}{3}}\right)^{1/2} \qquad L_A = \frac{3}{2} L = \frac{3}{2}\widetilde{L}$$

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Background solution

- The one-loop corrected action for in string frame is

$$S = \frac{1}{2\kappa_{10}^2} \int d^{10}x \sqrt{-g} \left[e^{-2\phi} \left(R + 4(\partial\phi)^2 - \frac{1}{12}|H_3|^2 \right) - \frac{2\lambda g_s^2}{\alpha'} \right]$$

- The equations of motion are

$$0 = \nabla^M \nabla_M \phi + \frac{1}{4} R - \frac{1}{48} |H_3|^2 - \nabla^M \phi \nabla_M \phi$$

$$0 = \nabla^P \left(e^{-2\phi} H_{MNP} \right)$$

$$0 = -\frac{1}{2} g_{MN} e^{2\phi} \Lambda - R_{MN} - 2\nabla_M \nabla_N \phi + \frac{1}{4} H_M{}^{PQ} H_{NPQ}$$

where $\Lambda = 2\lambda g_s^2/\alpha'$.

- Equations of motion (for $AdS_4 \times S^3 \times S^3$) give the following (with $\phi = 0$)

$$R_{\mu\nu} = -\frac{3}{L_A^2} g_{\mu\nu} \qquad R_{ab} = \frac{2}{L^2} g_{ab} \qquad R_{ij} = \frac{2}{\widetilde{L}^2} g_{ij} \qquad R_{\mu a} = R_{\mu i} = R_{ai} = 0$$

$$\Rightarrow R = -\frac{12}{L_A^2} + \frac{6}{L^2} + \frac{6}{\widetilde{L}^2}$$

and

$$H_3 = \frac{2}{\mathcal{L}}\, \epsilon_{S^3} + \frac{2}{\widetilde{\mathcal{L}}}\, \epsilon_{\widetilde{S}^3}$$

with

$$\mathcal{L}^{-2} = L^{-2} + \frac{1}{2}\Lambda \qquad \widetilde{\mathcal{L}}^{-2} = L^{-2} + \frac{1}{2}\Lambda \qquad \frac{1}{L^2} + \frac{1}{\widetilde{L}^2} = \frac{3\Lambda}{4}$$

Perturbations

- Introduce dilaton, metric, and B field perturbations as

$$\delta\phi = \phi$$

$$\delta g_{\mu\nu} = H_{\mu\nu} + g_{\mu\nu} M \qquad \delta g_{\mu a} = S_{\mu a} \qquad \delta g_{\mu i} = \widetilde{S}_{\mu i}$$

$$\delta g_{ab} = K_{ab} + g_{ab} N \qquad \delta g_{ai} = W_{ai} \qquad \delta g_{ij} = \widetilde{K}_{ij} + g_{ij} \widetilde{N}$$

$$\delta B_{\mu\nu} = X_{\mu\nu} \qquad \delta B_{\mu a} = Z_{\mu a} \qquad \delta B_{\mu i} = \widetilde{Z}_{\mu i}$$

$$\delta B_{ab} = \epsilon_{abc} V^c \qquad \delta B_{ai} = P_{ai} \qquad \delta B_{ij} = \epsilon_{ijk} \widetilde{V}^k$$

where $H_{\mu\nu}, K_{ab}$ and $\widetilde{K}_{ij}$ are traceless ($\mu, \nu \to AdS_3;\ a, b \to S^3;\ i, j \to \widetilde{S}^3$)

Gauge conditions

- Impose the Lorentz-like conditions

$$\nabla^a \delta g_{\mu a} = \nabla^b \delta g_{ab} = \nabla^a \delta g_{ai} = \nabla^a \delta B_{\mu a} = \nabla^a \delta B_{ab} = \nabla^a \delta B_{ai} = 0$$

which translate to the following

$$\nabla^a S_{\mu a} = 0 \qquad \nabla^b K_{ab} = 0 \qquad \nabla^a W_{ai} = 0$$

$$\nabla^a Z_{\mu a} = 0 \qquad \nabla_{[a} V_{b]} = 0 \qquad \nabla^a P_{ai} = 0$$

Spherical harmonics

- Introduce scalar, vector and tensor spherical harmonics over S^3 i.e. $Y^{(\ell,0)}$, $Y_a^{(\ell,\pm1)}$, and $Y_{ab}^{(\ell,\pm2)}$, defined for $\ell \geq 0$, $\ell \geq 1$, and $\ell \geq 2$ respectively (similarly for $\widetilde{Y}$)
- They satisfy useful identities

$$\Box Y^{(\ell,0)} = -\frac{\ell(\ell+2)}{L^2} Y^{(\ell,0)}$$

$$\nabla^a Y_a^{(\ell,\pm1)} = 0 \qquad \Box Y_a^{(\ell,\pm1)} = -\frac{(\ell^2+2\ell-1)}{L^2} Y_a^{(\ell,\pm1)} \qquad \epsilon_a^{\ bc} \nabla_b Y_c^{(\ell,\pm1)} = \pm\frac{(\ell+1)}{L} Y_a^{(\ell,\pm1)}$$

$$Y_{ba}^{(\ell,\pm2)} = Y_{ab}^{(\ell,\pm2)} \qquad g^{ab} Y_{ab}^{(\ell,\pm2)} = \nabla^b Y_{ab}^{(\ell,\pm2)} = 0, \qquad \Box Y_{ab}^{(\ell,\pm2)} = -\frac{\ell^2+2\ell-2}{L^2} Y_{ab}^{(\ell,\pm2)}$$

Field decompositions

- Different fields are expanded in spherical harmonics

$$\phi = \sum_{\ell=0}^{\infty} \sum_{\widetilde{\ell}=0}^{\infty} \phi^{(\ell,0)(\widetilde{\ell},0)} Y^{(\ell,0)} \widetilde{Y}^{(\widetilde{\ell},0)}$$

$$S_{\mu a} = \sum_{\ell=1}^{\infty} \sum_{\widetilde{\ell}=0}^{\infty} \left(S_{\mu}^{(\ell,1)(\widetilde{\ell},0)} Y_{a}^{(\ell,1)} + S_{\mu}^{(\ell,-1)(\widetilde{\ell},0)} Y_{a}^{(\ell,-1)} + S_{\mu}^{(\ell,0)(\widetilde{\ell},0)} \nabla_{a} Y^{(\ell,0)} \right) \widetilde{Y}^{(\widetilde{\ell},0)}$$

Field decompositions

$$K_{ab} = \sum_{\ell=2}^{\infty}\sum_{\widetilde{\ell}=0}^{\infty}\Big(K^{(\ell,2)(\widetilde{\ell},0)}Y_{ab}^{(\ell,2)} + K^{(\ell,-2)(\widetilde{\ell},0)}Y_{ab}^{(\ell,-2)} + K^{(\ell,1)(\widetilde{\ell},0)}\nabla_{(a}Y_{b)}^{(\ell,1)}$$

$$+K^{(\ell,-1)(\widetilde{\ell},0)}\nabla_{(a}Y_{b)}^{(\ell,-1)} + K^{(\ell,0)(\widetilde{\ell},0)}\nabla_{\{a}\nabla_{b\}}Y^{(\ell,0)}\Big)\widetilde{Y}^{(\widetilde{\ell},0)}$$

$$P_{ai} = \sum_{\ell=1}^{\infty}\sum_{\widetilde{\ell}=1}^{\infty}\Big(P^{(\ell,1)(\widetilde{\ell},1)}Y_a^{(\ell,1)}\widetilde{Y}_i^{(\widetilde{\ell},1)} + P^{(\ell,1)(\widetilde{\ell},-1)}Y_a^{(\ell,1)}\widetilde{Y}_i^{(\widetilde{\ell},-1)} + P^{(\ell,-1)(\widetilde{\ell},1)}Y_a^{(\ell,-1)}\widetilde{Y}_i^{(\widetilde{\ell},1)}$$

$$+P^{(\ell,-1)(\widetilde{\ell},-1)}Y_a^{(\ell,-1)}\widetilde{Y}_i^{(\widetilde{\ell},-1)} + P^{(\ell,1)(\widetilde{\ell},0)}Y_a^{(\ell,1)}\nabla_i\widetilde{Y}^{(\widetilde{\ell},0)} + P^{(\ell,-1)(\widetilde{\ell},0)}Y_a^{(\ell,-1)}\nabla_i\widetilde{Y}^{(\widetilde{\ell},0)}$$

$$+P^{(\ell,0)(\widetilde{\ell},1)}\nabla_a Y^{(\ell,0)}\widetilde{Y}_i^{(\widetilde{\ell},1)} + P^{(\ell,0)(\widetilde{\ell},-1)}\nabla_a Y^{(\ell,0)}\widetilde{Y}_i^{(\widetilde{\ell},-1)} + P^{(\ell,0)(\widetilde{\ell},0)}\nabla_a Y^{(\ell,0)}\nabla_i\widetilde{Y}^{(\widetilde{\ell},0)}\Big)$$

Surviving fields

- The gauge conditions translate to the following

$$S_\mu^{(\ell,0)(\widetilde{\ell},0)} = 0 \qquad K^{(\ell,\pm1)(\widetilde{\ell},0)} = 0 \qquad K^{(\ell,0)(\widetilde{\ell},0)} = 0$$

$$W^{(\ell,0)(\widetilde{\ell},\pm1)} = 0 \qquad W^{(\ell,0)(\widetilde{\ell},0)} = 0 \qquad Z_\mu^{(\ell,0)(\widetilde{\ell},0)} = 0$$

$$V^{(\ell,\pm1)(\widetilde{\ell},0)} = 0 \qquad P^{(\ell,0)(\widetilde{\ell},\pm1)} = 0 \qquad P^{(\ell,0)(\widetilde{\ell},0)} = 0$$

- Residual gauge transformations eliminate some extra fields for $\ell, \widetilde{\ell} = 0, 1 \rightarrow$ Treat $\ell, \widetilde{\ell} = 0, 1$ cases with caution.

Sectors

- There are six different kinds of sectors

$$(\ell,0)(\widetilde{\ell},\pm 2)$$

$$(\ell,\pm 1)(\widetilde{\ell},\pm' 1),\quad (\ell,0)(\widetilde{\ell},\pm 1)$$

$$(\ell,\pm 2)(\widetilde{\ell},0),\quad (\ell,\pm 1)(\widetilde{\ell},0),\quad (\ell,0)(\widetilde{\ell},0)$$

- In each kind of sector, there are further subcases that should be dealt with separately. For example, for $(\ell,0)(\widetilde{\ell},0)$, we have the following cases

$$\begin{aligned} &\ell,\widetilde{\ell}\geq 2, && \ell\geq 2,\widetilde{\ell}=1, && \ell\geq 2,\widetilde{\ell}=0 \\ &\ell=1,\widetilde{\ell}\geq 2, && \ell=1,\widetilde{\ell}=1, && \ell=1,\widetilde{\ell}=0 \\ &\ell=0,\widetilde{\ell}\geq 2, && \ell=0,\widetilde{\ell}=1, && \ell=0,\widetilde{\ell}=0 \end{aligned}$$

- There are 31 different kinds of sectors to study

Non-negative mass sectors

- All the fields in all subcases of the following sectors

$$(\ell, \pm 2)(\widetilde{\ell}, 0) \qquad (\ell, \pm 1)(\widetilde{\ell}, 0) \qquad (\ell, 0)(\widetilde{\ell}, \pm 1) \qquad (\ell, 0)(\widetilde{\ell}, \pm 2)$$

have non-negative masses $\rightarrow$ No BF bound violations

$(\ell,\pm 1)(\widetilde{\ell},\pm' 1)$ sectors

For all the subcases, we have two scalars W and P that satisfy the following equations

$$\Box_A W = \left(\frac{(\ell+1)^2}{L^2} + \frac{(\widetilde{\ell}+1)^2}{\widetilde{L}^2} + \Lambda\right) W + 2\left(\mp\frac{\ell+1}{L\,\mathcal{L}} \pm' \frac{\widetilde{\ell}+1}{\widetilde{L}\,\widetilde{\mathcal{L}}}\right) P$$

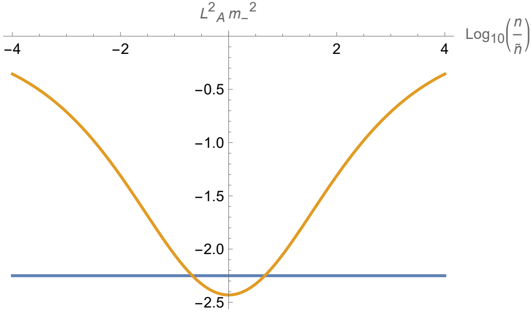
$$\Box_A P = 2\left(\mp\frac{\ell+1}{L\,\mathcal{L}} \pm' \frac{\widetilde{\ell}+1}{\widetilde{L}\,\widetilde{\mathcal{L}}}\right) W + \left(\frac{(\ell+1)^2}{L^2} + \frac{(\widetilde{\ell}+1)^2}{\widetilde{L}^2}\right) P$$

which gives the following masses

$$m^2_{\pm''} = \frac{(\ell+1)^2}{L^2} + \frac{(\widetilde{\ell}+1)^2}{\widetilde{L}^2} + \frac{\Lambda}{2} \pm'' \sqrt{4\left(\frac{\ell+1}{L\,\mathcal{L}} \mp \pm' \frac{\widetilde{\ell}+1}{\widetilde{L}\,\widetilde{\mathcal{L}}}\right)^2 + \frac{\Lambda^2}{4}}.$$

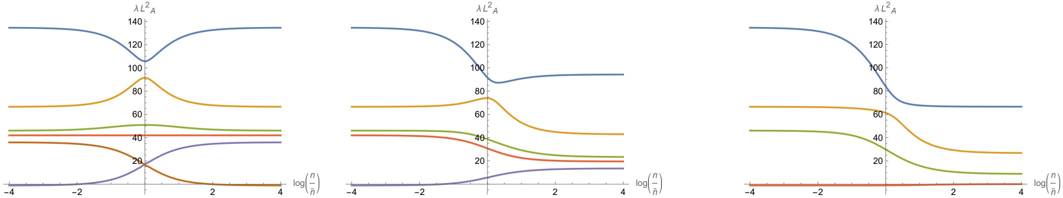
$(\ell, \pm 1)(\widetilde{\ell}, \pm' 1)$ sectors

$L_A^2 m_-^2$ for $\ell = \tilde{\ell} = 1$ and $\pm' = \mp$ (orange) plotted with the BF bound shown (blue)



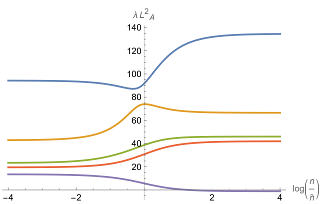
$(\ell, 0)(\widetilde{\ell}, 0)$ sectors with $\ell \geq 2$

$L_A^2 m^2$ for $\tilde{\ell} \geq 2, \tilde{\ell} = 1$ and $\tilde{\ell} = 0$ plotted against $\log(n/\widetilde{n})$. No BF bound violations found.



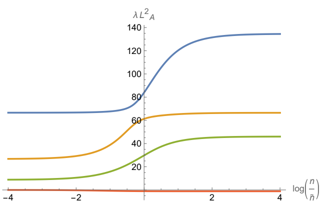
$(1,0)(\widetilde{\ell},0)$ sectors

$L_A^2 m^2$ for $\tilde{\ell} \geq 2, \tilde{\ell} = 1$ and $\tilde{\ell} = 0$ plotted against $\log(n/\widetilde{n})$. No BF bound violations found.



$(0,0)(\widetilde{\ell},0)$ sectors

$L_A^2 m^2$ for $\tilde{\ell} \geq 2, \tilde{\ell} = 1$ and $\tilde{\ell} = 0$ plotted against $\log(n/\tilde{n})$. No BF bound violations found.



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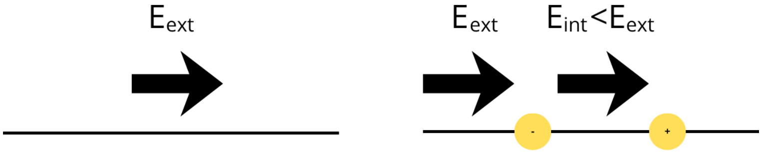
Brane nucleation

- One non-perturbative decay channel is "brane nucleation".
- Branes reduce the flux in the background

- One dimensional example is easy to understand

$$E_{\text{int}} = E_{\text{ext}} - \frac{2kq}{R^2} \quad (\text{as } R \to \infty)$$



- Mass $<$ Charge (Weak gravity conjecture)

NS5 brane

- NS5 brane acts as a domain wall in AdS_4
- It also wraps a 3D closed submanifold (3-cycle) of $S^3 \times \tilde{S}^3$. It looks like $a[S^3] + b[\tilde{S}^3]$ for $a, b \in \mathbb{Z}_0^+$

Charge/Tension ratio

- Define β as Charge/Tension for the NS5 brane
- Decay happens for $\beta > 1$
- For semi-classical approximation, $\beta \sim \mathcal{O}(1)$ (it breaks down for $\beta >> 1$)

- We have

$$\beta = \frac{a\ n(\widetilde{L}/L)^3 + b\ \widetilde{n}(L/\widetilde{L})^3}{aL^3 + b\widetilde{L}^3}\frac{\alpha' L_A}{3}$$

- We can write it terms of ratios

$$\beta = \sqrt{\frac{2}{3}}\frac{\zeta\xi^3\sqrt{1+4\xi^2} + \sqrt{4+\xi^2}}{(\zeta+\xi^3)\sqrt{1+\xi^2}}$$

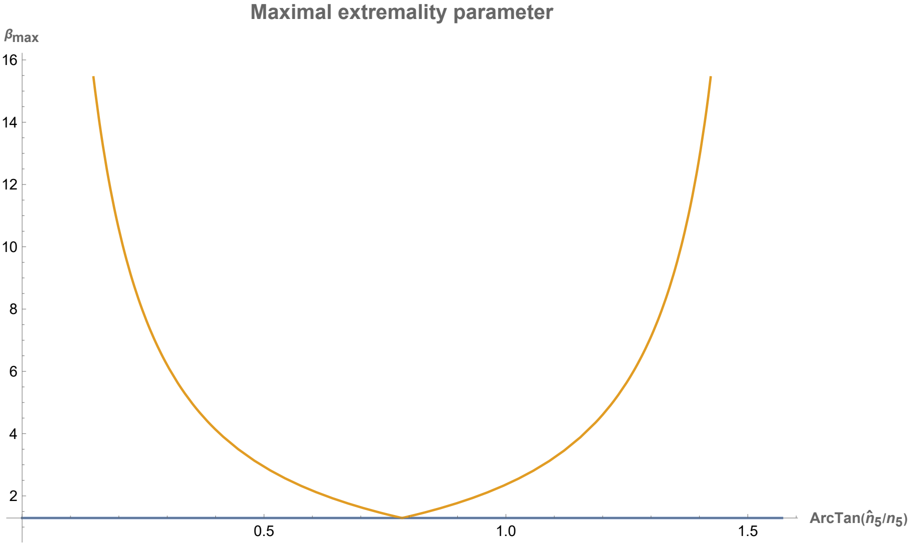
where

$$\xi = \frac{\widetilde{L}}{L} \qquad \zeta = \frac{a}{b} \qquad \mu = \frac{\widetilde{n}}{n} = \xi^3\sqrt{\frac{4+\xi^2}{1+4\xi^2}}$$

- We maximize β w.r.t ζ for a fixed ξ

$$\beta_{\text{max}} = \begin{cases} \xi^3\sqrt{\frac{2(1+4\xi^2)}{3(1+\xi^2)}} & (\xi \geq 1) \\ \frac{1}{\xi^3}\sqrt{\frac{2(4+\xi^2)}{3(1+\xi^2)}} & (\xi \leq 1) \end{cases}$$

- The non-perturbative decays bring the configuration to $\xi = 1$ (equal fluxes) where $\beta = \sqrt{5/3} \sim \mathcal{O}(1)$


Maximal extremality parameter
β_{max}
16
14
12
10
8
6
4
2
0.5
1.0
1.5
ArcTan($\hat{n}_5/n_5$)

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Future directions

- Non-perturbative analysis with torus moduli? (e.g. $AdS_3 \times S^3 \times T^4$, $AdS_3 \times S^3 \times S^3 \times S^1$, and even $AdS_3 \times S^3 \times K3$)
- Tachyons are removed if we replace $S^3 \times S^3$ with $S^3 \times \mathbb{R}P^3$. Does it work in detail?

Thanks for listening.

Questions?