SUSY AdS and Scale Separation

Fotis Farakos

NTUA

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Plan:

→ Introduction

→ 3D N=1

→ 3D N=2

→ Outlook

Introduction

What?

→ The low energy limit of string theory/quantum gravity leads to 10D supergravity.

→ We want to understand how such theories behave in lower dimensions after compactification, e.g. 4D, 3D, etc.

→ Scale separation means the characteristic length scale of the compact space is much smaller than that of the non-compact space

$$L_{X_{10-d}} \ll L_{AdS_d} \, .$$

Why?

$\rightarrow$ Pheno: our world is 4D therefore somehow we have to deduce from the microscopic theory of gravity.

$\rightarrow$ Theory: An interesting problem on its own which gives us a glimpse of the behavior of the microscopic theory.

$\rightarrow$ To simplify the problem we start from supersymmetric AdS.

How?

$\rightarrow$ Work with the 10D supergravity with maximal SUSY.

$\rightarrow$ Compactify on toroidal orbifolds and use stringy sources and fluxes that preserve some SUSY.

$\rightarrow$ Test our approximations, e.g. large volume, weak coupling, singularity resolutions, backreactions, etc.

Where?

$\rightarrow$ Not OK (?) for D>4 and no known examples.
Cribiori, Montella, '23

$\rightarrow$ No go for 4D N>1 and no known examples.
Cribiori, Dall'Agata, '22

$\rightarrow$ OK for 4D N=1 and known examples.
DeWolfe, Giryavets, Kachru, Taylor, '05,
Cribiori, Junghans, Van Hemelryck, Van Riet, Wrase, '21

Where?

$\rightarrow$ OK for 3D N=1 and known examples.

$\rightarrow$ OK for 3D N=2 and known examples.

$\rightarrow$ OK (?) for 3D N>2 but no known examples.

Where?

$\rightarrow$ No go for 2D N>1 and no known examples.
Cribiori, FF, Liatsos, '24

$\rightarrow$ OK for 2D N=1 but no known examples.

3D N=1

Known examples:

→ Massive IIA on G2

FF, Tringas, Van Riet, '20

→ Type IIB on G2-structure

Van Hemelryck, '25

→ Heterotic on G2-structure

Tringas and Wrase, '25

→ Massless IIA on G2-structure

Tringas, '26

Plan:

$\rightarrow$ 3D N=1 SG

$\rightarrow$ Our compactification

$\rightarrow$ The EFT

3D N=1 SG

- The 3D fields are the real bosons (metric and scalars)

$$g_{\mu\nu}(x) \quad , \quad \varphi^a(x)$$

and the fermions are their superpartners.

- The bosonic sector is

$$\mathcal{L} = R - G_{ab}\partial\varphi^a\partial\varphi^b - V(\varphi^a)\,,$$

with

$$V = G^{ab}\partial_a P\partial_b P - 4P^2\,.$$

- The scalar manifold metric is Riemann and the superpotential P is a real function of the scalars, $P(\varphi^a)$.

3D N=1 SG

- For SUSY AdS we have

$$\frac{\partial P}{\partial \varphi^a} = 0\,.$$

- Then for the SUSY AdS_3 vacuum energy we have

$$V = -4P^2 = -\frac{1}{L^2_{AdS}}\,.$$

- The ingredients of the 3D N=1 theory are dictated by the compactification.

Our compactification

- For the internal space we have

$$T^7/(Z_2)^3 \quad \text{(+ orientifolds)}$$

an orbifold that leads to G2 space after resolutions.

- The internal metric leads to 7 physical fields in 3D

$$s^i(x) \quad , \quad i = 1, \ldots, 7 \, ,$$

which are directly connected to the 7 radii r^i.

- The only other scalar that survives the orbifolding is the dilaton $\phi(x)$, which also measures the string coupling

$$g_s = e^{\phi} \, .$$

Our compactification

- The orbifold allows a specific basis of harmonic 3-forms Φ_i and 4-forms Ψ_i, for example

$$\Phi_1 = dy^1 \wedge dy^2 \wedge dy^3 \quad , \quad \Psi_1 = dy^4 \wedge dy^5 \wedge dy^6 \wedge dy^7 \, .$$

- Then the F_4 flux is

$$F_4 = \sum_{i=1}^{7} f^i \Psi_i \, ,$$

and the Romans mass is non-zero

$$F_0 = m \, .$$

- The H_3 flux is

$$H_3 = \sum_{i=1}^{7} h^i \Phi_i \, .$$

Our compactification

- Tadpole cancelation in the internal compact space leads to two non-trivial conditions with the presence of O6-planes.
- We have

$$\int_7 F_4 \wedge H_3 = 0\,,$$

which means

$$\sum_{i=1}^{7} f^i h^i = 0\,,$$

and leaves $f^i \sim N$ unbounded.

- We have per 3-cycle

$$\int F_0 \wedge H_3 = 2N_{O6}\,.$$

The superpotential

- The general form of the superpotential reads

$$P = \frac{1}{\mathrm{vol}(X_7)^2} \int_7 \left[e^{-\phi/2} \Phi \wedge \star H_3 + e^{\phi/4} \Phi \wedge F_4 + e^{5\phi/4} \star F_0 \right] ,$$

  where $\Phi = \sum_i s^i(x) \Phi_i$ and $\mathrm{vol}(X_7)$ is the volume of the G2.

- For our setup it becomes

$$\begin{aligned} P &= \frac{1}{\mathrm{vol}(X_7)^2} \left(e^{-\phi/2} \mathrm{vol}(X_7) \sum_i \frac{h^i}{s^i} \right. \\ &\qquad \left. + e^{\phi/4} \sum_i f^i s^i + e^{5\phi/4} \mathrm{vol}(X_7) m \right) , \end{aligned}$$

  where $\mathrm{vol}(X_7) = (\prod_i s^i)^{1/3}$.

Parametric scale separation

- Extremizing the superpotential

$$\frac{\partial P}{\partial \varphi^a} = 0 \quad , \quad \varphi^a = \phi, s^i \, ,$$

leads to SUSY AdS_3 with full moduli stabilization.

- We verify consistency of supergravity approach

$$g_s \sim N^{-3/4} \quad , \quad \text{Vol}(X_7) \sim N^{7/4} \, ,$$

for large F_4 flux, i.e. $N \gg 1$.

- Scale separation is achieved because

$$\frac{L_{X_7}}{L_{AdS_3}} \sim N^{-1/2} \, .$$

3D N=2

Known examples:

$\rightarrow$ Massive IIA on $CY_3 \times S^1$

Cribiori, FF, Zarafonitis, '26

Plan:

$\rightarrow$ 3D N=2 SG

$\rightarrow$ Our compactification

$\rightarrow$ The EFT

3D N=2 SG

- The 3D fields are the bosons (metric and complex scalars)

$$g_{\mu\nu}(x) \quad , \quad A^I(x)$$

and the fermions are their superpartners.

- The bosonic sector is

$$\mathcal{L} = R - G_{I\bar{J}}\partial A^I \partial \overline{A}^J - V(A, \overline{A}) \,,$$

with $G_{IJ} = \partial_I \partial_{\bar{J}} K$ and

$$V = e^K \left[G^{I\bar{J}} D_I W (D_J W)^* - 4|W|^2 \right] \,, \; D_I W = \frac{\partial W}{\partial A^I} + \frac{\partial K}{\partial A^I} W \,.$$

- The scalar manifold metric is Kähler and the superpotential W is a holomorphic function of the scalars, $W(A^I)$.

3D N=2 SG

- For SUSY AdS we have

$$\frac{\partial W}{\partial A^I} = 0\,.$$

- Then for the SUSY AdS_3 vacuum energy we have

$$V = -4e^K |W|^2 = -\frac{1}{L^2_{AdS}}\,.$$

- The ingredients of the 3D N=2 theory are dictated by the compactification.

Our compactification

- For the internal space we have

$$T^6/(Z_3)^2 \times S^1 \quad (+ \text{ orientifolds})$$

an orbifold that leads to $CY_3 \times S^1$ space after resolutions.

- The internal metric leads to four physical fields in 3D

$$R(x) \quad \text{and} \quad T^i(x) \quad , \quad i = 1, \ldots, 3 \,,$$

which describe the S^1 radius + 3D graviphoton and three T^2 radii of the CY_3 which combine with the B_2 axions.

- The dilaton combines with C_3 axion into

$$S(x) \,.$$

Our compactification

- The orbifold allows the CY_3 data (Ω, J) to combine with the S^1 one-cycle (η) into G2-structure

$$\Phi = \mathrm{Re}\Omega + \eta \wedge J \quad , \quad \Psi = \eta \wedge \mathrm{Im}\Omega + J \wedge J \, .$$

- Then the F_4 flux is

$$F_4 = f\left(\Psi_5 + \Psi_6 + \Psi_7\right) + f'(\Psi_1 + \Psi_2 + \Psi_3 + \Psi_4) \, ,$$

and the Romans mass is non-zero

$$F_0 = m \, .$$

- The H_3 flux is

$$H_3 = h(\Phi_1 + \Phi_2 + \Phi_3 + \Phi_4) + h'\left(\Phi_5 + \Phi_6 + \Phi_7\right) \, .$$

Our compactification

- Tadpole cancelation in the internal compact space leads to two non-trivial conditions with D6-branes and O6-planes.
- We have

$$\int_7 F_4 \wedge H_3 = 4f'h + 3fh' = 0\,,$$

which means we have unbounded

$$f \sim f' \sim N\,.$$

- We have per 3-cycle

$$\int F_0 \wedge H_3 = 2N_{O6} \quad \text{or} \quad -N_{D6}\,.$$

Kähler potential and superpotential

- The Kähler potential is

$$K = -\log(R+\overline{R}) - \sum_{i=1}^{3} \log(T_i + \overline{T}_i) - 4\log(S+\overline{S})\,.$$

- The superpotential is

$$\begin{aligned} W &= 2ih\,S - \frac{i}{2} f \sum_{i=1}^{3} T_i + 2im\,T_1 T_2 T_3 \\ &\quad + i\frac{h'}{2} S^2 \left[\sqrt{\frac{T_2 T_3}{R T_1}} + \sqrt{\frac{T_1 T_2}{R T_3}} + \sqrt{\frac{T_3 T_1}{R T_2}} \right] \\ &\quad - 2if' S \sqrt{\frac{T_1 T_2 T_3}{R}}\,. \end{aligned}$$

Parametric scale separation

- Extremizing the superpotential

$$\frac{\partial W}{\partial A^I} = 0 \quad , \quad A^I = R, S, T^i \, ,$$

leads to SUSY AdS_3 with full moduli stabilization.

- We verify consistency of supergravity approach

$$g_s \sim N^{-3/4} \quad , \quad \text{Vol}(X_7) \sim N^{7/4} \, ,$$

for large F_4 flux, i.e. $N \gg 1$.

- Scale separation is achieved because

$$\frac{L_{X_7}}{L_{AdS_3}} \sim N^{-1/2} \, .$$

Outlook

Scale separation?

- Orientifold backreaction?
  Junghans, '20
- Is large N infinite distance?
  Lüst, Palti, Vafa, '19,
  Shiu, Tonioni, Van Hemelryck, Van Riet, '22
- Orbifold resolutions?
  Junghans, '23
- Uplift to Dark Energy??

Thank you