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Resolving G_2 Manifolds in Scale separated models in Type IIA

Based on work with Fotis Farakos and Fien Apers. (To appear soon)

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Motivation

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But our world is 4d!
String theory has to give a good low energy EFT. (That describes our world)
What do we demand from our string models?

- Trustable effective theory in 4d
- Minimal supersymmetry $\mathcal{N} = 1$
- The standard model of particle physics.

The Landscape

As a first step we look for consistent scale separated solutions.
We demand the following features -

- $m_{kk}L_{AdS} >> 1$ or $L_{kk} << L_{ext}$
- N=1 SUSY.
- Parametric Scale separation.

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Arguments against them -

- Evidence from Swampland conjectures
- Lack of explicit dual CFTs
- Inconsistency of Uplifting the models/ Smearing approximations
- Construction requires singular manifolds with intersecting O-Planes

Review of String compactification

- We begin by assuming a product structure of the 10d spacetime - $X_d \times M$
- Start with a Ricci flat manifold, allow for the metric the fluctuate
- Fluctuation of metric can be written in terms of fluctuation of internal cycles
- These show up as moduli (scalars) in Low energy EFT.
- We dimensionally reduce the theory to a low dimensional one.
- We stabilize these moduli by turning on fluxes and generating a potential.

Scale separated solution in AdS_3

We have in particular an orbifold of the form

$$T^7/(Z_2)^3\,, \tag{1}$$

where the $(Z_2)^3$ group is given by the following three involutions -

$$\begin{aligned}
\Theta_\alpha &: y^i \to (-y^1, -y^2, -y^3, -y^4, y^5, y^6, y^7)\,,\\
\Theta_\beta &: y^i \to (-y^1, 1/2 - y^2, y^3, y^4, -y^5, -y^6, y^7)\,,\\
\Theta_\gamma &: y^i \to (1/2 - y^1, y^2, -y^3, y^4, -y^5, y^6, -y^7)\,,
\end{aligned} \tag{2}$$

This space is Equipped with G_2 structure $(\Phi) \to$ metric on manifold.
We also have a dual closed 4-form $(\Psi) \to \boxed{\text{Ricci Flat Manifold.}}$

Scale separated solution in AdS_3-Overview

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$$\mathrm{vol}(X) = \frac{1}{7}\int \Phi \wedge \star\Phi, \tag{3}$$

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Scale separated solution in AdS_3-Overview

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Ricci flat deformation can be written as deformation of Φ. (No. of moduli = b^3)

- These moduli are given by periods of the invariant three forms on associated cycles $s_i = \int_{C^i} \Phi$
- These G_2 manifold preserves $N = 2$ susy.
- We induce further involution by introducing O2 planes and O6 planes. (N=1) susy
- Ingredients- moduli(s_i, ϕ).
- All other moduli dont satisfy the parity wrt orientifolds or simply the cycles dont exist

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- Ingredients- moduli(s_i, ϕ).
- All other moduli dont satisfy the parity wrt orientifolds or simply the cycles dont exist
- Singularities can be resolved and the manifold remains G_2 [Joyce]

AdS3 type IIA fully moduli stabilized models

We also add more ingredients like D branes to cancel the following tadpoles

$$dF_p = H_3 \wedge F_{p-2} + J_{p+1} \tag{7}$$

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Insert fluxes $F_0(m), F_4(f), H_3(h)$.

- Since we have N=1 Susy, we find the supersymmetric minima which is naturally gives vacua for full theory.
- This superpotential is obtained by dimensional reduction of 10d to 3d.

AdS3 type IIA fully moduli stabilized models

We also add more ingredients like D branes to cancel the following tadpoles

$$dF_p = H_3 \wedge F_{p-2} + J_{p+1} \tag{9}$$

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Superpotential Extremization gives-

$$e^{\phi} \simeq \frac{h}{m^{1/4} f^{3/4}}, \quad s_{1,2,3,4,5,6,7} \simeq \frac{h}{m} e^{-7\phi/4}, \quad V_0 \simeq \frac{f^{49/16}}{m^{21/16} h^{7/4}}. \tag{10}$$

We also see from the minima of the potential -

$$\frac{L^2_{\mathrm{KK}}}{L^2_{\mathrm{AdS}}} \sim f^{-1} \tag{11}$$

Resolving the Orbifolds

The general procedure is the following-

- Locally each orbifold singularity has a resolution. (Depending upon structure of the fixed point)
- We can locally cut out the ball of radius a and replace the ball by a smooth euclidean Einstein solution.

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Heuristic argument of bosonic analysis of blow up moduli in DGKT-

$$S \subset S_{\text{kinetic}} \simeq \frac{1}{2\kappa_{10}^2} \int d^{10}x \sqrt{-g} e^{-2\phi}(R + e^{2\phi} m_0^2) \tag{12}$$

Reducing them to 4d and converting to Einstein frame -

$$S_{4d} = \int \sqrt{-g^E}(\tilde{R}_4 + \frac{e^{4\phi}}{Vol_{int}} m_0^2) \tag{13}$$

$Vol_{int} = Vol_0 - Ba^4$.
We see that extremization gives us $a = 0$..(Singular again)

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Non Zero vev for a^*

Resolution of G_2 manifold for AdS_3

- For these Joyce Orbifolds we have a singularity structure as- $\mathbb{T}^4/Z_2 \times T^3$
- Proven that this can be resolved by Eguchi Hansen space (Similar to the well known $K3$ manifolds)

$$ds^2 = \Delta^{-1} dr^2 + \frac{1}{4} r^2 \Delta (d\psi + \cos\theta d\phi)^2 + \frac{1}{4} r^2 d\Omega_2^2 \tag{18}$$

with $\Delta = 1 - (\rho/r)^4$ and $d\Omega_2^2 = d\theta^2 + \sin^2\theta d\phi^2$.

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So what next...?

Resolution of G_2 manifold for AdS_3

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The above procedure can not be followed in our case since the Flux terms dont contribute to the scaling of potential.

Instead we directly stabilize using the superpotential-

$$P = \frac{1}{8\mathcal{V}^2} \int \left(e^{-\phi/2} H_3 \wedge \star\Phi + e^{\phi/4} F_4 \wedge \Phi + e^{5\phi/4} \star F_0 \right) , \tag{21}$$

Volume correction, [LM,2003]

$$\mathcal{V} = V_0\, \Omega(u), \qquad \Omega(u) = 1 - \frac{8}{3} \sum_{\tau,n} \sum_{a=1}^{3} \frac{\left(u^{(\tau,n,a)}\right)^2}{s^{A(\tau,a)} s^{B(\tau,a)}} + O(u^4). \tag{22}$$

Resolution of G_2 manifold for AdS_3

Once again the fluxes are expanded in the associated form basis-

$$\eta_I = (\Phi_i, \chi_i) \in H^3(X_7), \quad \Psi_I = (\psi^i, \tilde{\chi}^i) \in H^4(X_7),$$

$$\begin{aligned} \Phi &= s^i \phi_i + u_a \chi_a \\ H_3 &= h_i \phi_i \\ F_4 &= e_i \psi_i + q_a \widetilde{\chi}^a \end{aligned} \tag{23}$$

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A look into the superpotential to leading order

$$P = P_0 + \sum_{a=1}^{3} L_a u_a + \frac{1}{2} \sum_{a=1}^{3} B_a u_a^2 + \text{higher order terms} \tag{25}$$

Resolution of G_2 manifold for AdS_3

Extremize it for bulk values at minima !

$$\frac{u_a^*}{\sqrt{s_a s_b}} \sim \frac{q_a}{f} \tag{26}$$

With their correction to bulk superpotential suppressed $O((q_a/f)^2)$.
We also check that the collapsing cycle still is parametrically large in l_s.

O planes on resolved spaces

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From covering torus persepective we have a problem-

Singular locus	Covering-space orientifold loci	Local sectors
F_α	$O6_1$/ $O6_2$	one $O6/O6$ pair
F_β	$O6_1$/ $O6_3$	one $O6/O6$ pair
F_γ	$O2$/ $O6_2$, $O6_3$/ $O6_4$	one $O2/O6$ sector and one $O6/O6$ sector

Table: Incidences before resolving the local $\mathbb{C}^2/\mathbb{Z}_2$ singularities.

Let us track where does each plane sit from the local patch.
Considering one particular fixed point generated by F_α

O planes intersection

On the local patch we define complex local coordinates - (z_1, z_2).
Invariant coordinates

$$U = z_1^2, \qquad V = z_2^2, \qquad W = z_1 z_2, \tag{27}$$

which obey

$$UV - W^2 = 0. \tag{28}$$

The space of directions approaching the singularity is $\mathbb{CP}^1$ paramterized by w.
And we have t orthogonal to the $\mathbb{CP}^1$

$$t = z_1^2, \qquad w = \frac{z_2}{z_1}. \tag{29}$$

Now we have a map from a singular point (U, V, W) to an Exceptional sphere $(t = 0, w)$

O Plane Intersection*

Tracking down our O plane locus from global coordinates y_i we check.
Both meet the exceptional divisor at

$$E_{\mathbb{R}} = \{t = 0,\ w \in \mathbb{R} \cup \{\infty\}\} \cong \mathbb{RP}^1 \cong S^1. \tag{30}$$

Which is a smooth non-self intersecting surface.

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Which is a smooth non-self intersecting surface.
So we have shown that there are no intersection of the O planes on resolved orbifold but they are the infact the same planes sitting on top of each other.

Caveat

All the above story is valid of O_6 planes in the setup.
Looking at the O_2 planes sitting in our internal space. We see that they are precisely sitting on the fixed points.
Is the Tadpole ruined and is our theory inconsistent?*

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Looking at the O_2 planes sitting in our internal space. We see that they are precisely sitting on the fixed points.
Is the Tadpole ruined and is our theory inconsistent?*
NO!!
Thanks to the higher order curvature coupling of the WZ terms of O6 planes.

Conclusion and Outlook

- We have shown that for these models with such singularity structure the Singular orbifold can be resolved
- It resolves at the right regime with keeping the scale separation intact
- O planes do not intersect

Thank You for Your Attention!