Asymmetric CFTs and GSUGRA II

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based on 1608.00595 and 1611.04617 by R. Blumenhagen, MF, E. Plauschinn

November 24, 2016

General Idea

Two separate ways to stabilize moduli:

- **SUGRA (TS): Fluxes/gaugings**
- **CFT (WS): (Asymmetric) Orbifolds**

Work on L-R asymmetric torodial orbifolds suggests a connection: After introducing the asymmetry one finds a flux algebra!

[Dabholkar, Hull '02,05; Condeescu, Florakis, Kounnas, Lüst '12,13]

GSUGRA $\sim$ ACFT?!

Overview

What we did:

Look at Gepner models + L-R asymmetric simple currents

[Gepner; Schellekens, Yankielowicz; Schellekens, Gato-Rivera]

Compare the result to a SUGRA with NSNS gaugings

Two papers together with R. Blumenhagen and E. Plauschinn:

- 1608.00595 Very concrete examples in 4D with $\mathcal{N} = 1$ SUSY
- 1611.04617 Classification of asymmetric Gepner models in 4D, 6D, 8D with extended SUSY to support conjecture.

Our results suggest: Yes! <u>G</u>SUGRA $\sim$ <u>A</u>CFT !

Recap: The 3^5 Gepner model

Gepners idea: Use tensored minimal SCFTs as the internal CFT of a string compactification.

Example: Take the CFT $(k=3)^5$ to describe a 6D internal space. The massless states look like e.g.

$$(\mathbf{3},4,1)(\mathbf{2},3,1)(\mathbf{0},1,1)^3 C \rightarrow x_1^{\mathbf{3}} x_2^{\mathbf{2}}$$
$$(\mathbf{2},3,1)(\mathbf{1},2,1)^3(\mathbf{0},1,1) C \rightarrow x_1^{\mathbf{2}} x_2 x_3 x_4$$

$\Rightarrow$ Combinatorics of complex structure deformations in $\mathbb{P}_{1,1,1,1,1}[5]$.
$\Rightarrow$ 3^5 model is IIB on the quintic at a certain point in moduli space.
$\Rightarrow$ $\mathcal{N}=2$ target space SUSY.

In general: More complicated $W\mathbb{CP}$

Now: Add a certain L-R asymmetric simple current in the first factor of the 3^5 model:

Note: Roughly said a simple current produces a new partition function thus new CFT from an given one.

Result:

- One supercharge from the left-movers, none from the right-movers $\rightarrow$ L-R asymmetry, $\mathcal{N} = 1$ **target space SUSY.**
- 4 minimal factors unaffected $\Rightarrow$ still **4 variables of weight 1**.
- Simple current splits first factor in **2 variables of weight 2**.

$\Rightarrow$ **The model has still the structure of a $W\mathbb{CP}$ with $w_i = 1, 1, 1, 1, 2, 2$ and polynomials of degree 5!**

Educated guess: Is this the CFT to the $\mathcal{N} = 2$ SUGRA of IIB on $\mathbb{P}_{1,1,1,1,2,2}[5, 3]$ with SUSY breaking fluxes?

$\mathcal{N}=2 \to \mathcal{N}=1$ **breaking:** [Louis, Smyth, Triendl '09,10; Louis, Hansen '13]

- Needs **simultaneous geometric + non-geometric gaugings thus DFT**
  No surprise: Our model is L/R asymmetric
- Resulting $\mathcal{N}=1$ **spectrum is highly constrained**. For the above $P_{1,1,1,1,2,2}[5,3]^{h_{12},h_{11}=83,2}$ only 6 possibilities:

$$(N_V, N_{\rm ax}) \in \{(80,0),(80,1),(81,0),(81,1),(82,1),(82,2)\}$$

Compare: Our model has $(N_V; N_{\rm ax}) = (80,0)$ ✓

Observation:

This ACFT looks like the (fully backreacted) string uplift of the GSUGRA of IIB on $P_{1,1,1,1,2,2}[5,3]$ + (SUSY breaking) fluxes!

More examples in our paper.

ACFT/GSUGRA conjecture:

A certain class of aymmetric Gepner models can be identified with the fully backreacted $\mathcal{N} = 1$ vacua of a $\mathcal{N} = 2$ GSUGRA.

Comments:

- We can compare the ACFT only to the *kinematics* of the GSUGRA, therefore its massless multiplet structure.
- Recall the flux scaling scenario from our group:
  Non-geometric (thus winding) fluxes generically have a backreaction $\mathcal{O}(1)$ onto the geometry and no dilute flux limit ("want so shrink their cycle").

  $\Longrightarrow$ [Blumenhagen, Font, MF, Herschmann, Plauschinn, Sekiguchi, Wolf '15]

  Our claim: After adjusting accordingly the minima of the GSUGRA can be uplifted to a full string solution.

ACFT/GSUGRA conjecture:

A certain class of aymmetric Gepner models can be identified with the fully backreacted $\mathcal{N} = 1$ vacua of a $\mathcal{N} = 2$ GSUGRA.

Consequences:

- Partial **SUSY breaking possible** beyond leading order.
- **Minima of GSUGRA** can correspond to **classical vacua of string theory**. The GSUGRA correctly captures the *kinematics* but is unlikely to describe the *dynamics* in a LEEA.
- **Non-geometric fluxes/gaugings** (DFT!) are part of the string dofs and **correspond to ACFTs**.
  See also [Dabholkar, Hull '02,05; Condeescu, Florakis, Kounnas, Lüst '12,13]

  Similar spirit: [Garcia-Etxebarria, Regalado]

Extended SUSY

Advantage: No superpotential, masses only through Higgs.
$\Rightarrow$ **Perfect to test the conjecture in a more controlled setup**

Ralphs talk: Asymmetric Gepner models in **6D** & **8D**.

- $\mathbb{T}^2, K3$: **No NS-NS fluxes** supportable
- $\mathbb{T}^4$: **SUSY breaking** kinematically **forbidden**

$\Rightarrow$ No explanation in terms of a GSUGRA possible!

✓ All models we found are (asymmetric) orbifolds of $\mathbb{T}^2, \mathbb{T}^4, K3$.
Note: $(-1)^{F_L}$ factor appeared often. E.g. the one from [Hellerman, McGreevy, Williams]

In the following: The more interesting 4D case!

4D: SUSY breaking

Still: No superpotential, only Higgs.
But: NS-NS fluxes supportable, more SUSY breakings allowed!

[Deser, Zumino '77; Cremmer, e.a. '78,79; Andrianopoli, D'Auria, Ferrara, Lledo '02]

Example: IIB on $\mathbb{T}^6$ has $\mathcal{N} = 8$ and therefore only the SUGRA multiplet $\mathcal{G}_{(8)}$ at the massless level. Some possible breakings:

$$\mathcal{G}_{(8)} \to \mathcal{G}_{(6)} + 2 \cdot \overline{S}^{\frac{3}{2}\text{massive}}_{(6)}$$

$$\mathcal{G}_{(8)} \to \mathcal{G}_{(4)} + (6 - 2k) \cdot \mathcal{V}_{(4)} \quad + \quad k \cdot \overline{\mathcal{V}}^{\text{massive}}_{(4)} \qquad k \in \mathbb{N}_0$$

Task

Run a stochastic search with up to 4 simultaneous simple currents to classify all asymmetric (non-geometric) Gepner models and see whether they are compatible with ACFT/GSUGRA! $\mathcal{O}(10^8)$ models!

Classification scheme:

$${}^{D}\mathfrak{N}_{[\mathcal{N}_L,\mathcal{N}_R]} \qquad D : \text{uncompactified directions}$$

$$\mathcal{N}_{L/R} : \text{counts the SUSY generators from the L/R of the CFT.}$$

Examples with only the SUGRA multiplet:

- ${}^{4}\mathfrak{N}_{[4,4]}$ thus $\mathcal{N}=8$. The $\mathbb{T}^6$ compactification.
- ${}^{4}\mathfrak{N}_{[2,4]}$ thus $\mathcal{N}=6$. Either broken $\mathcal{N}=8$ or $\mathbb{T}^6/(\mathbb{Z}_2^L\, S)$
- ${}^{4}\mathfrak{N}_{[1,4]}$ thus $\mathcal{N}=5$. Only interpretation is $\mathbb{T}^6/(\mathbb{Z}_2^L\, S, \tilde{\mathbb{Z}}_2^L\, \tilde{S})$

${}^4\mathfrak{N}_{[0,4]}$ has $\mathcal{N}=4$

Massless spectrum:

$$\mathcal{G}_{(4)} + n_V \times \mathcal{V}_{(4)} \ , \qquad n_V = 0, 2, 4, 6, 8, 10, 14, 18$$

$n_V = 18$: Asymmetric orbifold with $SU(2)^6$ gauge group

[Dixon, Kaplunovskiy, Vafa '87] $n_V = 6, \ldots, 18$ Coloumb branch

And the rest?

${}^{4}\mathfrak{N}_{[0,4]}$ has $\mathcal{N} = 4$

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$n_V = 18$: Asymmetric orbifold with $SU(2)^6$ gauge group

[Dixon, Kaplunovskiy, Vafa '87] $n_V = 6, \ldots, 18$ Coloumb branch

And the rest? Recall the super Higgs!

$$\mathcal{G}_{(8)} \to \mathcal{G}_{(4)} + (6 - 2k) \cdot \mathcal{V}_{(4)} \ + \ k \cdot \overline{\mathcal{V}}_{(4)}^{\text{massive}} \qquad k \in \mathbb{N}_0$$

✓ perfect **match between GSUGRA and ACFT!**

Note: A priori no reason for steps of two in the CFT!

${}^4\mathfrak{N}_{[1,2]}$ has $\mathcal{N} = 3$

Massless spectrum:

$$\mathcal{G}_{(3)} + n_V \times \mathcal{V}_{(3)} \ , \qquad n_V = 3, 7, 11, 13, 19$$

Fully explainable by super Higgs ($k \in \mathbb{N}_0$):

$\mathcal{N}'$	$\mathcal{N}$	massless spectrum
8 thus $\mathbb{T}^6$	3	$\mathcal{G}_3 + (3 - 2k) \cdot \mathcal{V}_3$
6	3	–
5	3	–
4 thus $\mathbb{T}^2 \times K3$	3	$\mathcal{G}_3 + (19 - 2k) \cdot \mathcal{V}_3$

${}^4\mathfrak{N}_{[0,2]}$ has $\mathcal{N}=2$

Massless spectrum: $\mathcal{G}_{(2)} + n_V \times \mathcal{V}_{(2)} + n_H \times \mathcal{H}_{(2)}$

1. $n_H - n_V = 1$ with $n_V = 1, 3, 5, 6, \ldots, 15, 17, \mathbf{19}, 20, 21, 22, 23$
2. $n_H - n_V = 13$ with $n_V = 3, 4, 5, \mathbf{7}, 8, 9, 10, 11$
3. $n_V - n_H = 11$ with $n_V = 13, 15, 17, \mathbf{19}, 21, 23$

Mechanisms at work:

a) One basic model (**fat**) + gauge enhancement with up to 4 (higgsable) $\mathcal{V}_{(2)} + \mathcal{H}_{(2)}$ pairs (same as in 6D)

b) SUSY breaking of $\mathbb{T}^2 \times K3$ thus $\mathcal{N}=4 \rightarrow \mathcal{N}=2$ with different number of short/long massive gravitino/vector multiplets. *Note the steps of one!*

1. $n_H - n_V = 1$ with $n_V = 1, 3, 5, 6, \ldots, 15, 17, \mathbf{19}, 20, 21, 22, 23$

   $n_V = 19$ is the $\mathbb{T}^2$ reduction of $\mathbb{T}^4/\{\Theta, \Theta S(-1)^{F_L}\} \in {}^6\mathfrak{N}_{[1,0]}$

   [Hellerman, McGreevy, Williams '04]; Θ reflectsion, S momentum shift

   Again: Up to 4 additional $\mathcal{V} + \mathcal{H}$ pairs!

   Alternatively $\mathcal{N} = 4 \to \mathcal{N} = 2$ breaking of $K3 \times \mathbb{T}^2$ with (only) short massive gravitino multiplets yields

$$n_V = 19 - k \qquad\qquad n_H = 20 - k \quad \checkmark$$

2. $n_H - n_V = 13$ with $n_V = 3, 4, 5, \mathbf{7}, 8, 9, 10, 11$

   $\mathcal{N} = 4 \to \mathcal{N} = 2$ breaking of $K3 \times \mathbb{T}^2$ with no short gravitino and six short vector multiplets gives

   $$n_V = 7 - k \qquad\qquad n_H = 20 - k \quad \checkmark$$

   Alternatively, the model with $n_V = 7$ is the $K3$ reduction of the $\mathbb{T}^2/\{(-1)^{F_L} SW\} \in {}^8\mathfrak{N}_{[1,0]}$ model, therefore

   $$\frac{\mathbb{T}^4 \times \mathbb{T}^2}{\{\mathbb{Z}_2, (-1)^{F_L} SW\}},$$

   Allows for discrete torsion $\epsilon = \pm 1$ between the $\mathbb{Z}_2$ factors! $\epsilon = -1$ gives $n_V = 19$ and $n_H = 8$. Indeed:

3. $n_V - n_H = 11$ with $n_V = 13, 15, 17, \mathbf{19}, 21, 23$
   Again in both cases: Up to 4 additional $\mathcal{V} + \mathcal{H}$ pairs!

For completeness: ${}^4\mathfrak{N}_{[2,2]}$ (symmetric) has $\mathcal{N}=4$

Massless spectrum:

$$\mathcal{G}_{(4)} + (2+n)\times\mathcal{V}_{(4)}\ , \qquad n_V = 2+n = 22, 14, 10, 6, 4$$

Clearly $n_V = 22$ is IIB on $\mathbb{T}^2 \times K3$. Rest is:

$$\mathrm{Orb}_{n,m} = \frac{\mathbb{T}^4 \times \mathbb{T}^2}{\mathbb{Z}_n S_m}$$

$\mathrm{Orb}_{n,m}$	twisted sector vectors	massless spectrum
$(2,2)$	$(1,\theta) = (6,0)$	$\mathcal{G}_{(4)} + 6\cdot\mathcal{V}_{(4)}$
$(3,3)$	$(1,\theta,\theta^2) = (4,0,0)$	$\mathcal{G}_{(4)} + 4\cdot\mathcal{V}_{(4)}$
$(4,2)$	$(1,\theta,\theta^2,\theta^3) = (4,0,10,0)$	$\mathcal{G}_{(4)} + 14\cdot\mathcal{V}_{(4)}$
$(6,3)$	$(1,\theta,\theta^2,\theta^3,\theta^4,\theta^5) = (4,0,0,6,0,0)$	$\mathcal{G}_{(4)} + 10\cdot\mathcal{V}_{(4)}$

Conclusion

- Concrete examples in 4D with $\mathcal{N} = 1$
- Classification of all asymmetric Gepner models in 4D, 6D and 8D with more SUSY

All examples support: **ACFT** $\sim$ **GSUGRA**

Concretely: The asymmetric Gepner models we constructed correspond to fully backreacted minima of GSUGRA with geometric + non-geometric gaugings/fluxes.