On non-perturbative effects and moduli stabilization from 10D

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String Phenomenology
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Work in progress with Iosif Bena, Mariana Graña & Nicolás Kovensky

Introduction

Existence of de Sitter vacua controversial in String compactifications

- Recently because swampland conjecture
- Before, lots of issues related to $\overline{D}3$-brane **uplifts**: tachyons, flatenning effects...
- Lead to a better understanding of KKLT proposal
- Realized of relevance of understanding non-pertubative effects better [Hamada, Hebecker, Shiu, Soler; Kallosh; Carta,Moritz,Westphal; Gautason, Hemelryck, Van Riet, Venken] & talks by Arthur, Jakob, Liam, Pablo,Thomas...

This talk: 10D physics of non-perturbatively stabilized 4D SUSY vacua

4D SUSY flux vacua in a nutshell

[Graña,Minasian,Petrini,Tomasiello '05]

Type IIB 4D SUSY compactification: $\exists \eta^{(i)} \neq 0$ & $\nabla'_m \eta^{(i)} = 0$

$$\epsilon^1 = \zeta_+ \otimes \eta_+^{(1)} + c.c. \quad , \quad \epsilon^2 = \zeta_+ \otimes \eta_+^{(2)} + c.c.$$

$\exists \eta^{(i)} \neq 0 \Leftrightarrow$ reduced structure group $\Leftrightarrow$ also $\exists$ geometric forms

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Useful: spinors $\rightarrow$ geometric **polyforms**

$$\Psi_\pm = \frac{-i}{|\eta^{(1)}|^2} \sum_p \frac{1}{p!} \eta_\pm^{(2)\dagger} \gamma_{m_1} \ldots \gamma_{m_p} \eta_+^{(1)} dy^{m_p} \wedge \ldots \wedge dy^{m_1}$$

SU(3) structure compactification ($\eta_+^{2\dagger}\eta_+^1 = ie^{i\theta}e^A$): $\Psi_+ \sim e^{iJ}$ & $\Psi_- \sim \Omega_3$

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- Polyforms allow to write 10D SUSY conditions in compact way
- SUSY conditions + flux EQs = all EOMs [Gaunlett,Gran,Gutowski, Luest, Mac Conamhna,Martelli, Pakis,Papadopoulos,Roest,Tsimpis,Waldram...]
- Allow to write superpotential using 10D data

4D flux vacua in a nutshell II

[Graña,Minasian,Petrini,Tomasiello '05]

Schematically, *classical* 10D SUSY conditions are (in Type IIB)

$$d_H(Re(\Psi_+)) = \quad -3Re(\bar{\mu}\Psi_-) \quad + \star_6 \hat{F}$$
$$d_H(\Psi_-) = \quad -2i\mu \; Im(\Psi_+)$$

where $\Lambda_4 = -3|\mu|^2$, $d_H \equiv d - H_3\wedge$ and

$$F = d_H C = Vol_4 \wedge \tilde{F} + \hat{F}$$

It obeys $F = \star_{10} F$, $d_H \hat{F} = j_Q$ & $0 = d_H \star_6 \hat{F}$

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$$d_H(Re(\Psi_+)) = \quad -3Re(\bar{\mu}\Psi_-) \quad + \star_6 \hat{F} + \langle\lambda\lambda\rangle \; PD[\Sigma]$$
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They get quantum corrected

- Flux correction motivated by [Baumann et al '10]

$$\langle\lambda\lambda\rangle_{D7} \neq 0 \quad \Rightarrow \quad \text{IASD} \;\; G_3 \quad \Rightarrow \quad \text{source:} \;\; \langle\lambda\lambda\rangle_{D7} G_3 \cdot \Omega_3$$

  and incorporated in this language by [Dymarsky,Martucci '10]
- This term got renewed attention

Superpotentials

The 10D superpotential in terms of holomorphic polyforms

$$W = \int_{X_6} \langle \Psi_-, d_H[Re(\Psi_+) - iC] \rangle \supset \int_{X_6} \Omega_3 \wedge (F_3 + ie^{-\phi} dJ)$$

If we consider a variation $\delta(e^{-\phi}J - iC_2)$

$$\mathcal{F} = \delta W \sim \int_{X_6} d\Omega_3 \wedge \delta(e^{-\phi}J - iC_2) \quad \Rightarrow \quad \mathcal{F} = 0 \Leftrightarrow d\Omega_3 = 0$$

Superpotentials & Quantum corrections

[Lust,Reffert,Schulgin,Tripathy '05; Koerber,Martucci '07; Dymarsky,Martucci '10]

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Consider 4d gauge theory with rigid SUSY

$$\int d^2\theta W(\psi) + \int d^2\theta \alpha(\psi) Tr(W^\alpha W_\alpha) + c.c. \quad , \quad W_\alpha = -i\lambda_\alpha + ...$$

Quantum corrected F-term:

$$0 = \mathcal{F}_i = \partial_i W - (\partial_i \alpha)(Tr(\lambda^\alpha \lambda_\alpha))$$

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If we consider a variation $\delta(e^{-\phi}J - iC_2)$ $\quad \left(\alpha_{D5} = \int_{\Sigma_2} e^{-\phi}J - iC_2 \right)$

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$$0 = \mathcal{F}_i = \partial_i W - (\partial_i \alpha)(Tr(\lambda^\alpha \lambda_\alpha)) = d\Omega_3 - (PD[\Sigma_2])(Tr(\lambda^\alpha \lambda_\alpha))$$

A nice matching / new supporting evidence

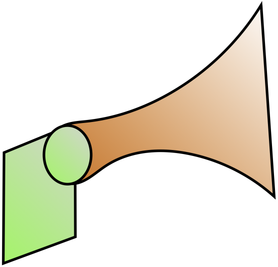
[Bena,Kovensky,Graña,AR]

[Heidenreich,McAllister,Torroba '10] 10D SUGRA solution mimicking SUSY KKLT

- $(\mathbb{C}^3/\mathbb{Z}_3)/\Omega_{O7}$ conical CY$_3$: 1 compact Σ_4
- IASD G_3: SU(2) structure (dynamical)

$$\Psi_- = \Psi_1 + \Psi_3 + \Psi_5$$

- KKLT & G_3^-: AdS$_4$
- Source term omitted



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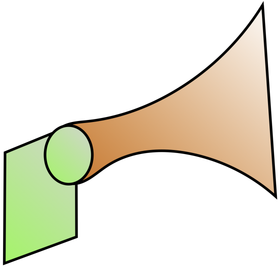

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[Dymarsky,Martucci '10] study some aspects of including $\langle\lambda\lambda\rangle_{D7}$

$$d\Psi_1 = \langle\lambda\lambda\rangle_{D7} PD[\Sigma_4] \quad \Rightarrow \quad \Psi_1 \neq 0$$

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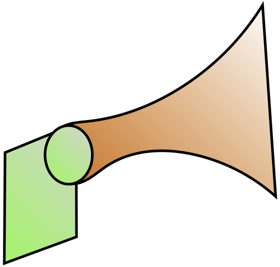

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- We found that when gluing both results $\quad W_0 = -Ae^{-a\sigma}(1 + \sharp\sigma)$
- For $\sharp = \dfrac{2a}{3}$ this is the KKLT F-term for σ

Non perturbative effects & Moduli stabilization

[Bena,Kovensky,Graña,AR]

Type IIB compactification with a condensate on D7-branes wrapping Σ_4

$$d(\Psi_1) = -2i\mu \, Im(\Psi_2) + \langle \lambda\lambda \rangle_{D7} PD[\Sigma_4]$$

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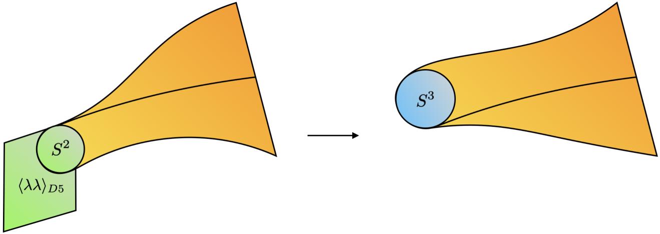

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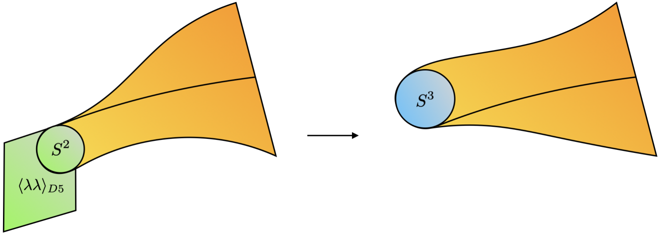

Geometric transition, but... what about moduli stabilization?

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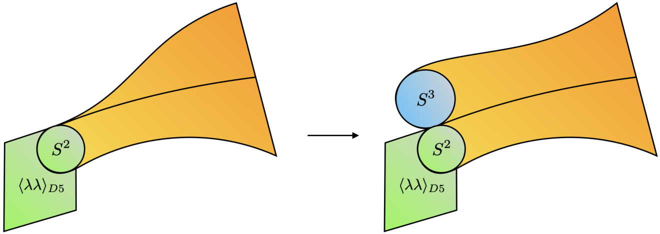

Geometric transition, but... what about moduli stabilization?

- If $\mu \neq 0$ (AdS_4) cycle is non-trivial - no geometric transition
  - Modulus gets stabilized in agreement with 4d EFT
- Moduli stabilization by NP effects *requires* AdS_4

Summing up

- We have the tools to describe SUSY compactifications from 10D
- We know how to quantum correct the SUSY conditions
- Gluing together two works related to SUSY KKLT vacuum: supporting evidence
- Moduli stabilization by NP effects requires AdS_4.
- New interesting geometries arise from these compactifications, but they are more involved than (conformal) CY-s.