Smearing and unsmearing KKLT AdS vacua

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Based on 2212.05074 (JHEP), in collaboration with **Mariana Graña** and **Dimitrios Toulikas**.

Can we understand precisely KKLT AdS vacua?

The [Kachru, Kallosh, Linde, Trivedi 03] construction for dS_4 in string theory involves a **4D EFT** description of a **susy AdS_4 vacuum** with

- gaugino (λ) condensation on D7 branes
- and a small (0,3) 3-form flux contribution
- which balance giving a small $\Lambda = -3|\mu|^2$
  and stabilizing the Kähler modulus

How does the full **10D solution** look like? Backreaction of $\langle \lambda\lambda \rangle$?

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Other recent papers on the same topic:

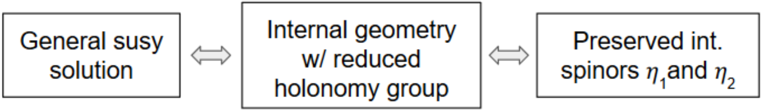
[Carta, Moritz, Retolaza, Westphal 17,19][Hamada, Hebecker, Shiu, Soler 18, 19 and 21]. [Kallosh 19][Gautason, Van Hemelryck, Van Riet, Venken 18,19][Bena, Graña, NK, Retolaza 19,20][Kachru, Kim, McAllister, Zimet 19][Demirtas, Kim, McAllister, Moritz & Rios-Tascon 19,20,21][Lüst, Vafa 22]...

GCG compactifications

GCG for type II 4D string vacua

[Hitchin 02, Gualtieri 04, Graña et al 05-06]

A useful description of 4D $\mathcal{N} = 1$ string compactifications:



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General susy solution $\Longleftrightarrow$ Internal geometry w/ reduced holonomy group $\Longleftrightarrow$ Preserved int. spinors η_1 and η_2

SU(3)×SU(3) structure: polyforms $\Psi_\pm$ w/ components $\eta_\pm^{2\dagger}\Gamma_{m_1\dots m_p}\eta_+^1$

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The susy conditions (zero $\delta\psi_M$ and $\delta\lambda$) read

$$d_H\left(e^{3A-\phi}\Psi_-\right) = 2i\mu e^{2A-\phi}\mathrm{Im}\,\Psi_+ \qquad d_H = d - H$$

$$d_H\left(e^{2A-\phi}\mathrm{Im}\,\Psi_+\right) = 0$$

$$d_H\left(e^{4A-\phi}\mathrm{Re}\,\Psi_+\right) = 3e^{3A-\phi}\mathrm{Re}\left(\bar{\mu}\Psi_-\right) + e^{4A}\tilde{F}$$

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These can be obtained as F- and D-flatness for [Koerber, Martucci 07,08]

$$W_{\rm gcg} = \int_{M_6}\langle e^{3A-\phi}\Psi_-, d_H[C+ie^{-\phi}\mathrm{Re}\Psi_+]\rangle \equiv \int_{M_6}\langle Z, dT\rangle \Rightarrow \langle W_{\rm gcg}\rangle \sim \mu$$

Example: IIB SU(3) structure compactifications

For type IIB with D3/D7 supersymmetry,

$$\eta^2_+ = -i\eta^1_+ \quad \Rightarrow \quad \Psi_- = i\,\Omega\ ,\ \Psi_+ = \exp(i\,J)$$

with $\Omega_{(3,0)}$ and $J_{(1,1)}$ the usual holomorphic and Kähler forms.

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while for μ and $G_3 = F_3 + ie^{-\phi}H$ we have

$$\mu = 0\,, \qquad G_3 \wedge \Omega = 0\,, \qquad (i - *_6)G_3 = 0,$$

so that G_3 must be ISD and without a (0,3) component.

Effect of the gaugino condensate

Gaugino condensate and backreaction 1

Susy condition 1 with localized gaugino condensate

$$d_H\left(e^{3A-\phi}\Psi_-\right) = 2i\mu e^{2A-\phi}\mathrm{Im}\,\Psi_+ - 2i\langle S\rangle\delta^{(2)}\left[\Sigma_4\right]$$

Motivated in [Martucci, Koerber 08, M,Dymarsky 10, Bena, Graña, NK, Retolaza 19]:
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$$\tau_{\mathrm{D7}} = i\frac{4\pi}{g^2_{\mathrm{YM}}} + \frac{\theta_{\mathrm{YM}}}{2\pi} = \int_{\Sigma_4}\left(C + ie^{-\phi}\mathrm{Re}\,\Psi_+\right)|_{\Sigma_4} = \int_{M_6}\langle T, -\delta^{(2)}(\Sigma_4)\rangle,$$

which gives the strength of the gaugino condensate in $\mathcal{N}=1$ SYM

$$\langle S\rangle = (16\pi^2)^{-1}\langle\lambda\lambda\rangle = \mu_0^3\exp\left(-2\pi i\tau_{\mathrm{D7}}(T)/N\right)\,,$$

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- encodes Kähler moduli stabilization in 10D language.

Gaugino condensate and backreaction 2

Susy condition 3 with localized gaugino condensate

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with $\delta^{(0)}[\Sigma_4]\,\mathrm{vol}_6 \equiv \langle\mathrm{Re}\,\Psi_+, \delta^{(2)}[\Sigma_4]\rangle$. Motivated in [Martucci, Dymarsky 10, Kachru, Kim, McAllister, Zimet 19] assuming almost SU(3) structure ($\Psi_- \to \Omega$).

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We argue this holds in generic GCG compactifications

Supersymmetry conditions $\Rightarrow$ Flux EOMs !

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including the source from the gaugino mass [Graña, NK, Retolaza 20]

$$S_{\lambda\lambda} = \int d^4x\,\left(\frac{i}{2}f\,\bar{\lambda}_+\gamma^{\mu}\nabla_{\mu}\lambda_+ + \frac{1}{2}m_{\lambda}\,\bar{\lambda}_-\lambda_+ + c.c.\right)\,,$$

$$m_{\lambda} = -\frac{i}{8\pi}\int_{M_6}\delta^{(0)}[\Sigma_4]\,e^{A}\left\langle\Psi_-, F + i\,d_H\left(e^{-\phi}\mathrm{Re}\,\Psi_+\right)\right\rangle\,.$$

Gaugino condensate backreaction: summary and consistency

Susy conditions with localized gaugino condensate terms

$$
\begin{aligned}
d_H\left(e^{3A-\phi}\Psi_-\right) &= 2i\mu e^{2A-\phi}\mathrm{Im}\,\Psi_+ - 2i\langle S\rangle\delta^{(2)}\left[\Sigma_4\right] \\
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This system is consistent with the superpotential $W_{\rm gcg}$ since

$$
\begin{aligned}
\langle W^{\rm loc}_{\rm gcg}\rangle &= -4\int_{M_6}\langle\langle S\rangle\delta^{(2)}[\Sigma_4]\,, e^{-\phi}\mathrm{Re}\,\Psi_+\rangle + \\
&\quad + i\int_{M_6}\langle e^{3A-\phi}\Psi_-, e^{-3A}\delta^{(0)}[\Sigma_4]\,\mathrm{Re}\left[\langle\bar{S}\rangle\Psi_-\right]\rangle = 0\,,
\end{aligned}
$$

Hence, $W_{\rm gcg}$ contains all relevant ingredients.

(similar to geometric transitions as described in [Martucci, Dymarsky 10])

Applications

See Dimitrios Toulikas' talk next!

KKLT from Smearing the gaugino condensate

Smearing D7s gaugino condensate as

$$\delta^{(2)}[\Sigma_4] \to \gamma e^{2A-\phi} J \,, \qquad \delta^{(0)}[\Sigma_4] \to 3\gamma e^{2A-\phi} \,,$$

reproduces 4d EFT KKLT results **exactly**. (small μ and (0,3) flux)

Localized solution at first order

Expanding modified Susy Eqs and flux BIs in $\langle\lambda\lambda\rangle$ [KKMZ 19]

Divergencies in the on-shell action

Bulk contribution exactly computable using [Lüst et al 08] even **without knowing the full localized solution**. Gives prediction for on-shell λ^4 terms in D7 action. Results similar to [Hamada et al 18-21].

Thank you! Any questions?