On gaugino condensates in ten dimensions

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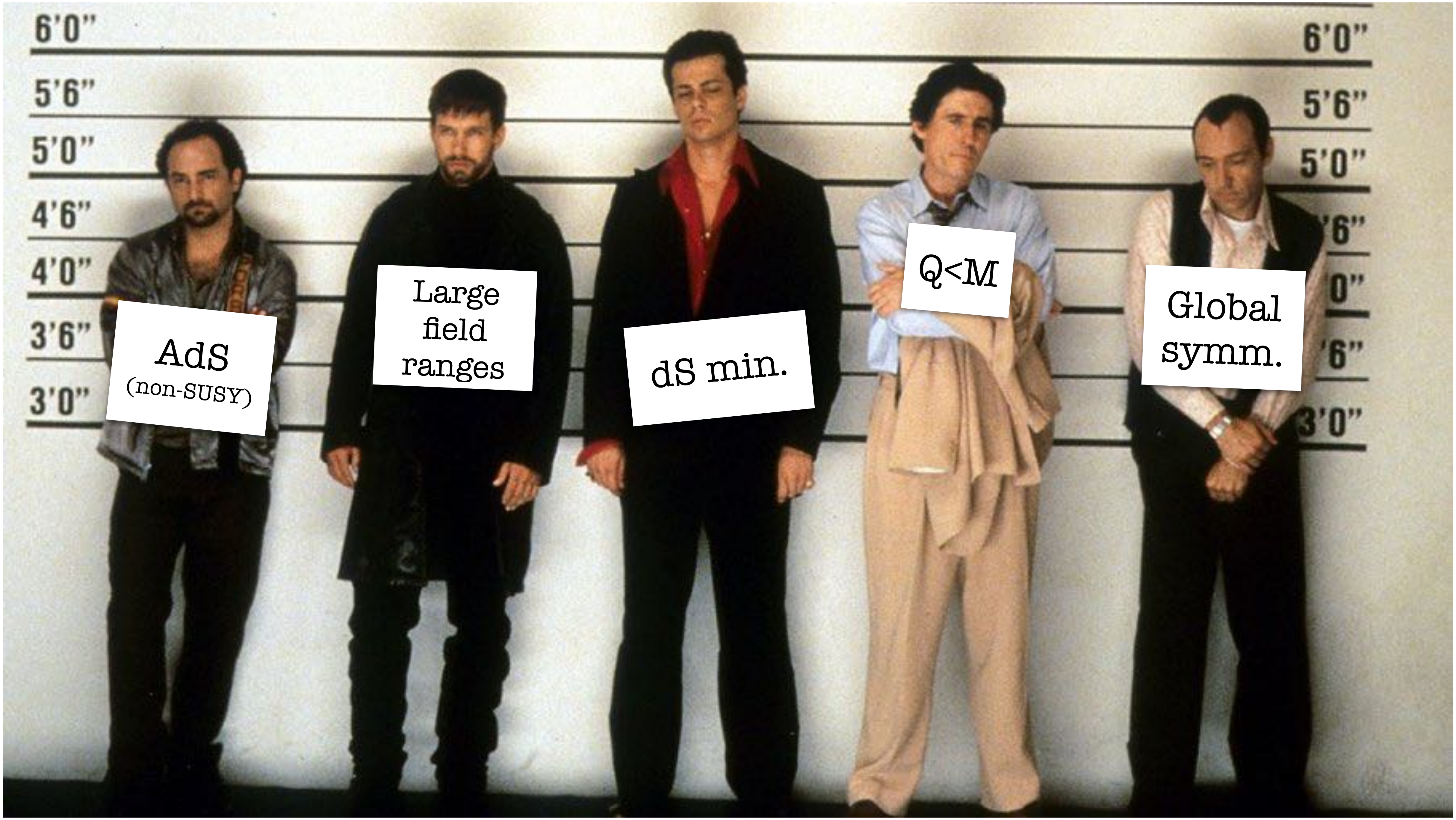
with Y. Hamada, A. Hebecker & G. Shiu - **1812.06097**, 1902.01410

The Swampland Lineup



KKLT from 10d perspective

- Consider Einstein equation in 10d and its trace over 4d indices:

$$\mathcal{R}_{MN} = T_{MN} - \frac{1}{8} g_{MN} T^L_L \implies R^\mu_\mu = \frac{1}{2}\left(T^\mu_\mu - T^m_m\right) \equiv -2\Delta$$

- For metric ansatz: $ds^2_{10} = \Omega^2(y)\,\left(\eta_{\mu\nu}\,dx^\mu\,dx^\nu + g_{mn}\,dy^m\,dy^n\right)$

$$\mathcal{V}_6\,\mathcal{R}(\eta) = -2\int d^6y\,\sqrt{g}\,\Omega^{10}(y)\Delta$$

Useful for no-go theorems: if Δ>0 one can rule out $\mathcal{R}(\eta) \geq 0$.

Maldacena, Nuñez ‘00

- Key question: how does gaugino condensation contribute to Δ?

Proposal: use 10d action with a source $\langle\lambda\lambda\rangle \sim e^{-aT}$

Moritz, Retolaza, Westphal ’17, ’18
Moritz, Van Riet, ‘18
Gautason, Van Hemelryck, Van Riet ‘18

KKLT from 10d perspective

- The relevant terms in the 10d action come from *bulk* 3-form fluxes and D7-*localized* gauginos

Up to λλ-terms: $\mathcal{L}_{10} \supset |G_3|^2 + G_3 \cdot \Omega_3 \, \lambda\lambda \, \delta_{D7}$

Camara, Ibañez, Uranga ’04;
Baumann et al. ‘06 ; Koerber, Martucci ’07

- Problem: $\langle\lambda\lambda\rangle \neq 0$ sources a flux that diverges on the D7-locus

$$G_3 = -\frac{1}{2}\,\Omega_3\,\lambda\lambda\,\delta_{D7} \qquad \Longrightarrow \qquad S_{10} \to |\lambda\lambda|^2 \delta(0)$$

The resulting action is divergent, but also quartic in gauginos

- Quartic gaugino terms are crucial in the 4d KKLT potential ($\sim e^{-2T}$)

Need to regularize the action to make sense of them

Gaugino actions in 10d

- Real co-dimension one sources:

  Non-compact — Horava, Witten ’96; Horava ’96; Mirabelli, Peskin ‘97

  Compact

- Real co-dimension two sources:

  Non-compact — Hamada, Hebecker, Shiu, PS ’18

  Compact

Gaugino actions in 10d

(co-dimension one)

- Divergences from localized co-dimension one sources and their resolutions have been long known

Horava, Witten '96; Horava '96

- 5d toy model with bulk flux G_1=dϕ and sources localized at y=0

Mirabelli, Peskin '97

$$S = -\int_{M_5} G_1 \wedge * G_1 - 2\, G_1 \wedge * \lambda\lambda\, \delta(y)\, dy$$

Divergences arise upon solving for ϕ:

$$G_1 = \lambda\lambda\, \delta(y)\, dy + G_1^{(0)} \qquad \Longrightarrow \qquad S \to (\lambda\lambda)^2\, \delta(0) + \ldots$$

Need to regularise the action by including $(\lambda\lambda)^2$ counterterms, in turn required by SUSY

Derendinger, Ibañez, Nilles '85; Dine, Rohm, Seiberg, Witten '85; …

Gaugino actions in 10d

(co-dimension one)

- Divergences from localized co-dimension one sources and their resolutions have been long known

Horava, Witten ’96; Horava ‘96

- 5d toy model with bulk flux $G_1 = d\phi$ and sources localized at $y=0$

Mirabelli, Peskin ‘97

Gaugino actions in 10d

(co-dimension one)

- Divergences from localized co-dimension one sources and their resolutions have been long known

Horava, Witten '96; Horava '96

- 5d toy model with bulk flux G_1=dϕ and sources localized at y=0

Mirabelli, Peskin '97

$$S = -\int_{M_5} (G_1 - \lambda\lambda\,\delta(y)\,dy) \wedge * (G_1 - \lambda\lambda\,\delta(y)\,dy)$$

Perfect square: eom for ϕ unmodified, but finite action.

$$G_1 = \lambda\lambda\,\delta(y)\,dy + G_1^{(0)} \qquad \Longrightarrow \qquad S \to \int_{M_5} G_1^{(0)} \wedge * G_1^{(0)} < \infty$$

Gaugino actions in 10d

(co-dimension one)

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Gaugino actions in 10d

(co-dimension one)

$$G_1 = \lambda\lambda\,\delta(y)\,dy + G_1^{(0)} \qquad \Longrightarrow \qquad S \to \int_{M_5} G_1^{(0)} \wedge * G_1^{(0)} < \infty$$

- $G_1^{(0)}$ is a constant (harmonic) piece
- **Bianchi identity** $dG_1=0$ satisfied since $d\left(\delta(y)\,dy\right) = 0$
- For a **compact** y-direction, G_1 is subject to flux quantization:

$$\int_y G_1 = \lambda\lambda + G_y^{(0)} = N \in \mathbb{Z} \qquad \Longrightarrow \qquad S \to \int_{M_4} |N - \lambda\lambda|^2$$

Gaugino actions in 10d

(co-dimension two)

Gaugino actions in 10d

(co-dimension two)

- Consider the brane transverse space to be parametrized by ‘z’:

$$S \stackrel{?}{=} -\int_{M_6} \left| G_1 - \lambda\lambda\, \delta(z)\, d\bar{z} \right|^2$$

This naive attempt fails: $G_1 \stackrel{?}{=} \lambda\lambda\, \delta(z)\, d\bar{z} + G_1^{(0)}$

Gaugino actions in 10d

(co-dimension two)

- Consider the brane transverse space to be parametrized by ‘z’:

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This naive attempt fails: $G_1 \stackrel{?}{=} \lambda\lambda\, \delta(z)\, d\bar{z} + G_1^{(0)} \Longrightarrow\ dG_1 \neq 0$

The reason is that the source is not closed: $d\left(\delta(z)\, d\bar{z}\right) \neq 0$

Non-closed source + Bianchi id. $\Rightarrow$ Infinite action

Gaugino actions in 10d

(co-dimension two)

- We would like to get a finite action without modifying its perfect square structure (SUSY) nor the G_1 eom.

- Notice: any form can be written as

$$\omega = \alpha + d\beta + d^\dagger\gamma = \text{(harm.)} + \text{(exact)} + \text{(co-exact)}$$

Define the projector onto closed forms: $\mathcal{P}[\omega] = \alpha + d\beta$

- Proposal: the correct action reads

$$S = -\int_{M_6} \left| G_1 - \mathcal{P}\left[\lambda\lambda\,\delta(z)\,d\bar{z}\right] \right|^2$$

Notice: eom unchanged since: $\int G_1 \wedge * d^\dagger\gamma = \int dG_1 \wedge * \gamma = 0$

Gaugino actions in 10d

(co-dimension two)

$$S = -\int_{M_6} \left| G_1 - \mathcal{P}\left[\lambda\lambda\, \delta(z)\, d\bar{z}\right] \right|^2$$

For **compact** transverse space (say T^2):

$$\delta(z) = \partial_z \bar{\partial}_z G_{T^2} + \frac{1}{V_{T^2}} \qquad \Longrightarrow \qquad \mathcal{P}\left[\delta(z) d\bar{z}\right] = d(\partial_z G_{T^2}) + \frac{1}{V_{T^2}}$$

- Solution:

$$G_1 = \lambda\lambda\, d(\partial_z G_{T^2}) + G_1^{(0)} \qquad \Longrightarrow \qquad S \to \int \left| G_1^{(0)} + \frac{\lambda\lambda}{V_{T^2}} \right|^2$$

As usual, $G_1^{(0)}$ is quantized: $\int_{S^1} G_1^{(0)} \in \mathbb{Z}$

Gaugino actions in 10d

(co-dimension two)

- The D7-brane case of interest poses no further obstacle:

Camara, Ibañez, Uranga ’04

$$S \;=\; -\int_{10} g_s \Big|G_3\Big|^2 - \sqrt{g_s}\,\bar{\lambda}\bar{\lambda}\,\delta_{D7}\,G_3\wedge\Omega_3$$
$$\longrightarrow\; -g_s\int\Big|G_3 - \frac{\lambda\lambda}{\sqrt{g_s}}\mathcal{P}\left[\delta(z)\overline{\Omega}_3\right]\Big|^2$$

Upon solving for $G_3 = d(\ldots) + G_3^{(0)}$:

$$S \to -g_s\Big|G_3^{(0)} - \frac{\lambda\lambda}{\sqrt{g_s}\,V_\perp}\,\overline{\Omega}_3\Big|^2$$

This correctly reproduces the appropriate g_s and Kahler mod. dependence of gaugino terms in the 4d SUGRA action

Hamada, Hebecker, Shiu, PS ’18; c.f. Kallosh ‘19

Conclusions

- Motivated by previous results (e.g. heterotic / Horava-Witten), we have proposed a 10d action for D7 gauginos that:

  Reproduces previously known $G_3.\lambda\lambda$ interactions

  Has a perfect square structure (SUSY)

  Is finite on-shell

  Reproduces standard 4d SUGRA terms upon compactification

Hamada, Hebecker, Shiu, PS '18, c.f. Kallosh '19

c.f. Hebecker & McAllister talks

- This proposal can be used to re-examine and back up the KKLT scenario from a 10d perspective.

Hamada, Hebecker, Shiu, PS '19; Carta, Moritz, Westphal '19
(see however Gautason, Van Hemelryck, Van Riet, Venken '19)

c.f. Hebecker & Van Riet talks