D-brane gaugino actions and their role in moduli stabilization

Pablo Soler
IBS-CTPU

with Y. Hamada, A. Hebecker & G. Shiu - 1812.06097, 1902.01410, 2105.11467

ePASCOS - IBS- June '21

D-brane gaugino actions and their role in KKLT

Pablo Soler
IBS-CTPU

with Y. Hamada, A. Hebecker & G. Shiu - 1812.06097, 1902.01410, 2105.11467

ePASCOS - IBS- June '21

KKLT review

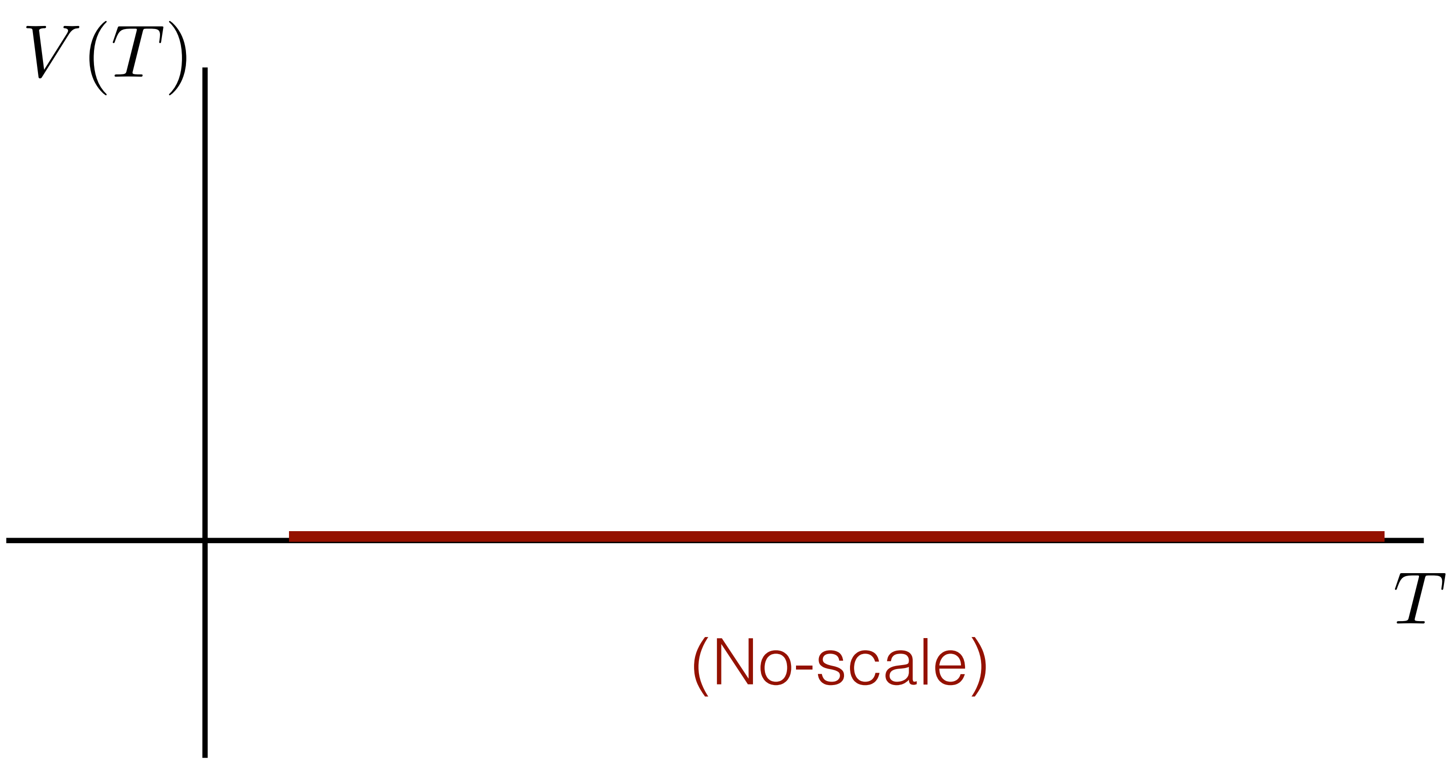
Kachru, Kallosh, Linde, Trivedi ‘03

KKLT: Step 0

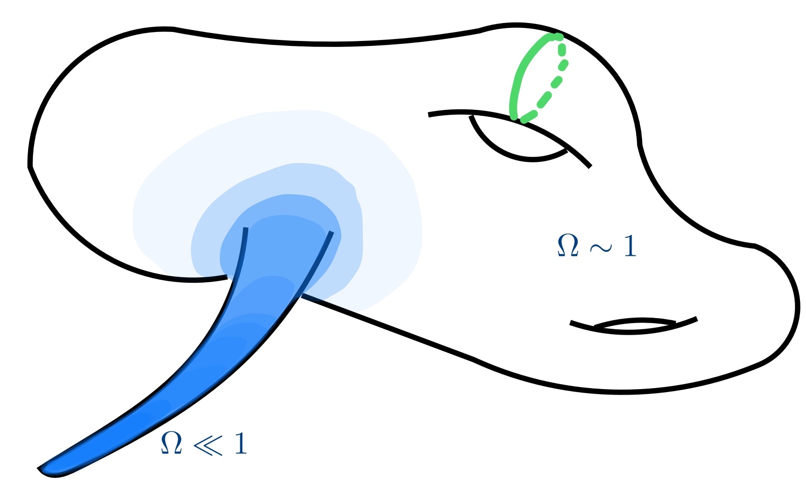
- **Step 0 (GKP)**: type IIB warped compactification with O7-planes, D3/ D7-branes and 3-form fluxes (cmplx. str. stabilized, one Kahler mod. T).

$$V(T) = e^{K}\left(\,|D_T W_0|^2 - 3\,|W_0|^2\right) = 0$$

$$\begin{cases} K \;=\; -\,3\log\left(T+\bar{T}\right) \\ W_0 = \displaystyle\int G_3\wedge\Omega \end{cases}$$



(No-scale)



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

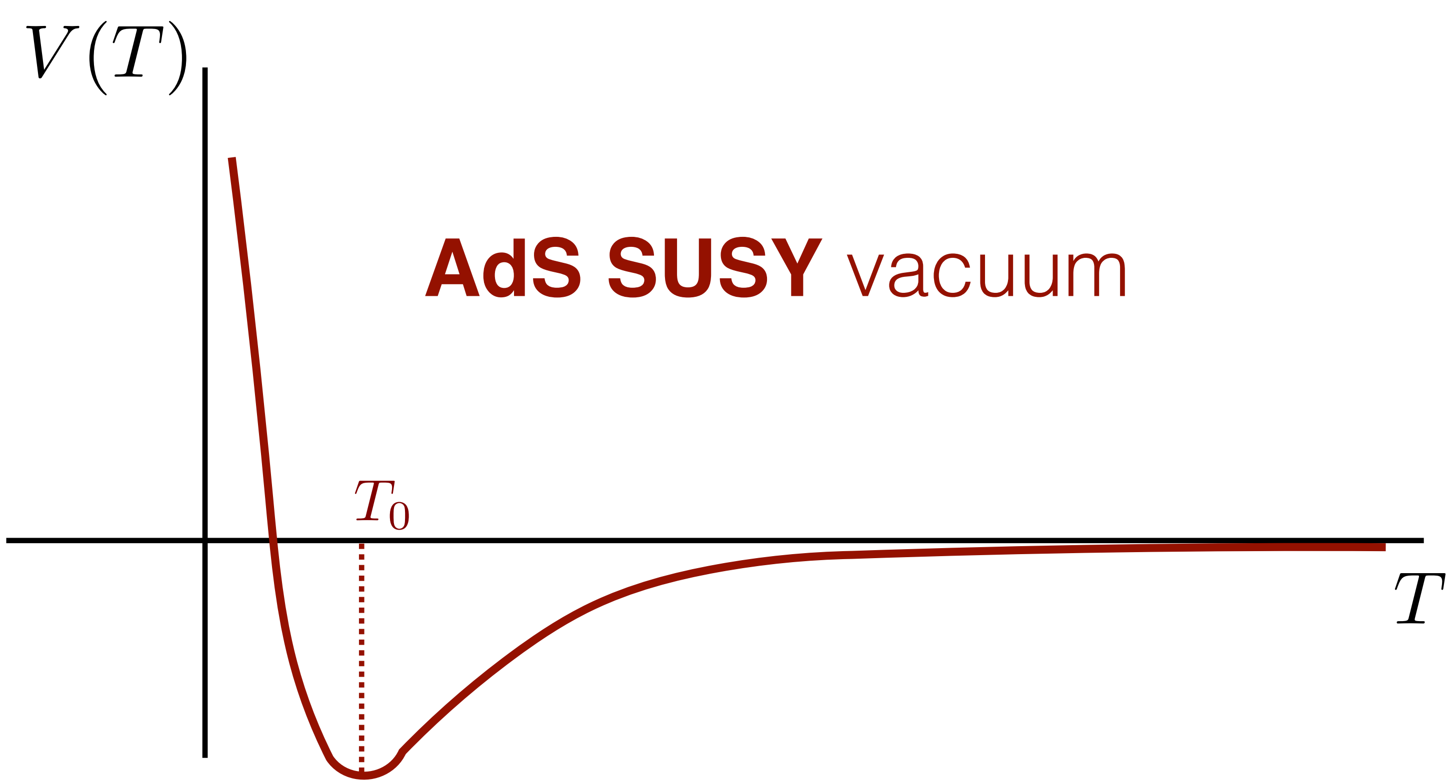
Giddings, Kachru, Polchinski '01

KKLT: Step 1

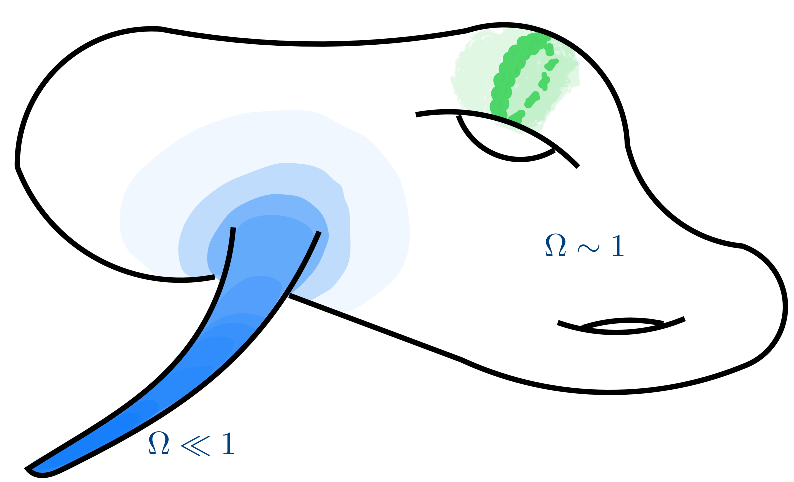
- **Step 1:** non-perturbative effects, e.g. gaugino condensation of $\mathcal{N}=1$ SYM on a D7-brane: $\langle\lambda\lambda\rangle \sim e^{-T}$

$$\begin{aligned} V(T) &= e^K\left(|D_T W_0 + e^{-K/2}\lambda\lambda|^2 - 3|W_0|^2\right) \\ &\xrightarrow{\langle\lambda\lambda\rangle\sim e^{-T}} e^K\left(|D_T W_0 - e^{-T}|^2 - 3|W_0|^2\right) \\ &\sim \left(-\frac{2}{T^2}W_0\, e^{-T} + \frac{1}{T}e^{-2T}\right) \end{aligned}$$

$$\begin{cases} K = -3\log(T+\bar{T}) \\ W \to W_0 + e^{-T} \end{cases}$$



AdS SUSY vacuum



Dine-Seiberg problem

$W_0 \sim e^{-T_0} \overset{!}{\ll} 1$

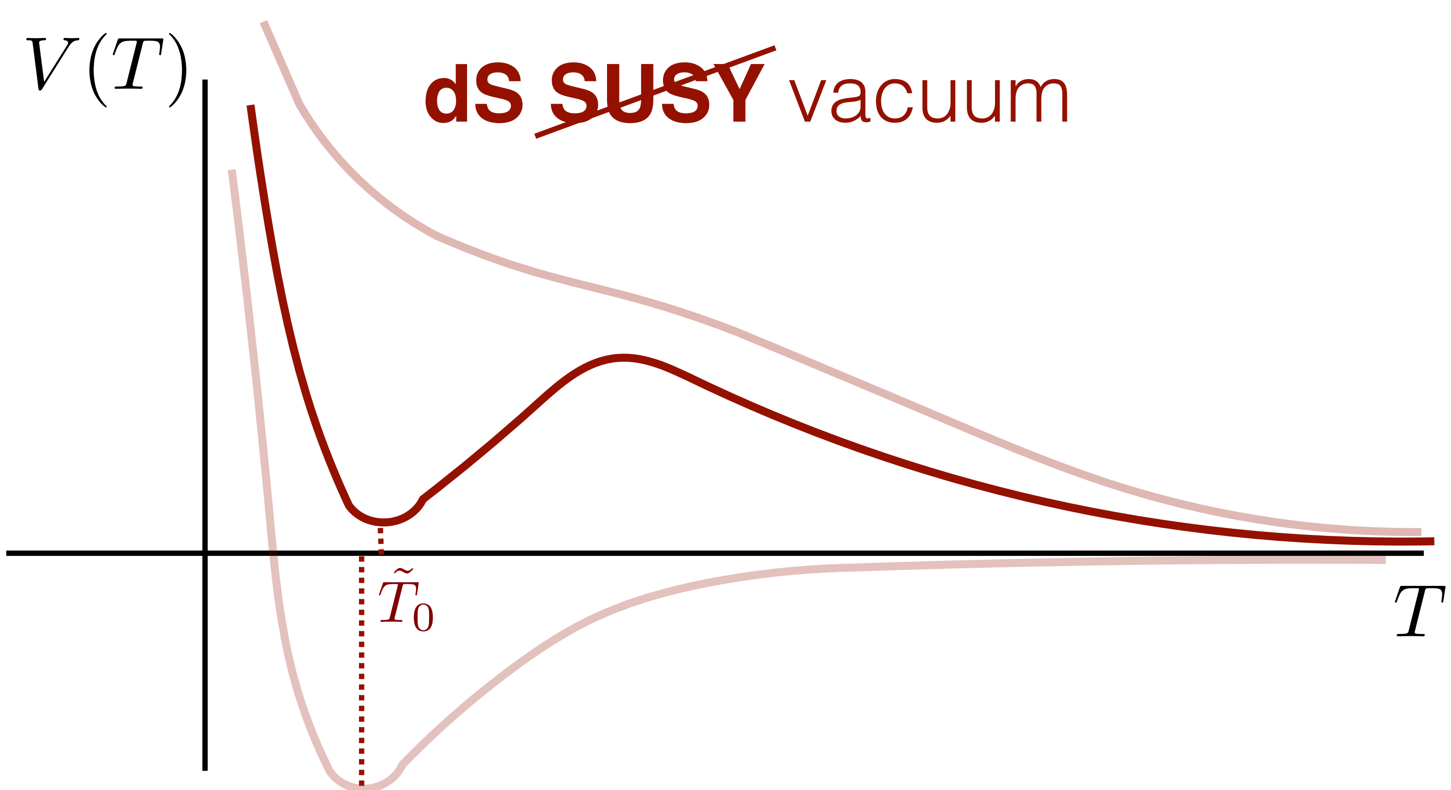
c.f. Liam's talk

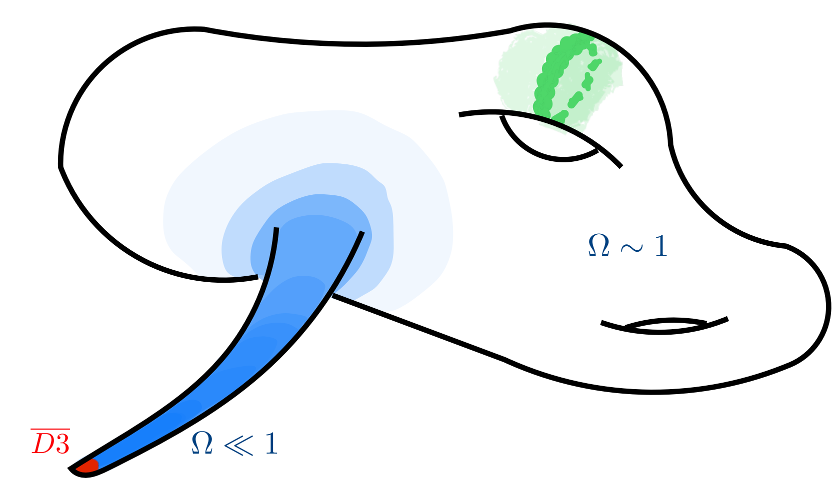
KKLT: Step 2

- **Step 2:** introduce a SUSY-breaking element, e.g. anti-D3 branes

$$V(T) \sim \left(-\frac{2}{T^2} W_0\, e^{-T} + \frac{1}{T} e^{-2T} \right) + \frac{\Omega^4 \mu_3}{T^2}$$

$$\begin{cases} K = -3 \log (T + \bar{T}) \\ W \to W_0 + e^{-T} \end{cases}$$





Dine-Seiberg problem

$$\Omega^4 \sim W_0 \sim e^{-\tilde{T}_0} \overset{!}{\ll} 1$$

c.f. Liam's talk

KKLT from a 10d perspective

10d no-go theorems

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

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

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

$$\mathcal{V}_6\, \mathcal{R}(\eta) = \int d^6y \sqrt{g}\ \Omega^8(y)\, \mathcal{R}(\eta) = -\int d^6y \sqrt{g}\ \Omega^{10}(y)\, \Delta$$

Useful for no-go theorems: most sources have Δ>0!

Maldacena, Nuñez ‘00

$\Delta \sim (T^m_m - T^\mu_\mu)$

10d no-go theorems

- **KKLT**: uplift from gaugino condensate and anti D3-branes

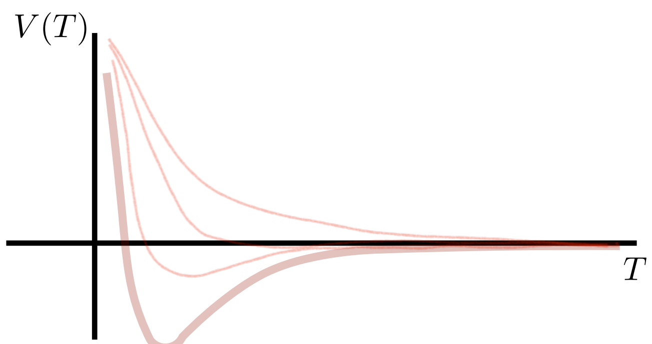
$$\mathscr{V}_6 \mathscr{R}(\eta) \approx - \int d^6y \sqrt{g}\ \Omega^{10}(y) \left(\Delta^{\langle \lambda\lambda \rangle} + \Delta^{\overline{D3}} \right)$$

$\Delta^{\overline{D3}}$: easily computed from the $\overline{\text{D3}}$-brane world-volume action

$\Delta^{\langle \lambda\lambda \rangle}$: inferred from the D7-brane action with $\lambda\lambda \to \langle \lambda\lambda \rangle \sim e^{-T}$

Claim: both $\Delta^{\langle \lambda\lambda \rangle}$ and $\Delta^{\overline{D3}}$ are strictly positive!? "Flattening"??

Problem: calculations of $\Delta^{\langle \lambda\lambda \rangle}$ were UV divergent and regularization dependent!!



Moritz, Retolaza, Westphal '17, '18
Moritz, Van Riet, '18
Gautason, Van Hemelryck, Van Riet '18

KKLT from 10d revisited

- We set to compute $\Delta^{\langle\lambda\lambda\rangle} \sim (T^m_{\ m} - T^\mu_{\ \mu})$ from the D7-action which (should) give rise to the 4d $\mathcal{N} = 1$ SYM

The action was known up to order $\lambda\lambda$ in gauginos

Camara, Ibanez, Uranga '04
c.f. Grana, Kovensky, Retolaza '20

$$S_{\lambda\lambda} \sim -\int |G_3|^2 - \overline{\lambda\lambda}\,\delta_{D7}\,(G_3 \cdot \Omega_3) + \text{c.c.} + \ldots$$

Problem: this action diverges if used to order $|\lambda\lambda|^2$

$$G_3 \sim \lambda\lambda\,\delta_{D7} + \ldots \qquad \Longrightarrow \qquad S_{\lambda\lambda} \sim \int |\lambda\lambda|^2 \delta_{D7}^2 \to \infty$$

For clarity: $g_s = \Omega(y) = 1$

$(*G_\pm = \pm i G_\pm)$

KKLT from 10d revisited

- Regularizing the D7 action turns out to be very challenging and has been completed only recently

$$\mathcal{L}_{\lambda\lambda} = -\frac{1}{2}|G_3|^2 + \sum_{i\in D7} \overline{\lambda}\overline{\lambda}_i \delta_i\, (G_3 \cdot \Omega_3) \;+\; \text{c.c.} \;-\; \frac{i}{2} G_3 \wedge \overline{G}_3$$

$$= -\left| G_+ - \sum_{i\in D7} \lambda\lambda_i\, \delta_i \overline{\Omega}_3 \right|^2 - |G_-^{(0)}|^2 + |G_+^{(0)}|^2 + \sum_{ij} \delta_i \delta_j\, \lambda\lambda_i \overline{\lambda\lambda}_j |\Omega|^2$$

  - Only the last term diverges (for i=j), but it also contains crucial finite contributions from (self) intersections of D7-stacks

$$\int \delta_i\, \delta_j\, |\Omega|^2 \to \int \delta_i \delta_j\, J \wedge J \wedge J = 3!\int \delta_i^{(2)} \wedge \delta_j^{(2)} \wedge J = 3!\mathcal{K}_{ij}$$

  - CY intersection numbers: $\mathcal{K}_{ij} = \int \omega_i \wedge \omega_j \wedge J\;, \qquad [\omega_i] \in H_+^{(1,1)}$

Hamada, Hebecker, Shiu, PS ’18, ’19, ’21

KKLT from 10d revisited

- With this insight, we can write a local finite action:

$$S = -\int_{10d} \left| G_+ - \sum_i \lambda\lambda_i \delta_i \overline{\Omega}_3 \right|^2 - \int_{10d} \left(|G_-^{(0)}|^2 - |G_+^{(0)}|^2 \right) + 3! \sum_{i,j} \lambda\lambda_i \overline{\lambda\lambda}_j \, \mathcal{K}_{ij}$$

Hamada, Hebecker, Shiu, PS, ’18, ’19, ’21
c.f. Kallosh ’19; Carta, Moritz, Westphal ’19;
Gautason, Van Hemelryck, Van Riet, Venken ’19;
Kachru, Kim, McAllister, Zimet ’19; Retolaza, Rogers, Tatar, Tonioni ’21

$\Delta \sim (T^m_{\ m} - T^\mu_{\ \mu})$

KKLT from 10d revisited

- With this insight, we can write a local finite action:

$$S = - \int_{10d} \left| G_+ - \sum_i \lambda \lambda_i \delta_i \overline{\Omega}_3 \right|^2 - \int_{10d} \left(|G_-^{(0)}|^2 - |G_+^{(0)}|^2 \right) + 3! \sum_{i,j} \lambda \lambda_i \overline{\lambda \lambda}_j \, \mathcal{K}_{ij}$$

1. Compute $\Delta^{\langle \lambda\lambda \rangle}$ and check that: $\mathscr{R}_\eta \sim \int \Delta = \mathscr{R}_{KKLT}$

TO DO

2. Check that S reduces to $S_{4d,\, sugra}$ upon CY compactification
3. Write S in a 10d covariant way: $\{\lambda, \Omega_3, J\} \to \Psi_8$

Hamada, Hebecker, Shiu, PS, ’18, ’19, ’21
c.f. Kallosh ’19; Carta, Moritz, Westphal ’19;
Gautason, Van Hemelryck, Van Riet, Venken ’19;
Kachru, Kim, McAllister, Zimet ’19; Retolaza, Rogers, Tatar, Tonioni ’21

$\Delta \sim (T^m_{\ m} - T^\mu_{\ \mu})$

KKLT from 10d revisited

- With this insight, we can write a local finite action:

$$S = -\int_{10d} \Big| G_+ - \sum_i \lambda\lambda_i \delta_i \overline{\Omega}_3 \Big|^2 - \int_{10d} \Big(|G_-^{(0)}|^2 - |G_+^{(0)}|^2 \Big) + 3! \sum_{i,j} \lambda\lambda_i \overline{\lambda\lambda}_j \, \mathcal{K}_{ij}$$

TO DO

1. Compute $\Delta^{\langle\lambda\lambda\rangle}$ and check that: $\mathscr{R}_\eta \sim \int \Delta = \mathscr{R}_{KKLT}$ ✓
2. Check that S reduces to $S_{4d,\,sugra}$ upon CY compactification ✓
3. Write S in a 10d covariant way: $\{\lambda, \Omega_3, J\} \to \Psi_8$ ✓

Hamada, Hebecker, Shiu, PS, ’18, ’19, ’21
c.f. Kallosh ’19; Carta, Moritz, Westphal ’19;
Gautason, Van Hemelryck, Van Riet, Venken ’19;
Kachru, Kim, McAllister, Zimet ’19; Retolaza, Rogers, Tatar, Tonioni ’21

Conclusions

Conclusions

- Lack of a D7-brane action to quartic gaugino order posed an obstacle to address some fundamental questions about string-dS

- We constructed such an action and dispelled some criticisms

  The EFT approach is valid **within the assumptions made**

  No-go claims fail because of a subtle interplay between $\Delta^{\langle\lambda\lambda\rangle}$ and $\Delta^{\overline{D3}}$.

- Our construction should be a useful tool to address other questions involving fermions on localized branes

Conclusions

- Lack of a D7-brane action to quartic gaugino order posed an obstacle to address some fundamental questions about string-dS

- We constructed such an action and dispelled some criticisms

  The EFT approach is valid **within the assumptions made**

  No-go claims fail because of a subtle interplay between $\Delta^{\langle\lambda\lambda\rangle}$ and $\Delta^{\overline{D3}}$.

- Our construction should be a useful tool to address other questions involving fermions on localized branes

Thanks!