Resolving spacetime singularities in flux compactifications & KKLT

based on: 2102.05281 with Federico Carta

(also: 1902.01412 with F. Carta & Alexander Westphal)

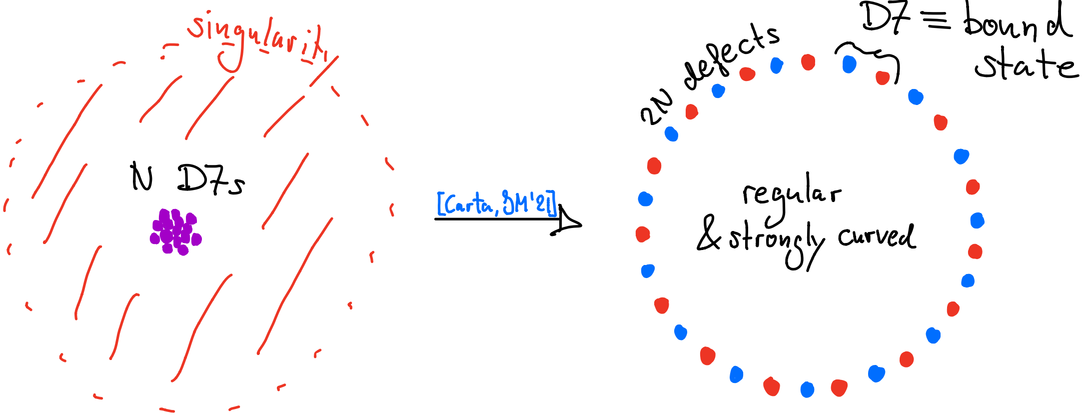
Jakob Moritz (Cornell)

preview:

issue: in KKLT loci hosting negative D3-charge surrounded by large singularity.

[Carta, JM, Westphal'19], [Gao, Hebecker, Junghans '20]

today: for special case of D7 on K3



Outline

I. Motivation: The singularity & why it matters

→ D. Junghans' talk

[Carta, JM, Westphal '19]
[Gao, Hebecker, Junghans '20]

II. Resolution of singularities

III. Comments on instanton expansion in KKLT:

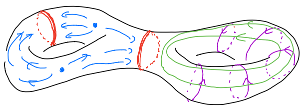
I Motivation

The setup:

- type IIB flux compactifications à la GKP

[Giddings, Kachru, Polchinski '01]

i.e. $\mathbb{R}^{1,3} \times_w CY_3$ + F_3 & H_3 fluxes



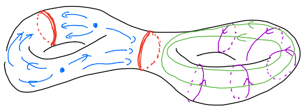
+ seven-branes (& D3 branes)

The setup:

- type IIB flux compactifications à la GKP [Giddings, Kachru, Polchinski '01]

i.e. $\mathbb{R}^{1,3} \times_w CY_3$ + F_3 & H_3 fluxes

+ seven-branes (& D3 branes)



$$ds^2 = \frac{1}{t} e^{2A(y)} \eta_{\mu\nu} dx^\mu dx^\nu + e^{-2A(y)} \underbrace{g^{CY}_{ij} dy^i dy^j}_{\text{unit volume Ricci-flat metric}}$$

warp factor

volume modulus: $t := \int d^6y \sqrt{g^{CY}} e^{-4A}$

The setup: (continued)

- conformal factor e^{-4A} sourced by D3-charge:

$$\boxed{-\nabla^2_{CY}\, e^{-4A} = \rho_{D3}}$$

[GKP '01], [Giddings, Maharana '05]

$\rightsquigarrow$ 10d e.o.m. collapse to electro-static problem in 6d

The setup: (continued)

- conformal factor e^{-4A} sourced by D3-charge:

$$\boxed{-\nabla^2_{CY}\, e^{-4A} = \rho_{D3}}$$

[GKP'01], [Giddings, Maharana'05]

$\rightsquigarrow$ 10d e.o.m. collapse to electro-static problem in 6d

$\rightsquigarrow$ solutions have modulus:

$$e^{-4A} \longrightarrow e^{-4A} + \delta t \quad \Longleftrightarrow \quad t \longrightarrow t + \delta t$$

The setup: (continued)

- conformal factor e^{-4A} sourced by D3-charge:

$$\boxed{-\nabla^2_{CY}\, e^{-4A} = \rho_{D3}}$$

[GKP '01], [Giddings, Maharana '05]

$\rightsquigarrow$ 10d e.o.m. collapse to electro-static problem in 6d

$\rightsquigarrow$ solutions have modulus:

$$e^{-4A} \longrightarrow e^{-4A} + \delta t \quad \Longleftrightarrow \quad t \longrightarrow t + \delta t$$

$\rightsquigarrow$ as $t \to \infty$: $\boxed{\mathrm{Vol}_{6d} \longrightarrow t^{3/2}}$

$$ds^2 \longrightarrow \frac{1}{t^{3/2}}\, \eta_{\mu\nu}\, dx^\mu dx^\nu + t^{\frac{1}{2}}\, g^{CY}_{ij}\, dy^i dy^j$$

(except near localized sources!)

Singularities near seven-branes:

- Wrapped seven-branes (on 4-cycles) carry negative D3-charge: (let's assume all of it)

$$Q^{7}_{D3} = -\frac{1}{24}\int_{\Sigma_4} c_2(\Sigma_4) \propto -\int_{\Sigma_4} R \wedge R < 0$$

[Green, Harvey, Moore '96]
[Cheung, Yin '97]

Singularities near seven-branes:

- Wrapped seven-branes (on 4-cycles) carry negative D3-charge: (let's assume all of it)

$$Q^{7}_{D3} = -\frac{1}{24}\int_{\Sigma_4} c_2(\Sigma_4) \propto -\int_{\Sigma_4} R\wedge R < 0$$

[Green, Harvey, Moore '96]
[Cheung, Yin '97]

$\Rightarrow$ solution close to Σ_4:

$$\boxed{e^{-4A} \approx \frac{|\rho^{\Sigma_4}_{D3}|}{2\pi}\log(r/r^*) < 0 \quad \text{at small radii } r < r^*}$$

$[ds^2 = \frac{1}{t}e^{2A}dx^2 + e^{-2A}dy^2]$

Singularities near seven-branes:

- Wrapped seven-branes (on 4-cycles) carry negative D3-charge: (let's assume all of it)

$$Q^7_{D3} = -\frac{1}{24}\int_{\Sigma_4} c_2(\Sigma_4) \propto -\int_{\Sigma_4} R \wedge R < 0$$ [Green, Harvey, Moore '96] [Cheung, Yin '97]

$\Rightarrow$ solution close to Σ_4: $$\boxed{e^{-4A} \approx \frac{|\rho^{\Sigma_4}_{D3}|}{2\pi} \log(r/r^*) < 0 \quad \text{at small radii } r < r^*}$$

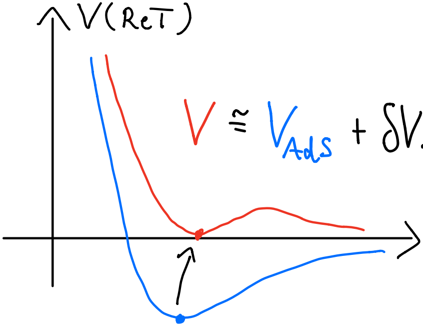
$\left[ds^2 = \frac{1}{t} e^{2A} dx^2 + e^{-2A} dy^2\right]$

at large volume: $r^* \longrightarrow \# e^{-\frac{2\pi}{|Q^7_{D3}|}\mathrm{Vol}(\Sigma_4)}$!
$(t \longrightarrow \infty)$

Intermediate volumes in KKLT

- KKLT uplift to dS from $\overline{D3}$ in KS-throat:

[Kachru, Kallosh, Linde, Trivedi '03] [Klebanov, Strassler '00], [Kachru, Pearson, Verlinde '01], ...



$$V \simeq V_{AdS} + \delta V_{\overline{D3}}$$

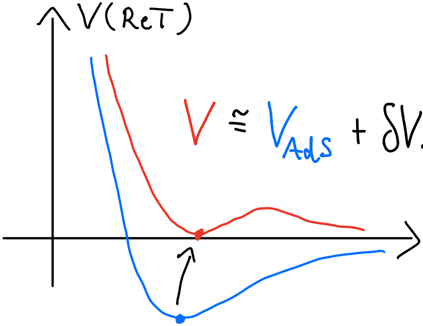
$$\mathrm{Re}\,T \sim t \text{ as } t \to \infty$$

$$\boxed{\begin{aligned} V_{AdS} &\sim e^{-\#\mathrm{Re}(T_0)} \\ \delta V_{\overline{D3}} &\sim e^{-\#\frac{Q_{D3}^{\text{throat}}}{R_{IR}^4}} \end{aligned}}$$

Intermediate volumes in KKLT

- KKLT uplift to $\underline{dS}$ from $\overline{D3}$ in KS-throat:

[Kachru, Kallosh, Linde, Trivedi '03] [Klebanov, Strassler '00], [Kachru, Pearson, Verlinde '01], ...



$V \simeq V_{AdS} + \delta V_{\overline{D3}}$

$\mathrm{Re}T \sim t$ as $t \to \infty$

$$\boxed{\begin{aligned} V_{AdS} &\sim e^{-\#\mathrm{Re}(T_0)} \\ \delta V_{\overline{D3}} &\sim e^{-\#\frac{Q_{D3}^{\text{throat}}}{R_{IR}^4}} \end{aligned}}$$

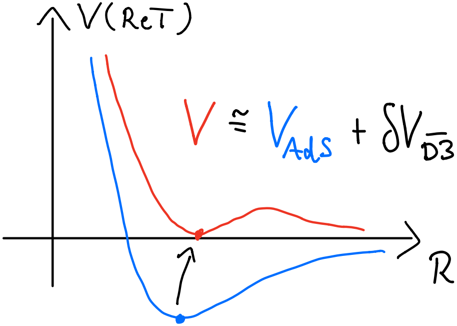
$\rightarrow$ For small enough uplift: $\dfrac{Q_{D3}^{\text{throat}}}{R_{IR}^4} \gtrsim \mathrm{Re}(T_0) \sim \mathrm{Vol}(\Sigma_4)$

$\rightarrow$ For SUGRA control: $R_{IR}^4 \gtrsim 1$

Intermediate volumes in KKLT

- KKLT uplift to dS from $\overline{D3}$ in KS-throat:

[Kachru, Kallosh, Linde, Trivedi '03] [Klebanov, Strassler '00], [Kachru, Pearson, Verlinde '01], ...



$\mathrm{Re}\,T \sim t$ as $t \to \infty$

$$V_{AdS} \sim e^{-\#\,\mathrm{Re}(T_0)}$$

$$\delta V_{\overline{D3}} \sim e^{-\#\frac{Q_{D3}^{\text{throat}}}{R_{IR}^4}}$$

$\to$ For small enough uplift: $\dfrac{Q_{D3}^{\text{throat}}}{R_{IR}^4} \gtrsim \mathrm{Re}(T_0) \sim \mathrm{Vol}(\Sigma_4)$

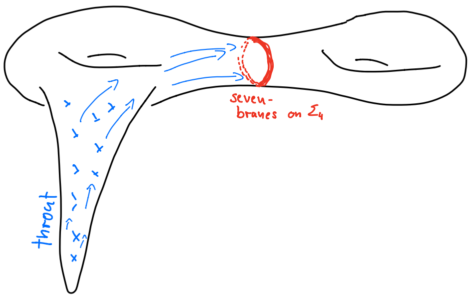
$\to$ For SUGRA control: $R_{IR}^4 \gtrsim 1$

$\Rightarrow$ $\boxed{\mathrm{Vol}(\Sigma_4) \lesssim Q_{D3}^{\text{throat}} \text{ at KKLT min.}}$

Intermediate volumes in KKLT (continued)

- But Q_{D3}^{throat} cancelled by negative charge on seven-brane stack: $Q_{D3}^{\text{throat}} \leq |Q_{D3}^{7}|$

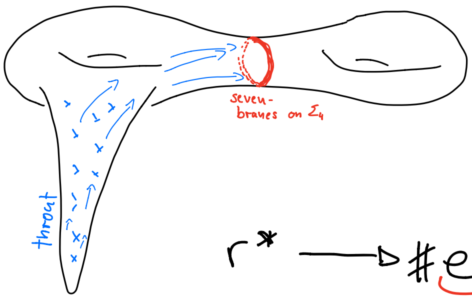
$$\Rightarrow \mathrm{Vol}(\Sigma_4) \lesssim |Q_{D3}^{7}|$$



Intermediate volumes in KKLT (continued)

- But Q_{D3}^{throat} cancelled by negative charge on seven-brane stack: $Q_{D3}^{\text{throat}} \leq |Q_{D3}^{7}|$

$$\Rightarrow \mathrm{Vol}(\Sigma_4) \lesssim |Q_{D3}^{7}|$$



$\Rightarrow$ lose exp. control over seven-brane singularity:

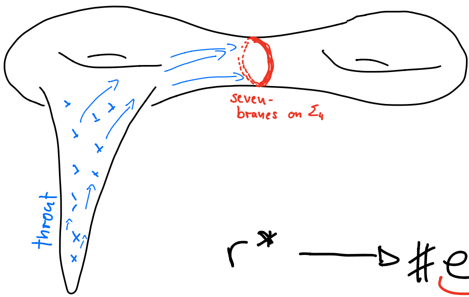
$$r^* \longrightarrow \# \underbrace{e^{-\frac{2\pi}{|Q_{D3}^{7}|}\mathrm{Vol}(\Sigma_4)}}_{\mathcal{O}(1)}$$

[Carta, JM, Westphal '19]
[Gao, Hebecker, Junghans '20]

Intermediate volumes in KKLT (continued)

- But Q_{D3}^{throat} cancelled by negative charge on seven-brane stack: $Q_{D3}^{\text{throat}} \leq |Q_{D3}^{7}|$

$$\Rightarrow \text{Vol}(\Sigma_4) \lesssim |Q_{D3}^{7}|$$



$\Rightarrow$ lose exp. control over seven-brane singularity:

$$r^* \longrightarrow \# \, e^{\underbrace{-\frac{2\pi}{|Q_{D3}^{7}|}\text{Vol}(\Sigma_4)}_{\mathcal{O}(1)}}$$

[Carta, JM, Westphal '19]
[Gao, Hebecker, Junghans '20]

$$\Rightarrow \boxed{\text{in KKLT, scale of D7-singularity is KK-scale}}$$

II Resolution of singularities

Analogy with F-theory:

- e^{-4A} near wrapped D7s:

$$\boxed{e^{-4A} \approx \frac{|\rho_{D3}^{\Sigma_4}|}{2\pi} \log(r/r^*) < 0 \quad \text{at} \quad r < r^*}$$

- $1/g_s$ near O7-plane:

$$\boxed{\frac{1}{g_s} \approx \frac{4}{2\pi} \log(r/r^*) < 0 \quad \text{at} \quad r < r^*}$$

Analogy with F-theory:

- e^{-4A} near wrapped D7s:

$$\boxed{e^{-4A} \approx \frac{|\rho_{D3}^{\Sigma_4}|}{2\pi} \log(r/r^*) < 0 \quad \text{at} \quad r < r^*}$$

?

- $1/g_s$ near O7-plane:

$$\boxed{\frac{1}{g_s} \approx \frac{4}{2\pi} \log(r/r^*) < 0 \quad \text{at} \quad r < r^*}$$

- F-theory:

O7 = bound state of two (p,q) 7-branes

[Sen '96], [Banks, Douglas, Seiberg '96]

Resolution of O7 via gauge instantons:

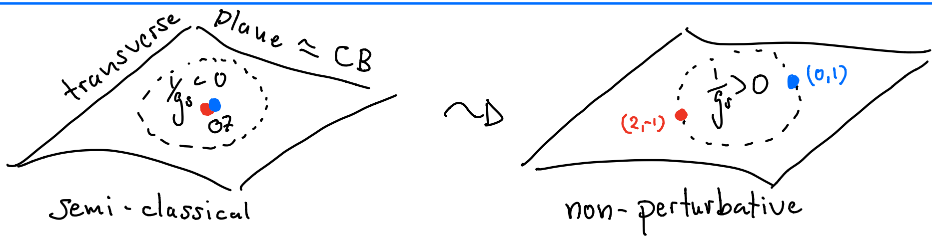
- $\frac{1}{g_s} \hat{=} \frac{4\pi}{g_{YM}^2}$ on 4d D3 world volume
- D3 probing O7: $\to$ Cartan $U(1) \subseteq Sp(2) \simeq SU(2)$ YM

Resolution of O7 via gauge instantons:

- $\frac{1}{g_s} \approx \frac{4\pi}{g_{YM}^2}$ on 4d D3 world volume
- D3 probing O7: $\to$ Cartan $U(1) \subseteq Sp(2) \simeq SU(2)$ YM

$\to$ $\boxed{\text{Coulomb branch of YM} \simeq \text{D3 position in } \mathbb{C}\text{-plane transverse to O7}}$

Seiberg-Witten solution:

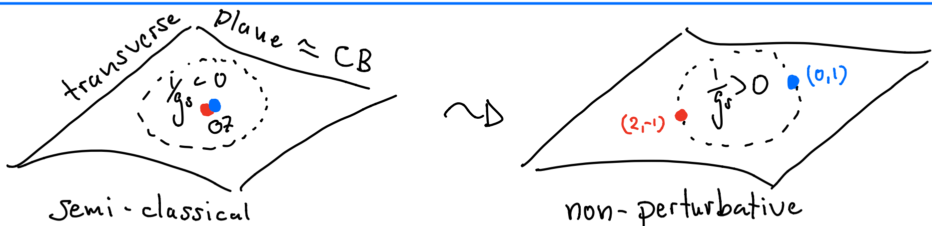


Resolution of O7 via gauge instantons:

- $\frac{1}{g_s} \simeq \frac{4\pi}{g_{YM}^2}$ on 4d D3 world volume
- D3 probing O7: $\rightarrow$ Cartan $U(1) \subseteq Sp(2) \simeq SU(2)$ YM

$\rightarrow$ $\boxed{\text{Coulomb branch of YM} \simeq \text{D3 position in } \mathbb{C}\text{-plane transverse to O7}}$

Seiberg-Witten solution:



$$\boxed{\text{splitting } O7 \rightarrow \underbrace{(2,-1) + (0,1)}_{\text{7-branes}} \Leftrightarrow \text{resolution of semi-classical singularity via Seiberg-Witten sol.}}$$

[Banks, Douglas, Seiberg '96]

The analogy:

	O7 + D3 in 10d $\longrightarrow$	?
gauge theory:	$\mathcal{N}=2$ $SU(2)$	
coupling:	$\tau := C_0 + i\frac{1}{g_s}$	
singularity:	$1/g_s < 0$ near O7	
	O7 = duality defect in 10d	
duality group:	$Sl(2,\mathbb{Z})_\tau$	
BPS dyons:	stretched (p,q)-strings	

The analogy:

	O7 + D3 in 10d $\longrightarrow$	N D7s on K3
gauge theory:	$\mathcal{N}=2$ $SU(2)$	$\mathcal{N}=2$ $SU(N)$
coupling:	$\tau := C_0 + i\frac{1}{g_s}$	
singularity:	$1/g_s < 0$ near O7	
	O7 = duality defect in 10d	
duality group:	$Sl(2,\mathbb{Z})_\tau$	
BPS dyons:	stretched (p,q)-strings	

The analogy:

	O7 + D3 in 10d $\longrightarrow$	N D7s on K3
gauge theory:	$\mathcal{N}=2$ $SU(2)$	$\mathcal{N}=2$ $SU(N)$
coupling:	$\tau := C_0 + i\frac{1}{g_s}$	$\tau' := \int_{K3} C_4 + i \int_{K3} d^4y \sqrt{g}\, e^{-4A} - \tau$
singularity:	$1/g_s < 0$ near O7	$e^{-4A} < 0$ near D7
	O7 = duality defect in 10d	
duality group:	$Sl(2,\mathbb{Z})_\tau$	
BPS dyons:	stretched (p,q)-strings	

The analogy:

	O7 + D3 in 10d $\longrightarrow$	N D7s on K3
gauge theory:	$\mathcal{N}=2$ $SU(2)$	$\mathcal{N}=2$ $SU(N)$
coupling:	$\tau := C_0 + i\frac{1}{g_s}$	$\tau' := \int_{K3} C_4 + i\int_{K3} d^4y\sqrt{g}\,e^{-4A} - \tau$
singularity:	$1/g_s < 0$ near O7	$e^{-4A} < 0$ near D7
	O7 = duality defect in 10d	D7 on K3 = duality defect in 6d (2,0)
duality group:	$Sl(2,\mathbb{Z})_\tau$	$O(5,21;\mathbb{Z}) \supseteq Sl(2,\mathbb{Z})_{\tau'}$
BPS dyons:	stretched (p,q)-strings	stretched (p',q')-strings

Resolution of wrapped D7s:

- Singularities in field theory $\longleftrightarrow$ mutually local defects coincide
- Singularities in classical YM - theory

  $\longleftrightarrow$ coinciding roots of char. pol.:

$$W(x) = \det(x\mathbb{1} - \underset{\text{adjoint scalar}}{\Phi}) = \prod_{i=1}^{N}(x - e_i)$$

Resolution of wrapped D7s:

- Singularities in field theory $\longleftrightarrow$ mutually local defects coincide
- Singularities in classical YM-theory

$\longleftrightarrow$ coinciding roots of char. pol.:

$$W(x) = \det(x\mathbb{1} - \underbrace{\Phi}_{\text{adjoint scalar}}) = \prod_{i=1}^{N}(x - e_i)$$

W-boson mass: $m_{ij} \propto |e_i - e_j|$

$\Rightarrow$ $\boxed{e_i = \text{pos. of } i\text{-th D7 in } \mathbb{C}}$

W-bosons = stretched F-string

Resolution of wrapped D7s: (continued)

- Singularities in quantum YM-theory [Seiberg, Witten '94], [Argyres, Faraggi '94], [Klemm, Lerche, Yankielowicz, Theisen '95], ...

$\longleftrightarrow$ coinciding roots of $W(x)^2 - \Lambda^{2N} \equiv W_+(x) W_-(x)$

with $\boxed{W_\pm(x) := W(x) \mp \Lambda^N \equiv \prod_{i=1}^{N} (x - e_i^\pm)}$

i.e. singularities when $e_i^+ = e_j^+$ or $e_i^- = e_j^-$, $i \neq j$

Resolution of wrapped D7s: (continued)

- Singularities in quantum YM-theory [Seiberg, Witten '94], [Argyres, Faraggi '94], [Klemm, Lerche, Yankielowicz, Theisen '95], ...

$\longleftrightarrow$ coinciding roots of $W(x)^2 - \Lambda^{2N} \equiv W_+(x) W_-(x)$

with $\boxed{W_\pm(x) := W(x) \mp \Lambda^N \equiv \prod_{i=1}^{N} (x - e_i^\pm)}$

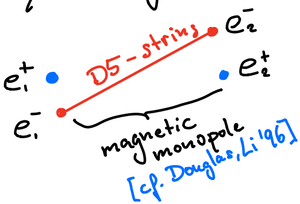
i.e. singularities when $e_i^+ = e_j^+$ or $e_i^- = e_j^-$, $i \neq j$

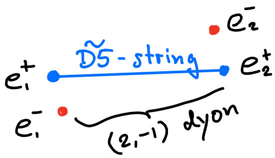
- Our proposal:

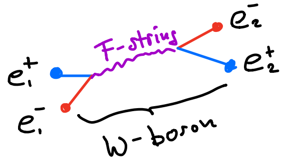
$$\boxed{\text{D7 at } e_i \equiv \text{bound state of mutually non-local } (p',q') \text{ branes at } \{e_i^+, e_i^-\}}$$

Resolution of wrapped D7s: (continued)

- dyons for $SU(2)$:

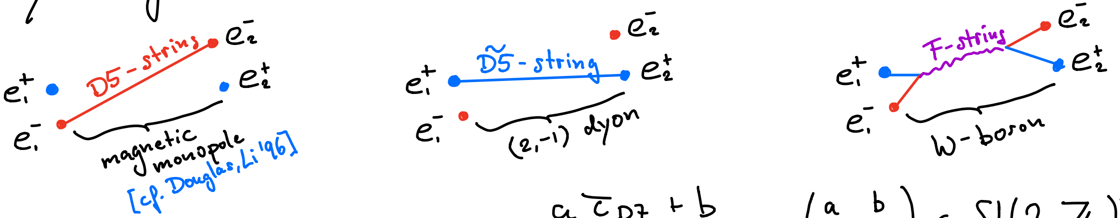






Resolution of wrapped D7s: (continued)

- dyons for $SU(2)$:



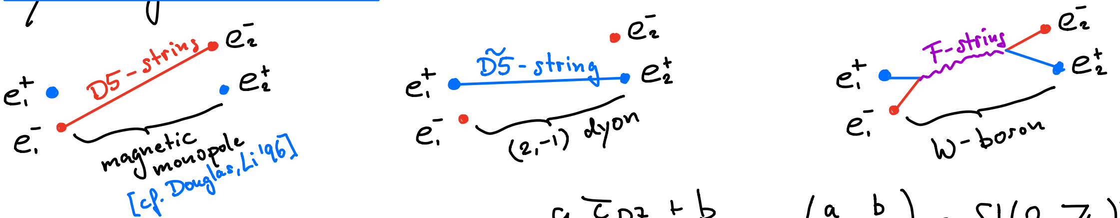
D7-monodromy: $\tau_{D7} \longrightarrow \dfrac{a\,\tau_{D7}+b}{c\,\tau_{D7}+d}$, $\begin{pmatrix} a & b \\ c & d \end{pmatrix} \in Sl(2,\mathbb{Z})'$

$$M_{D7} = \begin{pmatrix} -1 & 2 \\ 0 & -1 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -2 & 1 \end{pmatrix} \cdot \begin{pmatrix} -1 & 2 \\ -2 & 3 \end{pmatrix}$$

$\rightsquigarrow$ reproduces field theory monodromies

Resolution of wrapped D7s: (continued)

- dyons for $SU(2)$:

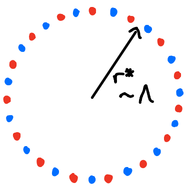


D7-monodromy: $\quad \tau_{D7} \longrightarrow \dfrac{a\,\tau_{D7}+b}{c\,\tau_{D7}+d}\,, \quad \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in Sl(2,\mathbb{Z})'$

$$M_{D7} = \begin{pmatrix} -1 & 2 \\ 0 & -1 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -2 & 1 \end{pmatrix} \cdot \begin{pmatrix} -1 & 2 \\ -2 & 3 \end{pmatrix} \quad \rightsquigarrow \text{reproduces field theory monodromies}$$

- origin of CB:

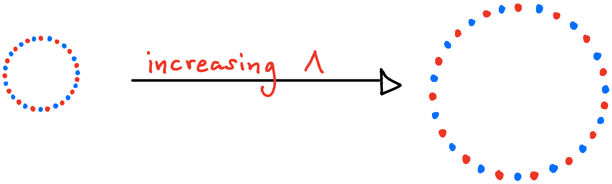
bulk interpretation of $U(1)_R \to \mathbb{Z}_{2N}$ by instantons $\longrightarrow$



"radial running of e^{-4A} halted by non-perturbative splitting of D7-branes"

Comments:

- as K3-volume modulus driven to strong coupling

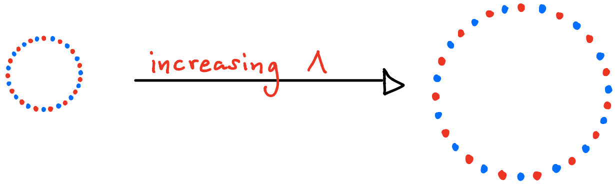


non-perturbative defects spread out in transverse plane.

$\Rightarrow$ semi-classical vanishing locus $e^{-4A} = 0$
replaced by effective co-dim. one membrane

Comments:

- as K3-volume modulus driven to strong coupling



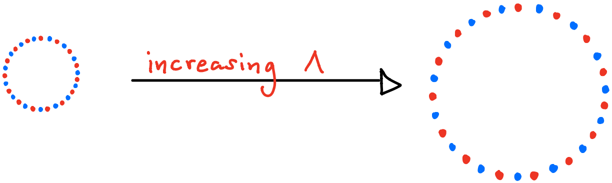
non-perturbative defects spread out in transverse plane.

$\Rightarrow$ semi-classical vanishing locus $e^{-4A} = 0$ replaced by effective co-dim. one membrane

- We show: "interior region" has $\mathcal{O}(1)$ local K3 volume.

Comments:

- as K3-volume modulus driven to strong coupling



$\boxed{\text{non-perturbative defects spread out in transverse plane.}}$

$\Rightarrow$ semi-classical vanishing locus $e^{-4A} = 0$
replaced by effective co-dim. one membrane

- we show: "interior region" has $\mathcal{O}(1)$ local K3 volume.

- aside: defects drawn in same color are mutually local
  $\rightarrow$ can be stacked on top of each other

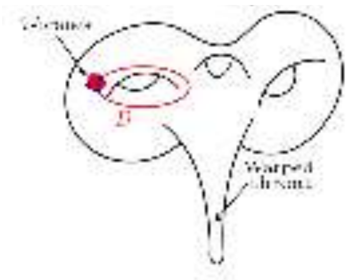
comparison with field theory $\Longrightarrow$ n mutually local defects host (A_1, A_{n-1}) Argyres-Douglas SCFTs [Argyres, Douglas '95]

III Instanton expansion in KKLT

KKLT dS vacua with strongly curved bulk:

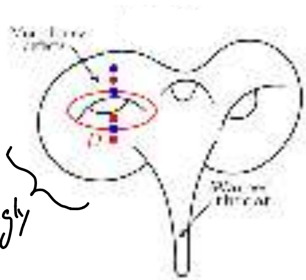
- have learnt: Near KKLT minimum, spreading of non-perturbative defects is macroscopic

⇝ $\boxed{\text{strongly curved 'inside region' occupies } \mathcal{O}(1)\text{-fraction of CY}}$



⟹

strongly curved



D = divisor hosting leading ED3 instanton

Q: Can this threaten the KKLT vacuum?

KKLT dS vacua with strongly curved bulk:

- size of strongly curved region depends (exponentially!) on Kähler moduli

  $\rightsquigarrow$ affects 4d EFT via non-perturbative corrections $\mathcal{O}\left(e^{-\frac{2\pi}{|Q|}T}\right)$
  (+ perhaps perturbative)

KKLT dS vacua with strongly curved bulk:

- size of strongly curved region depends (exponentially!) on Kähler moduli

  $\rightsquigarrow$ affects 4d EFT via non-perturbative corrections $\mathcal{O}(e^{-\frac{2\pi}{|Q|}T})$ (+ perhaps perturbative)

- superpotential: A $W(T) = W_0 + e^{-\frac{2\pi}{c}T} + \ldots$ with $c \sim |Q|$?

  yes, if c = dual Coxeter # of confining sector

  $\Rightarrow e^{-\frac{2\pi}{|Q|}T} \sim W_0 \ll 1$. $\Rightarrow$ no problem.

KKLT dS vacua with strongly curved bulk:

- size of strongly curved region depends (exponentially!) on Kähler moduli

  $\rightsquigarrow$ affects 4d EFT via <u>non-perturbative corrections</u> $\mathcal{O}(e^{-\frac{2\pi}{|Q|}T})$
  (+ <u>perhaps perturbative</u>)

- <u>superpotential</u>: (A) $W(T) = W_0 + e^{-\frac{2\pi}{c}T} + \dots$ with $c \sim |Q|$?

  yes, if <u>c = dual Coxeter #</u> of confining sector

  $\Rightarrow e^{-\frac{2\pi}{|Q|}T} \sim W_0 \ll 1$. $\Rightarrow$ <u>no problem</u>.

(B) $W(T) = W_0 + e^{-\frac{2\pi}{c}T} + \dots$ with $c \ll |Q|$

$\Rightarrow$ <u>no dangerous corr. to superpotential</u>.

KKLT dS vacua with strongly curved bulk:

[thanks to D. Junghans for discussion]

- Kähler potential? We don't know...

  But KKLT AdS vacua are highly robust against Kähler potential modifications:

  CS + τ: $0 = D_i W = \partial_i W + (\partial_i K) W_0 \approx \partial_i W$

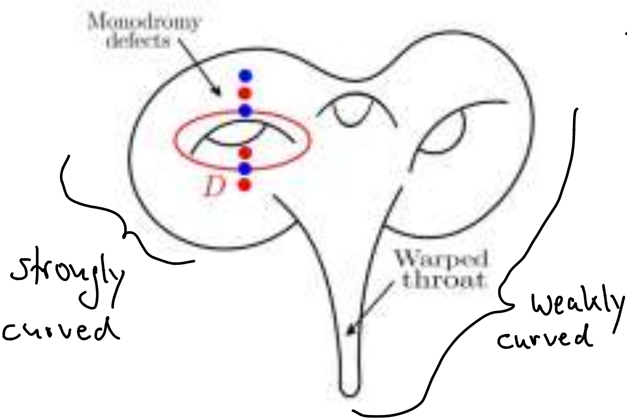
  Kähler mod.: $0 = D_T W \iff e^{-2\pi \frac{T}{c}} = \frac{\partial_T K}{\partial_T K - \frac{2\pi}{c}} W_0 \ll 1$

  unless corr. to K are fine-tuned:

  $$\partial_T K \Big|_{T = T_0 = \mathcal{O}(1)} - \frac{2\pi}{c} \sim |W_0| \ll 1$$

KKLT dS vacua with strongly curved bulk:

- <u>the uplift:</u> Unless divisor D 'hangs' all the way to bottom of throat, throat remains in SUGRA regime:



⇒ $\boxed{\text{expect no significant modifications to uplift potential}}$

Conclusions:

- reviewed issue of large singular region in KKLT
  [Carta, JM, Westphal '19], [Gao, Hebecker, Junghans '20]

Conclusions:

- reviewed issue of large singular region in KKLT
  [Carta, JM, Westphal '19], [Gao, Hebecker, Junghans '20]
- singularity resolved by splitting

$$\boxed{\text{D7 on K3} \longrightarrow \text{pair of mutually non-local defects.}}$$

$\Rightarrow$ matches: singularity structure ✓
monodromies of field theory ✓
central charges ✓

Conclusions:

- reviewed issue of large singular region in KKLT
  [Carta, JM, Westphal '19], [Gao, Hebecker, Junghans '20]
- singularity resolved by splitting

  $\boxed{\text{D7 on K3} \longrightarrow \text{pair of mutually non-local defects,}}$

  $\Rightarrow$ matches: singularity structure ✓
  monodromies of field theory ✓
  central charges ✓
- explained why we expect KKLT dS vacua to survive even in the seemingly dangerous regime.

Conclusions:

- reviewed issue of large singular region in KKLT
  [Carta, JM, Westphal '19], [Gao, Hebecker, Junghans '20]
- singularity resolved by splitting

  $\boxed{\text{D7 on K3} \longrightarrow \text{pair of mutually non-local defects.}}$

  ⇒ matches: singularity structure ✓
  monodromies of field theory ✓
  central charges ✓
- explained why we expect KKLT dS vacua to survive even in the seemingly dangerous regime.

Thanks!