(More on) Running Decompactifications, Sliding Towers, and the Distance Conjecture

based on 2306.16440 [hep-th],
with Muldrow Etheredge, Ben Heidenreich, Jacob McNamara, Tom Rudelius and Irene Valenzuela

Instituto de Física Teórica UAM-CSIC

Ignacio Ruiz, String Phenomenology 2023,
July 6, Institute for Basic Science, Daejeon

Universidad Autónoma de Madrid

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[Recall Irene Valenzuela talk!]

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1. (Quick) Review of the Distance Conjecture and Convex Hulls

Swampland Distance Conjecture [Ooguri, Vafa,'07]

Given $(\mathcal{M}, \mathsf{G})$ *the moduli space of a QG theory in* $d \geq 4$, *and,* $p_0 \in \mathcal{M}$ *as we move asymptotically far away in* $\mathcal{M}$, *there exists an infinite tower of light particles scaling as*

$$m(p) \sim m(p_0) \exp\{-\alpha d(p_0, p)\}$$

with $d(p_0, p)$ *(shortest) geodesic distance and* $\alpha > 0$ *an* $\mathcal{O}(1)$ *number.*

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We have different refinements on it:

Emergent String Conjecture: *Every of such infinite-distance limit in M is either a* ***emergent string limit*** *or a* ***decompactification limit****.* [Lee, Lerche, Weigand '19]

Sharpened Distance Conjecture: *The Distance Conjecture requires* [Etheredge, Heidenreich, Kaya, Qiu, Rudelius '22]

$$\alpha \geq \frac{1}{\sqrt{d-2}}$$

Scalar Weak Gravity Conjecture [Palti,'17]

In a QG theory with massless scalar fields, at every point in $\mathcal{M}$ *there exists a state with sufficiently large scalar charge-to-mass ratio*

$$\zeta_i \equiv -\partial_{\phi^i} \log m$$

with $\|\vec{\zeta}\| \geq \alpha_{\min}$ *and* $\alpha_{\min}$ *a* $\mathcal{O}(1)$ *constant.*

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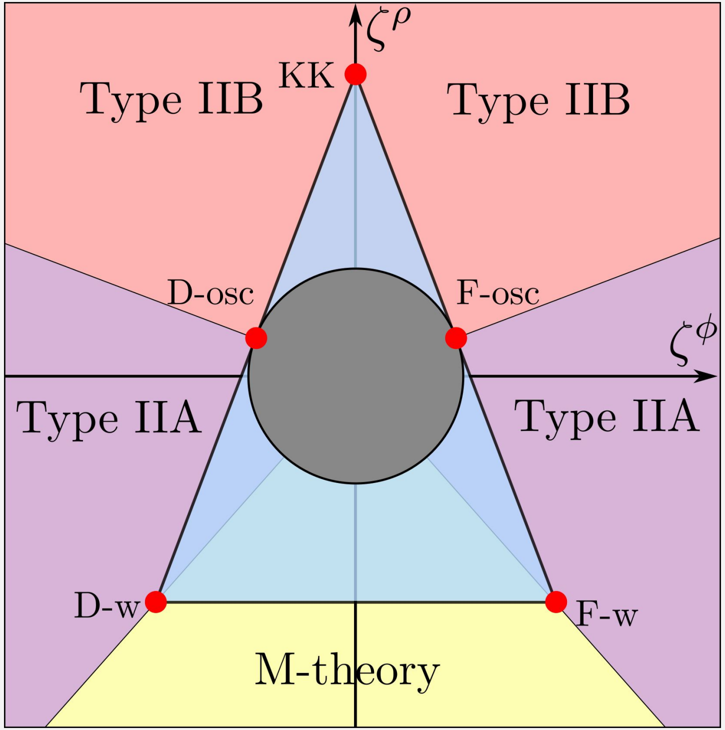
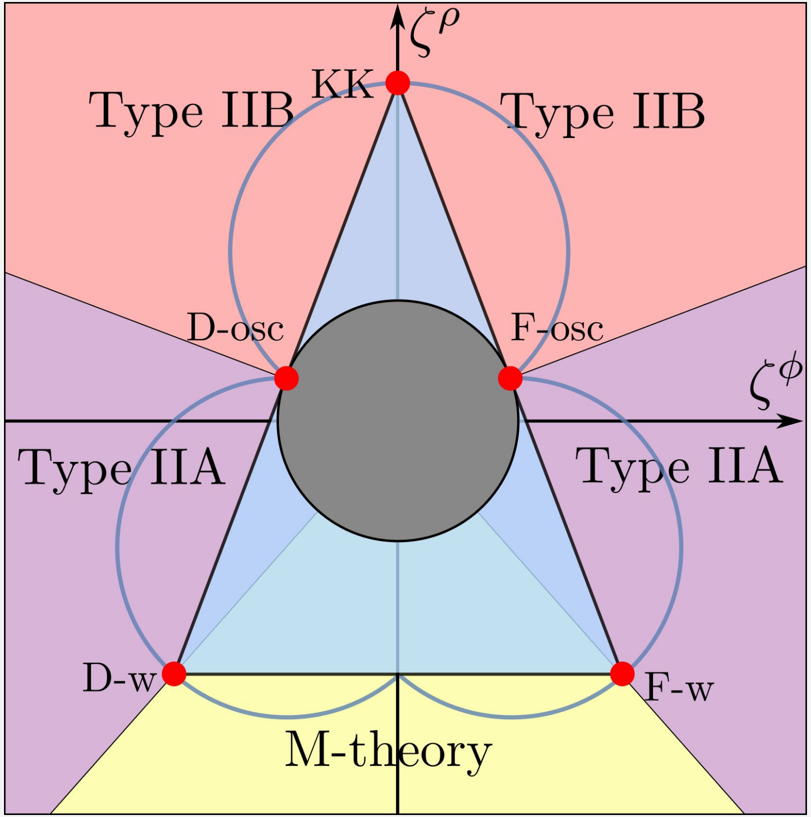
We can further constrain this:

Convex Hull SWGC: *In the SWGC, the convex hull generated by the* $\{\vec{\zeta}_I\}_I$ *vectors of all massive states must contain a ball of radius* $\alpha_{\min}$ *centered at the origin.* *[Calderón-Infante, Uranga, Valenzuela '21]*

CHSWGC & SDC: **IIB String Theory at S^1**



CHSWGC & SDC: IIB String Theory at S^1



We can obtain the decay rate along some direction $\hat{\tau}$ as

$$\alpha = \vec{\zeta} \cdot \hat{\tau}$$

[Recall Ben Heidenreich talk!]

2. A trickier case:
Heterotic String Theory in 9d

The moduli space of 9d Heterotic String Theory

After compactiftying heterotic string theory on S^1we obtain a 18-dimensional moduli space:

$$\mathcal{M} = \hat{\mathcal{M}} \times \mathbb{R}, \quad \hat{\mathcal{M}} = SO(17,1;\mathbb{Z})\backslash SO(17,1)/SO(17),$$

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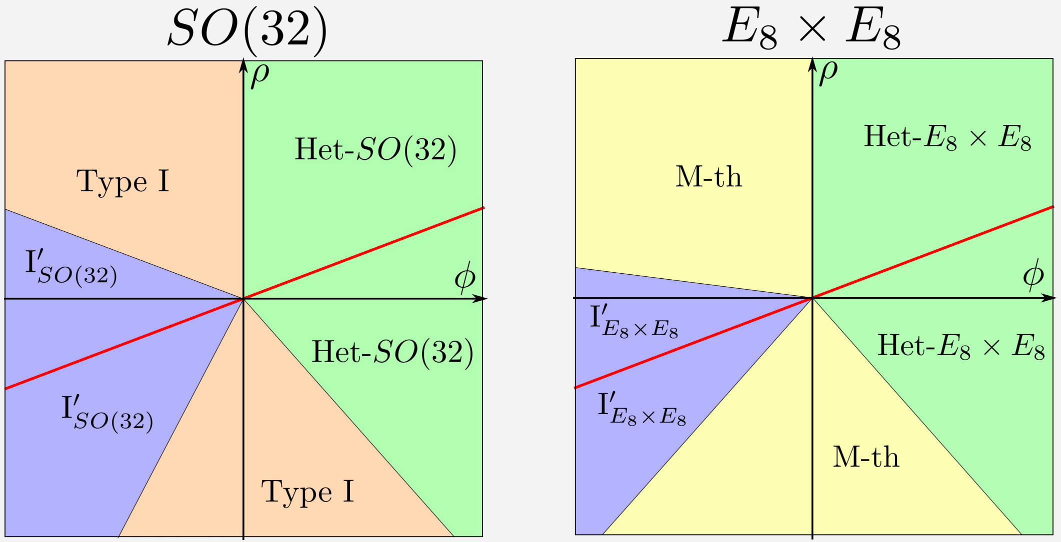
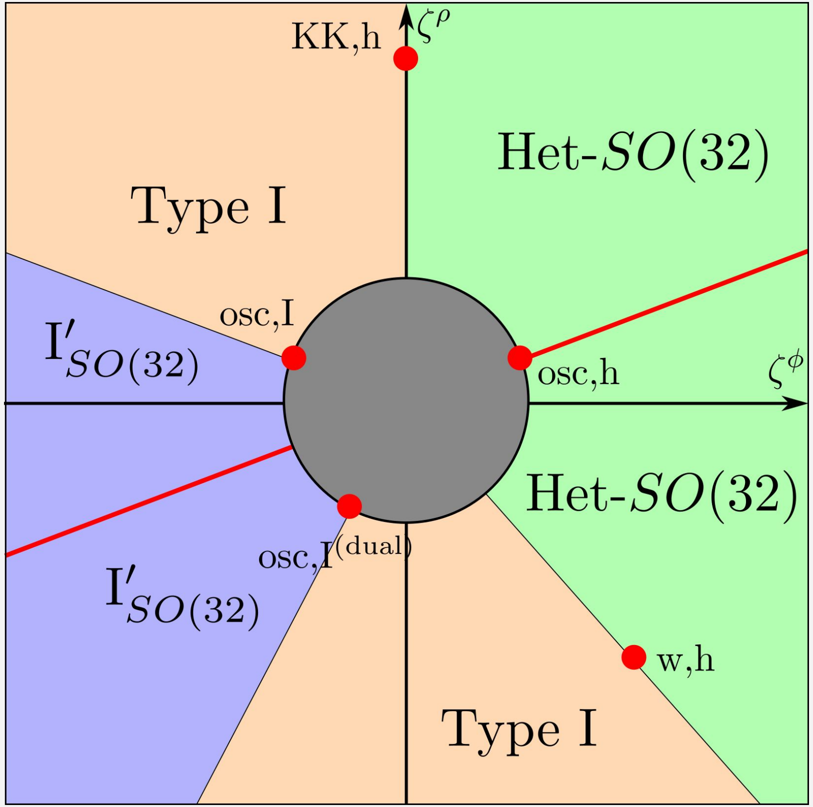
We will be interested in the $SO(32)$ and $E_8 \times E_8$slides of moduli space:



[Aharony, Komargodski, Patir '07]

A Puzzle in the $SO(32)$ slice



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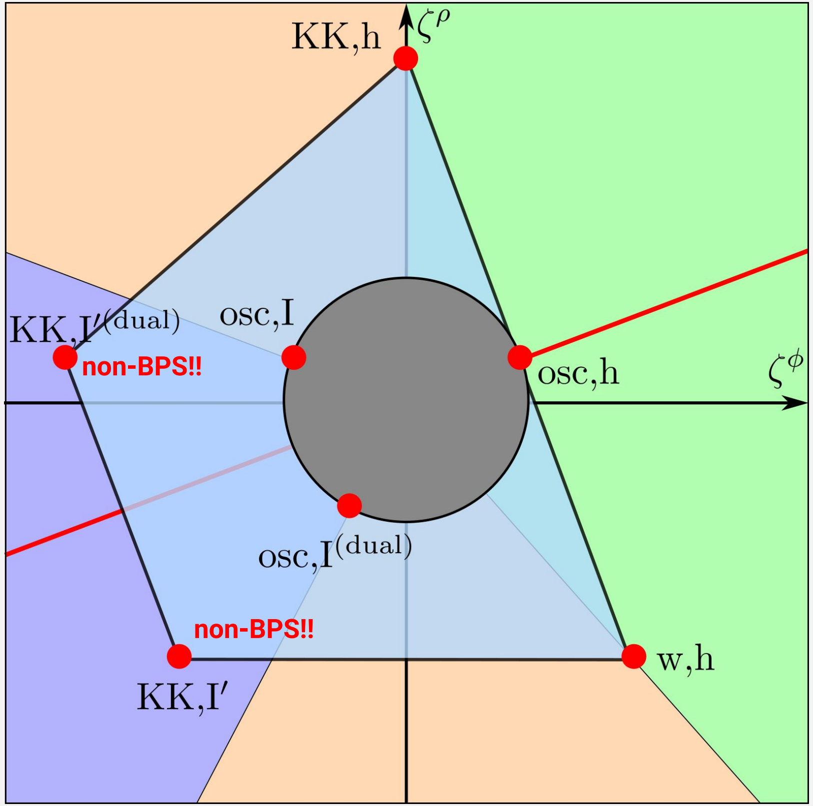

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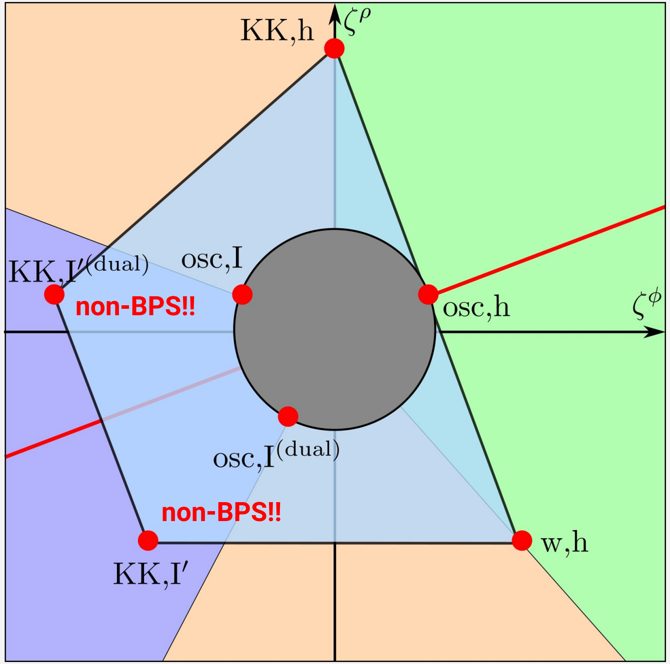

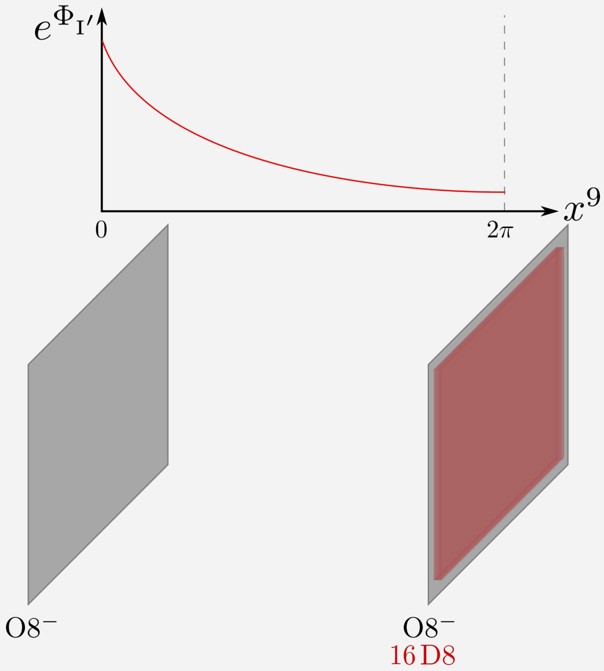

[Polchinski, Witten ‘95]

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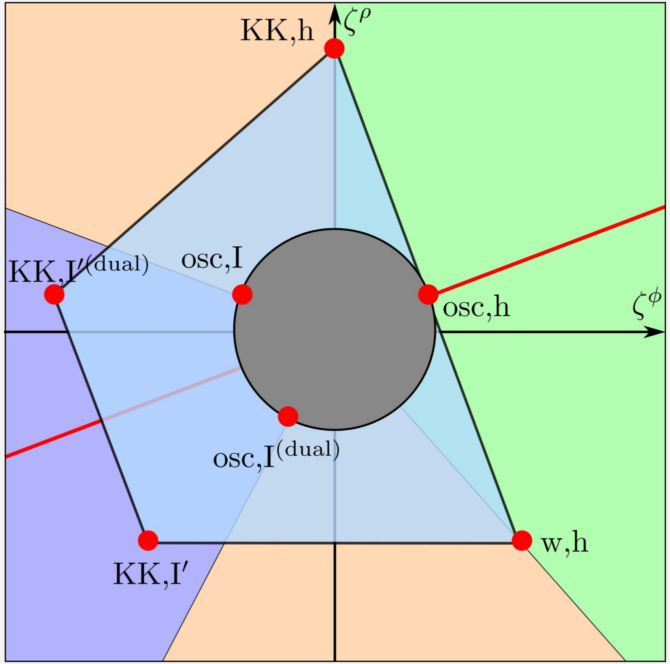
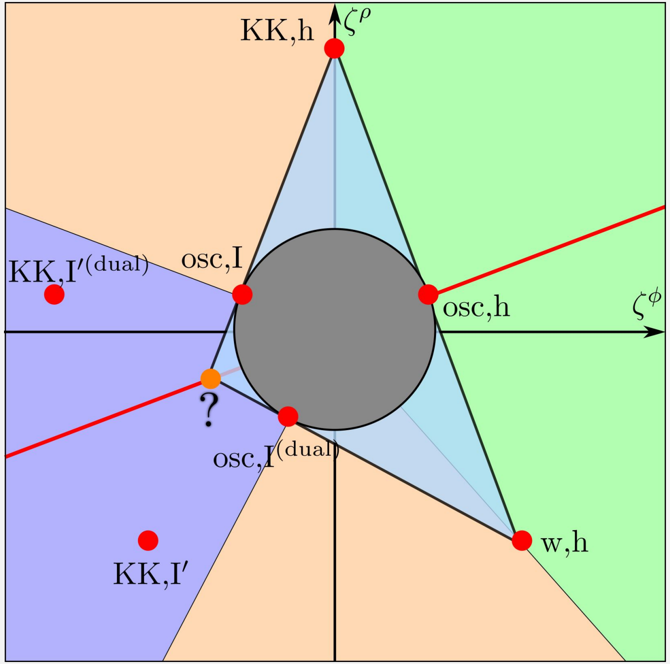




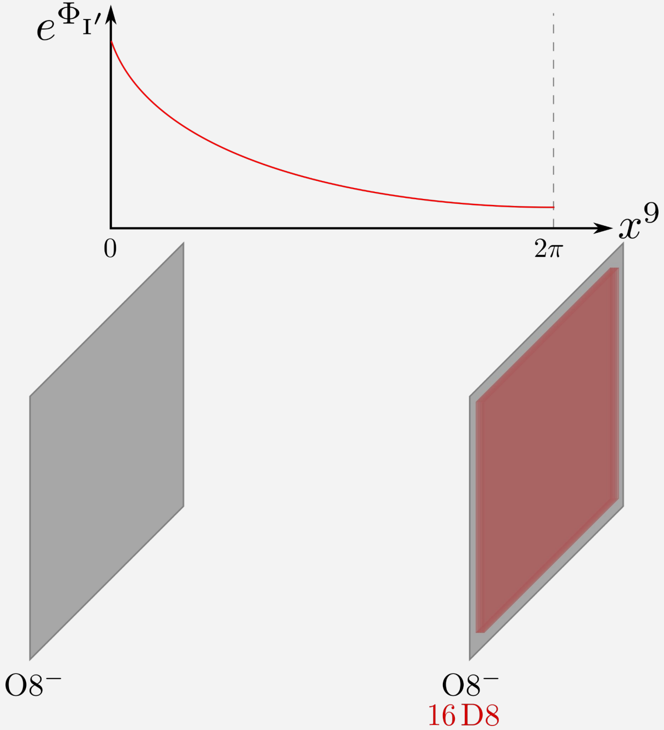
So... How do we solve this?

Resolution of the puzzle: Decompactification to a running solution

The running of the string coupling between the O8 induces a warped metric $g_{MN} = \Omega(x^9)^2\eta_{MN}$:

$$\left.\begin{aligned}\Omega(x^9) &= Cz(x^9)^{-1/6} \\ e^{\Phi(x^9)} &= z(x^9)^{-5/6}\end{aligned}\right\} z(x^9) \propto C(B + 8x^9)$$

For $B < \infty$ limits we decompactify to a running solution!



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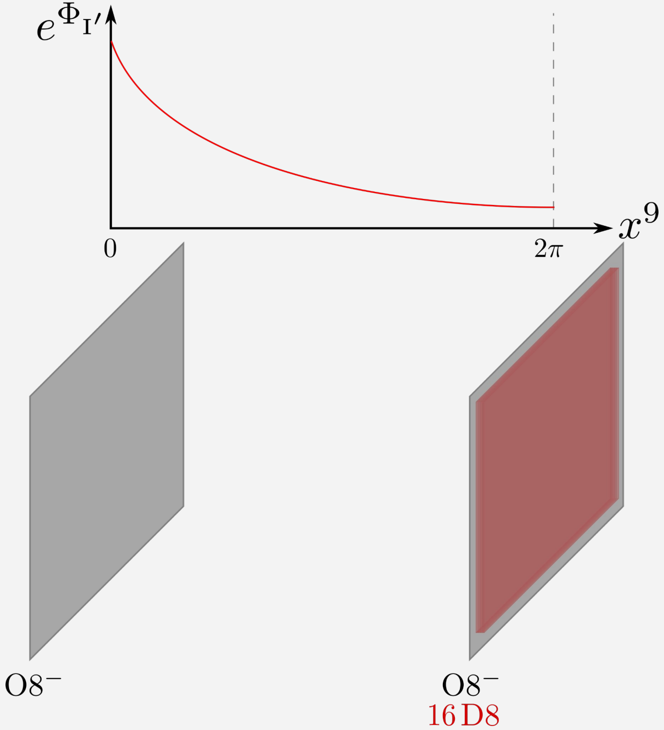

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This results in a non-trivial moduli dependence for the non-BPS KK modes:

$$m_{\mathrm{KK,\,I'}} = \left(\int_0^{2\pi} \mathrm{d}x^9 \hat{\Omega}^8 e^{-2\Phi_{\mathrm{I}'}} \right)^{-\frac{1}{7}} M_{\mathrm{Pl};9}$$

Resolution of the puzzle: Decompactification to a running solution

While flat, the moduli space metric is a complicated function of the moduli. Both kinetic and Laplacian terms contribute from the Ricci scalar reduction:

$$\mathsf{G}^{SO(32)} \sim \begin{pmatrix} B^{-2} & B^{-1}C^{-1} \\ B^{-1}C^{-1} & C^{-2} \end{pmatrix} \qquad \mathsf{G}^{SO(32)} \sim \begin{pmatrix} B^{-2/3} & C^{-1} \\ C^{-1} & C^{-2} \end{pmatrix}$$

$$(B \gg 1) \qquad\qquad (B \ll 1)$$

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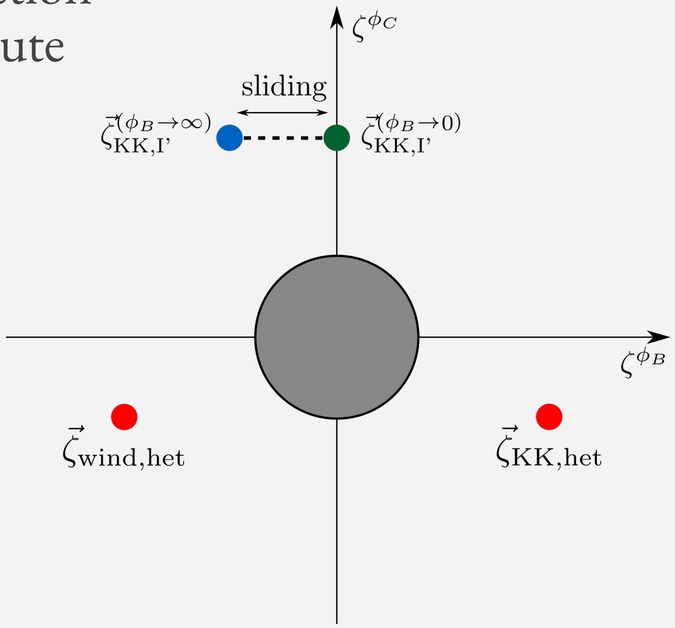
$$(B \gg 1) \qquad\qquad (B \ll 1)$$

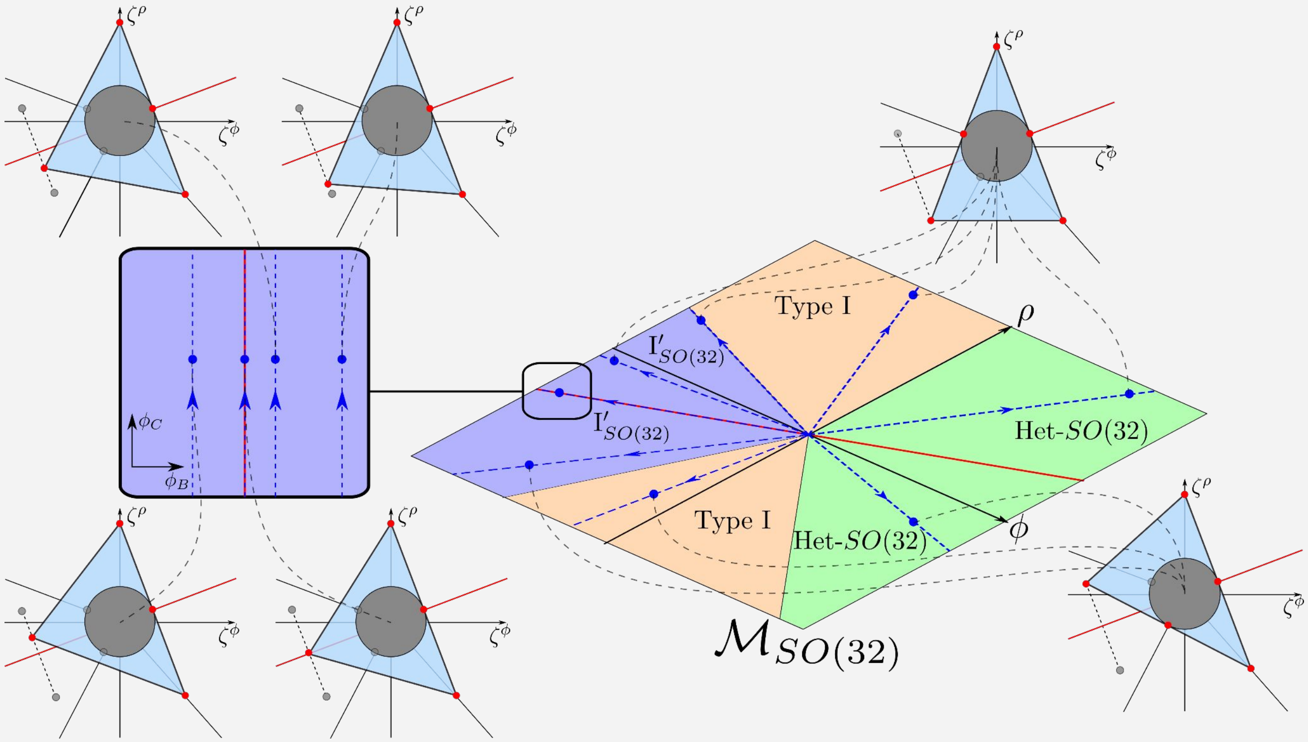
We are able to obtain flat coordinates ϕ_B and ϕ_C:

$$\vec{\zeta}_{\mathrm{KK,I'}} = \left(-\frac{3}{2}\left[\frac{2}{\sqrt{1-e^{-4\phi_B}}}+1\right]^{-1}, \frac{5}{2\sqrt{7}} \right)$$

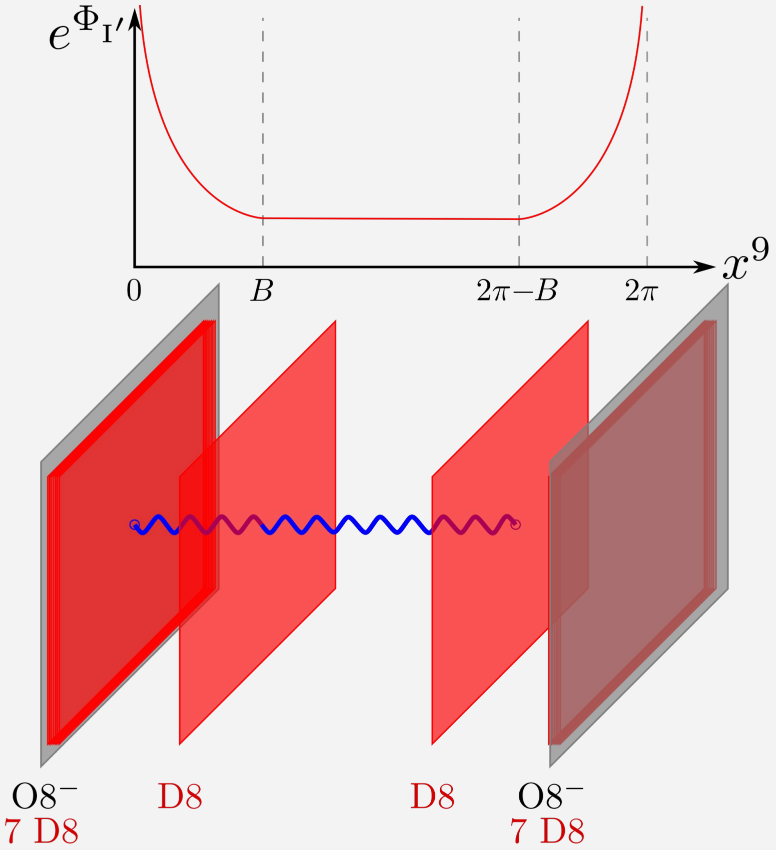
Slides depending on distance to self-dual line!!



Resolution of the puzzle:
Sliding of $\vec{\zeta}_{\text{KK, I}'}$ along moduli space



The analogous case: $E_8 \times E_8$ slice



[Polchinski, Witten ‘95; Aharony,Komargodski,Patir ’07]

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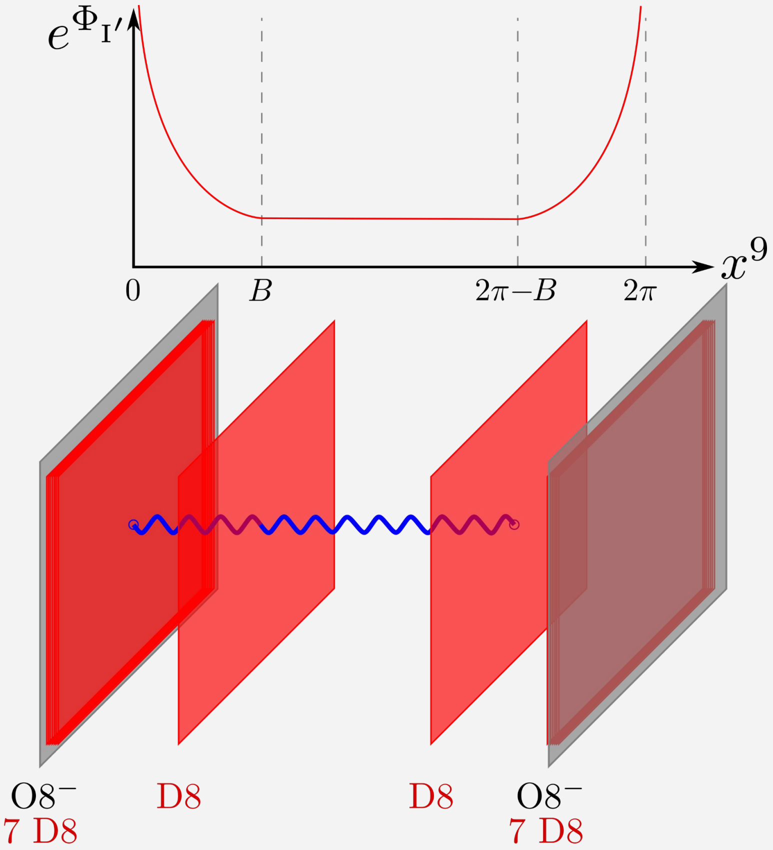
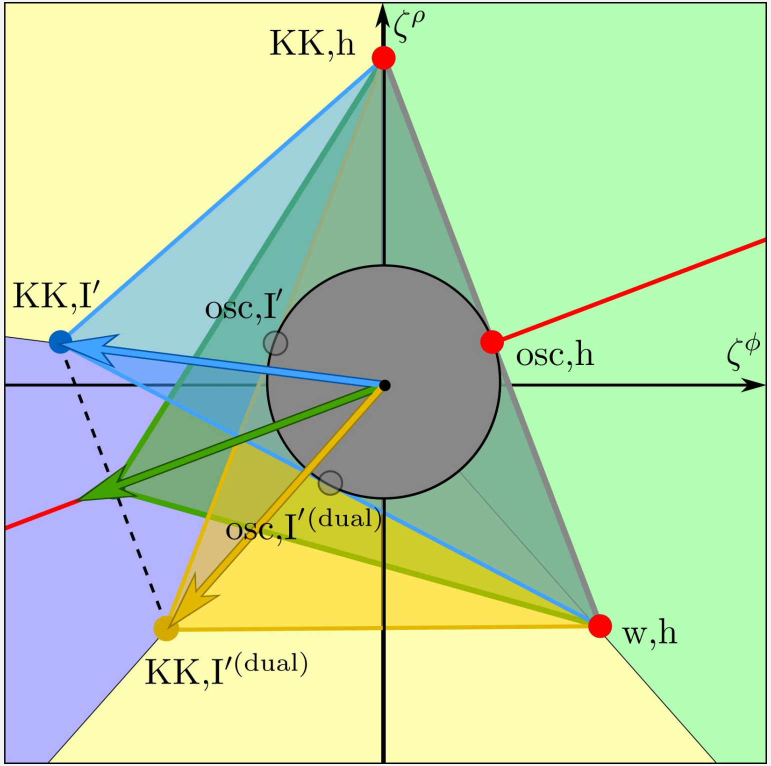
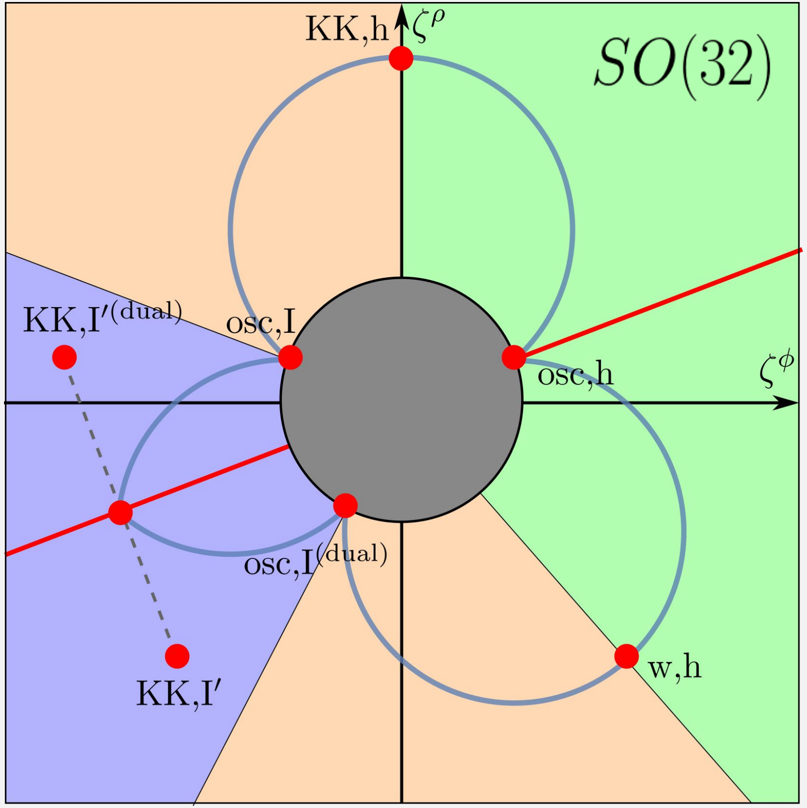
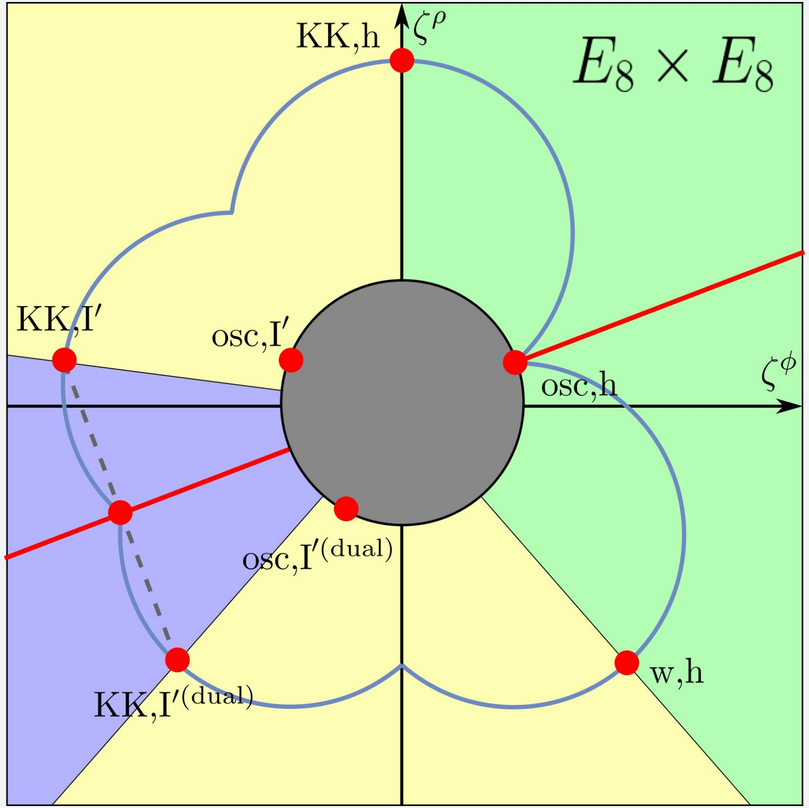




Sharpened distance conjecture is fulfilled





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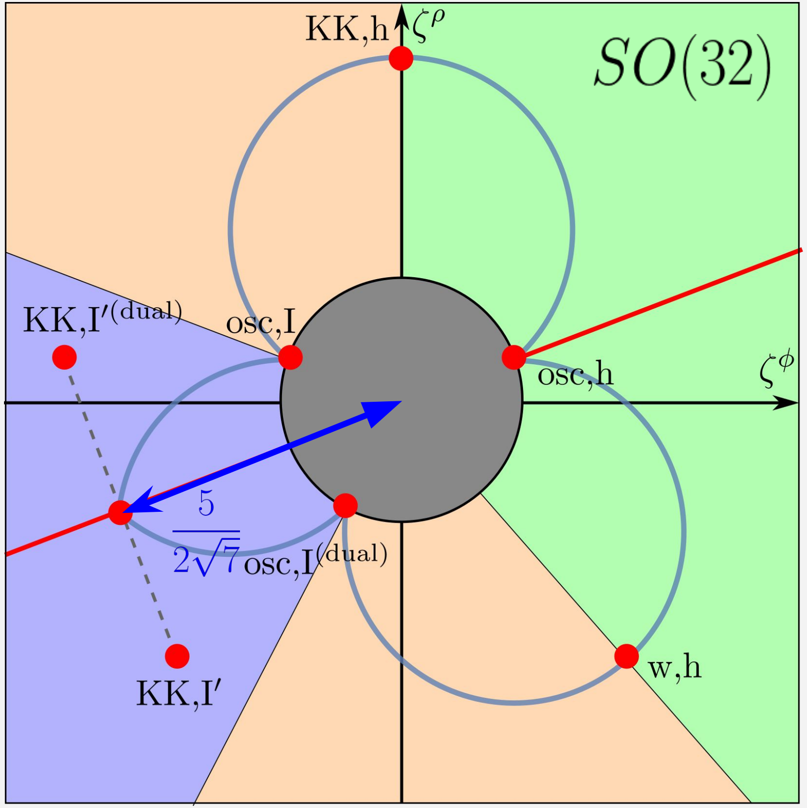

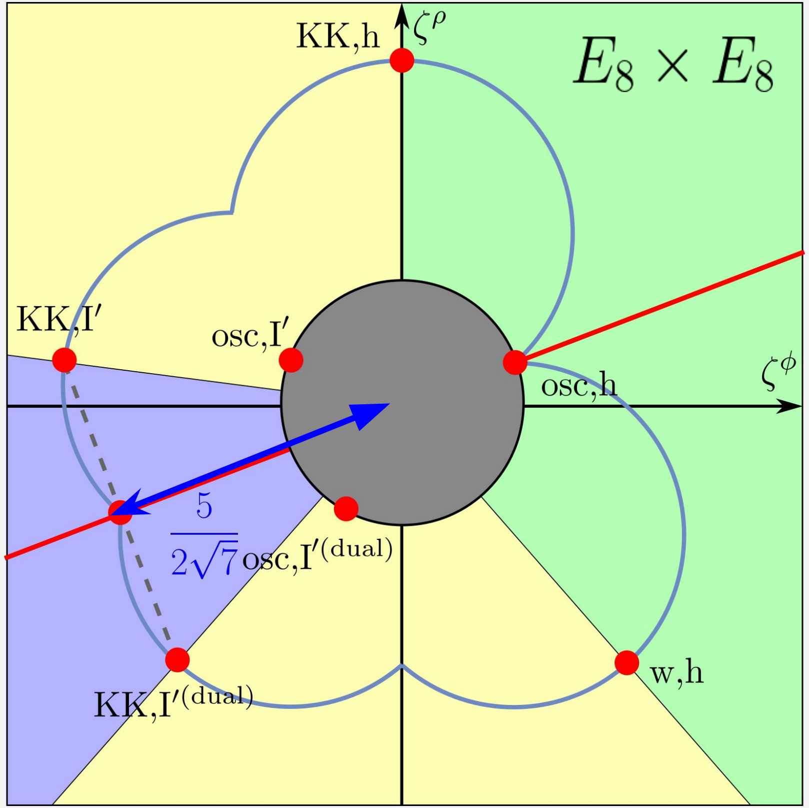

3. Conclusions

What have we obtained?

- We are able to explicitly compute **non-BPS KK** mass and exponential rate as function of the moduli space.
- The **Emergent String Conjecture** checked BUT important caveat:
  - **Decompactification** can be to a **running solution** → Changes in exponential rate
- The **Sharpened Distance Conjecture** and **Convex Hull Scalar Weak Gravity Conjecture** are fulfilled in a non-trivial way: **Sliding/jumping is needed!**
  - Also in more slides: $SO(16) \times SO(16)$, CHL string, AOA and AOB, second slice of $SO(32)$, new theories from [Montero, Parra de Freitas '19]→**No new behavior**

Shortcomings and future directions

- **Axions** are not taken into consideration:
  - Relevant for CHWGC and phenomenology!
- **Generality of sliding:** How does it extend to other dimensions and SUSY?
  - Universal features? Can we classify possibilities? *[Recall Ben Heidenreich talk!]*
  - Already working in cases with more moduli and d<9! *[Etheredge, Heidenreich, McNamara, Rudelius, IR, Valenzuela (to appear)]*

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In conclusion!

[See also Timo Weigand and Rafael Álvarez-García talks!]

Decompactification to running solutions and non-BPS towers are important for Swampland!

We are entering Swampland Precision Era!

Exciting problem to work in!

Thanks for the attention!

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more coming soon

STAY TUNED!

(questions welcomed)

Backup: Moduli space metric from Ricci reduction

9-dimensional Einstein metric:

$$\mathsf{g}_{\mu\nu} = \left(\frac{r}{r_0}\right)^{2/7} r_0^{1/4} \eta_{\mu\nu} \quad \text{with} \quad r = \int_0^{2\pi} \mathrm{d}x^9 \Omega^8 e^{-2\Phi_{\mathrm{I}'}}$$

We want

$$S_{\mathrm{I}'} \supset \frac{1}{2\kappa^2_{10,\mathrm{I}'}} \int \mathrm{d}^{10}x \sqrt{-\tilde{g}} \left\{ R_{\tilde{g}} - \frac{1}{2}\left(\partial \hat{\Phi}_{\mathrm{I}'}\right)^2 \right\} = \frac{1}{2\kappa^2_{9,\mathrm{I}'}} \int \mathrm{d}^9 x \sqrt{-\mathsf{g}} \left\{ R_{\mathsf{g}} - \mathsf{G}_{ab} \partial_\mu \varphi^a \partial^\mu \varphi^b \right\}$$

so that

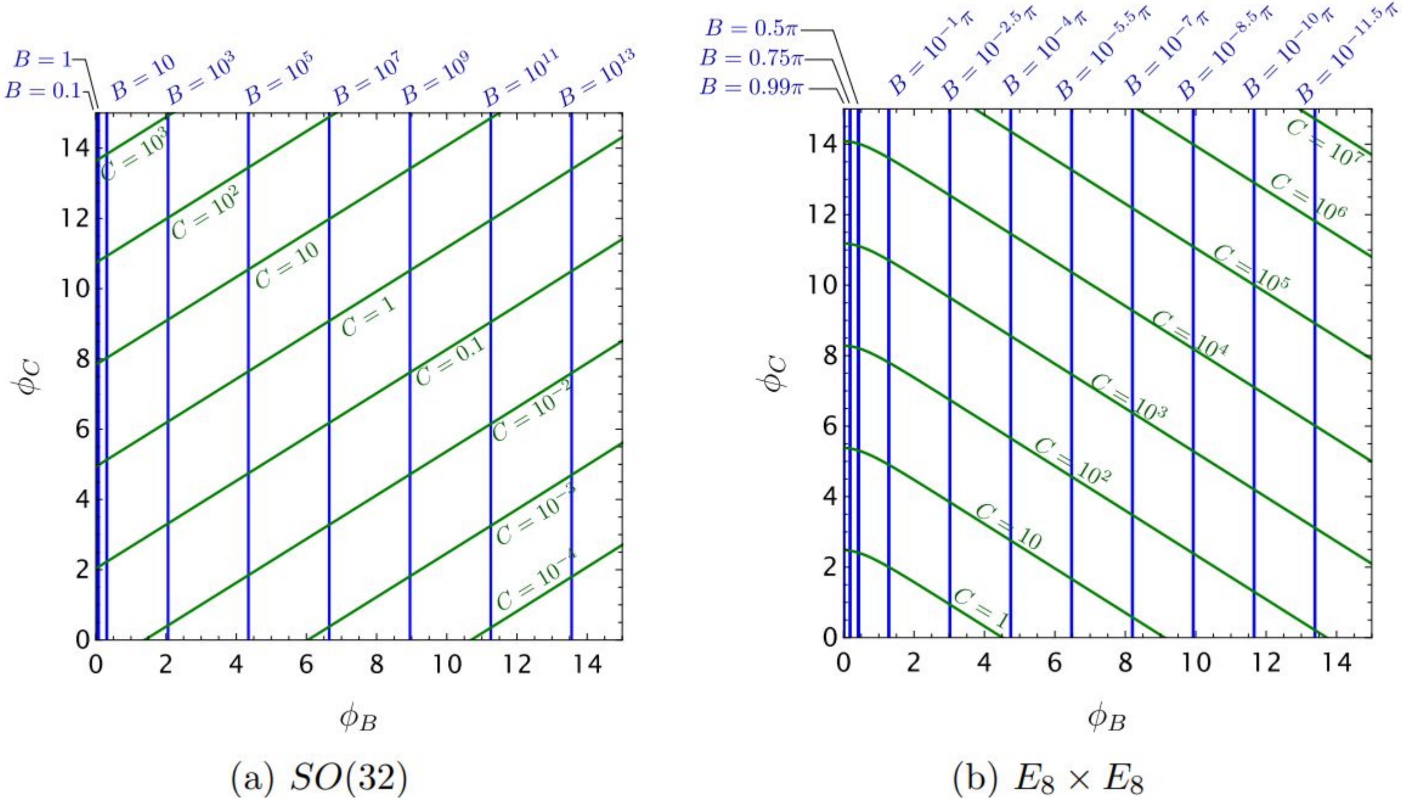
$$\mathsf{G}_{ab} \partial_\mu \varphi^a \partial^\mu \varphi^b = \frac{1}{r} \int_0^{2\pi} \mathrm{d}x^9 \Omega^8 e^{-2\hat{\Phi}_{\mathrm{I}'}} \left\{ \frac{7}{8} \left[\partial \log \left(\frac{\Omega^8 e^{-2\hat{\Phi}_{\mathrm{I}'}} r_0^{1/7}}{r^{8/7}} \right) \right]^2 + \frac{1}{2} (\partial \hat{\Phi}_{\mathrm{I}'})^2 \right\} + \delta^{(2)}_{\mathrm{kin}},$$

After integrating by parts and regularizing,

$$\delta^{(2)}_{\mathrm{kin}} = \hat{\delta} - \frac{1}{\sqrt{-\mathsf{g}}} \lim_{B \to \infty, 0} \left[\sqrt{-\mathsf{g}} \hat{\delta} \right]$$

$$\hat{\delta} = -\frac{2}{r} \int_0^{2\pi} \mathrm{d}x^9 \Omega^8 e^{-2\hat{\Phi}_{\mathrm{I}'}} \left\{ \left[\partial \log \left(\frac{\Omega^8 e^{-2\hat{\Phi}_{\mathrm{I}'}} r_0^{1/7}}{r^{8/7}} \right) \right]^2 + \frac{1}{7} \partial_\mu \log \left(\frac{r}{r_0} \right) \partial^\mu \log \left(\frac{\Omega^8 e^{-2\hat{\Phi}_{\mathrm{I}'}} r_0^{1/7}}{r^{8/7}} \right) \right\}$$

Backup: Coordinate curves in flat frame



Backup: Heterotic-Type I' Duality relations

Heterotic	$SO(32)$	$E_8 \times E_8$
R_{h}	$\frac{\pi}{2^{1/4}}(\alpha'_{\mathrm{I}'})^{1/2}\left(\int_0^{2\pi}\mathrm{d}x^9\hat{\Omega}^2\right)^{-3/4}\left(\int_0^{2\pi}\mathrm{d}x^9\hat{\Omega}^8 e^{-2\Phi_{\mathrm{I}'}}\right)^{-1/4}\left(\sum_{i=1}^{16}\hat{\Omega}^5 e^{-\Phi_{\mathrm{I}'}}\Big\rvert_{x^9=x^9_i}\right)^{1/2}$	$\sqrt{2}(\alpha'_{\mathrm{I}'})^{1/2}\left(\int_0^{2\pi-B}\mathrm{d}x^9\hat{\Omega}^2\right)^{3/4}\left(\int_0^{2\pi}\mathrm{d}x^9\hat{\Omega}^8 e^{-2\Phi_{\mathrm{I}'}}\right)^{-1}\left(\sum_{i=1}^{16}\hat{\Omega}^5 e^{-\Phi_{\mathrm{I}'}}\Big\rvert_{x^9=x^9_i}\right)^{5/4}$
g_{h}	$\frac{\sqrt{2}}{\pi}\left(\int_0^{2\pi}\mathrm{d}x^9\hat{\Omega}^2\right)^{3/2}\left(\int_0^{2\pi}\mathrm{d}x^9\hat{\Omega}^8 e^{-2\Phi_{\mathrm{I}'}}\right)^{-2}\left(\sum_{i=1}^{16}\hat{\Omega}^5 e^{-\Phi_{\mathrm{I}'}}\Big\rvert_{x^9=x^9_i}\right)^{-1/2}$	$\frac{2}{\pi}\left(\int_0^{2\pi-B}\mathrm{d}x^9\hat{\Omega}^2\right)^{1/2}\left(\int_0^{2\pi}\mathrm{d}x^9\hat{\Omega}^8 e^{-2\Phi_{\mathrm{I}'}}\right)\left(\sum_{i=1}^{16}\hat{\Omega}^5 e^{-\Phi_{\mathrm{I}'}}\Big\rvert_{x^9=x^9_i}\right)^{-3/2}$
Extra	$m_{\mathrm{KK,h}} = R_{\mathrm{h}}^{-1}$	$m_{\mathrm{w,h}} = \frac{R_{\mathrm{h}}}{2\pi\alpha'_{\mathrm{h}}} = \frac{D}{2\pi\alpha'_{I'}}2\int_0^{2\pi-B}\mathrm{d}x^9\Omega^2 = m_{\mathrm{w,I'}}$