DIPARTIMENTO
DI FISICA
E ASTRONOMIA
Galileo Galilei

INFN

EFT constraints from EFT strings

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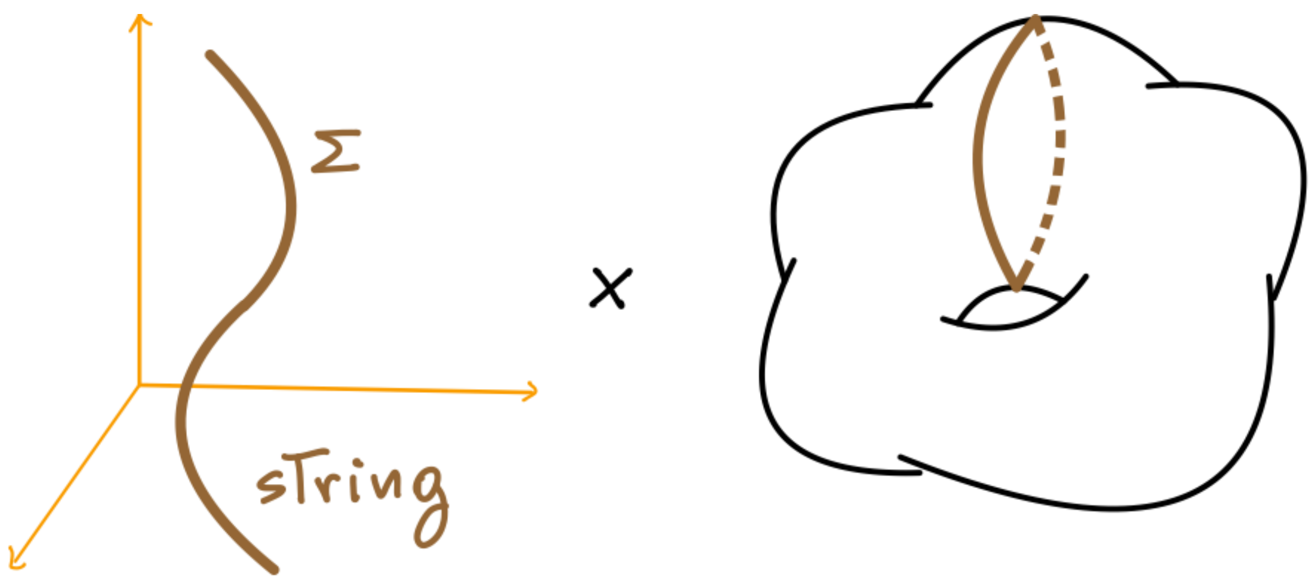
works in collaboration with: S. Lanza, F. Marchesano & I. Valenzuela

2104.05726, 2006.15154, 2205.04532

N. Risso & T. Weigand 2207.xxxx

SP2022 - Liverpool

- In QG models, EFTs are populated by strings and other extended objects



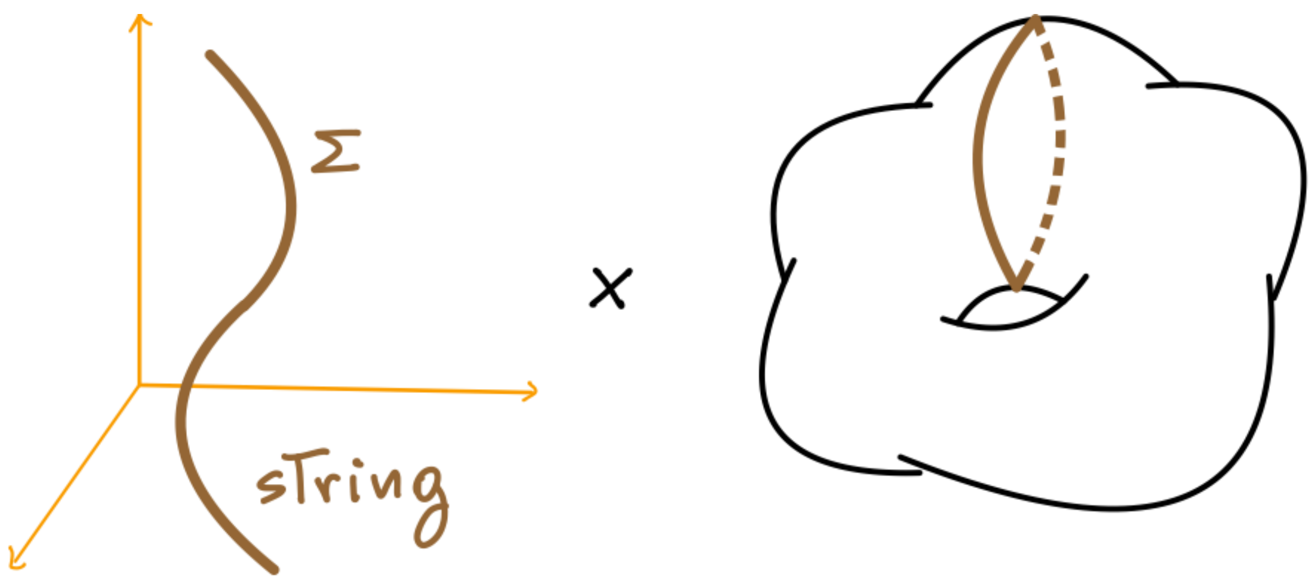
$$\int_{\Sigma} B_2$$

↓

existence by completeness hypothesis

[Polchinski ’03, Banks & Seiberg ’11, Halow-Ooguri ’18,...]

- In QG models, EFTs are populated by strings and other extended objects



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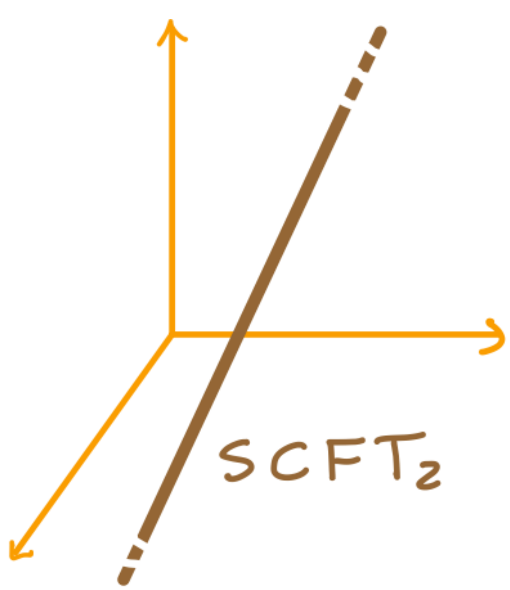
existence by completeness hypothesis

[Polchinski ’03, Banks & Seiberg ’11, Halow-Ooguri ’18,…]

- BPS strings as quantum probes of $d \geq 5$ supergravities!



Quantum consistency of IR $SCFT_2$

⇓

constraints on bulk EFT

[Kim-Shiu-Vafa `19]

[Lee-Weigand `19]

[Kim-Tarazi-Vafa ’20]

[Katz-Kim-Tarazi-Vafa ’20]

[Angelantonj-Bonnefoy-Condeescu-Dudas’20]

[Tarazi-Vafa ’21]

Strings in 4d?

- I'll focus on 'fundamental' BPS strings in d=4 $\mathcal{N}=1$ EFT

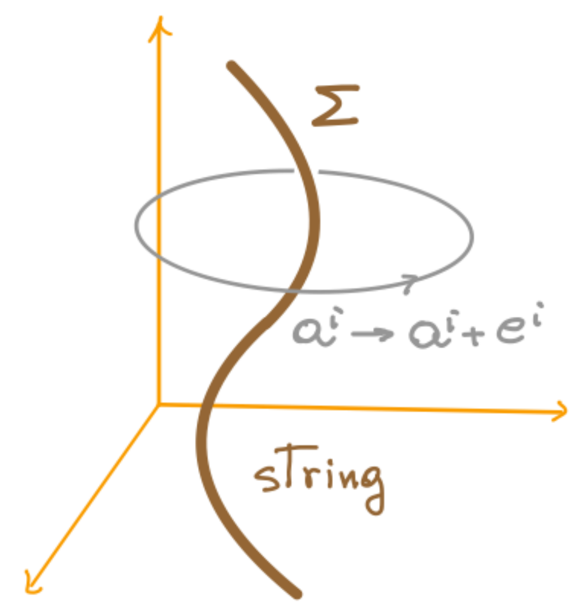
see also [Reece '18]

⇝ natural probes of quantum gravity UV completion

- $$S_{4d} = \frac{M_P^2}{2}\int_{\text{bulk}} R + \ldots - \int_\Sigma T_e \sqrt{-g} + e^i \int_\Sigma B_{2,i} + \ldots$$

[Lanza-Marchesano-LM-Sorokin '19]

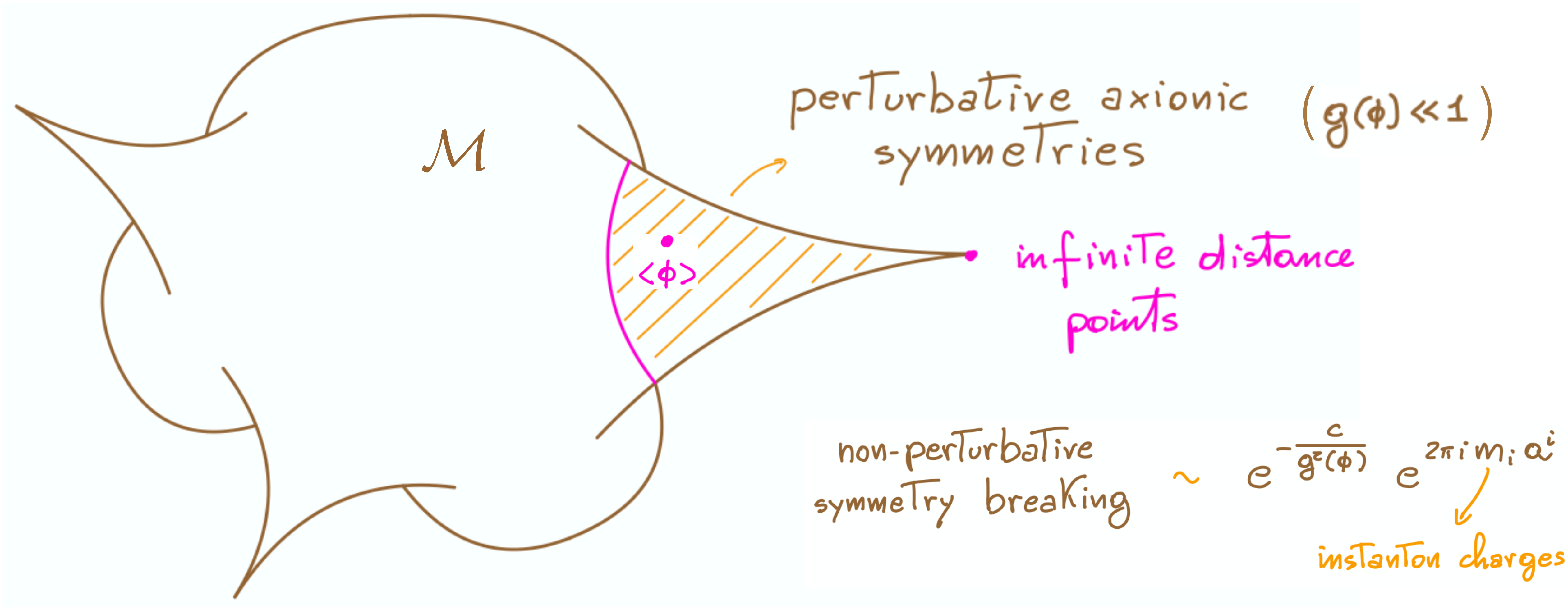
$dB_2 \sim * da$ ⟶ axionic strings!



Strings in 4d?

- Perturbative axionic shift symmetries

[Misner-Wheeler '56,...,
Kallosh-Linde-Linde-Susskind '95, ...,
Banks & Seiberg '06,...,
Harlow-Ooguri '19]



- Fundamental BPS strings as natural probes of asymptotic field space regions

Strings in 4d?

- Warning: strong back-reaction:
  - bulk vacuum destroyed
  - fields possibly driven to strongly coupled regions — See [Marchesano-Wiesner '22]
  - no IR SCFT fixed point

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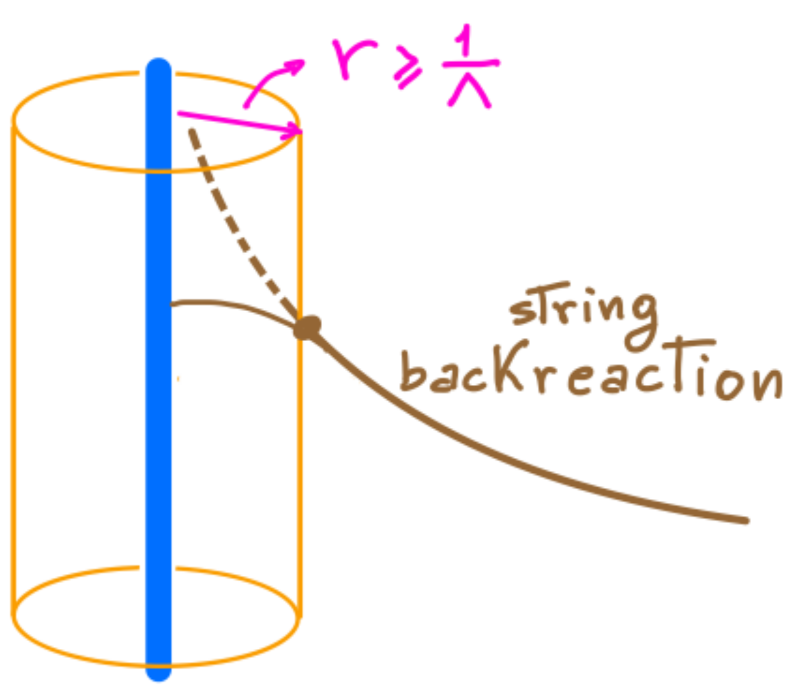
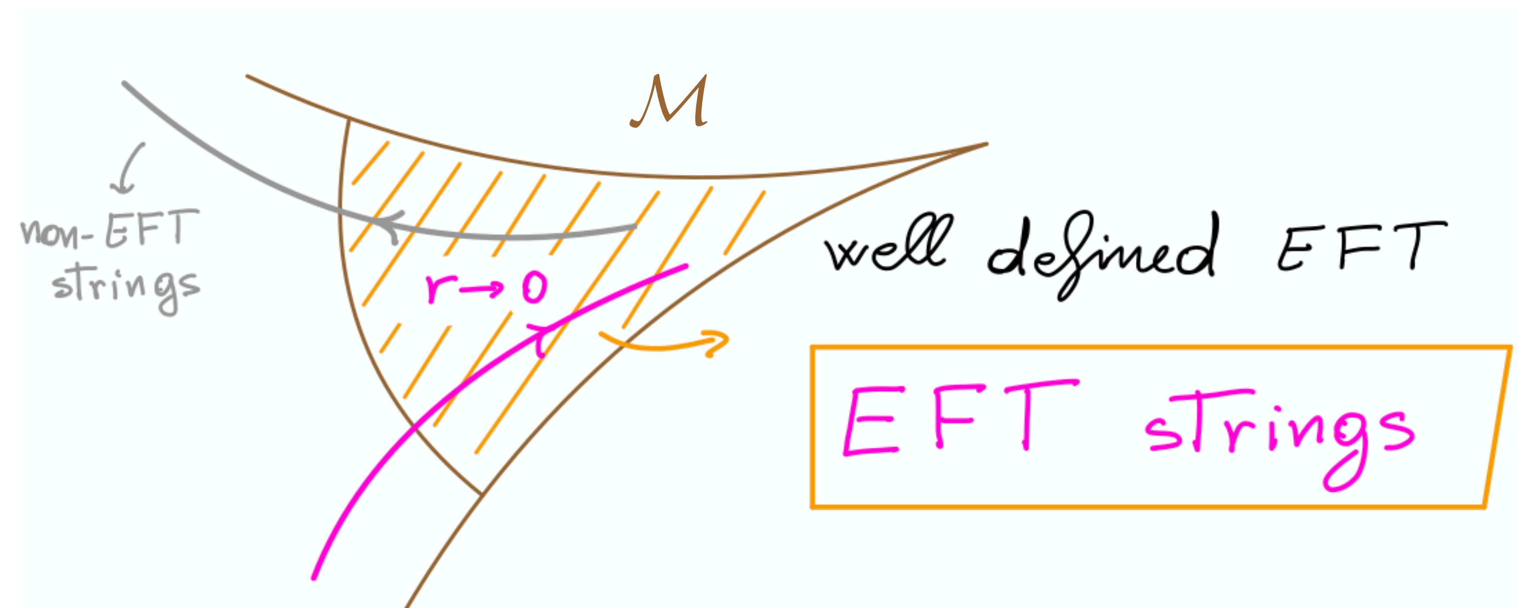
  - bulk vacuum destroyed
  - fields possibly driven to strongly coupled regions — see [Marchesano-Wiesner '22]
  - no IR SCFT fixed point

- However, strings can still have a well defined EFT description

[..., Goldberger&Wise '01,
Michel-Mintun-Polchiski-Puhm-Saad '14, Polchinski '15...,]





[Lanza-Marchesano-LM-Valenzuela '20-'21]

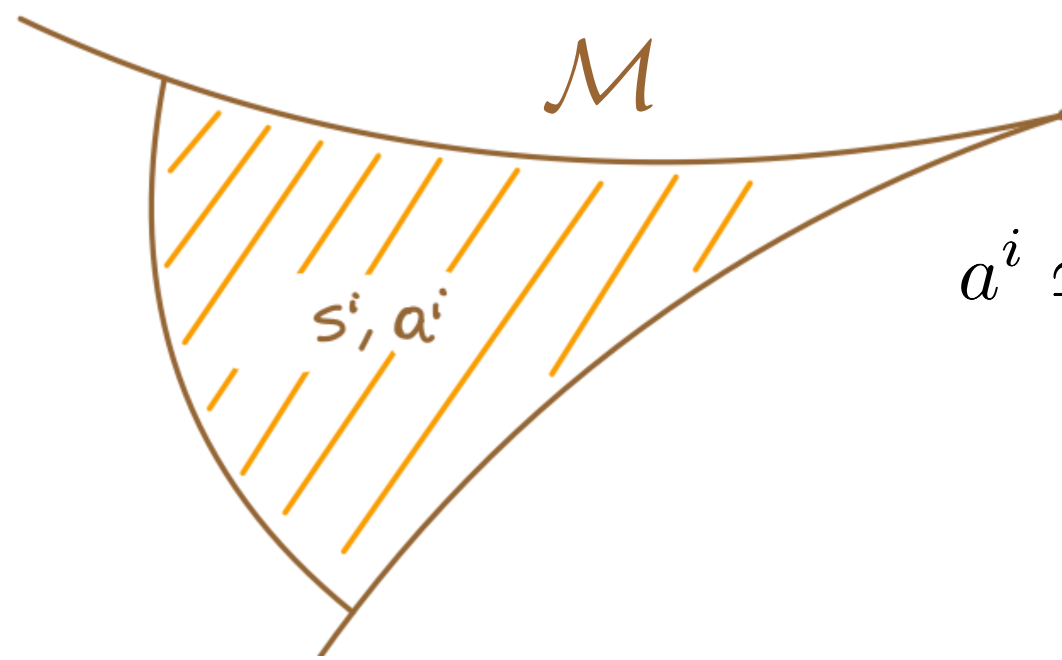
EFT strings

- Perturbative region:

$$t^i \equiv a^i + \mathrm{i}\, s^i$$

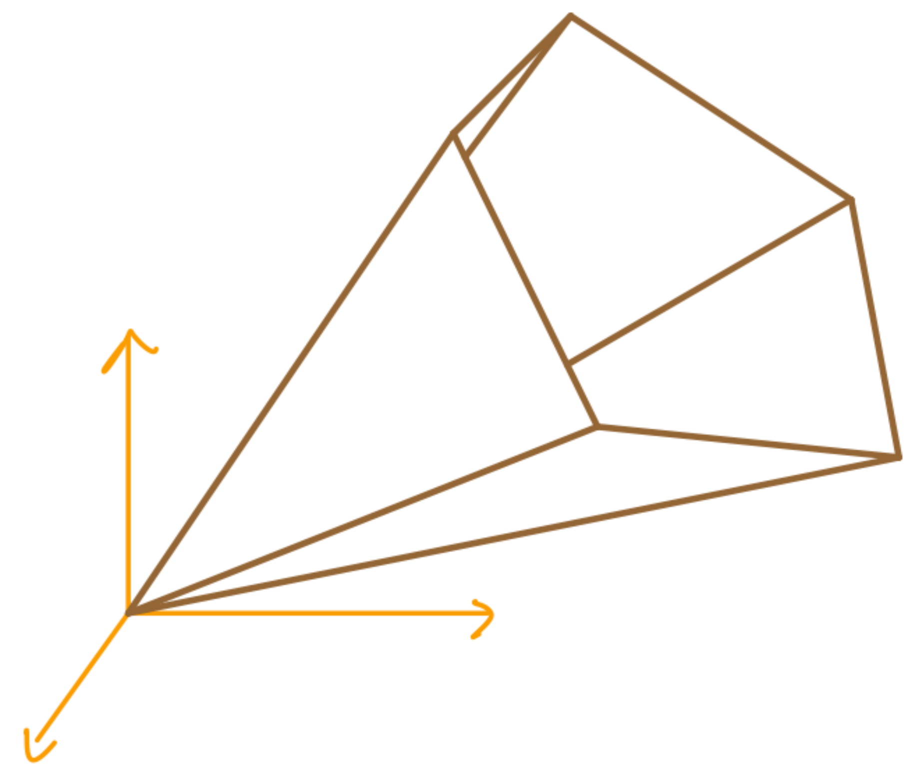
axions saxions

(chiral mult.)



$$a^i \simeq a^i + 1$$

- $\{s^i\} \in \{\text{saxionic cone}\}$



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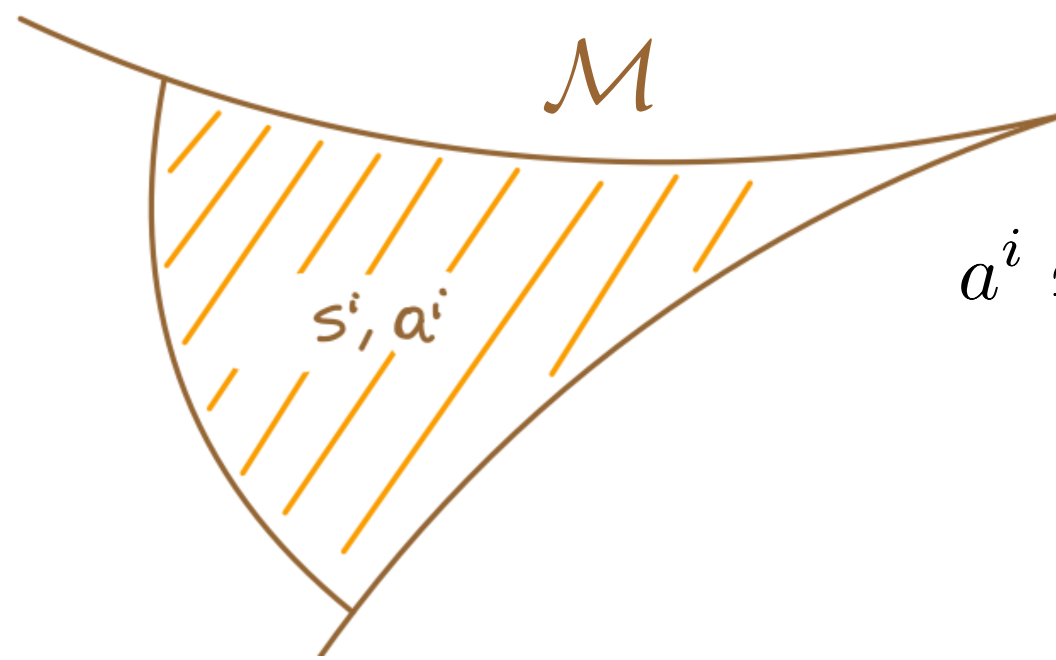
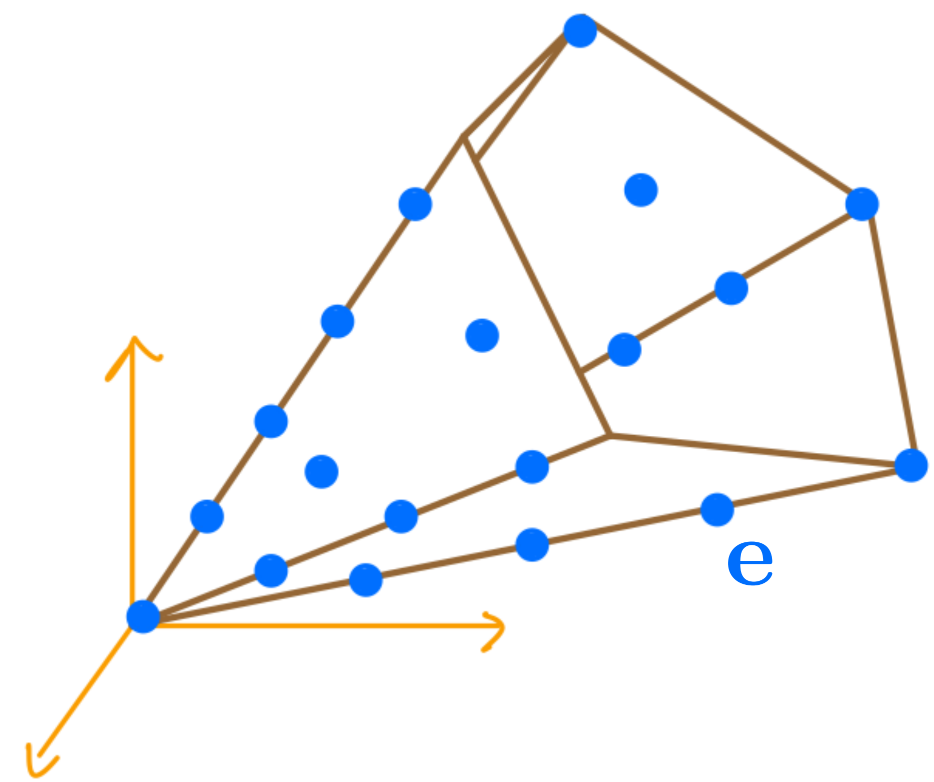


- $\{s^i\} \in \{\text{saxionic cone}\}$

- EFT string charges:

$$\mathbf{e} \equiv \{e^i\} \in \mathcal{C}_{\rm S}^{\rm EFT} \equiv \{\text{saxionic cone}\}_{\mathbb{Z}}$$



EFT strings strongly characterize asymptotic field space regions!

[Lanza-Marchesano-LM-Valenzuela ’20-’21]

[-> Irene, Stefano & Timo ’s talks]

see also

[Buratti, Calderón-Infante, Delgado, Uranga `21]

[Angius, Calderón-Infante, Delgado, Huertas, Uranga `22]

[Grimm, Lanza, Li `22]

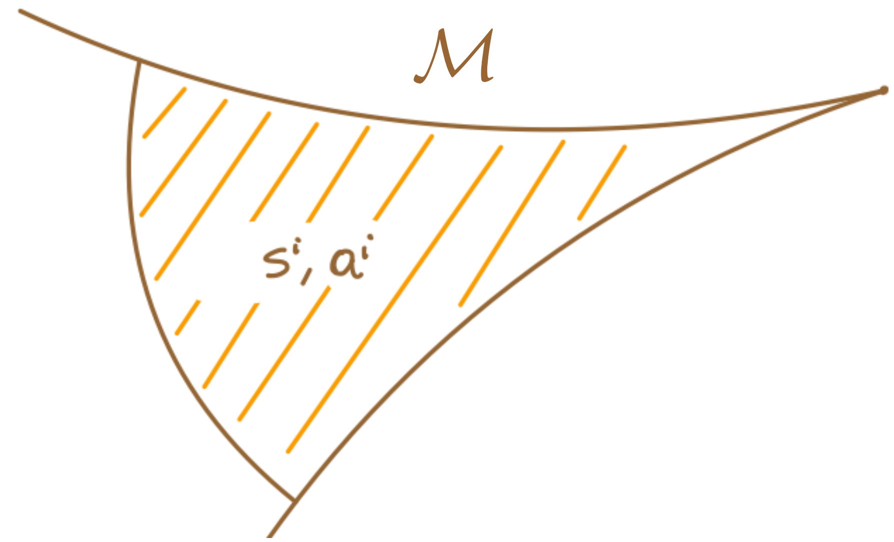
EFT strings probing gauge and (curvature)^2 terms

[LM-Risso-Weigand ’22]

- Bulk perturbative gauge group:

$$-\frac{1}{2}\int (C_i s^i + \dots)\ \mathrm{Tr}(F \wedge * F) - \frac{1}{2}\int (C_i a^i + \dots)\ \mathrm{Tr}(F \wedge F)$$

$\frac{1}{g^2} \gg 1$ in



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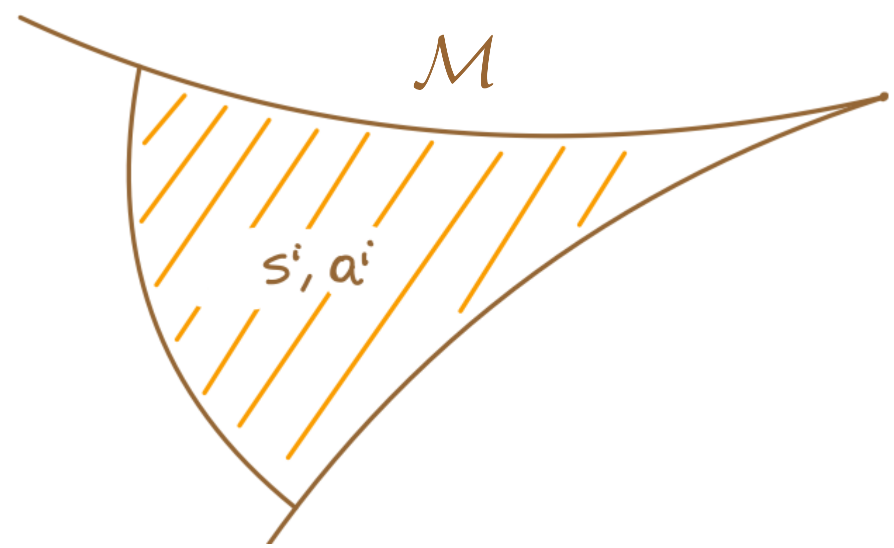

- Gauss-Bonnet and Pontryagin terms

$$-\frac{1}{48}\int \underbrace{(\tilde{C}_i s^i + \ldots)} \,[\mathrm{Tr}(R\wedge *R) + \ldots] - \frac{1}{48}\int (\tilde{C}_i a^i + \ldots)\,\mathrm{Tr}(R\wedge R)$$

sign ?

positivity suggested by

[…, Kallosh-Linde-Linde-Susskind '95, Cheung-Remmen '16, GarcíaEtxebarria-Montero-Sousa-Valenzuela '20, Aalsma-Shiu '22 …]

[-> Gary's talk]

- The axionic couplings detect the presence of EFT strings:

* $$S_{\text{bulk}} \supset \int a^i I_{4,i} = -\int \mathrm{d}a^i \wedge I_{3,i}$$

with $$I_{4,i} = \mathrm{d}I_{3,i} = -\frac{1}{2} C_i \,\mathrm{Tr}(F \wedge F) - \frac{1}{48} \tilde{C}_i \,\mathrm{Tr}(R \wedge R)$$

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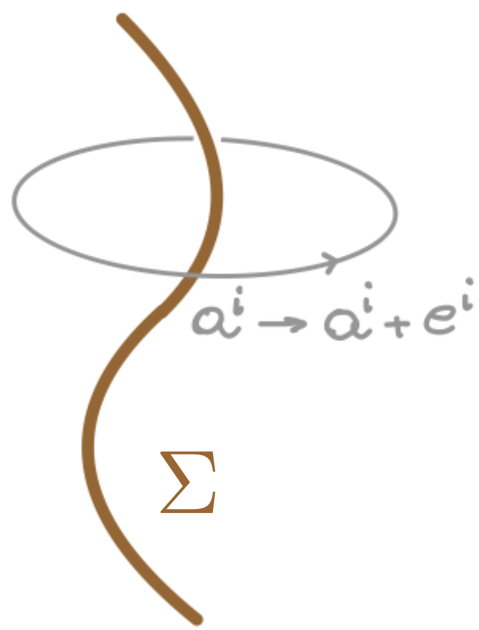
* $${\rm d}^2 a^i = e^i \delta_2(\Sigma)$$



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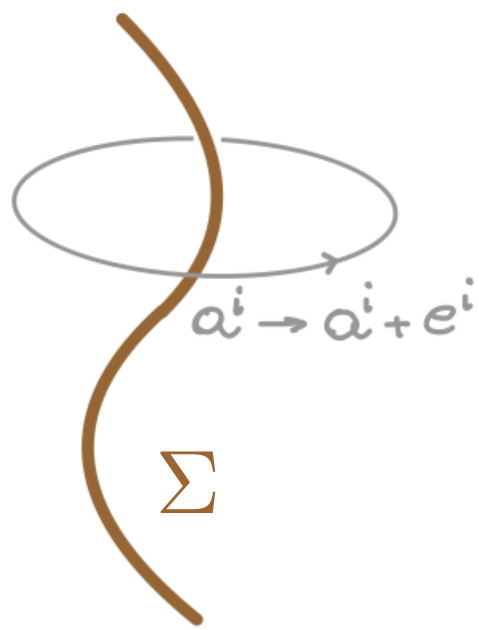

⇓

$$\delta\, S_{\text{bulk}} = -e^i \int_\Sigma \delta I_{2,i} \quad \neq 0$$

$$(\, \mathrm{d}\delta I_{2,i} = \delta I_{3,i} \,)$$

anomaly inflow [Callan-Harvey '85]

- Anomaly inflow must be cancelled by world-sheet `t Hooft anomaly

[Callan-Harvey '85]

$$I_4^{\text{ws}} = e^i I_{4,i} = -\frac{1}{2}(e^i C_i)\,\text{Tr}(F\wedge F) - \frac{1}{2}(e^i \tilde{C}_i)\,\text{Tr}(R_{\text{T}}\wedge R_{\text{T}}) - \frac{1}{2}(e^i \tilde{C}_i)\,\text{Tr}(R_{\text{N}}\wedge R_{\text{N}})$$

$$G = \prod_A U(1)_A \times \prod_I G_I \qquad SO(1,1)_{\text{T}} \qquad U(1)_{\text{N}}$$

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- We cannot assume IR SCFT as in [Kim-Shiu-Vafa `19, ...]

however...

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however...

- ... EFT strings support weakly-coupled (0,2) NLSM:

Fermion	#	$U(1)_{\rm N}$ charge	$U(1)_A$ charge	G_I repr.	(0,2) multiplet
λ_+	1	$\frac{1}{2}$	0	$\mathbf{1}$	chiral U
χ_+	$n_{\rm R}$	$-\frac{1}{2}$	0	$\mathbf{1}$	chiral Φ
ψ_-	$n_{\rm F}$	0	q_A	$\mathbf{r}_I$	Fermi Ψ_-
λ_-	$n_{\rm V}$	$\pm\frac{1}{2}$	0	$\mathbf{1}$	Fermi/Vector Λ_-

- Anomaly matching + $n_{\mathrm{R}}, n_{\mathrm{F}}, n_{\mathrm{V}} \in \mathbb{Z}_{\geq 0}$ $\Longrightarrow$ EFT constraints!

[LM-Risso-Weigand '22]

$$-\frac{1}{2}\int (C_i s^i + \ldots)\ \mathrm{Tr}(F \wedge *F) - \frac{1}{48}\int (\tilde{C}_i s^i + \ldots)\,[\mathrm{Tr}(R \wedge *R) + \ldots]$$

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positive GB coupling!

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(2) $\tilde{C}_i e^i \in 3\mathbb{Z}_{\geq 0}\,, \quad \forall \mathbf{e} \in \mathcal{C}_{\rm S}^{\rm EFT}$ $\longrightarrow$ $\tilde{C}_i s^i > 0$ positive GB coupling!

(3) $r(\mathbf{e}) \leq \frac{4}{3}\,\tilde{C}_i e^i\,, \quad \forall \mathbf{e} \in \mathcal{C}_{\rm S}^{\rm EFT}$ bounds on ranks determined by GB!

↑ total rank of gauge groups 'coupled' to $s^i = e^i$

Simplest example

- Single-field model

$$-\frac{1}{2}\int (Cs+\ldots)\ \mathrm{Tr}(F\wedge *F) - \frac{1}{48}\int (\tilde{C}s+\ldots)\ \mathrm{Tr}(R\wedge *R+\ldots)+\ldots$$

- $\{\text{saxionic cone}\} = \mathbb{R}_{>0}\ ,\quad \mathcal{C}_{\mathrm{S}}^{\mathrm{EFT}} = \mathbb{Z}_{\geq 0}$

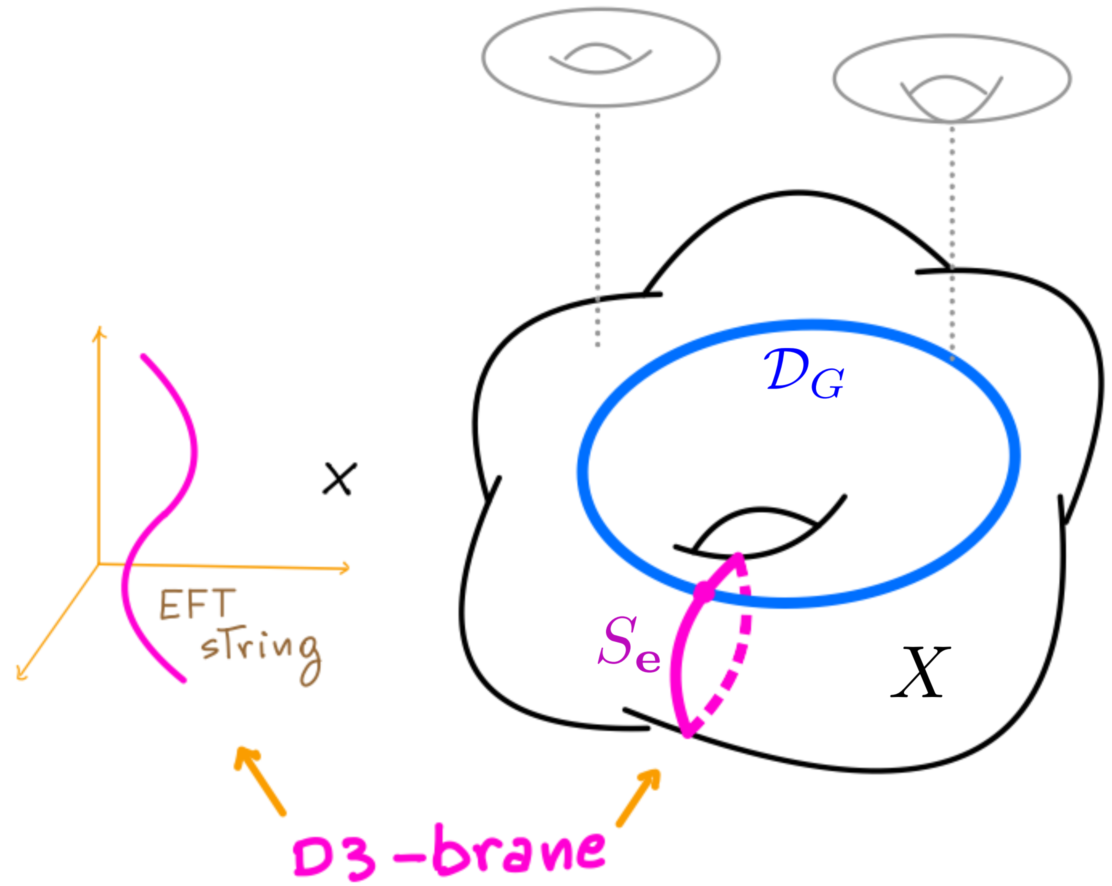
(1) $C \in \mathbb{Z}_{\geq 0}$

(2) $\tilde{C} = 3k \quad , \quad k \in \mathbb{Z}_{\geq 0}$

(3) $\mathrm{rk}(\mathfrak{g}) \leq \frac{4}{3}\tilde{C} \ = 4k$

UV test: F-theory models

- $\mathcal{C}_{\rm S}^{\rm EFT} = \{\text{movable curves } S_{\mathbf{e}}\}$



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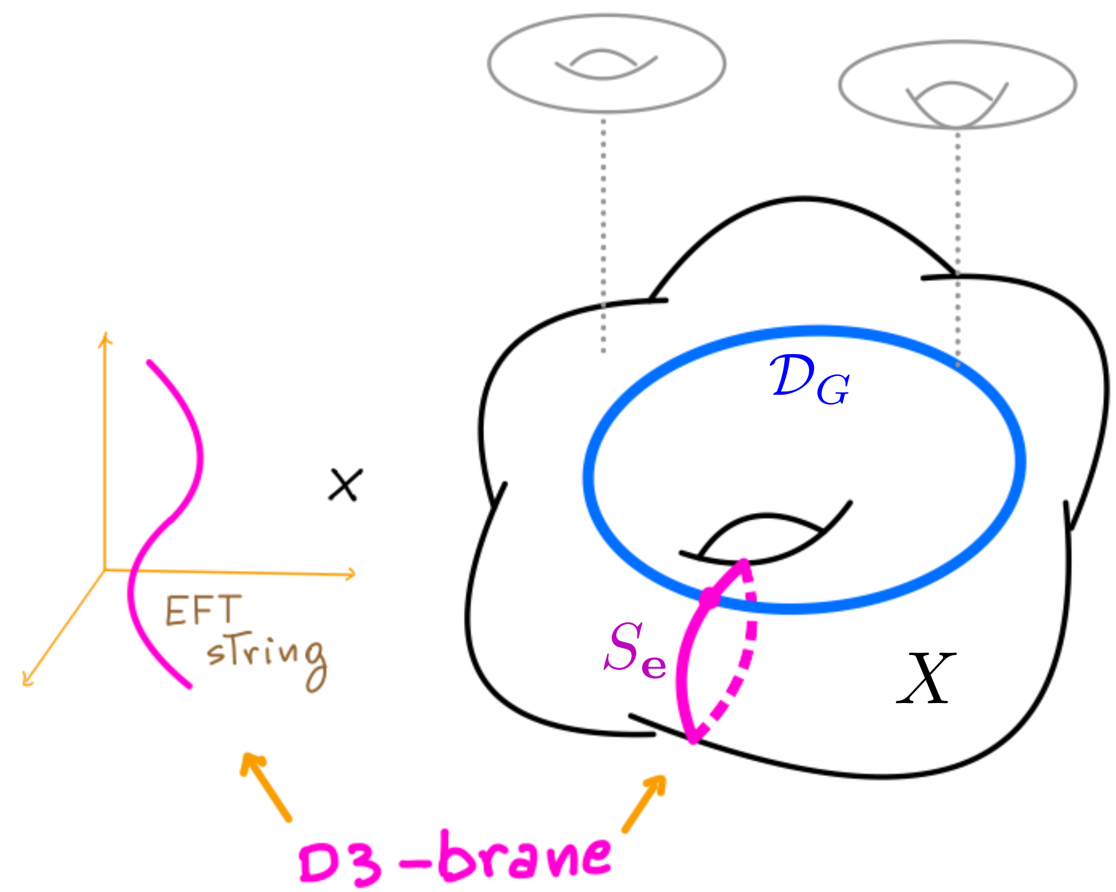

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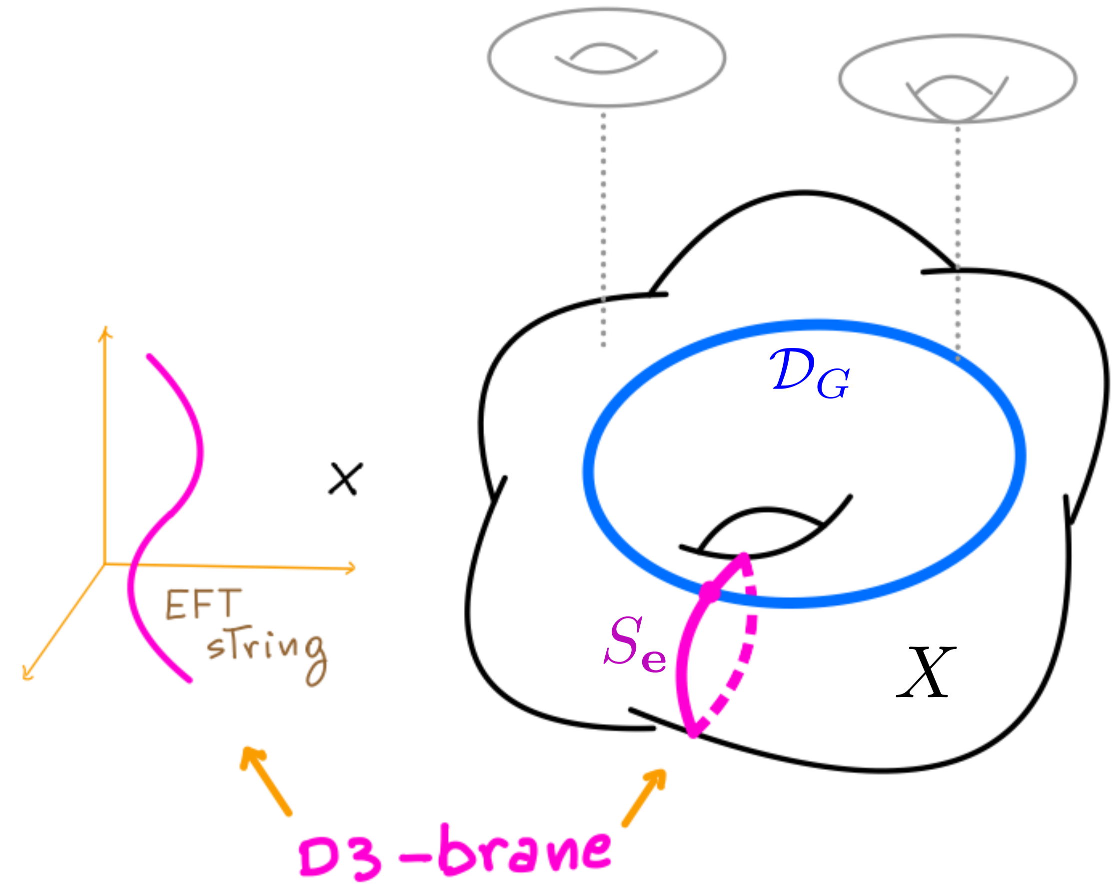

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(2) $\tilde{C}_i e^i = 6\, S_{\mathbf{e}} \cdot \overline{K}_X \in 3\mathbb{Z}_{\geq 0}$

(3) $$r(\mathbf{e}) = \sum_{I | \mathcal{D}^I \cdot \mathcal{S}_{\mathbf{e}} \neq 0} \text{rank}(G_I) \;\; \leq 8\, \mathcal{S}_{\mathbf{e}} \cdot \overline{K}_X$$

* matches Kodaira's bounds!

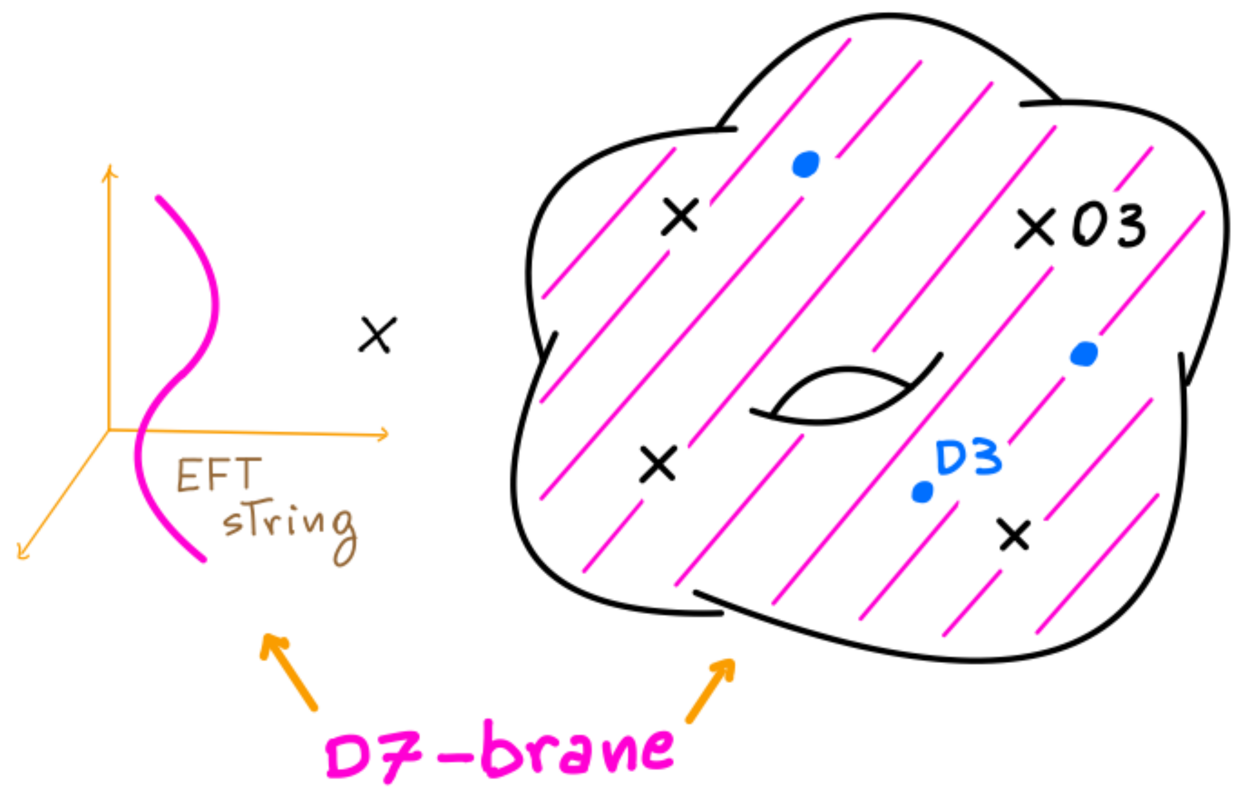
* bounds rank of Mordell-Weil group

see also [Lee-Weigand `19]

UV test: O3/D3 models

- EFT-string: D7-brane

(2) $\tilde{C}_i e^i = \frac{3}{16} n_{\text{O3}} \in 3\mathbb{Z}$



UV test: O3/D3 models

- EFT-string: D7-brane

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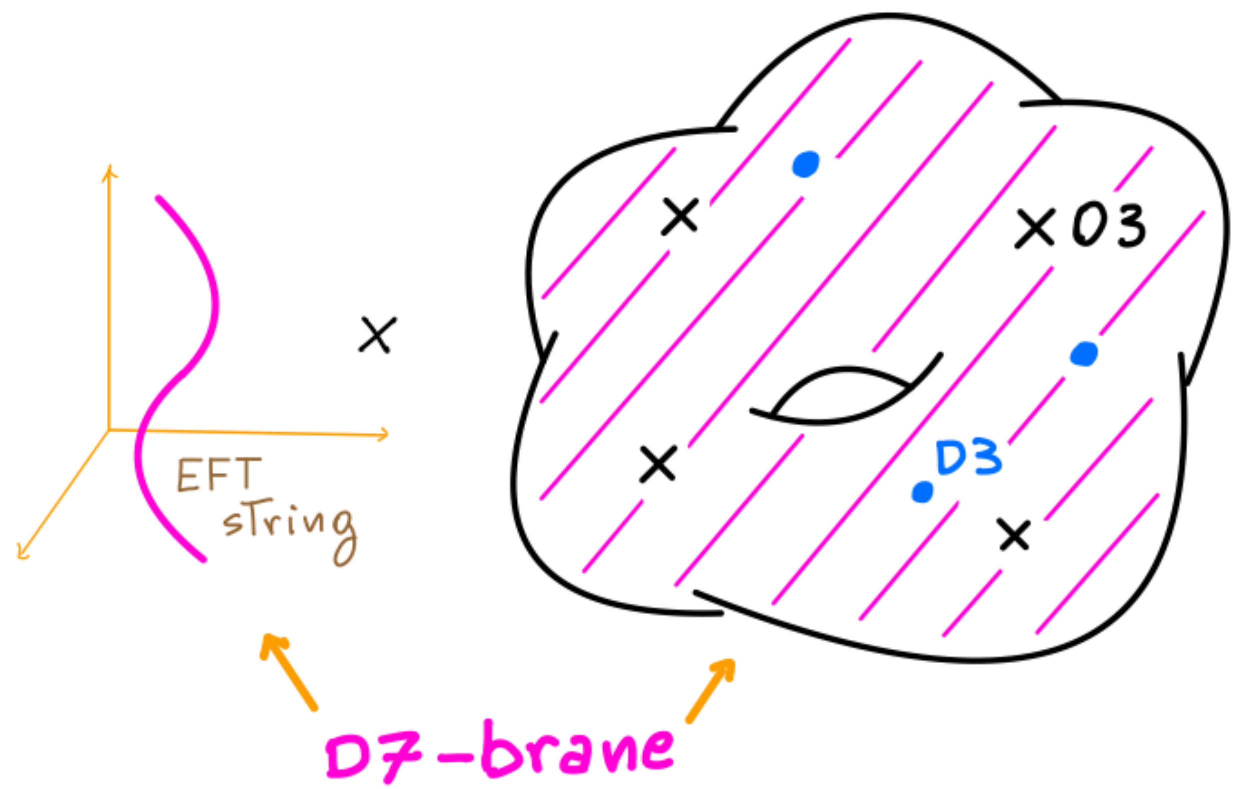
$\Downarrow$

$$n_{O3} \in 16\mathbb{N}$$



[Carta-Moritz-Westphal '20]

→ Tested over ~10^6 models by F. Carta

agrees with Theorem by [Favale '17]

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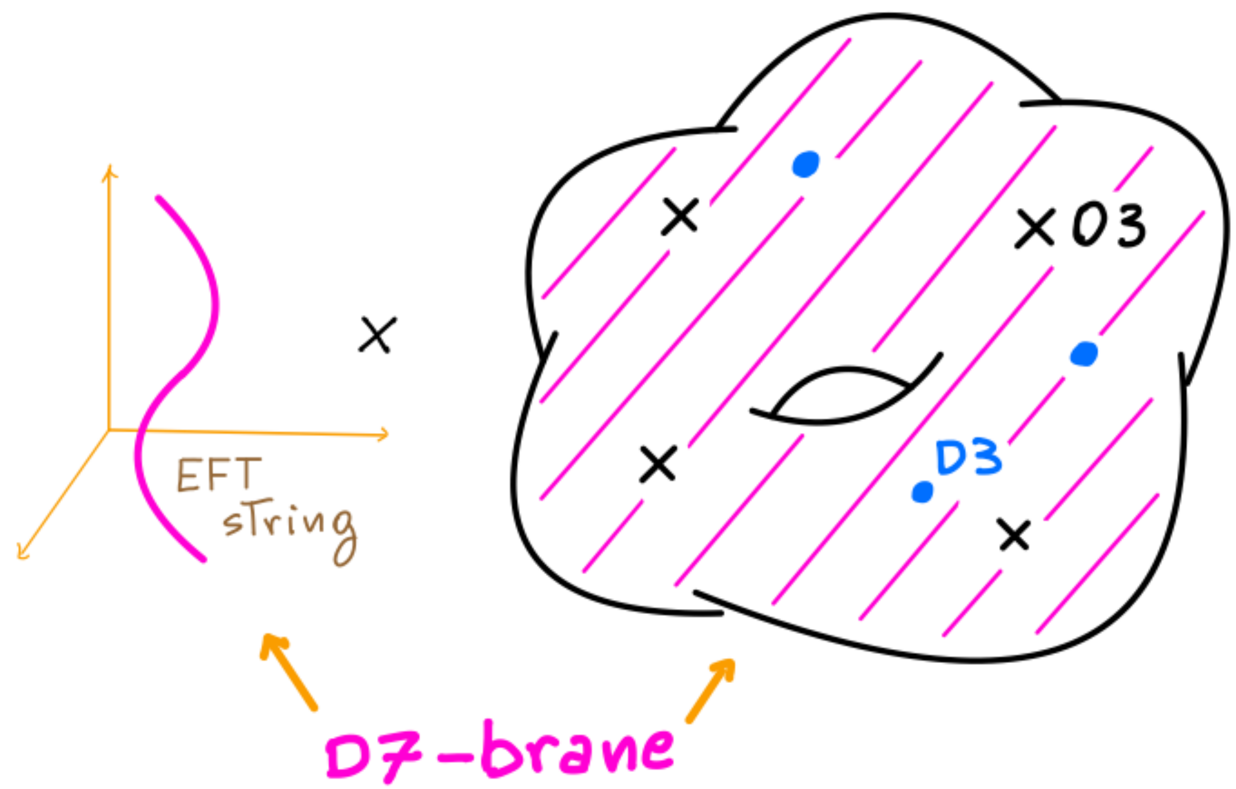

[Carta-Moritz-Westphal '20]

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(3) $r(\mathbf{e}) = n_{D3} \leq \frac{4}{3}\tilde{C}_i e^i = \frac{1}{4} n_{O3}$ $\longleftrightarrow$ $$4n_{D3} \leq n_{O3}$$

D3 Tadpole bound

Conclusions

- EFT strings are physical probes of asymptotic field space regions

- Constraints on gauge and (curvature)^2 sectors

  * Positivity of GB terms and upper bounds on gauge group ranks

  * All bounds microscopically verified (… so far)

  * Geometrical predictions (on O-planes, Mordell-Weil group, …)

- Possible contribution to anomaly inflow detecting hidden 5d structure

  ⟶ present in heterotic M-theory models

see upcoming paper [LM-Risso-Wegand '22]

A subtle contribution

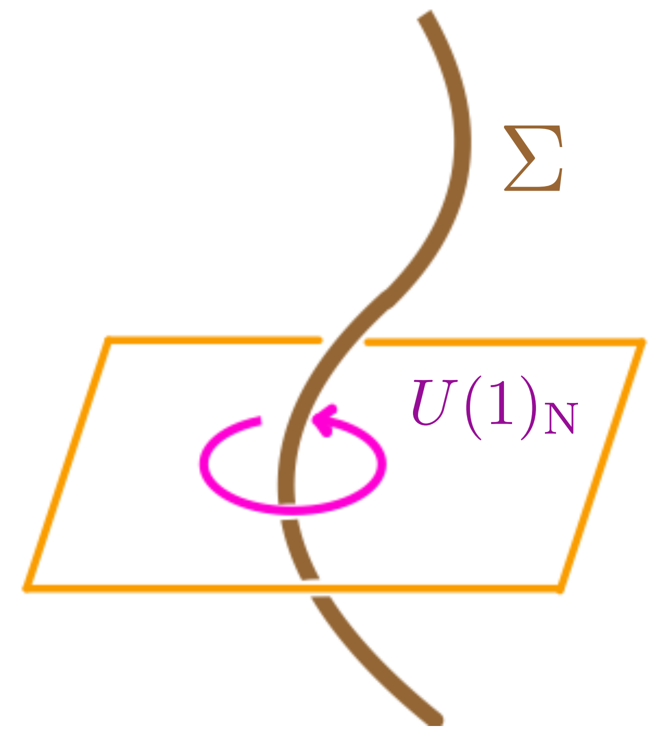
- Axionic strings in 4 dimensions can support additional term

[Witten `96]
[Becker-Becker `99]

$$-\frac{1}{24}\hat{C}_{ijk}e^j e^k \int_\Sigma \mathrm{d}a^i \wedge A_\mathrm{N}$$

it captures hidden 5d structure

$$\hat{C}_{ijk} \int_{5d} A^i \wedge F^j \wedge F^k$$



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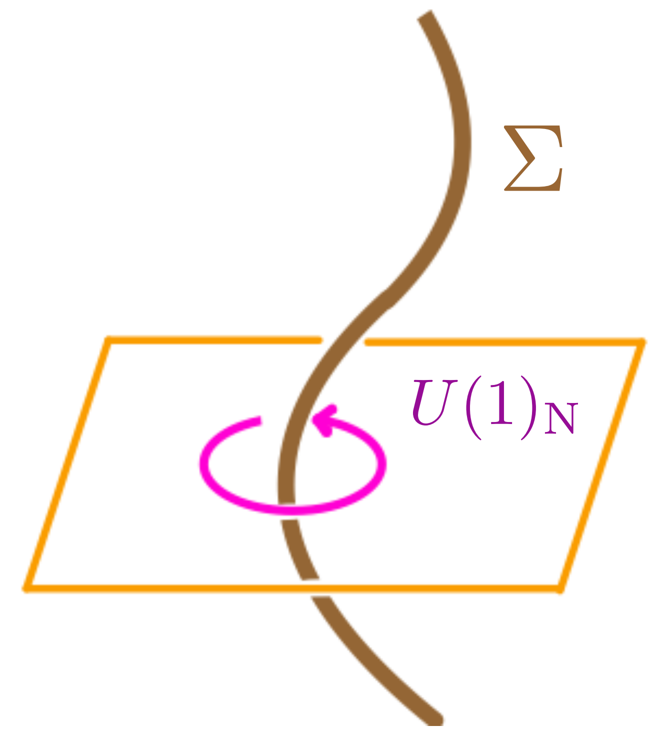


it captures hidden 5d structure

$$\hat{C}_{ijk} \int_{5d} A^i \wedge F^j \wedge F^k$$

$\Downarrow$

contributes to anomaly inflow and anomaly matching

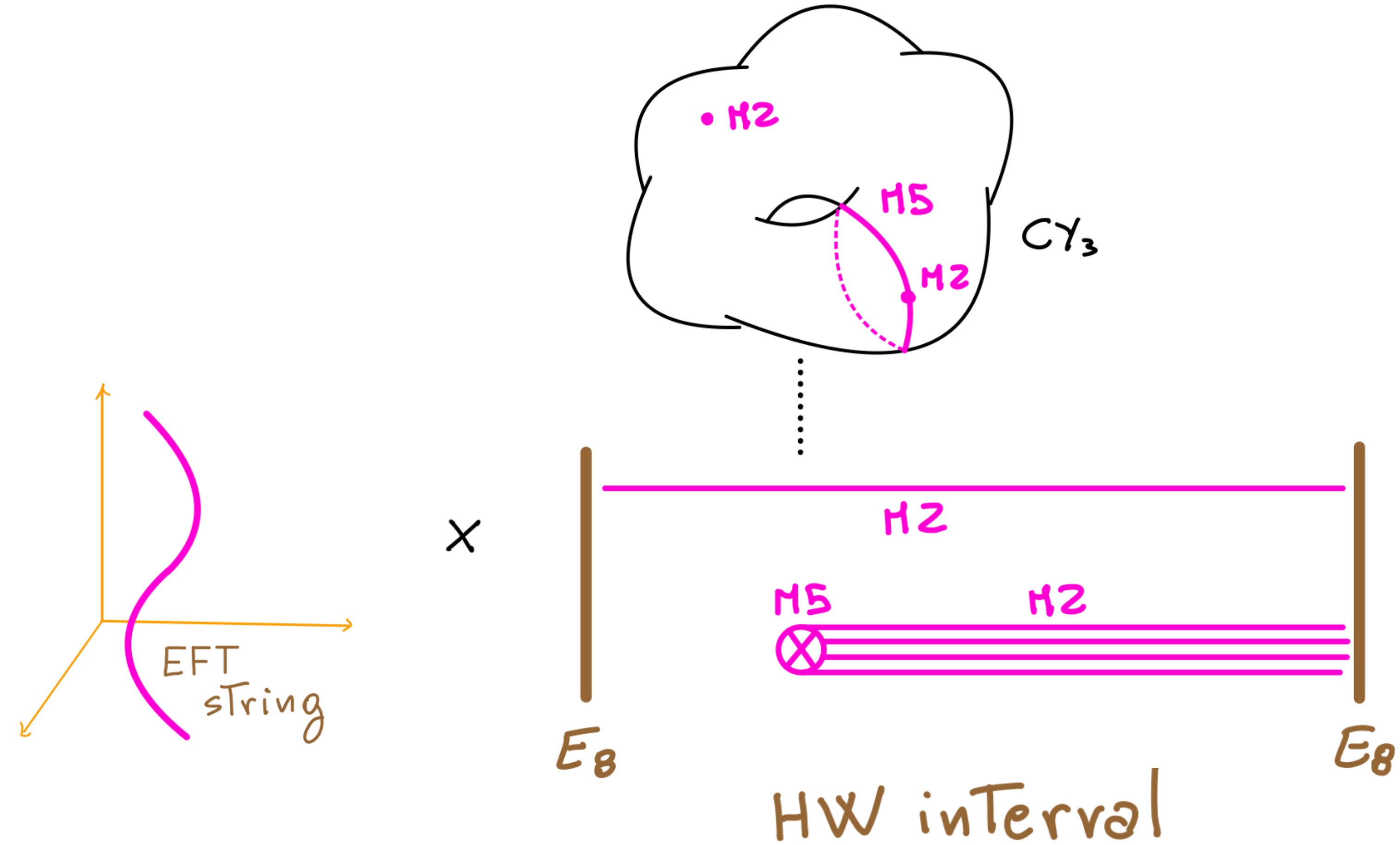
(2) $$4\tilde{C}_i e^i + \hat{C}_{ijk}e^i e^j e^k \in 3\mathbb{Z}\,, \quad \forall \mathbf{e} \in \mathcal{C}_{\mathrm{S}}^{\mathrm{EFT}}$$

(3) $$r(\mathbf{e}) \leq \frac{1}{3}\left(4\tilde{C}_i e^i + \hat{C}_{ijk}e^i e^j e^k\right)\,, \quad \forall \mathbf{e} \in \mathcal{C}_{\mathrm{S}}^{\mathrm{EFT}}$$

UV test: heterotic models

- EFT-strings:

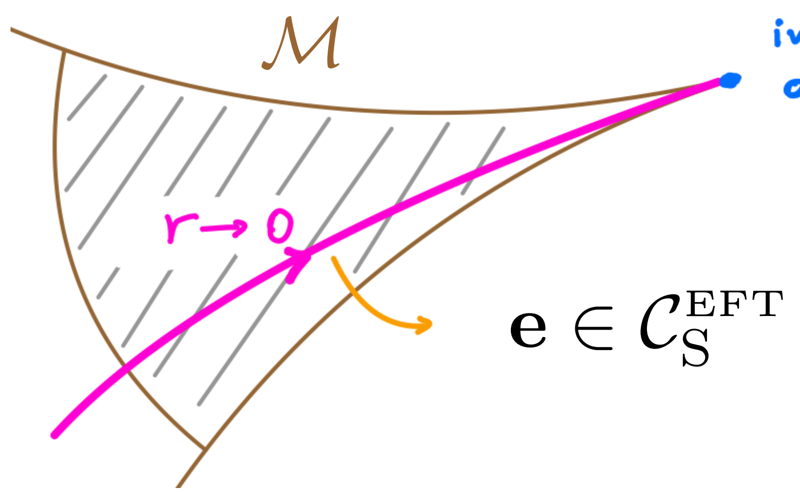
  * F1/M2
  * NS5/M5 on nef divisors
  * $\hat{C}_{ijk} = D_i \cdot D_j \cdot D_k$



(3) $\Longrightarrow$

$$r(\mathbf{e}_{\mathrm{F1}}) \leq 16 \quad ✓$$

$$r(\mathbf{e}_{\mathrm{NS5}}) \leq 8k + q \quad ✓$$

* 

Distant Axionic String Conjecture

(see also [Grimm, Lanza, Li '22])

* $\mathcal{T}_{\mathbf{e}} \to 0$ along EFT string flows

EFT realization of Distance Conjecture

[Ooguri-Vafa '06]

* $m^2_{\text{UV-tower}} \sim M_{\rm P}^2 \left(\frac{\mathcal{T}_{\rm e}}{M_{\rm P}^2}\right)^{w_{\mathbf{e}}} \longrightarrow 0$

$w_{\mathbf{e}} = 1, 2, 3$ scaling weight

Integral Scaling Weight Conjecture