Large field distances from EFT strings

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

2104.05726 , 2006.15154
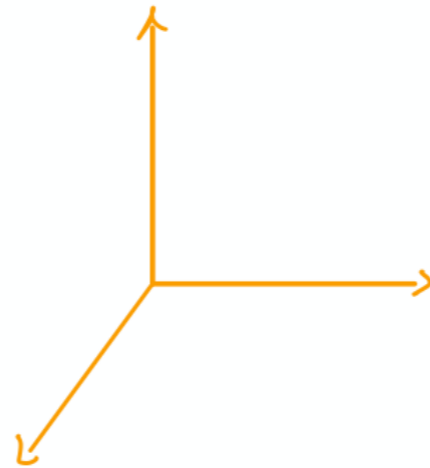
- In string models, plenty of fundamental 4d axions $(\;\phi = ve^{ia}\;)$

see also
[Reece '18]

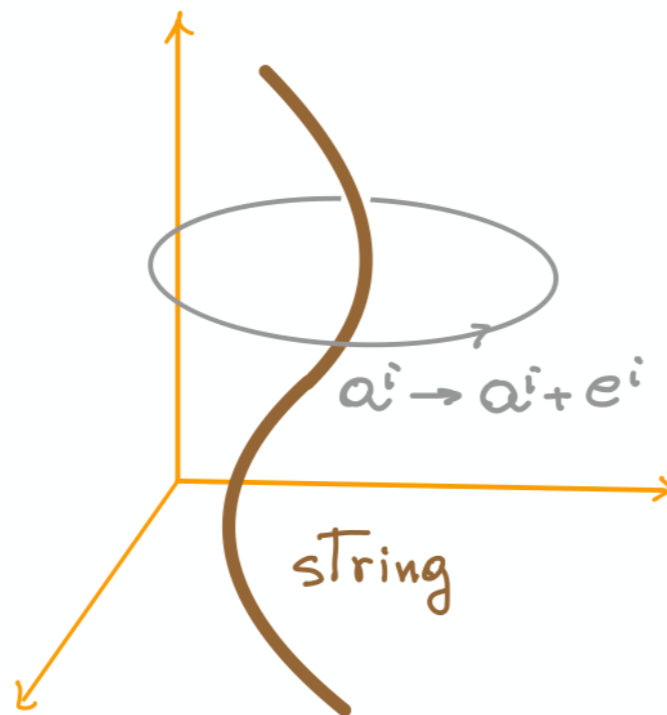$$A_q = a^i(x)\omega_i$$
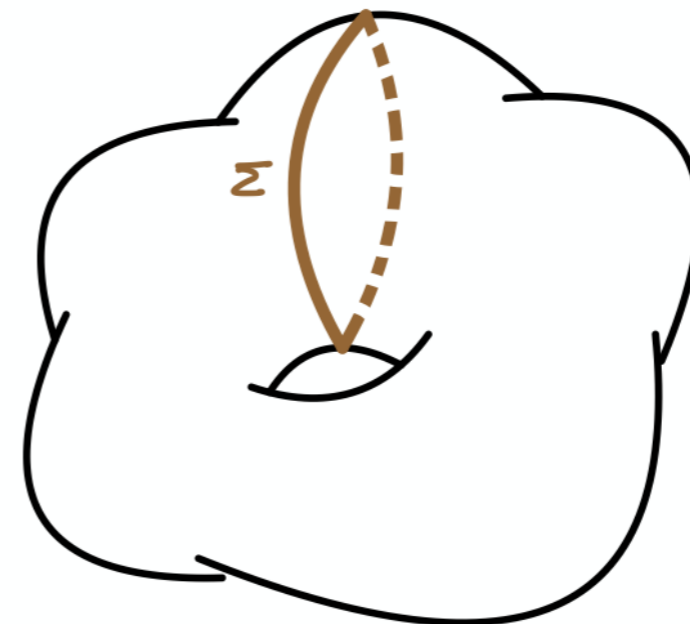
$$\omega_i \in H^q(X,\mathbb{Z})$$

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

$\times$

X

- Naturally associated with fundamental axionic strings

$a^i \to a^i + e^i$
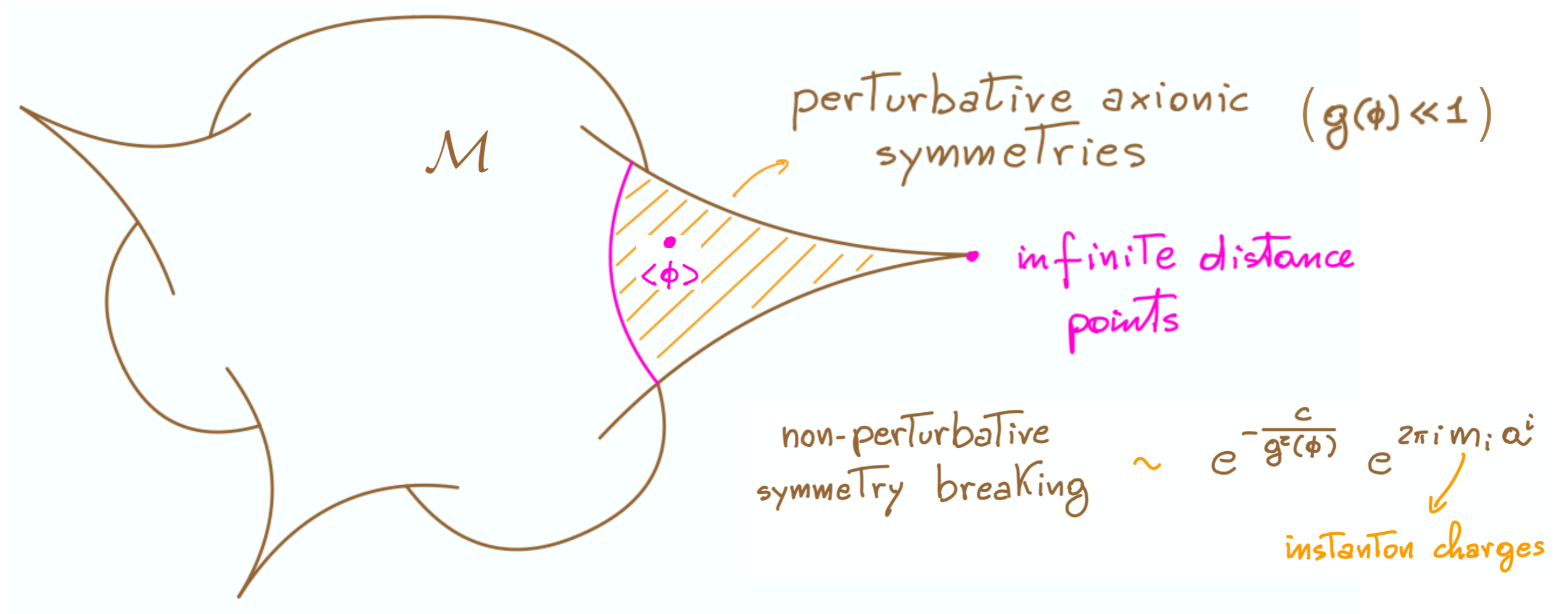
$\times$

string

Σ

no global
symmetries in QG $\implies$ perturbative
axionic symmetry! $a^i \to a^i + \text{const.}$

[..., Kallosh-Linde-Linde-Susskind '95, ...,
Banks & Seiberg '06,...]

$\mathcal{M}$

perturbative axionic
symmetries $(g(\phi) \ll 1)$

$\langle \phi \rangle$

infinite distance
points

non-perturbative
symmetry breaking $\sim e^{-\frac{c}{g^2(\phi)}} e^{2\pi i m_i a^i}$

instanton charges

Fundamental axionic strings as natural probes of asymptotic regions

String flows to infinite distances

- In $\mathcal{N}=1$ EFTs: $t^i \equiv a^i + \mathrm{i}\, s^i$ $\xleftrightarrow{\mathcal{N}=1 \text{ duality}}$ $\mathcal{B}_{2,i}\ ,\quad \ell_i = -\frac{1}{2}\frac{\partial K}{\partial s^i}$

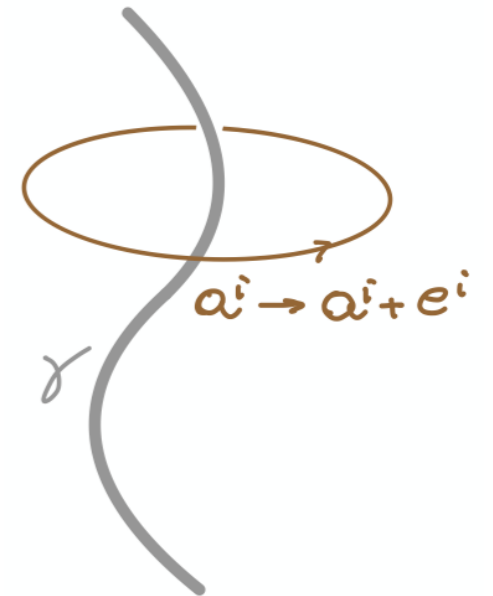 axions   saxions   dual saxions

  (chiral mult.)   (linear mult.)

  [Lindstrom-Rocek '83]

- EFT description

$$S_{4d} = \frac{M_P^2}{2}\int_{\text{bulk}} R + \ldots \; - \int_\gamma \mathcal{T}_e \sqrt{-g} \; + e^i \int_\gamma \mathcal{B}_{2,i} + \ldots$$
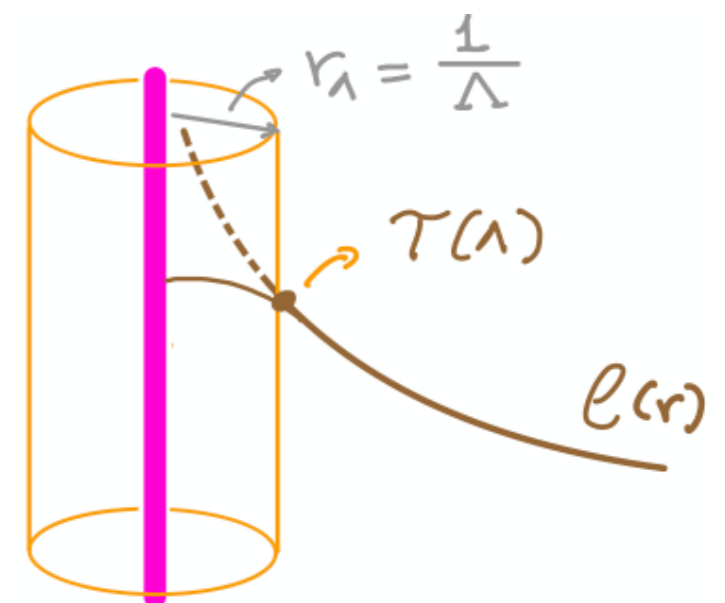
$$\mathcal{T}_{\mathbf{e}} = M_P^2 e^i \ell_i$$

[Lanza-Marchesano-LM-Sorokin '19]

$a^i \to a^i + e^i$

γ

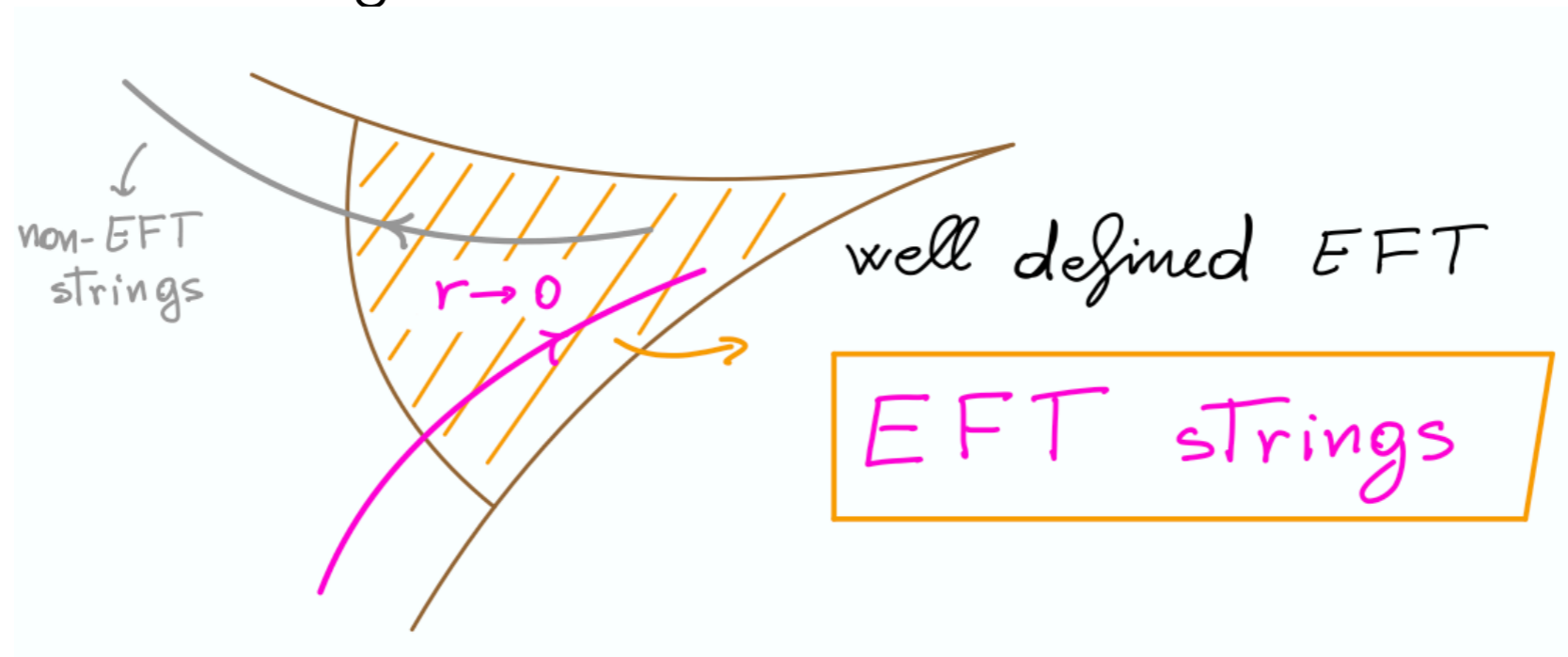- "Brany" EFT viewpoint: string backreaction as RG-flow

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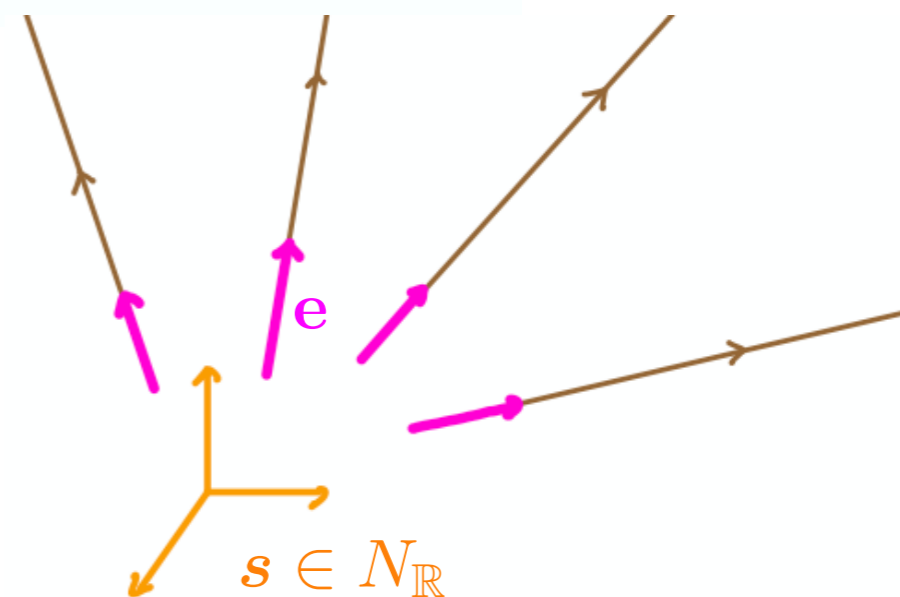Michel-Mintun-Polchiski-Puhm-Saad '14, Polchinski '15]

$r_\Lambda = \frac{1}{\Lambda}$

$\mathcal{T}(\Lambda)$

$\ell(r)$

- Different possible string flows

non-EFT strings

$r \to 0$

well defined EFT

EFT strings

- Near core region: BPS string flows

  [... Greene-Shapere-Vafa-Yau '90,
  Dabholkar-Gibbons-Harvey-Ruiz Ruiz '90, ...]

e

$s \in N_{\mathbb{R}}$

- In all considered string/M-theory models:

Infinite field distance points $\longleftrightarrow$ endpoints of EFT string flows $\Rightarrow$ Distant Axionic String Conjecture

From WGC to SDC

- In all string theory models:

$$\mathcal{Q}_\mathbf{e} \geq \gamma \mathcal{T}_\mathbf{e}$$

Weak Gravity bound

[Arkani-Hamed, Motl, Nicolis, Vafa `06]
[Hebecker-Soler `17]

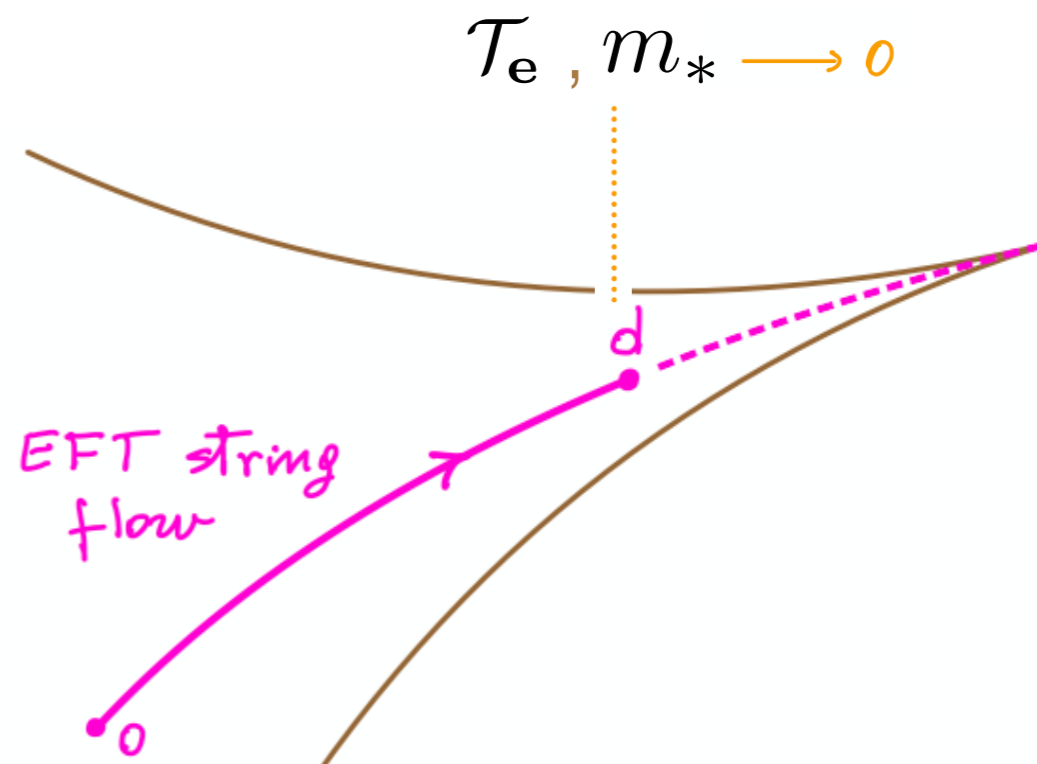$$\sqrt{\mathcal{G}_{ij} e^i e^j}$$

$$K = - \log P(s)$$

$\hookrightarrow$ homogeneous

- EFT string flow + WG-bound

$\Downarrow$

$$\mathcal{T}_\mathbf{e} \leq \mathcal{T}_\mathbf{e}^0 \exp(-\gamma d)$$

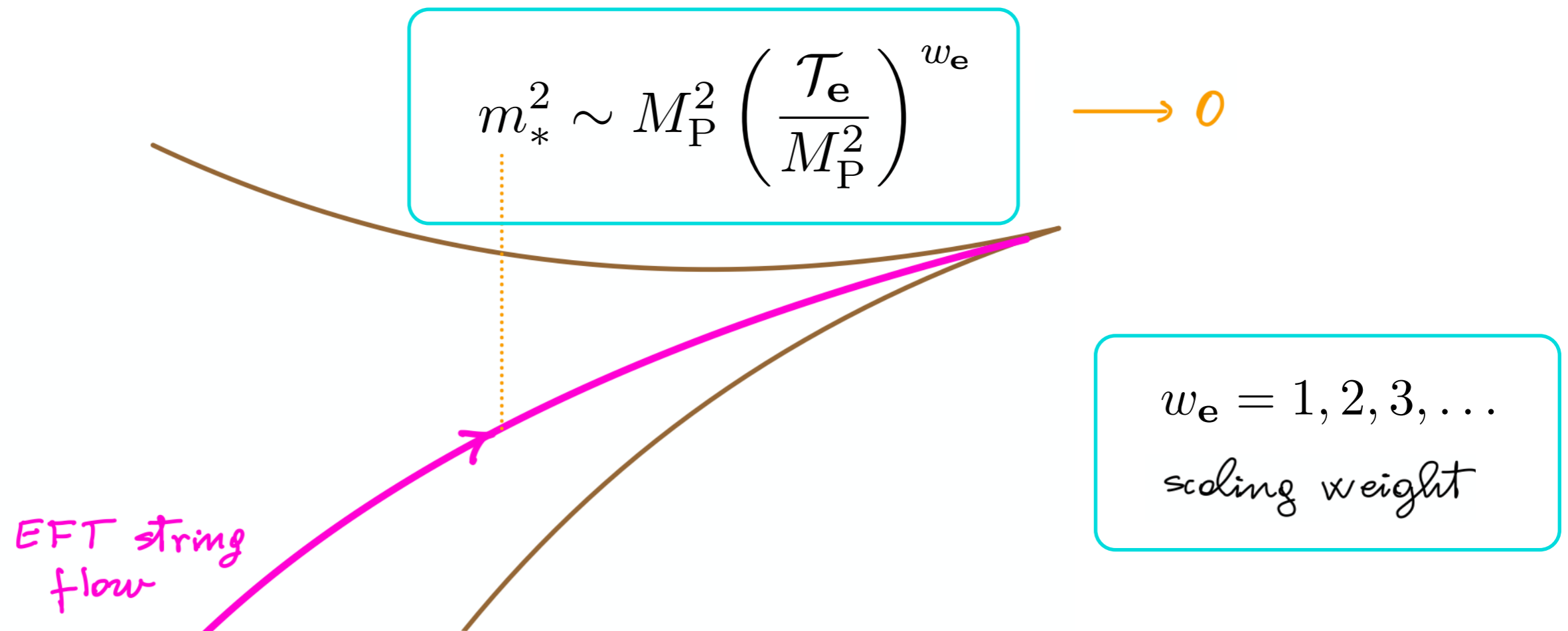EFT realization of
Swampland Distance Conjecture

[Ooguri-Vafa '06]

$\mathcal{T}_\mathbf{e} , m_* \longrightarrow 0$

d

EFT string flow

0

- Relation between $\mathcal{T}_\mathbf{e}$ and m_*?

EFT   microscopic

String/M-theory evidence ⟶ a second new swampland conjecture

$$m_*^2 \sim M_{\mathrm{P}}^2 \left(\frac{\mathcal{T}_{\mathbf{e}}}{M_{\mathrm{P}}^2} \right)^{w_{\mathbf{e}}} \quad \longrightarrow \; 0$$

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

scaling weight

EFT string flow

* UV information from EFT

* if $w_{\mathbf{e}} = 1$ EFT string modes compete with microscopic tower

Emergent String Conjecture ⟹ dual to F1 strings!

[Lee-Lerche-Weigand '19]

An example

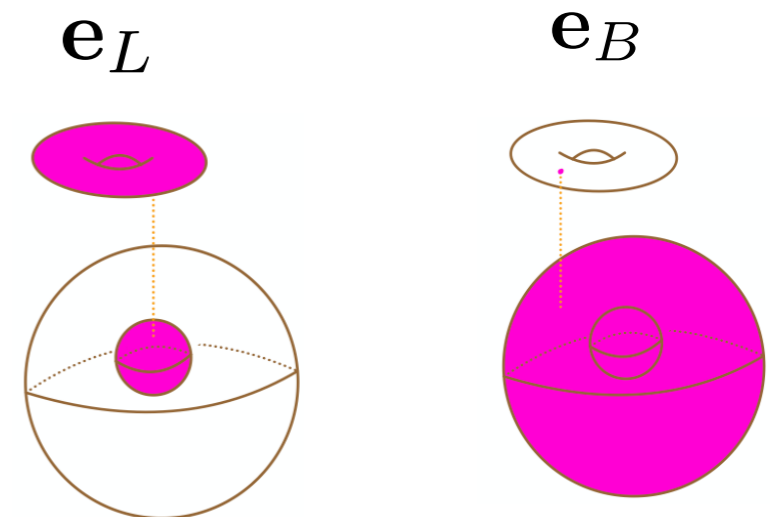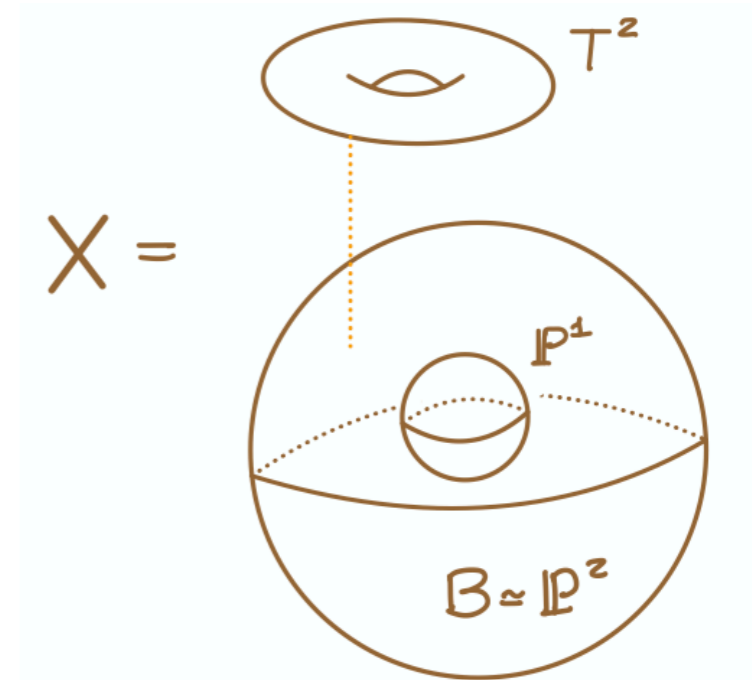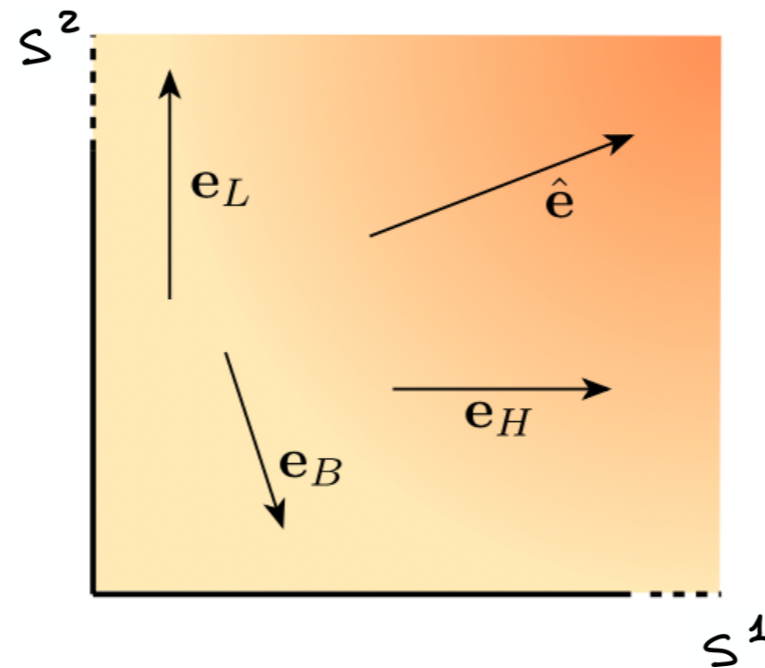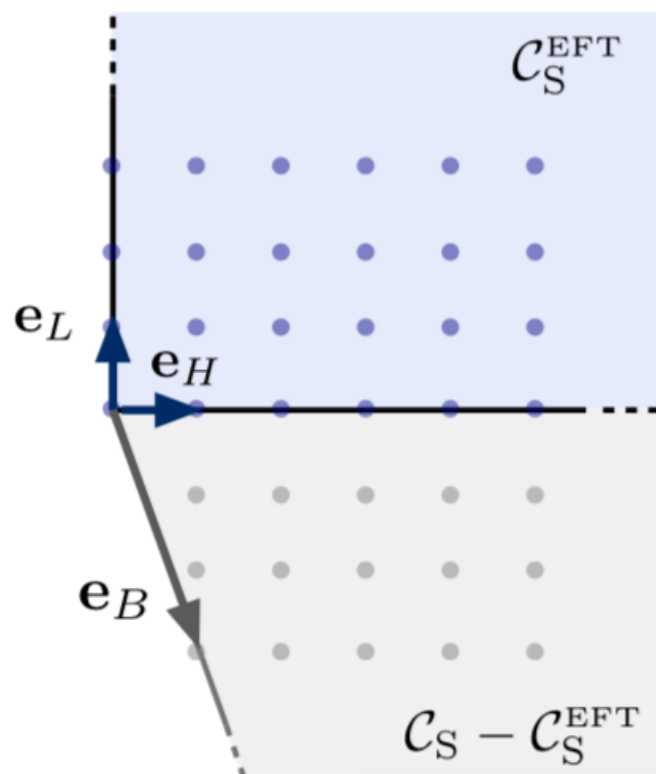# Heterotic compactification on $X = \mathrm{CY}_3$

[Candelas-Font-Katz-Morrison '94]

$$s \in (s^1, s^2) \quad \in \mathbb{R}^2_{>0}$$

$$\mathrm{Vol}(T^2) \qquad \mathrm{Vol}(\mathbb{P}^1)$$

T^2

$X =$

$\mathbb{P}^1$

$B \simeq \mathbb{P}^2$

string charges $\mathbf{e} \in \mathbb{Z}^2$

$\mathcal{C}_S^{\mathrm{EFT}}$

$\mathbf{e}_L$

$\mathbf{e}_H$

$\mathbf{e}_B$

$\mathcal{C}_S - \mathcal{C}_S^{\mathrm{EFT}}$

s^2

$\mathbf{e}_L$ $\quad \hat{\mathbf{e}}$

$\mathbf{e}_H$

$\mathbf{e}_B$

s^1

$\mathbf{e}_L$ $\qquad \mathbf{e}_B$

$$\mathbf{e}_H = \mathbf{e}_B + 3\mathbf{e}_L$$

BPS strings: $\mathcal{C}_S = \{\text{NS5 on effective divisors}\}$

EFT strings: $\mathcal{C}_S^{\mathrm{EFT}} = \{\text{NS5 on nef divisors}\}$
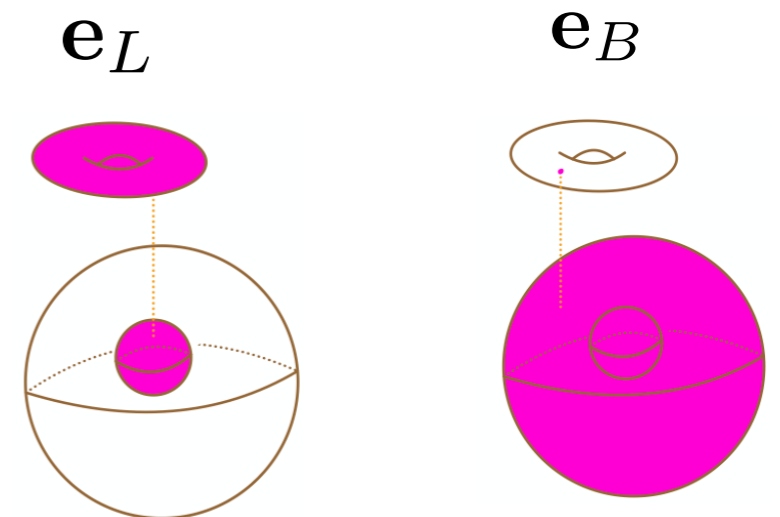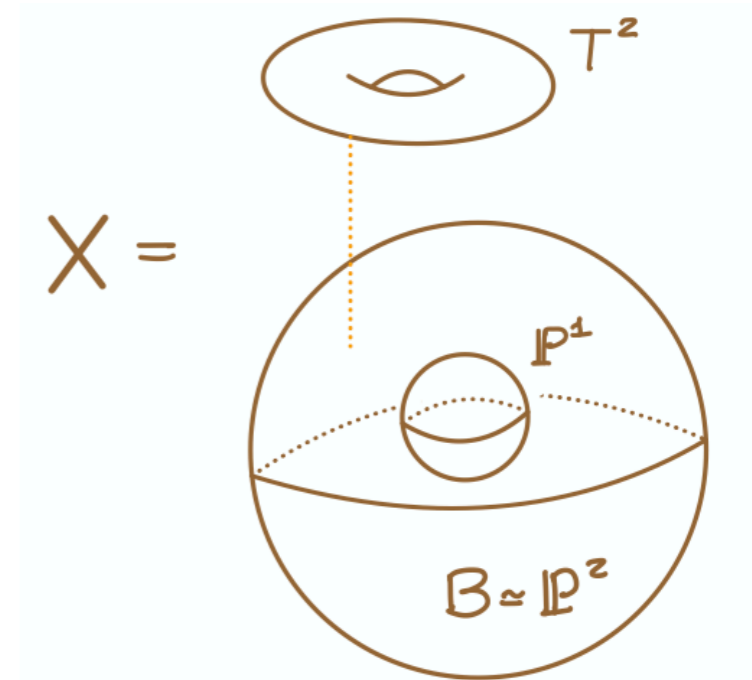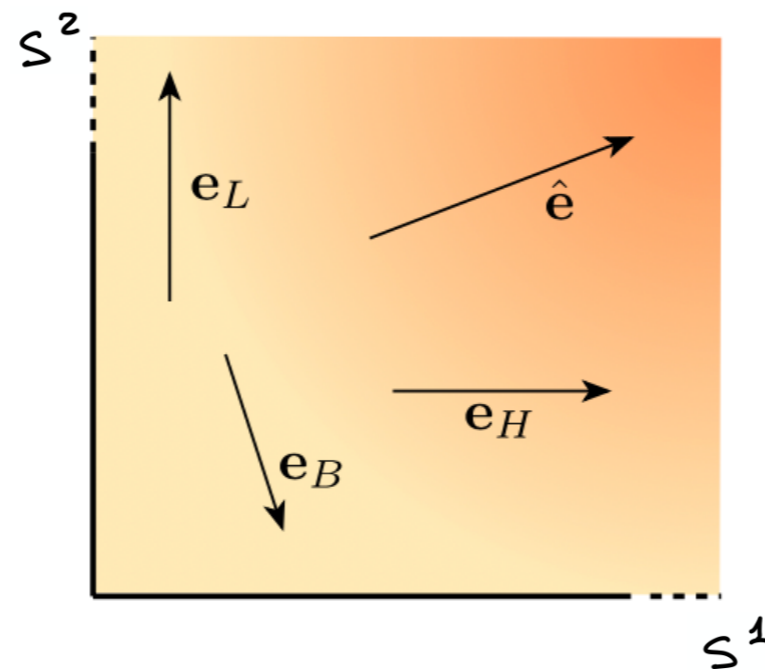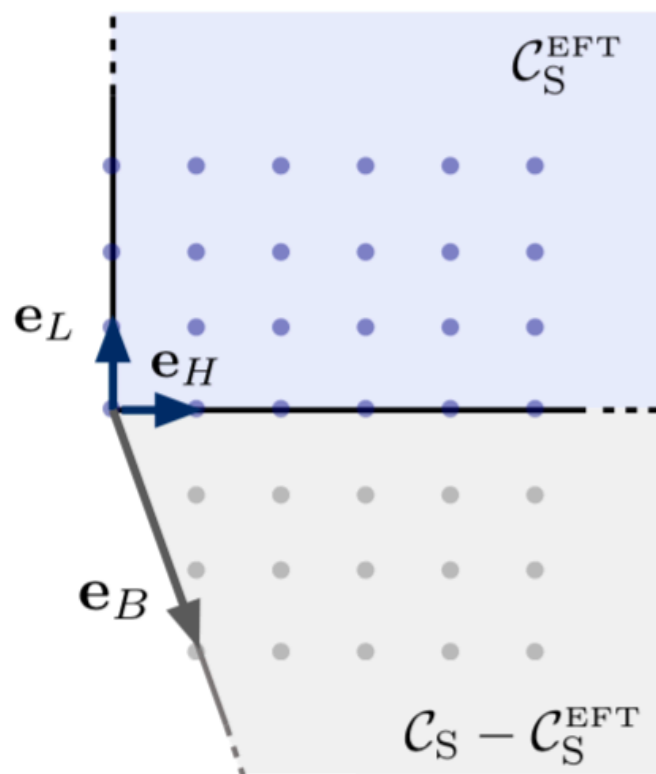
Heterotic compactification on $X = \mathrm{CY}_3$

[Candelas-Font-Katz-Morrison '94]

$$s \in (s^1, s^2) \quad \in \mathbb{R}^2_{>0}$$

$\mathrm{Vol}(T^2)$ $\mathrm{Vol}(\mathbb{P}^1)$

string charges $\mathbf{e} \in \mathbb{Z}^2$

$$T^2$$
$$X =$$
$$\mathbb{P}^1$$
$$B \simeq \mathbb{P}^2$$

$\mathcal{C}_S^{\mathrm{EFT}}$

$\mathbf{e}_L$ $\mathbf{e}_H$

$\mathbf{e}_B$

$\mathcal{C}_S - \mathcal{C}_S^{\mathrm{EFT}}$

s^2

$\mathbf{e}_L$ $\hat{\mathbf{e}}$

$\mathbf{e}_H$

$\mathbf{e}_B$

s^1

$\mathbf{e}_L$ $\mathbf{e}_B$

$$\mathbf{e}_H = \mathbf{e}_B + 3\mathbf{e}_L$$

scaling weight

$$w_{\mathbf{e}_L} = 2$$
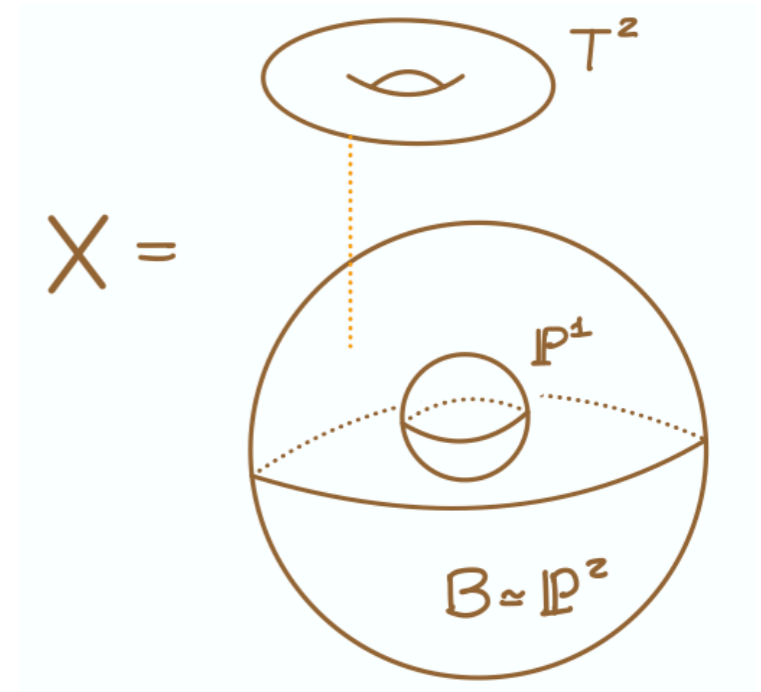$$w_{\mathbf{e}_H} = w_{\hat{\mathbf{e}}} = 3$$

- Heterotic compactification on $X = \mathrm{CY}_3$ [Candelas-Font-Katz-Morrison '94]

$$\boldsymbol{s} \in (\, s^1 \,,\, s^2 \,) \qquad \in \mathbb{R}^2_{>0}$$

$\mathrm{Vol}(T^2)$ $\qquad$ $\mathrm{Vol}(\mathbb{P}^1)$

$X =$

T^2

$\mathbb{P}^1$

$B \simeq \mathbb{P}^2$

- F1 string flow: $\quad \hat{s} = e^{-2\phi}\mathrm{Vol}(X) \to \infty \quad \Longleftrightarrow \quad e^{\phi} \rightsquigarrow 0$

$$w_{F1} = 1 \qquad (\sim \text{Emergent String})$$

[Lee-Lerche-Weigand '19]

Concluding remarks

* EFT strings characterise asymptotic field space regions

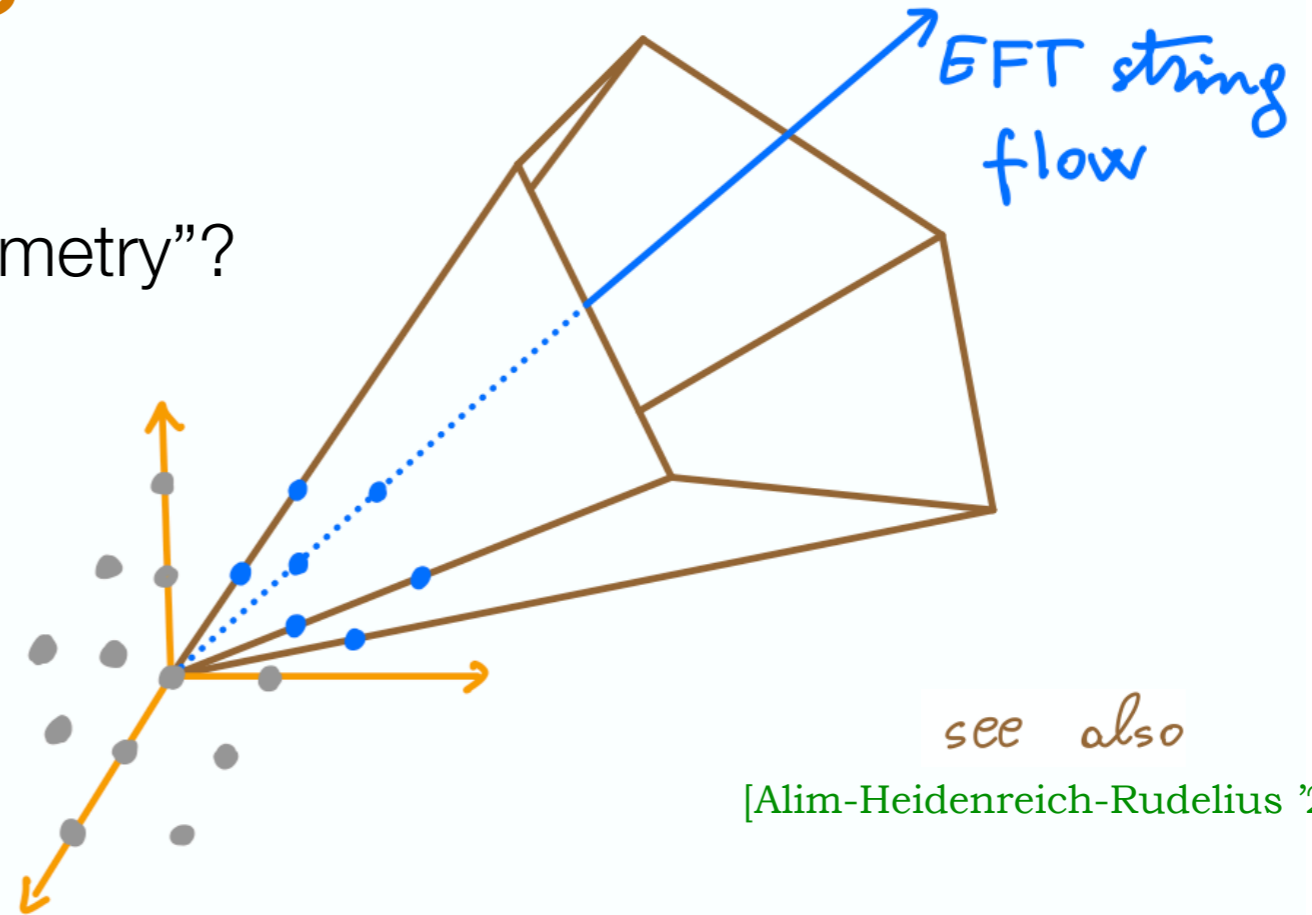   * EFT string flows as infinite field distance limits

    * EFT realisation of SDC

    * $m_*^2 \sim \mathcal{T}^w$ with $w = 1, 2, 3$

Concluding remarks

EFT string flow

📌 UV completion and "Positive Geometry"?

see also
[Alim-Heidenreich-Rudelius '21]

✳ EFT strings generate cone of 'movable' internal objects:
truly gravitational!

~ supergravity strings in $d \geqslant 5$

[Kim-Shiu-Vafa `19]

[Katz-Kim-Tarazi-Vafa '20]

✳ EFT string completeness

see also   [Katz-Kim-Tarazi-Vafa '20]

✳ Walls of stability

Concluding remarks

📌 Connection with cobordism conjecture   [Buratti, Calderón-Infante, Delgado, Uranga `21]

📌 Connection with moduli space holography?   [Grimm `20]
[Grimm, Monnee , van de Heisteeg `21]

📌 Swampland conditions from world-sheet matter?   [Kim-Shiu-Vafa `19]
[Lee-Weigand `19]
[Kim-Tarazi-Vafa '20]
[Katz-Kim-Tarazi-Vafa '20]
[Heidenreich-Reece-Rudelius '21]

📌 Phenomenology of EFT strings?   [March-Russell & Tillim `21]

Thanks