Generalized Symmetries, Gravity, and Topological Non-Decoupling

Jonathan J. Heckman

University of Pennsylvania

Based On:

hep-th/????.????? w/ Baume, Hübner, Torres, Turner, Yu

hep-th/????.????? w/ Cvetič, Hübner, Torres

hep-th/2305.09665 w/ Cvetič, Hübner, Torres

hep-th/2305.05689 w/ Dierigl, Montero, Torres

hep-th/2212.09743 w/ Hübner, Torres, Yu, Zhang

hep-th/2209.03343 w/ Hübner, Torres, Zhang

As Well As:

hep-th/1503.04806 w/ Del Zotto, Park, Rudelius

See Also Talks By:

Bhardwaj

Cvetic

Dierigl

Garcia Etxebarria

Hubner

Liu

Oehlmann

Wang

Question...

What is the Gauge Group of the Standard Model?

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a) $SU(3) \times SU(2) \times U(1)$

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b) $SU(3) \times SU(2) \times U(1)/\mathbb{Z}_m$ (for some $m = 2, 3, 6$)

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c) The question is too vague as stated.

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We need to know about other gauge groups.

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We need to know about other gauge groups.
And we need to know about charged states.

How To Tell?

Find all the charged states / their reps

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Find all the charged states / their reps

Note: In SM, nothing is “just” in rep of $SU(3)$:
(MSSM Chiral Mult. Not^n)

$$Q : (3, 2)_{+1/6}$$

$$U : (\overline{3}, 1)_{-2/3}$$

$$D : (\overline{3}, 1)_{+1/3}$$

How To Tell?

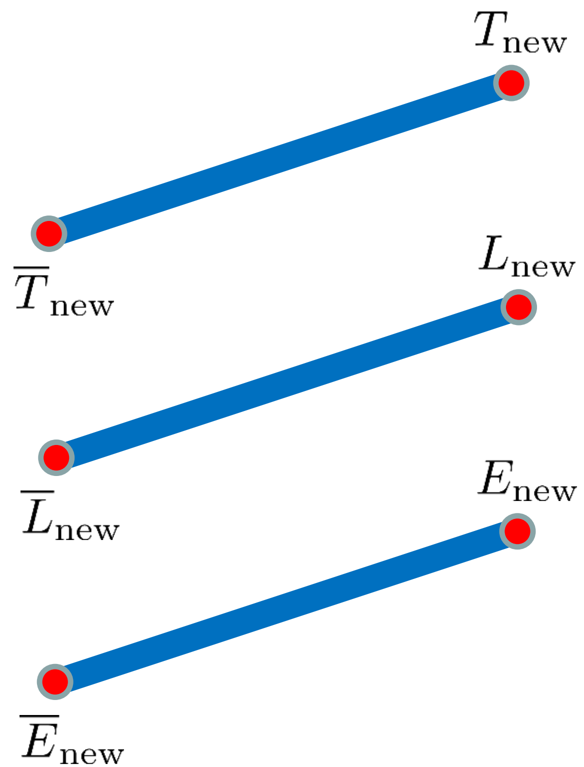
Find all the charged states / their reps

¿$SU(3) \times SU(2) \times U(1)$?

Find $T_{\text{new}} = (3,1)_0$

Find $L_{\text{new}} = (1,2)_0$

Find $E_{\text{new}} = (1,1)_q$



How To Tell?

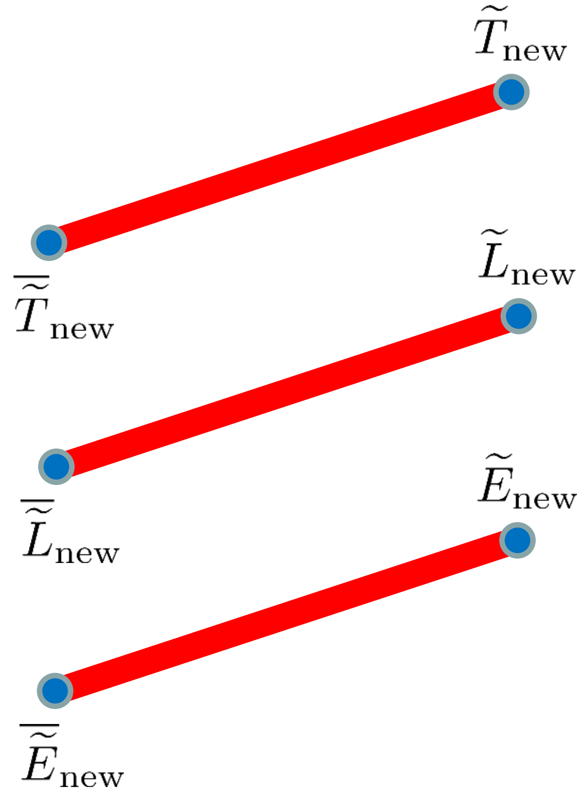
Find all the charged states / their reps

¿$SU(3) \times SU(2) \times U(1)/\mathbb{Z}_6$?

Find $\widetilde{T}_{\rm new}$

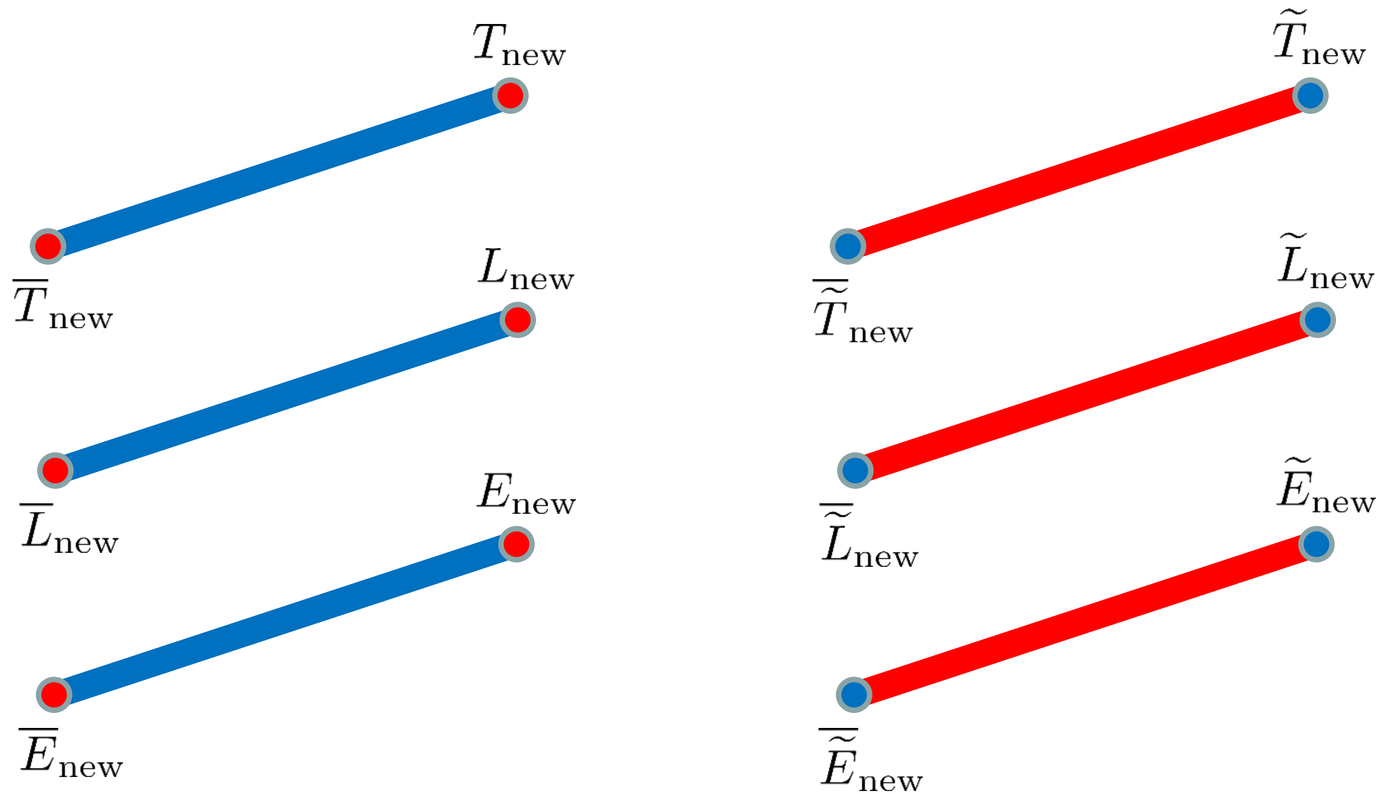
Find $\widetilde{L}_{\rm new}$

Find $\widetilde{E}_{\rm new}$



Formal Answer:

Find the spectrum of extended line operators



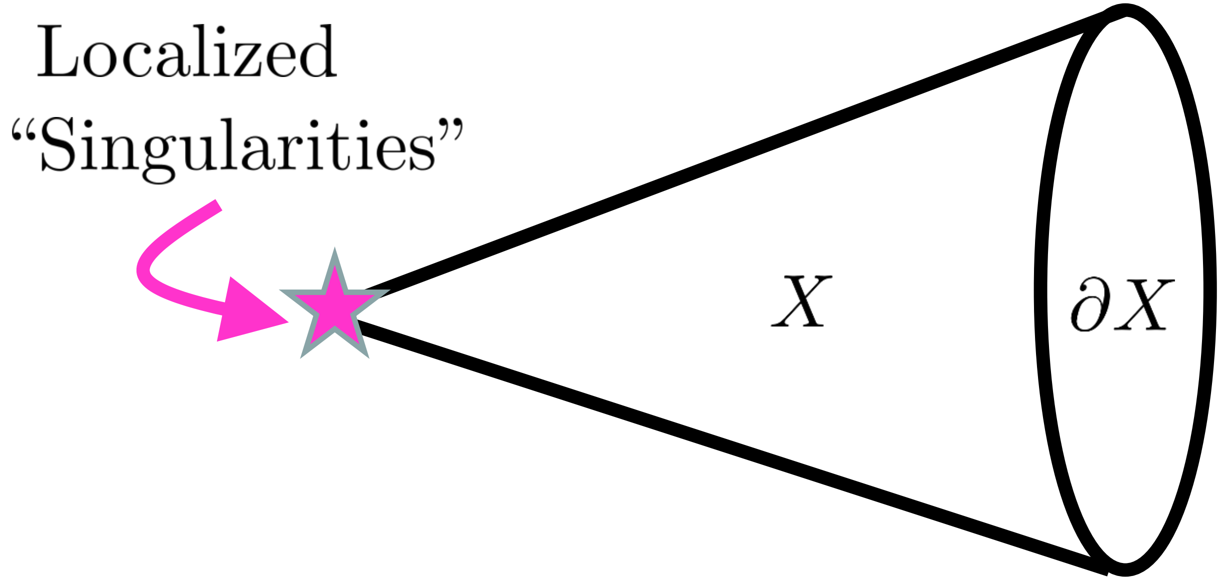
What is the Gauge Group of the Standard Model?

c) The question is too vague as stated.
We need to know about other gauge groups.
And we need to know about charged states.

Stringy Perspective

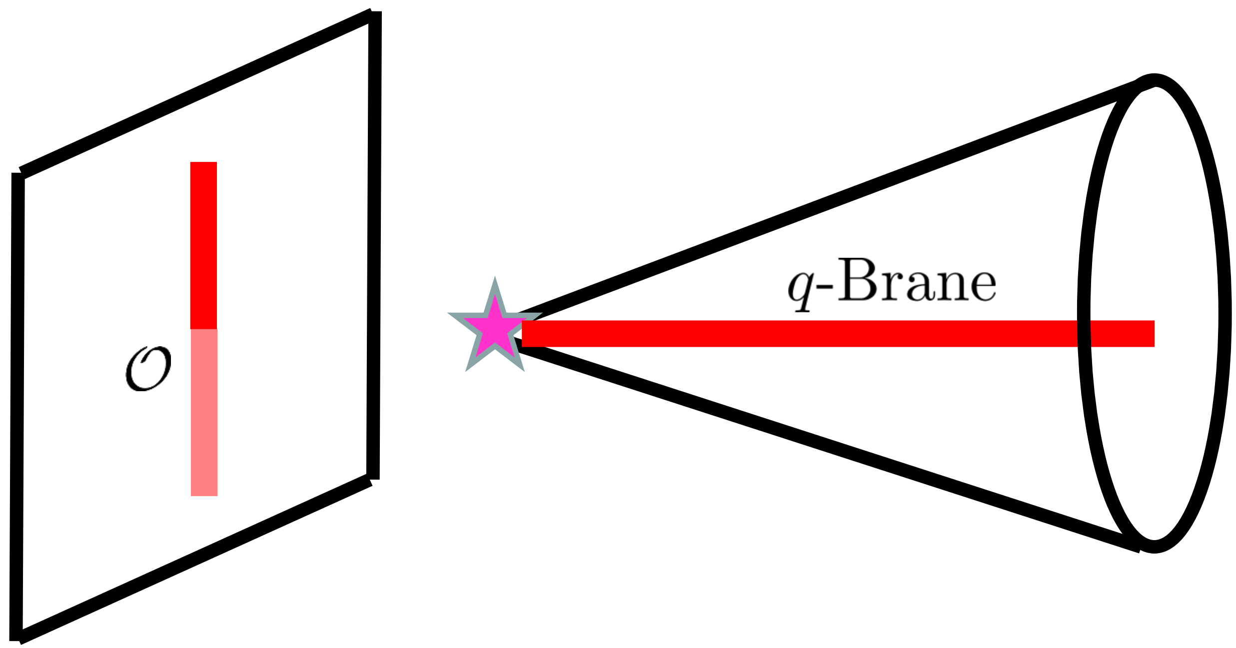
Engineering QFTs

String Background: $\mathbb{R}^{D-1,1} \times X_{\text{ncpct}}$



Del Zotto JJH Park Rudelius '15 Albertini Del Zotto Garcia Etxebarria Hosseini '20
Morrison Schafer-Nameki Willett '20

Engineering Heavy Defects



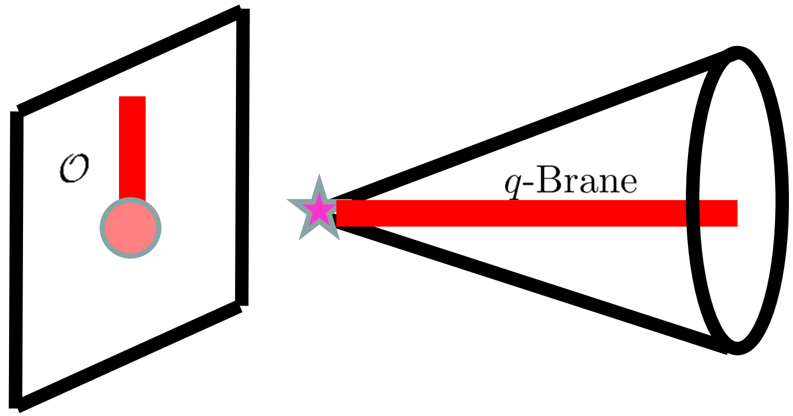
Wrap Brane on Cycle $\in H_{k+1}(X, \partial X)$

$\Rightarrow (q+1) - (k+1)$ dimensional defect in spacetime

Del Zotto JJH Park Rudelius '15 Albertini Del Zotto Garcia Etxebarria Hosseini '20

Morrison Schafer-Nameki Willett '20

Screening Heavy Defects



Wrap Brane on Cycle $\in H_{k+1}(X, \partial X)$

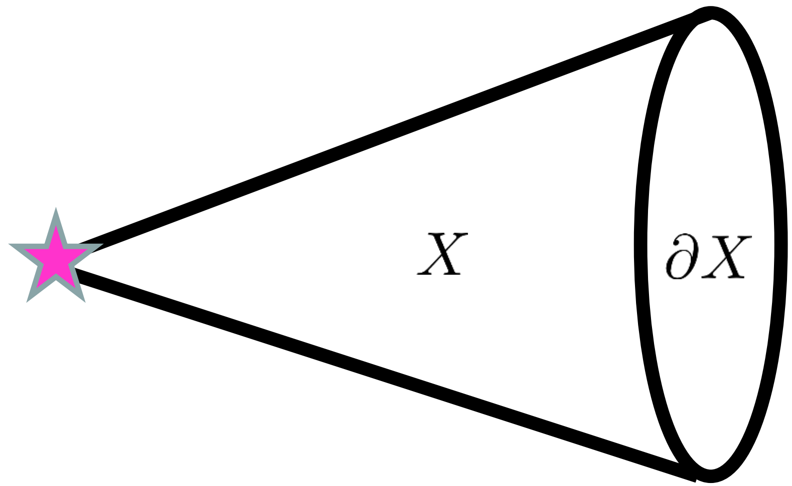
(Partially Screened) By q-Brane on $H^{\text{cpct}}_{k+1}(X)$

QFT Characterization: 

$((q+1)-(k+1))$-Form Symm: $\frac{H_{k+1}(X,\partial X)}{H^{\text{cpct}}_{k+1}(X)}$

Spectrum of Defects?

Choose Boundary Conditions on ∂X:

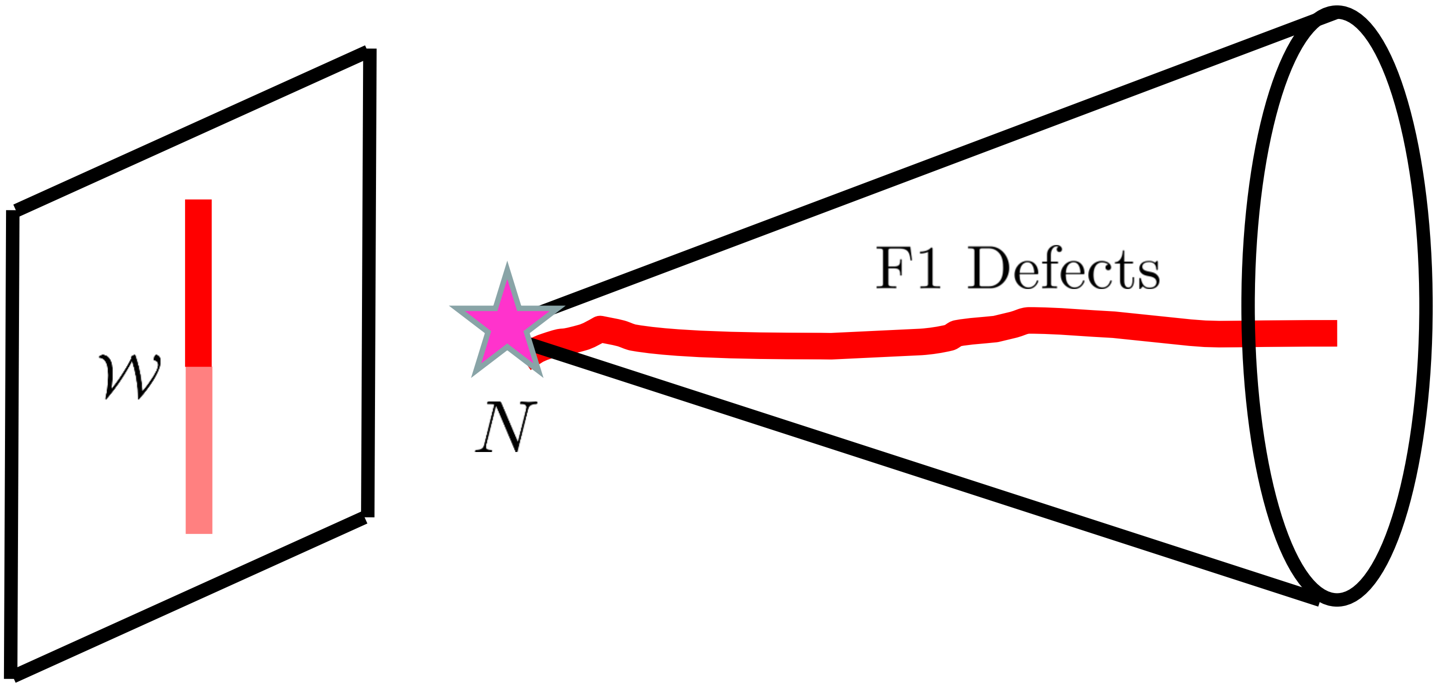


e.g., $SU(N)$ versus $SU(N)/\mathbb{Z}_N$

Example: N D3's on $\mathbb{C}^3$

Electric boundary conditions: $SU(N)$

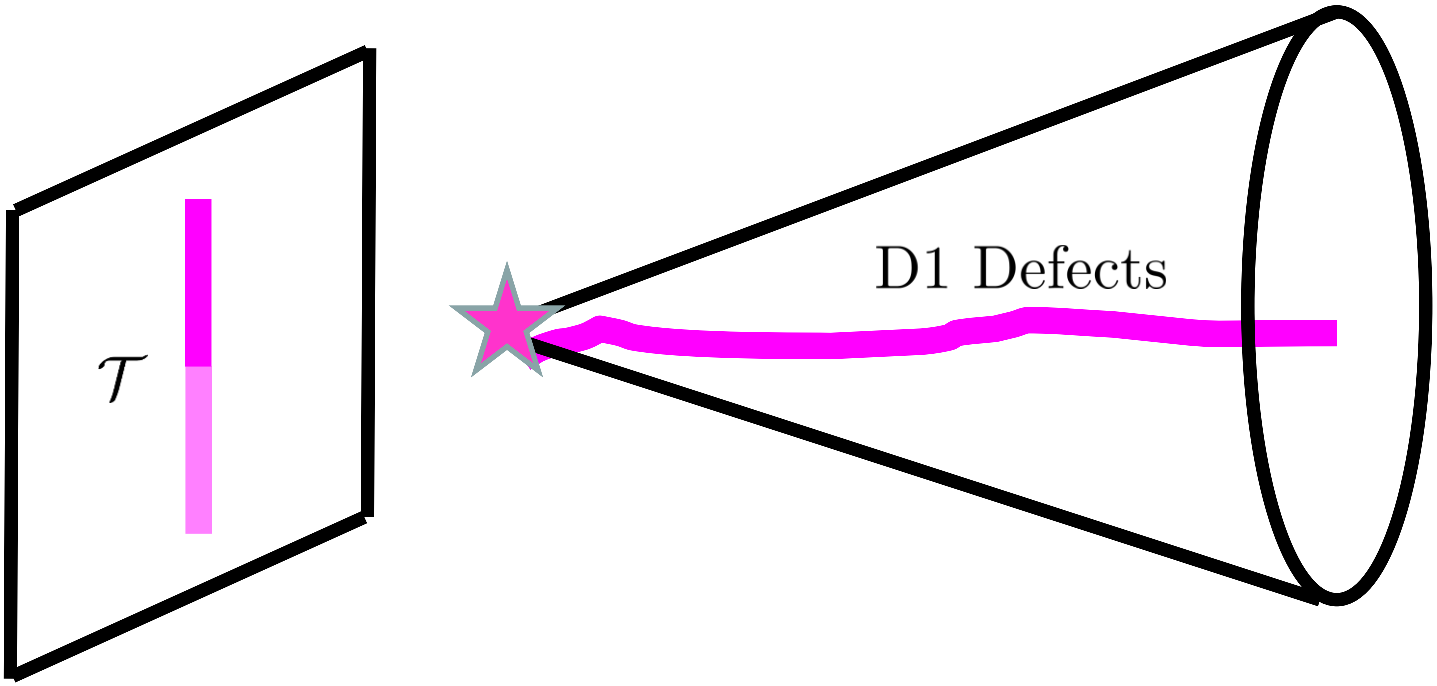
F1 Defects, but not D1 Defects (due to b.c.'s)



Example: N D3's on $\mathbb{C}^3$

Magnetic boundary conditions: $SU(N)/\mathbb{Z}_N$

D1 Defects, but not F1 Defects (due to b.c.'s)



Generalized Symmetries (Via Strings)

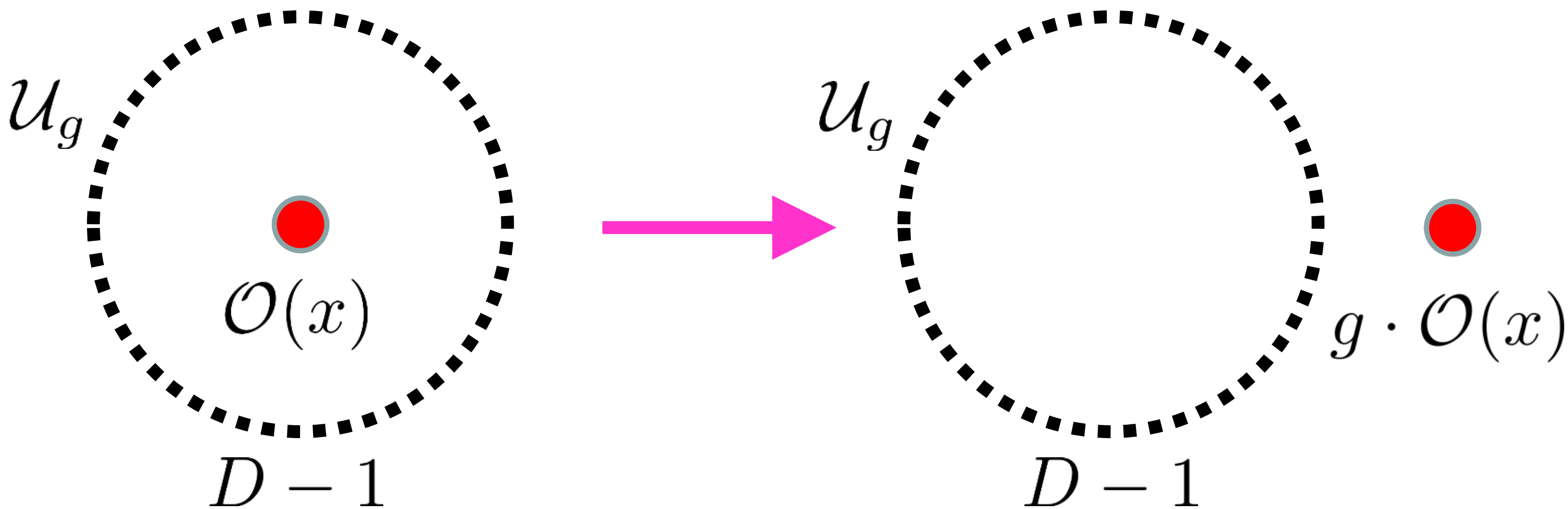
Generalized Symmetries

Gaiotto Kapustin Seiberg Willett '14

Main Idea: Global Symms are *Topological*

Consider D-dim^l QFT & Charged Local Op:

"Zero-Form Symmetry"



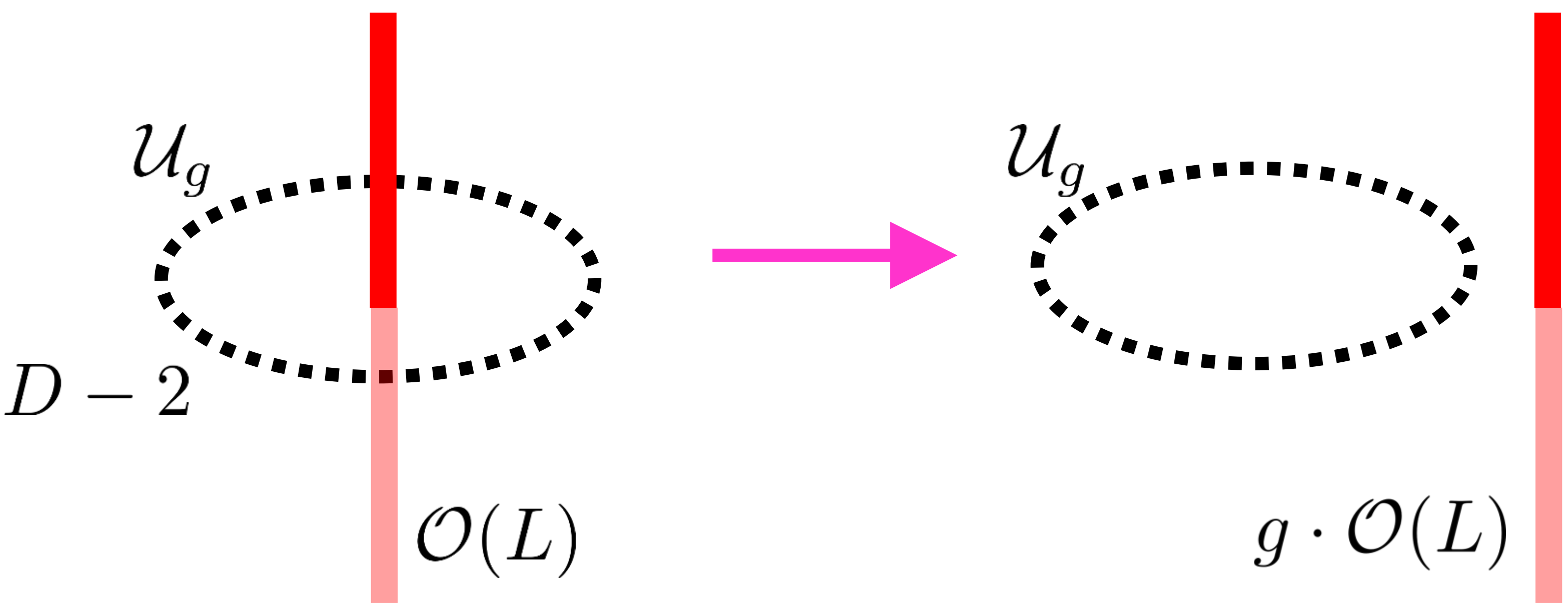
Generalized Symmetries

Gaiotto Kapustin Seiberg Willett '14

Main Idea: Global Symms are *Topological*

Consider D-dim^l QFT & Charged Line Op:

"One-Form Symmetry"



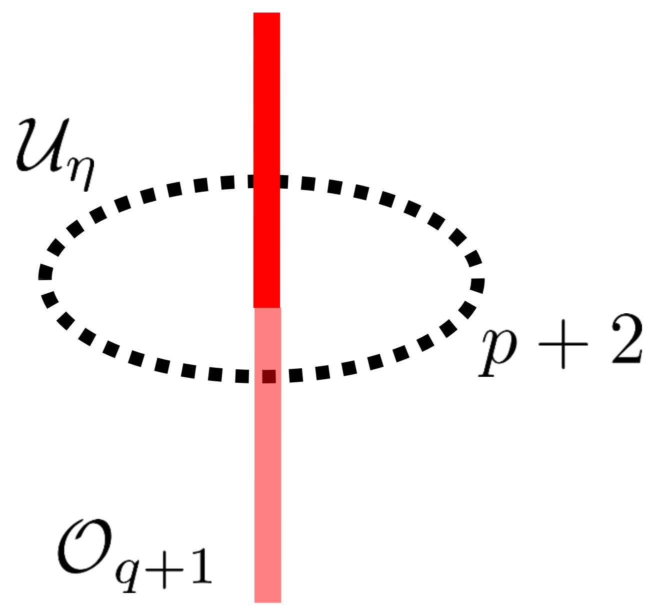
Symmetry Operators

Apruzzi Bah Bonetti Schafer-Nameki '22; Garcia-Etxebarria '22
JJH Hubner Torres Zhang '22; Cvetic JJH Hubner Torres '23

In SUGRA, q-brane links with $\mathcal{U}_\eta = e^{i\eta \int_{p+2} \widetilde{F}_{p+2}}$

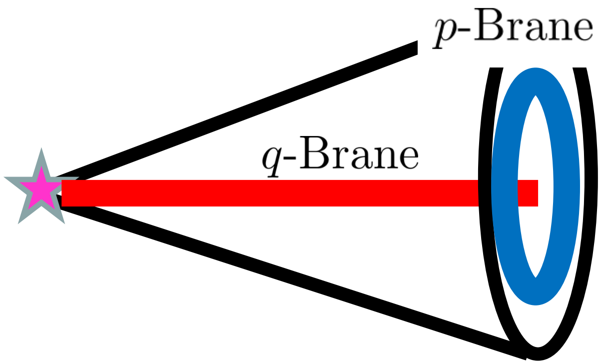
$(p+2) + (q+2) = \mathcal{D}_{\text{SUGRA}}$

Locally, $*dC_{q+1} = \widetilde{F}_{p+2}$

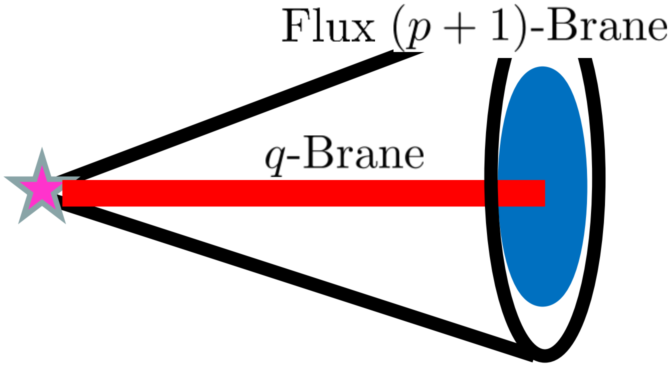


“Branes at Infinity”

- Discrete Symms

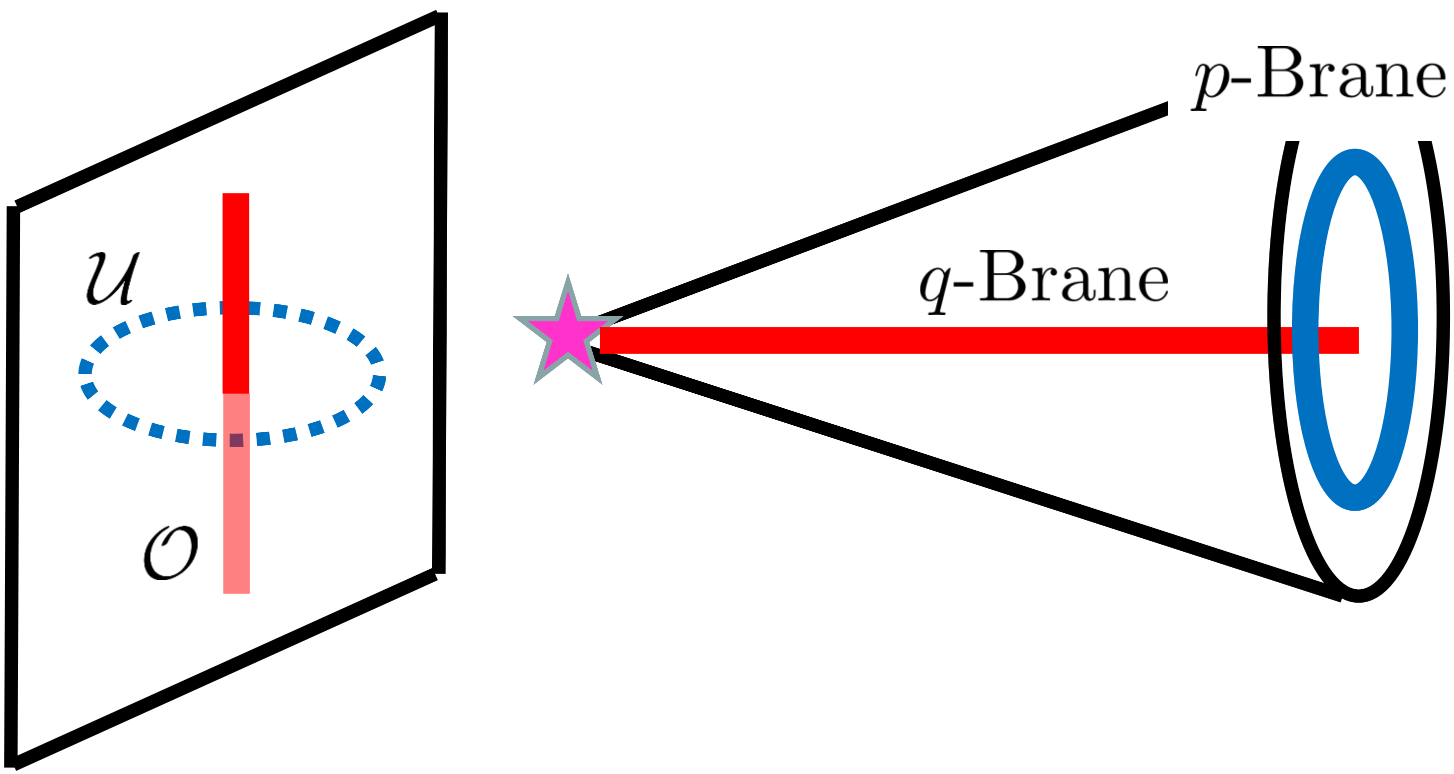


- Continuous Symms



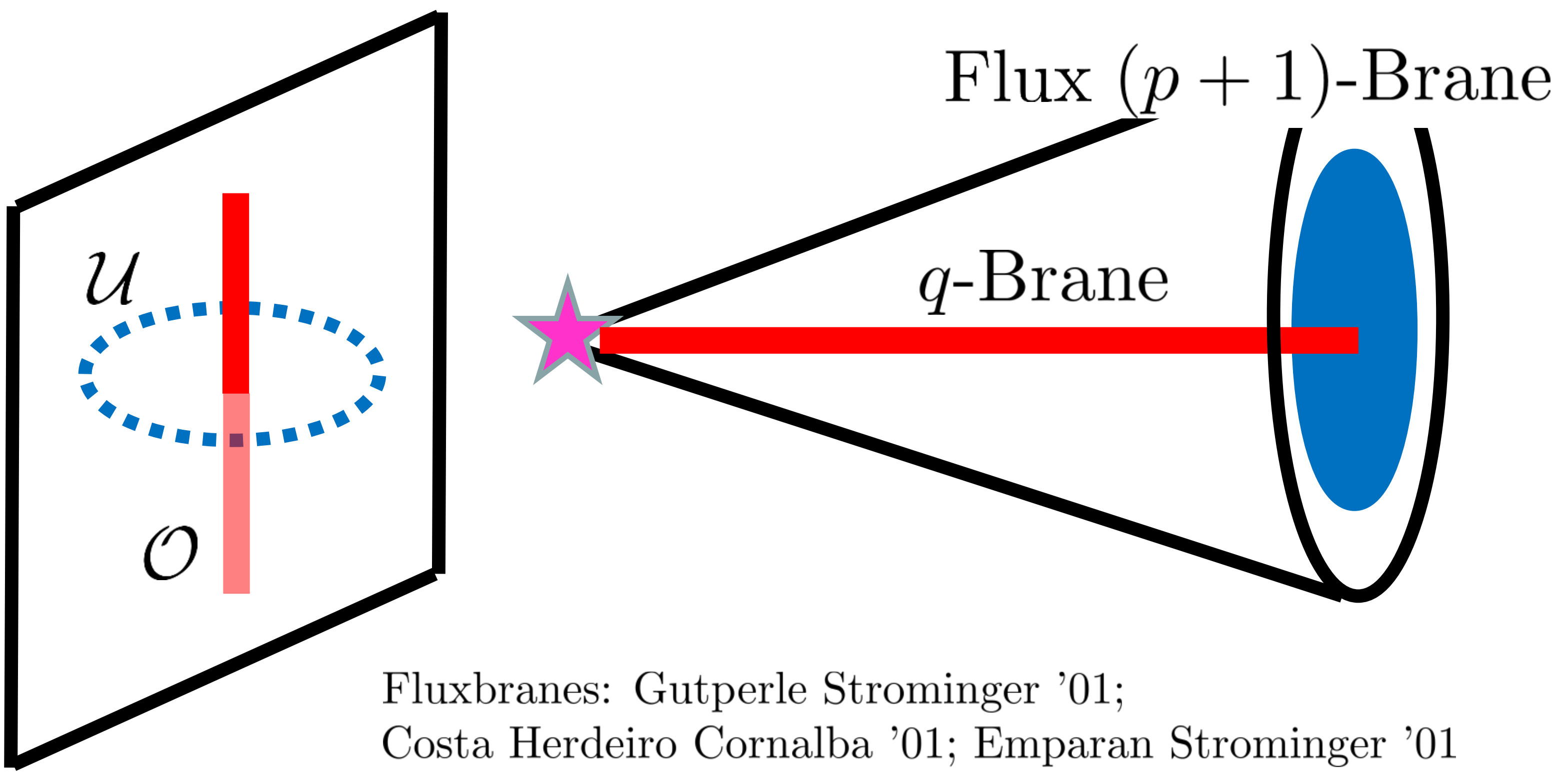
“Branes at Infinity”: $\mathbb{Z}_m^{(l)}$

Apruzzi Bah Bonetti Schafer-Nameki ’22; Garcia-Etxebarria ’22
JJH Hubner Torres Zhang ’22; Cvetic JJH Hubner Torres ’23



"Branes at Infinity": $U(1)^{(l)}$

Cvetic JJH Hubner Torres '23 (see also Garcia-Valdecasas '23)



Fluxbranes: Gutperle Strominger '01;
Costa Herdeiro Cornalba '01; Emparan Strominger '01

“Branes at Infinity”

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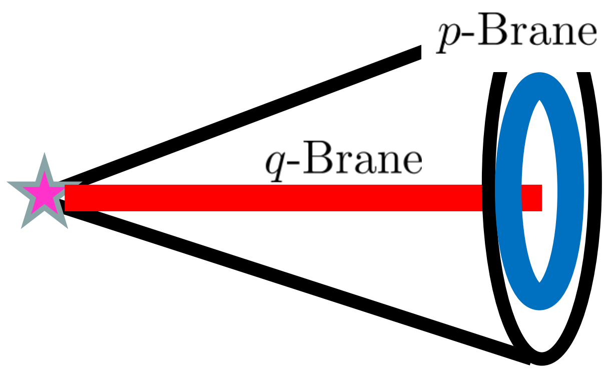

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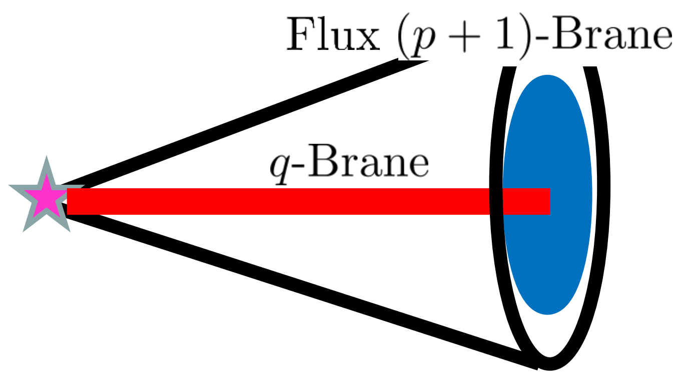


Some Examples...

- 6D SCFTs and 2-form symms
  hep-th/2209.03343 w/ Hubner, Torres, Zhang

- 4D Duality Defects via D3's on $\mathbb{C}^3/\Gamma$
  hep-th/2212.09743 w/ Hubner, Torres, Yu, Zhang

- Charge Conjugation of 6D $\mathcal{N} = (2,0)$ SCFTs
  hep-th/2305.05689 w/ Dierigl, Montero, Torres

- Verlinde's Monopole & $U(1)^{(1)}_{\mathrm{mag}}$
  hep-th/2305.09665 w/ Cvetic, Hubner, Torres

Some Examples...

- 6D SCFTs and 2-form symms

  Wrapped D3-Branes on 1-cyc $\in \partial X = S^3/\Gamma$

- 4D Duality Defects via D3's on $\mathbb{C}^3/\Gamma$

  Wrapped 7-Branes$_{\tau_{IIB}\,\text{const}}$ on $\partial X = S^5/\Gamma$

- Charge Conjugation of 6D $\mathcal{N} = (2,0)$ SCFTs

  Wrapped R7's on $\partial X = S^3/\Gamma$

- Verlinde's Monopole & $U(1)^{(1)}_{\text{mag}}$

  Wrapped Flux 4-Branes

Aside on Non-Invertibles

Generalizations of group:

$$\mathcal{U}_\gamma(\Sigma)\mathcal{U}_{\gamma'}(\Sigma) = \mathcal{U}_{\gamma\circ\gamma'}(\Sigma) + ...$$

$$\mathcal{U}_\gamma(\Sigma)\mathcal{U}_{\gamma'}(\Sigma) =$$

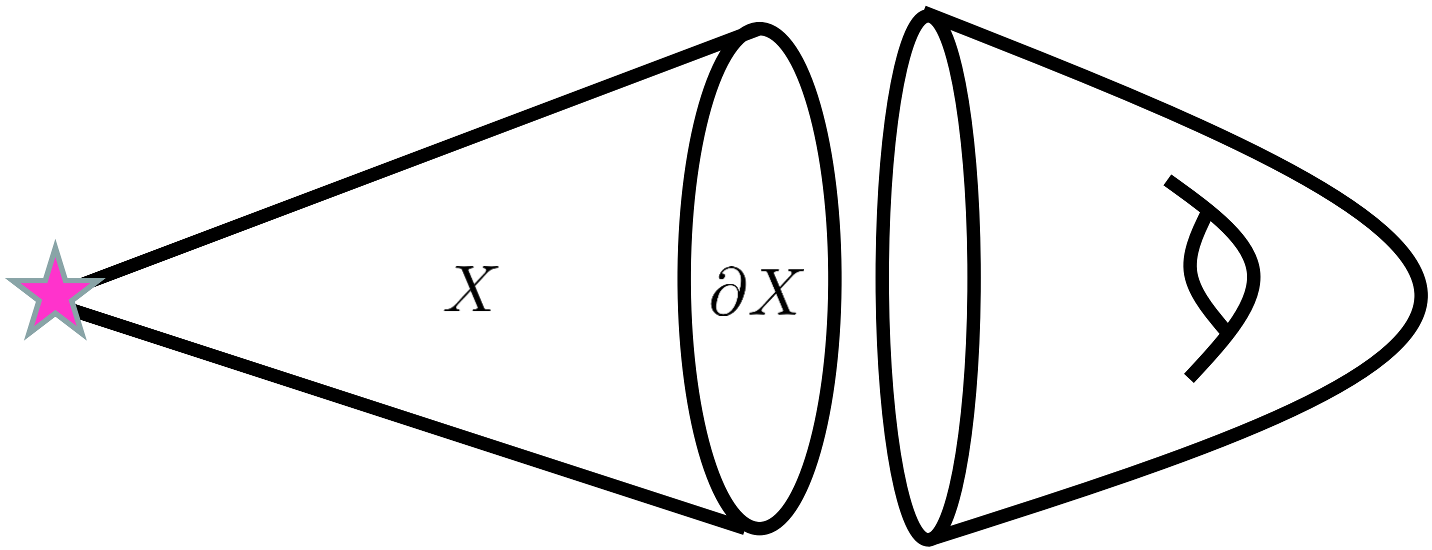
$$\int [Da][Da'] \exp\left(2\pi i \eta \int_\Sigma \mathrm{TFT}(\gamma) + \mathrm{TFT}(\gamma')\right)$$

(Follows From $\mathcal{S}_{WZ}$ of Branes)

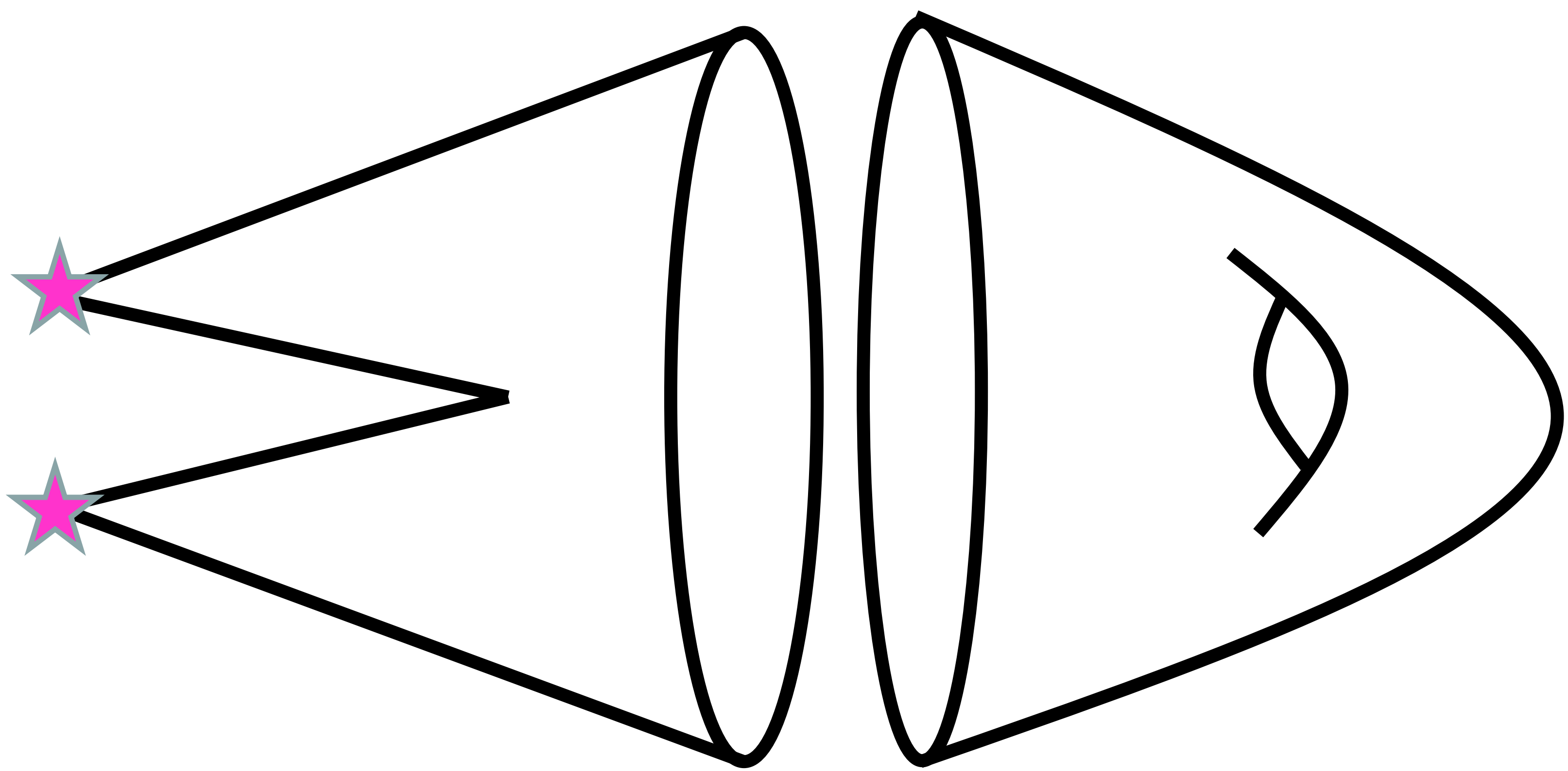
Apruzzi Bah Bonetti Schafer-Nameki '22; Garcia-Etxebarria '22
JJH Hubner Torres Zhang '22; JJH Hubner Torres Yu Zhang '22

What About $G_N \neq 0$?

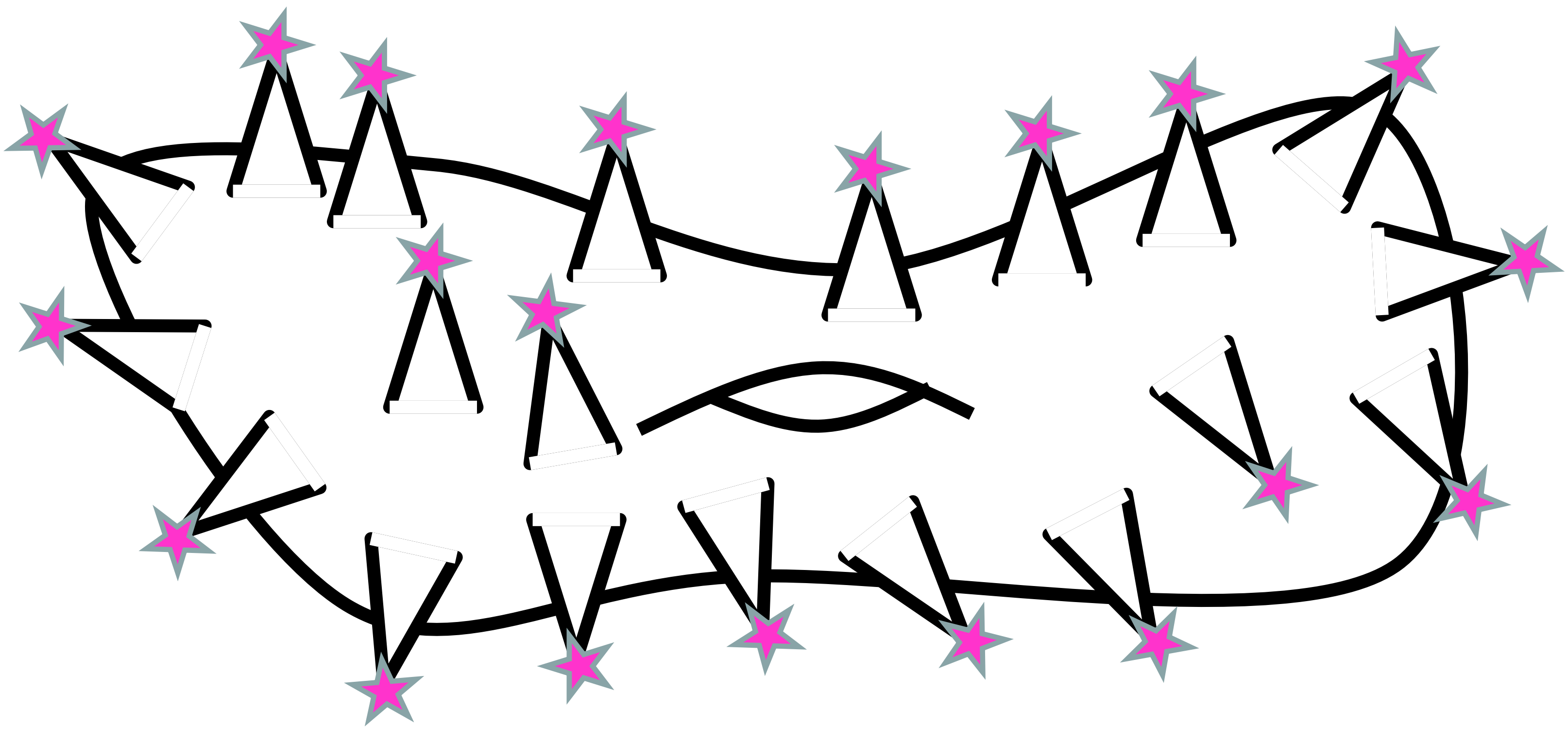
Engineering QFTs + Gravity



Or Maybe...



Or Maybe Even...



Defects & $G_N \neq 0$

1) The defect persists (but now it's dynamical)

2) The defect is metastable (unwinds in bulk)
(Verlinde '06, Cvetic JJH Hubner Torres '23)

3) The defect is shared (multiple throats)
Baume JJH Hubner Torres Turner Yu: To Appear

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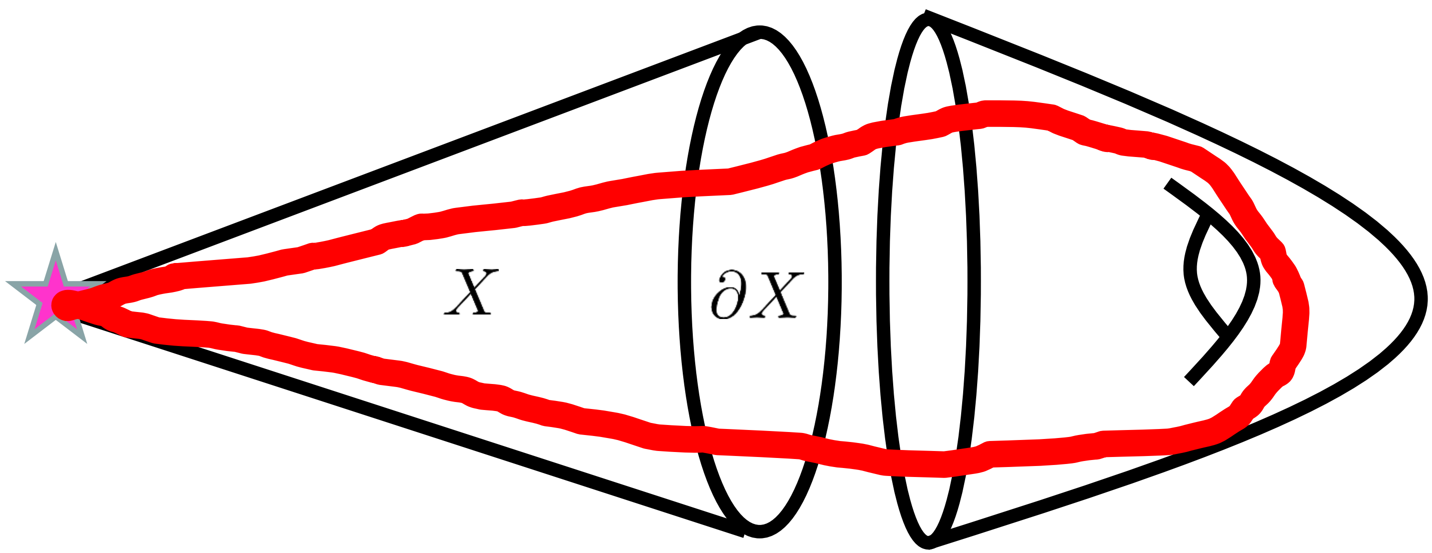

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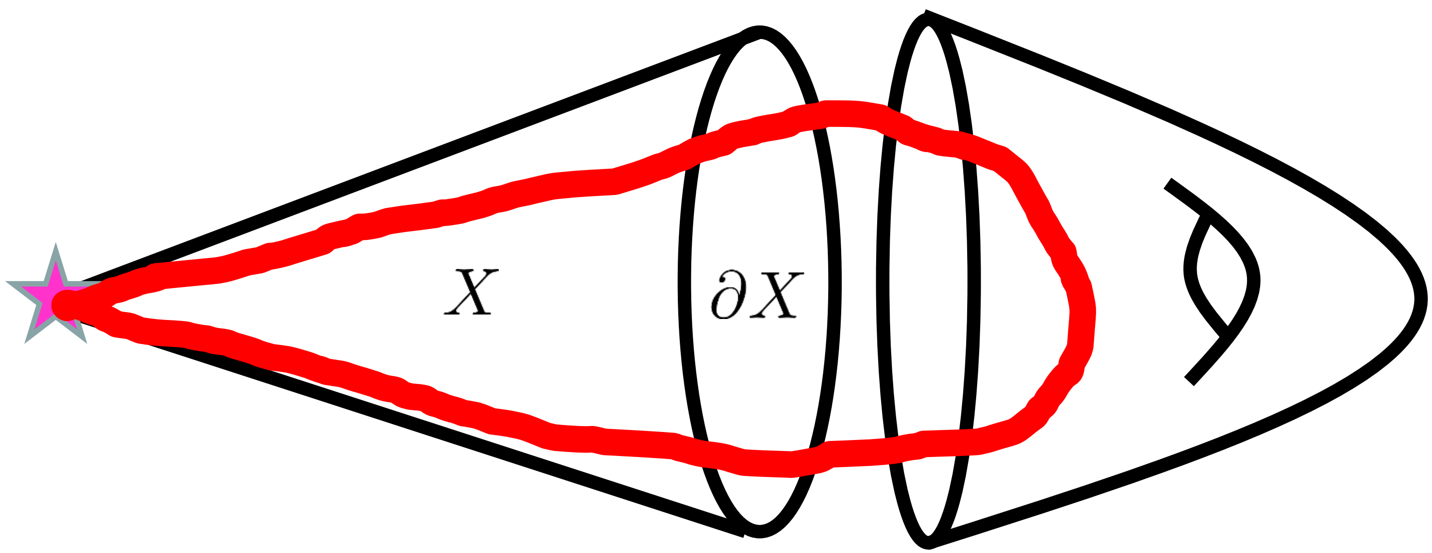

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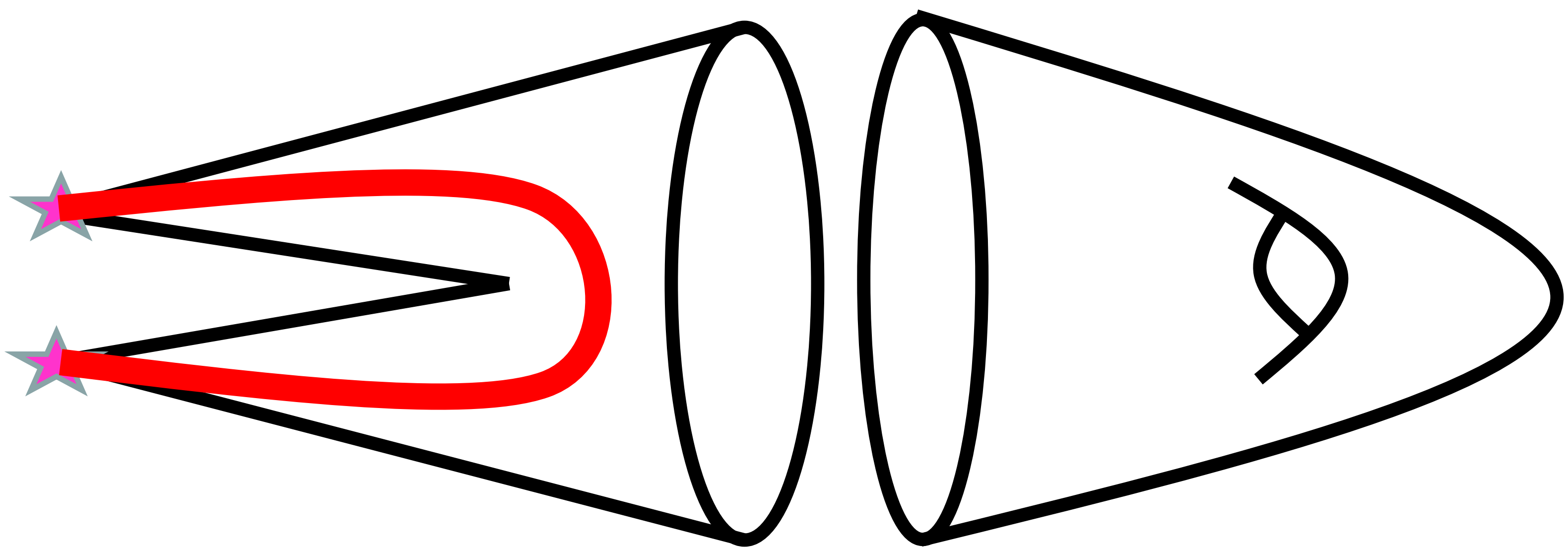
Baume JJH Hubner Torres Turner Yu: To Appear



Topological Non-Decoupling: No "Sequestering" Available

Baume JJH Hubner Torres Turner Yu: To Appear;

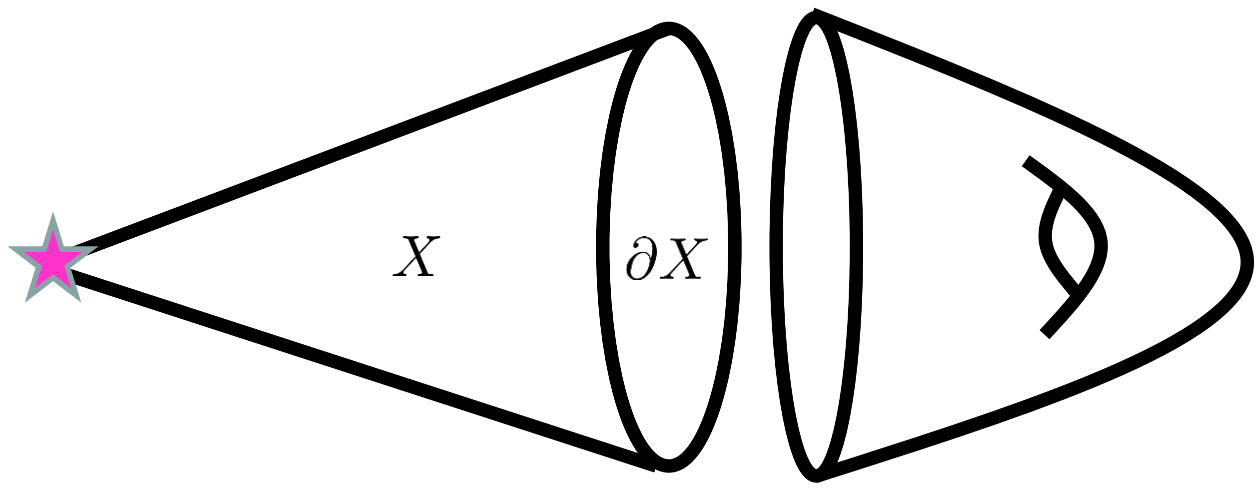
(see also JJH Vafa '19 as well as Kachru McAllister Sundrum '07)

Gluing into the Bulk

Gluing Boundary Conditions

Use Mayer-Vietoris:

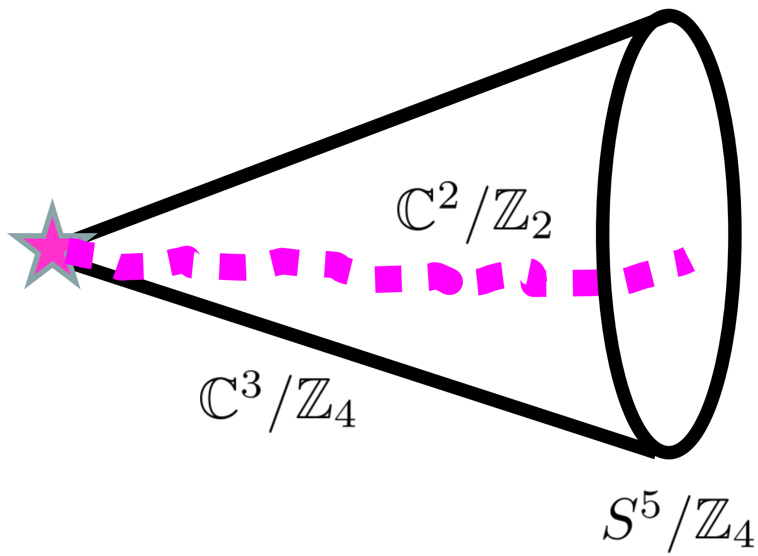
$$... \to H_{n+1}(Y) \to H_n(U \cap V) \to H_n(U) \oplus H_n(V) \to H_n(Y) \to ...$$

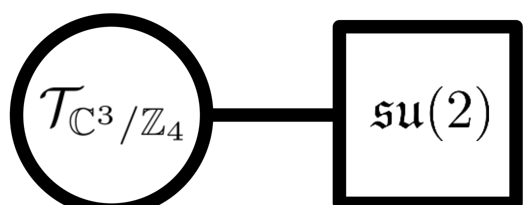


Example I:
5D SCFTs + Gravity

M-th on $\mathbb{C}^3/\mathbb{Z}_4$ (Local)

Local Model:
5D SCFT
$\mathcal{T}_{\mathbb{C}^3/\mathbb{Z}_4}$

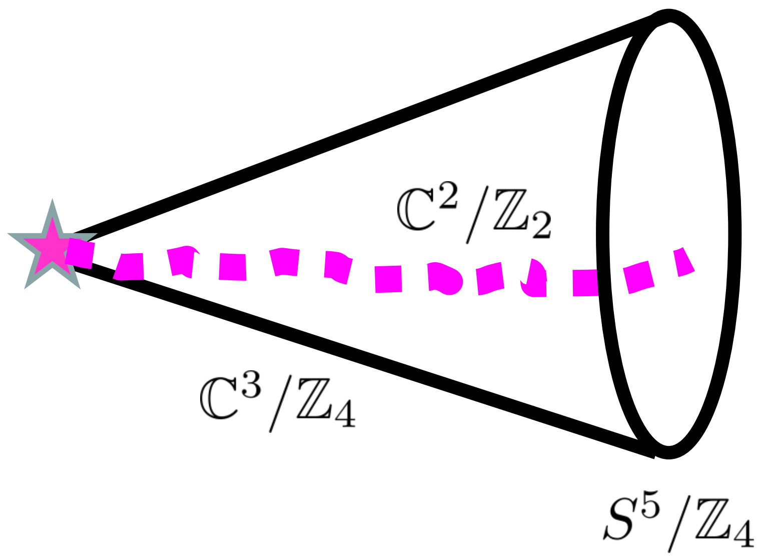




Apruzzi Bhardwaj Schafer Nameki Oh '21; Del Zotto JJH Meynet Moscrop Zhang '22; Cvetic JJH Hubner Torres '22; Del Zotto Garcia Etxebarria Schafer Nameki '22

M-th on $\mathbb{C}^3/\mathbb{Z}_4$ (Local)

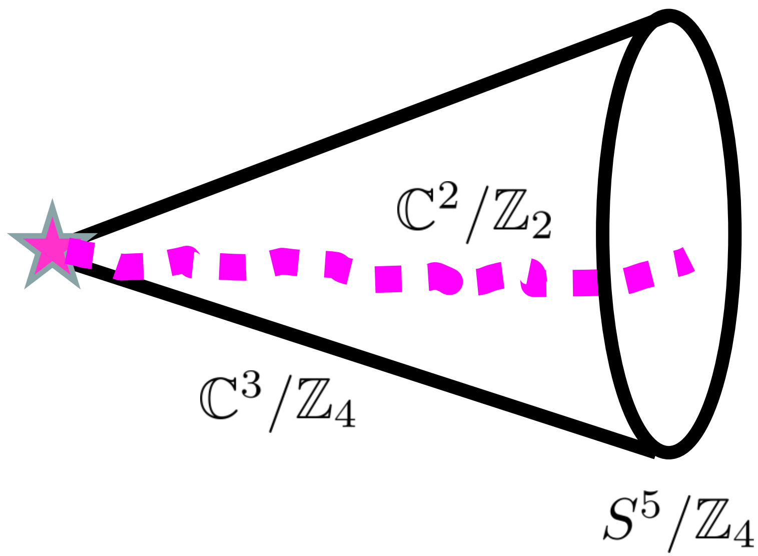
Local Model:
5D SCFT
$\mathcal{T}_{\mathbb{C}^3/\mathbb{Z}_4}$

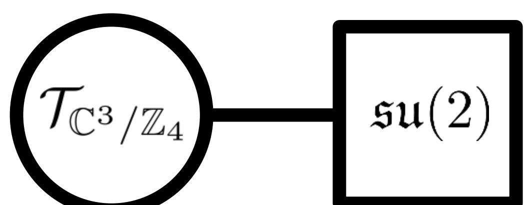


$SO(3)_{\text{flav}}$ 0-form symm
$\mathbb{Z}_2$ 1-form symmetry (acts on M2 line defects)
2-group (entwined 0- and 1-form symms)

M-th on $\mathbb{C}^3/\mathbb{Z}_4$ (Local)

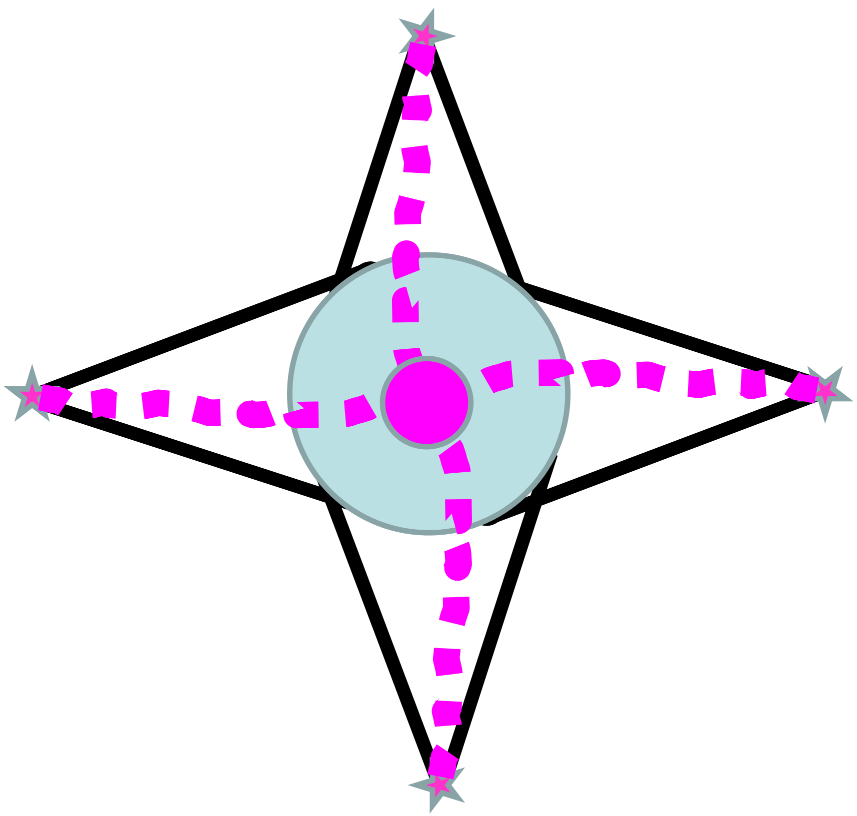
Local Model:
5D SCFT
$\mathcal{T}_{\mathbb{C}^3/\mathbb{Z}_4}$

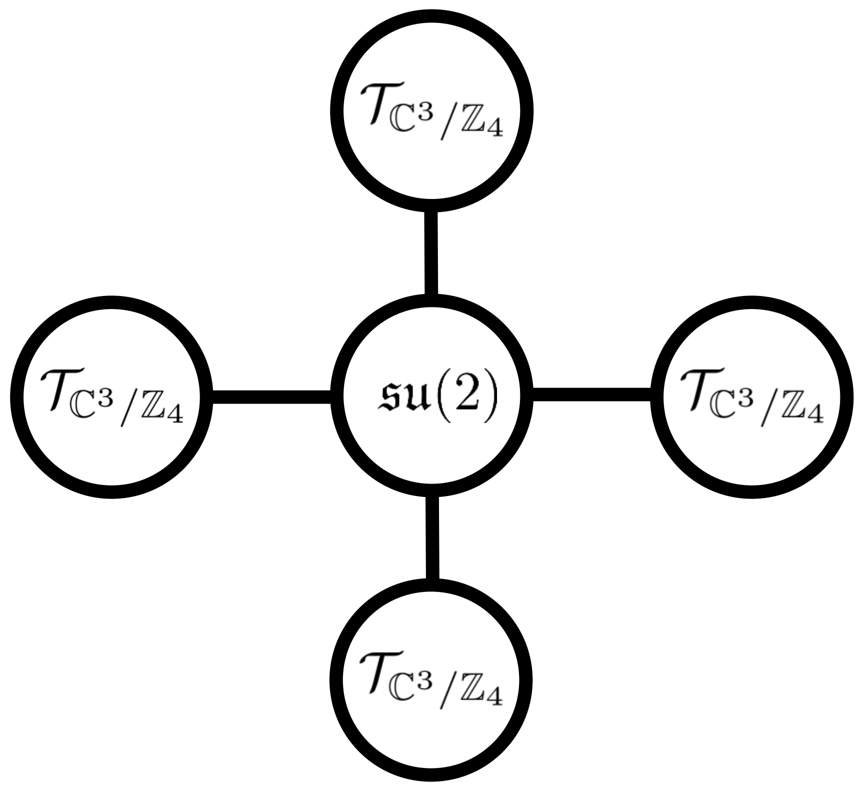




Cvetic JJH Hubner Torres: To Appear

M-th on $(\mathbb{C}^3/\mathbb{Z}_4)^{\#4}$ (Semi-Loc)





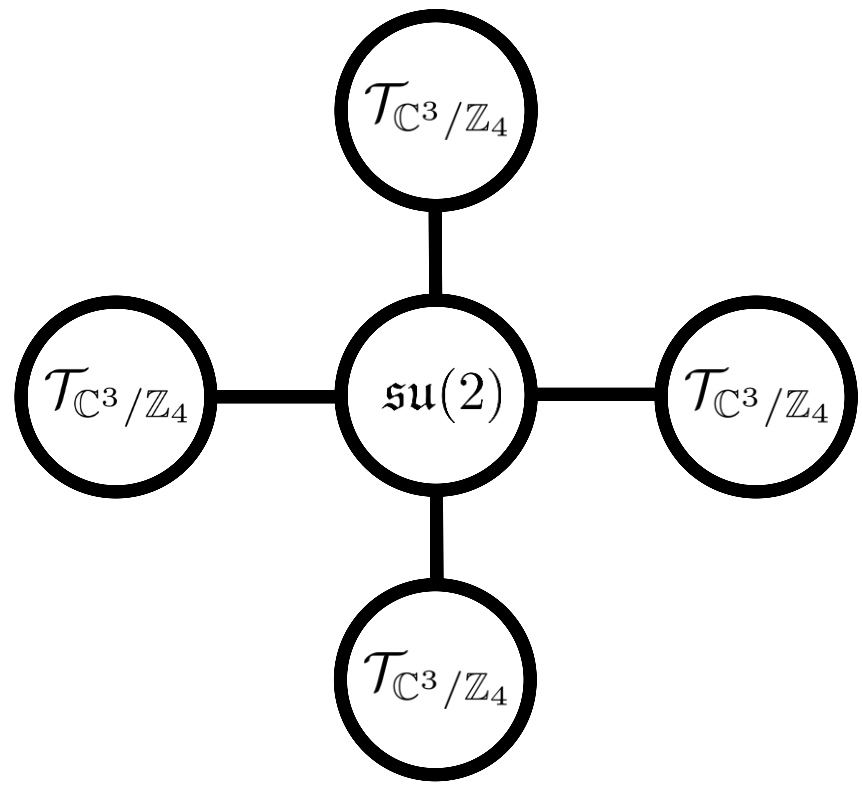
M-th on $(\mathbb{C}^3/\mathbb{Z}_4)^{\#4}$ (Semi-Loc)

Gauge Diagonal:

$\mathfrak{su}(2)_{\text{flav}}$ 0-form

$\mathbb{Z}_2$ 1-form

2-group "trivializes"



M-th on $T^6/\mathbb{Z}_4$ (Global)

16 $\mathcal{T}_{\mathbb{C}^3/\mathbb{Z}_4}$'s 10 $\mathfrak{su}(2)$'s and 5 $\mathfrak{u}(1)$'s

Full Gauge Group:

$$\frac{U(1)^5 \times \frac{[\mathbb{Z}_2^3 \times (\mathbb{Z}_4 \times SU(2))/\mathbb{Z}_2]^4 \times SU(2)^6}{\mathbb{Z}_4 \times \mathbb{Z}_2^2}}{\mathbb{Z}_4 \times \mathbb{Z}_2}$$

Cautionary Note

Full Gauge Group Depends On:

- Charged *massless* states
- Charged *massive* states

In Practice:

- Common to focus on just massless states...

Aside on F-theory

Same techniques can be used to extract gauge group in F-theory models (ell. CY)

"Mordell-Weil group of sections" bypassed (we give explicit examples for 6D vacua)

Cvetic JJH Hubner Torres: To Appear

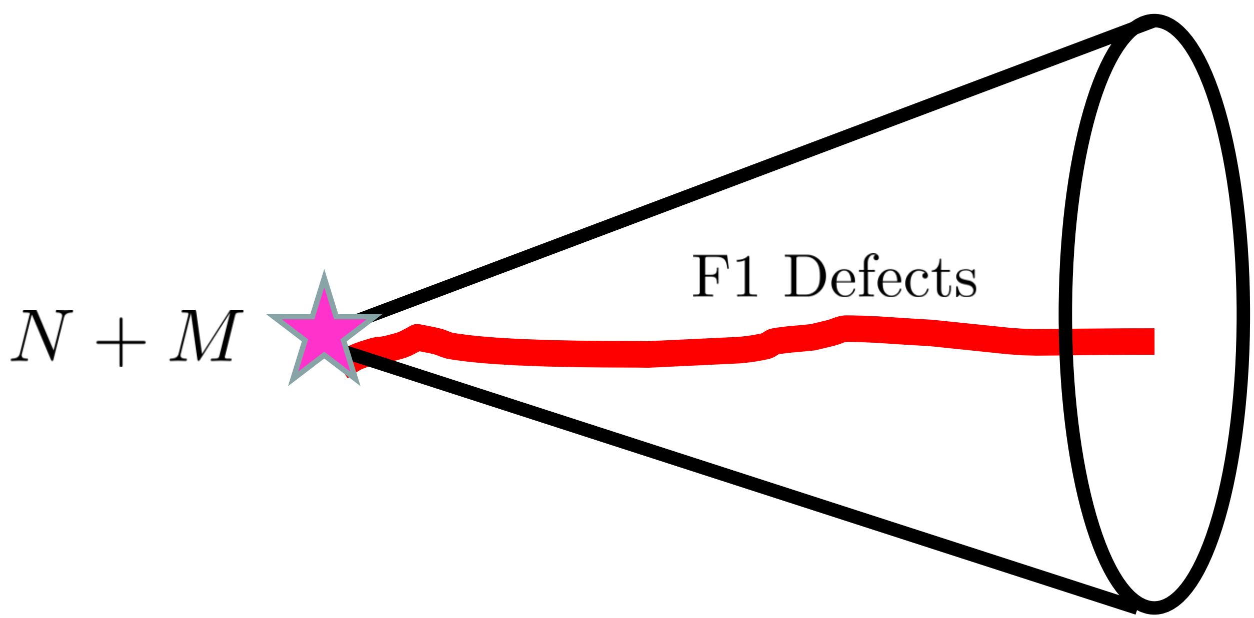
Example II:
Elec / Mag Ambiguities

Baume JJH Hubner Turner Torres Yu: To Appear

$N + M$ D3's on $\mathbb{C}^3$

Electric boundary conditions: $SU(N + M)$

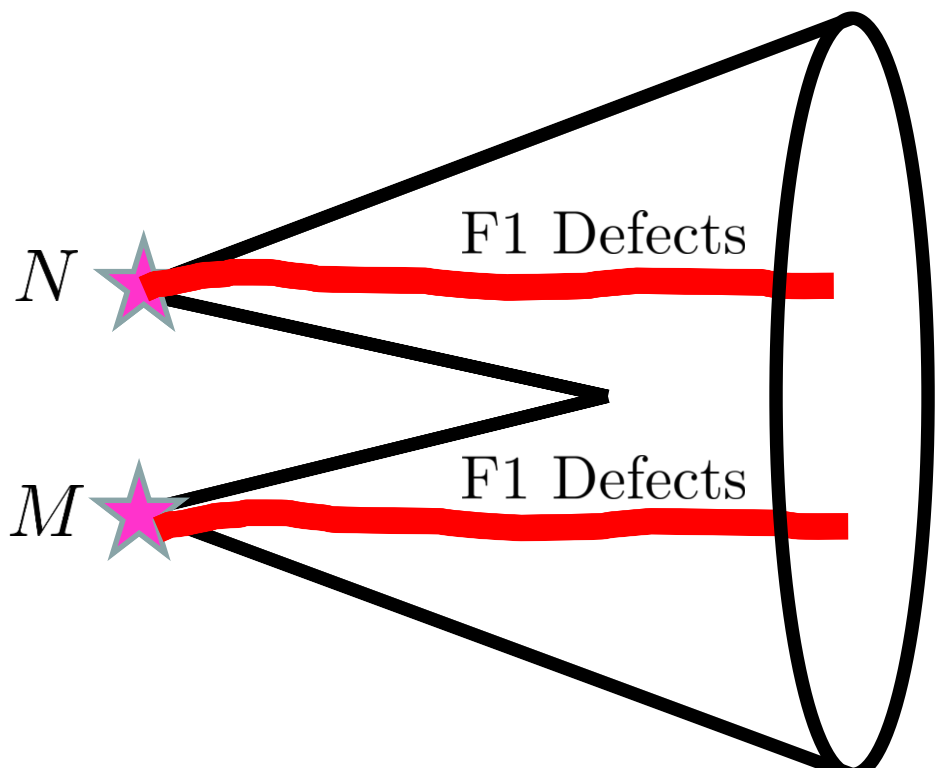
F1 Defects, but not D1 Defects (due to b.c.'s)



$N + M$ D3's on $\mathbb{C}^3$

Now separate the stacks:

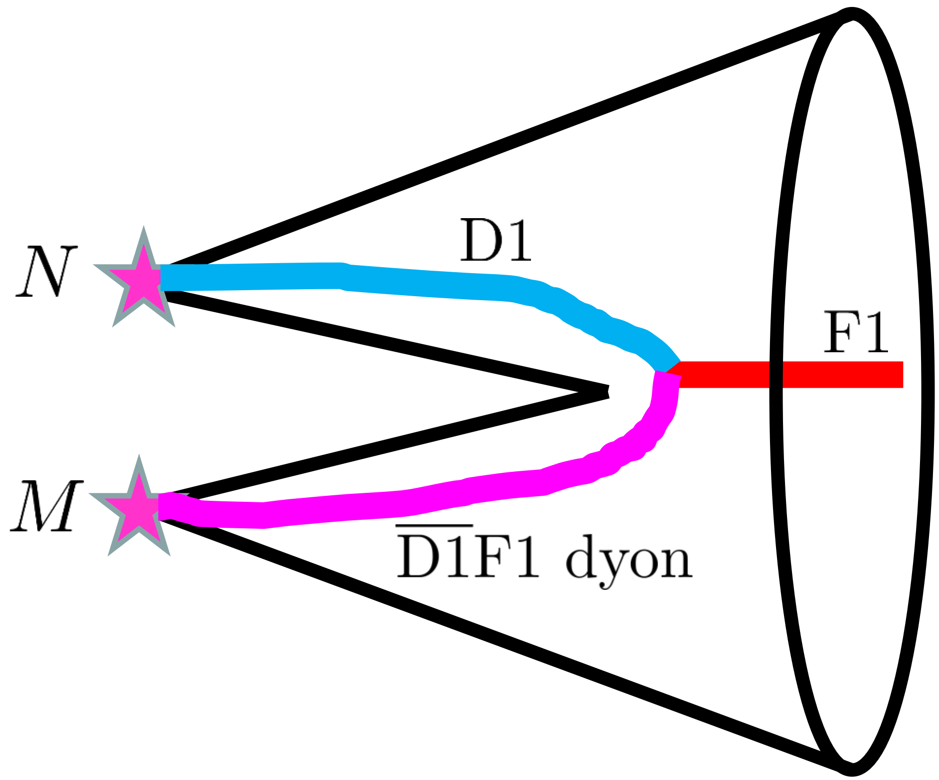
All the electric lines for $SU(N)$ & $SU(M)$



$N + M$ D3's on $\mathbb{C}^3$

Now separate the stacks:

But also magnetic & dyonic lines!



¿So, What is G_{SM}?

It Depends

¿So, What is $G_{\rm SM}$?

In stringy GUT (F-th, M-th, Het, ...),

$E_8 \to G_{SM}$ usually fixes it:

$SU(3) \times SU(2) \times U(1)/\mathbb{Z}_6$

But even in such “clean cases”

can have elec / mag ambiguities...

¿So, What is G_{SM}?

In stringy GUT (F-th, M-th, Het, ...),

$E_8 \to G_{SM}$ usually fixes it:

$SU(3) \times SU(2) \times U(1)/\mathbb{Z}_6$

In branes at singularities / $\cap$ branes,

there can be significant vis / extra mixing

Summary / Future

Summary / Future

Summary:

- Symm Ops via “Branes at Infinity”
- Adding Gravity / Throat Mixing
- Elec / Mag Ambiguities

Future Applications:

- Ensembles w/ Large N Averaging?
- Pheno of Topological Mixing?