Dual perspectives on strongly coupled SCFT

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1. Motivations and Themes

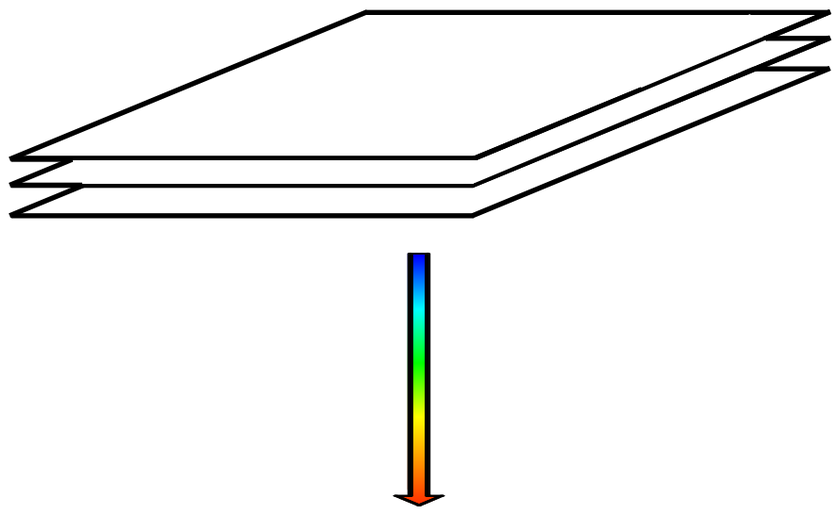
2. Recent Developments

based on collaborations with:

Ibrahima Bah, Federico Bonetti, Ruben Minasian, Thomas Waddleton; Kazunobu Maruyoshi, Jaewon Song

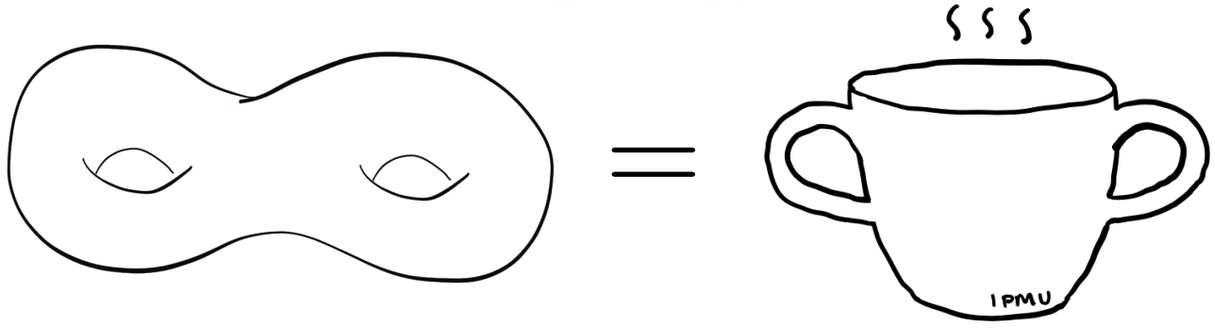
String theory as a framework to generate/study QFT

- Many nontrivial, strongly-coupled (S)QFTs arise as the IR **limit of branes** in string theory.



(S)QFT in 4 (or lower) dimensions

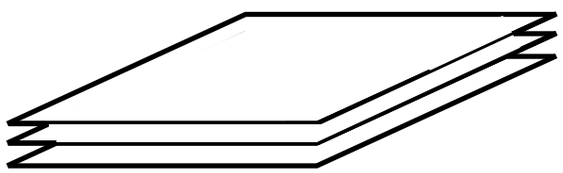
*characterized by the **topology** of the internal space*

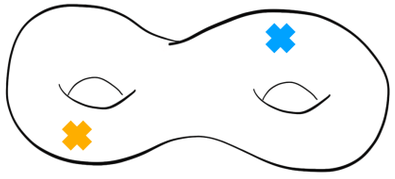


The Geometric Engineering Machine:

➤ Allows us to generate and geometrically organize large classes of strongly coupled QFTs. *Key example:*

INPUT:





- **brane configuration**

  N M5-branes → 6d SCFT on world volume

  [Witten 95; Strominger 95; Seiberg; …]

- **compact *d*-dim manifold**

  2d genus-g punctured Riemann surface

- **topological twist**

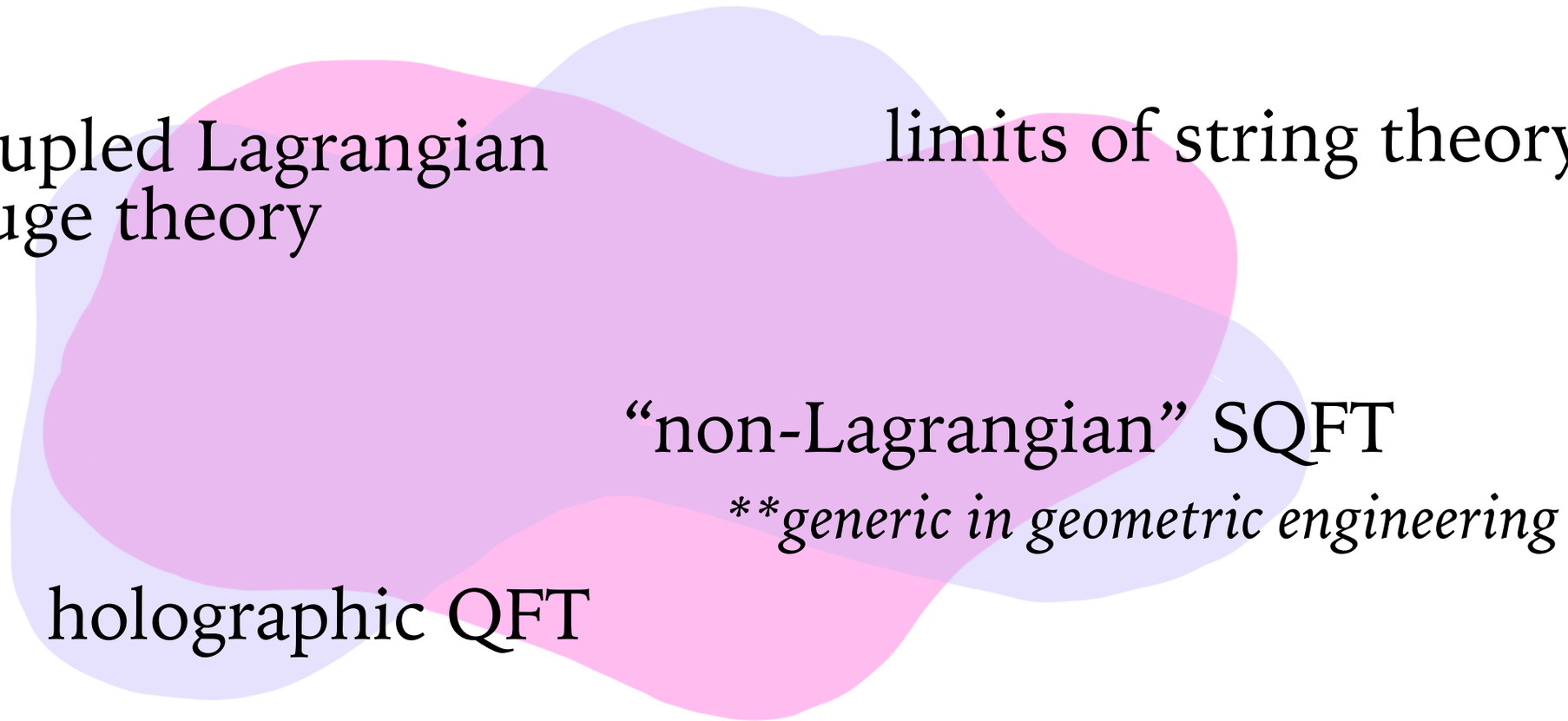
  to preserve $\mathcal{N} = 2$ Superconformal symmetry

OUTPUT: **(S)QFT in lower dimensions**

4d $\mathcal{N} = 2$ SCFT that depends on (N, g, puncture data, ..)

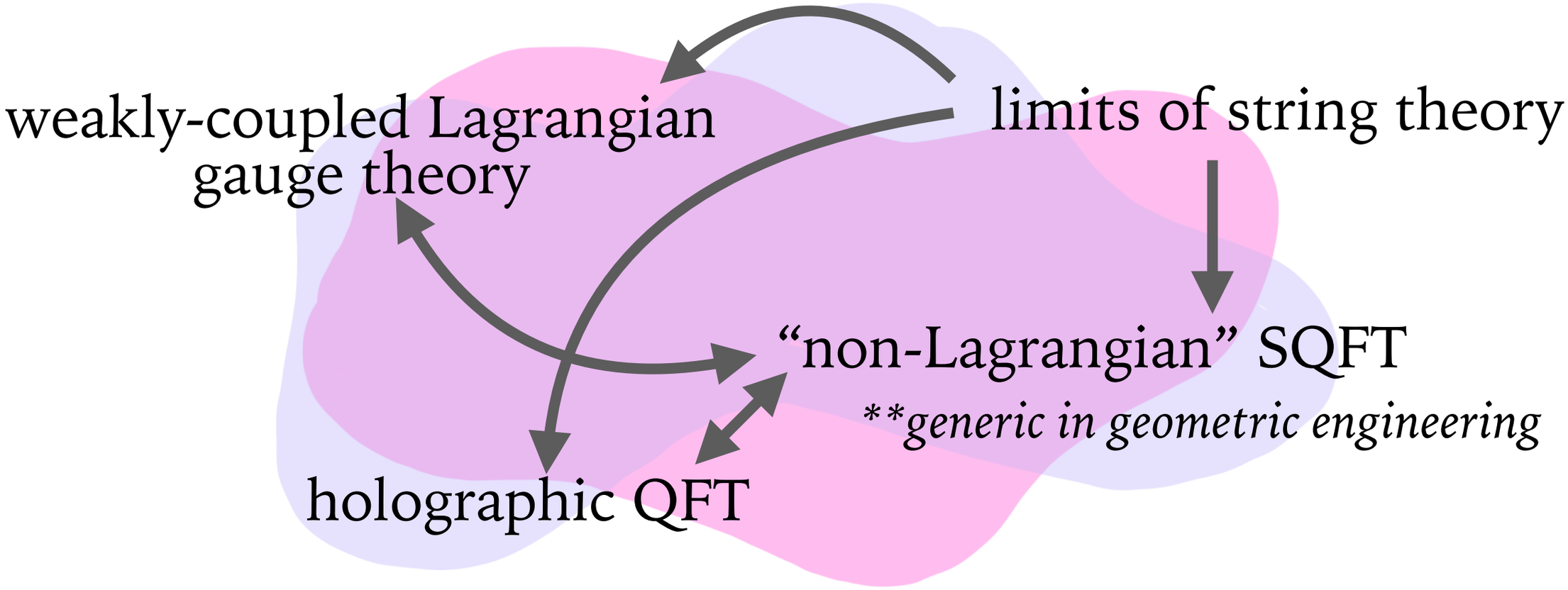
[Witten 95; Gaiotto 09; Gaiotto, Moore, Neitzke 09; …]

Motivation: A rich testing ground for exploring aspects of QFT



- Upshot: illuminate new corners of this landscape

Takeaway: there are deep (and often surprising!) interconnections in the landscape of QFT.



"↓" = { *RG flow; IR duality (universality); decoupling limit in string theory ("cross-dimensional duality"); AdS/CFT; …* }

Guiding principle:

Harness these interconnections to develop new tools for non-perturbatively computing QFT observables*

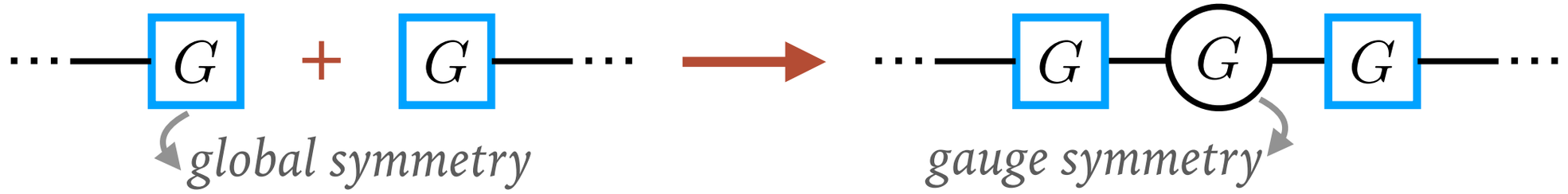
- Symmetry structure *('t Hooft anomalies, generalized symmetries)*;
  Operator content *(scaling dimensions of BPS operators, indices)*;
  Vacuum structure *(moduli space details, IR phase)*;
  d.o.f. *(central charges)*; …

*focus on SCFTs

Key useful idea: view the SCFTs that arise from geometric constructions as generalized matter sectors.

Free fields from geometric building blocks

- We build gauge theories by coupling free fields; *e.g.* gauging (subgroups of) global symmetries by coupling vector fields to the symmetry current.



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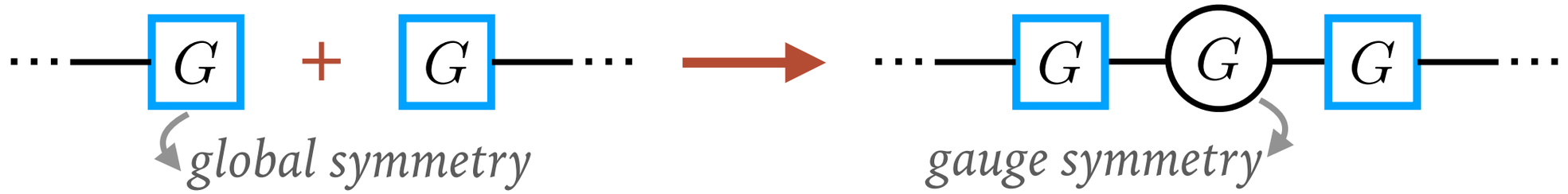
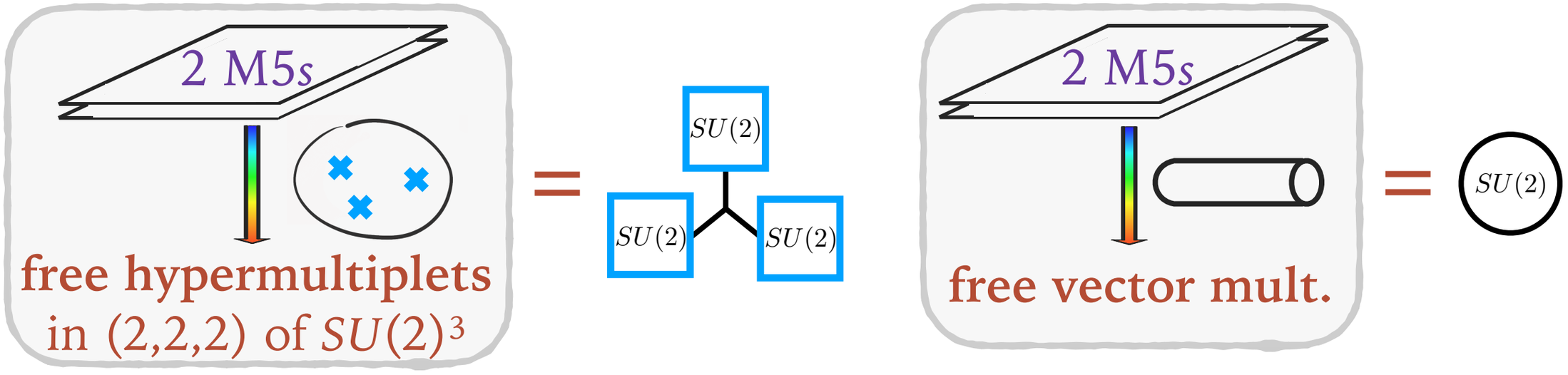




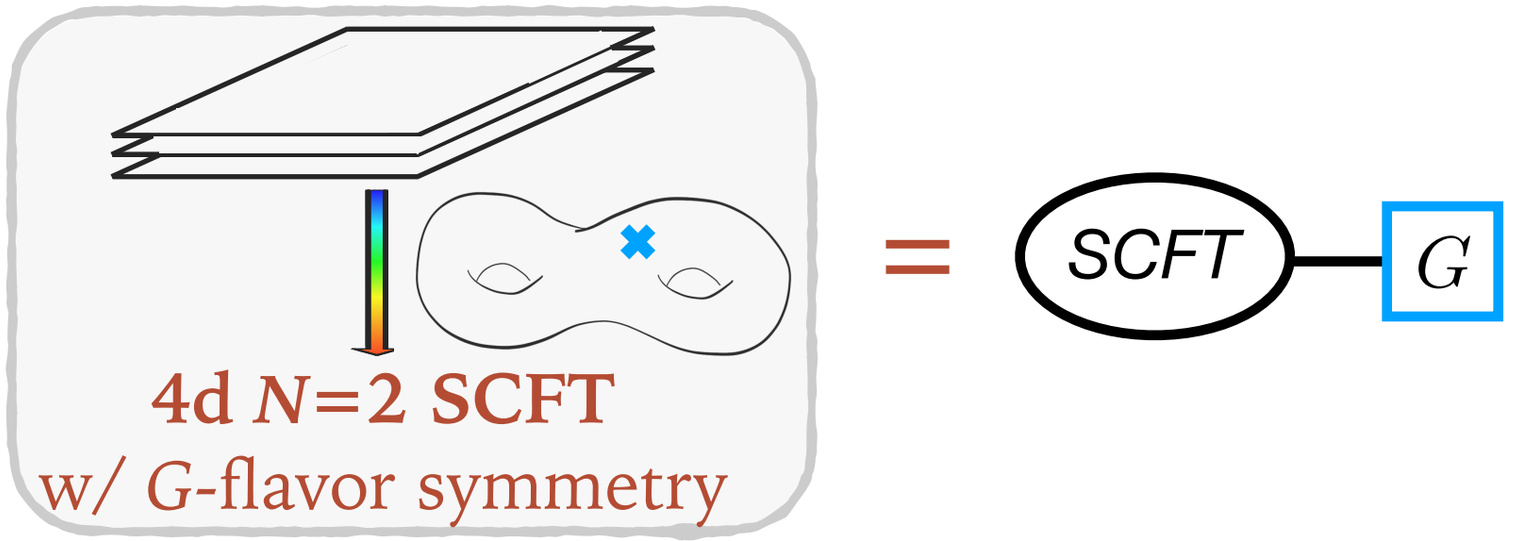
- **e.g.**

$SU(2)$ $N_f = 4$ gauge theory

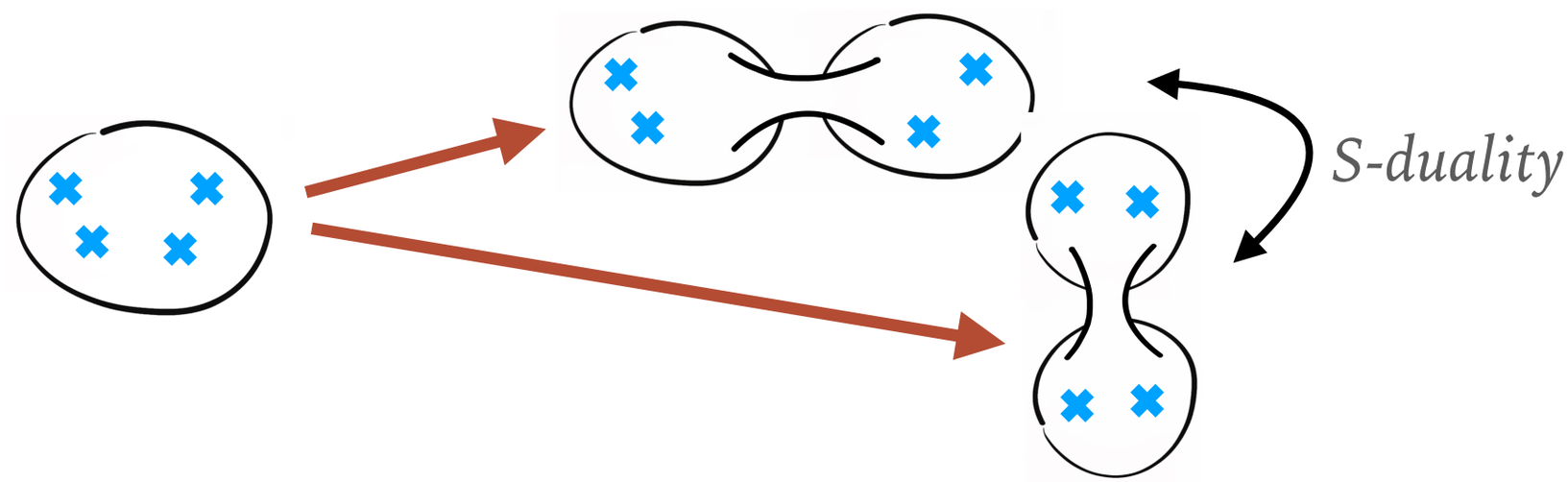
[Gaiotto 09]

Choice of generalized matter = classes of SCFTs

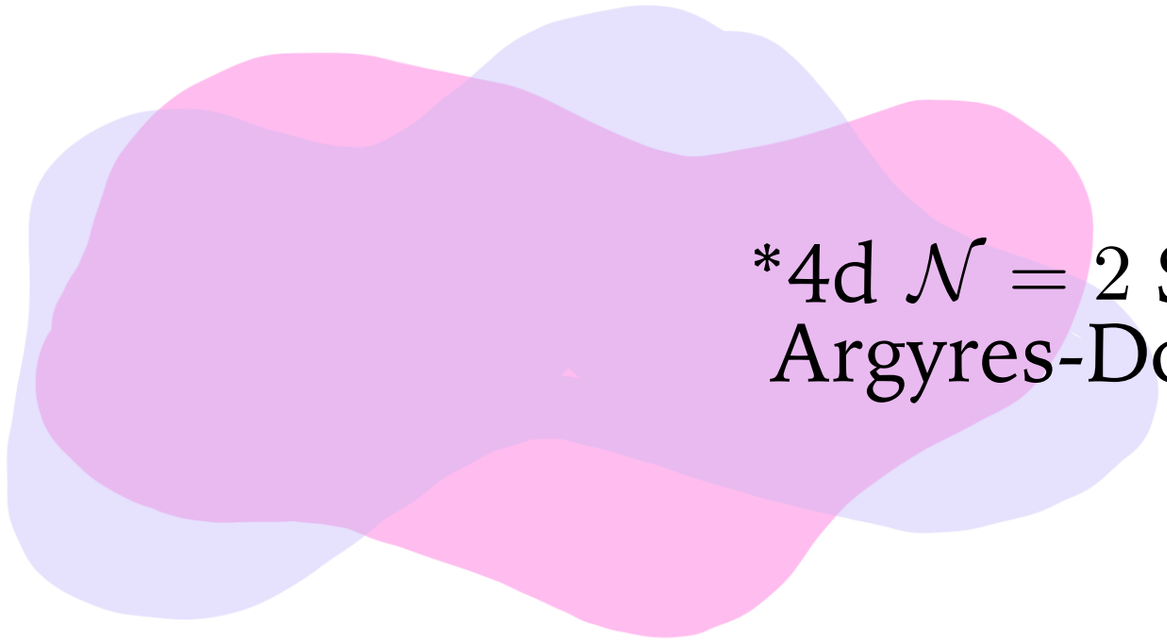
- More generally: consider (even strongly!) interacting SCFTs as **generalized matter sectors**



- Allows geometrization of QFT properties; *e.g.* pair-of-pants decompositions of the surface = different IR dual frames



2. Dual perspectives of AD SCFTs



*4d $\mathcal{N} = 2$ SCFTs of Argyres-Douglas type

The 4d $\mathcal{N}=2$ Argyres-Douglas SCFTs are very special

- First found at singular points on the moduli space of 4d $\mathcal{N}=2$ gauge theories where mutually **non-local** BPS states become light

  [Argyres, Douglas 95; Argyres, Plesser, Seiberg, Witten 95; Eguchi, Hori, Ito, Yang 96; …]

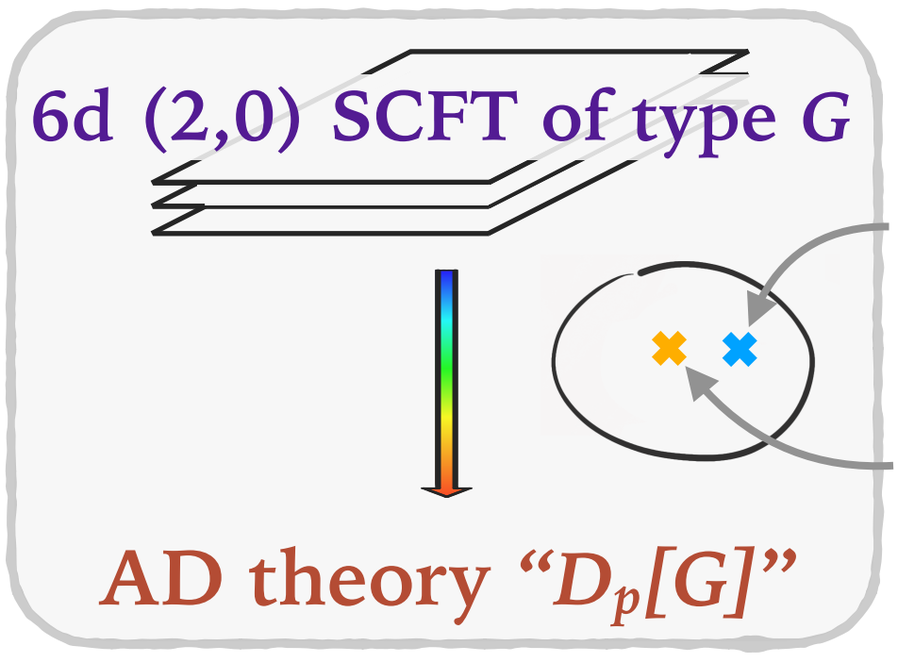
- "Non-Lagrangian"; intrinsically strongly coupled

- Possess relevant operators of **fractional scaling dimension** parameterizing their Coulomb branch

Geometric engineering AD theories

- Focus on the class:

  [Cecotti, Del Zotto 12; Bonelli, Maruyoshi, Tanzini 12; Cecotti, Del Zotto, Giacomelli 13; Xie 13; Xie, Wang 16]



full puncture w/ G flavor symmetry

can close to general regular puncture

irregular puncture labeled by $p \in \mathbb{Z}_+$

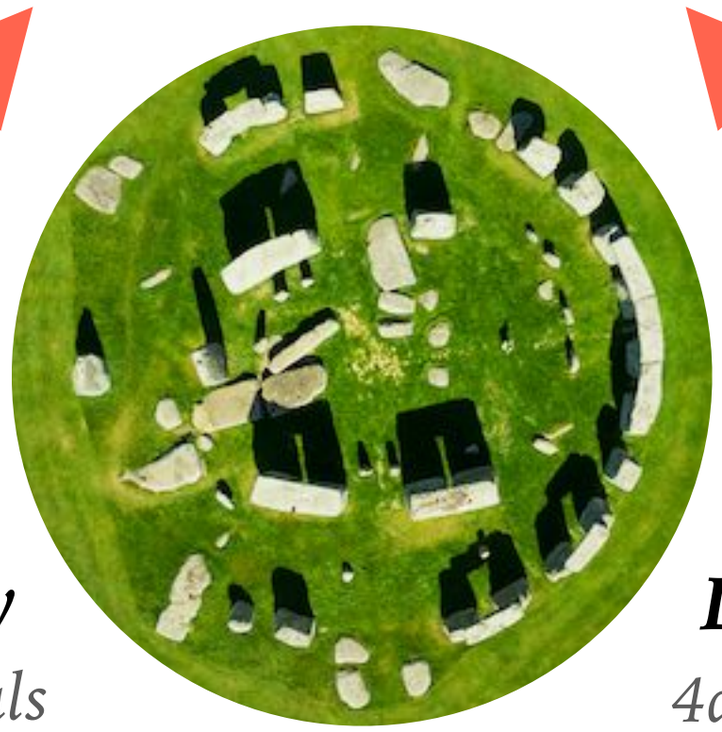
e.g. $G=SU(2)$ *is singular pt on CB of* $SO(2p)$ *SYM*

[Argyres, Maruyoshi, Tachikawa 12]

- Geometries with irregular punctures very rigid: restricted to genus 0 + max of 2 punctures for SCFT

Geometric engineering

from M5-branes



Holography

AdS_5 supergravity duals

[Bah, Bonetti, Minasian, **EN** 21, 21]
[Bah, Bonetti, **EN**, Waddleton 22]

Lagrangian duals

4d Lagrangian RG flows

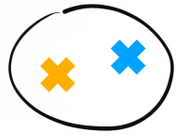
[Maruyoshi, **EN,** Song 23]

Holography highlights for AD theories

- We find $AdS_5 \times_w M_6$ solutions in 11d supergravity dual to the 4d $\mathcal{N} = 2$ $D_p[SU(N)]$ theories (+ generalizations)

  → **first identified duals of irregular punctures!**

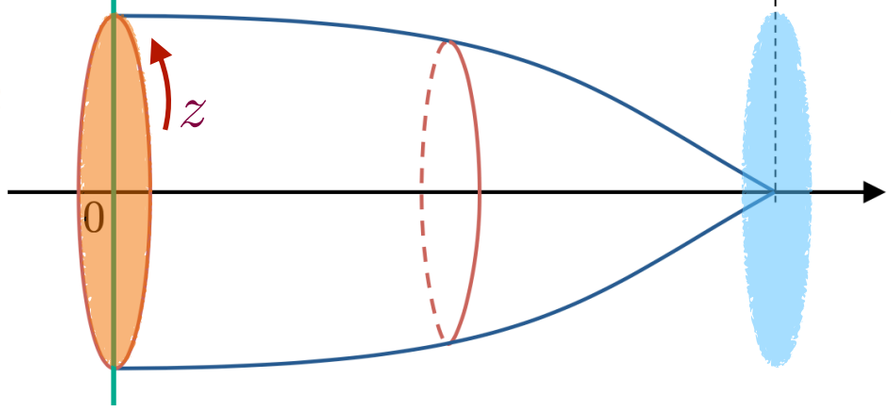
  [Bah, Bonetti, Minasian, **EN** 21, 21; Bah, Bonetti, **EN**, Waddleton 22]
  (*regular punctures:* [Maldacena, Nuñez 00; Gaiotto, Maldacena 09])
  see also [Couzens, Kim, Kim, Lee 22]

- Internal space $M_6 = S^4$ (transverse to M5's) $\times \Sigma$ (dual to ), $\Sigma =$ disk with orbifold singularity

$$\text{hol}(A)\big|_{\partial\Sigma} = \frac{p-1}{N}$$

irregular puncture

= smeared M5's on $AdS_5 \times S^1_z$



charge N monopole

regular puncture

duals known from [Gaiotto, Maldacena 09]; *see also* [Bah 15; Bah, Bonetti, Minasian, **EN** 18, 19]

Holography highlights for AD theories

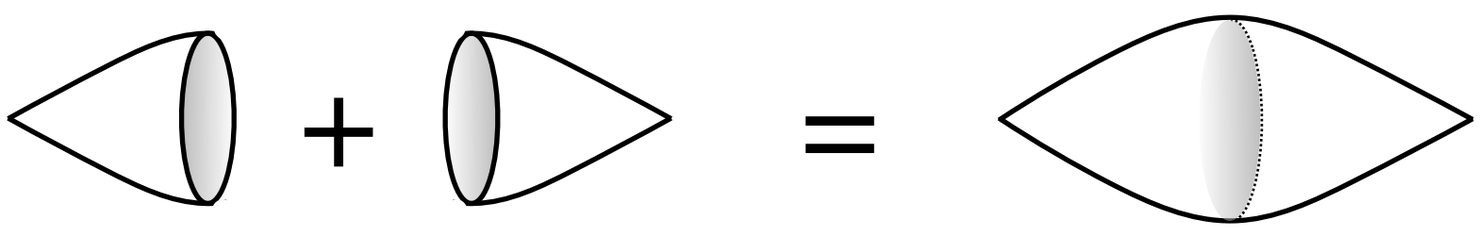
- Novel means of preserving SUSY: "half-spindle"
  - In the standard topological twist, covariantly constant spinors (supercharges) preserved by turning on a background magnetic field to cancel the curvature.
  - Here, the Killing spinors are **not** constant on Σ.

(flux through disk boundary; R-symmetry mixes with global S^1_z isometry)

c.f. "spindles" - [Ferrero, Gauntlett, Pérez Ipiña, Martelli, Sparks 20; Hosseini, Hristov, Zaffaroni 21; Boido, Pérez Ipiña, Sparks 21; Ferrero, Gauntlett, Martelli, Sparks 21; …]

Open Questions

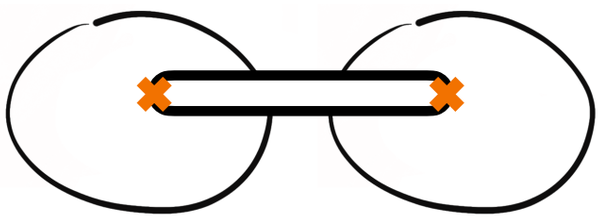
- New classes of SCFTs from "global" topological twists?
- New building blocks to realize strongly coupled 4d $\mathcal{N} = 1$ SCFTs?



glue opposite orientations

"spindle" solution

***pictorially — details not worked out!*



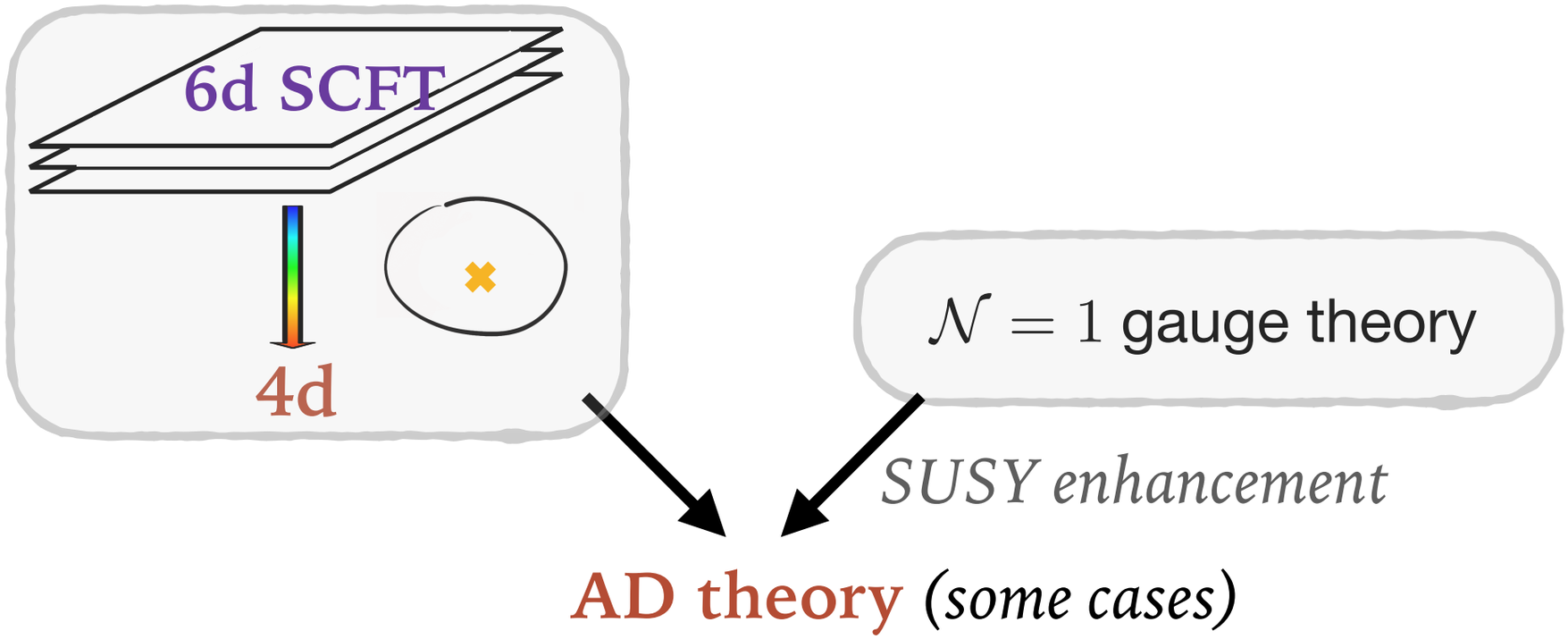
= ?

How to "glue" irregular punctures?

Lagrangians for non-Lagrangian theories

- No manifestly $\mathcal{N} = 2$ Lagrangian for AD theories, but in some cases dual $\mathcal{N} = 1$ Lagrangian quiver RG flows are known.

  [Maruyoshi, Song 16; Agarwal, Maruyoshi, Song 16; Giacomelli 17; Maruyoshi, **EN**, Song 18; …]

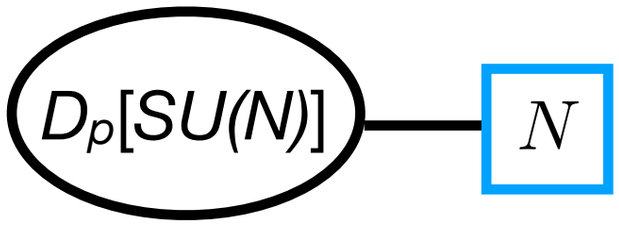


- Such dualities allow us to compute **new data** of the strongly coupled QFT, incl. emergent flavor symmetries & op dimensions.

  useful for duality checks of the holographic solutions

Recently: new examples of Lagrangian dualities for strongly coupled $\mathcal{N}=1$ SCFTs from $\mathcal{N}=1$ deformations of AD theories

Main observation:



+ *$\mathcal{N}=1$ superpotential deformation by smallest-dimension CB operator*

$$\Delta(u_0) = \frac{p+1}{p}$$

"=" $SU(N)$ adjoint chiral multiplet

[Bolognesi, Giacomelli, Konishi 15; Xie, Yan 21; Kang, Lawrie, Lee, Song 23; Maruyoshi, **EN**, Song 23]

Then, couple to N_f fundamentals → whole system dual to the fixed point of 4d $\mathcal{N}=1$ $SU(N)$ SQCD + an adjoint chiral multiplet.

[Kutasov, Seiberg, Schwimmer 95; Kutasov 95; Kutasov, Schwimmer 95]

Lesson: These unfamiliar SCFTs are actually much more closely related to more ordinary QFTs than we imagined!

Looking to the future: harness these developments to gain insights into strongly coupled QFTs with minimal/no supersymmetry.

Conclusions

- Geometric engineering provides a rich testing ground for exploring the (interconnected!) landscape of QFT.