Instituto de Física Teórica UAM-CSIC

European Research Council

SPLE Advanced Grant

5-brane webs and 5d, 6d SCFTs

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Based on the collaboration with

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[arXiv:1505.04439], [arXIv:1509.03300] and [arXiv:1512.08239]

24th of February 2016, **F-theory at 20** at Caltech

1. Introduction

- Understanding 6d $\boldsymbol{N}$ = (1, 0) SCFTs that have various interesting properties.

- An indirect way to study 6d SCFTs
  → Use a 5d gauge theory which has a 6d UV completion.

- In general, gauge theories in higher dimensions are not renormalizable. The gauge coupling becomes infinitely strong at high energies.

- Those gauge theories in higher dimensions may make sense at UV if they admit a UV fixed point.

- In the case of 5d gauge theories, the UV completion is given by either a 5d SCFT or a 6d SCFT.

- When the UV completion is a 6d SCFT, KK modes of the circle compactification may be identified with an infinite tower of instantons in the 5d theory.

What is a 5d gauge theory that has a 6d UV completion?

- Example: 5d SU(2) gauge theories with N_f flavors

Seiberg 96,
Morrison, Seiberg 96
Douglas, Katz, Vafa 96
Ganor, Morrison, Seiberg 96

(i) $N_f = 8 \rightarrow$ 6d SCFT called "E-string"

5d Nekrasov partition function = 6d elliptic genus

Kim, Kim, Lee, Park, Vafa 14

(ii) $N_f \leq 7 \rightarrow$ 5d SCFT with E_{N_f+1} flavor symmetry

- Can we generalize this, for example to higher rank cases?

- This question turns out to be quite non-trivial!

6d ??? on S^1

KK modes = instantons

5d SU(N>2) gauge theory with ??? flavors

decoupling flavors 

Other UV complete 5d SU(N>2) gauge theories?

- What is the landscape of UV complete 5d theories?

- I will address the questions from string theory.

I will argue that:

- String theory predicts new UV complete 5d gauge theories that admit a 6d UV completion and gives a direct relation between 5d and 6d.

- String theory also implies new 5d “UV dualities”.

- The landscape of UV complete 5d gauge theories may be largely expanded!

1. Introduction

2. 5d gauge theories from string theory

3. 5-brane webs and 6d SCFTs

4. New 5d UV dualities

5. Conclusion

2. 5d gauge theories from string theory

- We construct a 5d supersymmetric field theory with eight supercharges as the worldvolume theory on a 5-brane web.

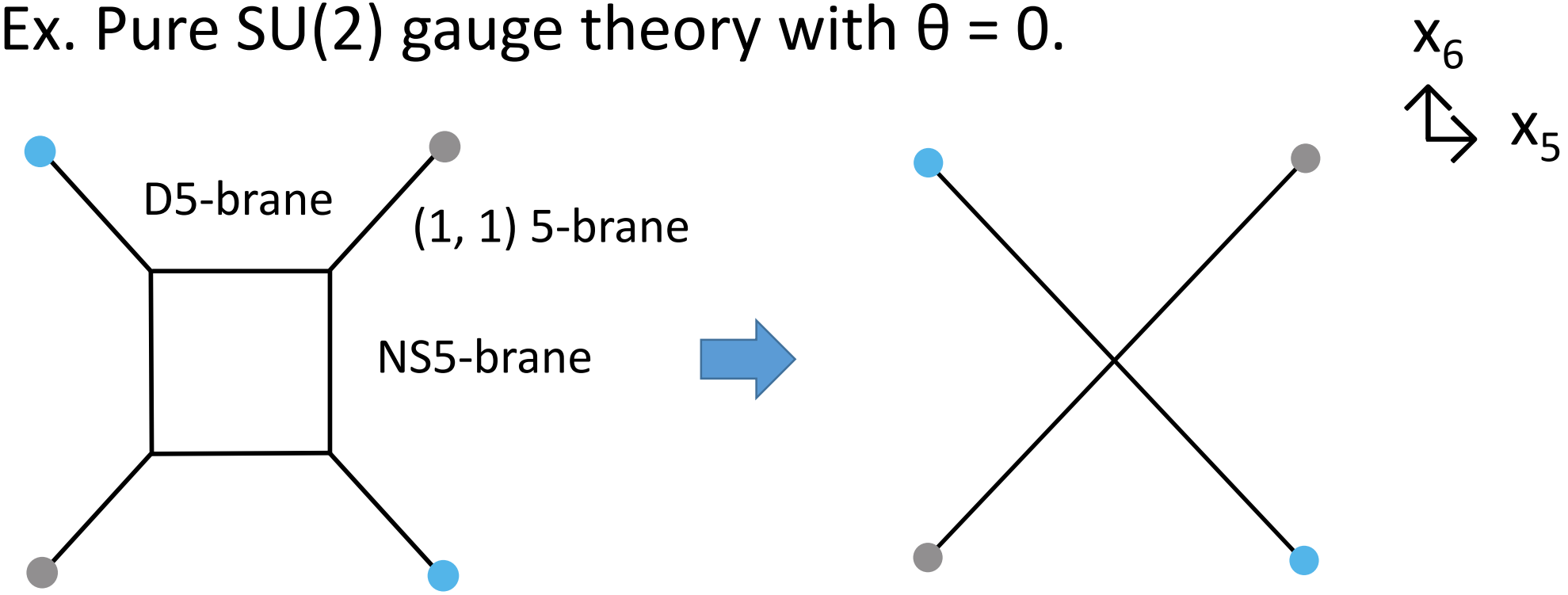
- The 5-brane configuration in Type IIB string theory.

	0	1	2	3	4	5	6	7	8	9
D5-brane	×	×	×	×	×	×				
NS5-brane	×	×	×	×	×		×			
(p, q) 5-brane	×	×	×	×	×	angle				
7-brane	×	×	×	×	×			×	×	×

5-brane web

Aharony, Hanany 97,
Aharony, Hanany, Kol 97
DeWolfe, Iqbal, Hanany, Katz 99

- Ex. Pure SU(2) gauge theory with $\theta = 0$.

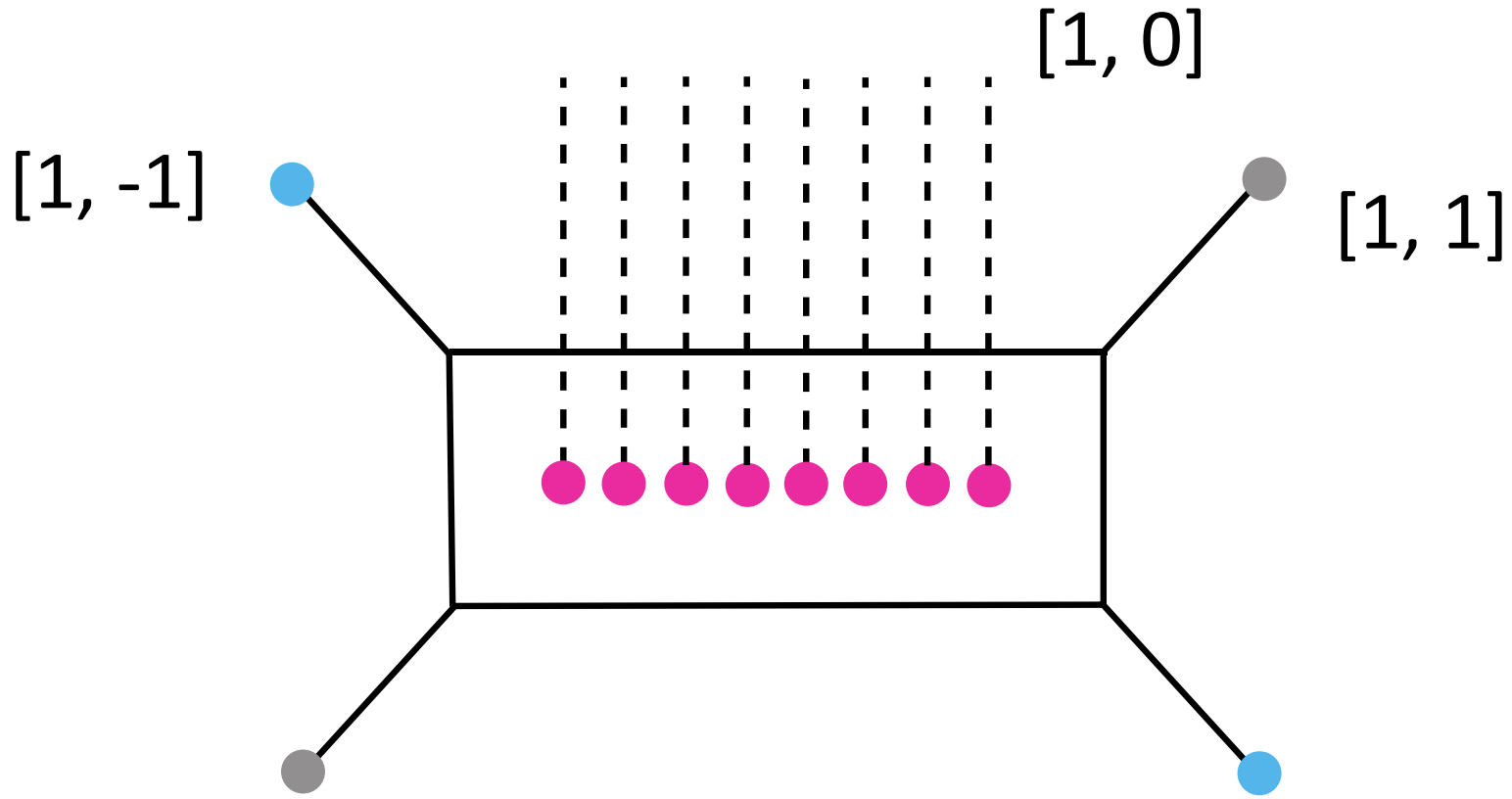


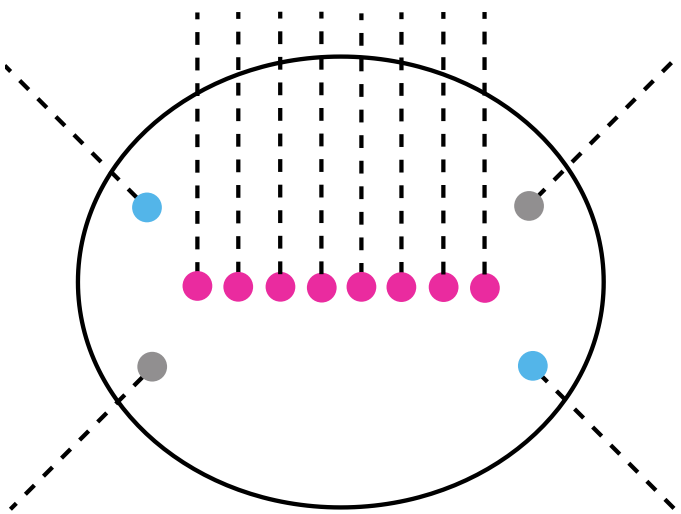
- This theory has a fixed point where the gauge coupling is infinitely strong.

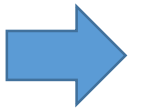
Seiberg 96

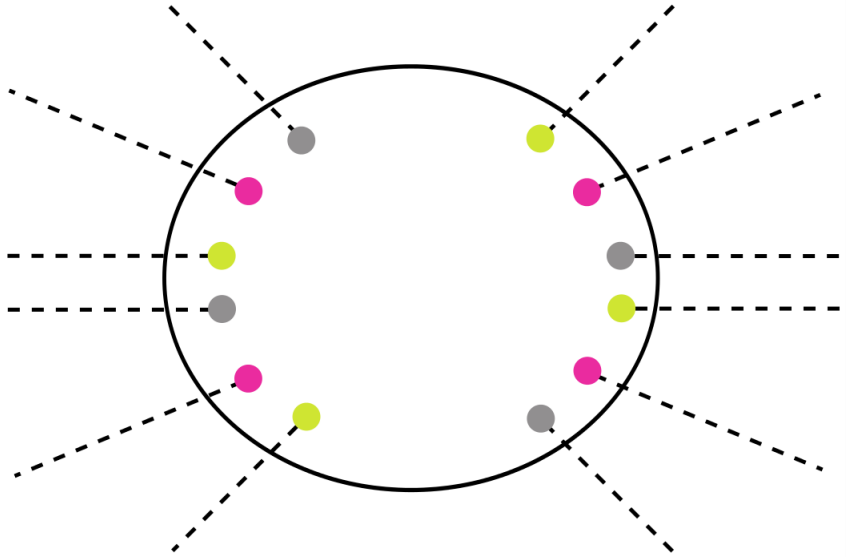
- Enhancement of flavor symmetry: U(1) $\rightarrow$ SU(2) = E_1.

- What happens if we consider the SU(2) gauge theory with 8 flavors? We know that its UV fixed point is the 6d E-string theory.

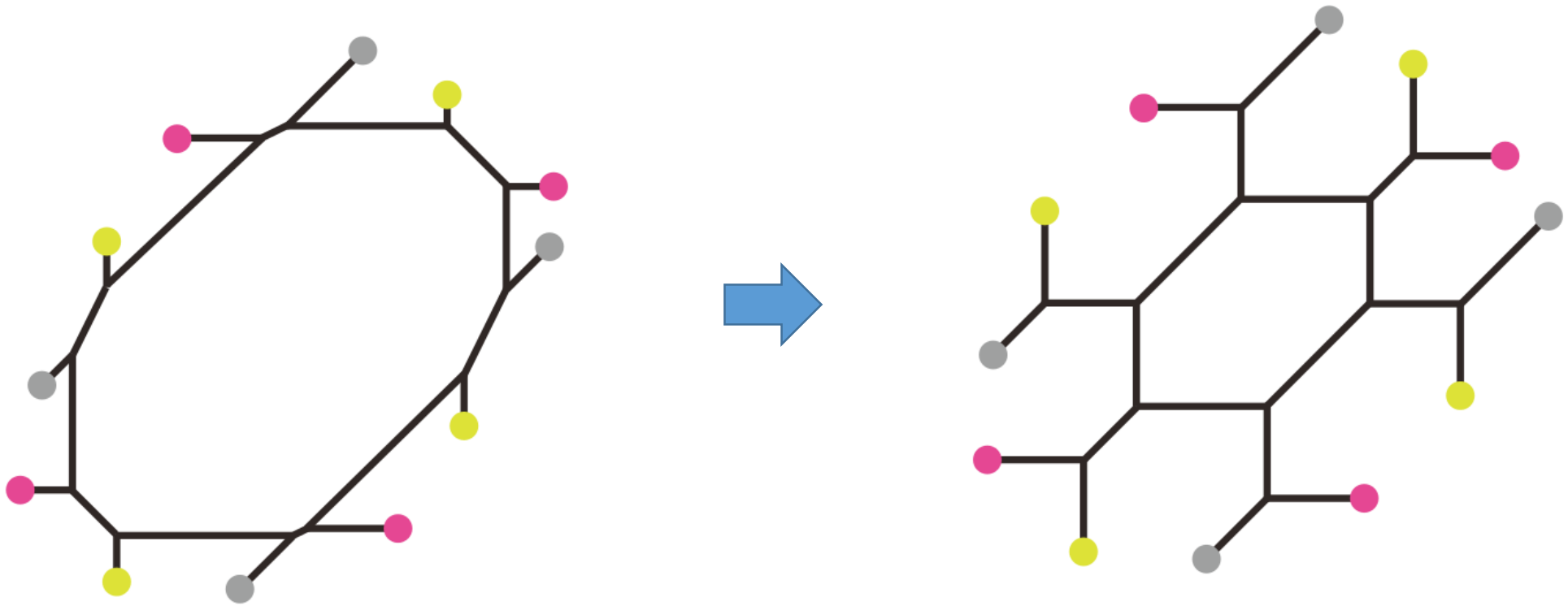


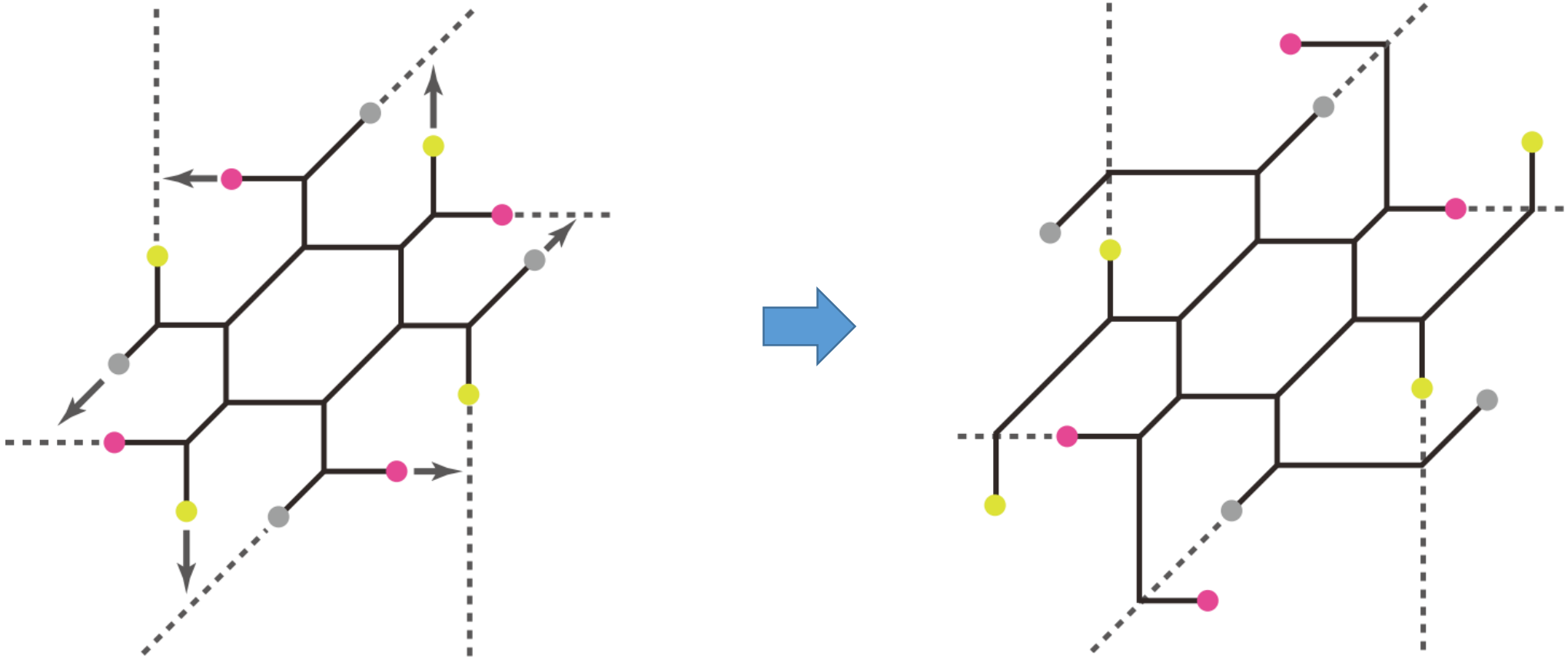




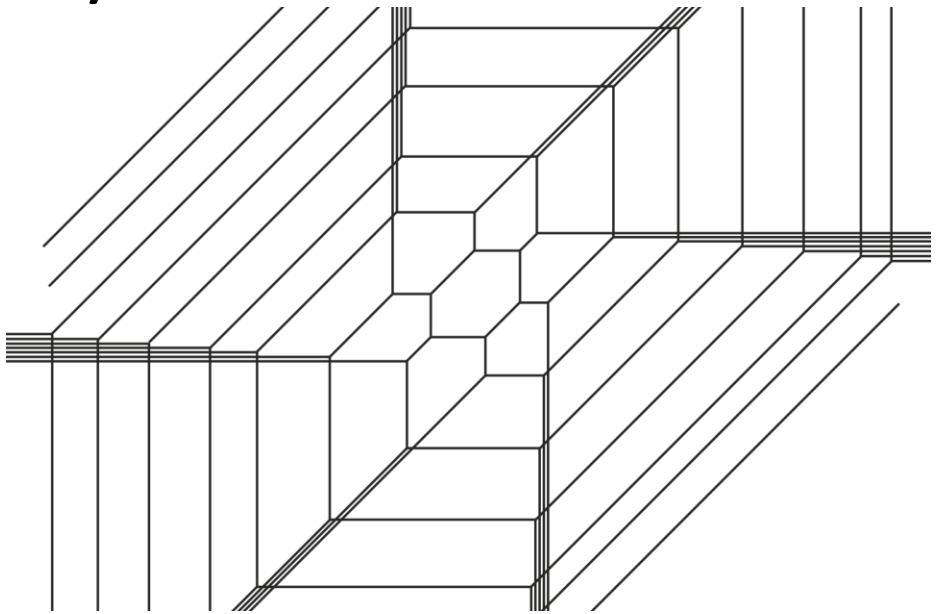


[0, 1]





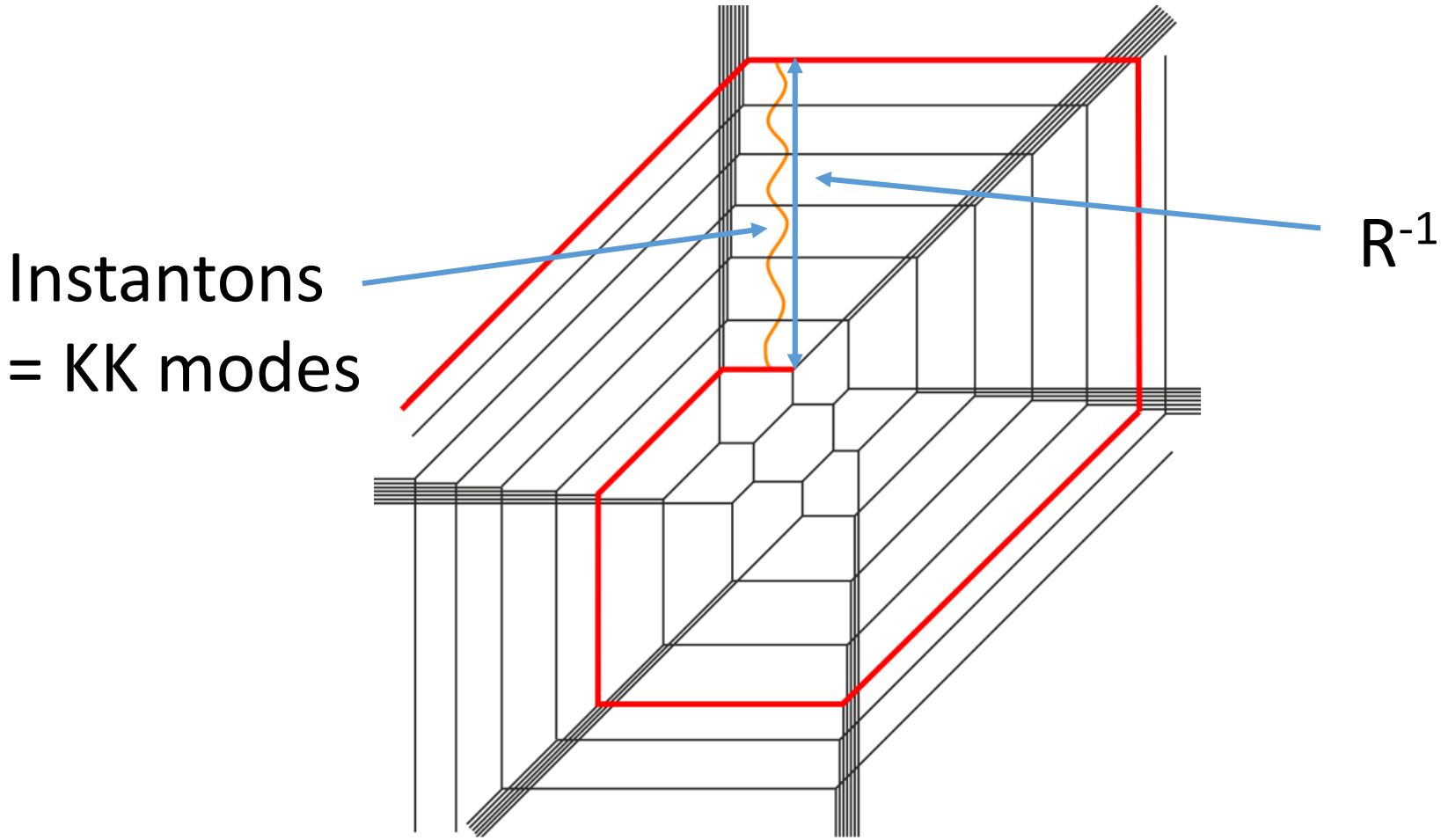
- Then the 5-brane web starts rotating when we pull 7-branes to infinity.



- The topological vertex computation reproduces the Nekrasov partition function of 5d SU(2) gauge theory with 8 flavors

Kim, Taki, Yagi 15

- The infinitely rotating structure is essential to reproduce the infinite tower of KK modes.



- Conjectures:

- The existence of a standard 5-brane web implies the corresponding 5d theory has a 5d UV fixed point.

- The existence of an infinitely rotating 5-brane web implies the corresponding 5d theory has a 6d UV fixed point.

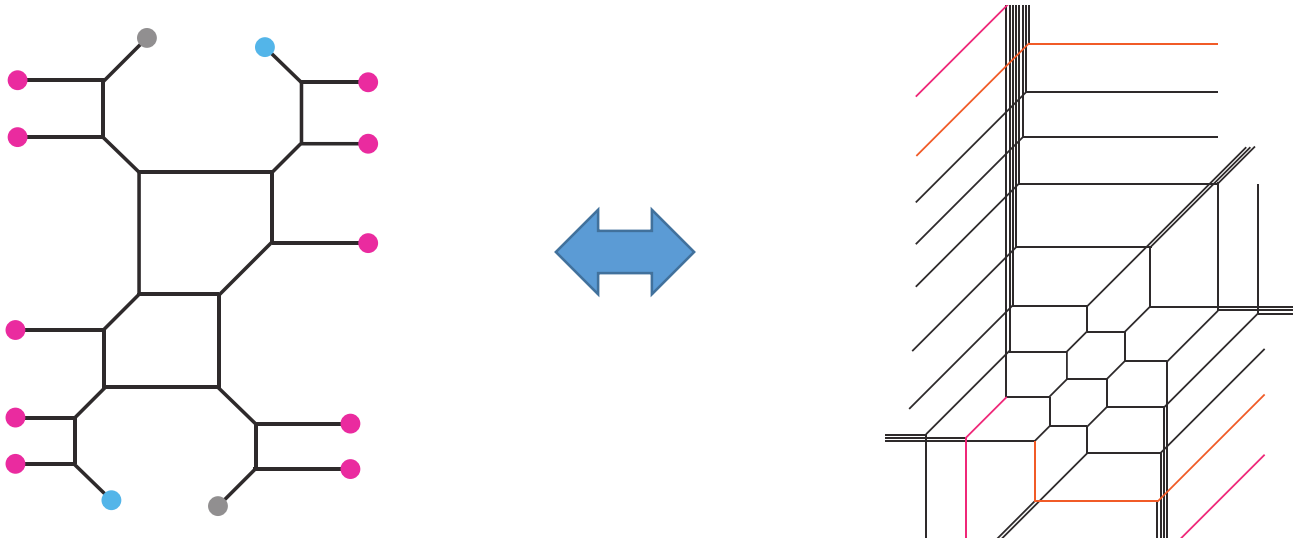
- Then let us think about the generalization by utilizing the infinitely rotating structure of 5-brane webs!

3. 6d SCFTs and 5-brane webs

- The generalization to higher rank cases is straightforward. The infinitely rotating structure of a 5-brane web appears when it yields a 5d SU(n) gauge theory with $N_f = 2n+4$ flavors.

Kim, Taki, Yagi 15

Ex. 5-brane web for 5d SU(3) with 10 flavors



- Does it corresponds to a 6d SCFT at UV? → Yes!

Hayashi, Kim, Lee, Taki, Yagi 15
Yonekura 15

- Our claim is

6d (D_{n+2}, D_{n+2}) minimal conformal matter theory on S^1

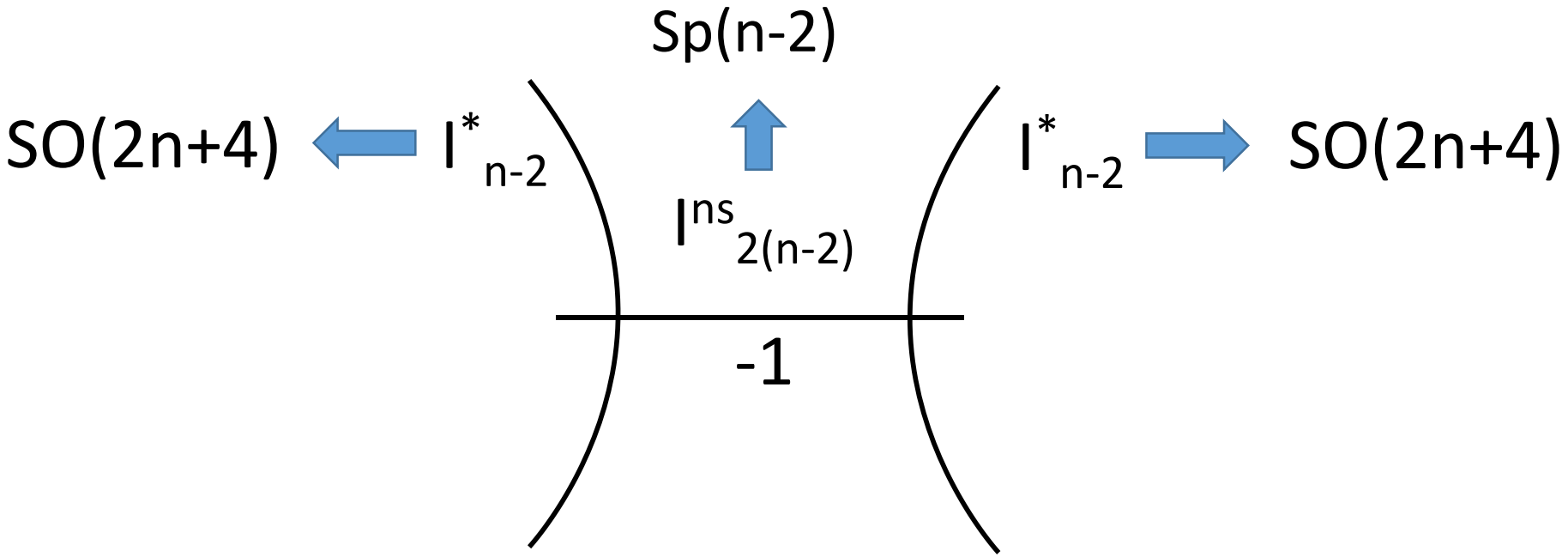
5d SU(n) gauge theory with $N_f = 2n+4$ & CS-level 0

- In fact, we can "derive" this claim by using a brane construction in string theory.

Hayashi, Kim, Lee, Taki, Yagi 15

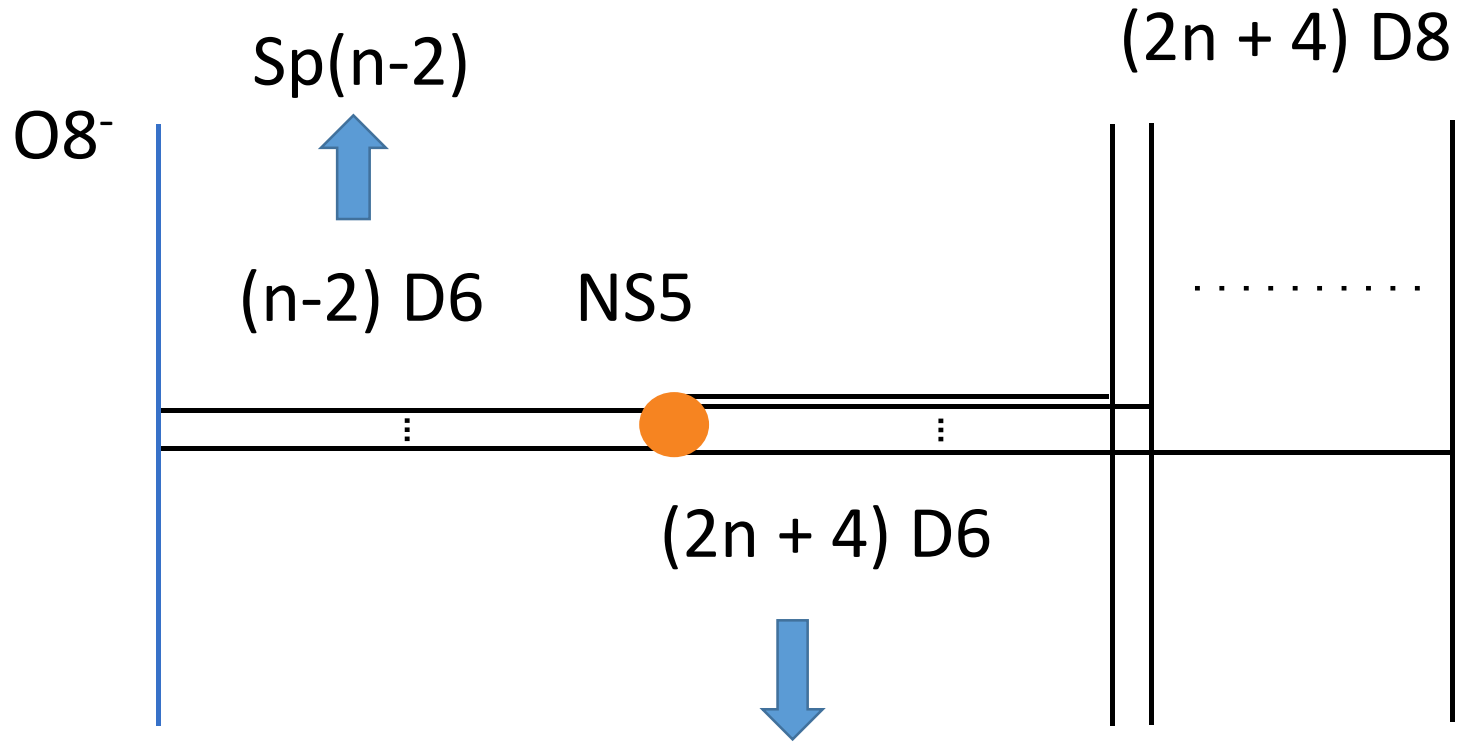
- On the tensor branch, the 6d (D_{n+2}, D_{n+2}) minimal conformal matter theory becomes a 6d Sp(n-2) gauge theory with 2n+4 fundamental hypermultiplets, coupled to a tensor multiplet.

Del Zotto, Heckman, Tomasiello, Vafa 14



- The type IIA brane configuration

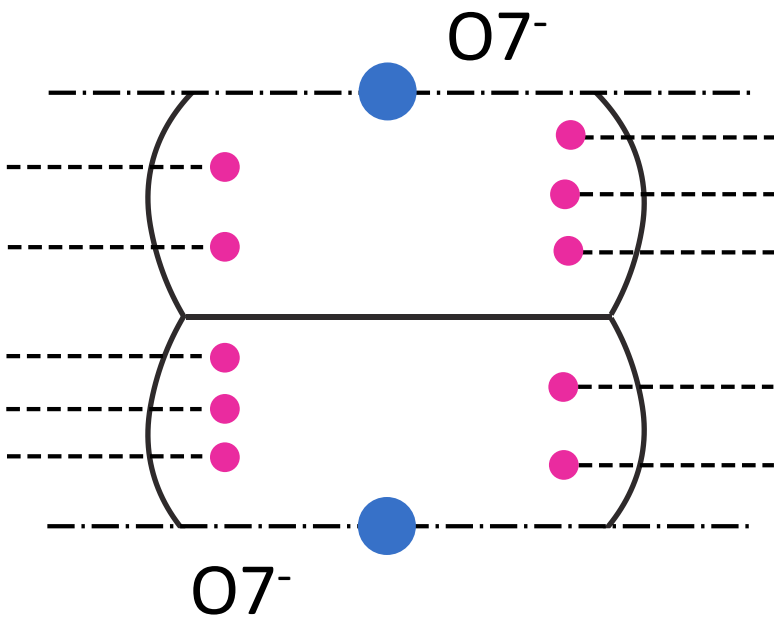
Brunner, Karch 97
Hanany, Zaffaroni 97

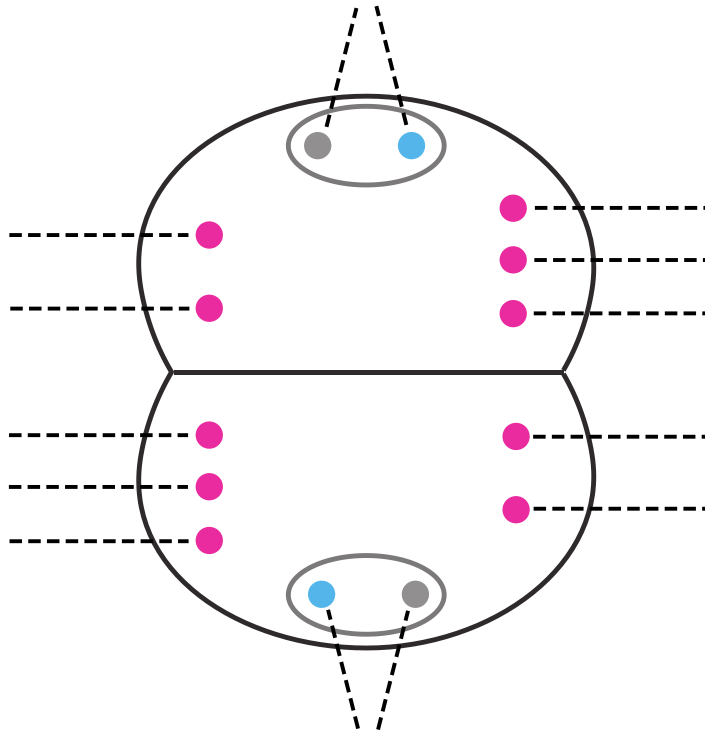


	0	1	2	3	4	5	6	7	8	9
D6-brane	×	×	×	×	×	×	×			
NS5-brane	×	×	×	×	×		×			
D8-brane	×	×	×	×	×		×	×	×	×
O8-plane	×	×	×	×	×		×	×	×	×

- We then compactify the x_6-direction on S^1 and perform the T-duality along the direction.

Ex. n = 3



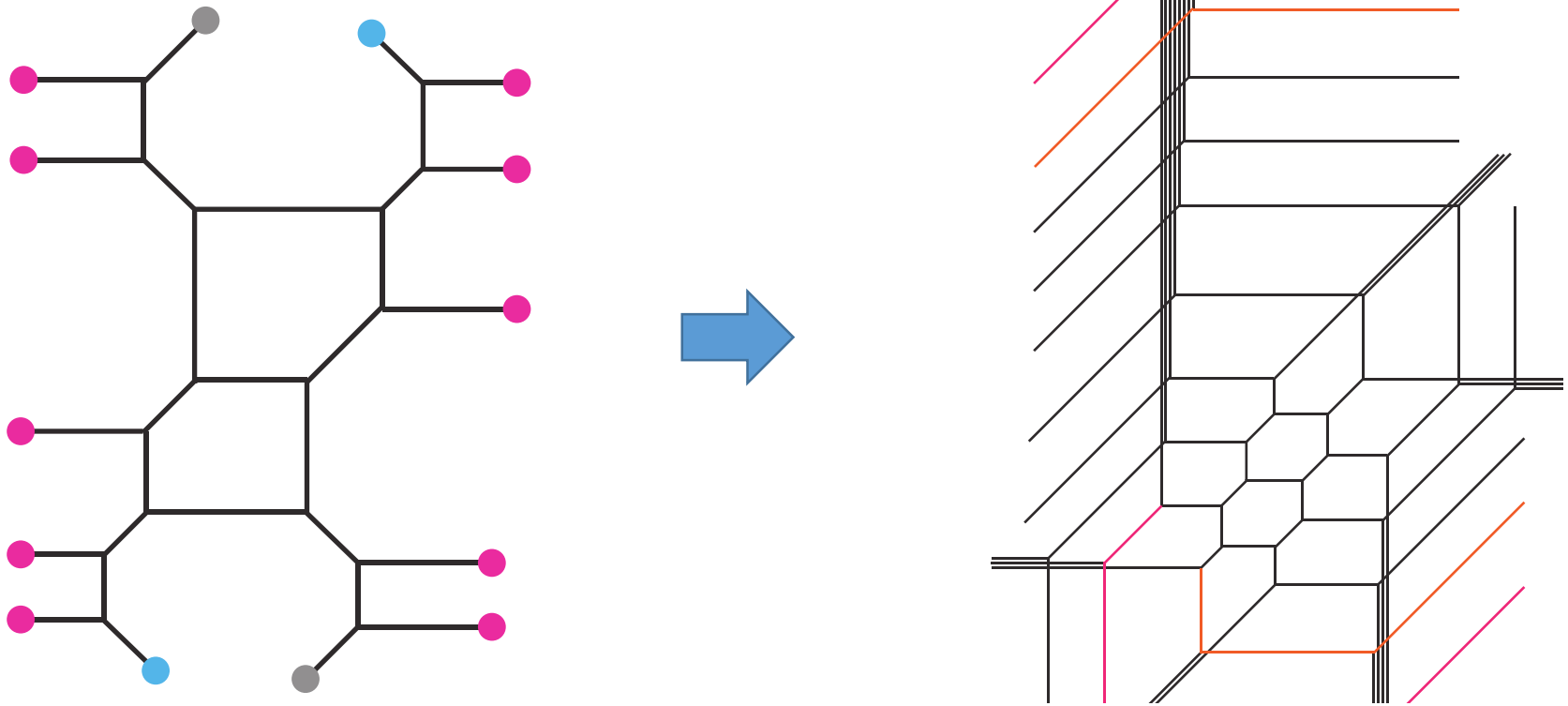


X_6

x_5

Resolving two O7-planes

- Pulling out the 7-branes outside the 5-brane loop yields the 5-brane web for the SU(3) gauge theory with $N_f = 10$ flavors.



- By decoupling flavors, we obtain 5d SU(n) gauge theories whose UV completion is 5d SCFTs.

5d SCFT 6d SCFT

$N_f = 0, \ldots\ldots, 2n, 2n+1, 2n+2, 2n+3, 2n+4$

Intriligator, Morrison, Seiberg 97 Bergman, Zafrir 14

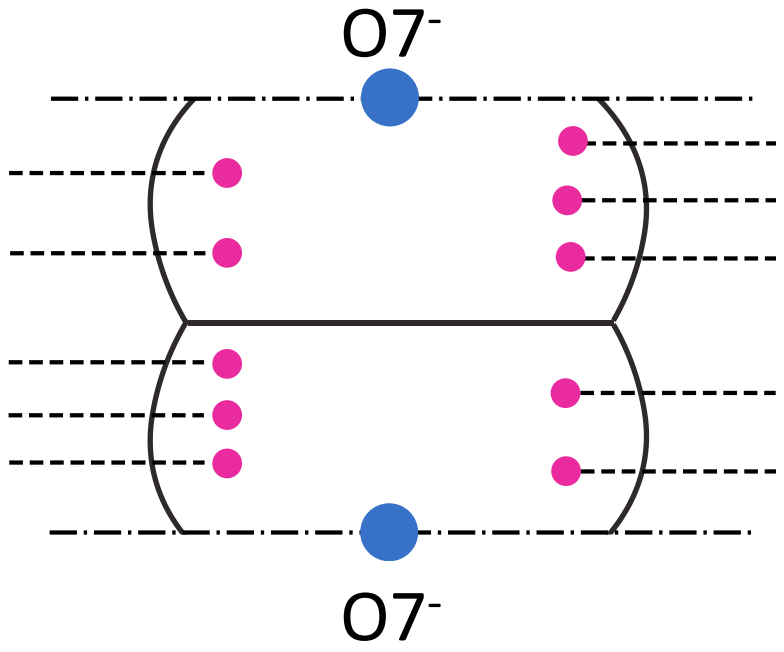
Hayashi, Kim, Lee, Taki, Yagi 15
Yonekura 15

6d (D_{n+2}, D_{n+2}) minimal conformal matter

- The condition for the UV completion

$$N_f + 2|k| \leq 2n + 4$$

- The infinitely rotating 5-brane web hides the structure of a “circle” given by the two O7$^-$-planes.



T-duality → 6d gauge theory on S^1

Resolving O7$^-$-planes → 5d gauge theory

- It is possible to generalize the analysis to other 6d SCFTs constructed by type IIA brane configurations.

(i) Including more NS5-branes gives new 5d A-type quiver gauge theories.

Yonekura 15
Zafrir 15,
Hayashi, Kim, Lee, Yagi 15
Ohmori, Shimizu 15

(ii) Including an ON^0-plane gives new 5d D-type quiver gauge theories.

Hayashi, Kim, Lee, Taki, Yagi 15

- Largely expands the landscape of 5d gauge theories!

Examples:

(i) 6d SU(2n) with $N_f = 2n+8$ and $N_a = 1$ on S^1

5d [n+3] – SU(n+1) – SU(n+1) – [n+3]

(ii) 6d [8]– SU(2n) –Sp(2n-4)–SO(4n)– Sp(2n-4) –[2n] on S^1

5d [4] – SU(n+3), [4] – SU(n+3) — SU(2n+2) – SU(2n-2) – SU(2n-6) – [2n-8]

4. New 5d UV dualities

- The derivation using the brane configuration also implies another interesting 5d dualities.

- 5d SU(n) $\leftrightarrow$ 5d Sp(n-1) duality

Gaiotto, Kim 15

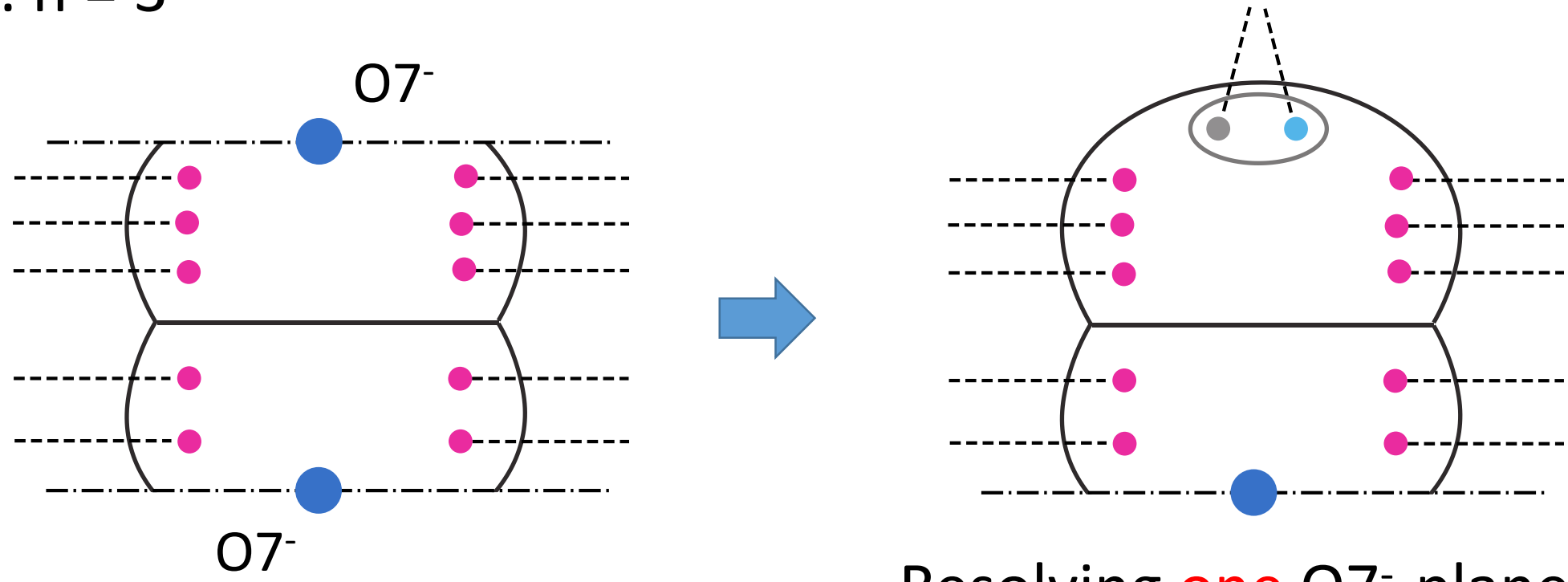
5d SU(n) gauge theory with N_f flavors & $|\kappa| = (n + 2 - N_f/2)$

5d Sp(n-1) gauge theory with N_f flavors

Why ???

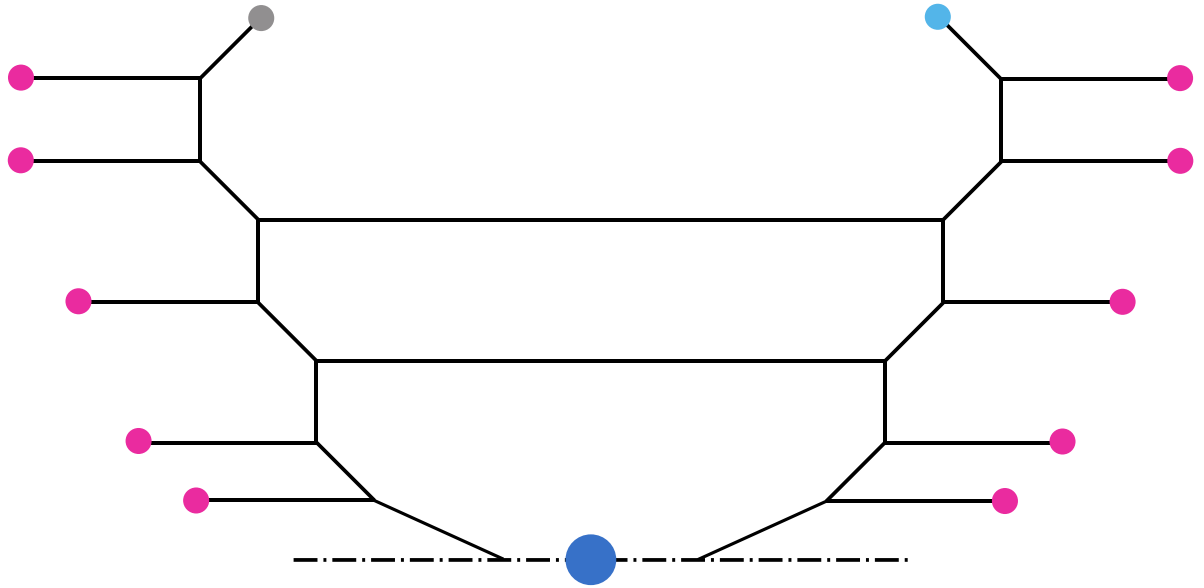
- The derivation again starts from the Type IIA brane configuration for the 6d Sp(n-2) gauge theory with N_f = 2n+4 flavors, coupled to a tensor multiplet.

Ex. n = 3



Resolving one O7-plane

- The resulting brane configuration is a 5d Sp(2) gauge theory with $N_f = 10$.



- In general, we obtain a 5d Sp(n-1) gauge theory with $N_f = 2n+4$.

Hayashi, Kim, Lee, Yagi 15

(D_{n+2}, D_{n+2}) minimal conformal matter

SU(n) with $N_f = 2n+4$ Sp(n-1) with $N_f = 2n+4$

- Decoupling flavors on both sides in the same way reproduces the 5d SU – Sp duality.

- The generalization to other 6d SCFTs yields various new 5d UV dualities.

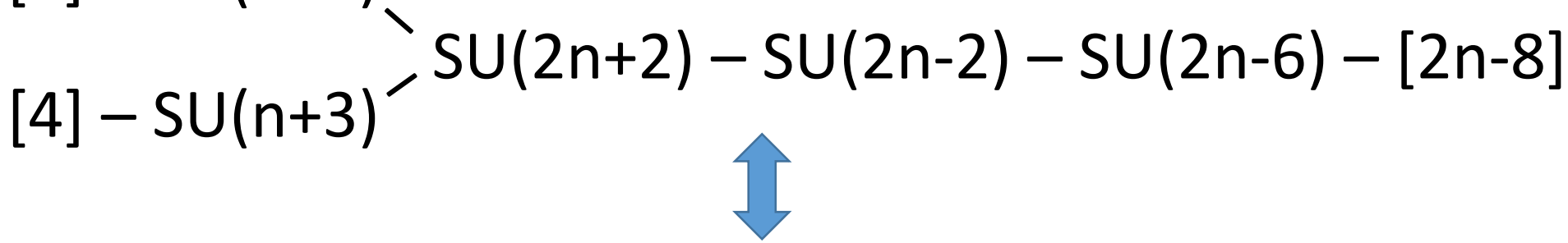
Hayashi, Kim, Lee, Yagi 15
Hayashi, Kim, Lee, Taki, Yagi 15

Examples:

(i) $[n+3] - SU(n+1) - SU(n+1) - [n+3]$

$SU(2n+1)$ with $N_f = 2n+7$ and $N_a = 1$

(ii)



$[8] - SU(2n+3) - Sp(2n-1) - SO(4n-2) - Sp(2n-5) - [2n-4]$

5. Conclusion

- 5-brane webs predict a large class of new 5d gauge theories that have a 5d or 6d UV completion.

- The combination of the T-duality and the resolution of O7-planes gives a way to directly identify the 6d UV completion of the new 5d gauge theories.

- The method also implies various new 5d UV dualities.