Higgsing towards E-strings

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Mainly based on

- arXiv:1510.03128 “Higgsing towards E-strings”
  with Seok Kim, Kimyeong Lee

Related works:

- arXiv:1504.04614 “6d String Chains”
  with Gadde, Haghighat, Seok Kim, Lockhart, Vafa
- arXiv:1411.2324 “Elliptic Genus of E-strings”
  with Seok Kim, Kimyeong Lee, Jaemo Park, Vafa

6d SCFTs

- There are many 6d superconformal field theories engineered from string theory.

- Famous examples include [Witten], [Strominger], [Ganor, Hanany]
  - N=(2,0) SCFT: type IIB string theory on ADE singularity. Type A_{N-1} theory describes a stack of N M5-branes.
  - N=(1,0) E_8 SCFT describes a stack of N M5-branes, probing the E_8 boundary wall of heterotic M-theory.

- Much more examples appeared in various literatures, from
  - brane systems at low energy: [Strominger], [Blum, Intriligator], [Intriligator], [Brunner, Karch], [Hanany, Zaffaroni], [Del Zotto et al.], …
  - F-theory on non-compact CY3s: [Morrison, Vafa], [Witten], [Aspinwall], [Bershadsky, Vafa], [Heckman et al.], …

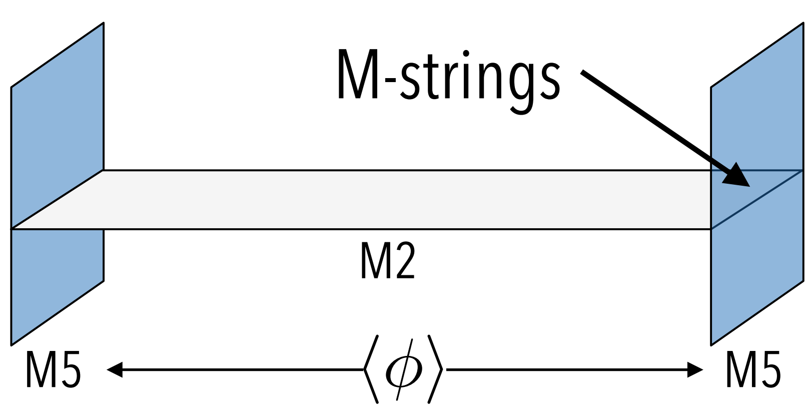
Self-dual strings

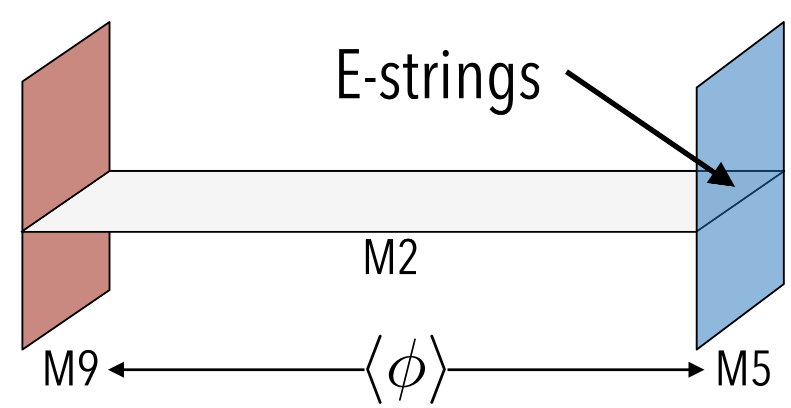
- 6d SCFTs contain interacting strings, which are
  - electric & magnetic sources of tensor multiplets

    $(B_{\mu\nu},\, \psi_+^A,\, \phi)$ with self-duality $H_{\mu\nu\rho} = (*H)_{\mu\nu\rho}$
  - Yang-Mills instantons (if there is a gauge symmetry)

$$k = \frac{1}{8\pi^2}\int d^4x\ \mathrm{tr}\,(F \wedge F) \in \mathbf{Z}$$

- These strings acquire non-zero tension in a tensor branch, which is parametrized by VEVs of tensor multiplet scalars.





Higgsing chain of theories

- For a 6d gauge theory, matter contents must be tuned in order to cancel the possible gauge anomaly.

SU(3)	$N_f = 0, 6, 12$
SU(2)	$N_f = 4, 10$

[Bershadsky, Vafa '97]

  - They are Higgsable to M-string theory & E-string theory.

    SU(3) with $N_f = 6$ → SU(2) with $N_f = 4$ → M-string theory
    SU(3) with $N_f = 12$ → SU(2) with $N_f = 10$ → E-string theory

- Our aim is to study self-dual strings of SU(2) and SU(3) gauge theories which are Higgsable to M-string & E-string theories.

Instanton moduli space

- As self-dual strings are also Yang-Mills instanton solitons, their worldsheet dynamics is described by non-linear sigma model whose target space is the instanton moduli space.

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- Instanton moduli space has small instanton singularity, which reflects UV incompleteness of 6d SYM. Working with singular moduli spaces is a very challenging task.

Instanton moduli space

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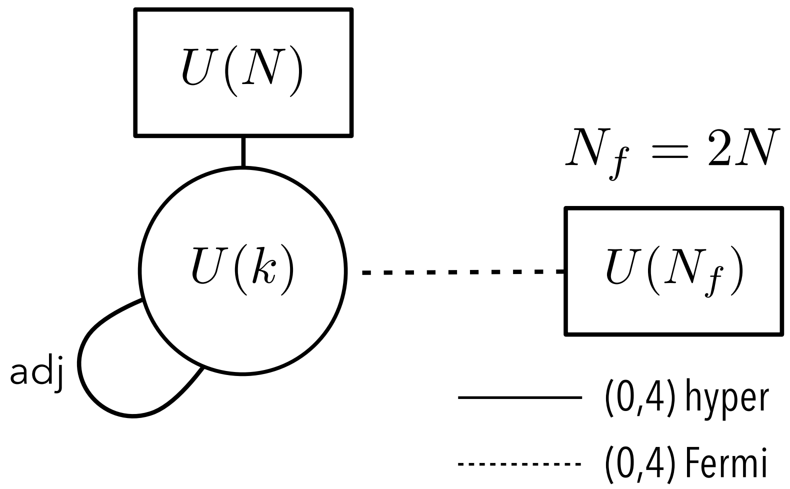
- The resulting ADHM gauge theory provides UV completion of non-linear sigma model in a sense that its Higgs branch recovers the instanton moduli space in IR, being away from small instanton singularity. [Witten '94]

ADHM gauge theory

- For SU(N) gauge theories Higgsable to M-string theory, the ADHM gauge theory for 'k' self-dual strings is



N=(0,4) SUSY generated by $Q^{\dot{\alpha}A}$

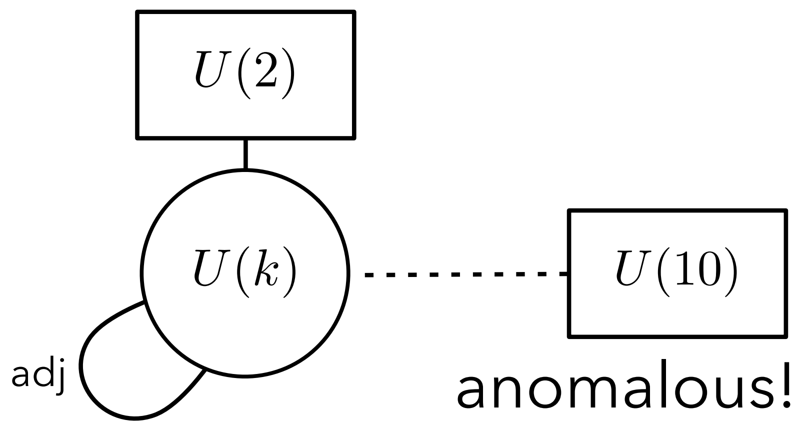
$$\underset{\alpha}{SU(2)} \times \underset{\dot{\alpha}}{SU(2)} \times \underset{A}{SU(2)} \times U(N) \times U(2N)$$

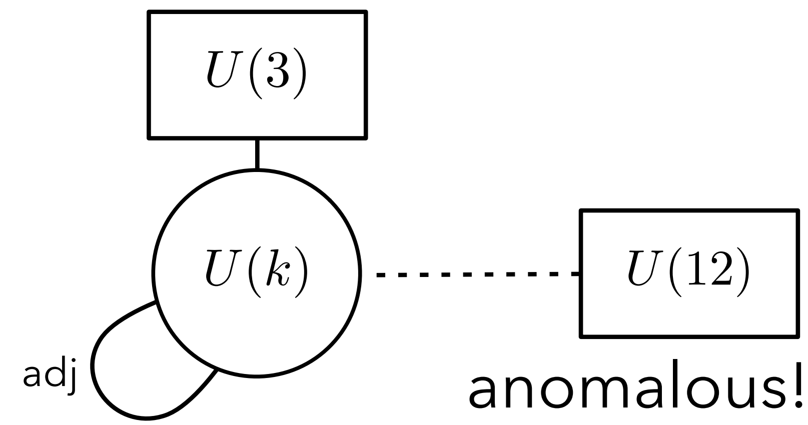
- This theory can be engineered using 'k' D2-branes on top of 'N' D6-branes, suspended between two NS5-branes.

  - N=1 case uplifts to M-string theory. [Haghighat et al. '13]

ADHM gauge theory

- For SU(3) and SU(2) theories Higgsable to E-string theory, naive ADHM construction does not yield a sensible theory.





- Hypermultiplets in

$$SU(3):\ \textsc{Anti}\,(\overline{\mathbf{3}},\overline{\mathbf{3}})=\mathbf{3},\qquad SU(2):\ \textsc{Anti}\,(\mathbf{2},\mathbf{2})=\mathbf{1}$$

representations provide different resolutions of singularity.

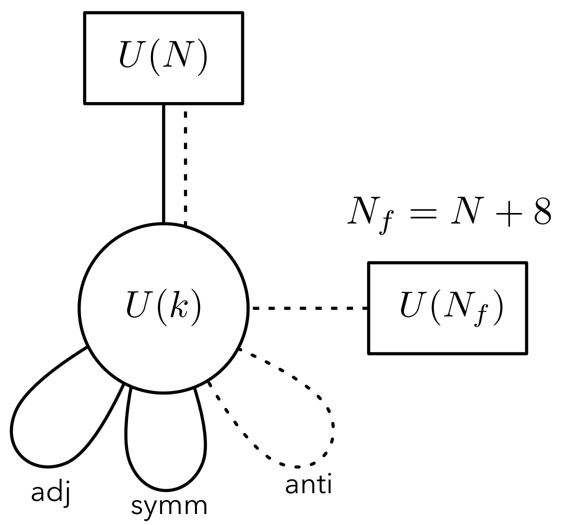
Having an antisymmetric hypermultiplet introduces extra degrees of freedom supported at small instanton singularity. It modifies the worldsheet gauge theory.

ADHM gauge theory

- Anomaly-free 2d gauge theory is found after interpreting

  6d SU(3) with $N_f = 12$ → 6d SU(3) with $N_f = 11$, $N_a = 1$.

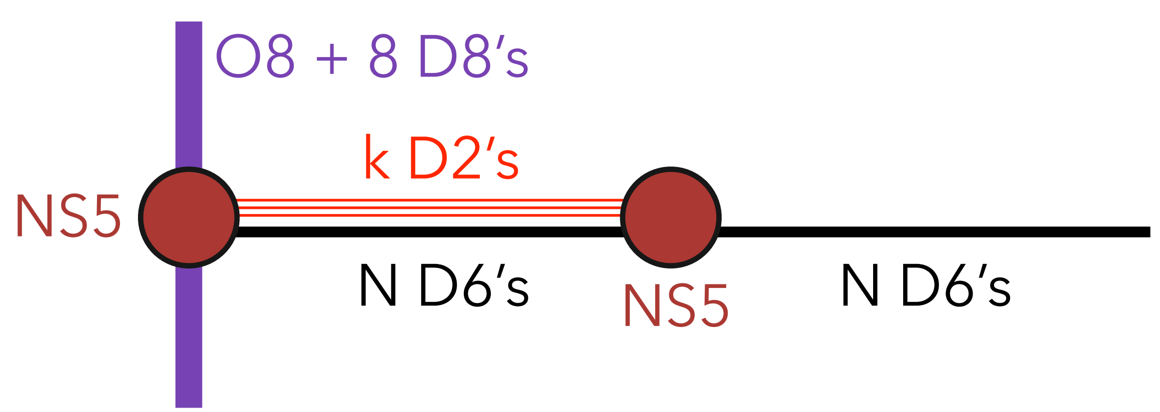
  6d SU(2) with $N_f = 10$ → 6d SU(2) with $N_f = 10$, $N_a = 1$.



N=(0,4) SUSY generated by $Q^{\dot{\alpha}A}$

SU(2) X SU(2) X SU(2)
X U(N) X U(N+8) X U(1)

- This theory can be engineered using ‘k’ D2-branes in



IR symmetry enhancement

- If our proposal is correct, the anomaly-free gauge theory should exhibit the flavor symmetries of underlying 6d QFTs. However, those are partly missing. We check if they emerge in IR by computing the elliptic genera. [Benini et al. '13]

$$\mathrm{Tr}_{\mathrm{RR}}\left[(-1)^F q^{H_L} \bar{q}^{H_R} e^{2\pi i \epsilon_1 (J_1+J_R)} e^{2\pi i \epsilon_2 (J_2+J_R)} e^{2\pi i M A} \prod_{l=1}^{N_f} e^{2\pi i m_l F_l} \prod_{i=1}^{N} e^{2\pi i a_i G_i}\right].$$

$$H_R = \{Q^{\dot{1}2}, Q^{\dot{2}1}\}$$

For example, at k=1,

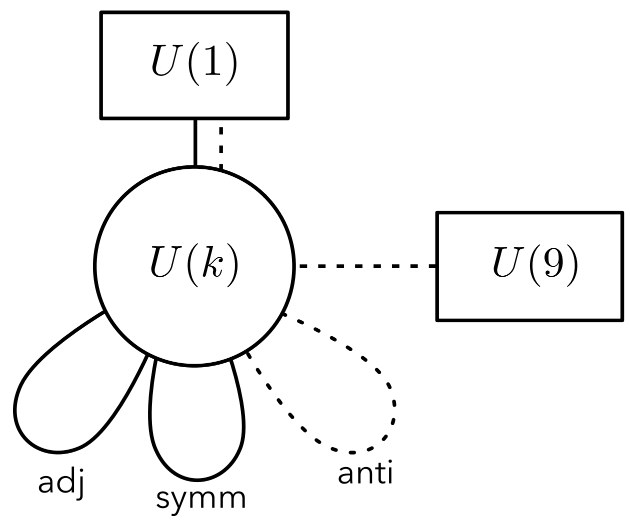
$$Z_1 = -\sum_{j=1}^{N} \frac{\eta^{-6} \prod_{l=1}^{N+8} \theta_1(a_j - \epsilon_+ - m_l)}{\theta_1(\epsilon_1)\theta_1(\epsilon_2)\theta_1(2a_j - 3\epsilon_+ + M)} \cdot \prod_{i \neq j} \frac{\theta_1(a_i + a_j - \epsilon_+ + M)}{\theta_1(a_j - a_i)\theta_1(2\epsilon_+ - (a_j - a_i))}$$
$$- \frac{1}{2} \frac{\eta^{-6}}{\theta_1(\epsilon_1)\theta_1(\epsilon_2)} \left[\frac{\prod_{l=1}^{N+8} \theta_1(\frac{\epsilon_+ - M}{2} - m_l)}{\prod_{i=1}^{N} \theta_1(\frac{3\epsilon_+ - M}{2} - a_i)} + (-1)^N \sum_{I=2}^{4} \frac{\prod_{l=1}^{N+8} \theta_I(\frac{\epsilon_+ - M}{2} - m_l)}{\prod_{i=1}^{N} \theta_I(\frac{3\epsilon_+ - M}{2} - a_i)} \right]$$

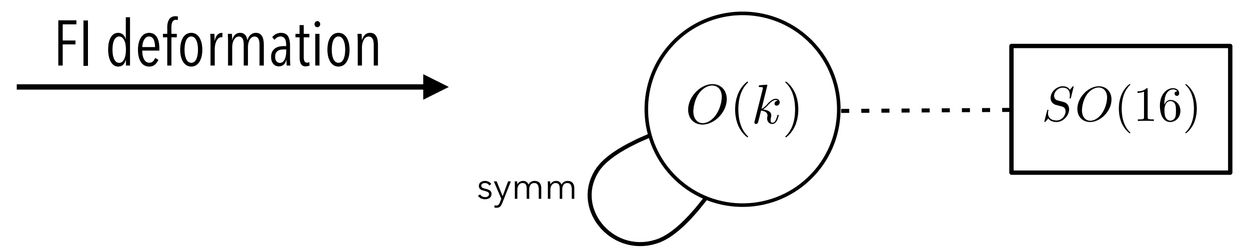
- After series expansion by $q = e^{2\pi i \tau}$, the BPS spectra exhibit

	SU(3)	SU(2)
Classical symmetry	S[U(11) X U(1)]	S[U(10) X U(1)]
IR symmetry	SU(12)	SO(20)

Multiple M5s probing M9

- At N=1, the brane system uplifts to E-string theory where an M5-brane is near the E_8 boundary wall intersecting Taub-NUT.



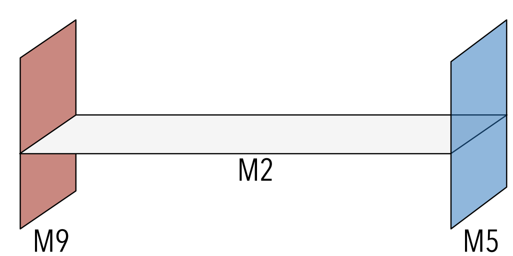


Known UV description of E-strings

[JK, Kim, Lee, Park, Vafa '14]

- The elliptic genus shows the IR symmetry enhancement.

Classical	S[U(9) X U(1)]	SO(16)
Infrared	E_8 X $SU(2)_F$	E_8



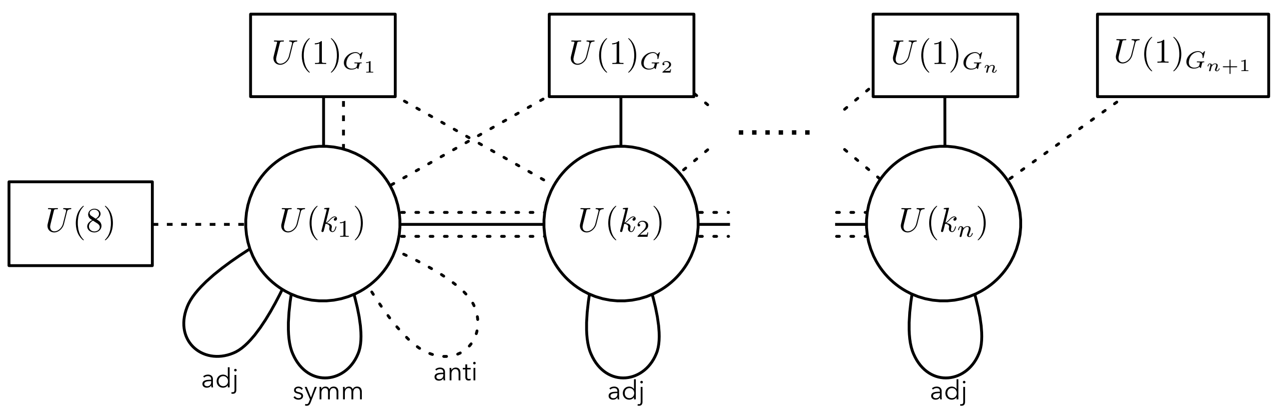
	0	1	2	3	4	5	6	7	8	9	10
M5	•	•		•	•	•	•				
M9	•	•		•	•	•	•	•	•	•	•
M2	•	•	•								

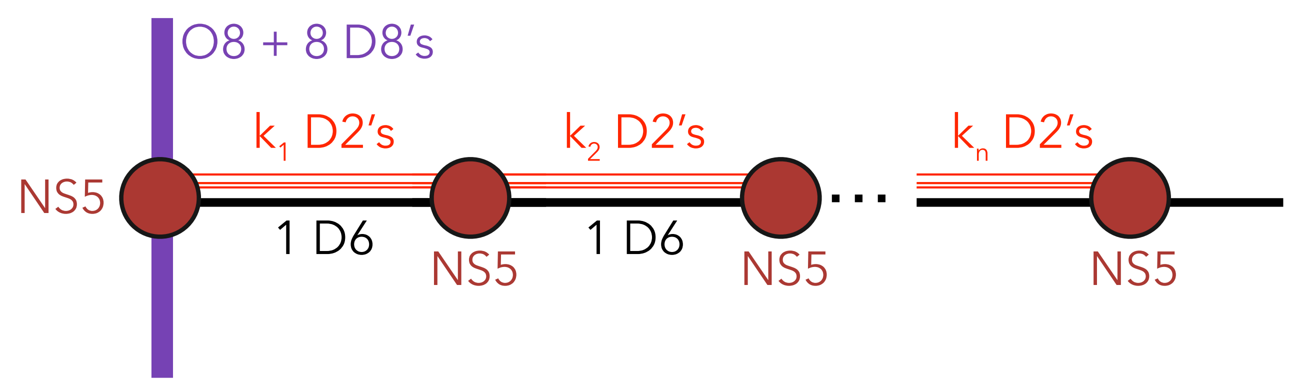
$SO(4) = SU(2) \times SU(2)_F$

For 1 M5-brane, no BPS states are charged under $SU(2)_F$, so both descriptions exhibit E_8 in IR and are equally useful.

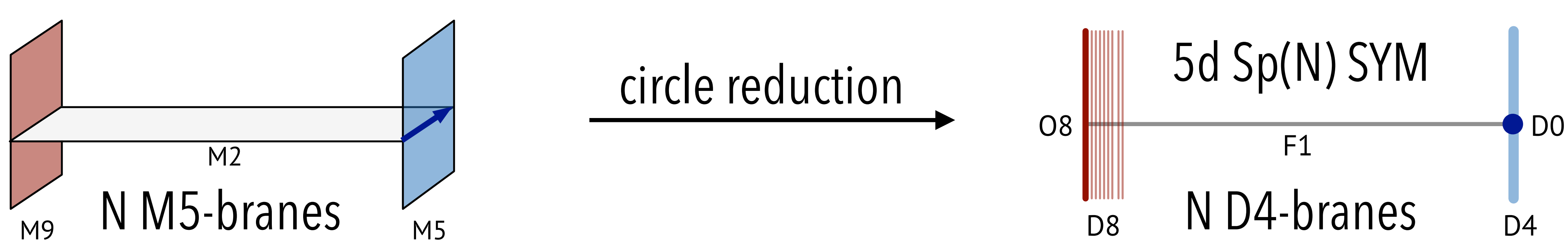
Multiple M5s probing M9

- However, one can study the fully refined BPS spectrum in case for multiple M5-branes probing the E_8 boundary wall only through the left description.





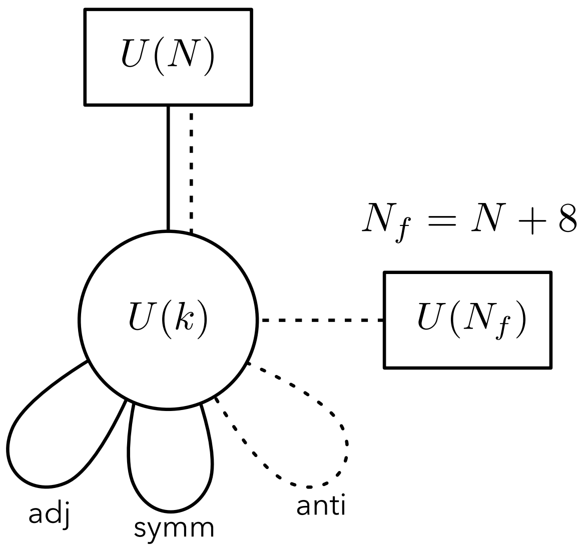
  - Without $SU(2)_F$ refinement, $Z_{n\,\text{M5}}^{\text{E-string}} = \left(Z_{1\,\text{M5}}^{\text{E-string}}\right)^n$
  - We studied the BPS spectrum with 2 M5-branes, which agrees with the 5d Sp(2) instanton partition function.

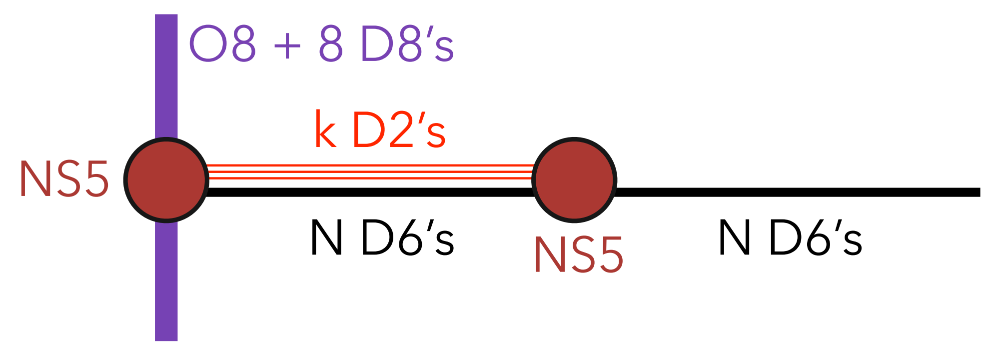


[Hwang, JK, Kim, Park '14]

Summary

- We proposed a UV description for self-dual strings in SU(3) with N_f = 12 → SU(2) with N_f = 10 → E-string theory





  - They exhibit the correct flavor symmetry of underlying 6d SCFTs after the IR symmetry enhancement.

- This enables us to study the fully flavored BPS spectrum of multiple M5-branes probing the E_8 boundary wall.