

Exploring SCFTs with Magnetic Quivers

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Based on long time collaboration with G. Arias-Tamargo, M. van Beest, S. Cabrera, S. Giacomelli, J. Grimminger, A. Hanany, R. Kalveks, M. Martone, A. Pini, S. Schäfer-Nameki, M. Sperling, G. Zafrir, Z. Zhong...

Today: mostly [\[2006.16994\]](#), [\[2110.11365\]](#)

Introduction

CFTs : Central role among QFTs:

- They are seeds to explore the landscape of QFTs via RG flow
- They encode aspects of quantum gravity via holography.

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In this talk, focus on 8 supercharges (+8 superconformal).

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→ What is the landscape of SCFTs?

Two approaches:

- "Top-down" explicit construction (Lagrangian, geometric engineering, brane systems, compactifications, ...)
- "Bottom-up" constraints (moduli space geometry, bootstrap, ...)

Superconformal Algebras

Dimension	Susy	Bosonic subalgebra	SCA
$d = 6$	$\mathcal{N} = (1, 0)$	$\mathfrak{so}(6, 2) \oplus \mathfrak{su}(2)_H$	$\subset \mathfrak{osp}(6, 2 1)$
$d = 5$	$\mathcal{N} = 1$	$\mathfrak{so}(5, 2) \oplus \mathfrak{su}(2)_H$	$\subset \mathfrak{f}(4)$
$d = 4$	$\mathcal{N} = 2$	$\mathfrak{so}(4, 2) \oplus \mathfrak{su}(2)_H \oplus \mathfrak{u}(1)_C$	$\subset \mathfrak{su}(2, 2 2)$
$d = 3$	$\mathcal{N} = 4$	$\mathfrak{so}(3, 2) \oplus \mathfrak{su}(2)_H \oplus \mathfrak{su}(2)_C$	$\subset \mathfrak{osp}(4 4)$

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SCFTs are

- "Rare" in 6d / 5d – isolated, rely on exceptional isomorphisms, non Lagrangian.
- More common in 4d (some Lagrangian ; existence of conformal manifolds). Classification?
- Very large number in 3d.

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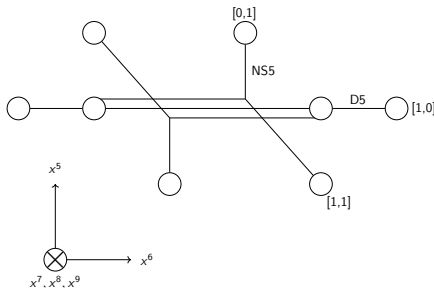
Existence of **Moduli space of vacua**, always contains **Higgs branch**.

Top-down construction (example: 5d)

- Geometric engineering : M-theory on canonical threefold singularity.

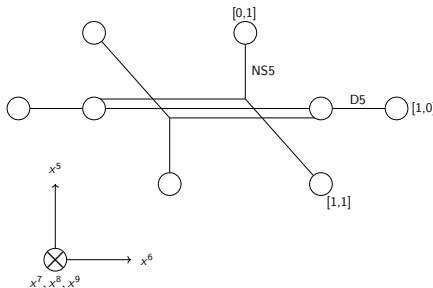
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- Brane systems : example of type IIB brane web



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- Brane systems : example of type IIB brane web



- Mixture of both : IIA with D6 on fibered ALE space.

[Intriligator, Morrison, Seiberg, Aharony, Hanany, Kol, Bergman, Rodríguez-Gómez, Zafrir, Del Zotto, Heckman, Jefferson, Katz, Kim, Vafa, Xie, Yau, Closset, Schäfer-Nameki, Wang, Hayashi, Yagi, ...]

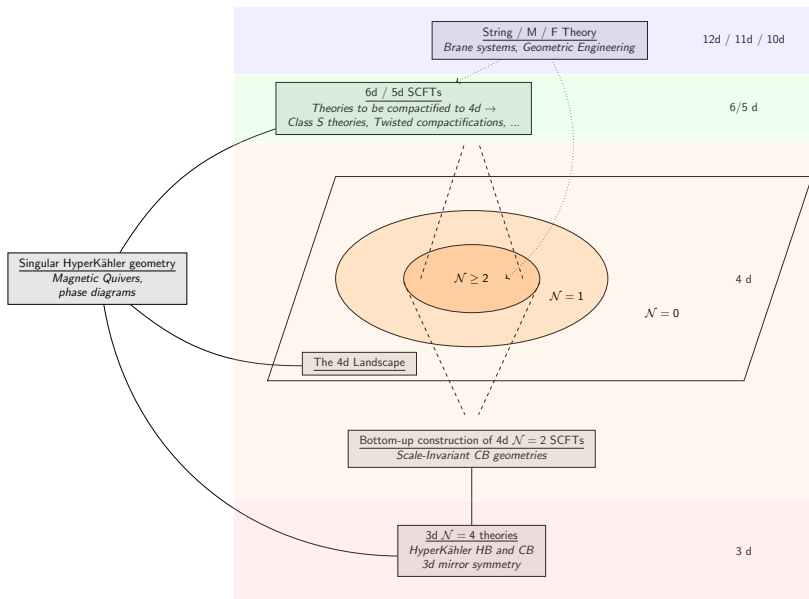
Bottom-up constraints

Classification of 4d rank 1 $\mathcal{N} = 2$ SCFT Coulomb branch geometries:

Flavor	CB geometry and deformation	$\Delta(u)$
E_8	$II^* \rightarrow \{I_1^{10}\}$	6
E_7	$III^* \rightarrow \{I_1^9\}$	4
E_6	$IV^* \rightarrow \{I_1^8\}$	3
D_4	$I_0^* \rightarrow \{I_1^6\}$	2
A_2	$IV \rightarrow \{I_1^4\}$	3/2
A_1	$III \rightarrow \{I_1^3\}$	4/3
\emptyset	$II \rightarrow \{I_1^3\}$	6/5
C_5	$II^* \rightarrow \{I_1^6, I_4\}$	6
$C_3 A_1$	$III^* \rightarrow \{I_1^5, I_4\}$	4
$C_2 U_1$	$IV^* \rightarrow \{I_1^4, I_4\}$	3
C_1	$I_0^* \rightarrow \{I_1^2, I_4\}$	2
$A_3 \rtimes \mathbb{Z}_2$	$II^* \rightarrow \{I_1^3, I_1^*\}$	6
$A_1 U_1 \rtimes \mathbb{Z}_2$	$III^* \rightarrow \{I_1^2, I_1^*\}$	4
U_1	$IV^* \rightarrow \{I_1^1, I_1^*\}$	3
$A_2 \rtimes \mathbb{Z}_2$	$II^* \rightarrow \{I_1^2, IV_{Q=1}^*\}$	6
$U_1 \rtimes \mathbb{Z}_2$	$III^* \rightarrow \{I_1^1, IV_{Q=1}^*\}$	4
\emptyset	$IV_{Q=1}^*$	3
C_1	$I_0^* \rightarrow \{I_2^3\}$	2

[Argyres, Lotito, Lü, Martone 18]

Landscape of SCFTs



The ID card of a 4d $\mathcal{N} = 2$ SCFT

These data can be **derived** from realizations of the theory, or can be **constrained** from bottom-up.

- Flavor symmetry
- Central charges
- Coulomb branch geometry
- Higgs branch geometry
- Seiberg-Witten curve / Integrable system
- Spectrum of BPS states
- Superconformal index [Kinney, Maldacena, Minwalla, Raju 05]
- VOA [Beem, Lemos, Liendo, Peelaers, Rastelli, van Rees 13]

The ID card of a 4d $\mathcal{N} = 2$ SCFT : Example

- Flavor symmetry : $\mathfrak{sp}(5)$, level $k = 7$.

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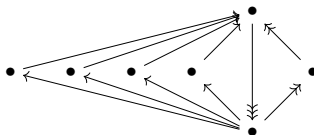
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- Coulomb branch geometry:
 - Complex Dimension = rank $r = 1$.
 - Scaling dimension $\Delta = 6$. Characteristic dimension $\kappa = 6$.
 - Singularity and deformation $II^* \rightarrow \{I_1^6, I_4\}$.

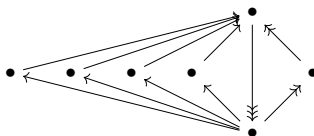
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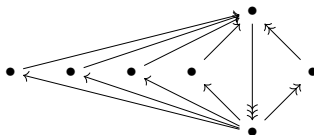
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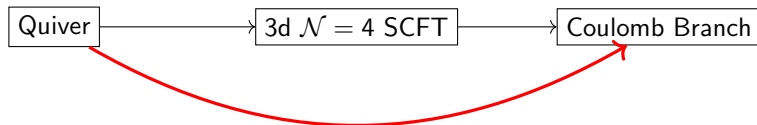
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- Superconformal index : deduced from class S construction [Chacaltana, Distler 11]
- Higgs branch geometry:
 - Quaternionic dimension $d_{HB} = n_h - n_v = 24(c - a) = 16$
 - **Magnetic Quiver** (see below)

Magnetic Quivers

The Higgs branch of an $SCFT_{8\text{ susy}}$ is a hyperKähler singular cone due to $\mathfrak{su}(2)_H$.
The Coulomb branch of a 3d $\mathcal{N} = 4$ SCFT is also a hyperKähler singular cone due to $\mathfrak{su}(2)_C$.



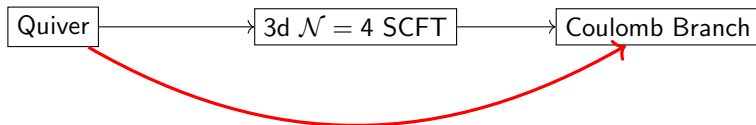
[Cremonesi, Hanany, Zaffaroni 14]

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A **magnetic quiver** is a combinatorial way to encode a hyperKähler singular cone.

Quiver> Generalized Quiver

Magnetic Quivers

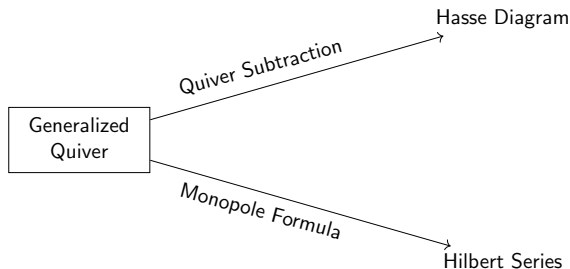
Let X be a hyperKähler singular cone (technically a *symplectic singularity* [Beauville 00]). We say that the (generalized) quiver Q is a **magnetic quiver** for X if

$$\mathcal{C}^{3d \mathcal{N}=4}(Q) = X .$$

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[AB, Cabrera, Grimminger, Hanany, Sperling, Zajac, Zhong 20]

Higgsing diagrams

Higgsing corresponds to quiver subtraction / Higgs branch singularities.

5d

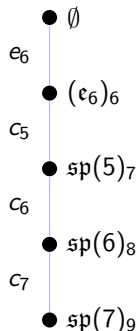
4d

$$\mathfrak{su}(2)_0 + 6F \rightarrow (\mathfrak{e}_6)_6$$

$$\mathfrak{su}(3)_0 + 8F \rightarrow \mathfrak{sp}(5)_7$$

$$\mathfrak{su}(4)_0 + 10F \rightarrow \mathfrak{sp}(6)_8$$

$$\mathfrak{su}(5)_0 + 12F \rightarrow \mathfrak{sp}(7)_9$$



Rank-1 4d $\mathcal{N} = 2$ magnetic quivers

Flavor	$\dim_{\mathbb{H}}(HB)$	Magnetic Quiver
E_8	29	Affine
E_7	17	
E_6	11	
D_4	5	
A_2	2	Dynkin
A_1	1	
\emptyset	0	

[AB, Grimminger, Hanany, Sperling, Zafir, Zhong 20]

Flavor	$\dim_{\mathbb{H}}(HB)$	Magnetic Quiver
C_5	16	
$C_3 A_1$	8	
$C_2 U_1$	4	
C_1	1	
$A_3 \rtimes \mathbb{Z}_2$	9	
$A_1 U_1 \rtimes \mathbb{Z}_2$	3	
U_1	1	
$A_2 \rtimes \mathbb{Z}_2$	5	
$U_1 \rtimes \mathbb{Z}_2$	1	
\emptyset	0	
C_1	1	

Quiver Subtraction Algorithm

INPUT:

- A (generalized) quiver
- A list of elementary symplectic singularities with a corresponding magnetic quiver.

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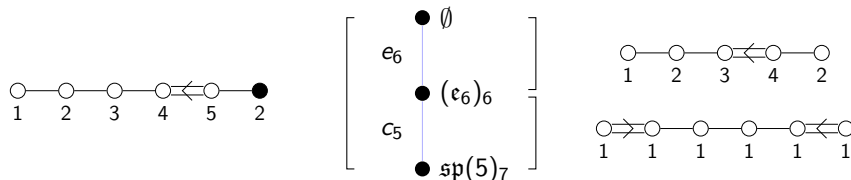
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Example:



Quiver Subtraction Algorithm

Reductionist approach to Higgs branch geometries :

- What is the list of atoms (elementary symplectic singularities)?
- What are the rules to combine them?

Slice	Framed quiver	Unframed quiver
a_n		
b_n		
c_n		
d_n		
e_6		
e_7		
e_8		

Slice	Framed quiver	Unframed quiver
f_4		
g_2		
ae_n		
ag_2		
cg_2		
$h_{n,k}$		
$\bar{h}_{n,k}$		
A_n		

Higgs Chiral ring (\hat{B} operators)

Hilbert series for the Higgs branch of the $\mathfrak{sp}(5)_7$ theory:

$$\frac{\left(1 + 2t + 40t^2 + 194t^3 + 1007t^4 + 4704t^5 + 18683t^6 + 67030t^7 + 220700t^8 + 657352t^9 + 1796735t^{10} \right. \\ \left. + 4540442t^{11} + 10610604t^{12} + 23011366t^{13} + 46535540t^{14} + 87887734t^{15} + 155277056t^{16} \right. \\ \left. + 257288236t^{17} + 400453203t^{18} + 585971786t^{19} + 807195575t^{20} + 1047954388t^{21} \right. \\ \left. + 1282842123t^{22} + 1481462886t^{23} + 1615002952t^{24} + 1662191888t^{25} + \dots \text{palindrome} \dots + t^{50} \right)}{(-1+t)^{32}(1+t)^{18}(1+t+t^2)^{16}}$$

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Refined plethystic logarithm :

$$t^2 : [20000]$$

$$t^3 : [00001]$$

$$t^4 : -[01000]$$

$$t^5 : -[10010]$$

$$t^6 : -[00200] - [20000] + [01000]$$

etc

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Refined plethystic logarithm :

$$\begin{aligned} t^2 &: [20000] \\ t^3 &: [00001] \\ t^4 &: -[01000] \\ t^5 &: -[10010] \\ t^6 &: -[00200] - [20000] + [01000] \\ &\text{etc} \end{aligned}$$

Highest weight generating function [Hanany, Kalveks 16]

$$\text{PE} \left[\sum_{i=1}^4 \mu_i^2 t^{2i} + t^4 + \mu_5 (t^3 + t^5) \right]$$

4d $\mathcal{N} = 2$ SCFTs at rank 2

[AB, Grimminger, Martone, Zafrir 21]

$\#$	d_{aff}	f	Quiver
1	$59 + 1$	$[u]_{13} \times \text{su}(2)_{13}$	
2	46	$\text{su}(20)_{16}$	
3	46	$[u]_{16}$	
4	$35 + 1$	$[u]_{16} \times \text{su}(2)_5$	
5	30	$\text{su}(2)_6 \times \text{su}(16)_{10}$	
6	26	$\text{su}(10)_{10}$	
7	$23 + 1$	$[u]_{12} \times \text{su}(2)_5$	
8	22	$\text{so}(14)_{10} \times \mathfrak{u}(1)$	
9	18	$\text{su}(2)_6 \times \text{su}(8)_6$	
10	14	$\text{sp}(12)_6$	

$\#$	d_{aff}	f	Quiver
33	23	$\text{su}(6)_{16} \times \text{su}(2)_6$	
34	13	$\text{su}(4)_{12} \times \text{su}(2)_7 \times \mathfrak{u}(1)$	
35	11	$\text{su}(3)_{16} \times \text{su}(3)_{16} \times \mathfrak{u}(1)$	
36	8	$\text{su}(3)_{16} \times \text{su}(2)_{16} \times \mathfrak{u}(1)$	
37	6	$\text{su}(2)_{16} \times \text{su}(2)_{16} \times \mathfrak{u}(1)^2$	
38	2	$\mathfrak{u}(1)^2$	
39	29	$\text{sp}(14)_6$	
40	17	$\text{su}(2)_6 \times \text{sp}(10)_7$	
41	15	$\text{su}(2)_{16} \times \text{sp}(8)_7$	
42	11	$\text{sp}(8)_6 \times \mathfrak{u}(1)$	

$\#$	d_{aff}	f	Quiver
11	12	$\text{so}(8)_6 \times \text{su}(2)_{16}$	
12	10	$\text{so}(6)_6$	
13	6	$\text{su}(2)_6^2$	
14	6	$\text{su}(3)_6 \times \text{su}(2)_{16}$	
15	6	$\text{su}(5)_6$	
16	4	$\text{su}(2)_{16,3} \times \text{su}(2)_{11,3}$	
17	2	$\text{su}(2)_{16,3} \times \mathfrak{u}(1)$	
18	2	$\text{su}(2)_{16,5}$	
19	1	$\text{su}(2)_{16,5}$	
20	1	$\mathfrak{u}(1)$	
21	0	\emptyset	

$\#$	d_{aff}	f	Quiver
44	19	$\text{su}(5)_{16}$	
45	6	$\text{su}(3)_{12} \times \mathfrak{u}(1)$	
46	3	$\text{su}(2)_{16} \times \mathfrak{u}(1)$	
47	32	$\text{sp}(12)_{16}$	See Table 7
48	8	$\text{sp}(6)_6 \times \text{so}(4)_6$	See Table 7
49	14	$\text{sp}(8)_6$	See Table 7
50	4	$\text{sp}(4)_{13,3}$?
51	28	$\text{sp}(8)_{13} \times \text{su}(2)_{16}$	
52	14	$\text{sp}(4)_6 \times \text{su}(2)_{16} \times \text{su}(2)_{16}$	
53	7	$\text{su}(2)_6 \times \text{su}(2)_{16} \times \mathfrak{u}(1)$	
54	6	$\text{su}(2)_{16} \times \text{su}(2)_{16}$	
55	2	$\text{su}(2)_6$	
56	2	$\text{su}(2)_{16}$	

$\#$	d_{aff}	f	Quiver
22	22	$\text{sp}(12)_{16}$	
23	20	$\text{sp}(4)_6 \times \text{sp}(8)_6$	
24	24	$\text{su}(2)_6^2 \times [\mathfrak{f}]_{16}$	
25	12	$\text{su}(2)_{16} \times \text{sp}(8)_6$	
26	11	$\text{su}(2)_{16} \times \text{sp}(6)_{16} \times \mathfrak{u}(1)$	
27	12	$\text{su}(2)_6^2 \times \text{so}(7)_6$	
28	16	$[\mathfrak{f}]_{16} \times \mathfrak{u}(1)$	
29	7	$\text{sp}(6)_6 \times \mathfrak{u}(1)$	
30	6	$\text{su}(3)_{16} \times \text{su}(2)_6^2$	
31	3	$\text{sp}(4)_6$	
32	2	$\text{su}(2)_{16} \times \text{su}(2)_{16}$	

$\#$	d_{aff}	f	Quiver
57	12	$[u]_{16} \times \text{su}(2)_{16}$	
58	4	$\text{su}(2)_{16,3} \times \text{su}(2)_{16}$	
59	6	$[u]_{16,3}$	
60	2	$\text{su}(2)_6$	
61	15	$\text{su}(3)_{16} \times \mathfrak{u}(1)$	
62	5	$\mathfrak{u}(1) \times \mathfrak{u}(1)$	
63	2	$\mathfrak{u}(1)$	
64	8	$\text{su}(2)_{16} \times \mathfrak{u}(1)$	
65	2	$\mathfrak{u}(1)$	
66	10	$\text{sp}(4)_{16} \times \text{su}(2)_{16}$?
67	2	$\text{su}(2)_{16}$	
68	2	$\text{su}(2)_{16}$	
69	0	\emptyset	

How to derive magnetic quivers?

Various methods can be used (in cooperation):

- Derivation from intersection numbers in brane systems [Cabrera, Hanany, Yagi 18], [AB, Cabrera, Grimminger, Hanany, Zhong 19], [Akhond, Carta, Dwivedi, Hayashi, Kim 20], [van Beest, AB, Eckhard, Schäfer-Nameki 20], [Akhond, Carta 21], [Sperling, Zhong 21] ...

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- Derivation from geometry of string backgrounds [Collinucci, Valandro 20], [Closset, Schäfer-Nameki, Wang 21], ...

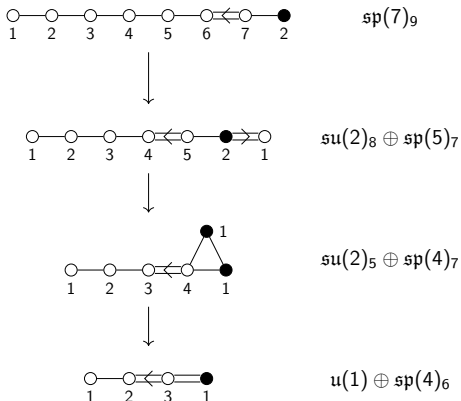
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- Guess based on knowledge of the chiral ring [Cabrera, Hanany, Zajac 18], [Arias-Tamargo, AB, Pini 21]
- etc...

RG flows

How is the RG flow read on magnetic quivers? [van Beest, Giacomelli 21]



General patterns have been identified but the detailed rules are under investigation.

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Future directions and open problems:

- What is the scope of magnetic quivers? Various extensions of the notions have already been proposed. What is the generic magnetic "object"?
- What other information can be extracted from magnetic quivers? E.g. [Nawata, Sperling, Wang, Zhong 21]
- Is there a possible bottom-up approach?
 - Classification of possible elementary slices (see recent progress in [Bellamy, Bonnafé, Fu, Juteau, Levy, Sommers 22])
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Thank you for your attention!