Toward a Universality Principle for Matter

Houri-Christina Tarazi

Based on work with Z.K. Baykara and W. Taylor

THE UNIVERSITY OF CHICAGO | THE LEINWEBER INSTITUTE FOR THEORETICAL PHYSICS

Kavli Institute for Cosmological Physics at The University of Chicago

IN THIS CONFERENCE WE CARE ABOUT

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STRINGS

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AND

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GEOMETRY

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} Possible String Theory Vacua

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Stringy Landscape

Why?

Stringy Landscape

Because string theory teaches us valuable lessons about quantum gravity and quantum field theory!

Geometric Stringy Landscape

Gives us large families of theories and a lot of intuition!

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Gives us large families of theories and a lot of intuition!

However the question of what is possible in string theory requires us to go away from ***Geometric Lamppost***

Geometric models always come with ϕ_{vol}

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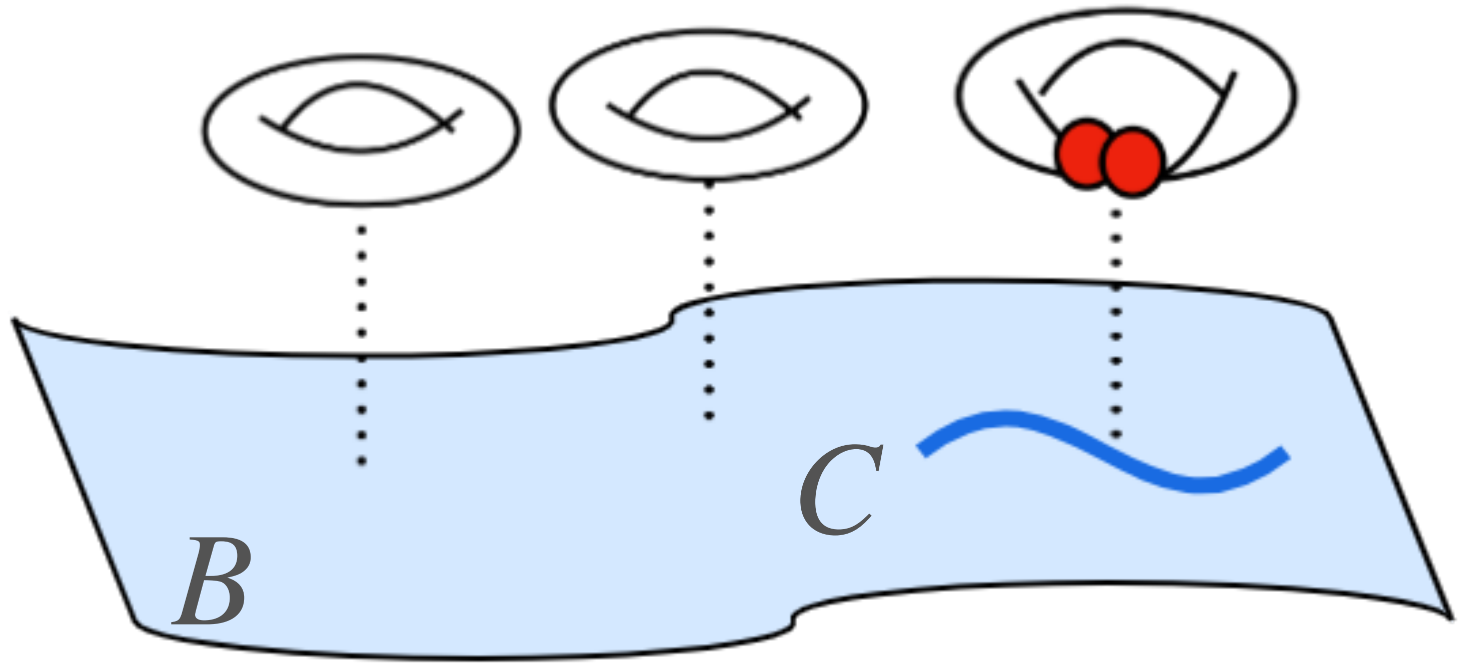
e.g. 6d $\mathcal{N} = 1$ Supergravity

F-theory on elliptic CY3



"Universal" Hypermultiplet: $Vol(B)$

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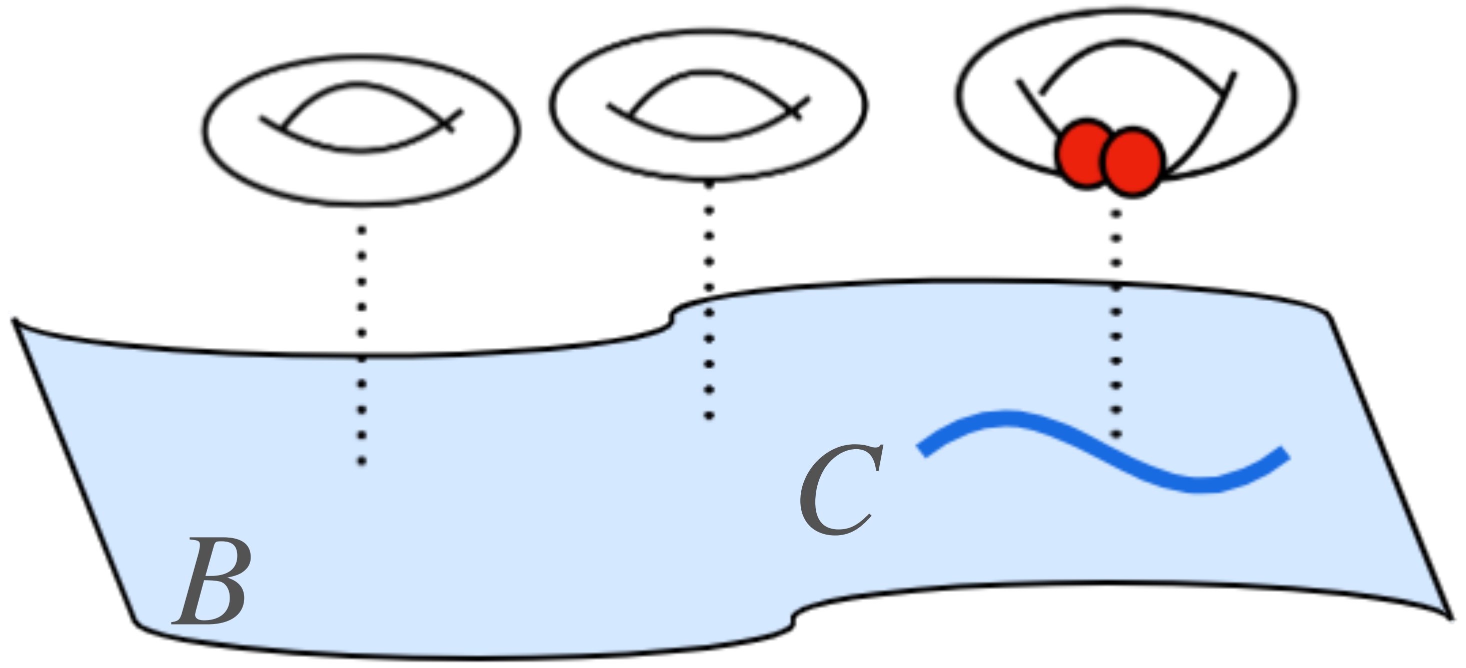

"Universal" Hypermultiplet: $Vol(B)$

Kodaira Condition: $12\, J \cdot a \geq \sum_i \nu_i\, J \cdot b_i$

T_{-a} T_{b_i}

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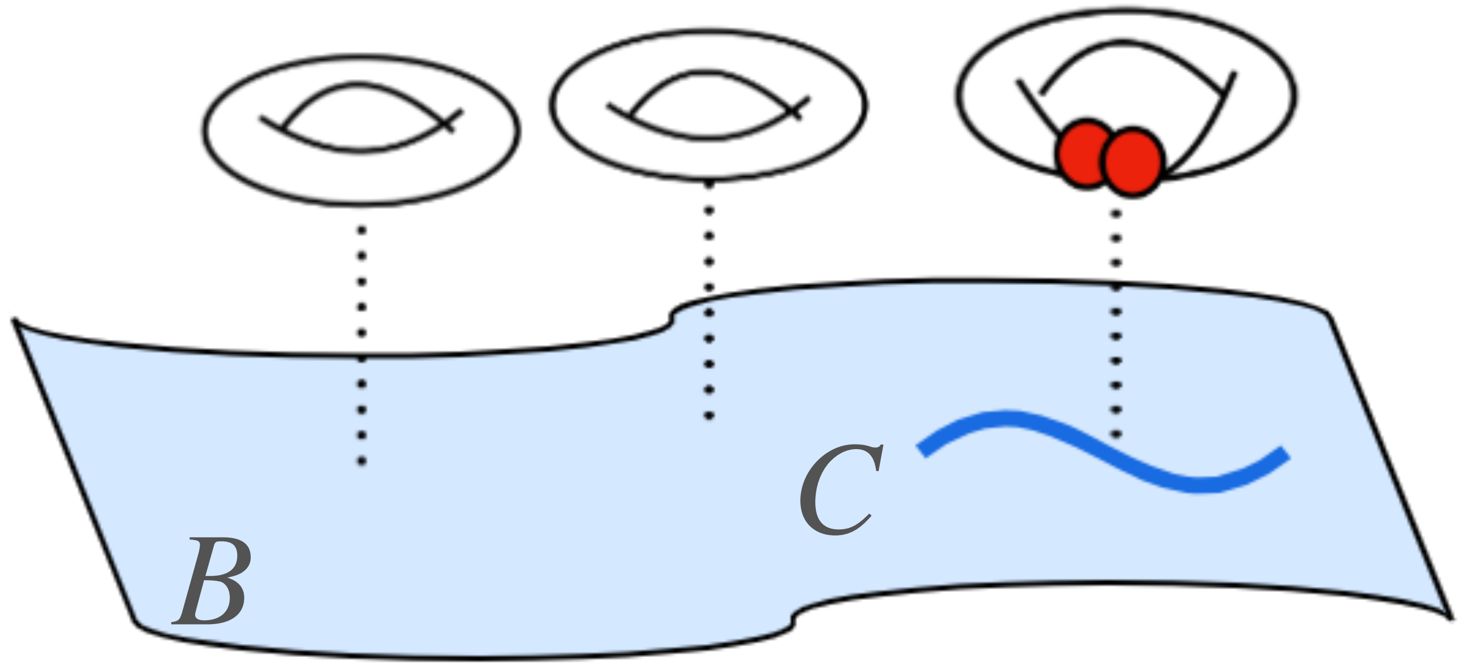

[Baykara, Hamada, HCT, Vafa 23']

"Universal" Hypermultiplet: $Vol(B)$ $\quad H_0 = 0$

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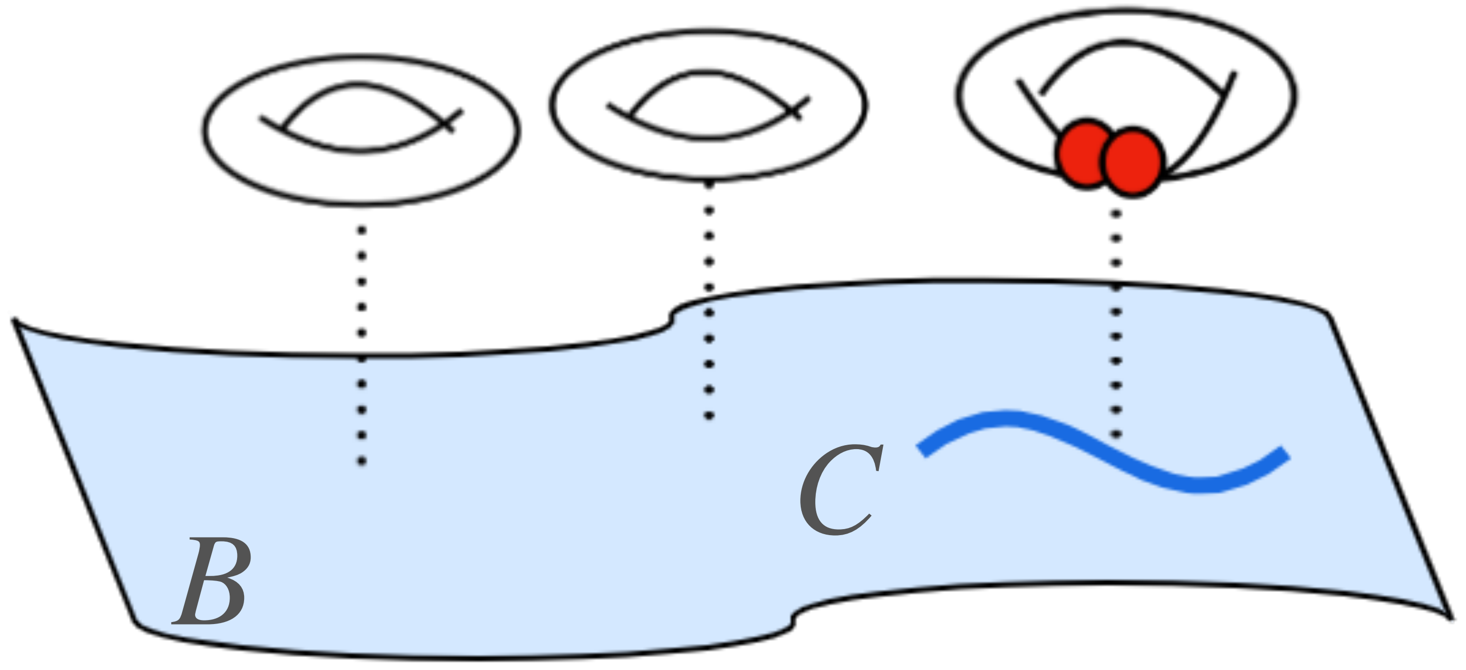

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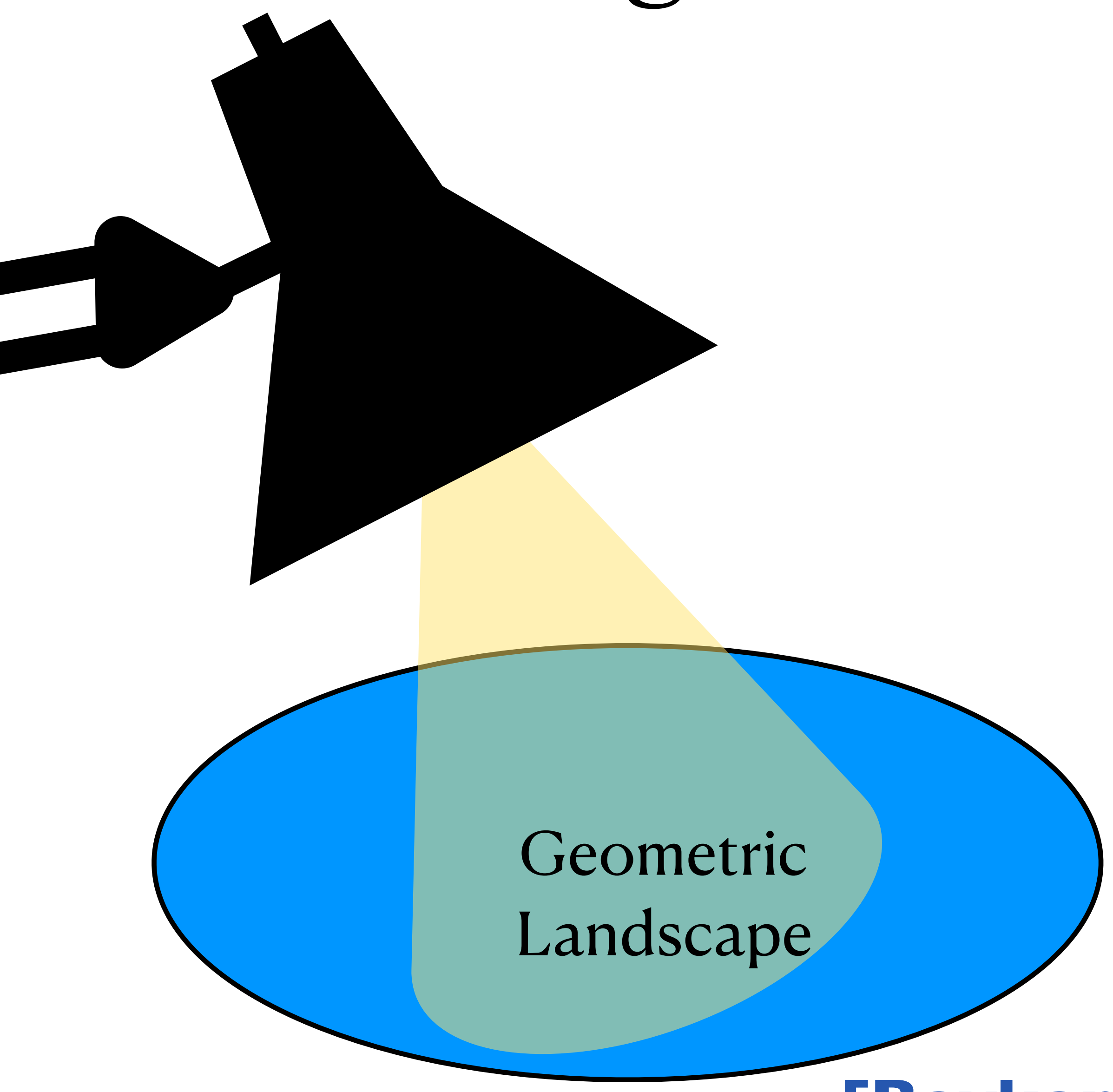

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"Universal" Hypermultiplet: $Vol(B)$ ✗

Kodaira Condition: ✗

Non-Susy String theories

No neutral scalars other than dilaton

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[Baykara, Hamada, HCT, Vafa 23']

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What these have in common?

Geometric models always come with ϕ_{vol}

e.g.

6d $\mathcal{N} = 1$ Supergravity — "Universal" Hyp✗multiplet: $Vol(B)$ ✗

[Baykara, Hamada, HCT, Vafa 23']

Kodaira Conditi✗: ✗

Non-Susy String theories — No neutral scalars other than dilaton ✓

[Baykara, HCT, Vafa 24']

What these have in common?

What do I mean by non-geometric?

What do I mean by non-geometric?

I could mean no target space geometry

e.g. Asymmetric Orbifolds

[Narain, Sarmadi,Vafa 87']

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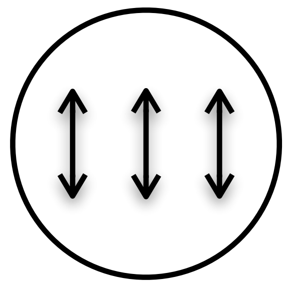

$\mathbb{Z}_2$

$\Gamma^{1,1}$

$p_R \to p_R \quad p_L \to -p_L$

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e.g. Asymmetric Orbifolds

[Narain, Sarmadi,Vafa 87']

Orbifolds by non-geometric symmetries

Symmetry of $\Gamma^{n,n}$ not of T^n

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Orbifolds by non-geometric symmetries

Quasicrystalline Orbifolds

[Harvey, Moore,Vafa 88'] [Baykara, HCT, Vafa 24']

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May or may not be related to geometric models

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Quasicrystalline Orbifolds → K3 sigma model

[Baykara, HCT,Vafa 24']

Asymmetric Orbifold → Elliptic CY3 with base $\mathbb{F}_n$

with $H_0 = 0$ and violates Kodaira conditions

[Baykara, Hamada, HCT,Vafa 24']

String Islands → Isolated

No scalar neutral or charged except dilaton

[Dabholkar, Harvey 98'] [Baykara, Parra De Freitas, HCT 25']

[Aldazabal, Andrés, Font, Narain, Zadeh 25']

6d $\mathcal{N}=1$ Supergravity

"Universal" Hypermultiplet: $Vol(B)$ ✗

Kodaira condition ✗

$$E_6 \times SU(3) \times E_8 \times SU(3)^2$$

$$2(\mathbf{27},\mathbf{3},\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{27},\mathbf{1},\mathbf{1},\underline{\mathbf{3},\mathbf{1}}) + (\mathbf{27},\mathbf{1},\mathbf{1},\underline{\overline{\mathbf{3}},\mathbf{1}})$$

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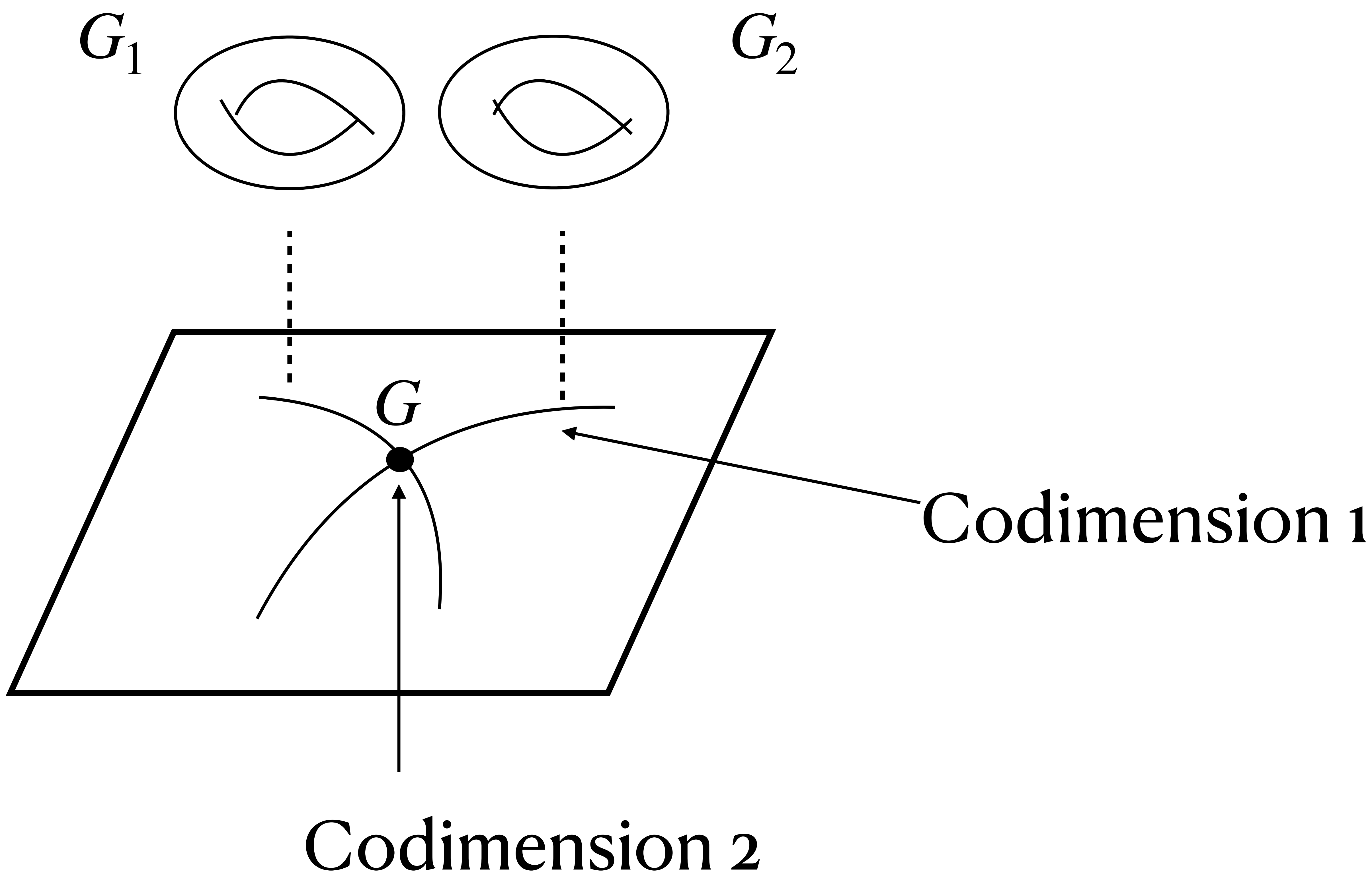
Cannot get this matter in standard F-theory

6d (1,0) theories are contained by anomalies but many potential theories are not in the swampland or have string realizations!

[Baykara, Hamada, HCT, Vafa 23']

Matter in F-theory

[Katz,Vafa 96']



Katz-Vafa

$$G \to G_1 \times G_2 \times U(1)$$

$$Adj(G) \to \ (R^a, q^a)$$

$$\Phi \sim t \in U(1)$$

Matter

$$(D + q_a t)\ \psi_a(t, \bar{t}) = 0$$

Matter in F-theory

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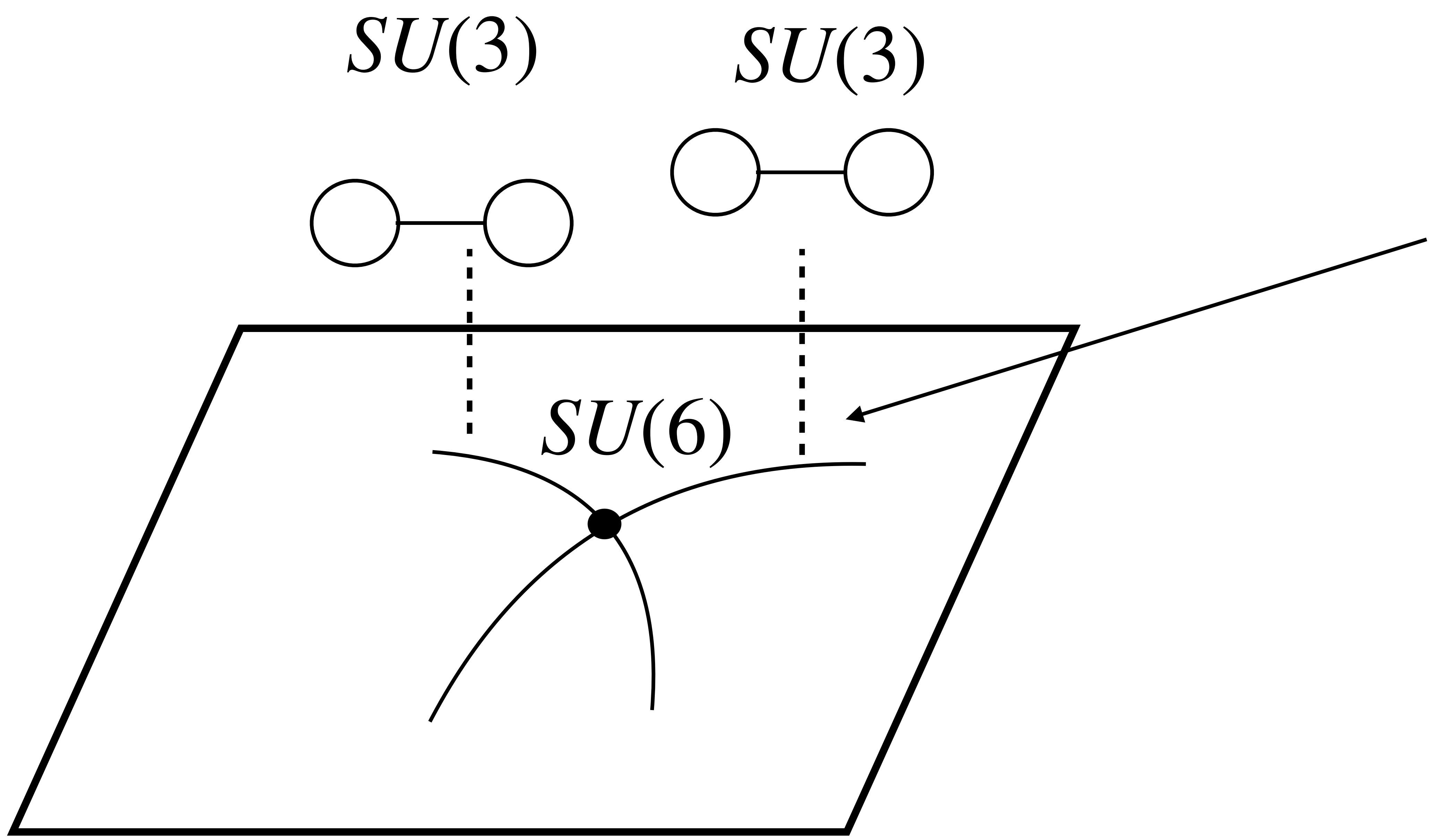
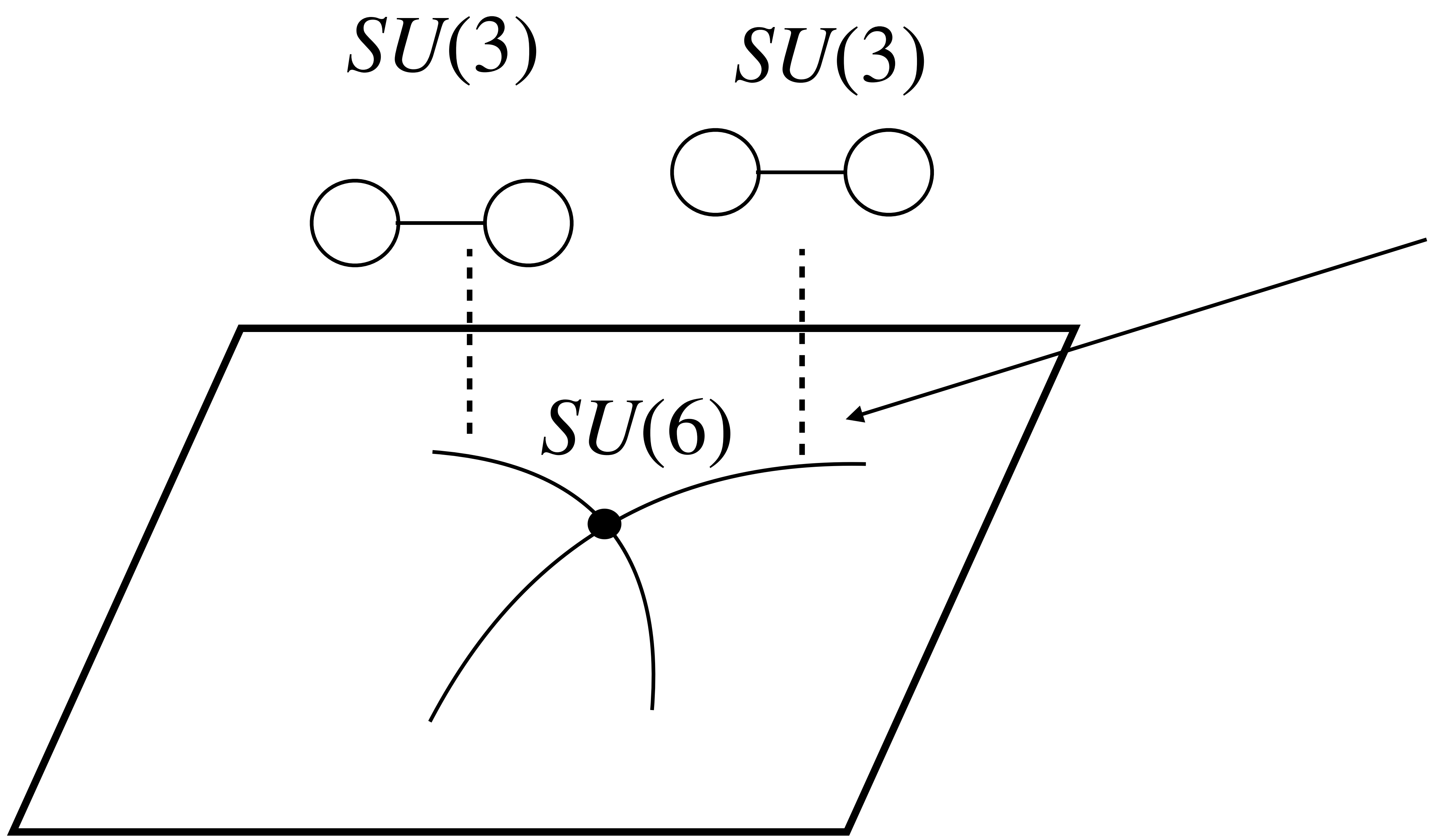


$$SU(6) \to SU(3) \times SU(3) \times U(1)$$

$$Adj_{SU(6)} \to (Adj_{SU(3)},1) + (1,Adj_{SU(3)})$$
$$+(3,\bar{3})_2 + (\bar{3},3)_{-2} + (1,1)_0$$

Matter in F-theory

[Katz,Vafa 96']



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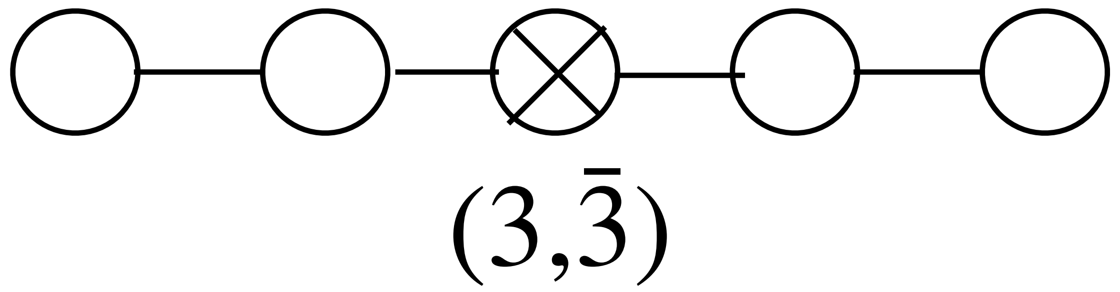
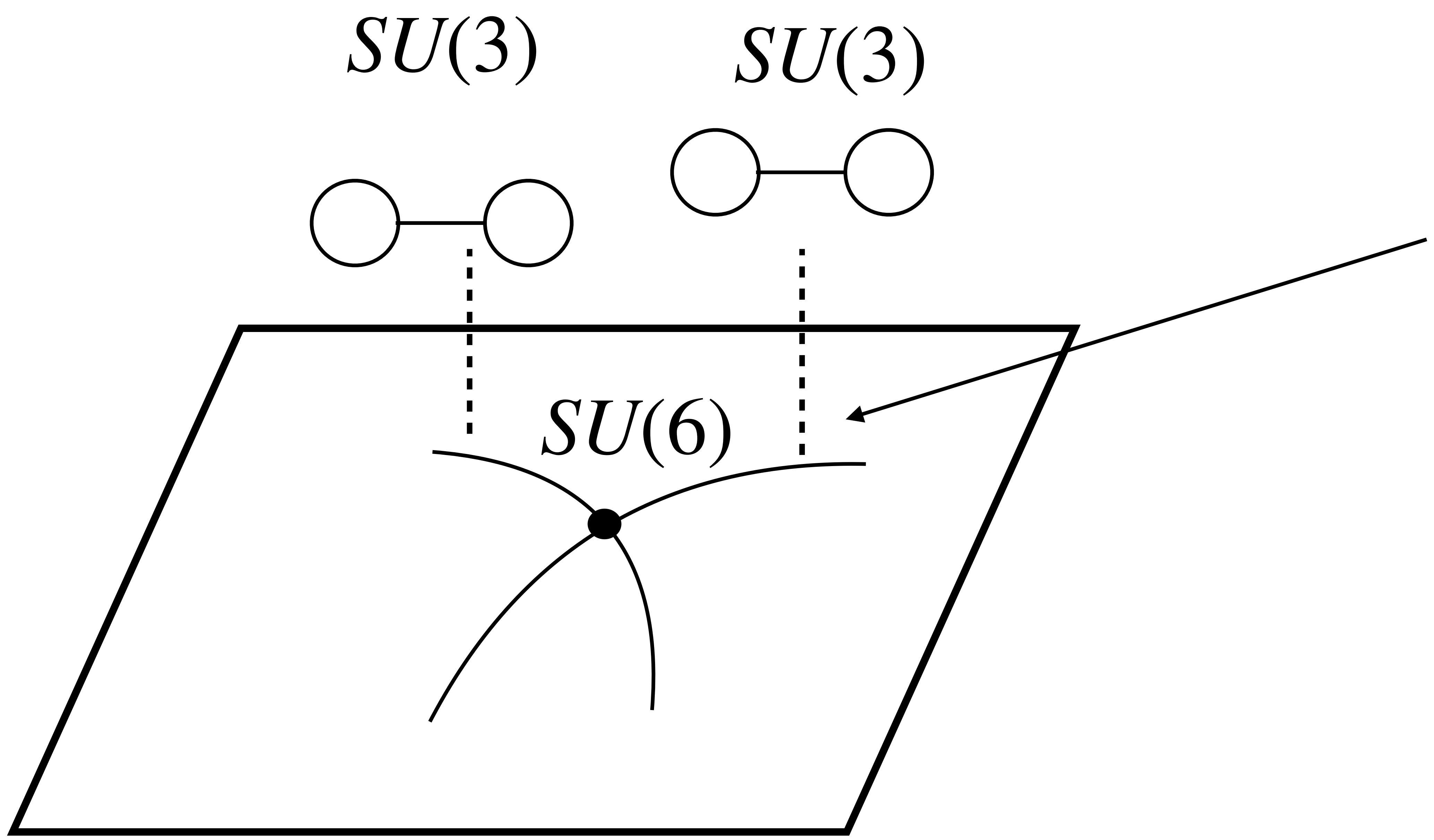


Matter in F-theory [Katz,Vafa 96']



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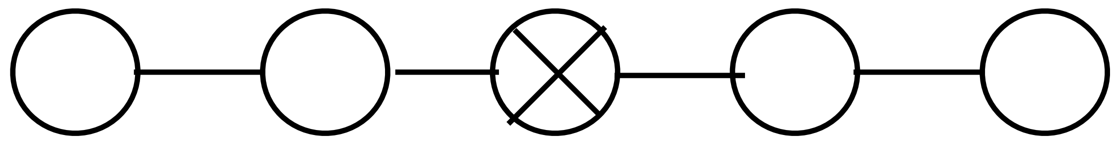

Physical Gauge symmetry: vector in $SU(3) \times SU(3)$

Matter: hyper in $(3,\bar{3})$ $\quad m \sim |\alpha(\Phi)| = |q_a\, t|$

$$E_6 \times SU(3) \times E_8 \times SU(3)^2$$

$$2(\mathbf{27}, \mathbf{3}, \mathbf{1}, \mathbf{1}, \mathbf{1}) + (\mathbf{27}, \mathbf{1}, \mathbf{1}, \underline{\mathbf{3}, \mathbf{1}}) + (\mathbf{27}, \mathbf{1}, \mathbf{1}, \underline{\overline{\mathbf{3}}, \mathbf{1}})$$

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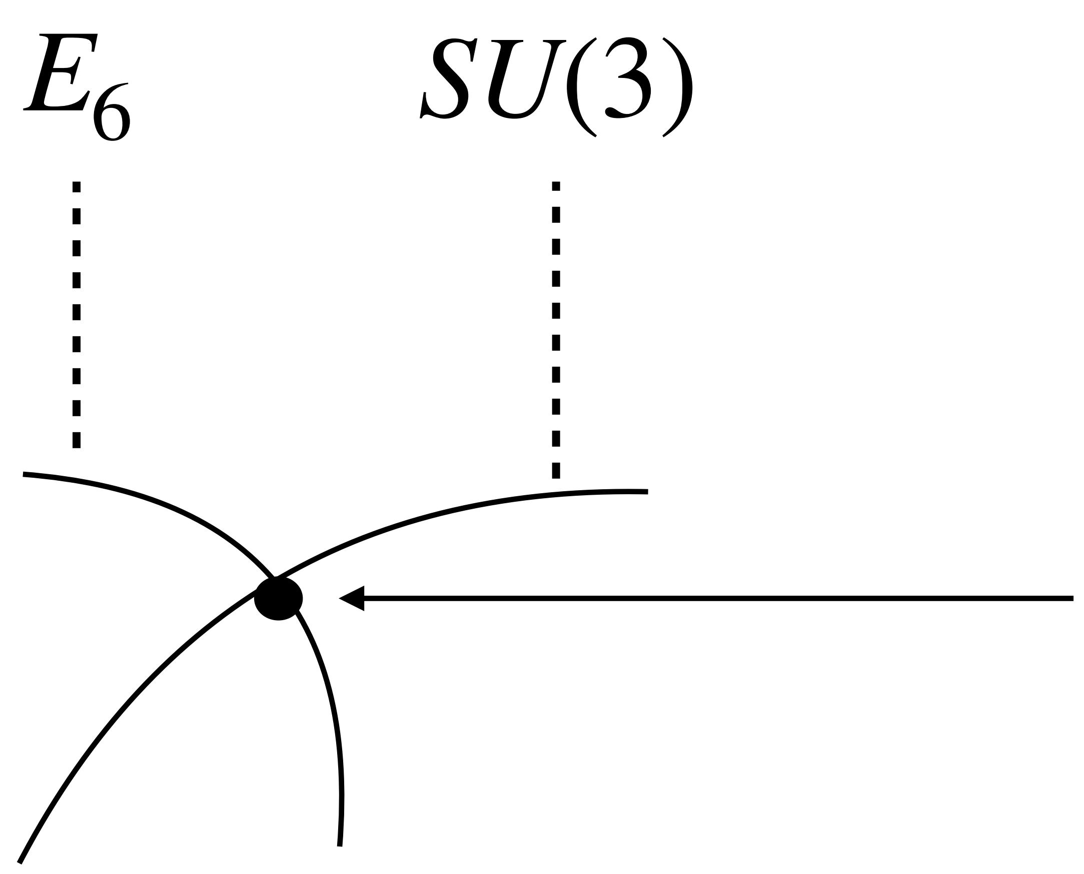

$$(f, g, \Delta) = (4,6,12)$$

Non-Kodaira

[Dixon, Harvey, Vafa, Witten 85' 86']

$$y^2 = x^3 + fx + g \qquad f \in O(K_B^{-4})$$

$$\Delta = 4f^3 + 27g^2 \qquad g \in O(K_B^{-6})$$

[Ludeling,Ruehle 14']

[Cvetic, Ling, Heckman18']

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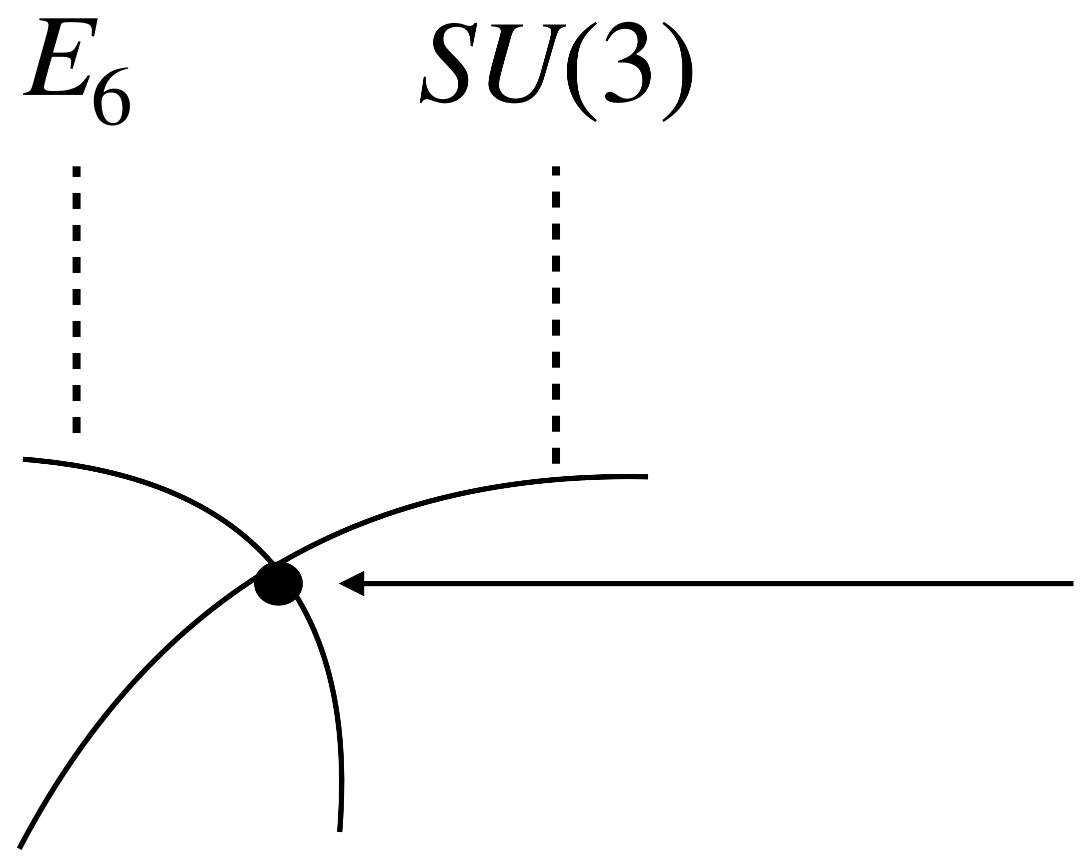

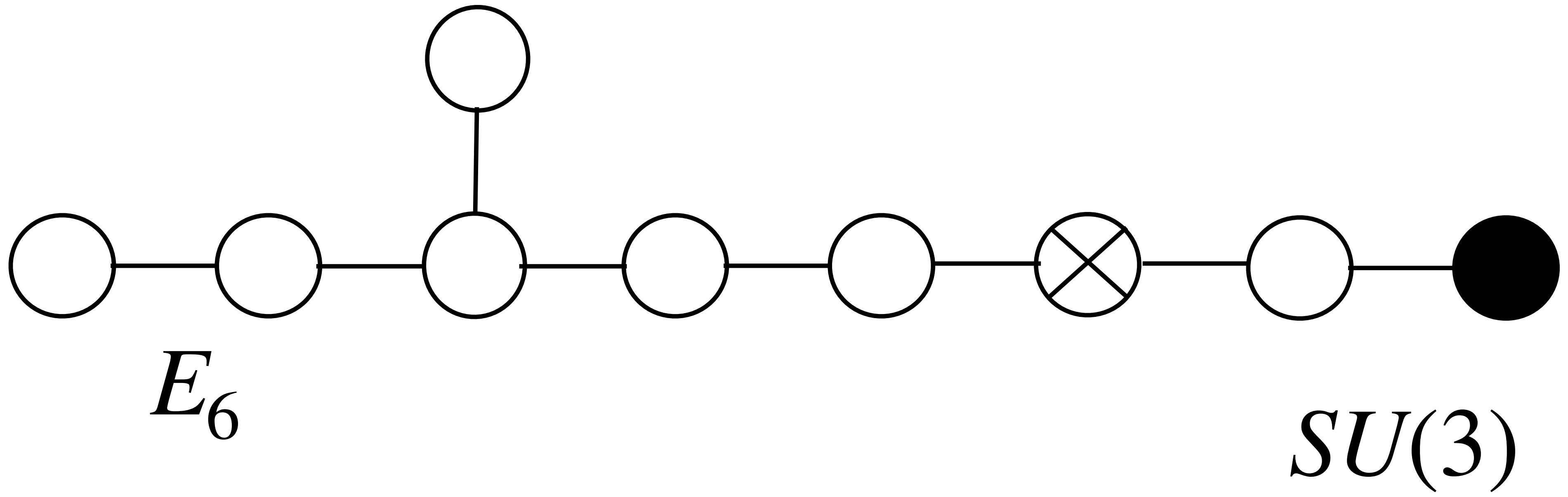

$$\hat{E}_8 \to E_6 \times SU(3)$$

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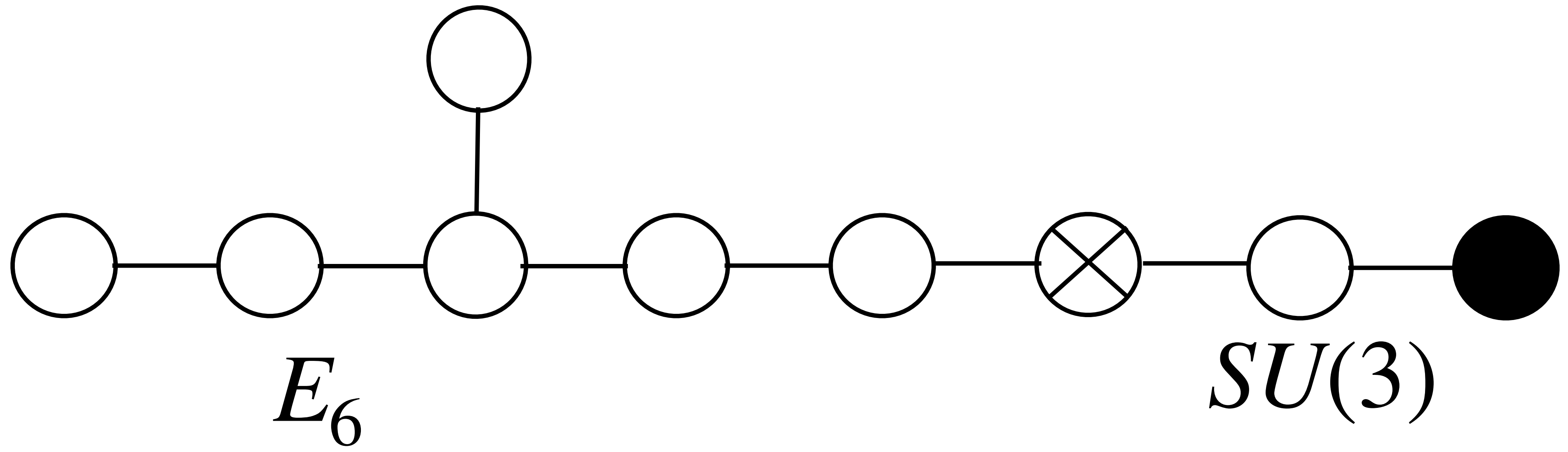
$\hat{E}_8$



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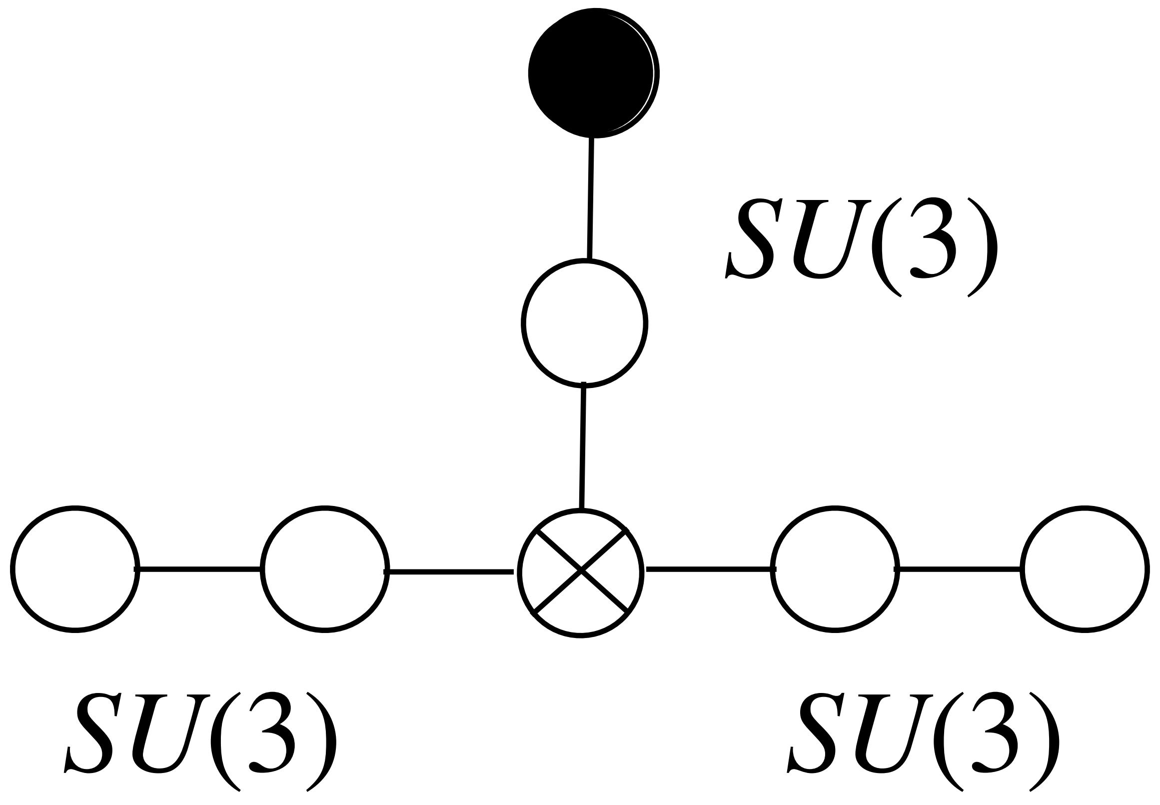
$\hat{E}_6$



$$\hat{E}_6 \to SU(3) \times SU(3) \times SU(3)$$

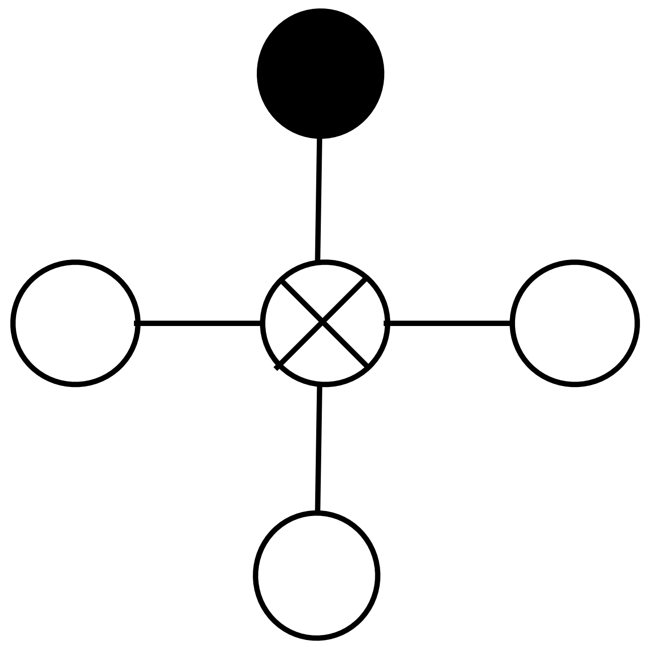
STRINGS

AND

~~GEOMETRY~~

Exotic Matter from Heterotic Orbifolds

$\hat{D}_4$



$SU(2)^4$ with $(\square, \square, \square, \square)$

Exotic Matter from Heterotic Orbifolds

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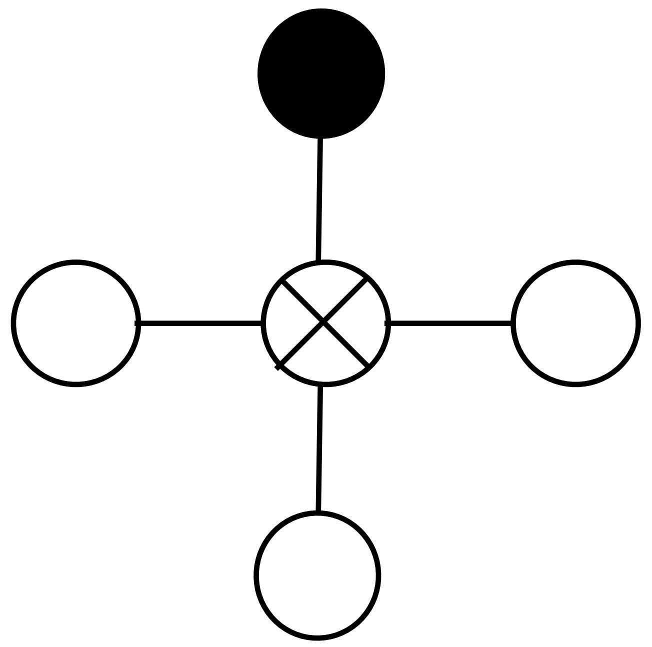

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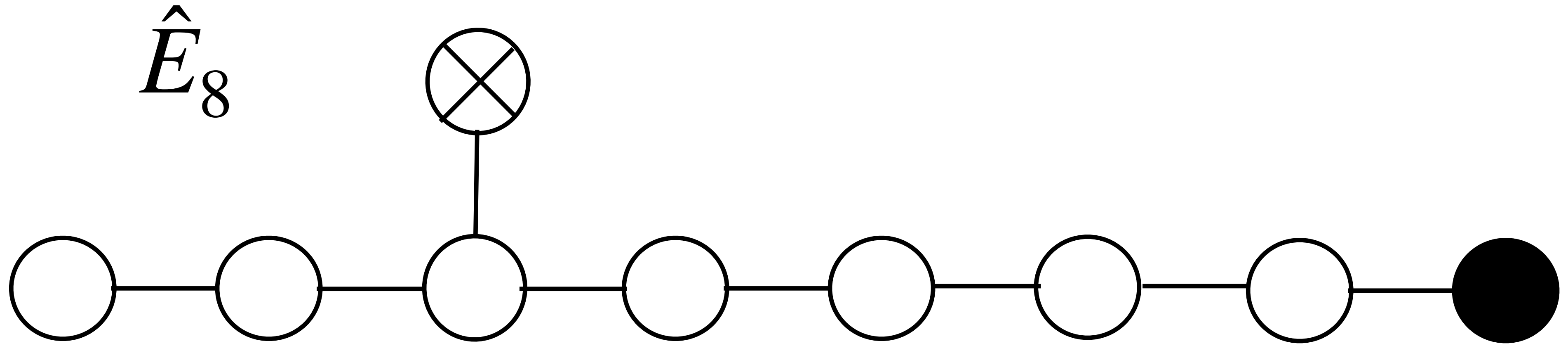

$SU(8)$ with $\begin{array}{|c|}\hline \\ \hline \\ \hline \\ \hline \\ \hline\end{array}$

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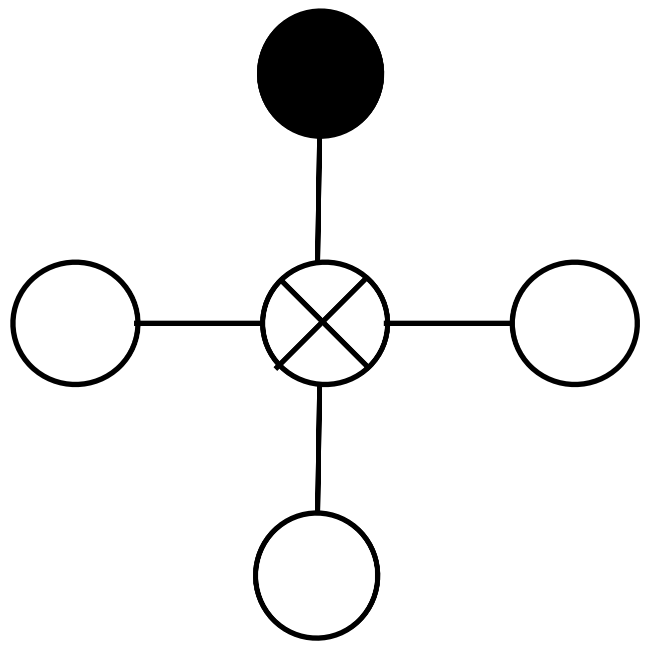

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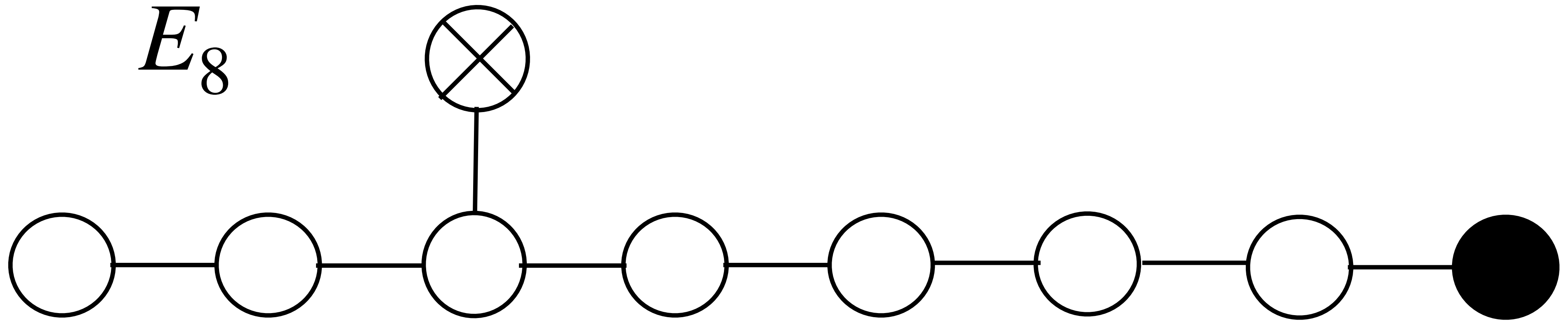
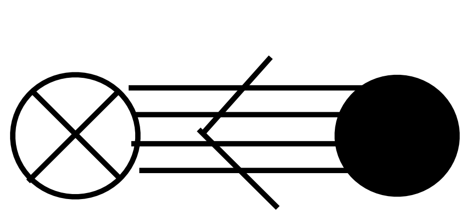


$SU(8)$ with $\begin{array}{c}\square\\ \square\\ \square\\ \square\end{array}$

$\hat{A}_2^{(2)}$



$SU(2)$ with $\square\square\square\square$

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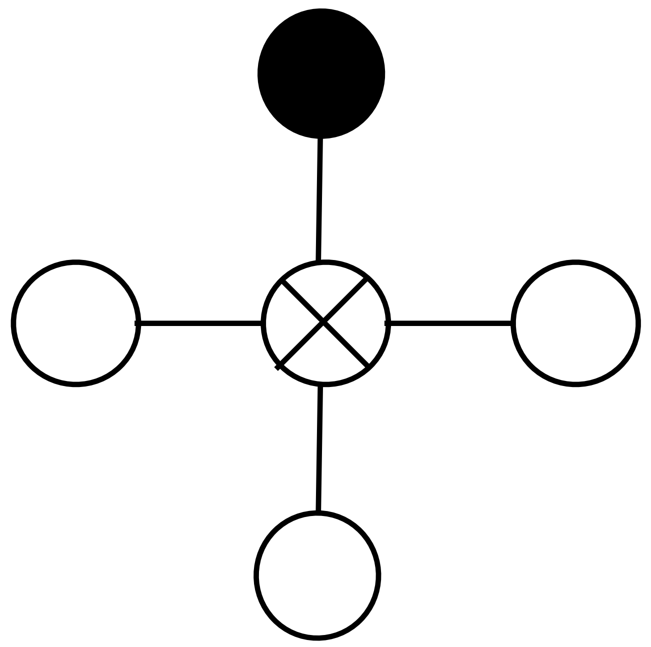
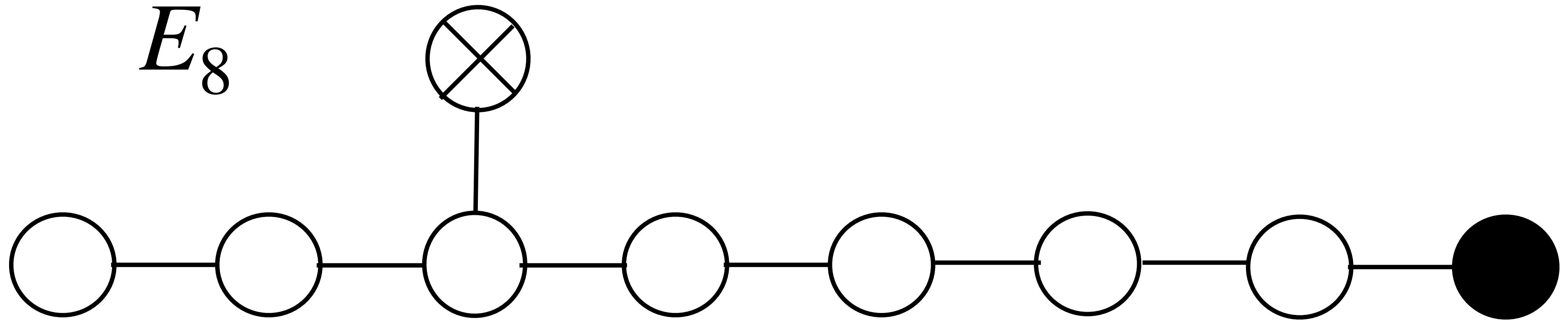
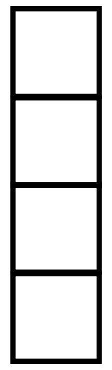


$SU(2)^4$ with (□, □, □, □)

$\hat{E}_8$



$SU(8)$ with 

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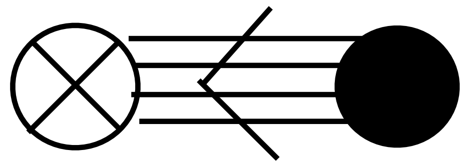
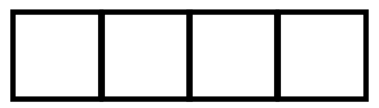
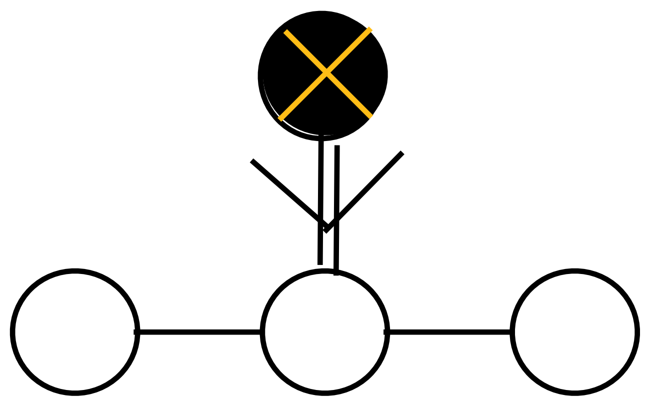
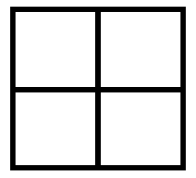


$SU(2)$ with 

$\hat{A}_{2k-1}^{(2)}$



$SU(4)$ with 

Exotic Matter from Heterotic Orbifolds

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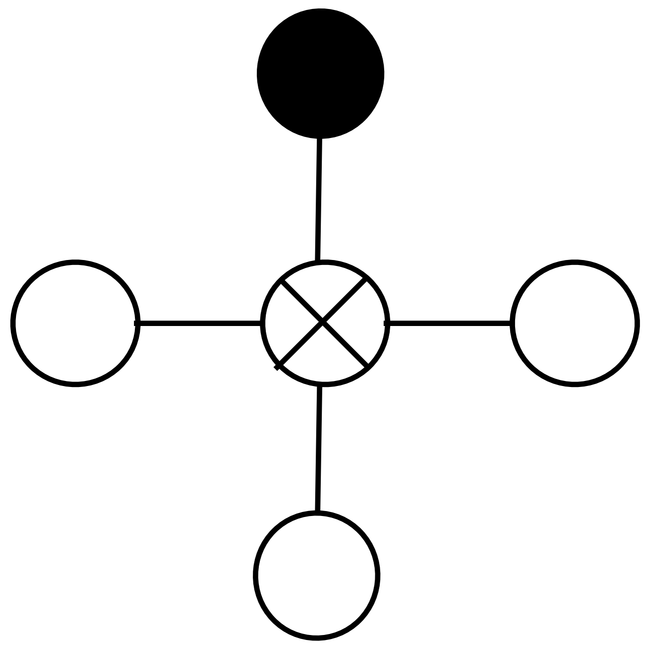
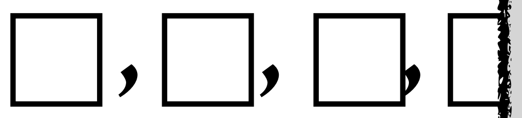
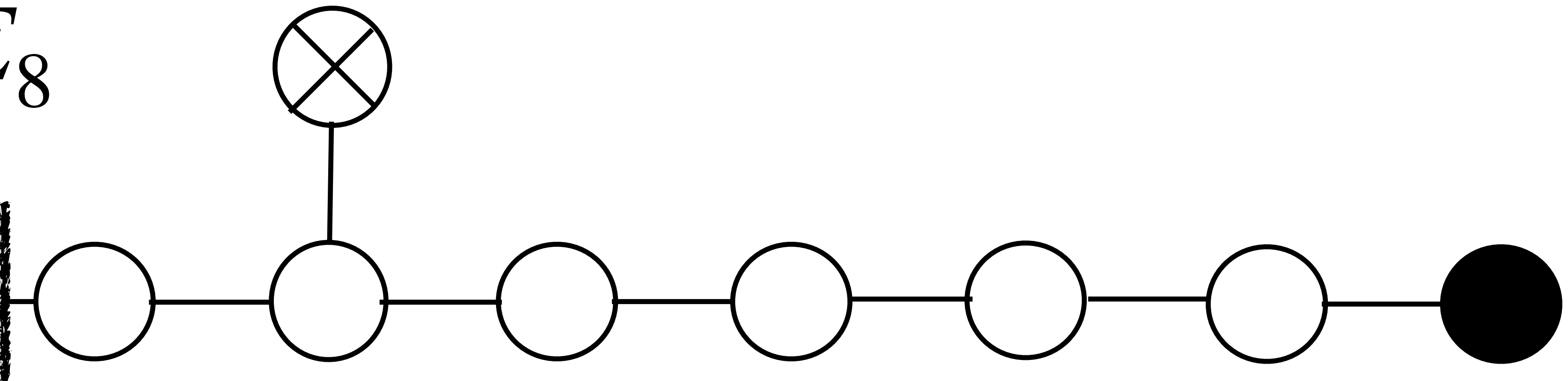


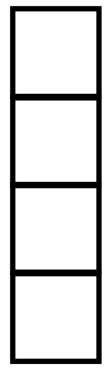
$SU(2)^4$ with (



$\hat{E}_8$



with



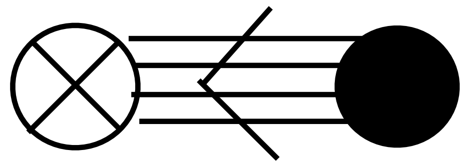
We construct an example from all affine branchings

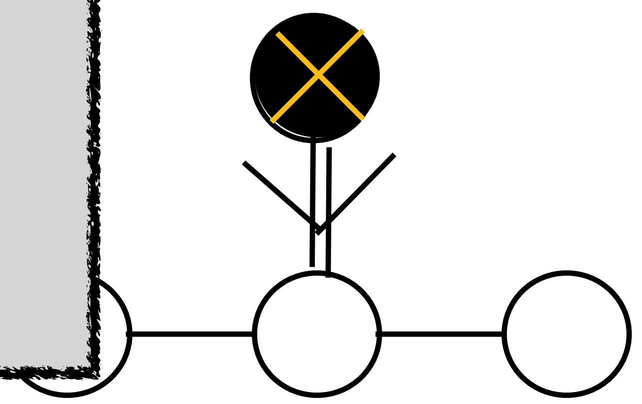
$$\hat{A}_N, \hat{D}_N, \hat{A}^{(2)}_N, \hat{D}^{(3)}_4 \ldots.$$

with

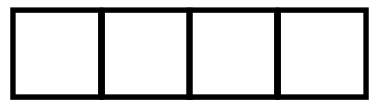
$$r \leq 26 - d$$

$\hat{A}^{(2)}_2$





$SU(2)$ with



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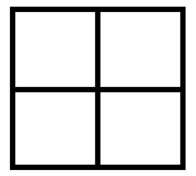
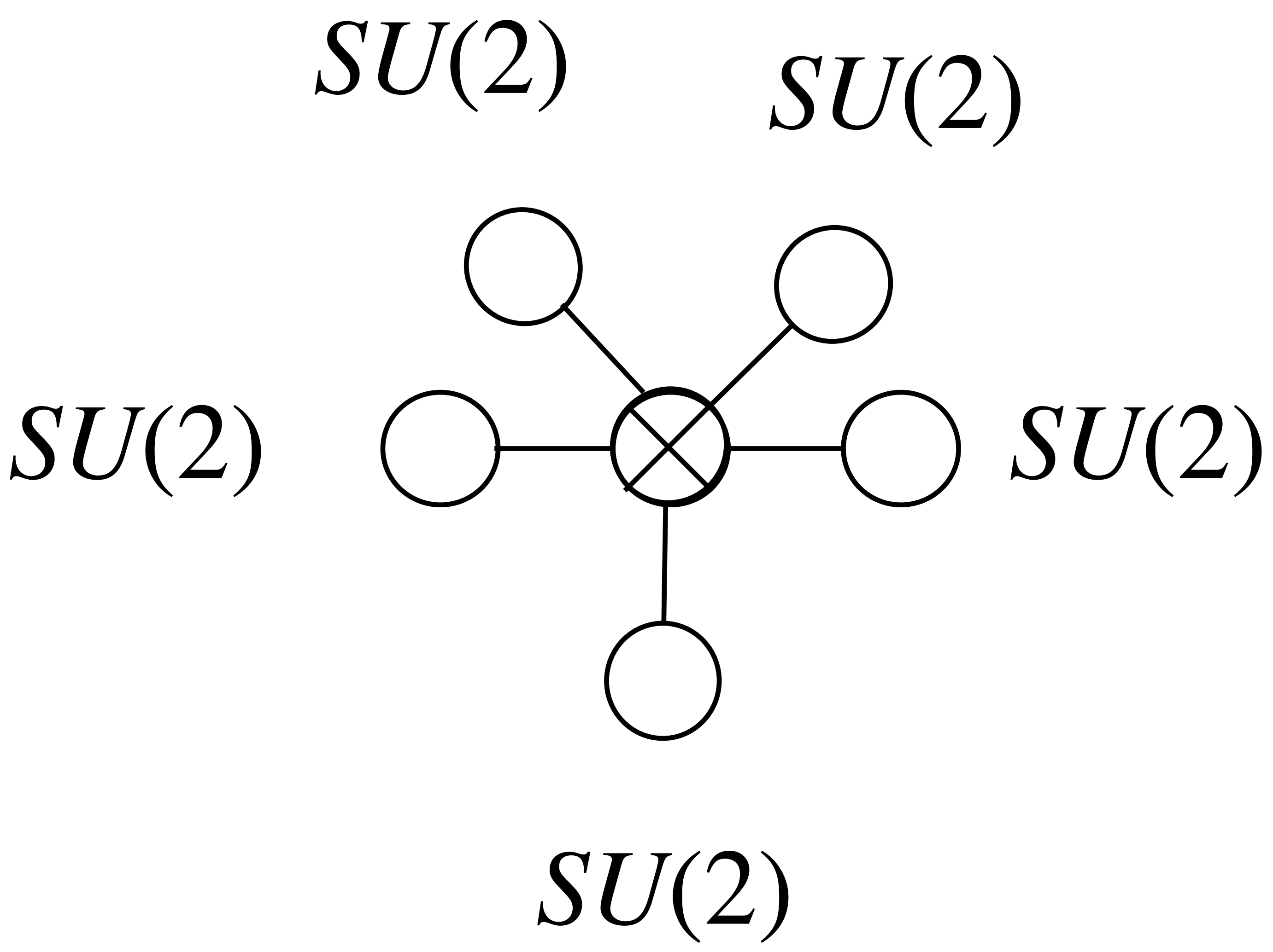


Exotic Matter from Heterotic Orbifolds

Why not something like?



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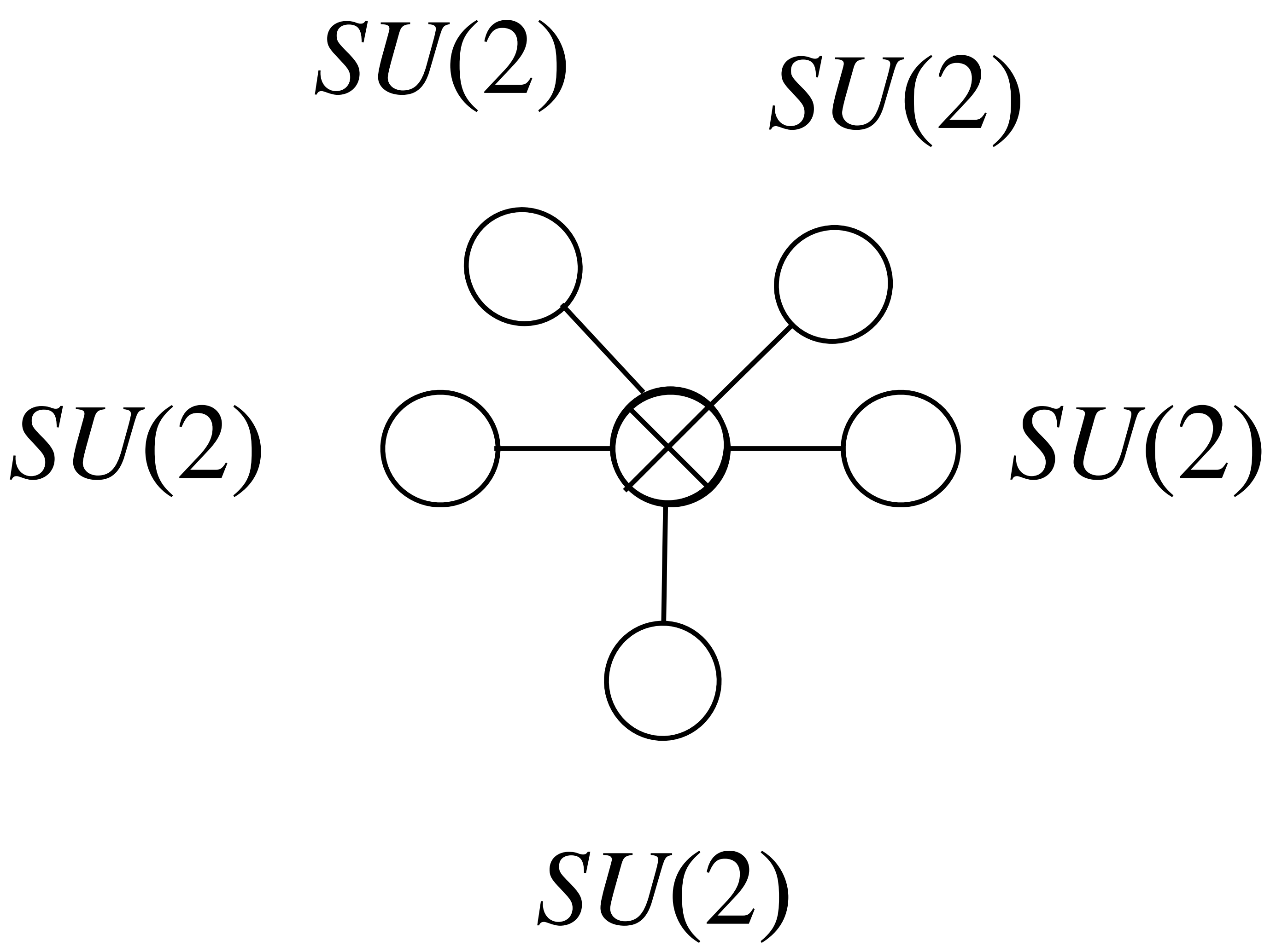

Not a Dynkin Diagram

Obvious from Untwisted-> always adjoint Higgsing

The representations are roots

How about twisted sectors?

The representations are no longer roots

But still come from Adjoint branching

$$E_6 \times SU(3) \times E_8 \times SU(3)^2$$

$$2(\mathbf{27},\mathbf{3},\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{27},\mathbf{1},\mathbf{1},\underline{\mathbf{3},\mathbf{1}}) + (\mathbf{27},\mathbf{1},\mathbf{1},\underline{\overline{\mathbf{3}},\mathbf{1}})$$

Shift only $V_L = \frac{1}{3}\omega_7^v$

$$+(\mathbf{1},\mathbf{3},\mathbf{1},\mathbf{3},\mathbf{3}) + (\mathbf{1},\mathbf{3},\mathbf{1},\underline{\mathbf{3},\overline{\mathbf{3}}}) + (\mathbf{1},\mathbf{3},\mathbf{1},\overline{\mathbf{3}},\overline{\mathbf{3}})$$

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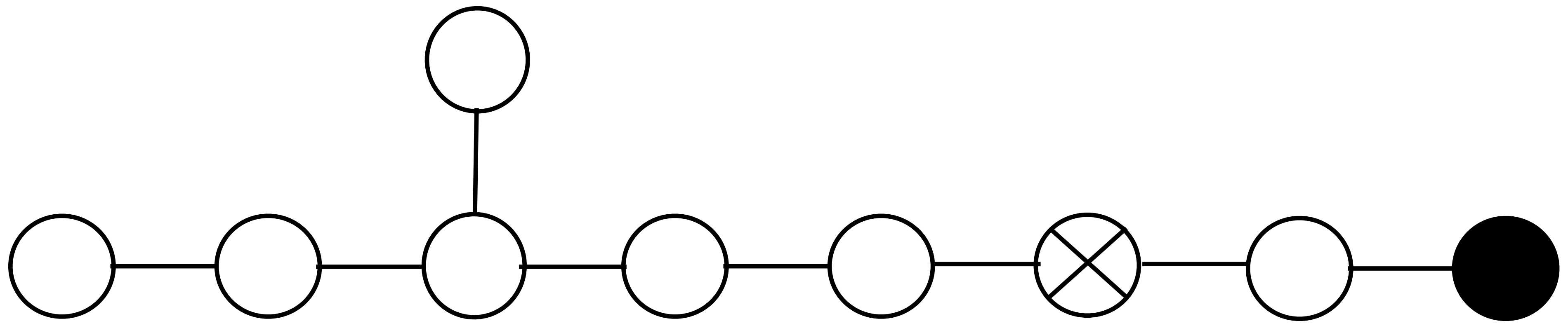
Untwisted Sector

$$\alpha \cdot V_L \in \mathbb{Z}$$



E_6 $SU(3)$

$$M_L^2 = \frac{P_L^2}{2} - 1$$

$P_L^2 = 2$ roots

$$E_6 \times SU(3) \times E_8 \times SU(3)^2$$

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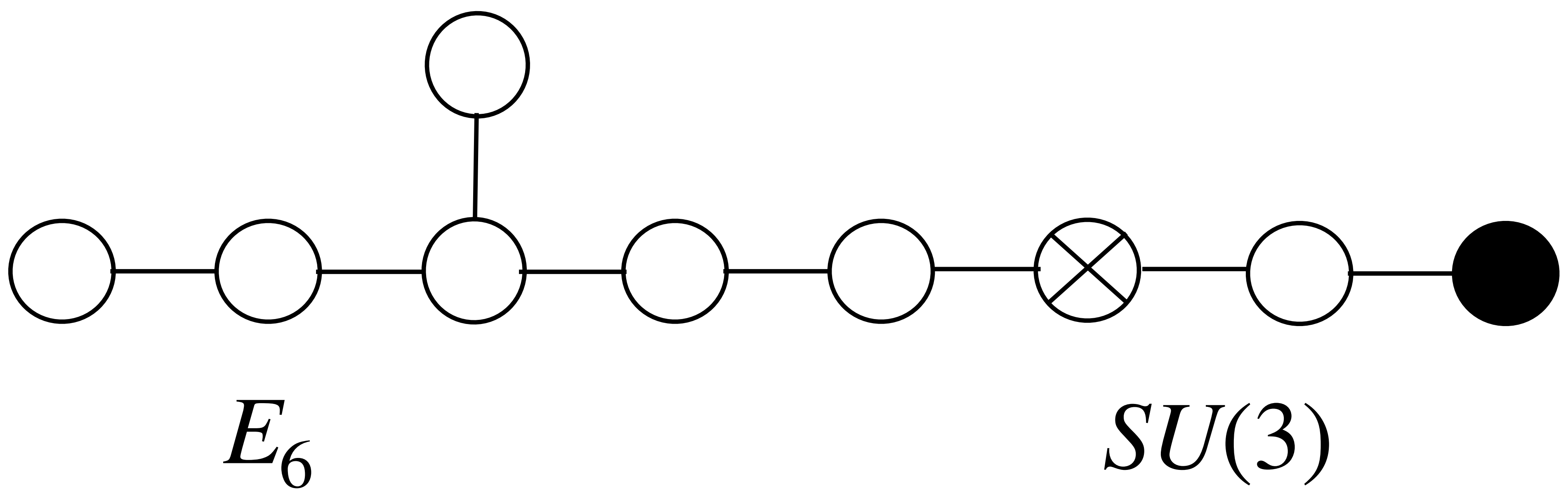

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Twisted Sector

$$P_L \to P_L + nV_L$$

$P_L^2 < 2$ not a root

$$M_L^2 = \frac{(P_L + nV_L)^2}{2} - 1$$

$$q_i = (P_L + nV_L) \cdot \alpha_i^v$$

$$E_6 \times SU(3) \times E_8 \times SU(3)^2$$

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$$+(\mathbf{1},\mathbf{3},\mathbf{1},\mathbf{3},\mathbf{3}) + (\mathbf{1},\mathbf{3},\mathbf{1},\underline{\mathbf{3},\bar{\mathbf{3}}}) + (\mathbf{1},\mathbf{3},\mathbf{1},\bar{\mathbf{3}},\bar{\mathbf{3}})$$

Shift only $V_L = \frac{1}{3}\omega_7^\vee$

Untwisted Sector

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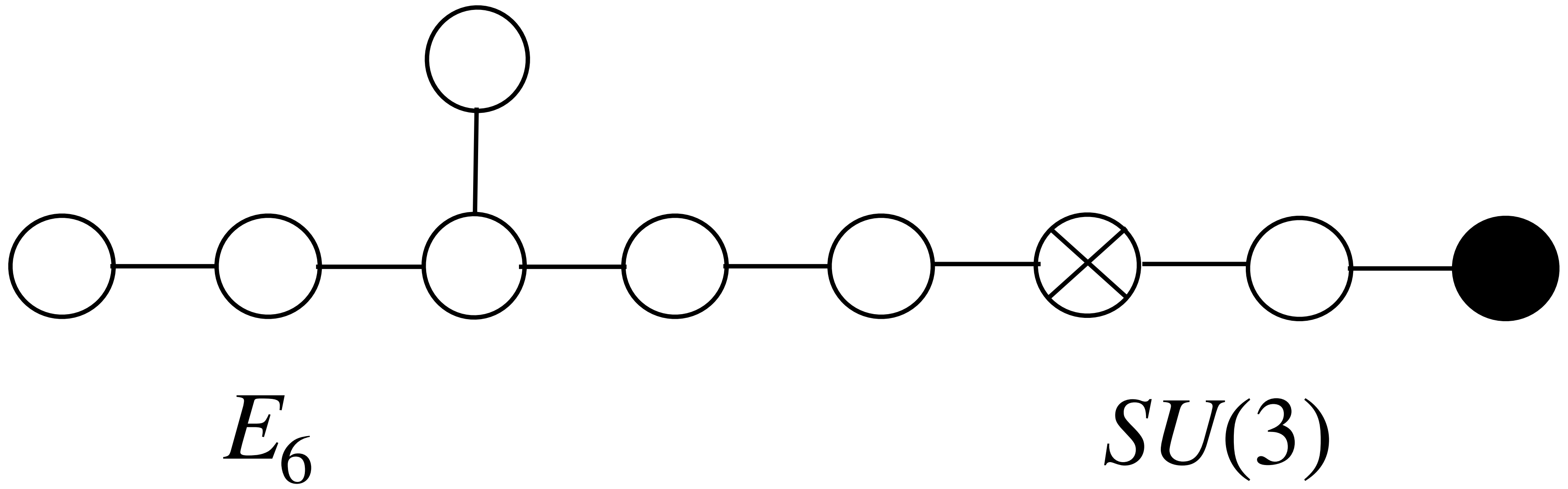

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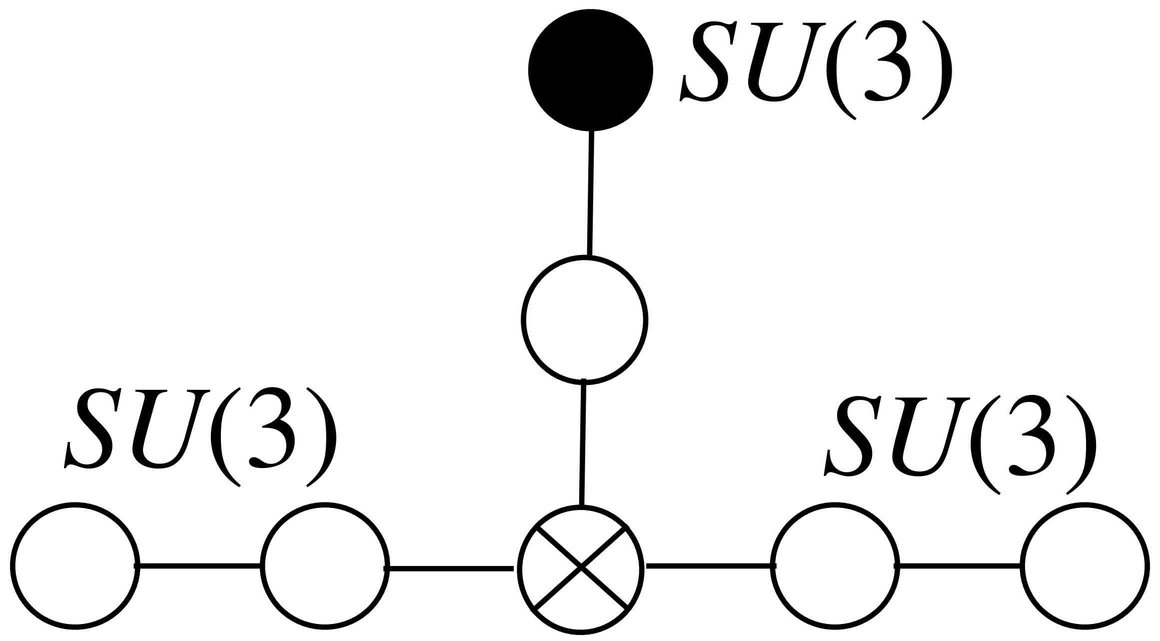

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Heterotic Toroidal Orbifolds

How about twists as well?

ϕ_L inner automorphism

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For the twisted sector:

twist ↓

$$M_L^2 = N_L + \frac{P_L^2}{2} + E_0 - 1$$

↖ $\frac{1}{2}\sum_i \phi_L^i(1-\phi_L^i)$

Heterotic Toroidal Orbifolds

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$$\frac{1}{2}\sum_i \phi_L^i(1-\phi_L^i)$$

$\Longleftrightarrow$

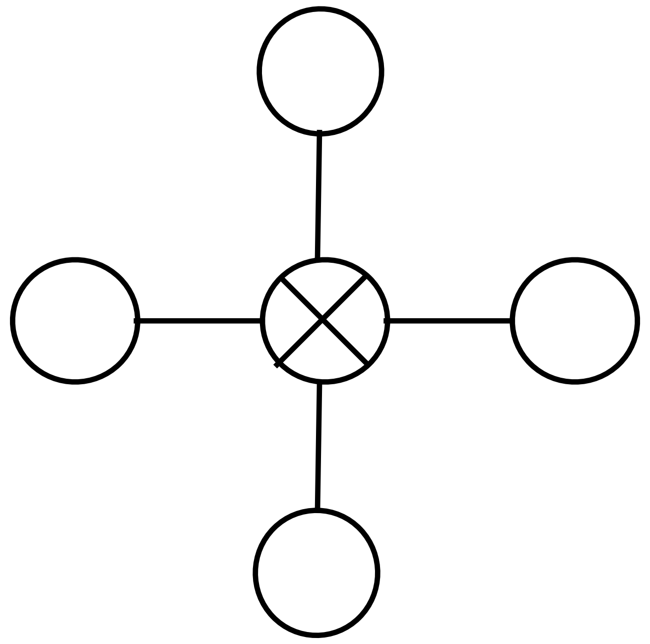
shift

$$M_L^2 = \tilde{N}_L + \frac{(\tilde{P}_L + V_L)^2}{2} - 1$$

The representations are not roots but they can be thought of as roots in a different basis
any inner automorphism twist can be exchanged with a shift

Exotic Matter from Heterotic Orbifolds

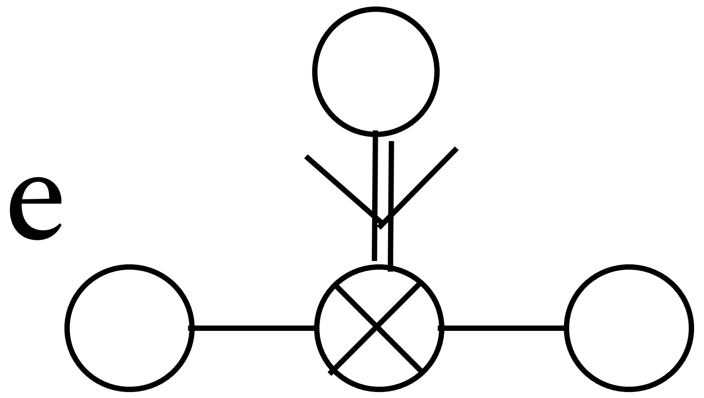
Are they all of the form of regular embeddings ?



There are adjoint embeddings that are not regular

e.g. outer automorphism of simple Lie algebra

It is if you think about it as deleting a node in twisted affine



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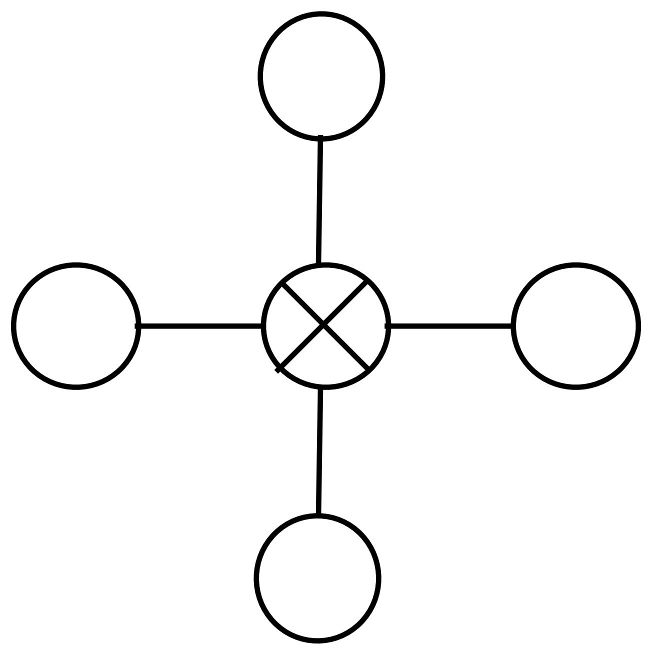

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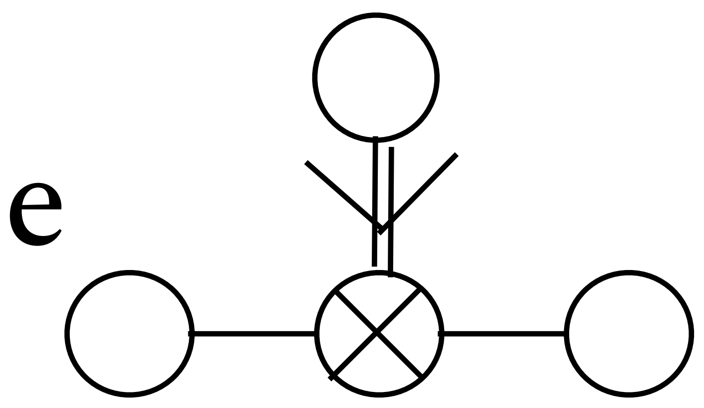

There are special embeddings that are not of this form, but they do not correspond to any Levi or pseudo-Levi so cannot be obtained by Higgsing or Wilson line

All massless free matter in heterotic orbifolds is the branching of some adjoint in a way that it corresponds to deleting nodes of an affine Dynkin diagram (up to outer automorphisms)

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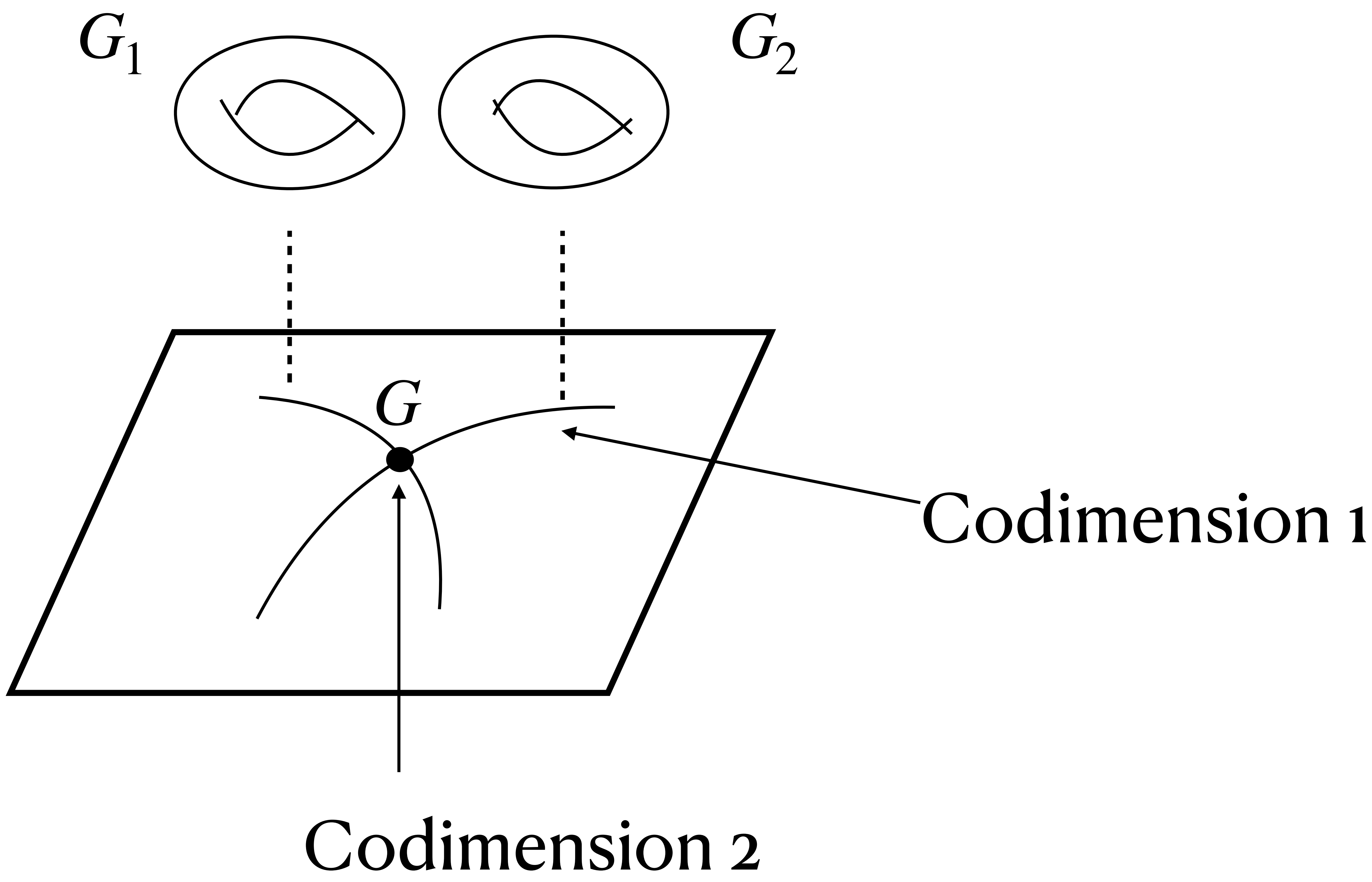
How about in other corners of string theory?

Matter in F-theory



Katz-Vafa

$$G \to G_1 \times G_2 \times U(1)$$

$$Adj(G) \to \quad (R^a, q^a)$$

$$\Phi \sim t \in U(1)$$

Matter

$$(D + q_a t)\ \psi_a(t, \bar{t}) = 0$$

Matter in F-theory

7 brane Hitchin system (A, Φ)

a weakly coupled 7-brane gauge theory, fluctuations transverse to the brane are encoded by the adjoint-valued Higgs field Φ

→ Diagonalizable — Ordinary F-theory (Complex structure)

→ Nilpotent — T-branes (axionic/RR-like moduli)

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[Cvetic, Heckman , Lin 18']

$E_6 \times SU(3)$
(27,3)

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Phenomenological applications!

Thank you very much