Orientifolds and new $\mathcal{N} = 1$ dualties

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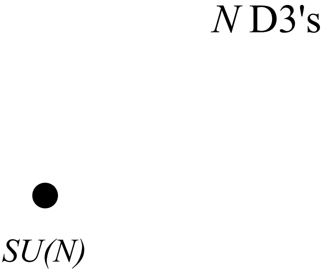
Motivation

Why hunt for [4d $\mathcal{N} = 1$] gauge theory dualities?

- Understand gauge theories at strong coupling
- Unlike AdS/CFT, finite N!
- Useful for phenomenology
- Better understanding of string theory

Invitation: Montonen-Olive duality ($\mathcal{N} = 4$)



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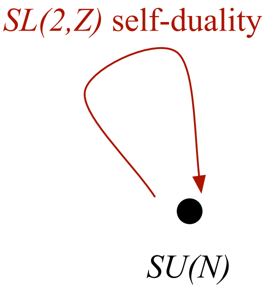
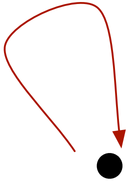


N D3's

$$\tau \to \frac{a\tau+b}{c\tau+d}$$

Invitation: Montonen-Olive duality ($\mathcal{N} = 4$)

SL(2,Z) self-duality



SU(N)

$$\tau \to \frac{a\tau+b}{c\tau+d}$$

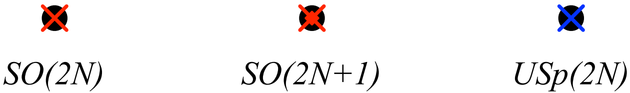
N D3's

$\Longrightarrow$

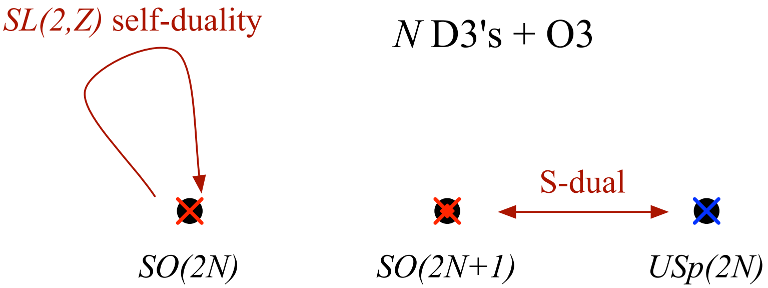
Type IIB String Theory:
Exact *SL(2,Z)* S-duality
(D3 invariant)

Invitation: $\mathcal{N} = 4$ orientifold dualities

N D3's + O3



Invitation: $\mathcal{N} = 4$ orientifold dualities



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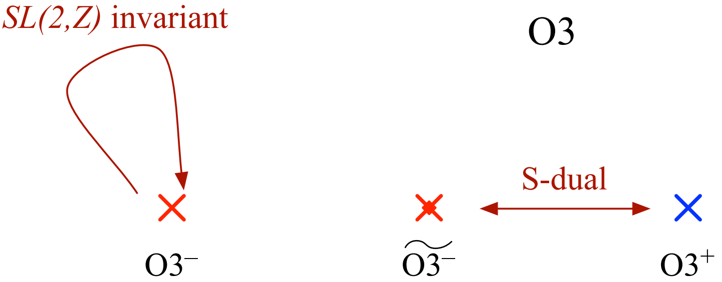

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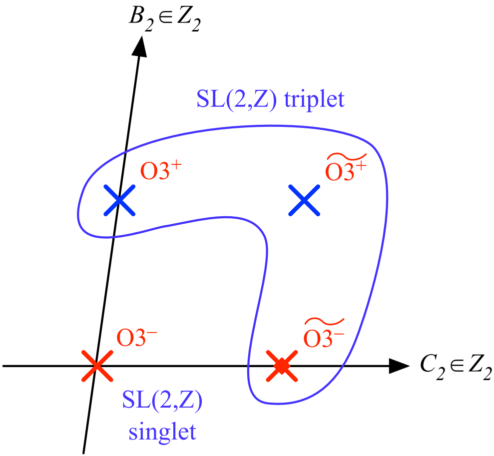

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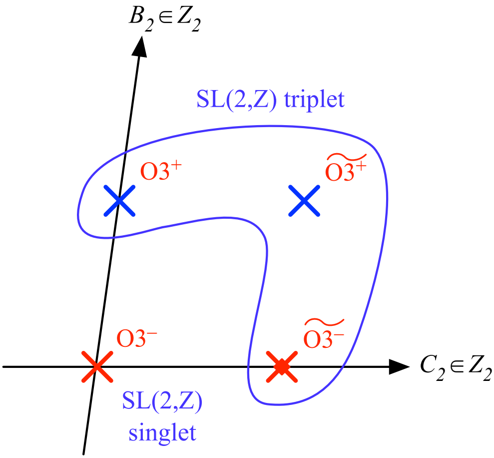

$$H^3(S^5/\mathbb{Z}_2, \tilde{\mathbb{Z}}) = \mathbb{Z}_2$$

Strategy

- D3 branes $SL(2,\mathbb{Z})$ invariant
- Orientifolds may break $SL(2,\mathbb{Z})$
- Can lead to gauge theory S-dualities

Flat background ($\mathcal{N}=4$)

What about D3's at Calabi-Yau singularity ($\mathcal{N}=1$)?

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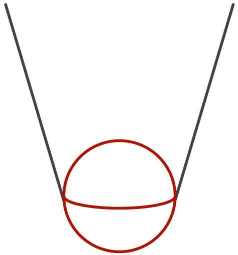
What about D3's at Calabi-Yau singularity ($\mathcal{N} = 1$)?

del Pezzo 0

"Simplest" $\mathcal{N} = 1$ singularity: $\mathbb{C}^3/\mathbb{Z}_3$ ($z^i \to e^{2\pi i/3} z^i$)

Calabi-Yau cone over $dP_0 = \mathbb{CP}^2$



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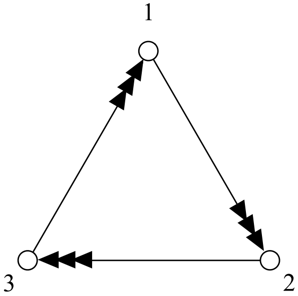

$$W = \epsilon_{ijk} X_{12}^i X_{23}^j X_{31}^k, \;\; \mathrm{SU}(3) \times \mathrm{U}(1)_R \text{ global symm.}$$

del Pezzo 0

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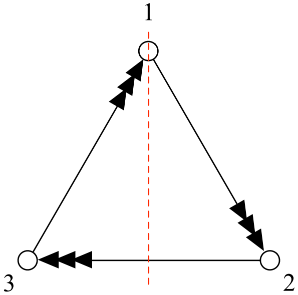

$\sigma : z^i \to -z^i$ (Compact O7 plane)

del Pezzo 0

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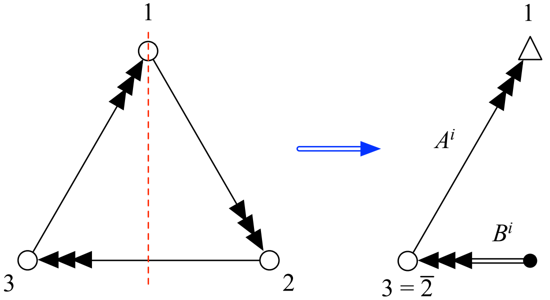

$W = \frac{1}{2}\epsilon_{ijk} A^i A^j B^k$, $\mathrm{SU}(3) \times \mathrm{U}(1)_R$ global symm.

del Pezzo 0

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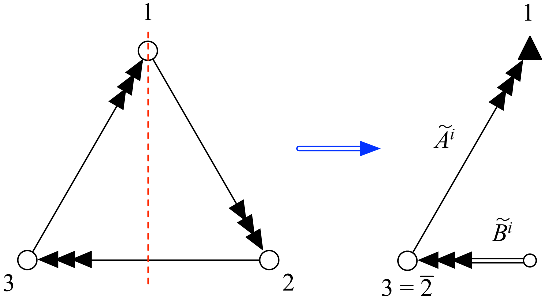


$W = \frac{1}{2}\epsilon_{ijk}\widetilde{A}^i\widetilde{A}^j\widetilde{B}^k$, $\mathrm{SU}(3) \times \mathrm{U}(1)_R$ global symm.

The orientifolds

	$SO(N-4)$	$SU(N)$	$SU(3)$	$U(1)_R$	$\mathbb{Z}_3$
A^i	$\square$	$\bar{\square}$	$\square$	$\frac{2}{3}+\frac{2}{N}$	ω_{3N}
B^i	1	$\begin{smallmatrix}\square\\\square\end{smallmatrix}$	$\square$	$\frac{2}{3}-\frac{4}{N}$	ω_{3N}^{-2}

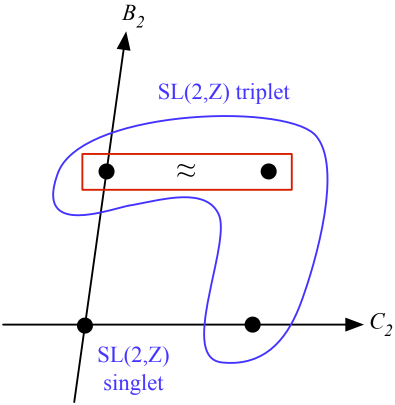
$$W = \frac{1}{2}\epsilon_{ijk}A^iA^jB^k$$

	$Sp(\tilde{N}+4)$	$SU(\tilde{N})$	$SU(3)$	$U(1)_R$	$\mathbb{Z}_3$
$\tilde{A}^i$	$\square$	$\bar{\square}$	$\square$	$\frac{2}{3}-\frac{2}{\tilde{N}}$	$\omega_{3\tilde{N}}$
$\tilde{B}^i$	1	$\square\!\square$	$\square$	$\frac{2}{3}+\frac{4}{\tilde{N}}$	$\omega_{3\tilde{N}}^{-2}$

$$W = \frac{1}{2}\epsilon_{ijk}\tilde{A}^i\tilde{A}^j\tilde{B}^k$$

A duality?

Is there a similar story to before? $H^3(S^5/\mathbb{Z}_6, \tilde{\mathbb{Z}}) = \mathbb{Z}_2$



Anomaly matching

Check hypothesis using 't Hooft anomaly matching

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$SO(N-4) \times SU(N)$ theory:

$SU(3)^3$	$\frac{3}{2}(N-3)N$
$SU(3)^2 \times U(1)_R$	$-\frac{1}{2}(N-3)N-6$
$U(1)_R^3$	$\frac{4}{3}(N-3)N-33$
$U(1)_R$	-9

$Sp(\tilde{N}+4) \times SU(\tilde{N})$ theory:

$SU(3)^3$	$\frac{3}{2}\tilde{N}(\tilde{N}+3)$
$SU(3)^2 \times U(1)_R$	$-\frac{1}{2}\tilde{N}(\tilde{N}+3)-6$
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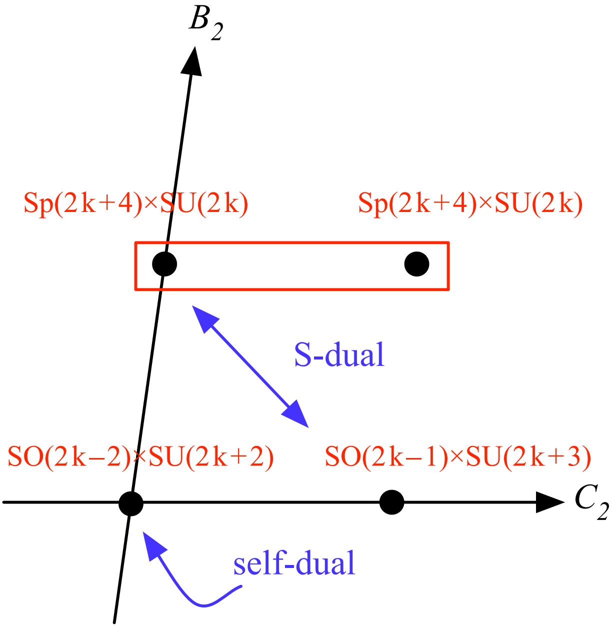
Anomalies match for $\tilde{N} = N-3$!


B_2
Sp(2k+4)×SU(2k)
Sp(2k+4)×SU(2k)
S-dual
SO(2k−2)×SU(2k+2)
SO(2k−1)×SU(2k+3)
C_2
self-dual

Moduli space

- Mesons match: $(AAB)^n \longleftrightarrow (\tilde{A}\tilde{A}\tilde{B})^n$
- Baryons of lowest possible R-charge:
  1. B^N, $Q_R = \frac{2(N-6)}{3}$, $Q_3 = \omega_3$
  2. $\tilde{A}^{\tilde{N}}$, $Q_R = \frac{2(\tilde{N}-3)}{3}$, $Q_3 = \omega_3$

$$B^N \longleftrightarrow \tilde{A}^{\tilde{N}}$$

$$\frac{2(N-6)}{3} = \frac{2(\tilde{N}-3)}{3} \longrightarrow N = \tilde{N} + 3$$

D3 charge

- Q_{D3} is $\mathrm{SL}(2,\mathbb{Z})$ invariant $\longrightarrow$ same for dual theories
- Compute using exceptional collections
- Get $Q_{D3} = N/2 - 3/4 \;\;,\;\; \tilde{Q}_{D3} = \tilde{N}/2 + 3/4$
- Reproduces the rank relation $\tilde{N} = N - 3$ again

$\mathcal{N}$-dependent checks

(1) $\mathrm{SU}(5) \longleftrightarrow \mathrm{Sp}(6) \times \mathrm{SU}(2)$

- Both have runaway vacuum
- No quantum moduli space to match

N-dependent checks

(2) $\mathrm{SO}(3) \times \mathrm{SU}(7) \longleftrightarrow \mathrm{Sp}(8) \times \mathrm{SU}(4)$

- $\mathrm{Sp}(8)$ s-confines, Seiberg dualize $\mathrm{SU}(4) \cong \mathrm{SO}(6)$
- Free IR fixed point
- Quantum moduli space: $\tilde{A}^4$ (w/ constraint)

- Turn on controlled vevs and compare with $\mathrm{SO}(3) \times \mathrm{SU}(7)$
- Some nontrivial checks... work in progress

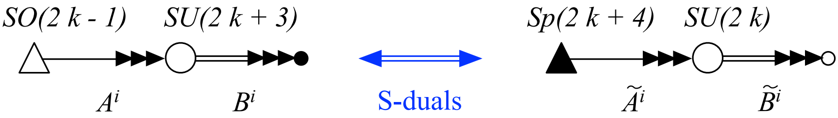
N-dependent checks

(3) Higher N

Expect:

- Quantum moduli space: mesonic <u>and</u> baryonic directions
- Interacting IR fixed point
- Difficult to check…

Summary



$$W = \frac{1}{2}\epsilon_{ijk}A^iA^jB^k \qquad\qquad W = \frac{1}{2}\epsilon_{ijk}\tilde{A}^i\tilde{A}^j\tilde{B}^k$$

- [Many] nontrivial checks
- Novel duality from gauge theory perspective
- "Cousin" of well known $\mathrm{SO}(2k+1) \leftrightarrow \mathrm{Sp}(2k)$ $\mathcal{N}=4$ duality

Conclusions

- Orientifolds can break $\mathrm{SL}(2,\mathbb{Z})$, lead to S-dual theories
- Interesting new dualities from $\mathcal{N}=1$ orientifold singularities
- $\mathbb{C}_3/\mathbb{Z}_3$ merely the simplest example of anomaly matching

Iñaki's talk:

- Superconformal index
- Construction of gauge theory using fractional branes
- Orientifold transition

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Iñaki's talk:

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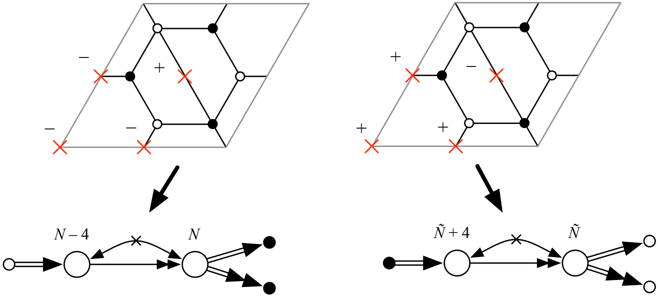
Backup slides

Example II

First del Pezzo:

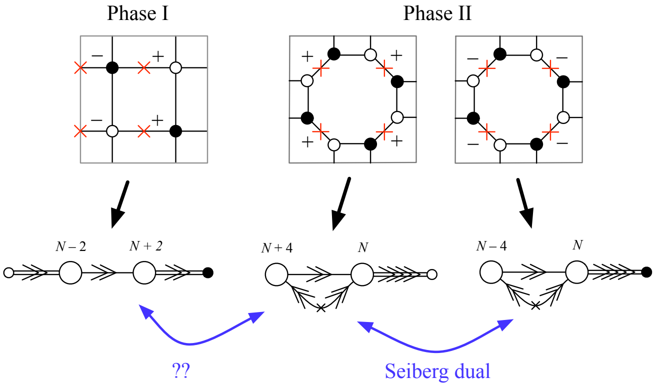


Anomalies match for $\tilde{N} = N - 2$, odd N.

Even N: moduli space mismatch

Example III

Zeroth Hirzebruch ($\mathbb{P}_1 \times \mathbb{P}_1$).



Anomalies match for all N; spectra do not match for even N

Exact duality?

Is the duality exact?

- Hard to answer in field theory
- Beta functions: $(b_{SO}, b_{SU}) = (-18, 9)$, $(b_{Sp}, b_{SU}) = (9, -9)$
- $\longrightarrow$ effective field theory between Λ_{IR} and Λ_{UV}
- Not easy to check whether dual theories different in the UV
- Have to go back to string theory…