Bifid Throats for Axion Monodromy Inflation

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Based on arXiv:1504.02103,
by A.R., A. Uranga & A. Westphal

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Axion Monodromy Inflation

- In *Large Field Inflation* you need:
  - Control over corrections to inflaton potential
  - UV completion of inflation

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Our best inflaton candidate: A **String Theory Axion**
$\Longrightarrow$ shift symmetry protects $V(\phi)$ against corrections

In Type IIB we have many axions...

$$b = \int_{\Sigma_2} B_2 \quad ; \quad c = \int_{\Sigma_2'} C_2$$

$$b \sim b + f_b \quad ; \quad c \sim c + f_c$$

Axion Monodromy Inflation

In String Theory axions have $f < M_p$ Banks et al.

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Two possible ways of having *Large Field Inflation*:

- Many-axion models Kim, Nilles, Peloso; Dimopoulos et al

  (but... Rudelius; Montero et al; Brown et al; Bachlechner et al; Hebecker et al; Blumenhagen et al; Ruehle & Wieck; Junghans)

- Axion *Monodromy* models
  - **5-brane Axion Monodromy**
    McAllister, Silverstein & Westphal
  - F-term Axion Monodromy
    Marchesano, Shiu, Uranga; Hebecker et al, Blumenhagen et al

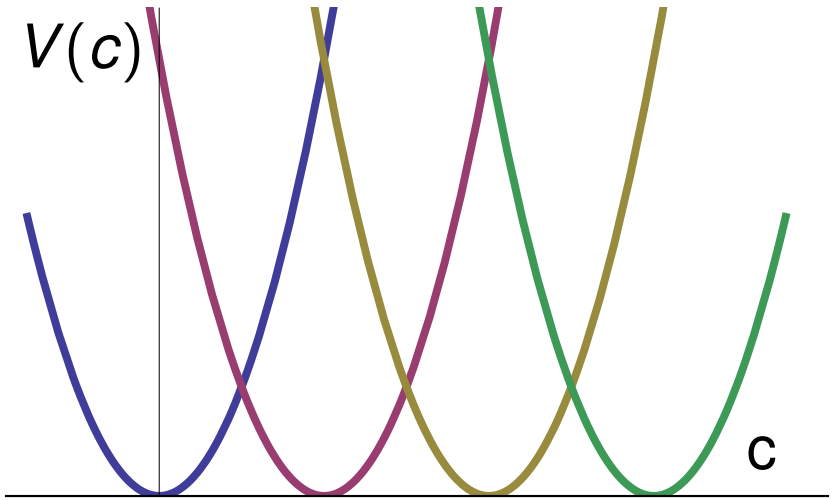
5-brane Axion Monodromy Inflation

McAllister, Silverstein & Westphal

Non-perturbative object (5-brane) creates potential for axion

For a NS5-brane: DBI-like action gives a potential $(c = \int_{\Sigma_2} C_2)$

$$V(c) \sim \sqrt{1 + c^2} \qquad \textit{and} \qquad c \sim c + f_c$$



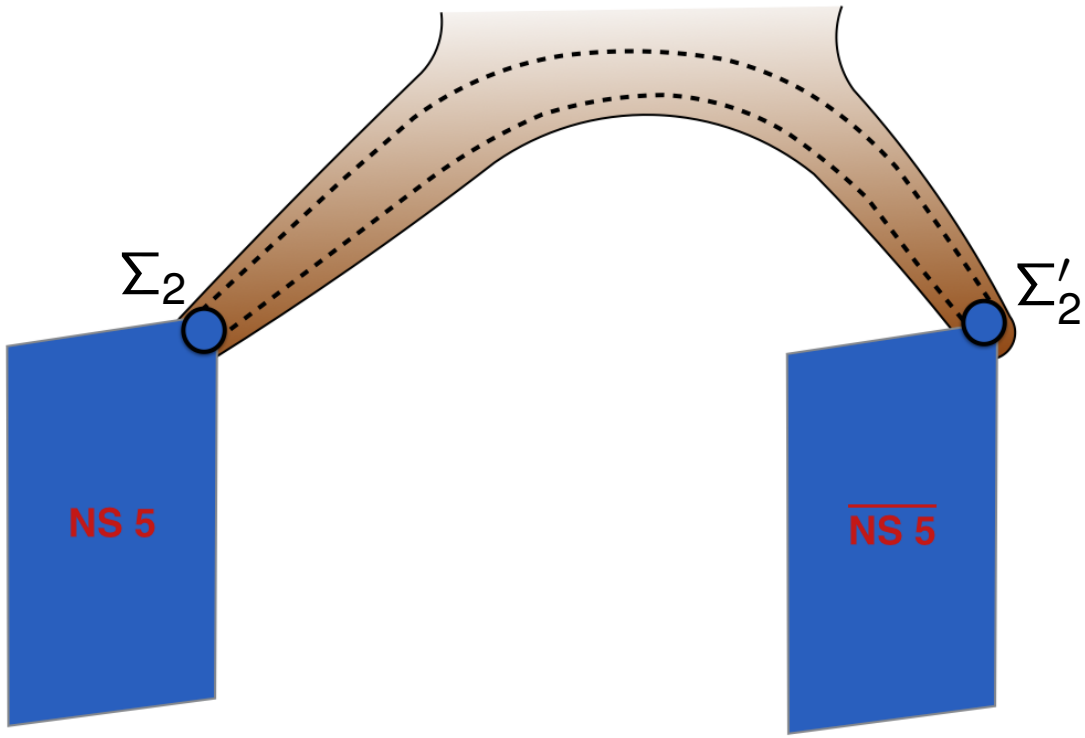
5-brane Axion Monodromy Inflation

McAllister, Silverstein & Westphal

1. Tadpoles $\rightarrow NS5 - \overline{NS5}$ in $\Sigma_2 \sim \Sigma_2'$
2. Closed string twisted fields associated to $\Sigma_2 \sim \Sigma_2'$

$$V(z) \sim \log z$$ Conlon

3. Attraction vs. Warping : use **Throats** (Klebanov-Strassler...)



5-brane Axion Monodromy Inflation

Flauger, McAllister, Pajer, Westphal, Xu

Inflationary energy backreaction may affect 4-cycle volumes

$\Downarrow$

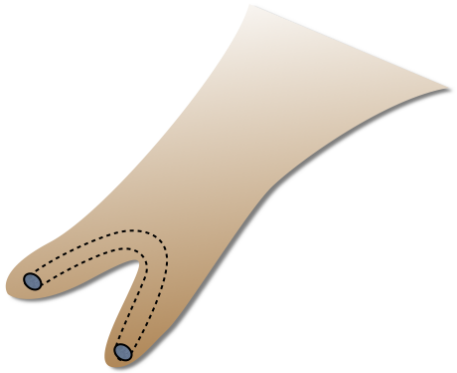
Corrections to moduli stabilization potential
(from D3-brane instantons, etc.)

$\Downarrow$

Corrections to inflation potential

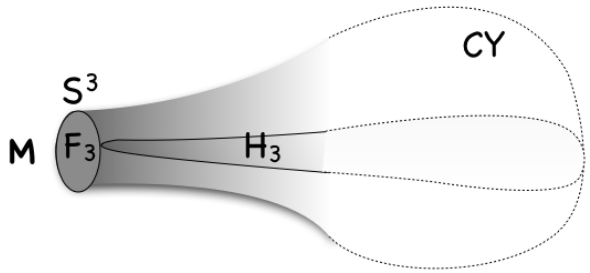
Solution (again): warping
Bifid Throats

From bulk looks like a dipole



Throats I: the Conifold

- Start with cone over $X_5 \sim S^2 \times S^3$: $ds_6^2 = dr^2 + r^2 d\Omega_{X_5}^2$ and put D3 branes on the bottom. Near horizon: $AdS_5 \times X_5$
- Admits a **Holographic** dual Gauge theory description
- Complex deformation: grow a S^3 on the bottom, hold by fluxes in SUGRA solution Klebanov-Strassler



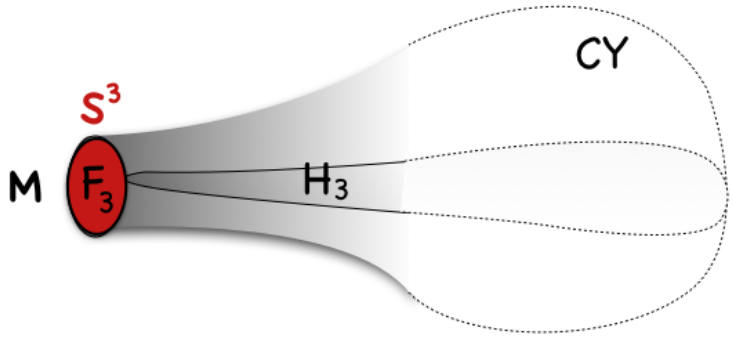
- Suppression of scales on the bottom due to warping

  Randall & Sundrum; H. Verlinde; Giddings, Kachru & Polchinski

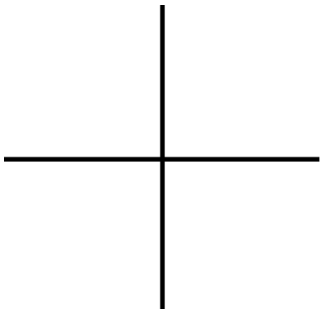
Throats II: Simple Bifid Throat

Toric geometry: Web diagrams

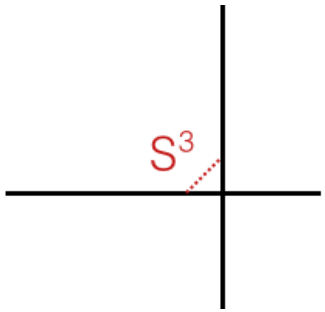
The (deformed) conifold



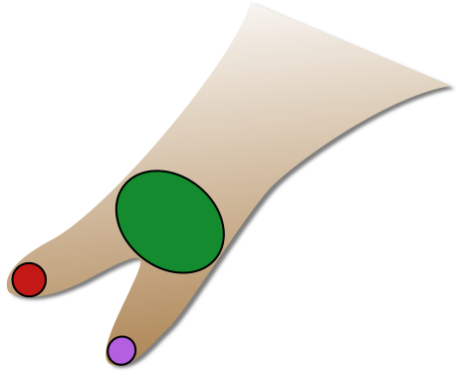
Singular



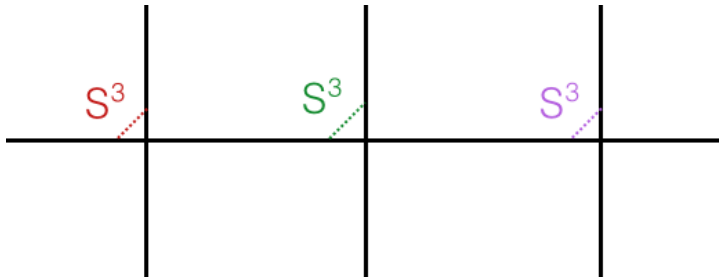
Deformed



Simple Bifid Throat (other X_5)

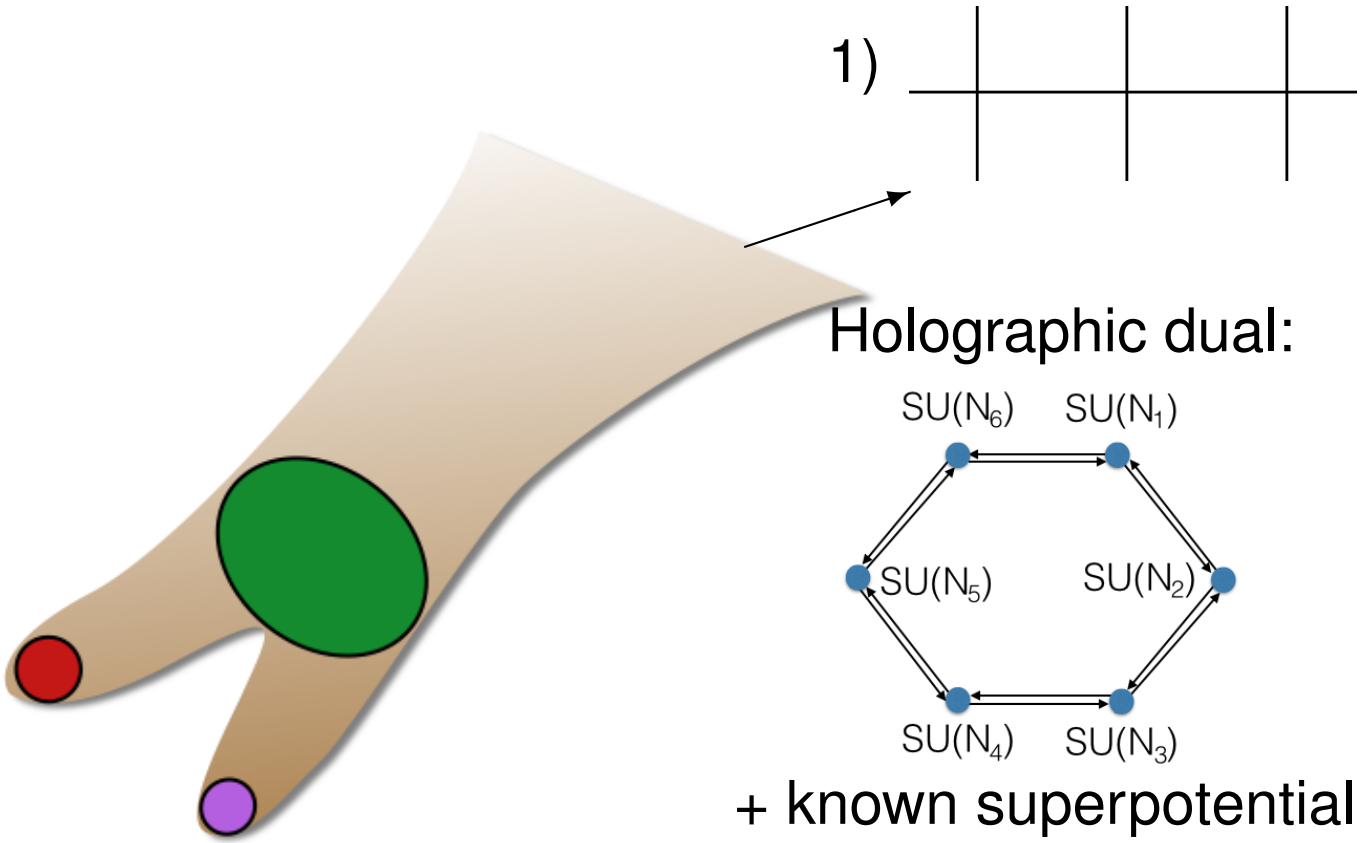


3 indep. deformations:
$\mathbb{Z}_3$ orbifold of conifold



Throats II: Simple Bifid Throat

Base of cone X_5 changes as one goes to smaller radius
(= gauge theory changes as one goes to the IR)



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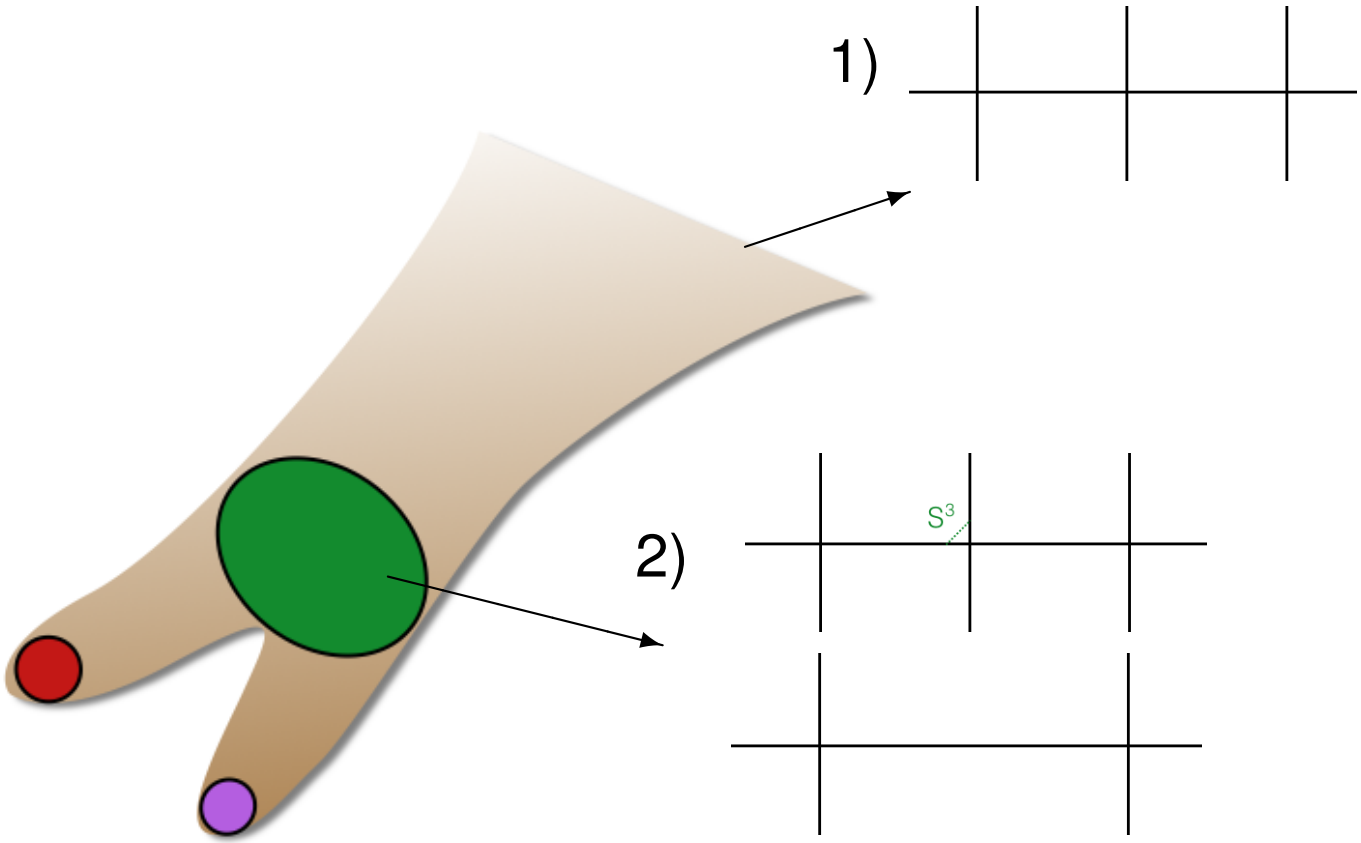

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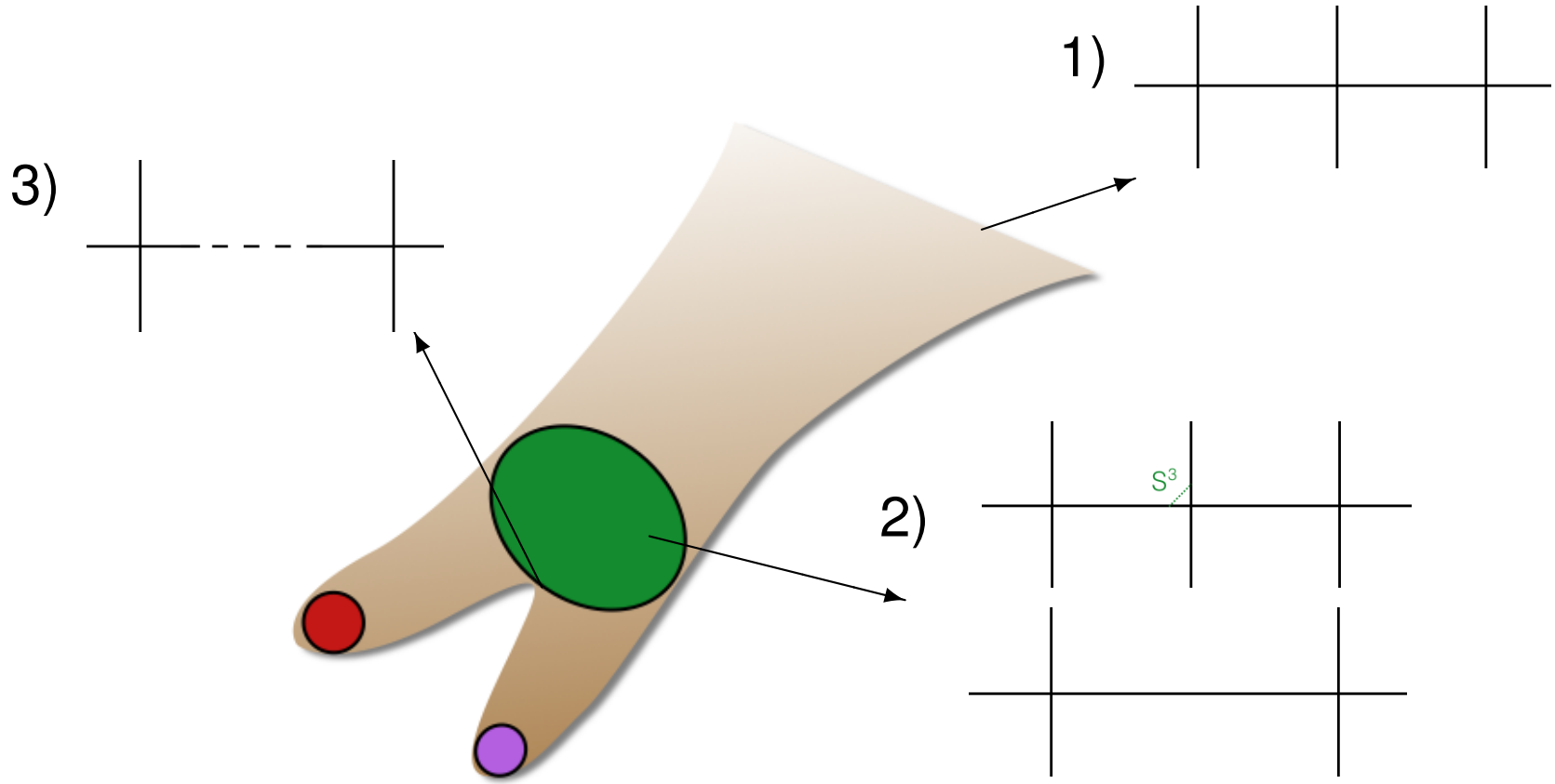

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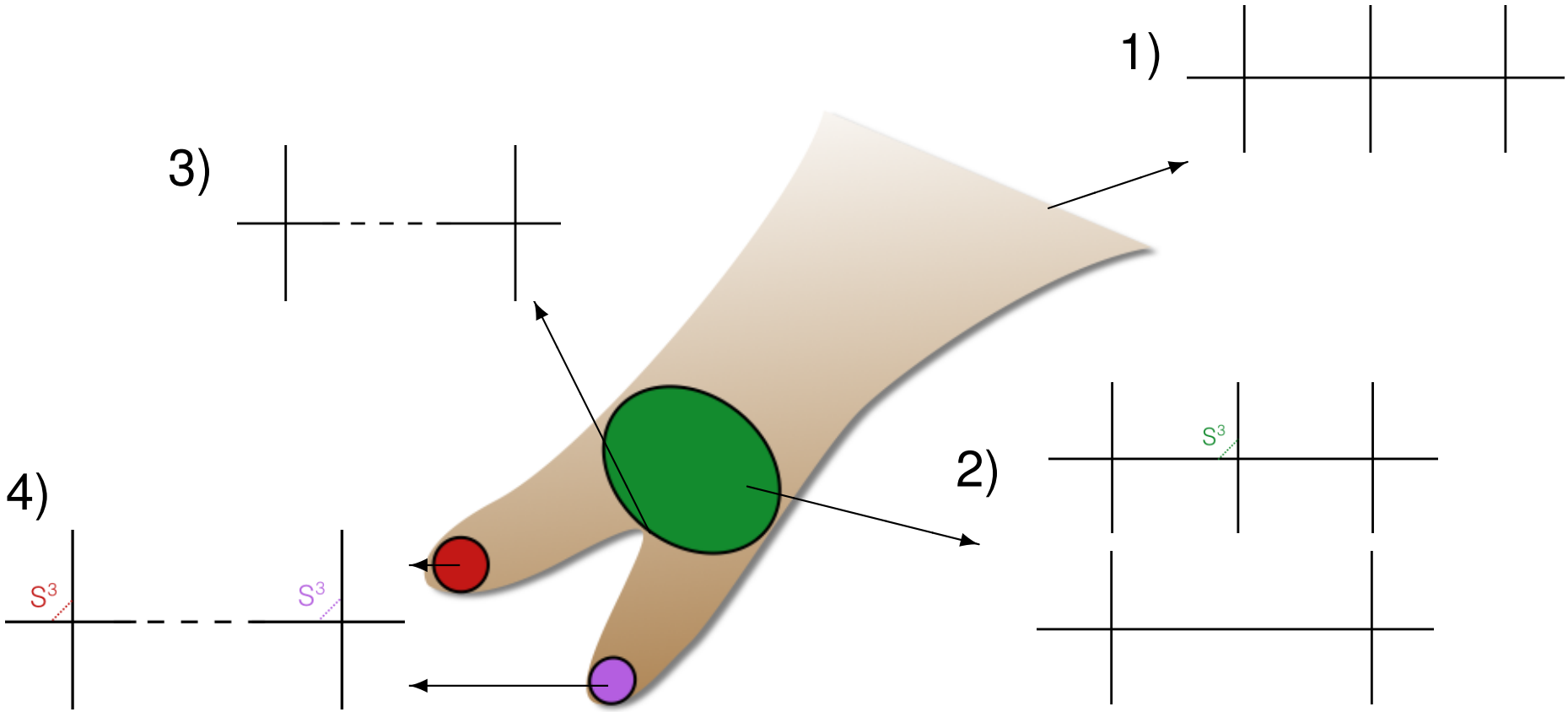
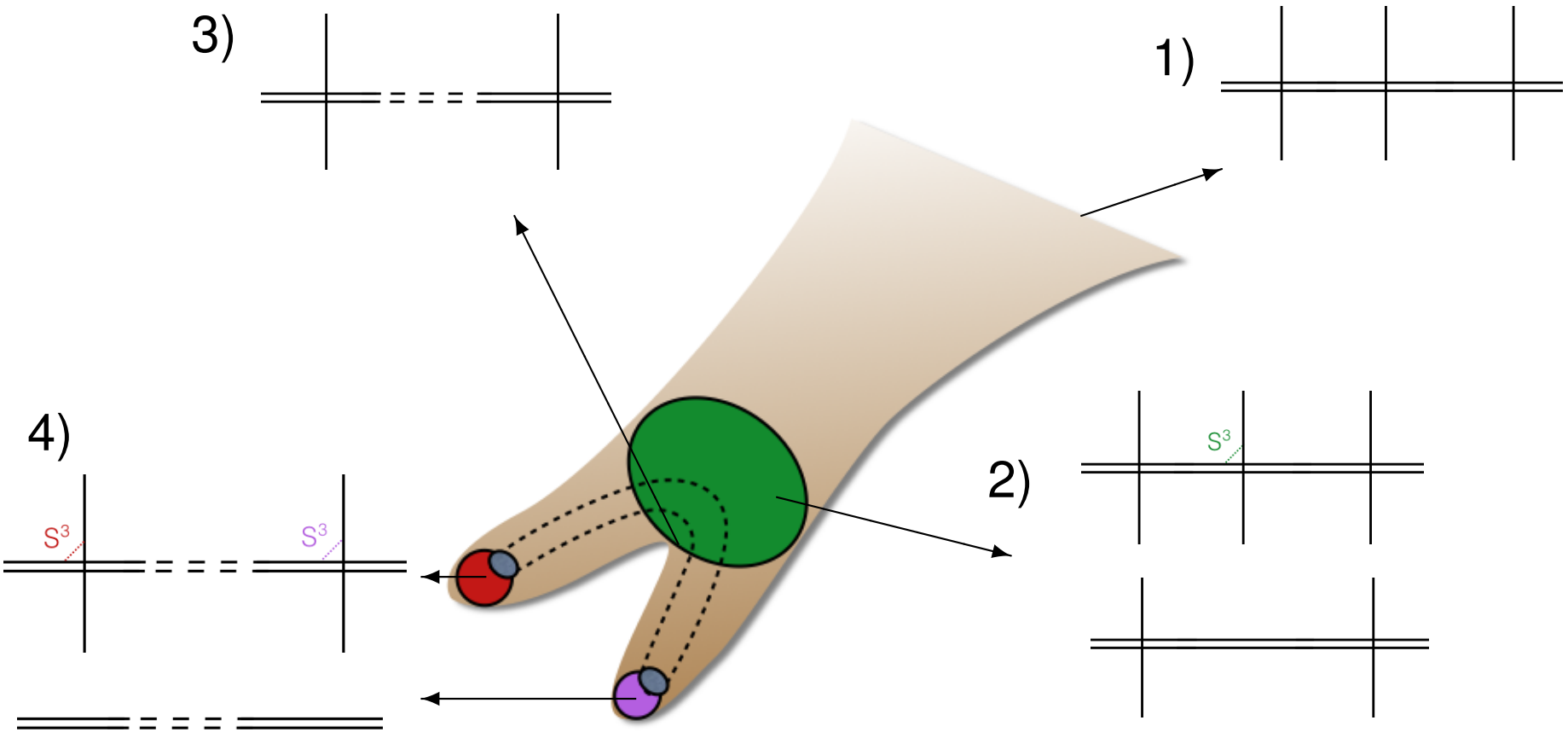


Throats III: Bifid Throat with homologous 2-cycles

In order to have homologous 2-cycles at the bottom take an extra $\mathbb{Z}_2$ action: $\mathbb{Z}_3 \times \mathbb{Z}_2$ orbifold of conifold



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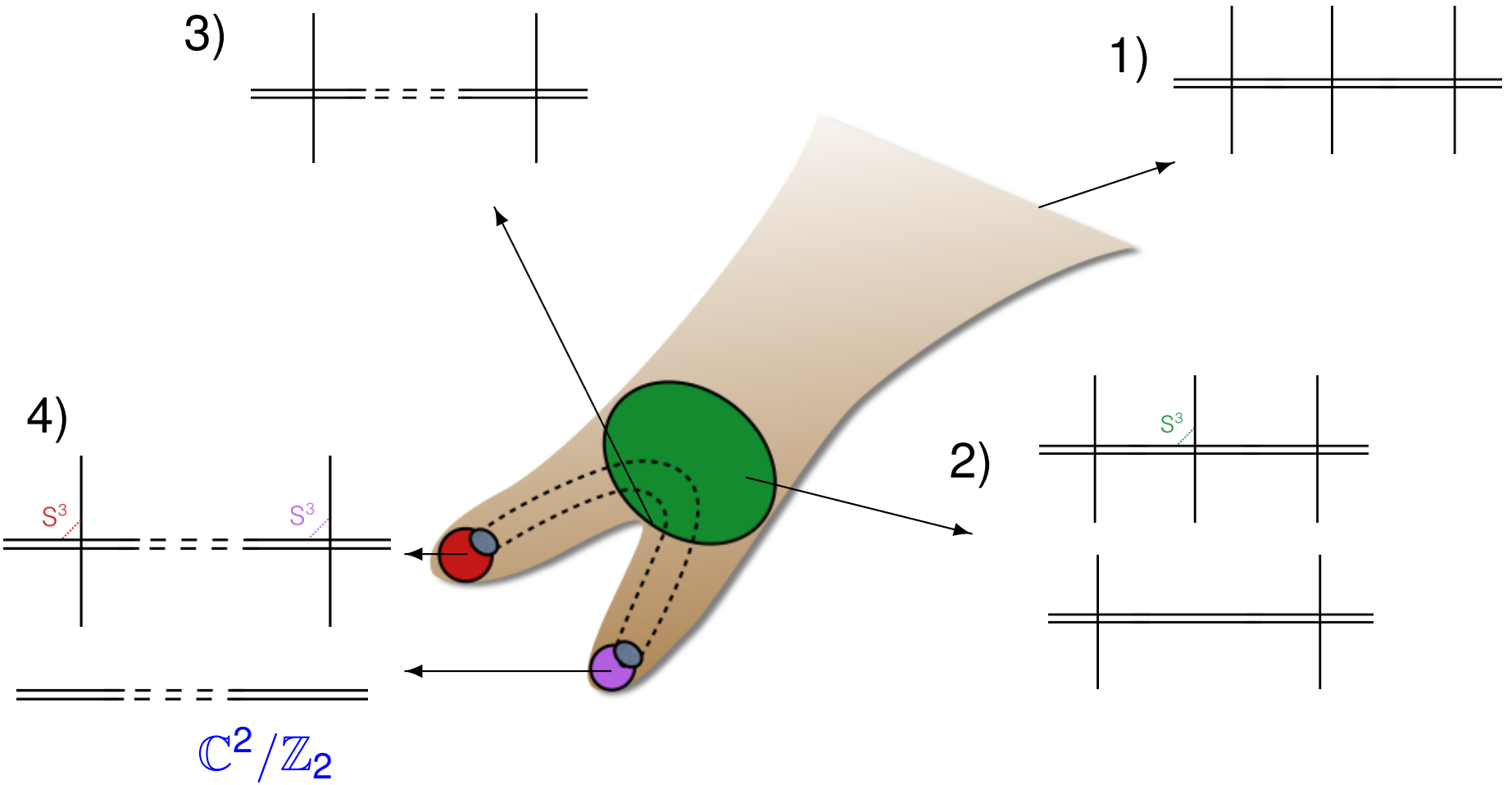

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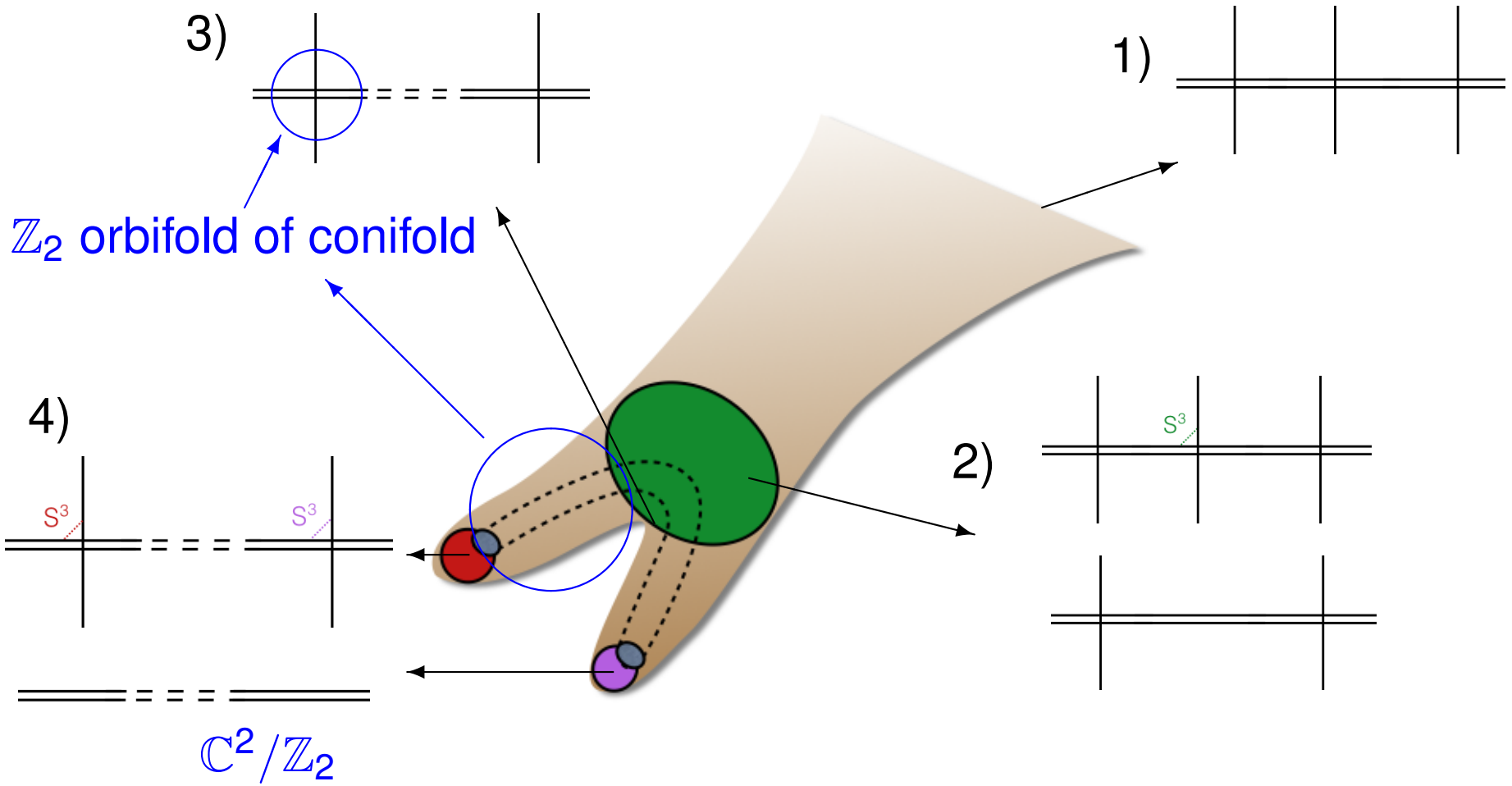
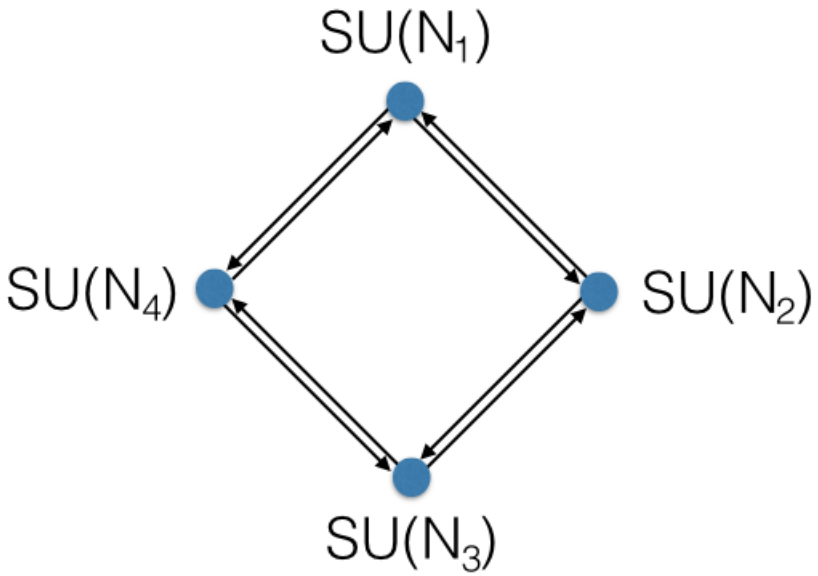


Holography I: Daughter Throats

We have a $\mathbb{Z}_2$ orbifold of the conifold



Ranks: from ...

Geometry

$$N_1 = N$$
$$N_2 = N$$
$$N_3 = N$$
$$N_4 = N$$

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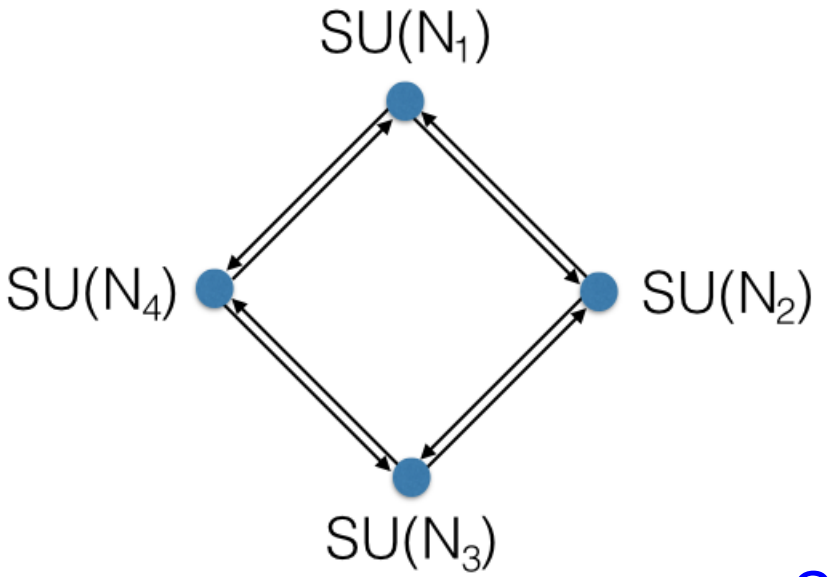

Ranks: from ...

Geometry + fluxes

$$\begin{aligned} N_1 &= N + P \\ N_2 &= N \\ N_3 &= N + P \\ N_4 &= N \end{aligned}$$

Cascade of Seiberg Dualities

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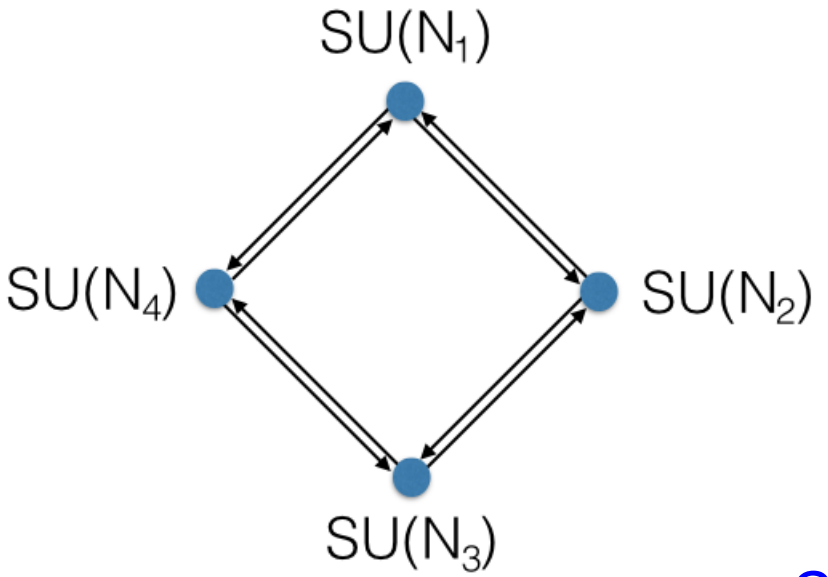

Ranks: from ...

Geometry + fluxes + **Brane(s)**[1]

$$\begin{aligned} N_1 &= N + P + K \\ N_2 &= N + K \\ N_3 &= N + P \\ N_4 &= N \end{aligned}$$

Cascade of Seiberg Dualities

[1] What about antibranes? ; They are D5-s here, not NS5-s

Holography II: The log profile Conlon

Take the brane(s) out of the bottom along the $\mathbb{C}^2/\mathbb{Z}_2$ curve: some bifundamentals get vevs & ranks of gauge groups change making modes masive. Integrate out massive modes to relate scales in e.g. group 1:

$$\Lambda_1^{4P} = \Lambda_1^{4P+2K} z^{-2K}$$

And as the dynamical scale of any gauge group is

$$\Lambda^{3N_c-N_f} = \mu^{3N_c-N_f} \exp\left(\frac{1}{g^2_{\mathrm{YM}}(\mu)} + i\theta\right)$$

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In the holographic picture the log profile is gauge coupling dependence on the Coulomb branch parameter

$$\frac{1}{g^2_{\rm YM}(\mu)} \sim K \log z$$

Backreaction

Compare contribution from brane(s) to background flux contributions

$$\frac{\Delta g_{\rm YM}^{-2}(\mu)}{g_{\rm YM}^{-2}(\mu)} \sim \frac{K}{P}\log\frac{z}{\Lambda'} < \frac{K}{P}\log\frac{\Lambda}{\Lambda'}$$

Λ and Λ' are scales associatted to big and daughter throats respectively. For the geometry to work we need a hierarchy

$$\Lambda \gg \Lambda'$$

Backreaction

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$$\frac{\Delta g_{\rm YM}^{-2}(\mu)}{g_{\rm YM}^{-2}(\mu)} \sim \frac{K}{P}\log\frac{z}{\Lambda'} < \frac{K}{P}\log\frac{\Lambda}{\Lambda'} \simeq 2.3\times\frac{K}{P} \ll 1$$

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$$\Lambda \gg \Lambda'$$

Impossing COBE normalization of curvature perturbations at $\phi_c = 11 M_p$ (60e-folds), a typical value would be $\Lambda \simeq 10\Lambda'$.

The backreaction is small compared to the effects of fluxes

Thank you :)

Extra winding due to suppression of f

The effect of warping affects the axion decay constant

$$f \sim e^{-\frac{2\pi K}{3Mg_s}}$$

So axion winds around potential more times ($\sim \frac{1}{f} \sim e^{\frac{2\pi K}{3Mg_s}}$)

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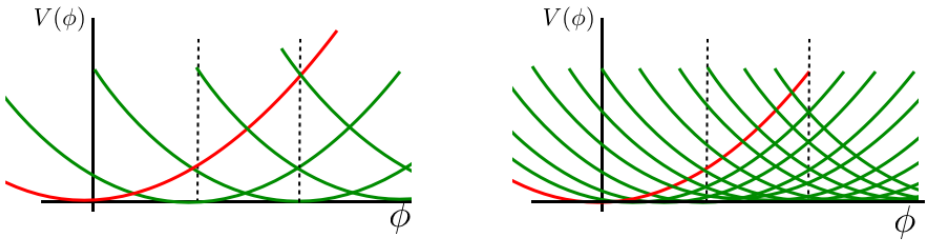
Not a big problem Franco, Galloni, A.R., Uranga

Field tunneling: D3-brane creation with less energy state inside

$$P \sim \exp\left(-\frac{4\pi}{3}\frac{27T_{D3}^4}{4(\Delta V)^3}\right) \ll 1$$



Extra exponential suppression in probability of other routes

Fluxes are fractional branes

Take the most simple case: the conifold