Infrared behaviour of Duality cascades and warped throats

Angel M. Uranga

TH Division, CERN
and IFT-UAM/CSIC, Madrid

Based on:

S. Franco, A. Hanany, A.M.U, hep-th/0502113
J.F.G. Cascales, F. Saad, A.M.U, hep-th/0503079
S. Franco, A. Hanany, F. Saad, A.M.U, hep-th/0505040

Strings '05, Toronto, 14th July 2005

Motivation

• AdS/CFT correspondence between quiver gauge theory on D3-branes at CY singularity X_6 and IIB theory on $\mathrm{AdS}_5 \times Y_5$

• Going non-conformal by addition of fractional branes in the quiver side and 3-form fluxes on 3-cycles of Y_5 on the IIB side
$\longrightarrow$ Warped throats and cascading gauge theories provide non-trivial examples of holography for non-conformal cascading and IR confining gauge theories. [Klebanov, Strassler]

• Story is well-understood for conifold, where confinement of gauge theory related to complex deformation of the throat
• Cascades and throats with fluxes are known for other singularities
[Franco, He, Herzog, Walcher; Ejaz, Herzog, Klebanov]
$\longrightarrow$ Extend IR understanding to other singularities

The conifold case

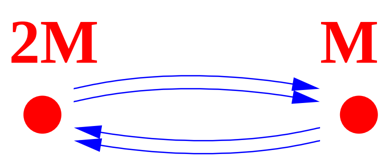
[Klebanov, Strassler]

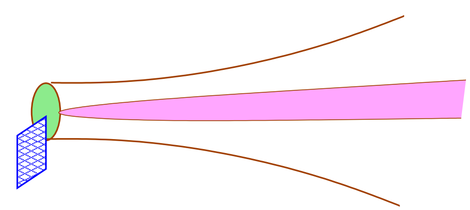
- The gauge theory $SU(N) \times SU(N+M)$ suffers a cascade of Seiberg dualities as the RG scale runs to the infrared

$$SU(N) \times SU(N+M) \rightarrow SU(N) \times SU(N-M) \rightarrow$$
$$\rightarrow SU(N-2M) \times SU(N-M) \rightarrow \cdots$$

- For $N = KM$, this proceeds for K steps, the left over IR theory is $SU(M)$ with no charged matter, confines and develops a gaugino condensate.

- Probe the dual geometry by using e.g. M additional D3-brane probes





For $N_f = N_c$ there is a quantum deformed moduli space. D3-brane probe moduli space corresponds to mesonic branch

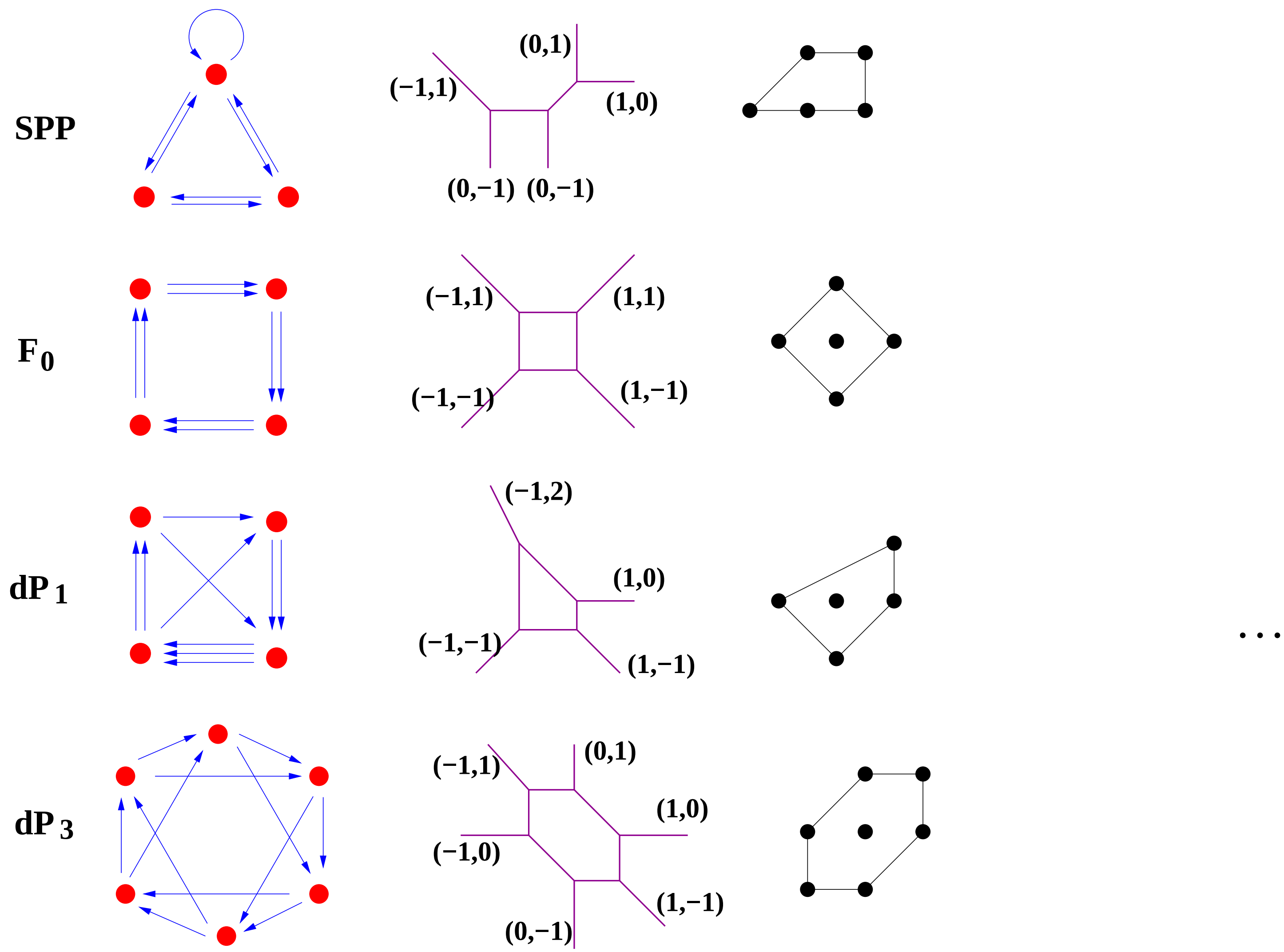
$$\det \mathcal{M} = M_{11}M_{22} - M_{12}M_{21} = \epsilon \rightarrow \text{Deformed conifold}$$

Toric singularities

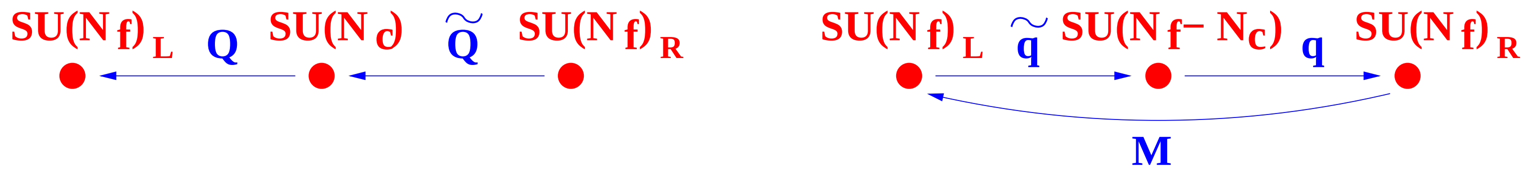
- Diverse techniques to obtain quiver for toric singularities

Partial resolution, mirror symmetry, exceptional collections, ...

- Some examples of quivers and toric/web diagrams



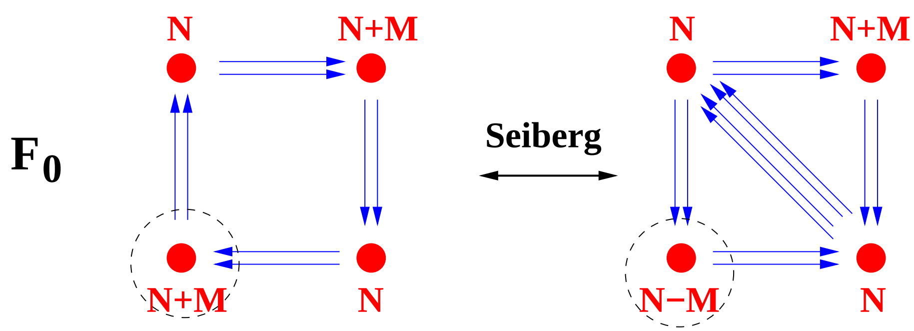
Seiberg duality



• For a single node in a quiver gauge theory: Reverse arrows, introduce mesons, and take into account superpotential

[Beasley, Plesser; Feng, Hanany, He, A.U.]

• Example of F_0



• Cascades of Seiberg dualities for several quiver gauge theories with fractional branes $\rightarrow$ F_0, SPP, dP_n's, $Y^{p,q}$, ...

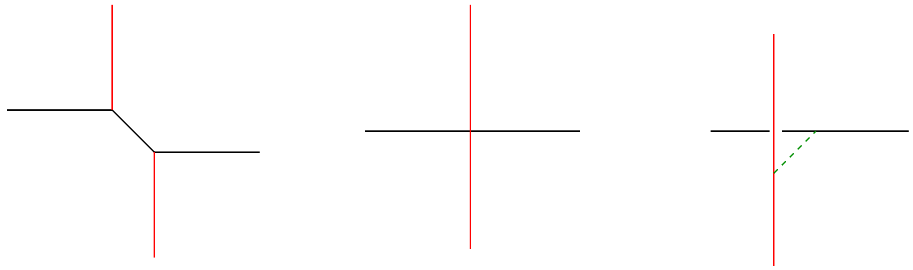
[Franco, He, Herzog, Walcher; Ejaz, Herzog, Klebanov; Franco, Hanany, A.U;...]

• Supported by singular warped conical throats (of Klebanov-Tseytlin type) for dP_n's, $Y^{p,q}$ [Franco, He, Herzog, Walcher; Ejaz, Herzog,Klebanov]

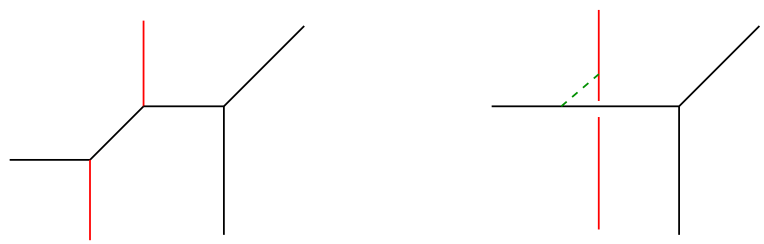
Complex deformations

• Complex deformations are easily identified in web diagram as recombinations of external legs into subwebs
⟶ Higgs branch of 5d theory [Seiberg, Morrison; Aharony, Hanany, Kol]
⟶ Decomposition of toric polygon as Minkowski sum [Altmann]

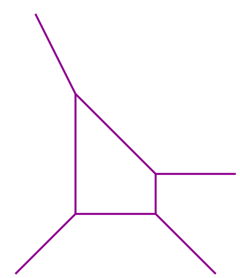
• Familiar example: Conifold



• But other examples too! Ex: SPP



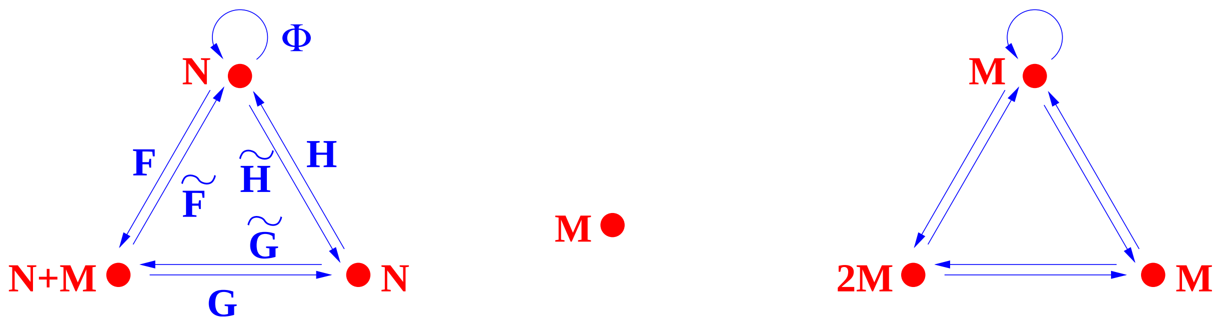
• Also cases with no deformation: $Y^{p,q}$



• Result: One to one map with gauge theory behaviour!

The SPP example

- Duality cascade triggered by fractional brane, ending in confining theory.
- Web suggests complex deformation. Probe using additional D3's



- Deformation of mesonic branch

$$\det \mathcal{M} = \epsilon \quad , \quad \mathcal{M} = \begin{pmatrix} FG & F\tilde{F} \\ \tilde{G}G & \tilde{G}\tilde{F} \end{pmatrix}$$

Node $2M$ confines, vevs for $\mathcal{M} \propto \mathbf{1}_{2M}$ break to $N = 4$ $U(N)$

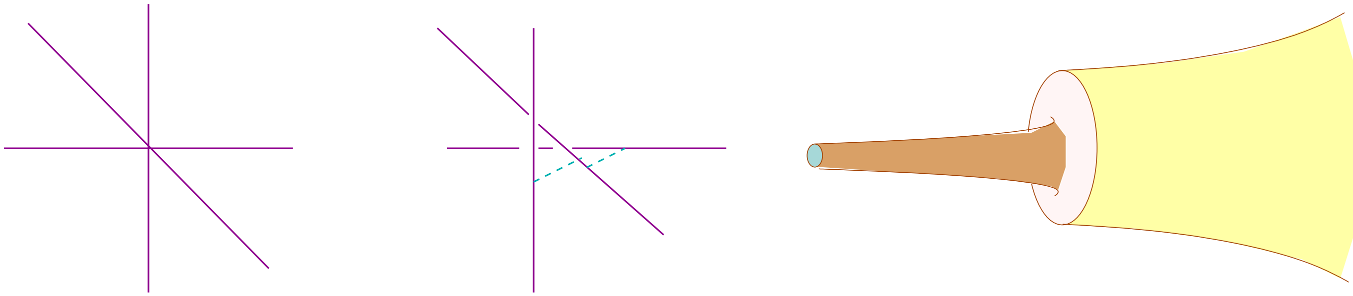
- Moduli space deformed to smooth

$$xy - zw^2 = 0 \quad \rightarrow \quad xy - zw^2 = \epsilon w$$

$\longrightarrow$ Complex deformation to smooth geometry

The cone over dP_3

- The geometry has a two-dimensional branch of complex deformations

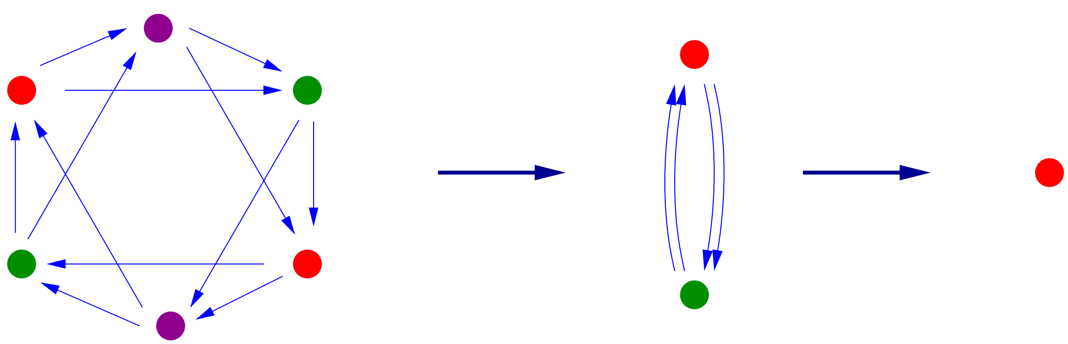


- In the regime of hierarchically different sizes, sequential deformation:

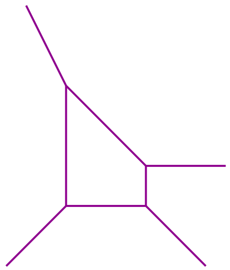
cone over $\mathrm{dP}_3 \rightarrow$ conifold $\rightarrow$ smooth

- Suggests two stages of infrared partial confinement
- Full agreement with gauge theory pattern:

Duality cascade $\rightarrow$ Partial confinement. to conifold th. $\rightarrow$ Subsequent cascade $\rightarrow$ Confinement



Cases with no deformation



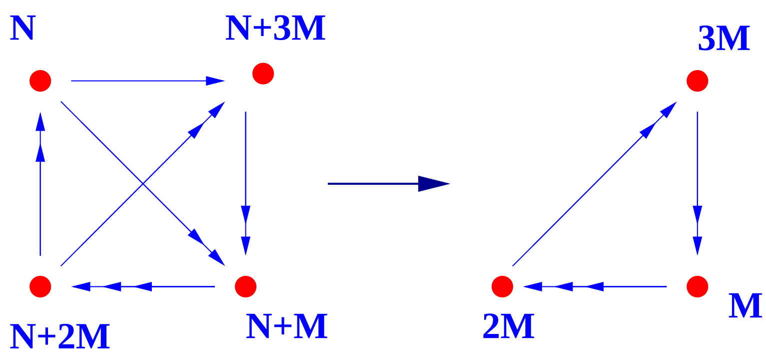
- Many geometries do not admit complex deformations

For instance, $Y_{p,q}$ (first order deformation in [Burrington, Liu, Mahato, Pando-Zayas] is obstructed at second order)

- But UV cascades, and dual singular throats with fluxes exist.

What is the IR behaviour? Smooth out the supergravity singularity?

- Analyze using gauge theory! [Berenstein, Herzog, Ouyang, Pinansky; Franco, Hanany, Saad, A.U; Bertolini, Bigazzi, Cotrone]



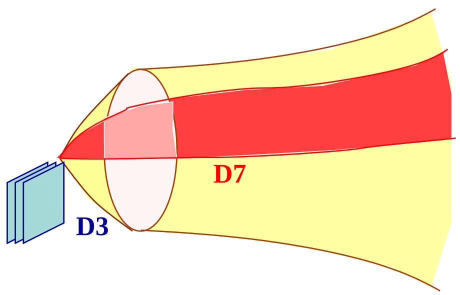
→ No vacuum $N_f < N_c$ ADS F-term pushes vevs to infinity
(D-flatness does not forbid it: absence of $U(1)$'s or dynamical FI's)

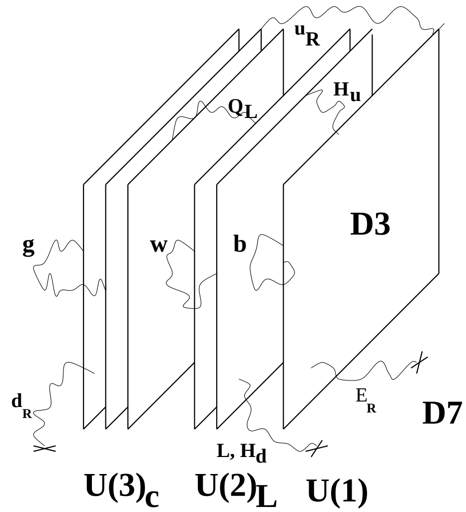
- Suggests no smoothing of supergravity throat

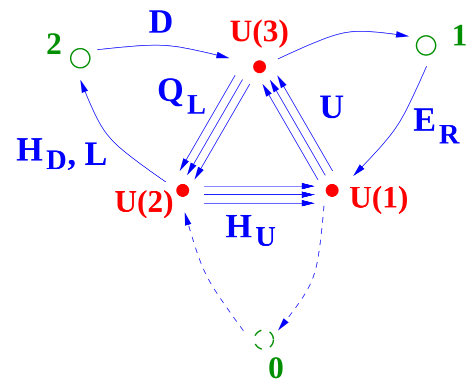
The SM on the throat

• Model building application:

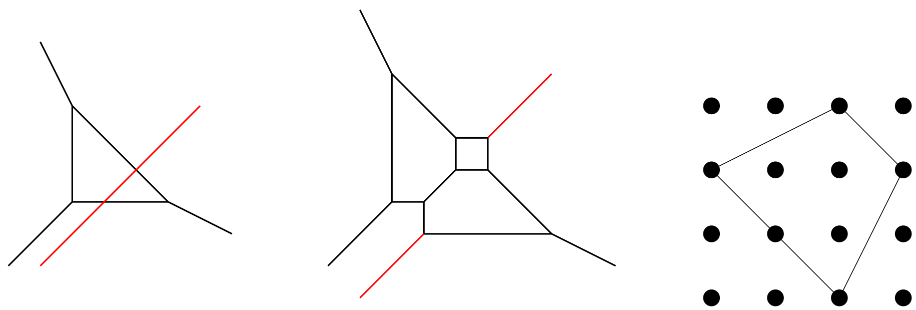
SM on D-branes at $\mathbf{C}^3/Z_3$ at the end of a throat [Cascales, Saad, A.U.]







• Use a geometry which admits a deformation to $\mathbf{C}^3/Z_3$

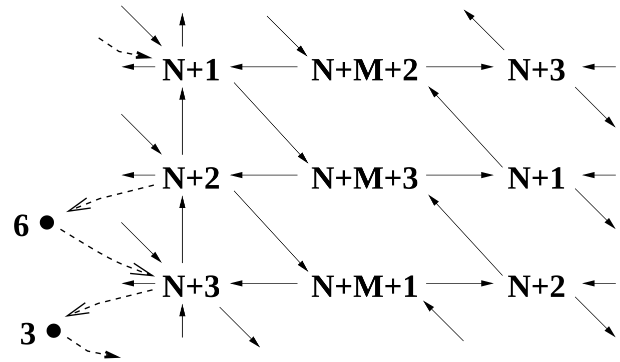


$\longrightarrow$ Orbifold of the SPP

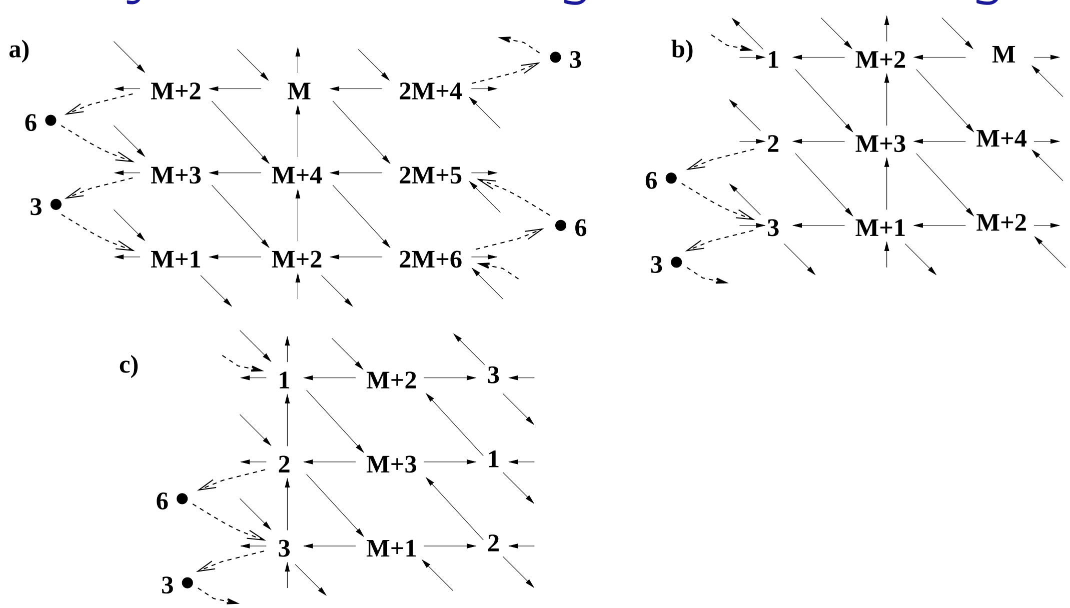
• Quiver is known: Holographic dual of the SM on the throat

$\longrightarrow$ Peculiar technicolor: Cascade of Seiberg dualities, ending in partial confinement leaving the SM degrees of freedom

• Quiver of the UV theory at a particular point in the Seiberg duality cascade



• Quivers of the theory at the last stages of cascading



Conclusions

- Branes at singularities offer a tractable way to study the interplay between gauge and string theory dynamics

- We have reviewed the correspondence between duality cascades and warped throats, with an emphasis on
  - Complex deformations and IR confinement
  - Absence of complex deformations and no vacuum

- Progress in understanding the structure of throats / cascades with richer geometry / dynamics at its bottom / infrared
  $\longrightarrow$ Terminal singularities, multiwarp throats, ...

- Model building application: Holographic dual of the Standard Model on the throat

- Hopefully, many other insights and answers to come

Strings 07

Madrid

25-29 June 2007

Instituto de Fisica Teorica UAM-CSIC

Appendix: Sample computation: $dP_3 \to$ conifold

The superpotential reads

$$\begin{aligned} W &= X_{12}X_{23}X_{34}X_{45}X_{56}X_{61} + X_{13}X_{35}X_{51} + X_{24}X_{46}X_{62} - \\ &- X_{23}X_{35}X_{56}X_{62} - X_{13}X_{34}X_{46}X_{61} - X_{12}X_{24}X_{45}X_{51} \end{aligned}$$

The $SU(2M)$ nodes 2 and 4 condense, we have mesons

$$\begin{aligned} \mathcal{M} &= \begin{bmatrix} M_{63} & M_{62} \\ M_{53} & M_{52} \end{bmatrix} = \begin{bmatrix} X_{61}X_{13} & X_{61}X_{12} \\ X_{51}X_{13} & X_{51}X_{12} \end{bmatrix} \\ \mathcal{N} &= \begin{bmatrix} N_{36} & N_{35} \\ N_{26} & N_{25} \end{bmatrix} = \begin{bmatrix} X_{34}X_{46} & X_{34}X_{45} \\ X_{24}X_{46} & X_{24}X_{45} \end{bmatrix} \end{aligned}$$

and baryons $\mathcal{B}$, $\tilde{\mathcal{B}}$, $\mathcal{A}$, $\tilde{\mathcal{A}}$, with

$$\det \mathcal{M} - \mathcal{B}\tilde{\mathcal{B}} = \Lambda^{4M} \quad ; \quad \det \mathcal{N} - \mathcal{A}\tilde{\mathcal{A}} = \Lambda^{4M}$$

The superpotential reads

$$\begin{aligned} W &= M_{62}X_{23}N_{35}X_{56} + M_{53}X_{35} + N_{26}X_{62} - \\ &- X_{23}X_{35}X_{56}X_{62} - M_{63}N_{36} - M_{52}N_{25} + \\ &+ X_1 (\det \mathcal{M} - \mathcal{B}\tilde{\mathcal{B}} - \Lambda^{4M}) + X_2 (\det \mathcal{N} - \mathcal{A}\tilde{\mathcal{A}} - \Lambda^{4M}) \end{aligned}$$

Along the mesonic branch, in the abelian case

$$\begin{aligned} W &= M_{62}X_{23}N_{35}X_{56} - X_{23}X_{35}X_{56}X_{62} - M_{63}N_{36} - M_{52}N_{25} + \\ &+ M_{53}X_{35} + N_{26}X_{62} + M_{63}M_{52} - M_{53}M_{62} + N_{36}N_{25} - N_{26}N_{35} \end{aligned}$$

Using the equations of motion

$$W = X_{23}N_{35}X_{56}M_{62} - X_{23}M_{62}X_{56}N_{35}$$

Going non-Abelian, the gauge group is $SU(M)_{25} \times SU(M)_{36}$.

The conifold theory