Dynamical Supersymmetry Breaking from D-branes at Singularities

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Motivation

• Gauge dynamics from D-branes at singularities
Relation between properties of the gauge theory and properties of the singularity. Both in conformal and non-conformal cases:
- Confinement vs. geometric transitions [Vafa; Klebanov, Strassler]
- Removal of SUSY vacuum for D-branes at obstructed singularities [Berenstein, Herzog, Ouyang, Pinansky; Franco, Hanany, Saad, A.U; Bertolini, Bigazzi, Cotrone]
Realization of Dynamical Supersymmetry Breaking with D-branes?

• Recent discussion of local SUSY breaking metastable minima in very simple system [Intriligator, Seiberg, Shih]
- $N = 1$ SYM with massive flavours $m \ll \Lambda$
Parametrically low decay rate to far-away supersymmetric vacua.
Realization in string theory?

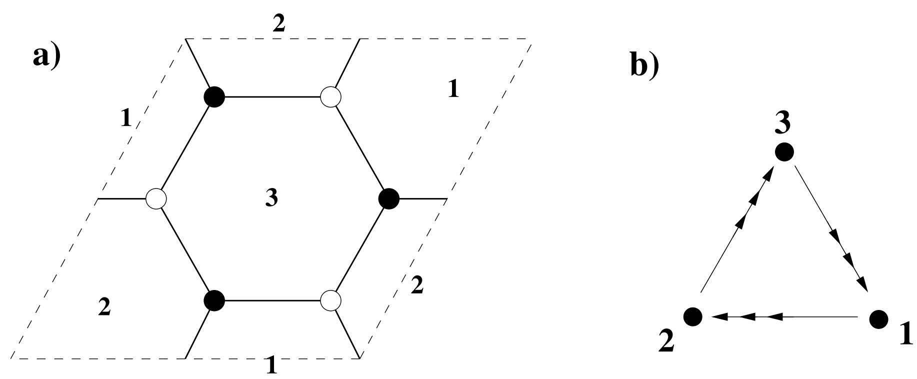
• Application of local configurations of D-branes with DSB to string model building
- Towards gauge mediated supersymmetry breaking
[Diaconescu, Florea, Kachru, Svrcek]

D3-branes at singularities

• Systems of D3-branes at singular points in the transverse CY space lead to intricate $N = 1$ gauge theories, whose structure is nicely encoded in dimer diagrams

- Periodic tiling of the plane, with faces giving gauge factors, edges giving chiral bi-fundamentals, and nodes giving superpotential couplings

[Hanany, Kennaway; Franco, Hanany, Kennaway, Vegh, Wecht]

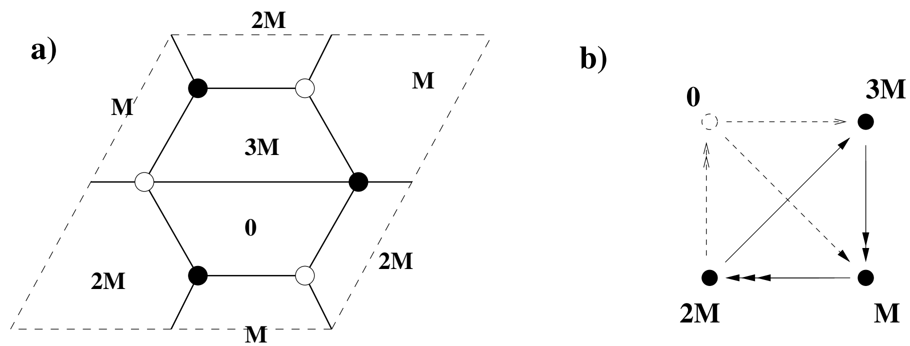


• Dimer techniques allow to obtain the gauge theory on D3-branes at any toric singularity

• Fractional branes: Anomaly free assignments of ranks on gauge factors (faces) $\longrightarrow$ Non-conformal theories

DSB fractional branes

• Consider the theory on the volume of M fractional D3-branes at the dP_1 singularity



• We have $U(3M) \times U(2M) \times U(1)$ with $W = X_{23}X_{31}Y_{12} - X_{23}Y_{31}X_{12}$

• The $U(1)$'s have Green-Schwarz anomaly cancellation and disappear; their FI terms are dynamical vevs of closed Kahler moduli.
$\rightarrow$ Effectively neither $U(1)$ vector multiplet, nor D-term constraint.

DSB branes: No SUSY vacuum

- In the regime where the $SU(3M)$ dominates, we have an Affleck-Dine-Seiberg superpotential $M_{21} = X_{23}X_{31}$, $M'_{21} = X_{23}Y_{31}$

$$W = (\, M_{21}Y_{12} \,-\, M'_{21}X_{12}\,) + M \left(\frac{\Lambda_3^{7M}}{\det \mathcal{M}} \right)^{\frac{1}{M}} \quad ; \quad \mathcal{M} = (M_{21}; M'_{21})$$

- No SUSY vacuum

$F_{X_{12}}$, $F_{Y_{12}}$ send $M_{21}, M'_{21} \to 0$, and then $F_{M_{21}}$, $F_{M'_{21}}$ send $X_{12}, Y_{12} \to \infty$.
[Berenstein, Herzog, Ouyang, Pinansky; Franco, Hanany, Saad, A.U; Bertolini, Bigazzi, Cotrone]

- Assuming canonical Kahler potential, scalar potential has runaway behaviour [Franco, Hanany, Saad, A.U; Intriligator, Seiberg]

- Runaway can be stopped if e.g. Kahler moduli are fixed, so FI terms are effectively no longer dynamical, and $U(1)$ D-terms reappear.

- All similar to $SU(5)$ with $10 + \overline{5}$ in [Lykken, Poppitz, Trivedi]

The ISS model [Intriligator, Seiberg, Shih]

- Consider $SU(N_c)$ SYM with N_f massive flavors,

with $m \ll \Lambda_{SQCD}$ and $N_c + 1 \leq N_f \leq \frac{3}{2}N_c$,

$\rightarrow$ Seiberg dual is infrared free $\rightarrow$ Canonical Kahler potential.

- Dual is $SU(N)$ SYM with $N = N_f - N_c$, with N_f flavors q, $\tilde{q}$,

and mesons Φ, with $W = h\mathrm{Tr}\, q\Phi\tilde{q} - h\mu^2\mathrm{Tr}\,\Phi$

$\rightarrow$ SUSY breaking at tree level:

$F_\Phi = \tilde{q}^i q_j - \mu^2\delta^i_j \neq 0$ since $rk(\mathbf{1}_{N_f}) = N_f > rk(\tilde{q}q) = N$

- Classical moduli space with $V_{min} = (N_f - N)|h^2\mu^4|$

$$\Phi = \begin{pmatrix} 0 & 0 \\ 0 & \Phi_0 \end{pmatrix} \; ; \; q = \begin{pmatrix} \varphi_0 \\ 0 \end{pmatrix} \; ; \; \tilde{q}^T = \begin{pmatrix} \tilde{\varphi}_0 \\ 0 \end{pmatrix}, \quad \text{with} \;\; \tilde{\varphi}_0\varphi_0 = \mu^2\mathbf{1}_N$$

One-loop Coleman-Weinberg potential leads to a minimum at

$$\Phi_0 = 0, \qquad \varphi_0 = \tilde{\varphi}_0 = \mu\mathbf{1}_N$$

The ISS model [Intriligator, Seiberg, Shih]

• Include the $SU(N)$ gauge interactions

For generic Φ, flavors q, $\tilde{q}$ are integrated out, leaving $SU(N)$ SYM with scale Λ'

$$\Lambda'^{3N} = h^{N_f} \det \Phi \, \Lambda^{-(N_f - 3N)}$$

with Λ the Landau pole scale of the IR free theory.

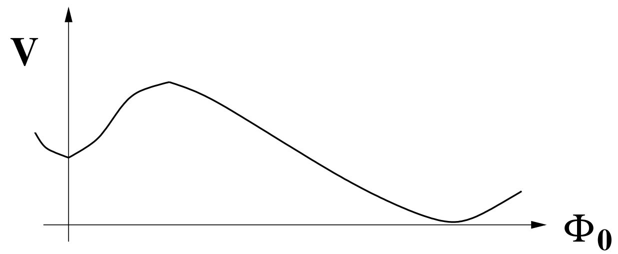
→ Complete superpotential

$$W = N \left(h^{N_f} \Lambda^{-(N_f-3N)} \det \Phi \right)^{1/N} - h\mu^2 \, \mathrm{Tr} \, \Phi$$

→ There are $N_f - N$ supersymmetric minima

$$\langle h \Phi_0 \rangle = \mu \epsilon^{-\frac{N_f - 3N}{N_f - N}} \mathbf{1}_{N_f} \text{ where } \epsilon \equiv \frac{\mu}{\Lambda}$$

• For $\epsilon \ll 1$, local SUSY breaking minimum is parametrically long-lived

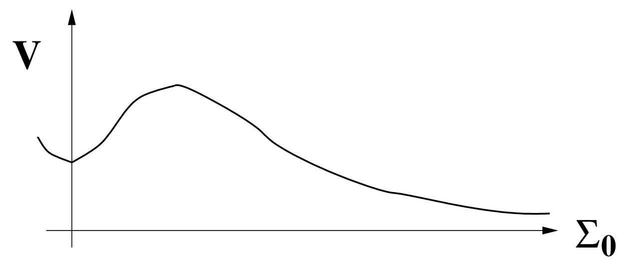


$$S \simeq |\epsilon|^{-\frac{4(N_f - 3N)}{N_f - N}} \gg 1$$

Generalization: Adding massless flavours [Franco, A.U.]

• SQCD Consider $SU(N_c)$ with $N_{f,0}$ massless and $N_{f,1}$ massive flavours
To have rank SUSY breaking in dual theory, need $N_{f,1} > N$
i.e. $N_{f,1} > N_{f,1} + N_{f,0} - N_c \rightarrow N_{f,0} < N_c$
Repeat ISS-like analysis:
- Almost local minimum: $\Phi_{00} (= \tilde{Q}_0 Q_0)$ remains flat at one loop
- At large fields, Φ_{00} is a runaway direction (as without ISS flavours)
$\rightarrow$ Suggests no local minimum, but saddle point and runaway

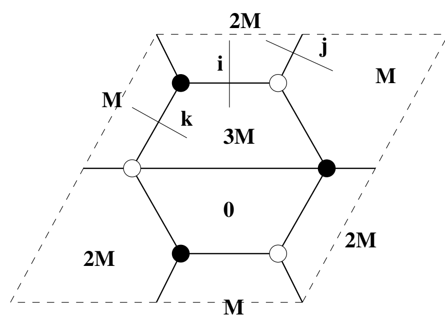
• SSQCD Add field Σ_0, with $W = Q_0 \Sigma_0 \tilde{Q}_0$ to render Φ_{00} massive
Repeat ISS-like analysis;
$\rightarrow$ Local minimum for all fields!
$\rightarrow$ At large fields, Σ_0 is a runaway direction (as without ISS flavours)

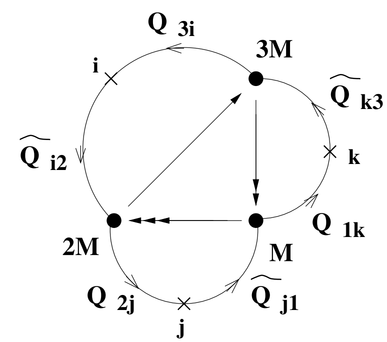


• The condition $N_{f,0} < N_c$, and the cubic coupling to Σ_0 are present in gauge theories of D-branes at obstructed geometries

Flavoured dP_1 [Franco, A.U.]

- Add massive flavours to the theory of fractional branes at dP_1





$$
\begin{aligned}
W &= \lambda\,(\,X_{23}X_{31}Y_{12} - X_{23}Y_{31}X_{12}\,) \\
W_{flav.} &= \lambda'\,(\,Q_{3i}\tilde{Q}_{i2}X_{23} + Q_{2j}\tilde{Q}_{j1}X_{12} + Q_{1k}\tilde{Q}_{k3}X_{31}\,) \\
W_m &= m_3\,Q_{3i}\tilde{Q}_{k3}\delta_{ik} + m_2\,Q_{2j}\tilde{Q}_{i2}\delta_{ji} + m_1\,Q_{1k}\tilde{Q}_{j1}\delta_{kj}
\end{aligned}
$$

- For $SU(3M)$, $N_{f,0} < N_c$, hence the dual is IR free

$$
\begin{aligned}
W &= h\,\Phi_{ki}\tilde{Q}_{i3}Q_{3k} - h\mu^2 \mathrm{tr}\,\Phi + h\mu_0\,(\,M_{21}Y_{12} - M'_{21}X_{12}\,) + \\
&+ h\,(\,M_{21}X_{13}X_{32} + M'_{21}Y_{13}X_{32} + N'_{k1}Y_{13}Q_{3k}\,) + \\
&+ \lambda'\,Q_{2j}\tilde{Q}_{j1}X_{12} - h_1\,\tilde{Q}_{k1}X_{13}Q_{3k} - h_2\,Q_{2i}\tilde{Q}_{i3}X_{32}
\end{aligned}
$$

- Repeating ISS-like analysis: One-loop potential for classical moduli

$\rightarrow$ Local minimum separated by a large barrier from runaway at infinity

String theory realization

- Consider D3-branes at a singularity, and add D7-branes passing through it

→ D7-branes wrap non-compact supersymmetric 4-cycles in toric singu

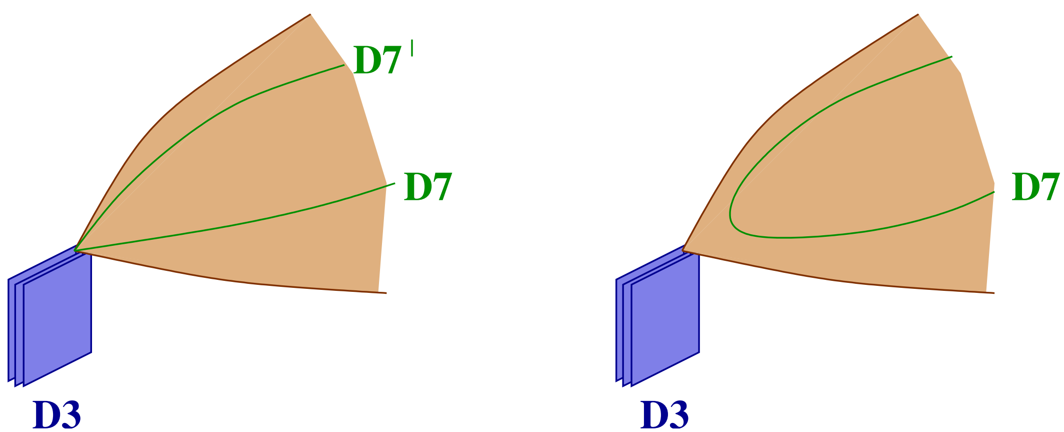
→ Flavours arise from D3-D7 open strings

→ Flavour masses from D7-D7’ field vevs (due to 73-37-77’ couplings): D7-branes recombine and move away from D3-branes

- Dimer diagrams efficiently describe these properties for general toric singularities (and dP_1 in particular).

[Franco, A.U.]

- Geometric picture



Local models of GMSB [García-Etxebarria, Saad, A.U.]

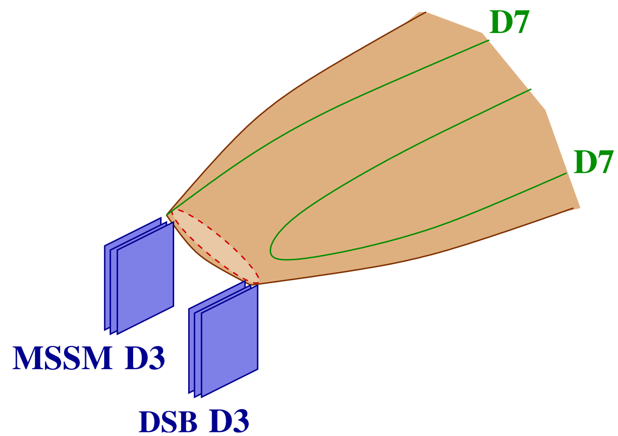
• Consider local CY's with two singular points, with D-branes

$\longrightarrow$ Two chiral gauge sectors decoupled at massless level

• For suitable singularities, and D-brane systems at them,

$\longrightarrow$ MSSM-like sector e.g. D3/D7's at $\mathbf{C}^3/\mathbf{Z}_3$ [Aldazabal, Ibáñez, Quevedo, A.U.]

$\longrightarrow$ Gauge sector with DSB e.g. D3/D7's at dP_1 singularity



• Models of Gauge mediation in string theory

$\longrightarrow$ Similar in spirit to [Diaconescu, Florea, Kachru, Svrcek]

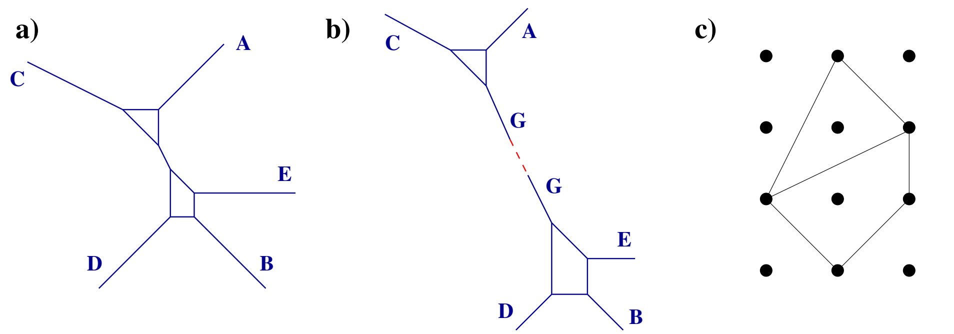
$\longrightarrow$ Local model, enough for substringy separation: UV insensitivity

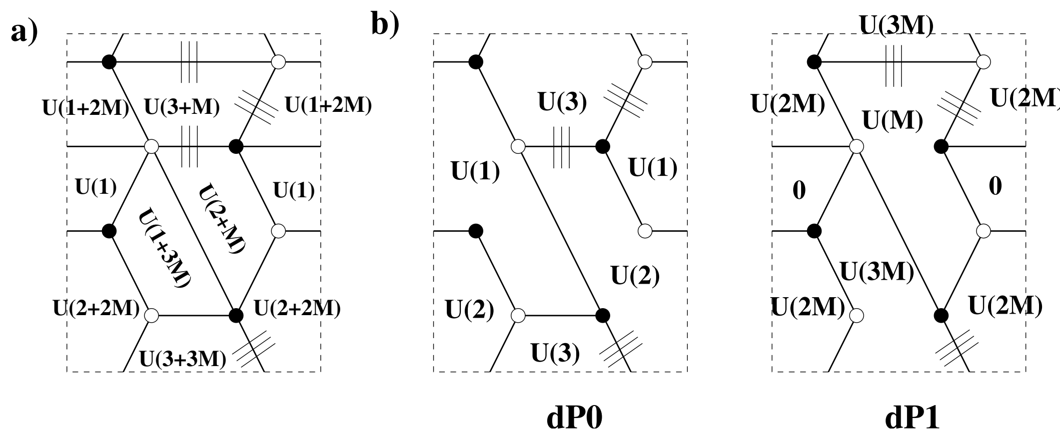
$\longrightarrow$ Separation related to Kahler or complex modulus

$\longrightarrow$ Spectrum and interactions of massive messengers is computable

A simple example

- For sub-stringy separtion, better described as small blow-up of gauge theory of D-branes at the singularity in the coincident limit
- A simple example: Partial resolution of $X^{3,1}$ singu to $C^3/\mathbf{Z}_3$ and dP_1





- General framework, flexible enough to implement many other models

Conclusions

• D-branes at singularities can be used to engineer gauge theories with interesting infrared dynamics

• We have studied differents aspects of dynamical SUSY breaking in systems of D-branes at singularities
Important role of fractional D-branes at obstructed geometries (DSB branes), like dP_1 theory
$\longrightarrow$ Runaway for systems of just D3-branes
$\longrightarrow$ Local SUSY-breaking minimum for D3/D7's

• Many applications come to mind
$\longrightarrow$ String models of GMSB
$\longrightarrow$ Supergravity dual of DSB gauge theories (subtle...)

• Need to improve techniques to carry out gauge theory analysis
$\longrightarrow$ Insight from dimer diagrams?

• We expect interesting progress in these directions