Metastable Vacua and Geometric Engineering

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with Radu Tatar

- Seiberg duality between weakly/strongly coupled SUSY theories
- ISS model: non-SUSY metastable vacua
- Our goal: to extand class of metastable vacua

1. Metastable Vacua in SUSY Gauge Theories
2. Geometry and Brane Realisation of SUSY Gauge Theories
3. String Theory Constructions of Metastable Vacua
4. Future Directions and Conclusions

- Consider $\mathcal{N}=2, SU(N_c)$ with N_f Fundamental flavours

- Denote the flavours $Q^i, \tilde{Q}^i, i=1,\cdots,N_f$ and $M^i_j = Q^i\tilde{Q}_j$

- $W = \frac{1}{2}\tilde{\mu}\tilde{\Phi}^2 + \frac{1}{2}\mu M^2 + \tilde{Q}(\lambda\Phi + \tilde{\lambda}M)Q + \xi\Phi + \tilde{\xi}M$

- Consider mass for fields $\tilde{\Phi}$, Φ and integrate out

  $W_e = \frac{\lambda_e^2}{2\mu_e}(\tilde{Q}Q)^2 + \frac{\xi_e\lambda_e}{\mu_e}\tilde{Q}Q$

  $W_m = \frac{\lambda_m^2}{2\mu_m}(\tilde{q}q)^2 + \frac{\xi_m\lambda_m}{\mu_m}\tilde{q}q$

- General SUSY solution: vev of $\tilde{q}q$: $\nu = \frac{\mu\xi}{\lambda}$.

- $\tilde{Q}Q$ and $\tilde{q}q$ have rank k:

  $SU(N_f)\times SU(N_c) \rightarrow SU(N_f-k)\times SU(N_c-k)\times SU(k)$ (electric)

  $SU(N_f)\times SU(N_f-N_c) \rightarrow SU(N_f-k)\times SU(N_f-N_c-k)\times SU(k)$ (magnetic)

One other set of vacua are non-SUSY vacua.

nonzero vev of $\tilde{q}q$ are split into:

- rank k with eigenvalue ν as before
- an extra non-zero block of rank n denoted $\tilde{\phi}\phi$

1. $n = N_f - k$, near origin of $\Phi, \tilde{\phi}, \phi$, theory $SU(n - N_c)$ with n light flavours

2. If $n < N_f - k$, first step is to go to $SU(N_f - N_c)$ with $n + k$ flavours.

Second step go to $SU(N_f - N_c - k)$ with n flavours by giving vev to k flavours.

Coefficient of the linear term in Φ is small (as in ISS) and the coefficient of the quadratic term in Φ is smaller.

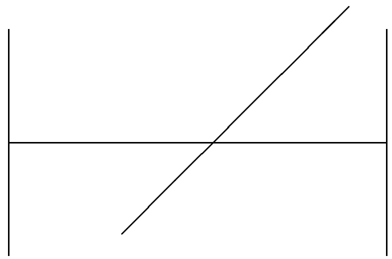

Figure 1: Configuration of branes with Massless Quarks

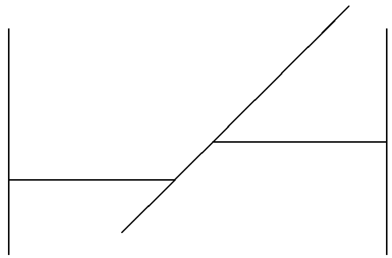

Figure 2: Configuration of branes with Massive Quarks

- • Branes stretched in NS (012345), NS'(012389), D4(01236)
  - IIA: Config. with D4/NS, IIB: Geometrical Engineering with wrapped D5

  Figure 1: Group is $SU(N_f) \times SU(N_c)$ with Massless Quarks

  Figure 2: Group is $SU(N_f) \times SU(N_c)$ with Massive Quarks

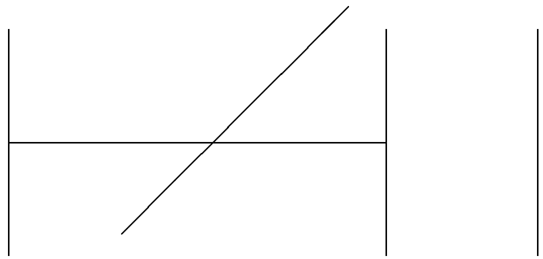

Figure 3: Electric configuration of branes with N_f Massless Quarks

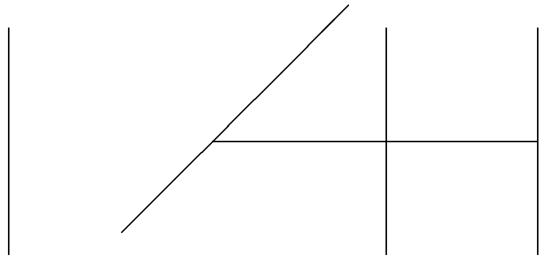

Figure 4: Magnetic configuration of branes with N_f Massless Quarks

T-duality Between IIA with D4 branes and IIB with D5 branes

– D4 branes on interval $\rightarrow$ D5 branes on P^1 cycles

$\mathcal{N} = 2 \rightarrow \mathcal{N} = 1$ Without Linear Terms for $\mathcal{N} = 2$ adjoints

Denote the P^1 cycles by A, B, C from left to right.

Seiberg duality exchange of A and C cycles

1) Rightmost cycle is closed (electric theory).

2) Leftmost cycle is closed (magnetic theory)

Electric Theory (A, B, C), Magnetic Theory (A', B', C')

Requirement: $N_f\ A\ +\ N_c\ B\ =\ N_f\ A'\ +\ (N_f - N_c)\ B'$

$$B'\ =\ -\ B,\ A'\ = A\ +\ B$$

This implies the following change in the D5 brane distribution:

N_c D5 branes on B cycle $\rightarrow \bar{N}_c$ D5 branes on B cycle

N_f D5 branes on A $\rightarrow N_f$ D5 on $A + B$ cycle

Tachyon Condensation occurs between branes wrapping the B cycle

N_c anti D5 and N_f D5 $\rightarrow N_f - N_c$ D5 branes

Seiberg Duality: $(N_f - N_c)$ on B and N_f on A

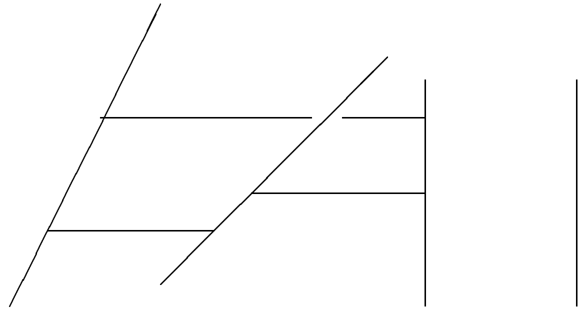

Figure 5: $k \neq 0$ Electric configuration

From left to right NS in v_θ, NS in $v = x^4 + ix^5$ and NS in $w = x^8 + ix^9$

- $\mathcal{N} = 1, SU(N_f - k) \times SU(N_c - k) \times SU(k)$ obtained by putting $N_f - k$ D4 branes between v_θ and v NS branes, $N_c - k$ D4 branes between the v and w NS branes and k D4 branes between v_θ and w NS branes.

- For ISS model: $\theta = \frac{\pi}{2}$ so v_θ, w are parallel

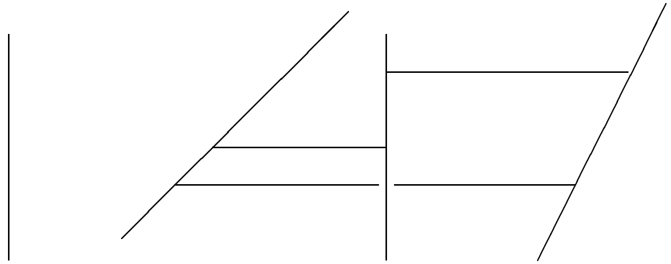

Figure 6: $k \neq 0$ Magnetic before tachyon condensation

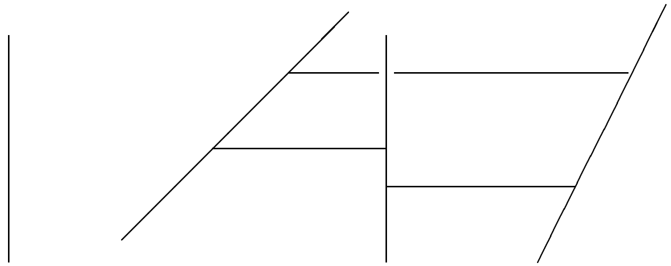

Figure 7: $k \neq 0$ Magnetic after tachyon condensation

Further recombination between the $N_f - N_c$ color branes and the k branes.

- Gauge group becomes $SU(N_f - N_c - k)$.
- Tachyon condensation 1st between $\overline{N_c - k}$ and N_f D4s then 2nd with k D4s

- Metastable Vacua phase structure richer than ISS model.

- Electric theory: flavour group is $SU(N_f - n - k) \times SU(n)$

  Corresponds to 2 stacks of D5 branes wrapped on 2 P^1 cycles

- Magnetic Theory: $N_c - k$ anti D5 branes and 2 stacks of n and $N_f - n - k$ D5 branes

  1. If $N_c - k$ anti D5 branes and $N_f - n - k$ D5 branes annihilate $\rightarrow$ $N_f - N_c - n$ D5 branes

     Decay goes towards a SUSY vacuum with $k + n$ flavours with vev

  2. If $N_c - k$ anti D5 branes and n D5 branes annihilate $\rightarrow n - N_c + k$ D5 branes

     Non-SUSY vacuum with k branes and $N_f - k - n$ D5 branes wrapped on two non-holomorphic cycles

Conclusions:

- Geom. Engineering is a powerful approach to obtain Field Theory results. It has been successful to give insights into Strongly Coupled Regime.
- Metastable non-SUSY Vacua in String Theory are quite hard to obtain because there is no clear recipe as for the SUSY case.
- Can make the some cycles non-compact - massive quarks
- Natural generalisation to the case of product groups and orientifolds.
- Geometrically engineer JHEP 0806:003,2008 and generalise to heirarchical quark masses.