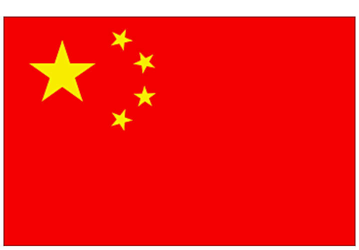
超対称性破缺的真空景観

Landscape of Supersymmetry Breaking Vacua in Geometrically Realized Gauge Theories

大栗博司（加州理工学院）

based on work in collaboration
with Yutaka Ookouchi: hep-th/0606061



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The discovery that simple supersymmetric theories have meta-stable vacua with broken supersymmetry may lead to a new paradigm in phenomenological model building.

Intriligator, Seiberg, and Shih (hep-th/0602239)

(1) This makes it easier to construct models that break SUSY.

==> much more variety

(2) The gauge theory perspective may help us understand the landscape of string vacua.

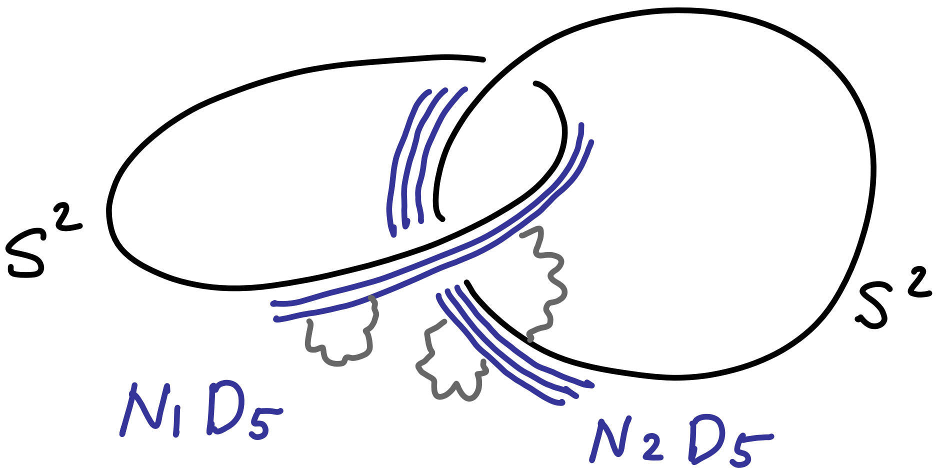
(3) If we can describe the SUSY breaking vacua geometrically in the string theory language, it would expand the utility of the geometric engineering.

Related work:
Franco and Uranga (hep-th/0604136)

However, not all models have locally stable supersymmetry breaking vacua.

Problem: flat directions

We studied models that are realized geometrically by D brane probes wrapping cycles of CY 3-folds.

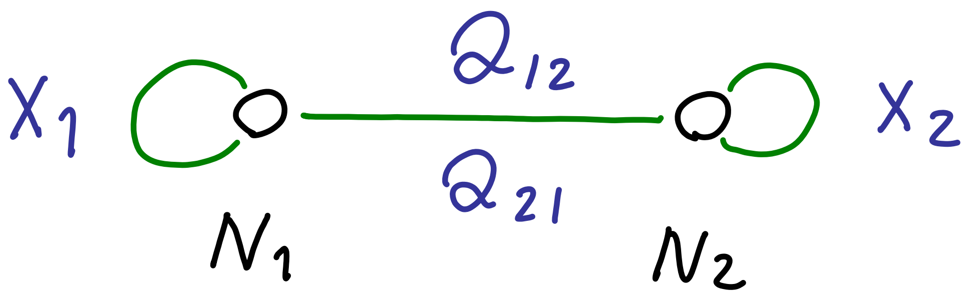


We found that field content and gauge symmetry emerging from string theory conspire to ensure that the supersymmetry breaking configurations are locally stable in all directions.

The model:

$\mathcal{N} = 1$ supersymmetric quiver gauge theory

Cachazo, Katz, and Vafa (hep-th/0108120)



Superpotential:

$$W = W_1(X_1) + W_2(X_2)$$
$$+ \, \mathrm{tr}\, Q_{21} X_1 Q_{12} + \mathrm{tr}\, Q_{12} X_2 Q_{2}$$

This corresponds to the geometry:

$$u^2 + v^2 + y\,(y + W_1'(x))\,(y - W_2'(x)) = 0$$

A_2 fibration over $\mathbb{C}$

We assume:

- $\Lambda_1 \gg \Lambda_2$

  Geometrically, $\mathrm{vol}\, S^2_{(1)} \ll \mathrm{vol}\, S^2_{(2)}$

The first gauge group becomes strongly coupled when the second is still perturbative.

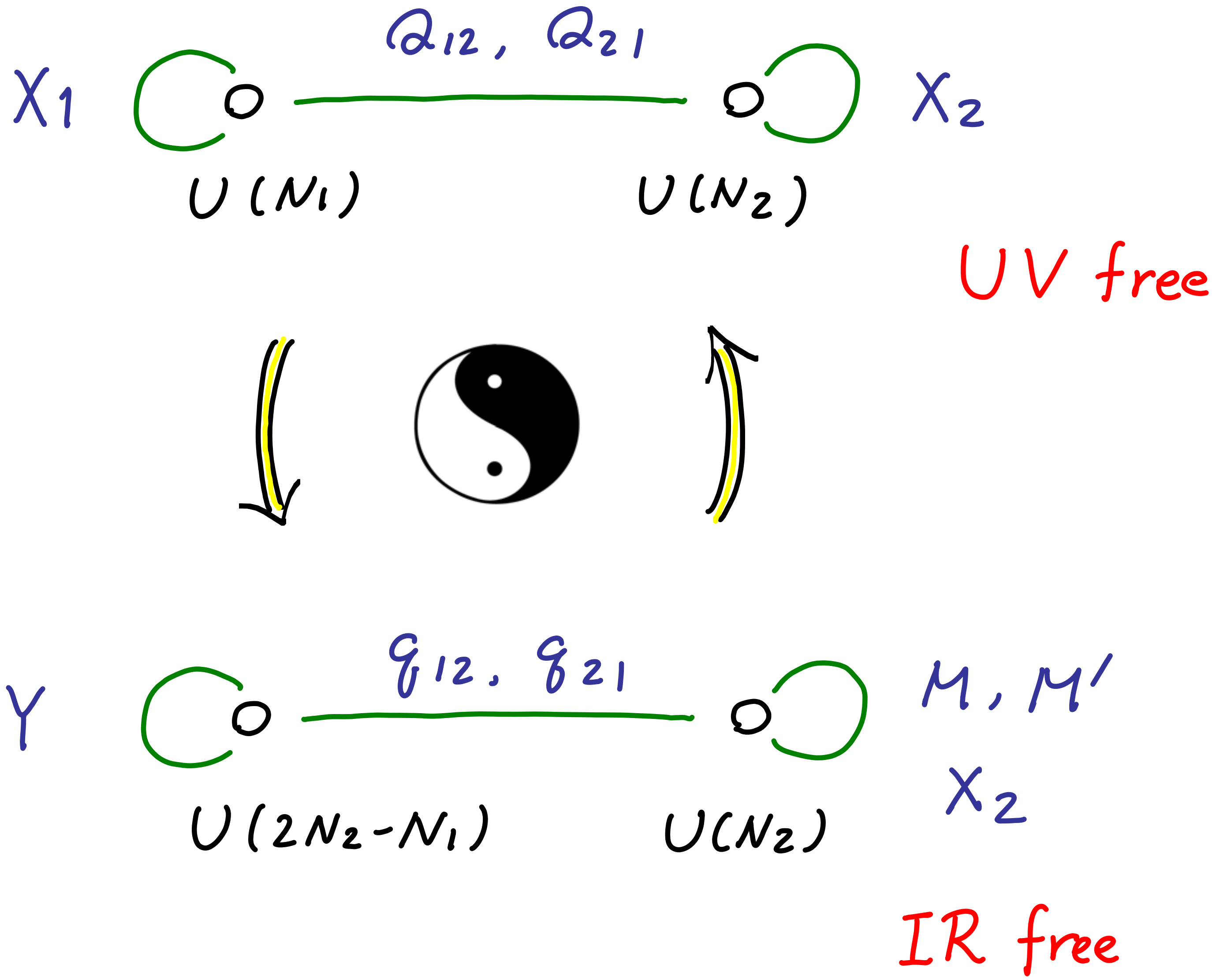
We can take the dual of the first gauge group.

Kutasov (hep-th/9503086)
Kutasov and Schwimmer (hep-th/9505004)

We also assume:

- $\frac{1}{2} N_1 < N_2 < \frac{2}{3} N_1$
- $W_1(X_1) = t_0 \left(\frac{1}{3} X_1^3 - t_1^2 X_1 \right)$

The original description is UV free.
The dual description is IR free.



$$
\begin{aligned}
\tilde{W} = \; & \tilde{W}_1(Y) + W_2(X_2) \\
& + \mathrm{tr}\, M\,(q_{21}q_{12} - \mu^2 \mathbb{1}) \\
& + \mathrm{tr}\, M'(q_{21} Y q_{12} - X_2)
\end{aligned}
$$

This description is suitable to study low energy physics, in particular the vacuum structure.

Vacua of the $U(2N_2-N_1)\times U(N_2)$ theory

At the tree level, there is no solution to the F-term conditions.

The D and F-term potentials can be minimized by:

$$q_{21} = \begin{pmatrix} \mu \mathbb{1} \\ 0 \end{pmatrix}, \qquad q_{12} = \underbrace{(\mu \mathbb{1},\ 0)}_{N_2} \Big\} 2N_2 - N_1$$

$$Y = \begin{pmatrix} +t_1 & & & & 0 \\ & \ddots & & & \\ & & +t_1 & & \\ & & & -t_1 & \\ & & & & \ddots \\ 0 & & & & -t_1 \end{pmatrix} \begin{matrix} \} r_1 \\ \\ \} r_2 \end{matrix} \qquad U(2N_2-N_1) \to U(r_1)\times U(r_2)$$

$$X_2 \sim q_{21}\, Y\, q_{12}, \qquad M' = 0$$

$$M = \left(\begin{array}{c|ccc} 0 & & 0 & \\ \hline 0 & x_1 & & \\ & & \ddots & \\ & & & x_{N_1-x_N} \end{array}\right) \begin{matrix} \} 2N_2 - N_1 \\ \} N_1 - N_2 \end{matrix}$$

flat directions !

Since the dual theory is infrared free, the low energy effective potential for the flat directions can be evaluated perturbatively.

The one-loop effective potential gives positive $(\text{mass})^2$ for all $x_1, \cdots, x_{N_1-N_2}$.

$\therefore$ All the moduli are locally stabilized.

There are $2N_2 - N_1 + 1$ meta-stable vacua.

They are distinguished by unbroken gauge symmetry:

$$U(2N_2 - N_1) \to U(r_1) \times U(r_2)$$

$$r_1 + r_2 = 2N_2 - N_1$$

$$U(N_2) \to U(N_1 - N_2)$$

What will happen to the vector multiplet for the unbroken gauge symmetry?

(1) The model has no R symmetry.

(2) The supersymmetry breaking is accompanied by soft B-terms:

$$\sim \mu^2 \, \mathrm{tr} \left[\begin{pmatrix} 0 & 0 \\ 0 & \mathbb{1}_{N_1-N_2} \end{pmatrix} q_{21} q_{12} \right]$$

This generates gaugino masses.
The low energy limit is the bosonic pure QCD.

The supersymmetry is not restored in the infrared.
The lowest energy excitations around each meta-stable vacuum are QCD glueballs.

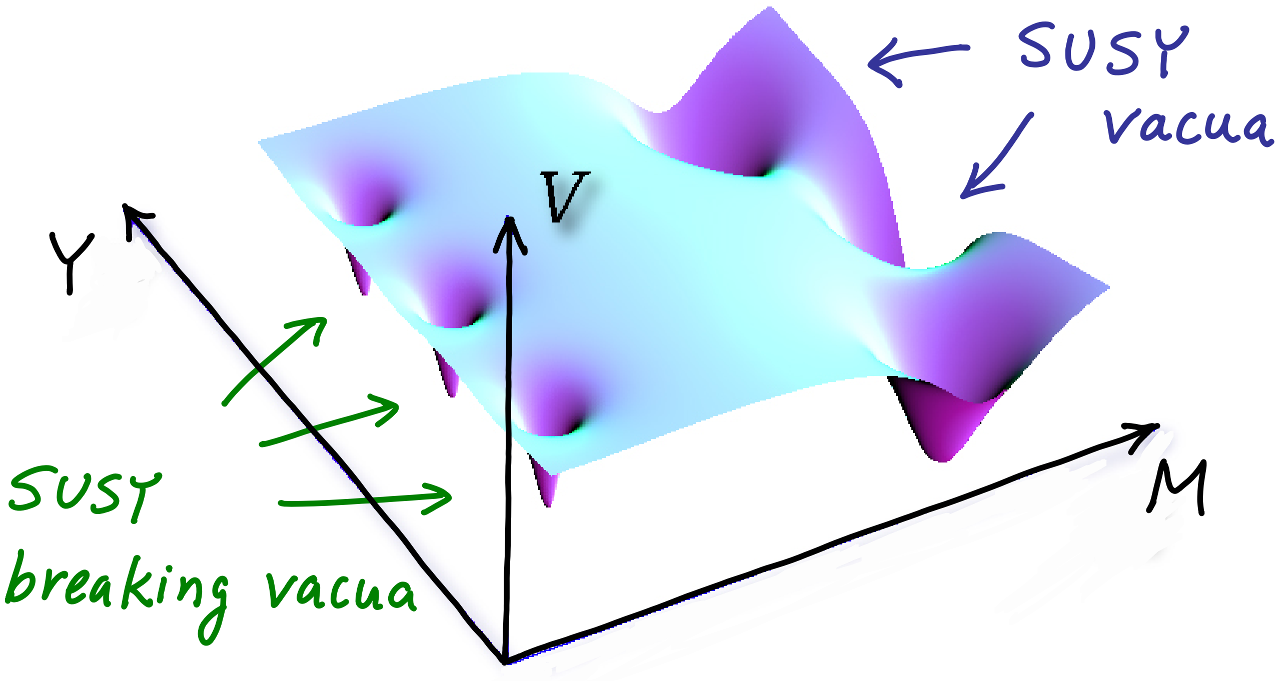
In the original description, one can show that there are supersymmetric vacua.

In the dual description, both the supersymmetry breaking vacua and the supersymmetric vacua can be identified and studied in the same framework.

The supersymmetry breaking vacua are meta-stable:

> The decay rates of the meta-stable vacua into the supersymmetric vacua can be made parametrically small.
>
> This part of the story is essentially the same as that for the case studied by Intriligator, Seiberg, and Shih.

(1) The quiver gauge theory has
a landscape of SUSY breaking vacua:



(2) Each SUSY breaking vacua has no flat direction.

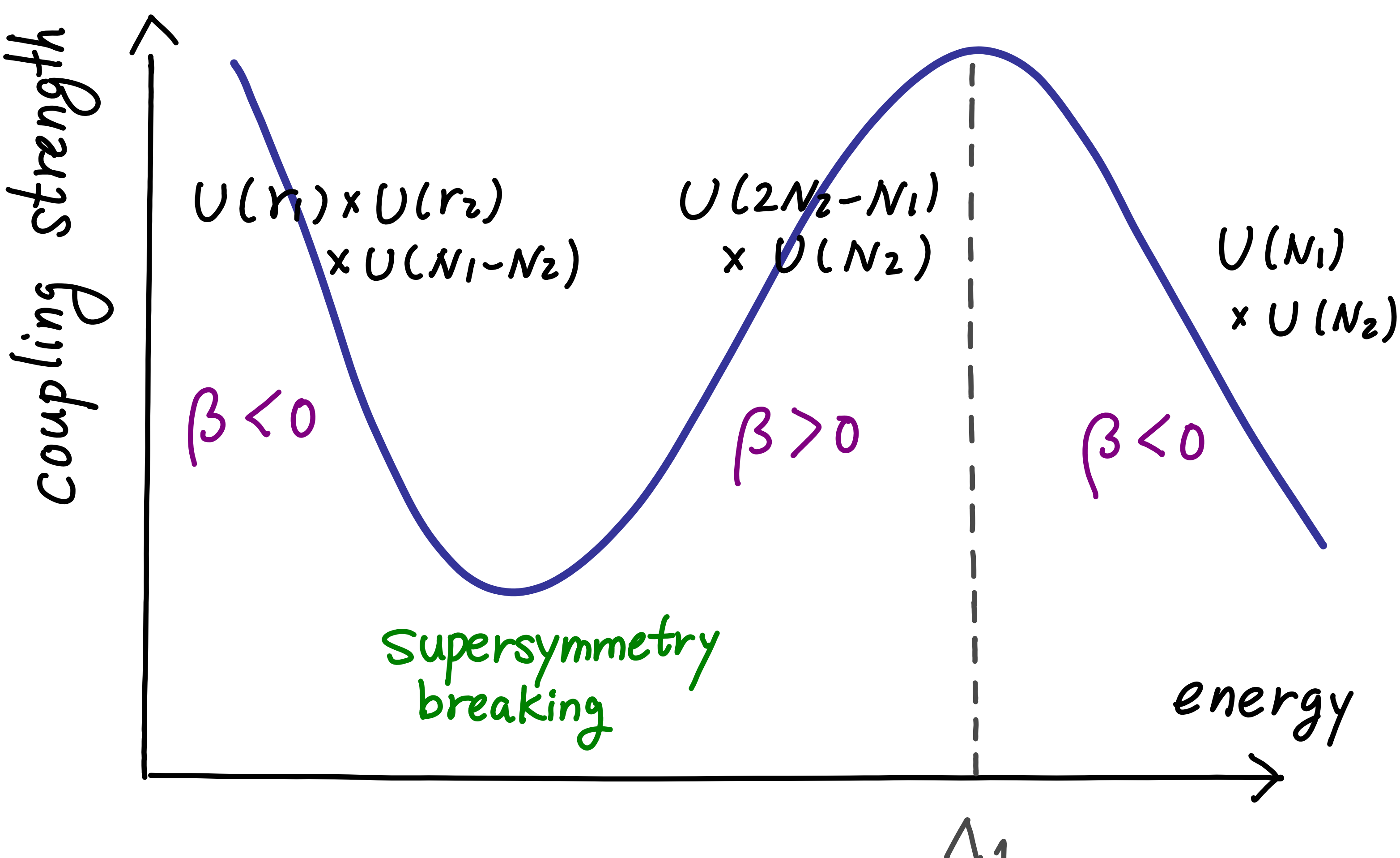
The M directions are stabilized at one-loop.
The model has no global symmetry.

(3) The low energy structure is rich --- next page:

The low energy structure of this model is rich.

As we move toward low energy, we encounter different features of the model:

(1) original high energy descripion $\beta < 0$
(2) dual description $\beta > 0$
supersymmetry breaking!
(3) bosonic pure QCD $\beta < 0$
confinement



Comments

1. Not all supersymmetric gauge theories have meta-stable vacua of this type.

For example, if the U(N2) symmetry were not gauged, but if it were a global flavor symmetry, we would miss some D-term conditions, leading to a runaway behavior.

The geometric construction by string theory produces exactly the right combination of field content and gauge symmetry so that the supersymmetry breaking configurations are locally stable.

We are currently studying other models that arise as low energy limits of string theory.

2. Study of supersymmetry breaking meta-stable vacua gauge theories may provide new insights into the landscape of string vacua.

In particular, when the gauge theories are conformal, the meta-stable vacua would be dual to the KKLT compactifications.

It would be interesting to study properties of the meta-stable vacua of gauge theories from the geometric point of view of string theory.

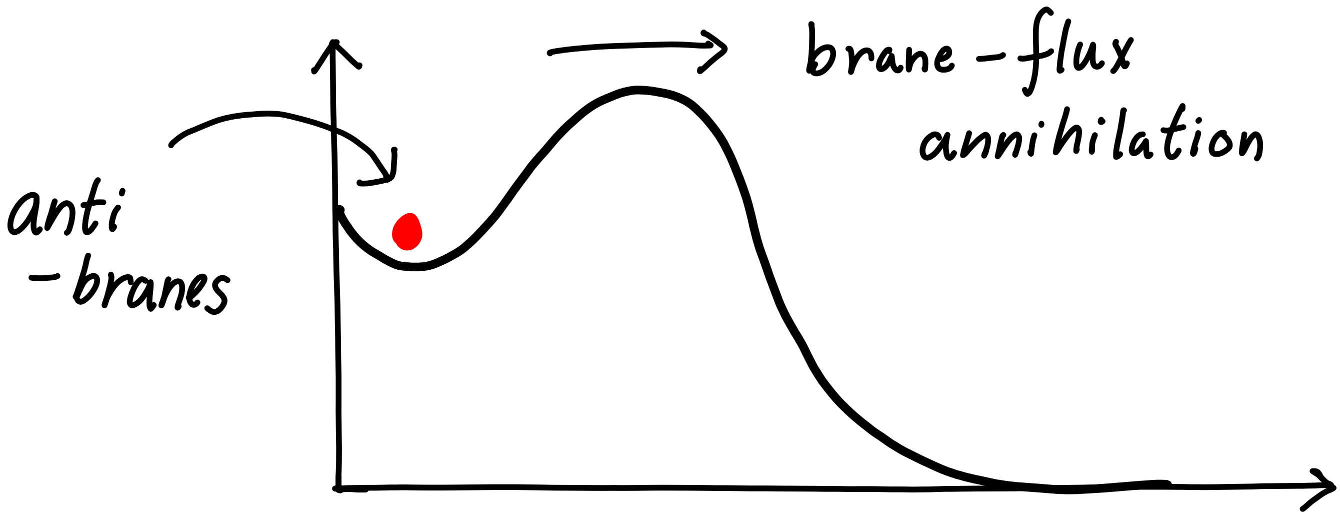
This has been attempted earlier, for example in de Boer, Hori, Oz + H.O. (hep-th/9801060) using the M theory five brane.

We hope to revisit this issue from the new perspective that is emerging.

Under investigation:

The $\hat{A}_1$ quiver theory

Supersymmetry breaking vacua have been identified in the string theory side by Kachru, Pearson, and Verlinde (hep-th/0112197).



We are currently studying the gauge theory side of the story.

For general quiver theories:

We hope to extend the geometric interpretation of the dualities by Cachazo, Fiol, Intriligator, Katz, and Vafa (hep-th/0110028) to the regimes where the dual descriptions are infrared free.