On the ubiquity of meta-stable vacua

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Last year, Intriligator, Seiberg and Shih discovered that supersymmetric QCD with massive flavors has meta-stable vacua when $N_c < N_f < 3N_c/2$.

This raises various questions:

-- How generic is this phenomenon?

-- Is it useful for model building?

-- Can we realize it in string theory?

-- How does the story change
when the gravity is turned on?

How generic is this phenomenon?

Perturbed Seiberg-Witten theories

Ookouchi, Park + H.O.
(0704.3613)

This is about N=1 theories obtained by perturbing N=2 theories with superpotentials.

Consider an arbitrary N=2 gauge theory.

Choose a generic point *p* on the Coulomb branch.

e.g. pure SU(2) theory

Perturbed Seiberg-Witten theories

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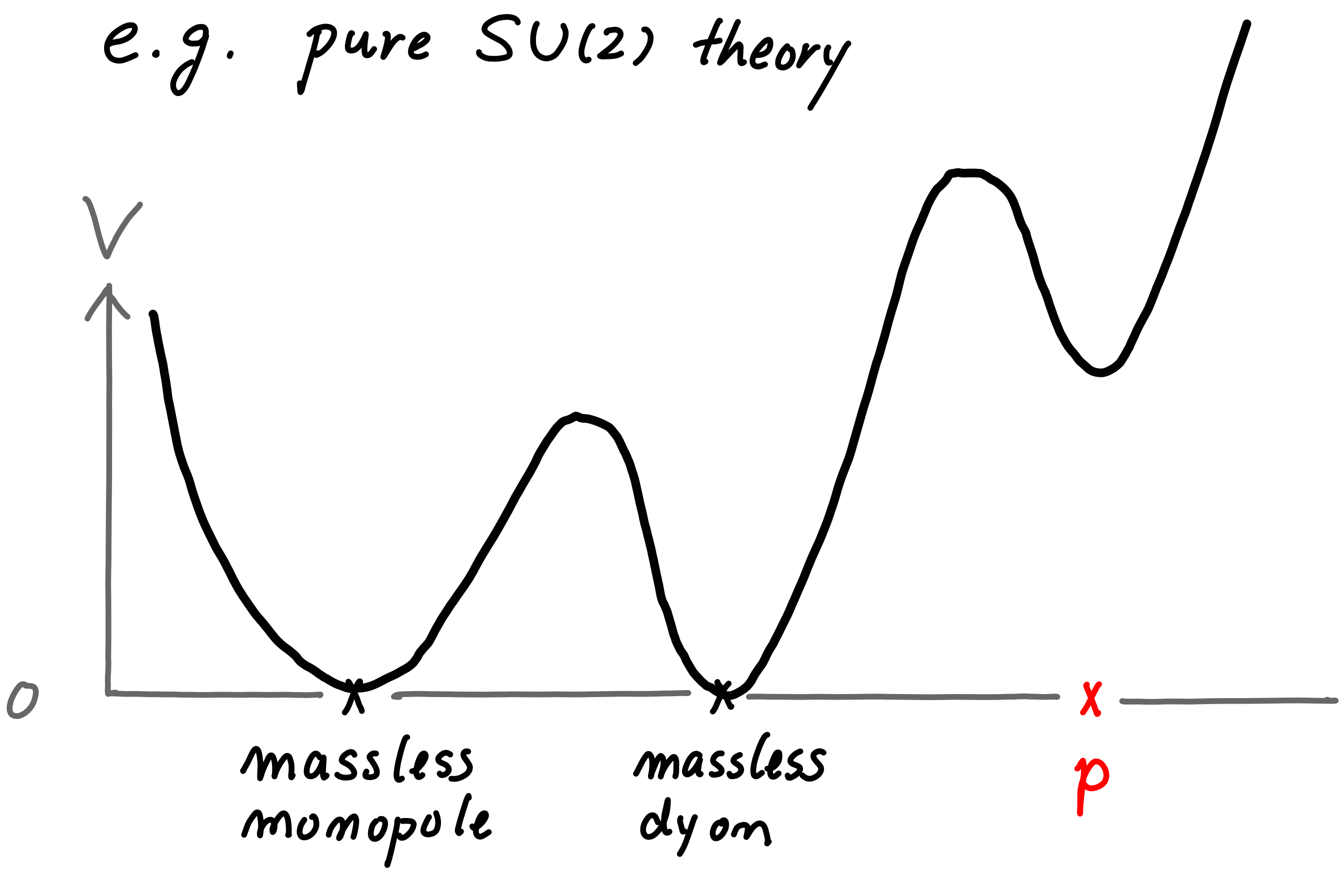
One can find a superpotential *W* which generates a meta-stable vacuum at *p*.



This follows from the positivity of the sectional curvature on the Coulomb branch.

In general, in geodesic coordinates:

$$g_{i\bar{j}}(z) = g_{i\bar{j}}(0) + R_{i\bar{j}k\bar{\ell}}\, z^k \bar{z}^{\bar{\ell}} + \cdots$$

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Choose $W = k_i z^i$, where $z^i(p) = 0$
and k_i is a constant vector.

$$V = g^{i\bar{j}}\, \partial_i W\, \bar{\partial}_{\bar{j}} \bar{W}$$

$$= g^{i\bar{j}}(0) k_i k_{\bar{j}} + \underbrace{R^{i\bar{j}}{}_{k\bar{l}}\, k_i \bar{k}_{\bar{j}}}_{\text{positive definite}}\, z^k z^{\bar{l}} + \cdots$$

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The positivity is a consequence of the rigid limit of special geometry:

$$g_{i\bar{j}} = \mathrm{Im}\, \partial_i \partial_j F \quad \leftarrow \text{prepotential}$$

Comments:

For gauge group G = SU(2) or SU(3), one can choose W to be a single-trace operator.

Such deformation can be realized in string theory.

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If we turn on gravity, the sectional curvature for vector multiplets in N=2 supergravity is not positive definite.

With gravity:

$$V = e^{K}\left(g^{i\bar{j}} D_i W \bar{D}_{\bar{j}} \bar{W} - 3 |W|^2 \right)$$

Denef and Douglas (hep-th/0404116) have shown that:

For flux compactification with one modulus, there are no meta-stable de Sitter vacua in the large complex structure region.

Note that the curvature of the moduli space is negative in this region.

Surprizingly, they also found no meta-stable de Sitter vacua even in the conifold region, where the curvature turns positive.

Quiver Gauge Theories

Kawano, Ookouchi + H.O.
(0704.1085)

Any quiver gauge theory with adjustable superpotentials for the adjoint fields and masses for the bifundamental fields has meta-stable vacua in some range of its parameters.

Many of these gauge theories have geometric realizations in string theory.

Douglas, Moore
(hep-th/9603167)

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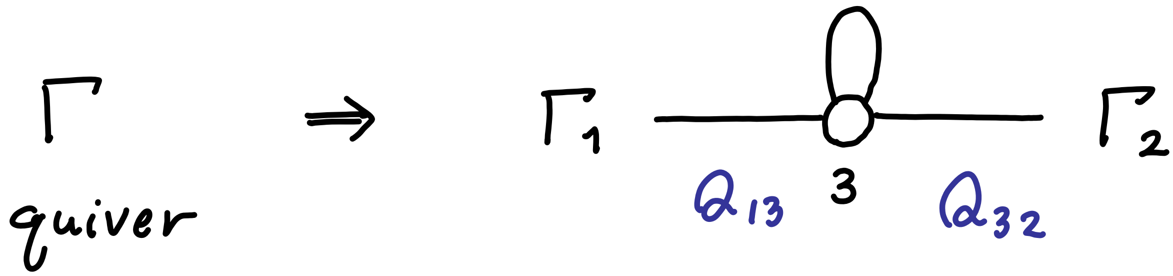
Cachzo, Katz, Vafa
(hep-th/0108120)

Consider the following situation:



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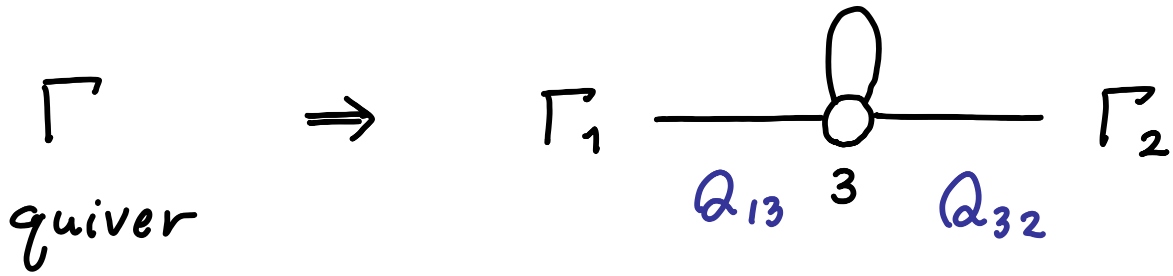

Γ_1 can be the ISS model or its variant, which has meta-stable vacua.

The meta-stable vacua are not disturbed if the interactions through the node 3 are weak.

Note: This argument would not work if we are looking for models without SUSY vacua since small perturbations may generate SUSY vacua.

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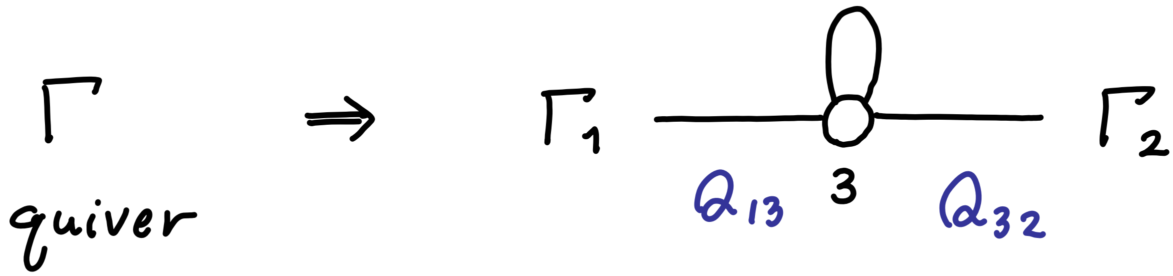

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The supersymmetry breaking effect can be communicated to Γ_2 by the simple gauge mediation.

$$W_{messenger} \sim (m + F\theta^2)\, Q_{32} Q_{23}$$

$$F \leftarrow \langle Q_{31} Q_{13} \rangle$$

SUSY breaking will propagate through the quiver diagram.

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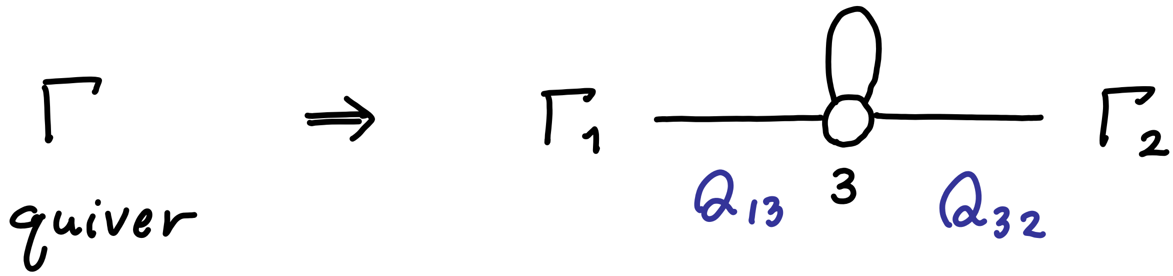

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This idea was recently applied to study meta-stable vacua in the *An* quiver theories.

Amariti, L.Girardello, Mariotti (0706.3151)

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for some ranges of parameters.

In contrast,
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Difference between $>$ and $=$.

These field theory models have
frozen parameters.

When the gravity is turned on,
they become dynamical.

One should worry about stabilizing
them in an appropriate range.

Application to Model Building

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Meta-stability requires > rather than = .

This simplifies model building.

Constructing models without SUSY vacua is hard.

-- Witten index (e.g., non-zero for SQCD)
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Many of the difficulties can be avoided
by accepting meta-stability.

-- Witten index and Nelson-Seiberg theorem are not obstructions any more.

-- Greater flexibilities.

e.g., Superpotential can be generic.

In particular, we can break the R-symmetry and generate the gaugino masses at one-loop.

Direct Mediation Model:

Hidden sector fields carry standard model charges.

The ISS model itself is difficult to use since the R-symmetry is unbroken.

How about breaking the R-symmetry explicitly by superpotential?

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$SU(N_c)$ group with N_f flavors $(Q_i, \tilde{Q}_i)$

$$W_{ISS} = \sum_{i=1}^{N_f} m_i Q_i \tilde{Q}_i$$

add

$$\delta W = \sum_{ijkl} c_{ijkl} Q_i \tilde{Q}_j Q_k \tilde{Q}_l .$$

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This model can be naturally realized on D-branes at Calabi-Yau singularities.

Argurio, Bertolini, Franco, Kachru (hep-th/0703236)

We choose:

$$(m_i) = (\overbrace{m, \ldots, m}^{N_F - N_c}, \overbrace{\mu, \ldots, \mu}^{N_c})$$

appropriate c_{ijkl}

so that there is a meta-stable vacuum with unbroken global symmetry:

$$SU(N_F - N_c) \times SU(N_c) \times U(1)$$

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This vacuum is long-lived if:

$$m \gg \mu$$

c_{ijkl} : appropriate range

Couple this to the Standard Model by:

$$SU(3) \times SU(2) \times U(1) \subset SU(N_F - N_c)$$

Masses of gauginos, scalars, and gravitino come out to be phenomenologically attractive values,

and the Landau pole problem can be avoided,

if we choose:

$$10^8\,\mathrm{GeV} \lesssim \mu \lesssim 10^9\,\mathrm{GeV}$$

$$10^{13}\,\mathrm{GeV} \lesssim m \lesssim 10^{15}\,\mathrm{GeV}$$

C_{ijkl} : appropriate range

$$(C^2 \sim m \Lambda^{-3})$$

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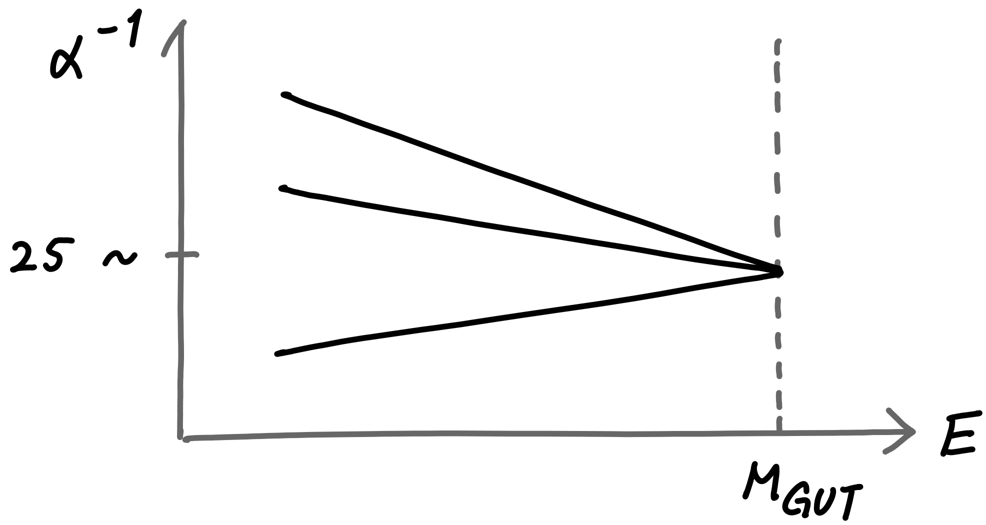

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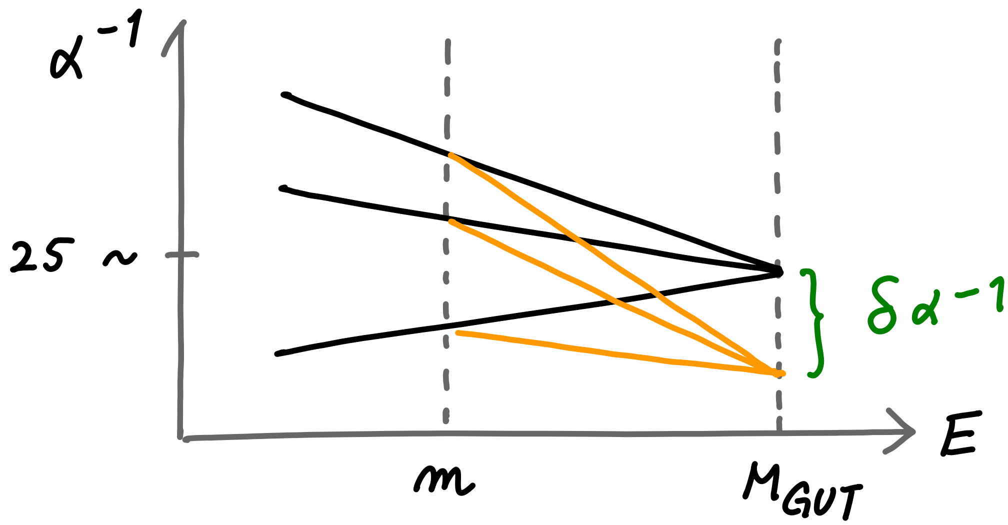

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There have been model building activities making use of related ideas:

Murayama, Nomura (hep-ph/0612186, 0701231)	
Csaki, Shirman, Terning	(hep-ph/0612241)
Aharony, Seiberg	(hep-ph/0612308)
Abel, Khoze	(hep-ph/0701069)
Amariti, Girardello, Mariotti	(hep-th/0701121)
Dudas, Mourad, Nitti	(0706.1269)

.....

Conclusion

Meta-stable vacua appear to be ubiquitous in field theories.

Accepting them allows greater flexibility in model building.

Realizing them in string theory is easier.

It may lead to new technical advances in string theory.

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How does the story change when the gravity is turned on?

How can we tell when they are not in the Swampland?