Stringy Instantons

do new things

and

in the presence of

Quiver Gauge Theories

with

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hep-th/0610003

media-level view of the situation:

We know how to make quasi-realistic gauge theories.

We know how moduli can be stabilized.

What happens when we try to
do both at the same time?

A Motivating Puzzle

In IIB on a CY with fluxes, `KKLT, hep-th/0302...`

the kahler moduli are stabilized by

a superpotential generated by euclidean D3-branes.

$$\Delta W \propto e^{-\rho} \qquad \rho \sim \int_X \left(J^2 + i C^{(4)} \right)$$

The shift symmetry of $\mathrm{Im}\ \rho$ is broken only by this.

Now suppose there are some space-filling branes present.

Why might we care about the case with branes?

1. In such systems, the Standard Model must live on such a brane!

2. There exists a beautiful characterization of which quivers should dynamically break SUSY. When they are decoupled, they run away.

3. It's a necessary ingredient for understanding global structure of stringy configuration space.

Kahler moduli become charged fields:

The open-string gauge group is $G = \prod_a U(N_a)$

Some of the $U(1) \subset U(N_a)$ will be anomalous.

This anomaly is cancelled by shifts of $\mathrm{Im}\ \rho$

$\Delta W \propto e^{-\rho}$ isn't gauge invariant!

lessons

The point: the quiver field theory gets perturbed by baryonic operators which affect its vacuum structure.

This is a general mechanism for generating operators which grow when the gauge symmetry is very higgsed -- not strong gauge theory effects.

These operators are in general dangerously irrelevant.

Field theories whose vacua get pushed to large vevs are a source of UV sensitivity.

Outline

0. Motivation

1. 'SUSY breaking by obstructed deformation'

and its discontents

2. Stringy nonperturbative effects

in the presence of space-filling branes

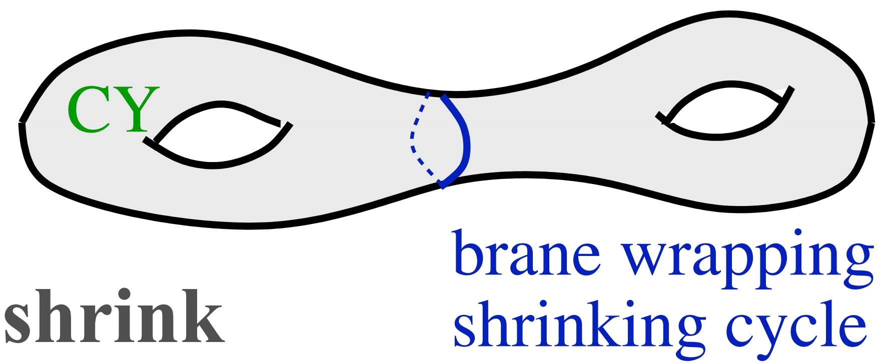
3. D3 instantons in a CY with dP_1 singularity

4. Vacuum structure

DSB by D-branes?

D-branes carry gauge theories.
Interesting ones live on branes at singularities.

Singularities arise from shrinking things.



What can shrink supersymmetrically?

shrinking a curve in CY → conifold.

Next case: surfaces

A surface in a CY which can be shrunk **is a del Pezzo surface.**

Branes stuck to shrinking dPs

Berenstein Herzog Ouyang Pinansky, hep-th/0505029
Franco Hanany Saad Uranga, hep-th/0505040
Bertolini Bigazzi Coltrone, hep-th/0505055

gauge-string duality

gaugino condensates ⟷ complex structure deformations

(Klebanov-Strassler, Vafa)

del Pezzo cones are not complete intersections

(unlike conifold)

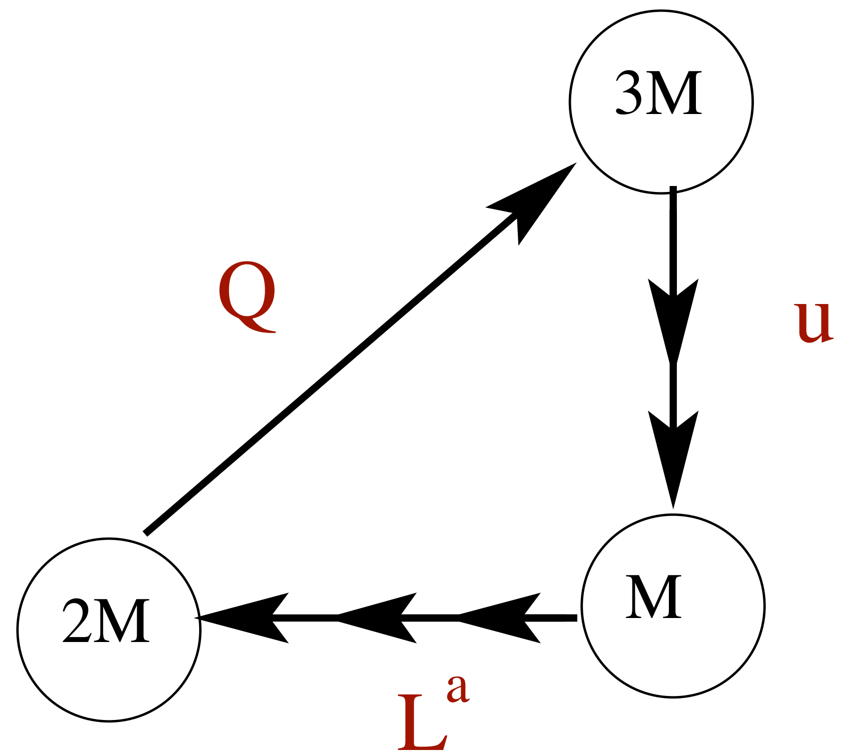
⇒ hard to deform (Altmann)

Looks like gravity dual of Konishi anomaly:

$$\mathrm{tr} W_\alpha W^\alpha \propto \frac{\partial W}{\partial \phi} = F_\phi$$

the DSB representation of dP_1

Lots of work was done
to figure out what quiver
corresponds to what geometry.



very similar to 3-2 model

Affleck Dine Seiberg 1984

$$W_{\text{tree}} = \lambda_{ia}\ Q u^i L^a$$

$$a = 1, 2, 3\ i = 1, 2$$

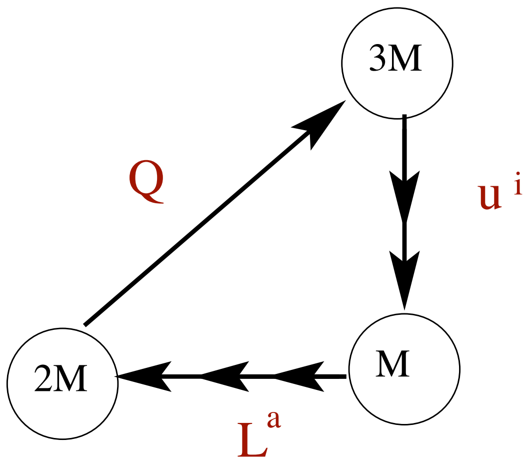
breaks flavor symmetry $SU(3) \times SU(2) \longrightarrow SU(2)_{\text{diag}}$

$SU(M)$ and $U(1)$ factors are IR free.

Symmetries of the quiver

	gauge symmetries			global symmetries		
	$SU(3M)$	$SU(2M)$	$SU(M)$	$[SU(2)$	$U(1)_F$	$U(1)_R]$
Q	$\mathbf{3M}$	$\overline{\mathbf{2M}}$	$\mathbf{1}$	$\mathbf{1}$	1	-1
$\overline{u}$	$\overline{\mathbf{3M}}$	$\mathbf{1}$	$\mathbf{M}$	$\mathbf{2}$	-1	0
L	$\mathbf{1}$	$\mathbf{2M}$	$\overline{\mathbf{M}}$	$\mathbf{2}$	0	3
L_3	$\mathbf{1}$	$\mathbf{2M}$	$\overline{\mathbf{M}}$	$\mathbf{1}$	-3	$-1,$

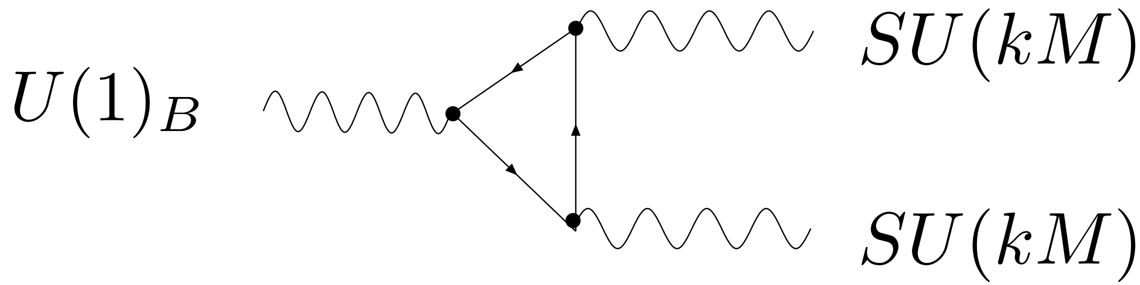
$$W_{\text{tree}} = \lambda Q \epsilon_{ij} u^i L^j$$

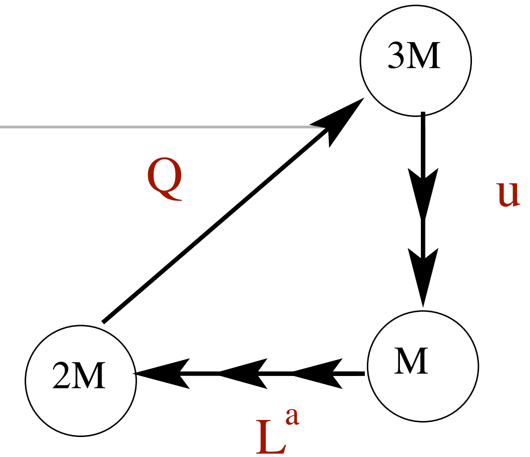


For M=1, SU(3) has $N_f = N_c - 1$

$$\Rightarrow \quad W_{ADS} = \frac{\Lambda_3^7}{\det Q \cdot u}$$

anomalies in U(1)s





Mixed anomalies give mass to the baryonic U(1)s by the GS mechanism.

Dine Seiberg Witten 1985

$$L = ... + \phi \, \mathrm{tr} F \wedge F + m^2 (\partial\phi + A)^2$$

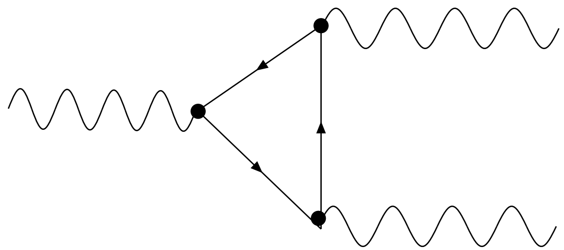
ϕ is a RR axion.

$$A \to A + d\lambda$$
$$\phi \to \phi - \lambda$$

Light closed strings are inextricably involved in the problem.

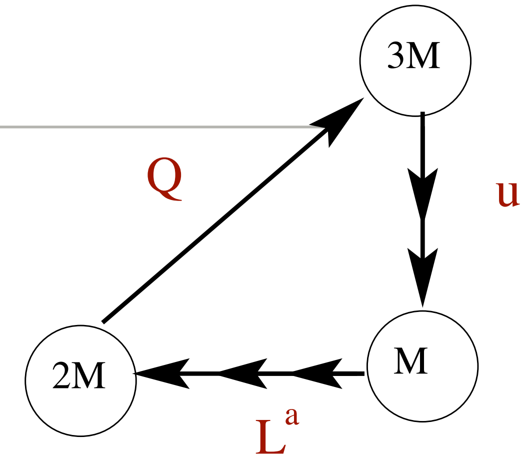
anomalies from U(1)s

$U(1)_R$



$U(1)_{B,\alpha}$

$U(1)_{B,\beta}$



The R-charge is also anomalous: $\partial_\mu j^\mu_R = r_\alpha r_\beta F_\alpha F_\beta$

In the noncompact model, this is cancelled by a coupling to other RR fields:

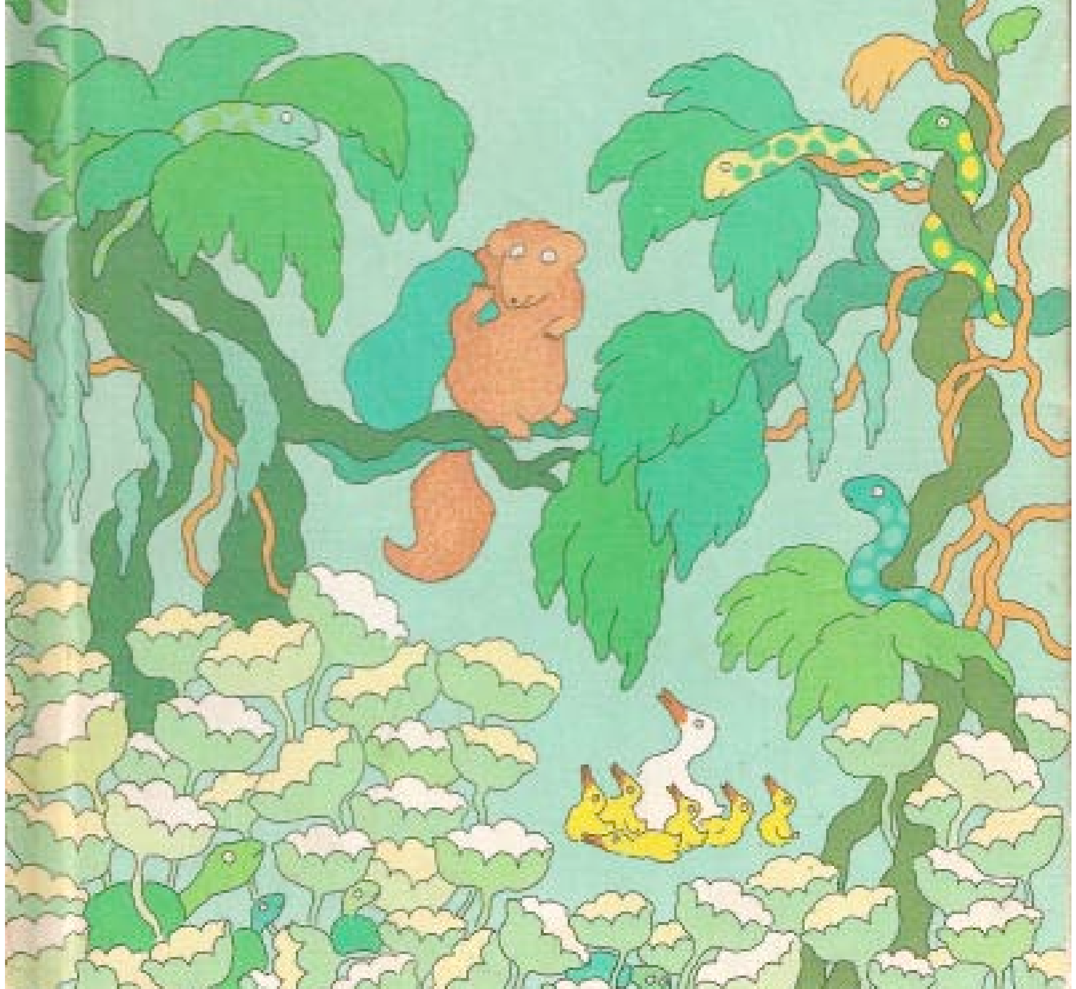
$$S = ... + \int_{R^{3,1}} C^{(2)} \wedge r_\alpha F_\alpha \qquad \delta C^{(2)} = \epsilon r_\beta F_\beta$$

RR 2-form, projected out in compact model.

The Runaway Quiver

by K. Intriligator and N. Seiberg

pictures by Jose Aruego & Ariane Dewey



Runaway

Intriligator Seiberg, hep-th/0512347 :

The theory with gauge group $SU(3) \times SU(2)$ (M=1)

has no vacuum at finite distance in field space.

L s run away: $\mathcal{V}(V) \propto (V^\dagger V)^{-1/6}$

$$V^a \equiv \det(L^a, L^b)\epsilon_{abc}$$

'SUSY-BOG' crucially used D-term conditions

from $U(1)_B$ s:

$\sum |L|^2 = \xi$ → L's are bounded.

This isn't the end of the story:

This is the theory in a certain decoupling limit of "local dP_1" where

$$m(U(1)_B) \rightarrow \infty.$$

In a compact CY, with $m_s < \infty$, $U(1)_B$s matter.

m = axion kinetic term, mass of A

$$m = m_s \times K_{\phi\phi}(t)$$

ϕ normalizable ⟺ m finite

let's assume that we're studying

a **compact** CY containing a dP singularity.

⟹ finite kinetic terms, finite mass for gauge bosons.

(It can be embedded in a compact CY.

Diaconescu Florea Kachru Svrcek, hep-th/0512170)

Massive U(1)s matter

Arkani-Hamed Dine Martin, hep-ph/9803432

integrating out massive gauge bosons

induces kahler corrections which

add the D-term potential

$$\Delta K = -\frac{g_X^2}{M_X^2} q_i q_j \phi^{\star i}\phi_{\ i}\phi^{\star j}\phi_j$$

⇒ Their D-terms must be imposed in finding vacua.

Including the baryonic U(1)s

There are two independent anomalies.

dP_1 has two 2-cycles, c, f .

$$\phi_S \equiv \int_{dP_1} C^{(4)}_{RR} \qquad \phi_c \equiv \int_{dP_1} C^{(2)}_{RR} \wedge c \qquad \phi_f \equiv \int_{dP_1} C^{(2)}_{RR} \wedge f$$

We find their charges by demanding that

$$\delta\Gamma_{\text{eff}} = -\delta \left(\sum_{\alpha=1}^{3} \int_{\text{branes},\ \alpha} \sum_p C^{(p)}_{RR} \wedge \sqrt{\text{Td}} \wedge \text{ch} V_\alpha \wedge \text{tr}_\alpha F \wedge F \right)$$

	$U(1)_1$	$U(1)_2$	$U(1)_3$
$e^{i\phi_S}$	0	-6	6
$e^{i\phi_c}$	1	2	-3
$e^{i\phi_f}$	2	4	-6

$\exists$ Neutral combination: $2\phi_c - \phi_f$

“Kahler moduli are charged”

important question:

kahler moduli in IIB are stabilized by

euclidean D3-branes $\Delta W \sim e^{-\rho}$

Witten, hep-th/9604030
KKLT, hep-th/0301240

$$\rho \equiv \int_D (J^2 + i C^{(4)}_{RR}) = \sigma + i\phi_S$$

but now this isn’t gauge invariant!

$$\rho \mapsto \rho + i\lambda, \; A_B \mapsto A_B + d\lambda$$

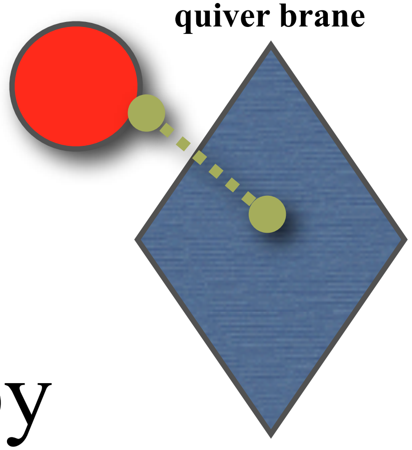
How to make a gauge-inv’t potential for kahler moduli?

A hint

A Note on zeros of superpotentials in F theory.
Ori J. Ganor (Princeton U.) . PUPT-1672, Dec 1996. 12pp.
Published in **Nucl.Phys.B499:55-66,1997**
e-Print Archive: **hep-th/9612077**

Massless strings stretching between the instanton and spacefilling branes

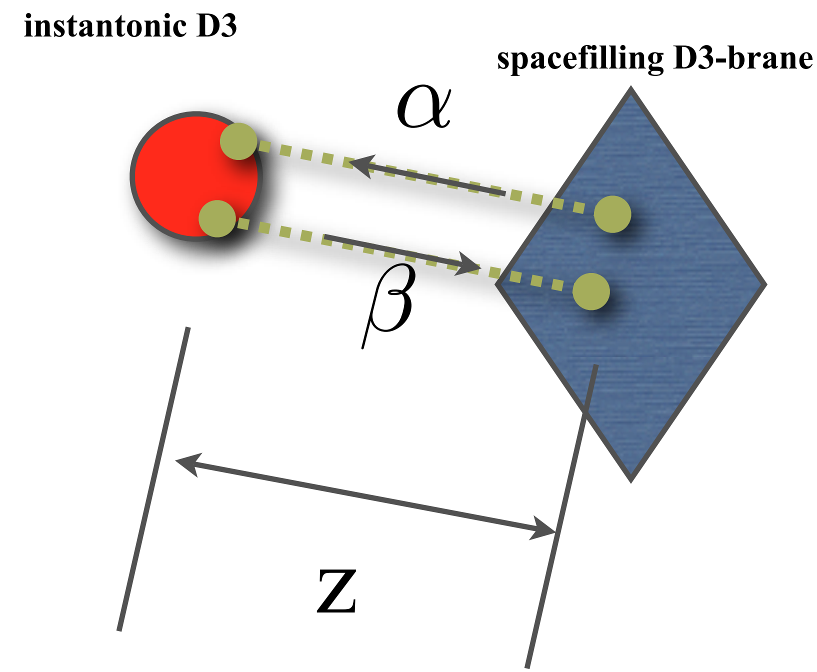
act like collective coords of the instanton, and couple to quiver fields.



Integrating out these modes multiplies the instanton contribution by a function of the quiver fields.

The instanton prefactor is a field theory operator

Ganor, hep-th/9612077



$$L_{\mathrm{disc}} = \alpha \cdot Z \cdot \beta$$

an ordinary
Grassmann integral

$$\Delta W(\rho, Z) \sim e^{-\rho} \int d\alpha d\beta \; e^{\alpha \cdot Z \cdot \beta} \sim Z \; e^{-\rho}$$

Which D-branes contribute?

del Pezzo D-geometry

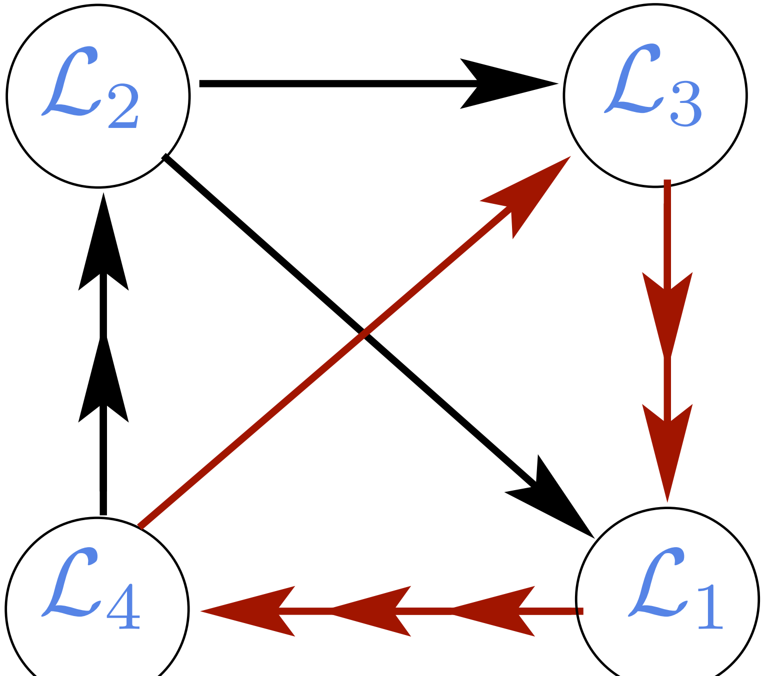
Wijnholt Herzog Walcher Aspinwall Karp Melnikov Nogin...

an "exceptional collection" of branes on dP_1 is:

$$\{\mathcal{L}_1, \ldots, \mathcal{L}_4\} \equiv$$

$$\{\mathcal{O}_{dP_1}, \mathcal{O}_{dP_1}(c+f), \overline{\mathcal{O}_{dP_1}(f)}, \overline{\mathcal{O}_{dP_1}(c)}\}$$

(the DSB representation above is $\mathcal{L}_1 \oplus 2\mathcal{L}_4 \oplus 3\mathcal{L}_3$)



we need to know this because we are going to study euclidean branes and their interactions with these D7s

Counting Ganor strings

Twisting of 3-7 strings:

reduction of hypermultiplet on dP

$$SO(10) \supset SO(4)_{\mathbf{R}^4} \times SO(4)_{dP_1} \times SO(2)_{\perp}$$

$$S = \left(S''_+ \oplus S''_+\right) \oplus \left(S_+ \oplus S_-\right) \oplus \left(N^{\frac{1}{2}} \oplus N^{-\frac{1}{2}}\right)$$

$$S_+ = K^{1/2} \oplus \left(K^{1/2} \otimes \Omega^{0,2}\right) \qquad S_+ = K^{1/2} \otimes \Omega^{0,1} \quad K = N$$

3-7 bosons transform as

$$\left(S''_+ \otimes \mathcal{L}_A \otimes \mathcal{L}^\star_B\right) \oplus \left(S''_- \otimes \mathcal{L}^\star_A \otimes \mathcal{L}_B\right)$$

3-7 fermions transform as:

$$\left(S' \otimes S_+ \otimes \mathcal{L}_A \otimes \mathcal{L}^\star_B\right) \oplus \left(S' \otimes S_- \otimes \mathcal{L}^\star_A \otimes \mathcal{L}_B\right)$$

Counting Ganor strings

net number of 3-7 bosons is counted by

$$h^0(dP, \mathcal{L}_A \otimes \mathcal{L}_B^\star) - h^0(dP, \mathcal{L}_B \otimes \mathcal{L}_A^\star)$$

net number of 3-7 fermions is counted by

$$\chi(\mathcal{L}_A \otimes \mathcal{L}_B^\star) \equiv \sum_{p=0}^{3} (-1)^p h^p(dP, \mathcal{L}_A \otimes \mathcal{L}_B^\star)$$

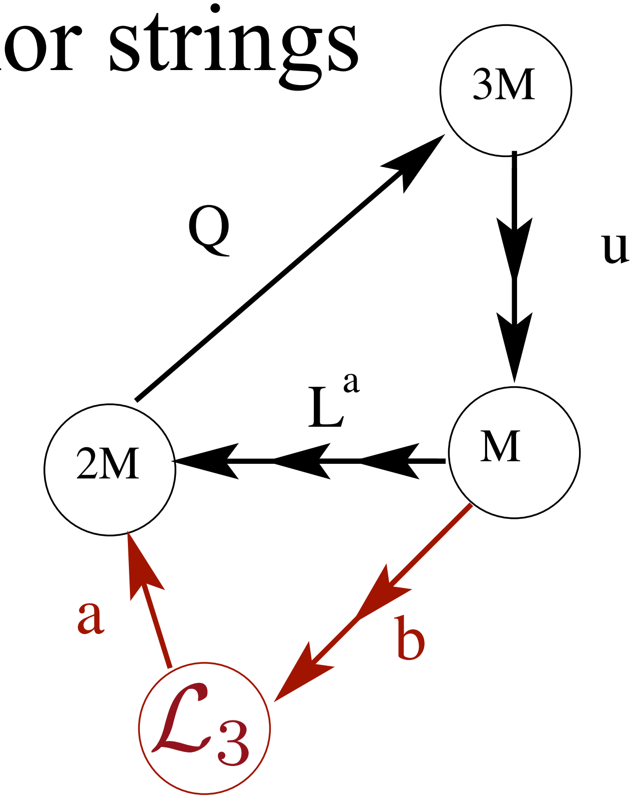
The ADS instanton is a D3 brane

(for M=1)

D3 on SU(3) node = field theory instanton

There is a net number of *bosonic* Ganor strings

$$L_{\text{disc}} \sim a(Q \cdot u^i) b_i$$



$$\Delta W \propto \int dadb\; e^{a(Q\cdot u)b} = \frac{1}{\det Q \cdot u}$$

see: Bershadsky et al, hep-th/9612052

What about Witten's criterion?

Witten, hep-th/9604030

In the M-theory lift, an M5-brane wrapping a divisor D contributes $\exp\left(-\int_D \left(J^3 + iC^{(6)}\right)\right)$.

This carries R-charge: $2\chi(D) = 2\sum_{p=0}^{3}(-1)^p h^{0,p}(D)$

If this is to be a term in W: $\chi = 1$

Our D3-branes lift to M5-branes with $\chi = 0$.

The R-symmetry of the quiver is anomalous.

Other instantons

For a certain class of line bundles

$$X_n \equiv \overline{\mathcal{O}(2(1-n)c + nf)}$$

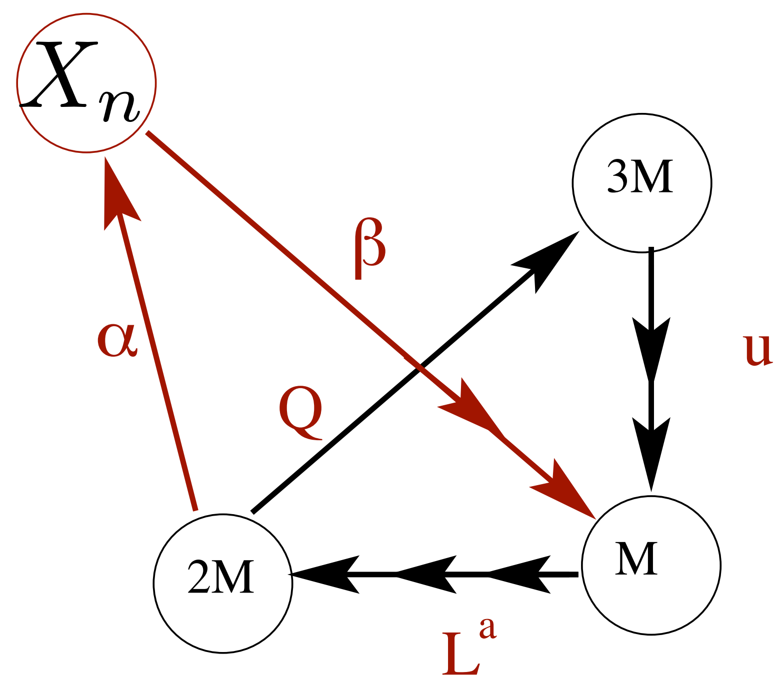
there is a net number of *fermionic* Ganor strings

$$L_{\rm disc} \sim \alpha(L^a d^i_a)\beta_i$$

d^i_a are some numbers

$$\Delta W \propto \int d\alpha d\beta \; e^{\alpha(L^a)\beta_i d^i_a}$$

$$= \det\left(L^1, L^2\right) = V^3$$



This cancels the charges of the instanton action factor.

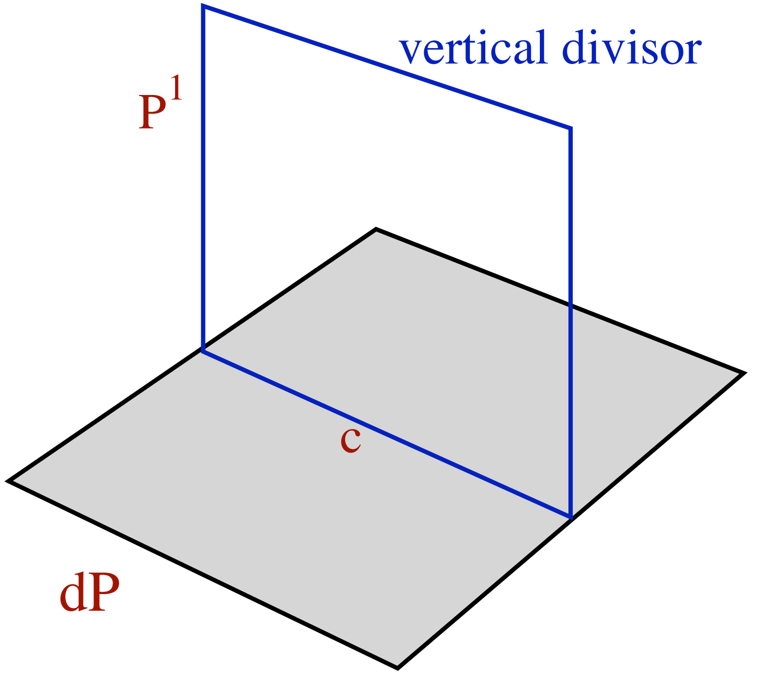
Other instantons

1 Many other candidate instantons vanish because of unpaired fermion zeromodes:

All euclidean D-strings.

2 'vertical' branes:

$\mathbb{P}^1 \rightarrow$ curve in dP_1



are more model-dependent.

stabilize fiber volume.

cartoon of result

$$W = QuL + \frac{e^{-\rho_1}}{\mathrm{det}Qu} + e^{-\rho_2}\mathrm{det}(L^2, L^3)$$

The baryon preserves the flavor symmetry, and breaks the $U(1)_R$.

more accurate version of result

$$W = \lambda Q u^i L^j \epsilon_{ij} + \frac{e^{-\rho_1}}{\det Qu}$$

$$+ \left(\sum_n c_n e^{-n\rho'} \right) \det(L^2, L^3)$$

contribution of D3 on X_n and multicovers.

Vacuum structure?

Effect of baryon term

If the baryon breaks the flavor symmetry,
we get the 3-2 model.

Poppitz Shadmi Trivedi, hep-th/9606184

It doesn't.

But: there is still no SUSY vacuum.

And: the potential grows at large fields.

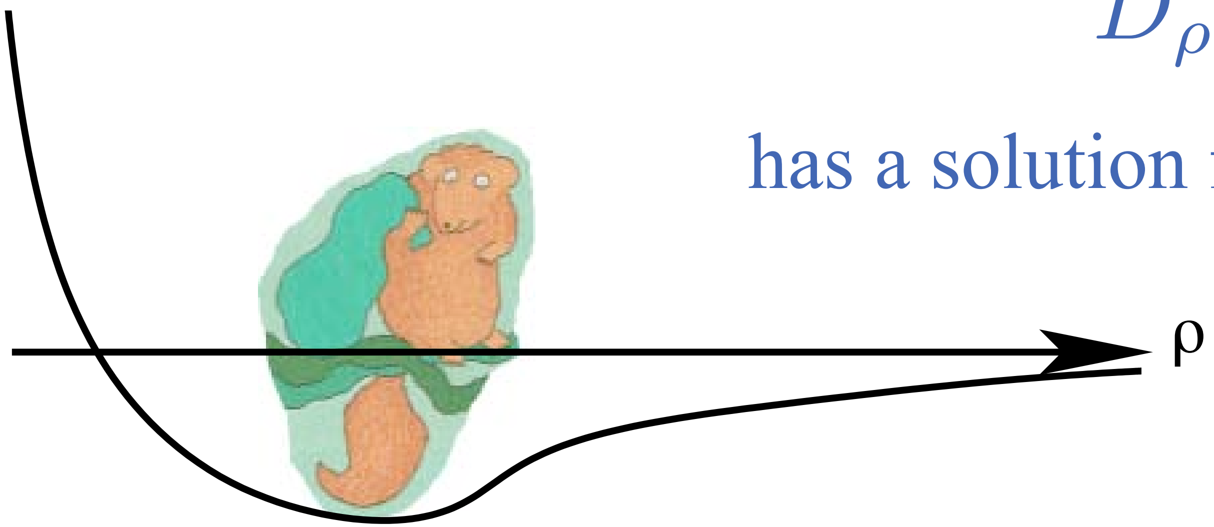
It would be nice to understand the structure of the effective potential in more detail.

Summary of vacuum structure

For Kahler moduli, like KKLT. $W = W_0 + \langle \mathcal{O} \rangle e^{-\alpha\rho}$

$$D_\rho W = 0$$

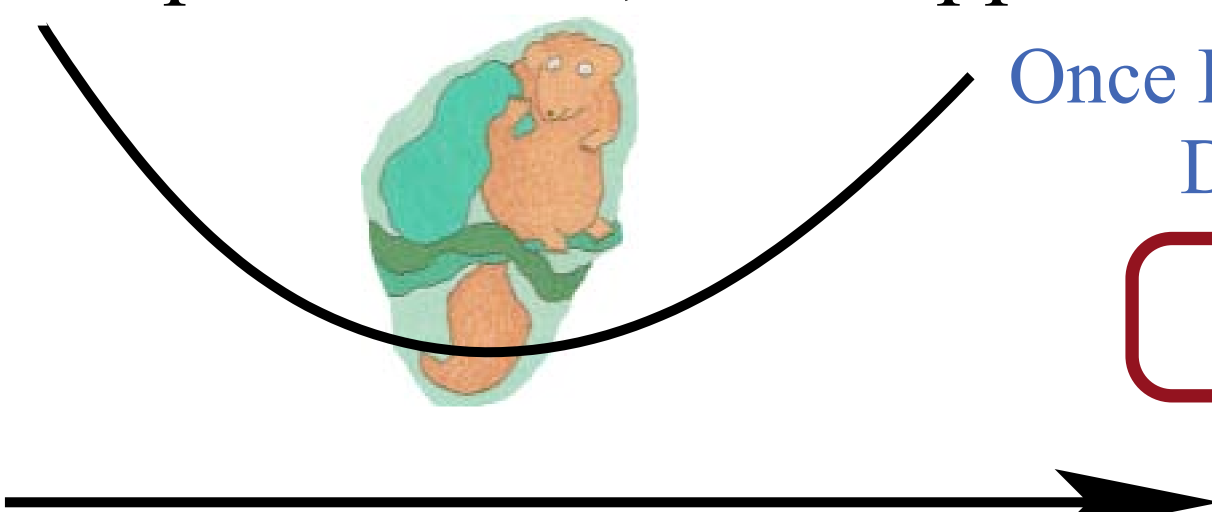
has a solution for generic $K(\rho, \bar{\rho})$.



For quiver fields, like Poppitz et al.

Once Kahler moduli are massive
D-term stops runaway.

$$\langle F \rangle \propto \Lambda_3^{\#}$$



quiver fields

Conclusions

A comment about jumping

The alignment of ‘central charges’ on the quiver locus breaks at some real codim 1 wall in kahler moduli sp. (curves of marginal stability).

Does this mean that the superpotential is discontinuous? Surely no.

Stokes phenomenon: saddle points move on and off the steepest-descent contour, integral remains analytic.

related recent work

application to mu terms: $\mu H_u^\alpha H_d^\beta \epsilon_{\alpha\beta}$ is a baryon.

Buican, Malyshev, Morrison, Verlide, Wijnholt, hep-th/0610007

application to neutrino masses: $m\nu^\alpha \nu^\beta \epsilon_{\alpha\beta}$ is a baryon.

B-L is the anomalous U(1).

Ibanez, Uranga, hep-th/0609213

Blumenhagen, Cvetic, Weigand, hep-th/0609191

also: Lust et al, hep-th/0609...

Final comments

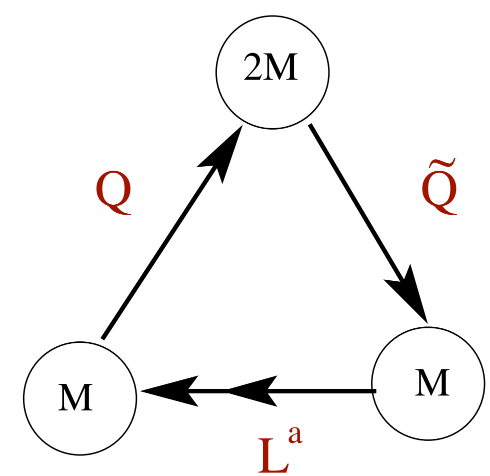
1 V can be thought of as position of D3 dissolved in quiver.

$\Delta W \propto V$ reduces to Ganor's result.

2 $\Delta W \propto V$ is not a field theory instanton here, but perhaps it is in another UV completion.

3 Sensitivity to embedding in compact model?

4 This technology generalizes to other DSB representations:



the end