Supersymmetry breaking from anti-branes in flux compactifications

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Based on: arXiv:1102.2403, 1106.6165 with I.Bena, G.Giecold, M.Graña, N.Halmagyi
arXiv:1110.2513, 1202.3789 + work in progress

Cortona, 31 Maggio 2012

Motivation

- Supergravity duals of N=1, non-conformal gauge theories are by now well understood:
  - Branes on orbifolds
  - Branes on conifolds

Many people in the audience;
Klebanov&Strassler;
Maldacena&Nunez;
...

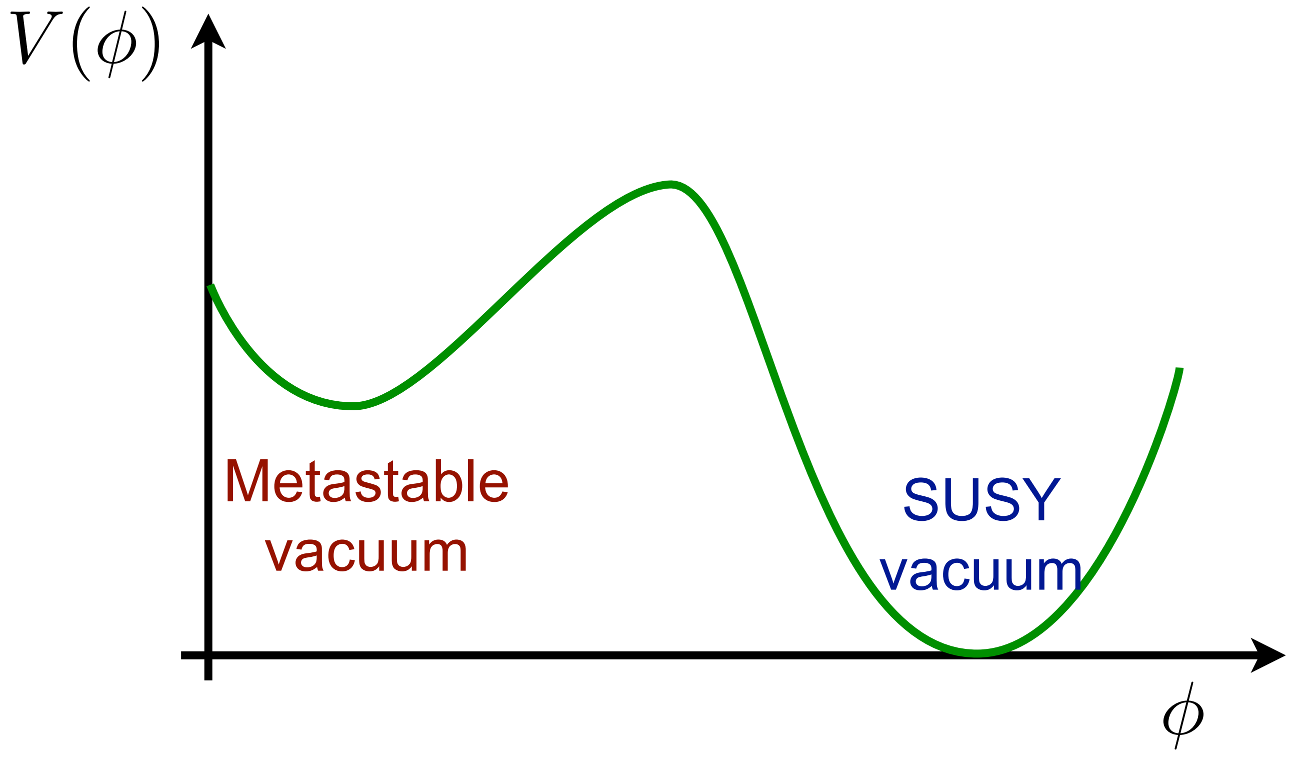
- We want to study (spontaneous) SUSY breaking in these models.

- Computing the scalar potential is difficult (strongly coupled QFT)
  - Use a field theory duality
  - Use gauge/gravity duality.

Motivation

- Metastable vacua in field theory: Intriligator, Seiberg, Shih 06

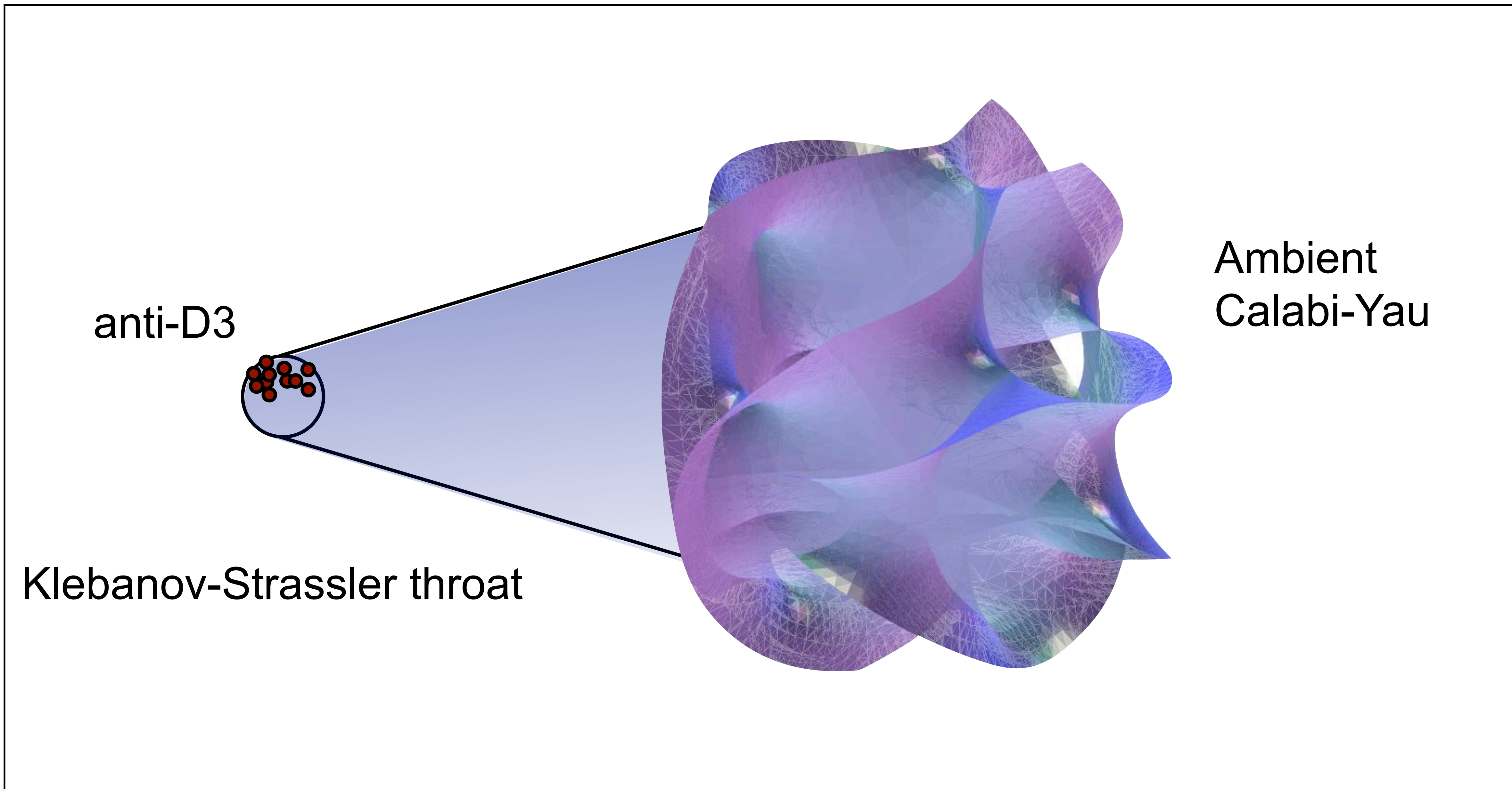
  SU(N_c) SQCD + N_f flavors



- Evidence for metastable state in type IIB and M-theory:
  - anti-D3 in KS (deformed conifold) Kachru, Pearson, Velinde 01
  - anti-M2 in CGLP (warped Stenzel space) Klebanov, Pufu 10

Motivation

- Many phenomenological models based on anti-D3 ~~SUSY~~:
  - ~~SUSY~~ at exponentially low scales; dS vacua, KKLT; models of inflation; ...



Motivation

- We consider a non-compact background: study the metastable state in field theory.

- Brane embedding of the ISS mechanism doesn't work:
  - $g_s=0$ seems fine
  - $g_s\neq 0$ destroy the metastable state.

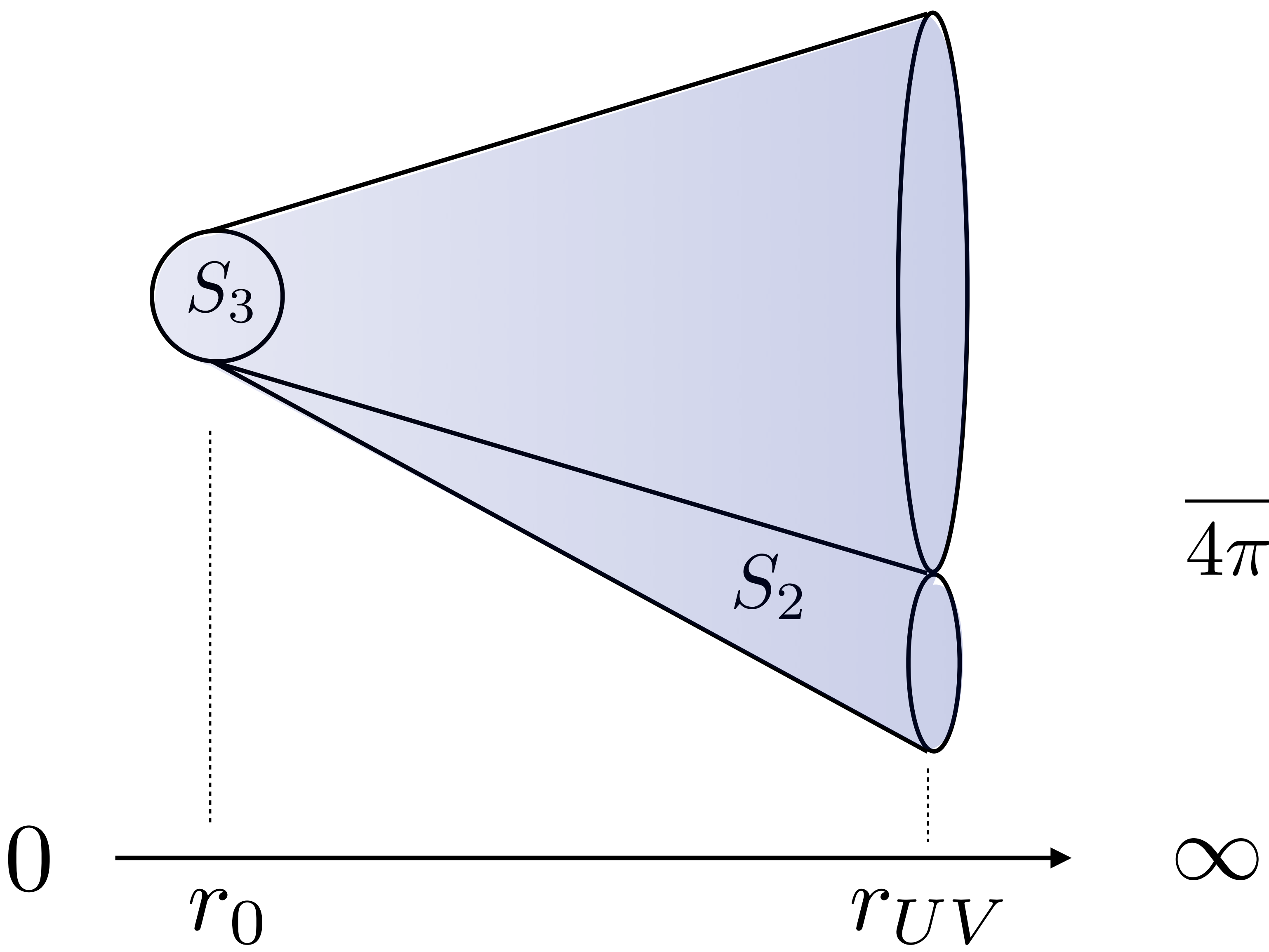
Bena, Gorbatov, Hellerman, Seiberg, Shih 06

➡ Do metastable vacua survive the backreaction?

- Give a constructive answer!

SUSY configuration

- Klebanov-Strassler (KS) geometry



$$\frac{1}{4\pi^2\alpha'}\int_{S^3} F_3 = M$$

$$\frac{1}{4\pi^2\alpha'}\int_{S^2\times[r_0,r_{UV}]} H_3 = K$$

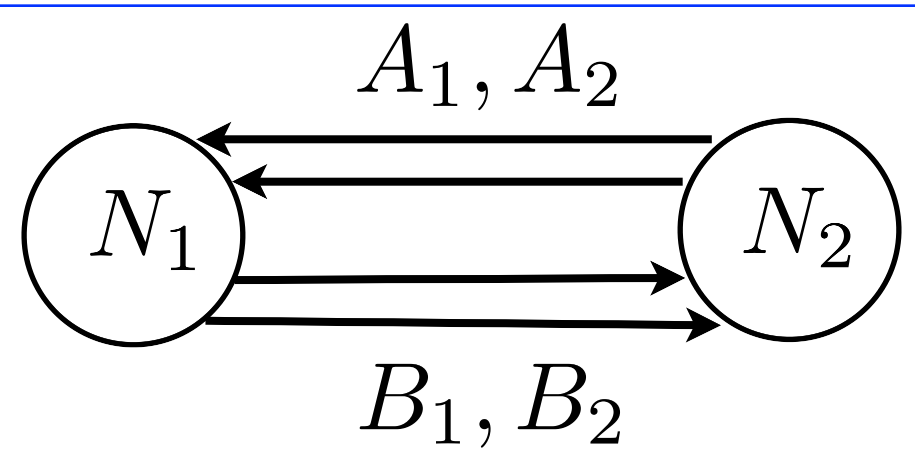
Dual gauge theory

- N=1 SUSY, gauge group:

$$SU(N_1) \times SU(N_2)$$

$$N_1 = (k+1)M + p$$
$$N_2 = kM + p$$

- Matter:



$$A_i \in (N_1, \bar{N}_2)$$
$$B_i \in (\bar{N}_1, N_2)$$

- Interactions:

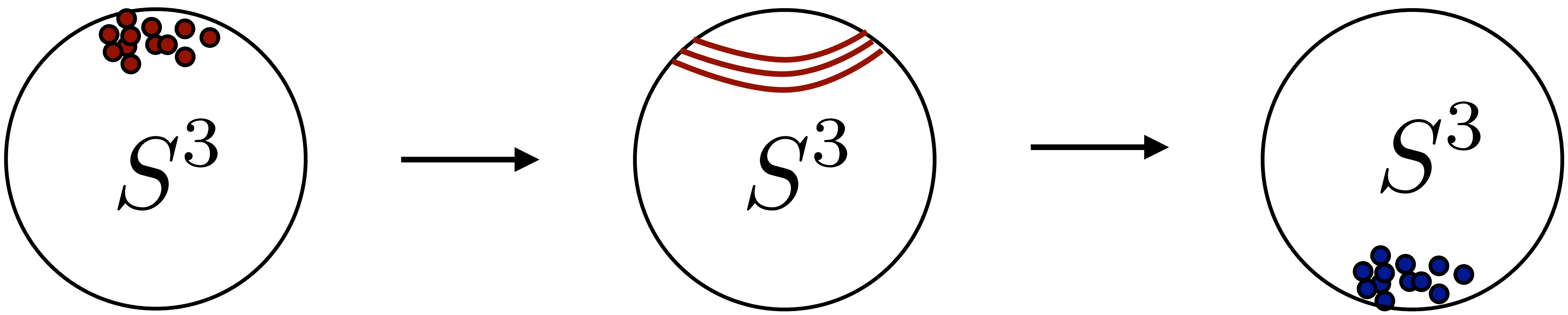
$$W = \lambda_1 Tr(A_i B_j A_k B_l)\epsilon^{ik}\epsilon^{jl}$$

- Cascade of Seiberg dualities, chiral symmetry breaking, confinement, ...

Kachru, Pearson, Verlinde 01

Metastable proposal

- Anti-D3 branes at the tip of the deformed conifold:



p anti-D3	NS5	$M-p$ D3
$Q_{D3}^{Max}(r_{UV}) =$	metastable state	$Q_{D3}^{Max}(r_{UV}) =$
$KM-p$		$(K-1)M+M-p$

$$Q_{D3}^{Max}(r) = \frac{1}{(4\pi^2\alpha')^2}\int_{T_r^{1,1}} \mathcal{F}_5$$

Computing the backreaction: the strategy

1. Smear the anti-branes on the sphere

   - The solution depends only on the radial variable

2. First order perturbation in $\frac{p}{M}$

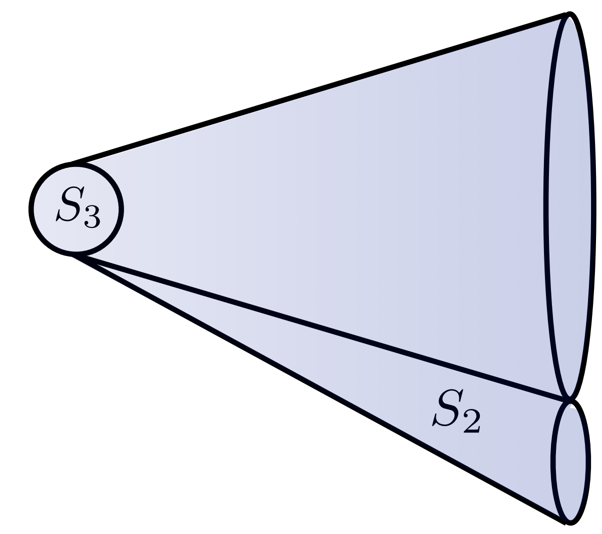
3. Get the full interpolating solution, which connects the IR to the UV

4. Impose IR boundary conditions

5. The UV behavior is then fixed, see if we can impose correct b.c.

Our Ansatz

- We use the following Ansatz:



$$\phi^a = (\underbrace{x, y, p, A}_{\text{metric}}, \underbrace{f, k, F}_{\text{fluxes}}, \underbrace{\Phi}_{\text{dilaton}})$$

$$ds^2_{10} = e^{2A}\, ds^2_{1,3} + e^{-6p-x}\, g_6^2 + e^{x+y}\, \left(g_1^2 + g_2^2\right) + e^{x-y}\, \left(g_3^2 + g_4^2\right) + e^{-6p-x}\, g_5^2\,,$$

$$SU(2) \times SU(2) \times \mathbb{Z}_2$$

$$H_3 = d\Big[f\, g_1 \wedge g_2 + k\, g_3 \wedge g_4\Big]\,,$$

$$F_3 = 2P\, g_3 \wedge g_4 \wedge g_5 + d\Big[F\,(g_1 \wedge g_3 + g_2 \wedge g_4)\Big]\,,$$

$$F_5 = \mathcal{F}_5 + *\mathcal{F}_5\,, \quad \mathcal{F}_5 = \Big(F\,k + f(2P - F)\Big) g_1 \wedge g_2 \wedge g_3 \wedge g_4 \wedge g_5\,,$$

$$C_0 = 0\,.$$

Borokhov, Gubser 02

Smearing + first order

- Linearize the problem:

KS solution

$$\phi_a(\tau) = \phi_a^0(\tau) + \phi_a^1(\tau) + \mathcal{O}\big((p/M)^2\big)$$

- We obtain 2n first-order ODE's for $\phi_a^1(\tau)$

$$\frac{d\xi_a}{d\tau} + \xi_b \, M^b{}_a(\phi_0) = 0\,,$$

~~SUSY~~ int. constants X_a

$$\frac{d\phi_1^a}{d\tau} - M^a{}_b(\phi_0)\,\phi_1^b = G^{ab}\,\xi_b\,.$$

SUSY int. constants Y_a

$$\xi^a = \frac{d\phi_1^a}{d\tau} - \delta\left(\frac{1}{2}G^{ab}\frac{\partial W}{\partial \phi^b}\right)$$

deviations from the (fake) KS first-order flow

Solution

- We found an analytic solution, valid for all τ

Bena, Giecold, Grana, Halmagyi, SM 11

B.1 Analytic expressions for the ξ_a modes

$$\tilde{\xi}_1 = X_1\, h(\tau)\,, \tag{121}$$

$$\begin{aligned}\tilde{\xi}_3 &= -\frac{5}{3}\,X_1\,h(\tau) - \frac{32}{3}\,P^2\,X_1\,\mathrm{csch}^2\tau\,\left(\sinh\tau\,\cosh\tau - \tau\right)^{4/3} \\ &\quad -\frac{128}{9}\,P^2\,X_1\,\left(\sinh\tau\,\cosh\tau-\tau\right)\,j(\tau) + 2\,X_3\,\left(\cosh\tau\,\sinh\tau - \tau\right)\,,\end{aligned} \tag{122}$$

$$\tilde{\xi}_4 = -X_1\,h(\tau) + X_4\,, \tag{123}$$

$$\tilde{\xi}_5 = -\frac{16\,P}{3}\,X_1\,j(\tau) + X_5\,, \tag{124}$$

$$\tilde{\xi}_6 = -\frac{1}{\sinh\tau}\,\lambda_6(\tau) - \frac{\cosh\tau\,\sinh\tau - \tau}{2\,\sinh\tau}\,\lambda_7(\tau)\,, \tag{125}$$

$$\tilde{\xi}_7 = -\frac{\cosh\tau}{\sinh^2\tau}\,\lambda_6(\tau) + \frac{-3+\cosh 2\,\tau + 2\,\tau\,\coth\tau}{4\,\sinh\tau}\,\lambda_7(\tau)\,, \tag{126}$$

$$\tilde{\xi}_8 = P\,\left(\tau\,\coth\tau - 1\right)\,\coth\tau\,\tilde{\xi}_5 - P\,\frac{\tau\,\coth\tau - 1}{\sinh\tau}\,\tilde{\xi}_6 - \frac{1}{6}\,X_1\,h(\tau) + X_8\,, \tag{127}$$

$$\begin{aligned}\tilde{\xi}_2 &= -\frac{2}{3}\,X_3\,\tau\,\cosh\tau + \frac{1}{3}\,X_4\,\cosh\tau + P\,X_6\,\mathrm{csch}\tau\,\left(\coth\tau - \tau\,\mathrm{csch}^2\tau\right) \\ &\quad + P\,X_5\,\mathrm{csch}\tau\,\left(1 - 2\,\tau\,\coth\tau + \tau^2\,\mathrm{csch}^2\tau\right) + X_2\,\sinh\tau \\ &\quad + \frac{1}{2}\,P\,X_7\,\left(-2\,\tau\,\coth^3\tau + \mathrm{csch}^2\tau + \tau^2\,\mathrm{csch}^4\tau\right)\,\sinh\tau \\ &\quad - \frac{1}{108}\,X_1\,\Big[3\,\mathrm{csch}^3\tau\,h(\tau)\,\left(6\,\tau - 5\,\sinh 2\,\tau + \sinh 4\,\tau\right) \\ &\quad + 2\,P^2\,\mathrm{csch}^5\tau\,\big(-15 + 24\,\tau^2 + 16\,\cosh 2\,\tau - \cosh 4\,\tau - 32\,\tau\,\sinh 2\,\tau + 4\,\tau\,\sinh 4\,\tau\big) \\ &\quad \times\left[4\,\sinh^2\tau\,j(\tau) - 6\,\left(\cosh\tau\,\sinh\tau - \tau\right)^{1/3}\right]\Big]\,,\end{aligned} \tag{128}$$

where

$$\lambda_6(\tau) = X_6 + \frac{1}{2}\,\left(-\tau + \coth\tau - \tau\,\coth^2\tau\right)\,\tilde{\xi}_5(\tau) + \frac{1}{6}\,\frac{X_1}{P}\,h(\tau)\,, \tag{129}$$

$$\begin{aligned}\lambda_7(\tau) &= X_7 - \mathrm{csch}^2\tau\,\tilde{\xi}_5(\tau) + \frac{16}{3}\,P\,X_1\,\mathrm{csch}^2\tau\,\left(\cosh\tau\,\sinh\tau - \tau\right)^{1/3} \\ &\quad + \frac{64}{9}\,P\,X_1\,j(\tau)\,.\end{aligned} \tag{130}$$

B.2 Analytic solutions for the ϕ_1^a's

Holding our breath, we recap the analytic solutions for all eight $\tilde{\phi}_1^a$ modes found in [6]:

$$\begin{aligned}\tilde{\phi}_8 &= Y_8 - 64\,X_8\,j(\tau) + \frac{X_7}{P}\,h(\tau) - 64\,P\,X_6\int^\tau \frac{\left(u\,\coth u - 1\right)}{\sinh^2 u\,\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du \\ &\quad + \frac{2}{P}\,h(\tau)\,\tilde{\xi}_5(\tau) + \frac{16}{3}\,X_1\,\mathrm{csch}^2\tau\,\left(\cosh\tau\,\sinh\tau - \tau\right)^{1/3}\,h(\tau) + \frac{64}{9}\,X_1\,h(\tau)\,j(\tau) \\ &\quad + \frac{64}{3}\,X_1\int^\tau \frac{\left(\sinh^2 u + 1 - u\,\coth u\right)}{\sinh^2 u\,\left(\cosh u\,\sinh u - u\right)^{2/3}}\,h(u)\,du\,,\end{aligned} \tag{131}$$

$$\tilde{\phi}_2 = \mathrm{csch}\tau\,\Lambda_2(\tau)\,, \tag{132}$$

$$\tilde{\phi}_3 = \frac{1}{\sinh 2\,\tau - 2\,\tau}\,\Lambda_3(\tau)\,, \tag{133}$$

$$\begin{aligned}\tilde{\phi}_1 &= Y_1 + \frac{40}{9}\,X_4\,j(\tau) - \frac{2}{3}\,\tilde{\phi}_3(\tau) - \frac{160}{9}\,X_3\int^\tau \left(\cosh u\,\sinh u - u\right)^{1/3}\,du \\ &\quad + \frac{5}{3}\int \coth u\,\Lambda_2'(u)\,du - \frac{5}{3}\,\coth\tau\,\Lambda_2(\tau) + \frac{2560}{27}\,P^2\,X_1\int^\tau \mathrm{csch}^2 u\,\left(\cosh u\,\sinh u - u\right)^{2/3}\,du \\ &\quad + \frac{10240}{81}\,P^2\,X_1\int^\tau \left(\cosh u\,\sinh u - u\right)^{1/3}\,j(u)\,du - \frac{80}{27}\,X_1\int^\tau \frac{h(u)}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du\,,\end{aligned} \tag{134}$$

$$\tilde{\phi}_5 = \frac{1}{2}\,\mathrm{sech}^2(\tau/2)\,\left[\tau + 2\,\tau\,\cosh\tau - \left(2 + \cosh\tau\right)\,\sinh\tau\right]\,\Lambda_5(\tau) + \frac{1}{1+\cosh\tau}\,\Lambda_6(\tau) + \Lambda_7(\tau)\,, \tag{135}$$

$$\tilde{\phi}_6 = \left[\tau\,\left(2 - \frac{1}{1-\cosh\tau}\right) - \coth(\tau/2) + \sinh\tau\right]\,\Lambda_5(\tau) + \frac{1}{1-\cosh\tau}\,\Lambda_6(\tau) + \Lambda_7(\tau)\,, \tag{136}$$

$$\tilde{\phi}_7 = \left(-\cosh\tau + \tau\,\mathrm{csch}\tau\right)\,\Lambda_5(\tau) - \mathrm{csch}\tau\,\Lambda_6(\tau)\,, \tag{137}$$

$$\begin{aligned}\tilde{\phi}_4 &= \frac{1}{h(\tau)}\Big\{Y_4 - \frac{16}{3}\,X_1\int^\tau \frac{h(u)^2}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du + 32\,P\int^\tau \frac{\left(u\,\coth u - 1\right)\,\mathrm{csch}^2 u\,\Lambda_6(u)}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du \\ &\quad + 16\,P\int^\tau \frac{\Lambda_7(u)}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du + \frac{32}{5}\,P\int^\tau \left(u\,\coth u - 1\right)\,\mathrm{csch}^2 u\,\left(\cosh u\,\sinh u - u\right)^{1/3} \\ &\quad \times\left[5\,\Lambda_5(u) + 2\,P\,\left(-\tilde{\phi}_1(u) + \tilde{\phi}_3(u)\right)\right]\,du\Big\}\,,\end{aligned} \tag{138}$$

where

$$\begin{aligned}\Lambda_2 &= Y_2 - 16\,P\,X_7\int^\tau \frac{\left(-2\,u\,\coth^3 u + \mathrm{csch}^2 u + u^2\,\mathrm{csch}^4 u\right)\,\sinh^2 u}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du \\ &\quad - 32\,P\,X_6\int^\tau \frac{\coth u - u\,\mathrm{csch}^2 u}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du - 32\,P\,X_5\int^\tau \frac{1 - 2\,u\,\coth u + u^2\,\mathrm{csch}^2 u}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du \\ &\quad - \frac{32}{3}\,X_4\int^\tau \frac{\cosh u\,\sinh u}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du + \frac{64}{3}\,X_3\int^\tau \frac{u\,\cosh u\,\sinh u}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,du \\ &\quad - 48\,X_2\,\left(\cosh\tau\,\sinh\tau - \tau\right)^{1/3} + \frac{8}{9}\,X_1\int^\tau \frac{6\,u - 5\,\sinh 2\,u + \sinh 4\,u}{\sinh^2 u\,\left(\cosh u\,\sinh u - u\right)^{2/3}}\,h(u)\,du \\ &\quad - \frac{32}{9}\,P^2\,X_1\int^\tau \frac{-15 + 24\,u^2 + 16\,\cosh 2\,u - \cosh 4\,u - 32\,u\,\sinh 2\,u + 4\,u\,\sinh 4\,u}{\sinh^4 u\,\left(\cosh u\,\sinh u - u\right)^{1/3}}\,du \\ &\quad + \frac{64}{27}\,P^2\,X_1\int^\tau \frac{-15 + 24\,u^2 + 16\,\cosh 2\,u - \cosh 4\,u - 32\,u\,\sinh 2\,u + 4\,u\,\sinh 4\,u}{\sinh^2 u\,\left(\cosh u\,\sinh u - u\right)^{2/3}}\,j(u)\,du\,,\end{aligned} \tag{139}$$

$$\begin{aligned}\Lambda_3 &= Y_3 - \frac{32}{3}\,X_4\int^\tau \left(\cosh u\,\sinh u - u\right)^{1/3}\,du - \frac{112}{3}\,X_1\int^\tau \left(\cosh u\,\sinh u - u\right)^{1/3}\,h(u)\,du \\ &\quad - \frac{80}{3}\int^\tau \left(\cosh u\,\sinh u - u\right)^{1/3}\,\tilde{\xi}_3(u)\,du + 2\,\tau\,\coth\tau\,\Lambda_2(\tau) - 2\int^\tau u\,\coth u\,\Lambda_2'(u)\,du\,,\end{aligned} \tag{140}$$

$$\begin{aligned}\Lambda_5 &= Y_5 - \frac{1}{2}\,P\,\left(\tau\,\coth\tau - 1\right)\,\mathrm{csch}^2\tau\,\tilde{\phi}_8(\tau) - 32\,P\int^\tau \frac{\left(u\,\coth u - 1\right)\,\mathrm{csch}^2 u}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,\tilde{\xi}_8(u)\,du \\ &\quad + \frac{1}{4}\,X_7\int^\tau \mathrm{csch}^4 u\,\left[2\,u\,\left(2 + \cosh 2\,u\right) - 3\,\sinh 2\,u\right]\,h(u)\,du - X_6\int^\tau \frac{2 + \cosh 2\,u}{\sinh^4 u}\,h(u)\,du \\ &\quad + \int^\tau \mathrm{csch}^2 u\,\left[-3\,\coth u + u\,\left(2 + 3\,\mathrm{csch}^2 u\right)\right]\,h(u)\,\tilde{\xi}_5(u)\,du - \frac{1}{2}\,P\,\frac{\cosh\tau\,\sinh\tau - \tau}{\sinh^4\tau}\,\Lambda_2(\tau) \\ &\quad + \frac{1}{2}\,P\int^\tau \mathrm{csch}^4 u\,\left(\cosh u\,\sinh u - u\right)\,\Lambda_2'(u)\,du - \frac{X_1}{6\,P}\int^\tau \left(2 + \cosh 2\,u\right)\,\mathrm{csch}^4 u\,h^2(u)\,du \\ &\quad + \frac{16}{9}\,P\,X_1\int^\tau \mathrm{csch}^4 u\,\left[2\,u\,\left(2 + \cosh 2\,u\right) - 3\,\sinh 2\,u\right]\,j(u)\,h(u)\,du \\ &\quad + \frac{4}{3}\,P\,X_1\int^\tau \mathrm{csch}^6 u\,\left(\cosh u\,\sinh u - u\right)^{1/3}\,\left[2\,u\,\left(2 + \cosh 2\,u\right) - 3\,\sinh 2\,u\right]\,h(u)\,du\,,\end{aligned} \tag{141}$$

$$\begin{aligned}\Lambda_6 &= Y_6 - \frac{1}{2}\,P\,\left[-\tau + \coth\tau + \tau\,\left(-2 + \tau\,\coth\tau\right)\,\mathrm{csch}^2\tau\right]\,\tilde{\phi}_8(\tau) \\ &\quad - 32\,P\int^\tau \frac{\left[-u + \coth u + u\,\left(-2 + u\,\coth u\right)\,\mathrm{csch}^2 u\right]}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,\tilde{\xi}_8(u)\,du \\ &\quad + \frac{1}{2}\,X_7\int^\tau \left[\cosh 2\,u + \mathrm{csch}^2 u\,\left(3 + 2\,u^2 - 6\,u\,\coth u + 3\,u^2\,\mathrm{csch}^2 u\right)\right]\,h(u)\,du \\ &\quad + X_6\int^\tau \mathrm{csch}^2 u\,\left[3\,\coth u - u\,\left(2 + 3\,\mathrm{csch}^2 u\right)\right]\,h(u)\,du \\ &\quad + \int^\tau \left[1 + \left(3 + 2\,u^2 - 6\,u\,\coth u\right)\,\mathrm{csch}^2 u + 3\,u^2\,\mathrm{csch}^4 u\right]\,h(u)\,\tilde{\xi}_5(u)\,du \\ &\quad - \frac{1}{2}\,P\,\left[2\,\coth^2\tau\,\left(-1 + \tau\,\coth\tau\right) + \mathrm{csch}^2\tau - \tau^2\,\mathrm{csch}^4\tau\right]\,\Lambda_2(\tau) \\ &\quad + \frac{1}{2}\,P\int^\tau \left[2\,\coth^2 u\,\left(-1 + u\,\coth u\right) + \mathrm{csch}^2 u - u^2\,\mathrm{csch}^4 u\right]\,\Lambda_2'(u)\,du \\ &\quad + X_1\int^\tau \Big\{\frac{\mathrm{csch}^4 u\,\left[-2\,u\,(2 + \cosh 2\,u) + 3\,\sinh 2\,u\right]}{12\,P}\,h(u) + \frac{1}{36}\,P\,\mathrm{csch}^6 u \\ &\quad \times\left[8\,j(u)\,\sinh^2 u + 6\,\left(\cosh u\,\sinh u - u\right)^{1/3}\right]\left[-28 + 32\,u^2 + \left(31 + 16\,u^2\right)\,\cosh 2\,u \right. \\ &\quad \left. - 4\,\cosh 4\,u + \cosh 6\,u - 48\,u\,\sinh 2\,u\right]\Big\}\,h(u)\,du\end{aligned} \tag{142}$$

$$\begin{aligned}\Lambda_7 &= Y_7 + P\,\left[-\tau + \coth\tau + \tau\,\left(-2 + \tau\,\coth\tau\right)\,\mathrm{csch}^2\tau\right]\,\tilde{\phi}_8(\tau) \\ &\quad + 64\,P\int^\tau \frac{\left[-u + \coth u + u\,\left(-2 + u\,\coth u\right)\,\mathrm{csch}^2 u\right]}{\left(\cosh u\,\sinh u - u\right)^{2/3}}\,\tilde{\xi}_8(u)\,du \\ &\quad + X_7\int^\tau \left[-1 + \left(-3 - 2\,u^2 + 6\,u\,\coth u\right)\,\mathrm{csch}^2 u - 3\,u^2\,\mathrm{csch}^4 u\right]\,h(u)\,du \\ &\quad + X_6\int^\tau \mathrm{csch}^4 u\,\left[2\,u\,\left(2 + \cosh 2\,u\right) - 3\,\sinh 2\,u\right]\,h(u)\,du \\ &\quad + \int^\tau \left[-2 - 2\,\mathrm{csch}^2 u\,\left(3 + 2\,u^2 - 6\,u\,\coth u + 3\,u^2\,\mathrm{csch}^2 u\right)\right]\,h(u)\,\tilde{\xi}_5(u)\,du \\ &\quad - P\,\mathrm{csch}^2\tau\,\left(1 - 2\,\tau\,\coth\tau + \tau^2\,\mathrm{csch}^2\tau\right)\,\Lambda_2(\tau) \\ &\quad + P\int^\tau \mathrm{csch}^2 u\,\left(1 - 2\,u\,\coth u + u^2\,\mathrm{csch}^2 u\right)\,\Lambda_2'(u)\,du \\ &\quad + X_1\int^\tau \Big\{\frac{\mathrm{csch}^4 u\,\left[2\,u\,\left(2 + \cosh 2\,u\right) - 3\,\sinh 2\,u\right]}{6\,P}\,h(u) - \frac{1}{9}\,P\,\mathrm{csch}^6 u \\ &\quad \times\left[8\,j(u)\,\sinh^2 u + 6\,\left(\cosh u\,\sinh u - u\right)^{1/3}\right] \\ &\quad \times\left[-9 + 16\,u^2 + 8\,\left(1 + u^2\right)\,\cosh 2\,u + \cosh 4\,u - 24\,u\,\sinh 2\,u\right]\Big\}\,h(u)\,du\,.\end{aligned} \tag{143}$$

C IR and UV expansions of our analytic solutions

C.1 IR expansions

The IR behavior of the modes is obtained by Taylor expanding h, j and the integrands in (131-138), performing the indefinite integral over τ (instead of the integral from 1 to τ), and adding an integration constant Y_a^{IR} (since the conjugate momenta ξ_a do not involve integrals other than h and j, we do not have to introduce a second set of integration constants X^{IR} different from the one used in (121)-(127)).

Previous results: Borokhov, Gubser 02; Kuperstein, Sonnenschein 03; Apreda 03; DeWolfe, Kachru, Mulligan 08; McGuirk, Shiu, Sumitomo 09; Bena, Grana, Halmagyi 09; Dymarsky 11

The force on probe branes

- Universal behavior:

$$F_{D3} = \frac{X_1}{(\sinh 2\tau - 2\tau)^{2/3}} \sim \frac{X_1}{r^5} + \mathcal{O}\left(\frac{1}{r^{11}}\right)$$

$$r \sim e^{\tau/3}$$

- IR boundary conditions will fix

$$X_1^{\bar{D}3} \sim p$$

- Perfect agreement with force on anti-branes probing the backreaction of BPS branes (easy).

Kachru, Kallosh, Linde, Maldacena, McAllister, Trivedi 03

IR boundary conditions

- Full solution: 16 dimensional space of parameters (X_a, Y_a)

- We require:

$$h(\tau) \sim \frac{p}{\tau} + \mathcal{O}(\tau^0)$$
$$\mathcal{F}_5 \sim -p\,\mathrm{vol}_5 + \mathcal{O}(\tau)$$

$\longrightarrow$ Fix 6 int. constants + $Y_7, X_1 \sim p$

- 16 - 1 (zero energy condition) - 8 (IR boundary conditions) = 7

- Left with a 7 dimensional subspace of deformations.

Caveat

- We find an IR singularity, proportional to p:

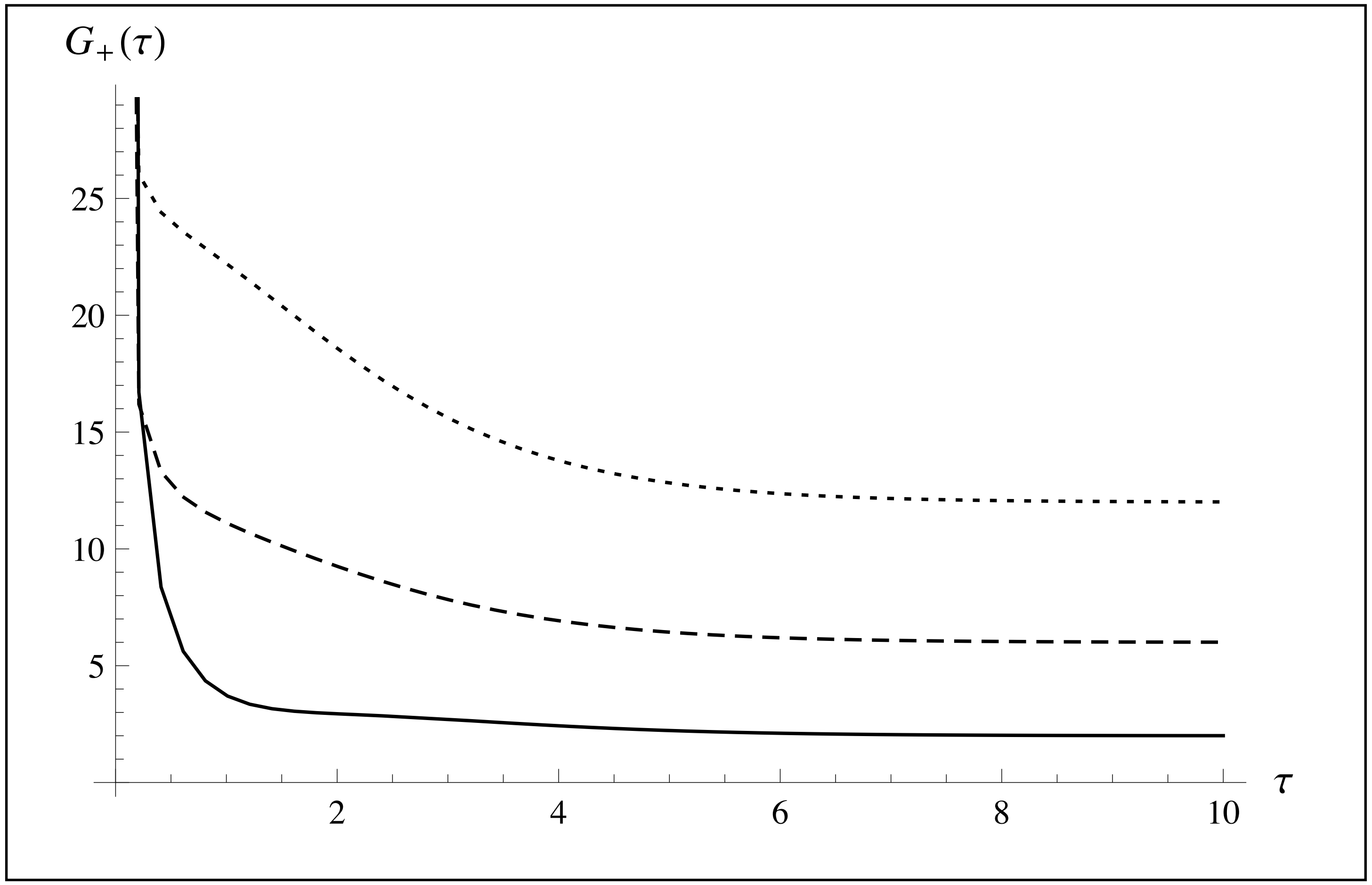
$$G_+ \sim G_- \sim \frac{p}{\tau}$$

(but finite action)

McGuirk, Shiu, Sumitomo 09

Bena, Grana, Halmagyi 09

SM 12



Plot of G_+ with legs on the S^3

$$G_\pm = \star G_3 \pm i G_3$$

Caveat

- No brane interpretation

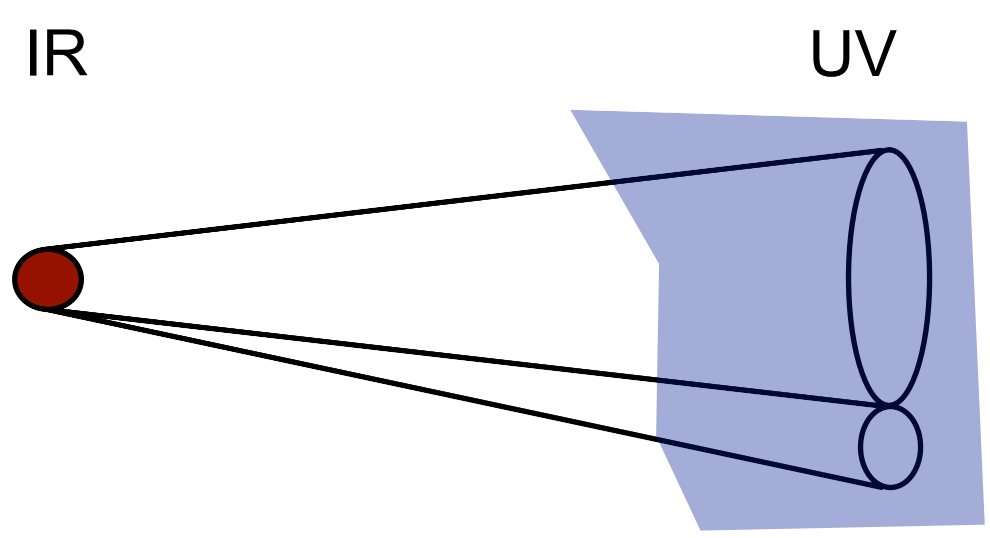
- Generic feature of anti-brane solutions

Blaback, Danielsson, Junghans, Van Riet, Wrase, Zagermann et al 11

- Preliminary results on the non-linear solution seem to confirm the presence of such singularities.

IN PROGRESS

- Let’s pretend the singularity is acceptable... look at the UV!



UV behavior

- Schematic UV behavior of all modes:

dim Δ	non-norm/norm	integration constants
8	r^4/r^{-8}	Y_4/X_1
7	r^3/r^{-7}	Y_5/X_6
6	r^2/r^{-6}	X_3/Y_3
5	r/r^{-5}	$---$
4	r^0/r^{-4}	$Y_7, Y_8, Y_1/X_5, X_4, X_8$
3	r^{-1}/r^{-3}	$X_2, X_7/Y_6, Y_2$
2	r^{-2}/r^{-2}	$---$

$$\dim \mathcal{O} = \Delta$$

Normalizable modes $(r^{-\Delta})$ $\quad \rightarrow \quad \langle \mathcal{O} \rangle$

Non-normalizable modes $(r^{\Delta-4})$ $\quad \rightarrow \quad \delta\mathcal{L} = \mathcal{O}$

UV behavior

- Schematic UV behavior of all modes:

Force mode

dim Δ	non-norm/norm	integration constants
8	r^4/r^{-8}	Y_4/X_1
7	r^3/r^{-7}	Y_5/X_6
6	r^2/r^{-6}	X_3/Y_3
5	r/r^{-5}	$---$
4	r^0/r^{-4}	$Y_7, Y_8, Y_1/X_5, X_4, X_8$
3	r^{-1}/r^{-3}	$X_2, X_7/Y_6, Y_2$
2	r^{-2}/r^{-2}	$---$

= fixed by IR boundary conditions

Charge mode

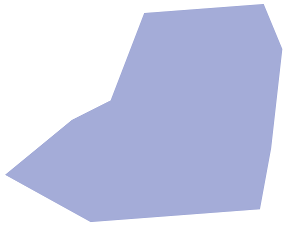
UV behavior

- Schematic UV behavior of all modes:

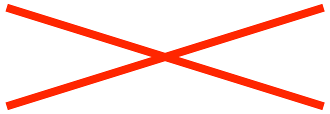
Force mode

dim Δ	non-norm/norm	integration constants
8	r^4/r^{-8}	X_4/X_1
7	r^3/r^{-7}	X_5/X_6
6	r^2/r^{-6}	X_3/Y_3
5	r/r^{-5}	$---$
4	r^0/r^{-4}	$Y_7, Y_8, Y_1/X_5, X_4, X_8$
3	r^{-1}/r^{-3}	$X_2, X_7/Y_6, Y_2$
2	r^{-2}/r^{-2}	$---$

Charge mode



= fixed by IR boundary conditions



= set to zero

All integration constants fixed in terms of p!

The anti-D3 solution (UV)

$$X_1 = \frac{3\pi}{4h_0^2} p$$

$$\tilde{\phi}_8 = -\frac{64}{3}\, 2^{1/3}\, e^{-4\tau/3}\, h_0\, X_1\, (\tau - 1) - 288\, 2^{2/3}\, e^{-8\tau/3}\, P^2\, X_1 + \mathcal{O}(e^{-10\tau/3})\,, \tag{83}$$

$$\tilde{\phi}_2 = -418.571\, e^{-\tau}\, P^2\, X_1 + \frac{16}{3}\, 2^{1/3}\, e^{-7\tau/3}\, h_0\, X_1\, (1 + 8\tau) + \mathcal{O}(e^{-3\tau})\,, \tag{84}$$

$$\tilde{\phi}_3 = -\frac{32}{3}\, 2^{1/3}\, e^{-4\tau/3}\, h_0\, X_1 + 2\, e^{-2\tau}\, (1186.08 - 418.571\, \tau)\, P^2\, X_1 - \frac{1152}{5}\, 2^{2/3}\, e^{-8\tau/3}\, P^2\, X_1 + \mathcal{O}(e^{-10\tau/3})\,, \tag{85}$$

$$\tilde{\phi}_1 = 428.85\, P^2\, X_1 + \frac{8}{3}\, 2^{1/3}\, e^{-4\tau/3}\, h_0\, X_1 - \frac{2}{3}\, e^{-2\tau}\, (1325.73 - 837.143\, \tau)\, P^2\, X_1 + \frac{24}{5}\, 2^{2/3}\, e^{-8\tau/3}\, P^2\, (29 + 40\, \tau)\, X_1 + \mathcal{O}(e^{-10\tau/3})\,, \tag{86}$$

$$\tilde{\phi}_5 = 312.743\, P^3\, X_1 + e^{-\tau}\, (-1361.84 + 418.571\, \tau)\, P^3\, X_1 - 4\, 2^{1/3}\, e^{-4\tau/3}\, h_0\, P\, X_1\, (1 + 8\, \tau) + 2\, e^{-2\tau}\, (1361.84 - 837.143\, \tau)\, P^3\, X_1 + \mathcal{O}(e^{-7\tau/3})\,, \tag{87}$$

$$\tilde{\phi}_6 = 312.743\, P^3\, X_1 + e^{-\tau}\, (1361.84 - 418.571\, \tau)\, P^3\, X_1 - 4\, 2^{1/3}\, e^{-4\tau/3}\, h_0\, P\, X_1 (1 + 8\, \tau) + 2\, e^{-2\tau}\, (1361.84 - 837.143\, \tau)\, P^3\, X_1 + \mathcal{O}(e^{-7\tau/3})\,, \tag{88}$$

$$\tilde{\phi}_7 = e^{-\tau}\, (943.269 - 418.571\, \tau)\, P^3\, X_1 - \frac{4}{125}\, 2^{1/3}\, e^{-7\tau/3}\, h_0\, P\, (1199 + 80\, \tau\, (1 + 10\, \tau))\, X_1 + \mathcal{O}(e^{-11\tau/3})\,, \tag{89}$$

$$\tilde{\phi}_4 = 171.54 P^3 X_1 + \frac{4\, 2^{1/3}\, e^{-4\tau/3}\, h_0\, (7 + 32\, \tau)\, X_1}{3\, (4\, \tau - 1)} - \frac{625.486 P^2 X_1}{(4\, \tau - 1)} + \mathcal{O}(e^{-2\tau})\,. \tag{90}$$

Maxwell charge

- Look at the Maxwell charge:

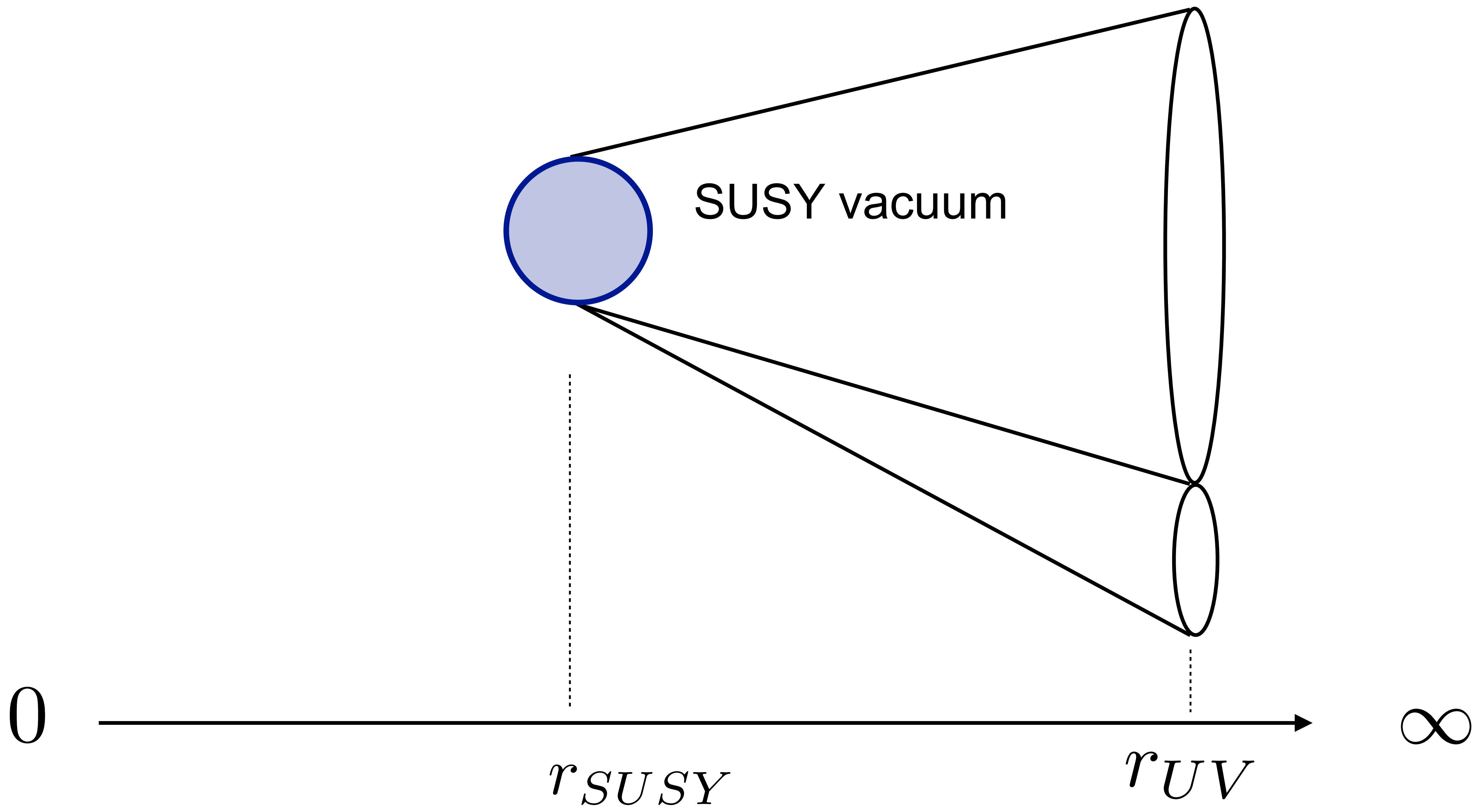
$$Q_{D3}^{Max} = \frac{1}{(4\pi^2\alpha')^2}\int_{T_r^{1,1}} \mathcal{F}_5$$
$$\sim p + \log\frac{r}{\epsilon^{2/3}}\,, \qquad r \to \infty$$

- This quantity should be the same for the two vacua. This fix:

$$\frac{\epsilon_{MS}}{\epsilon_{SUSY}} \neq 1$$

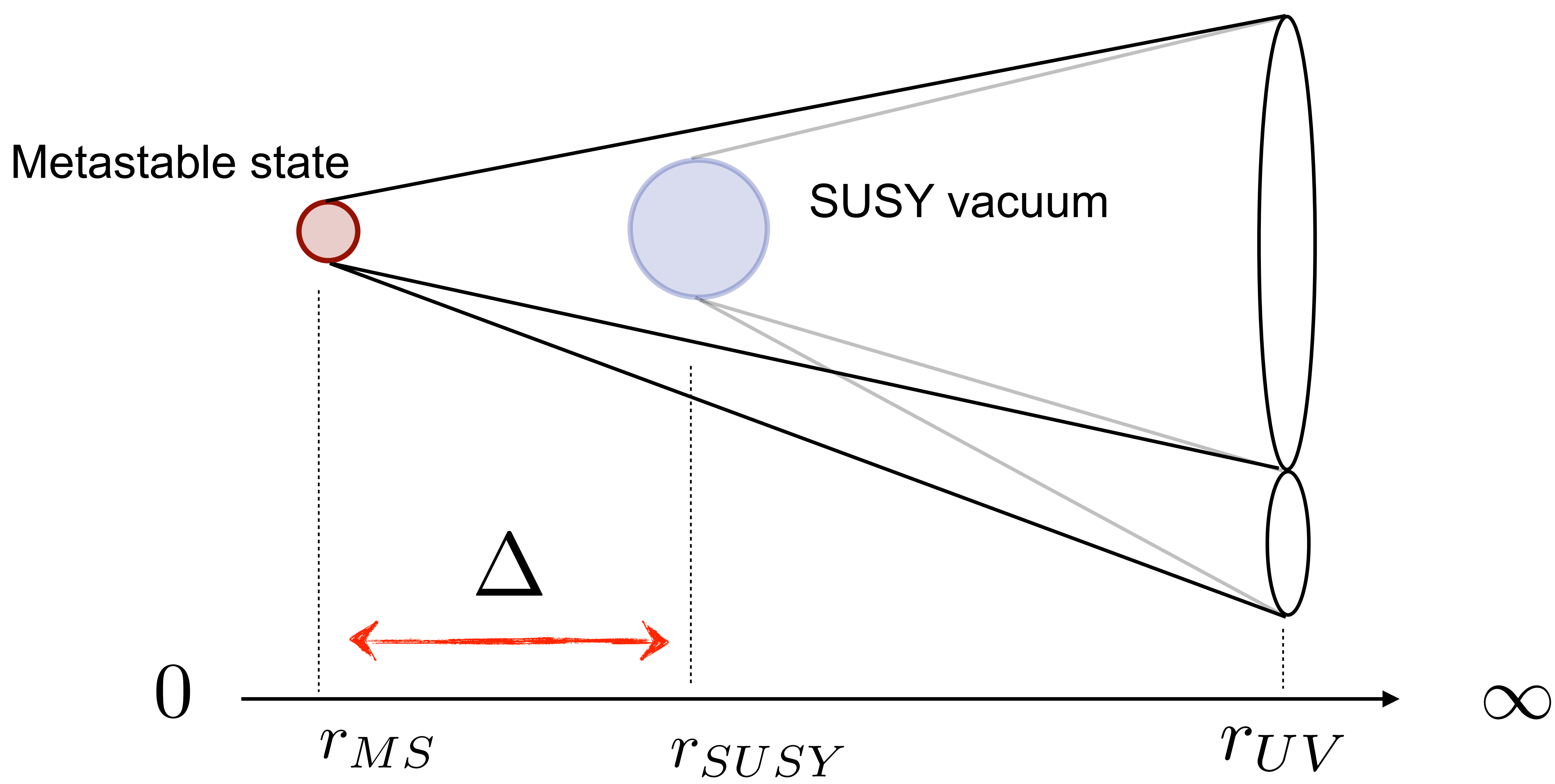
- This is related to the ratio of confinement scales.

Maxwell charge



Maxwell charge

"Anti-branes shrink the tip"



$$\Delta \sim 4.6178... \frac{p}{M}$$

Anti-M2

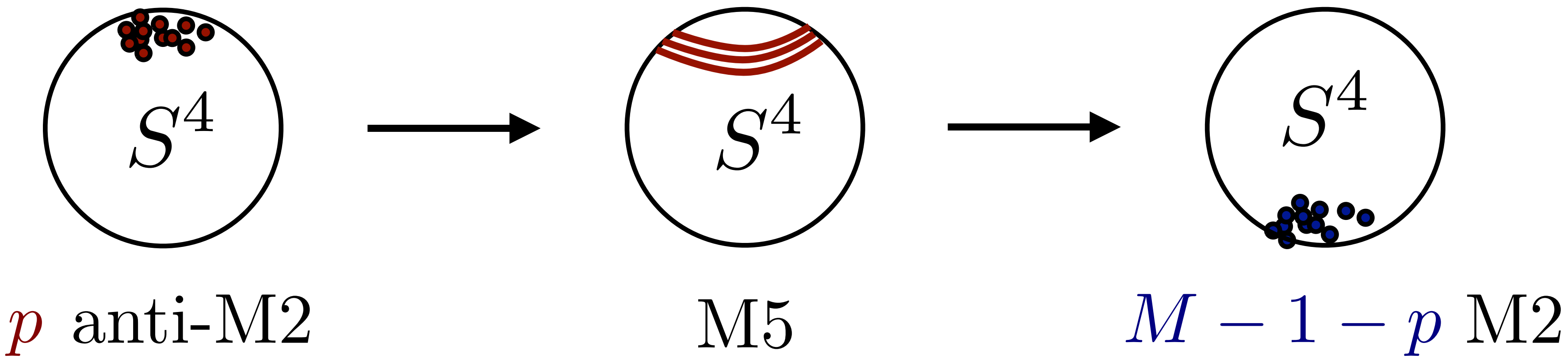
- SUSY configuration:

Cvetič, Gibbons, Lü, Pope 00

(2+1)-dimensional theory dual to $AdS_4 \times V_{5,2}$

- Metastable proposal

Klebanov, Pufu 10



- Same kind of IR singularity in G_4 flux

Bena, Giecold, Halmagyi 10

- The linearized backreaction is analytic and the UV works fine.

SM 11

Summary

- ➡ Found full first-order backreacted solution for anti-branes in flux compactifications

- ➡ Explicit computation of the force felt by probe branes
  - agreement with computation à la KKLMMT

- ➡ IR singularities, no brane interpretation

- ➡ It would be interesting to compute the confinement scale directly from the field theory and compare to our result

- ➡ Check (un)stability.

Summary

Thank you.