SUSY Breaking in the Klebanov-Strassler Background by Anti-D3 Branes

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based on arxiv:0912.3519

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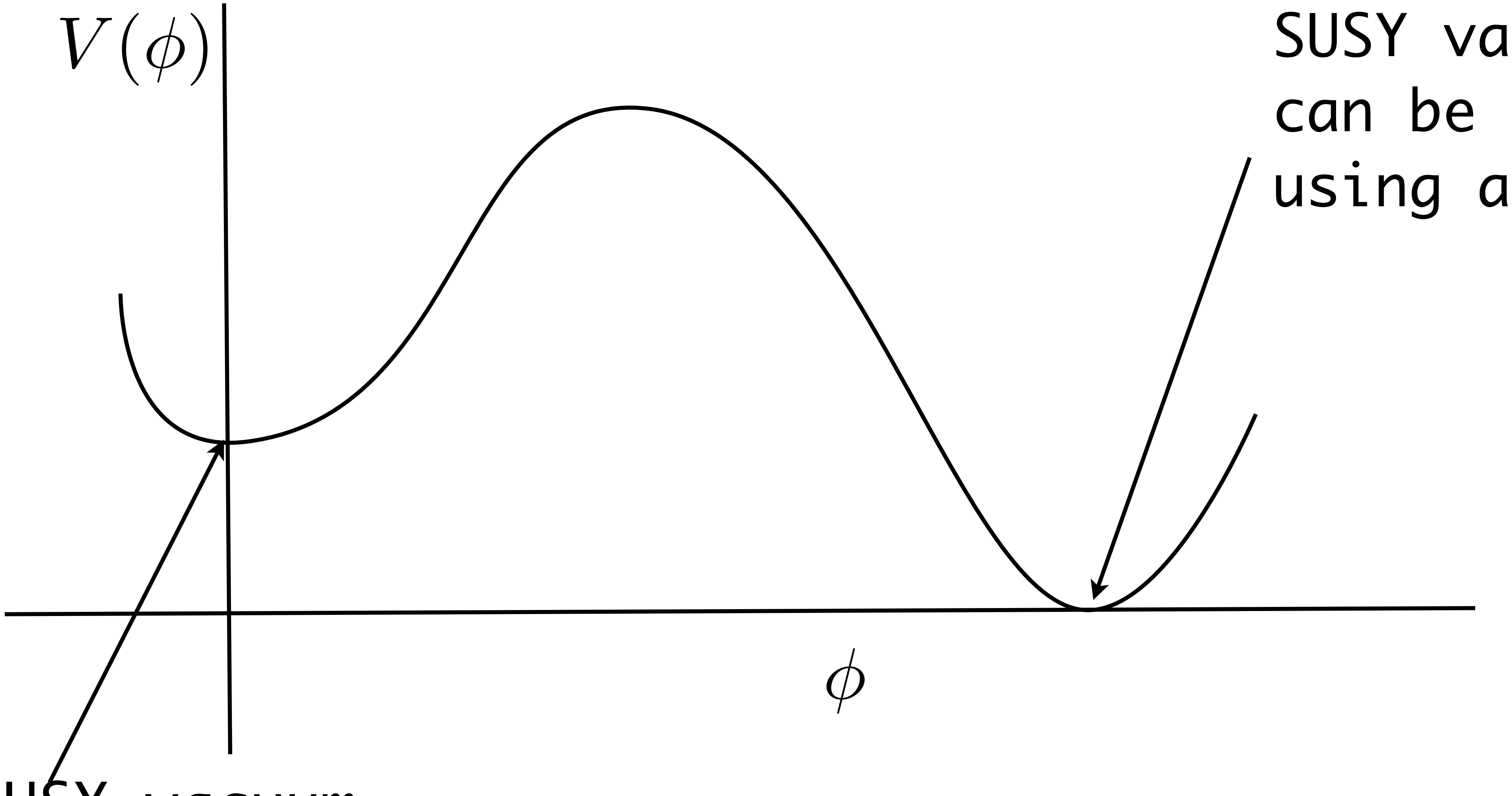
and work in progress...

Outline

- Review of meta-stable vacua, flux compactifications and the Klebanov-Strassler (KS) Background
- KPV proposal for spontaneous susy breaking in the KS background
- Our computation of the spectrum around KS
- The anti-D3 brane in the Klebanov-Strassler background

Meta-Stable Vacua in Field Theory



SUSY vacuum,
can be found
using an index

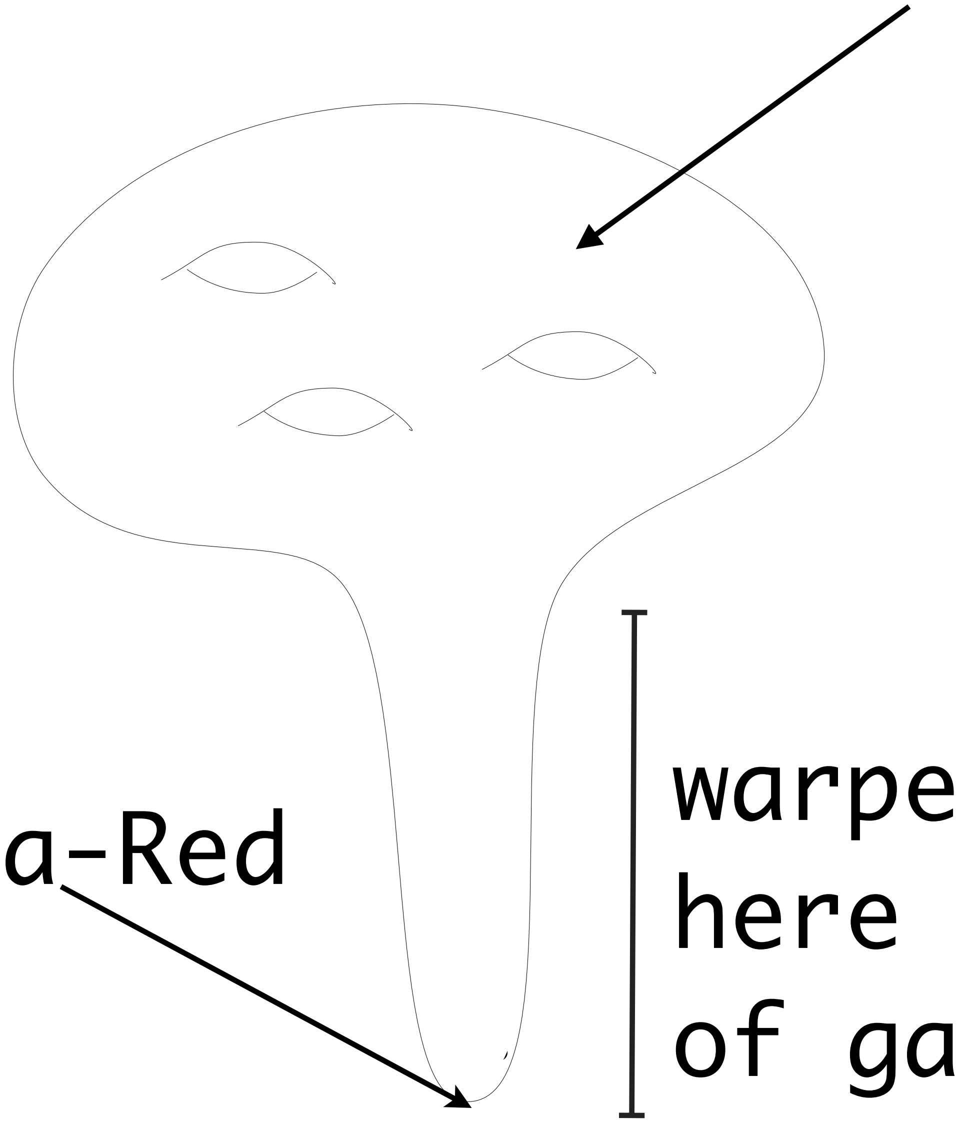
non-SUSY vacuum

scalar potential $\xrightarrow{?}$ spontaneous SUSY breaking

- Non-SUSY vacua are difficult to identify. In general, strongly coupled QFT $\longrightarrow$ hard to calculate $V(\phi)$

- Strategies to study the scalar potential
    - Limit oneself to the holomorphic sector
    - Use a field theory duality
    - Use gauge/gravity duality
    - perhaps perturbation theory in simple examples

Flux Compactifications in String Theory



six dimensional internal geometry gives the 4d UV completion by gravity

+ moduli stabilization
(hard problem)

Infra-Red

warped throat region,
here we can utilize the power of gauge/gravity duality

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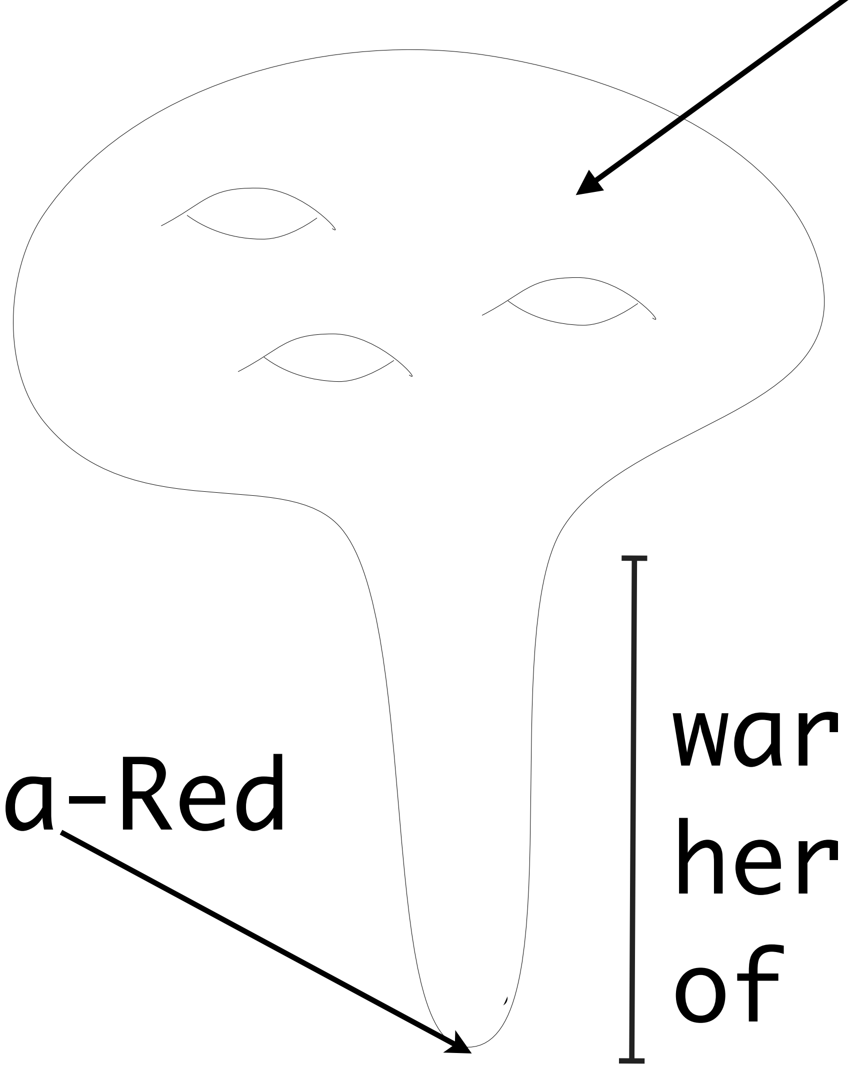

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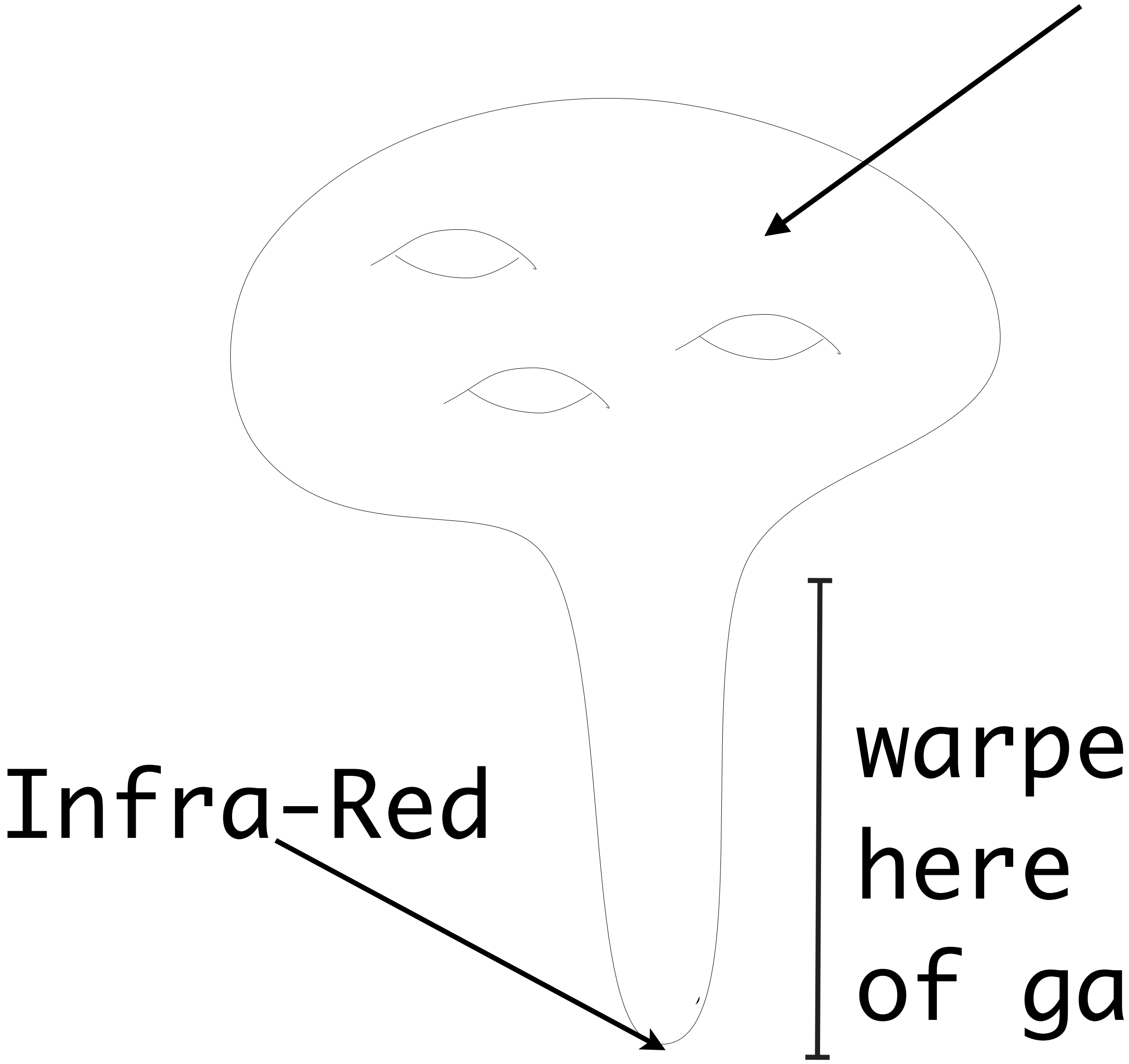
how is SUSY broken?

Flux Compactifications in String Theory



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warped throat region,
here we can utilize the power of gauge/gravity duality

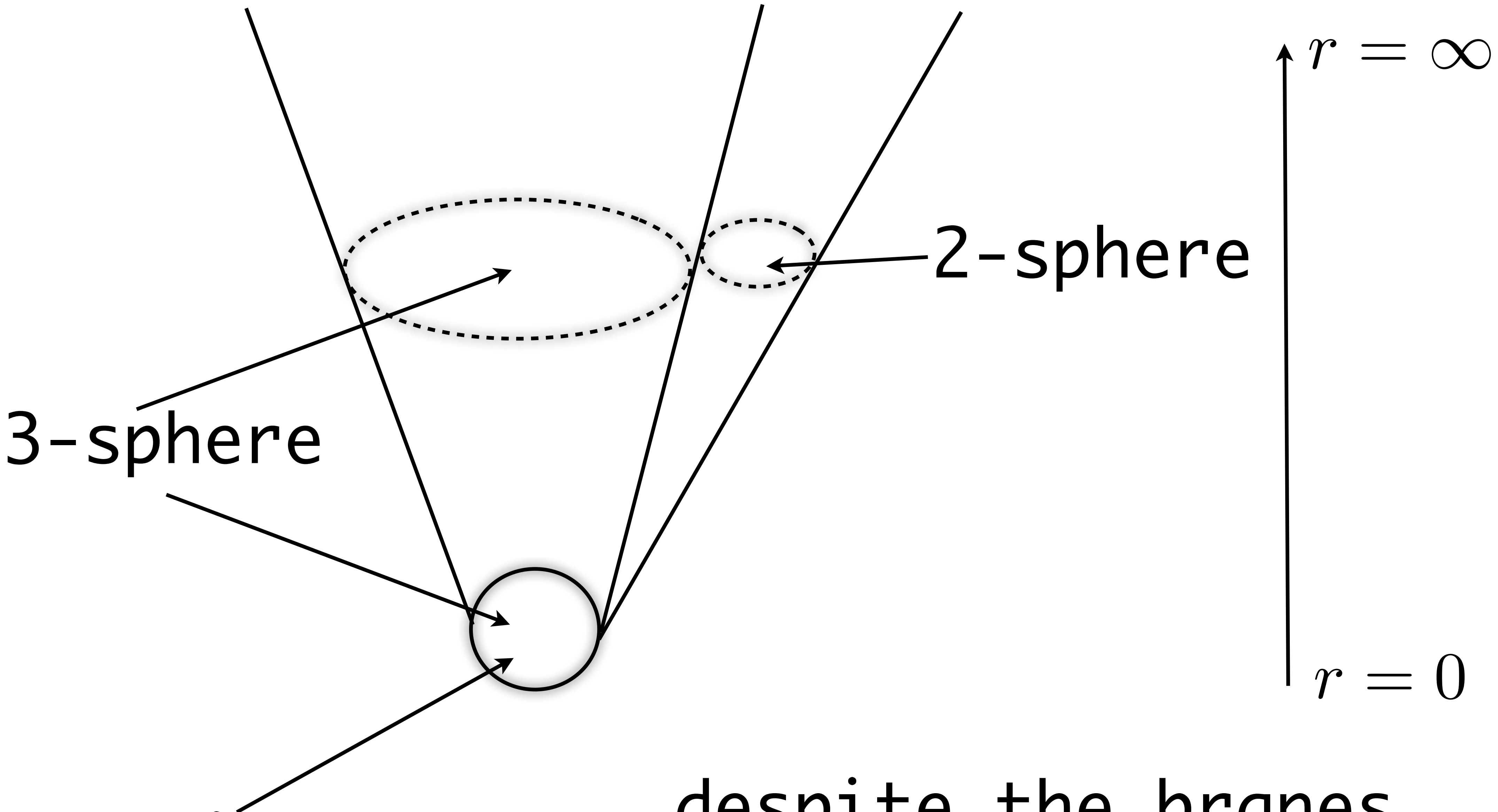
how is SUSY broken?

at what scale is SUSY broken?

Warped Throat Region:
The Klebanov-Strassler Background

The Deformed Conifold $R^{(6)}_{ij} = 0$

Klebanov-Strassler '99



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

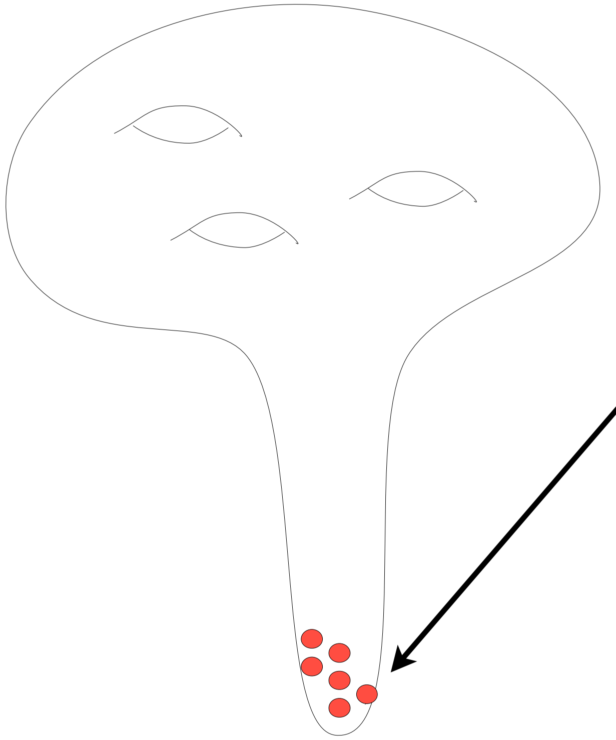
despite the branes dissolved in flux, this is a smooth sugra solution

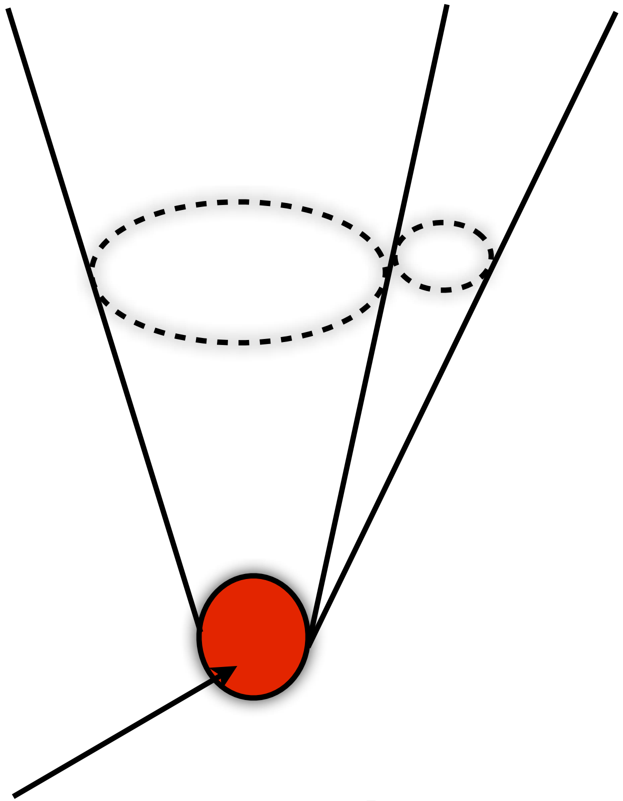
KPV proposal for spontaneous SUSY breaking

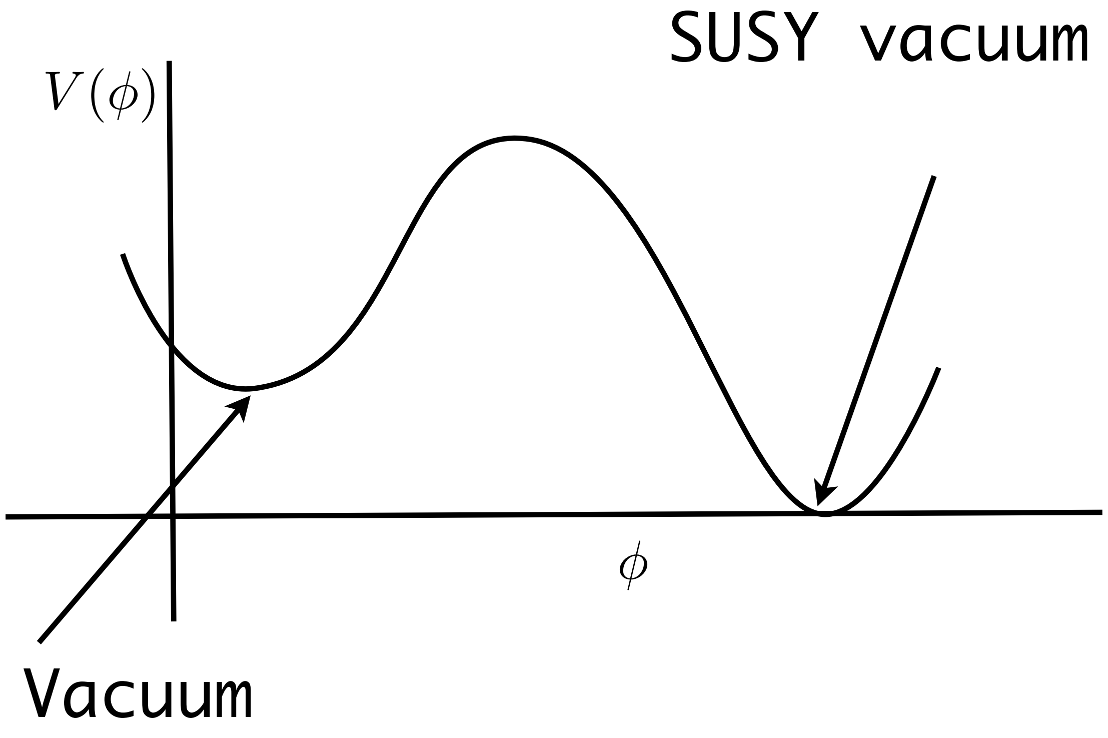
Kachru/Pearson/Verlinde '01

Probe Approx'

A stack of P anti-D3 branes in the IR breaks SUSY

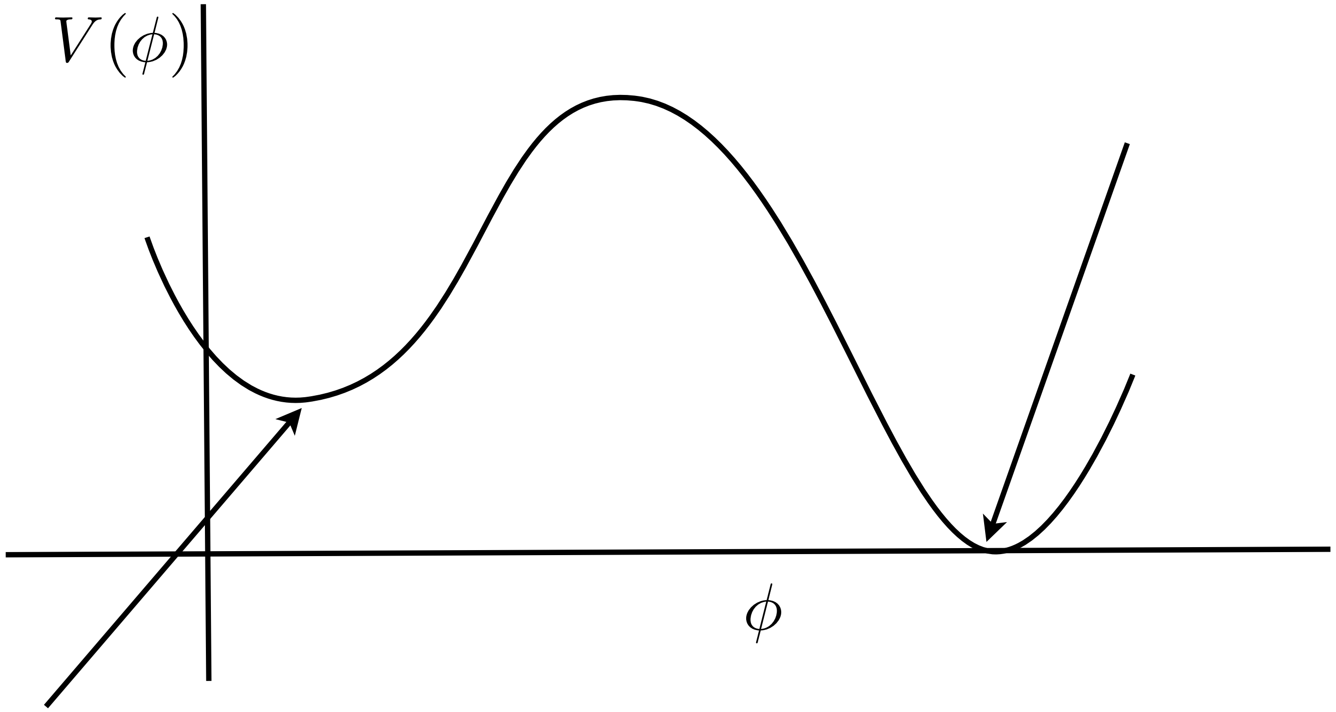






We will preserve the symmetries of the sphere by smearing the anti-D3 branes

KPV proposal for spontaneous SUSY breaking



SUSY vacuum $q_b = 0$

KPV Vacuum

$$-\overline{N} < q_b < 0$$

$$q_b = \int_{T_0^{11}} F^{(5)}$$

$$\boxed{\begin{aligned} \mathcal{Q}_{D3}^{Max} &= q_b + q_f \\ &= -\overline{N} \end{aligned}}$$

$$q_f = \int_{X_6} H^{(3)} \wedge F^{(3)}$$

$$= \left(\int_{T_\infty^{11}} - \int_{T_0^{11}}\right) F^{(5)}$$

Our Goal: find the supergravity solution for the backreacted anti-D3 branes

- This exact supergravity solution would determine unambiguously whether the SUSY breaking by anti-D3 branes is explicit or spontaneous.
- If it is spontaneous, this solution would be very useful for model building, explicit SUSY breaking is less useful
- We work in perturbation theory around the KS background in $\overline{N}/M$

AdS/CFT Review: VEV's/Deformations

- In AdS space, the wave equation for a scalar field has two possible behaviours near the boundary.

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

$$\phi \sim r^{d-\Delta} \longleftrightarrow \text{Deformation by } \delta S = \int d^d x \mathcal{O}(x)$$

$$\phi \sim r^{-\Delta} \longleftrightarrow \langle \mathcal{O}(x) \rangle$$

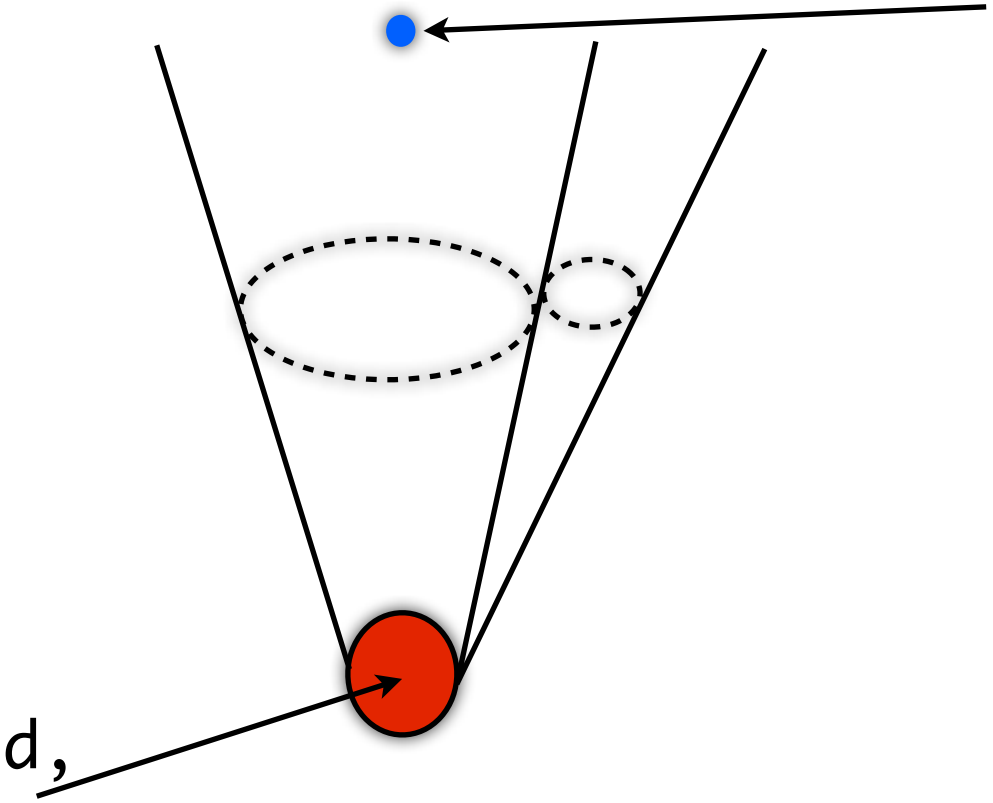
- In the UV the KS solution is almost AdS, up to logarithm terms
- The physical modes in the UV can only be determined by fixing the IR b.c.'s.

$SU(2) \times SU(2) \times \mathbb{Z}_2$ invariant KS scalar spectrum

UV Behavior of the spectrum

dim Δ	non-norm/norm	int. constant
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}	$- - -$

- The X_i break SUSY
- The Y_j preserve SUSY



Probe D3 in the UV
feels an inward force
iff $X_1^{UV} > 0$

Backreacted,
anti-D3's

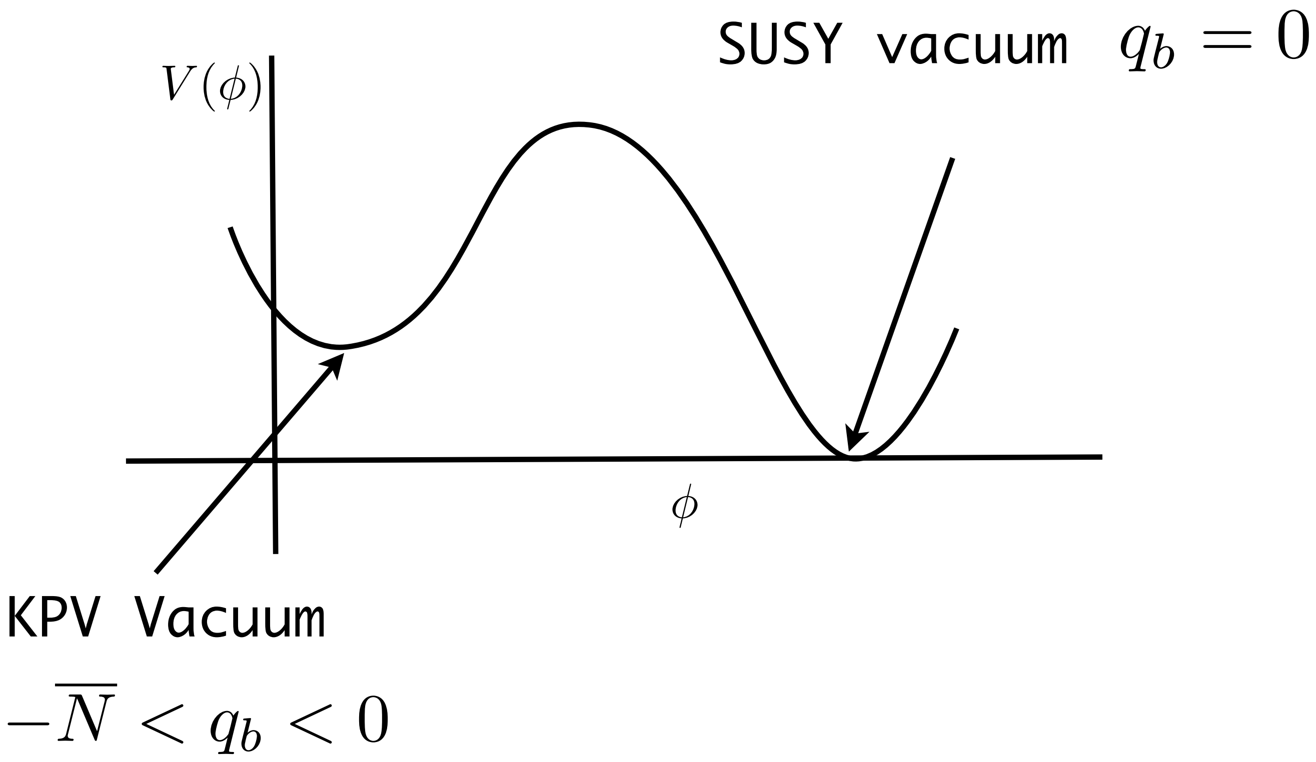
- Universal asymptotic UV falloff for the force on a probe D3 brane in perturbed KS background

$$F \sim \frac{X_1}{r^5} + \mathcal{O}(r^{-11})$$

- X_1 is solely responsible for a force on a probe D3 brane!

Our Strategy

- First enforce UV boundary conditions of the SUSY vacuum



- Examine IR boundary conditions and allow for physical singularities

- If no such IR boundary conditions can be found, we would then conclude that the UV boundary conditions must be changed

IR Singularities

We find various singularities
in the IR

- warp factor $\sim \tau^{-1}$

  and thus $R \sim F_{(5)}^2 \sim \tau^{-4}$ ✓

perfectly physical, due to
the smeared anti-D3 branes

- However, we also find a highly unusual singularity

$$H_{(3)}^2 \sim F_{(3)}^2 \sim \tau^{-2}$$ ✗

which has no physical interpretation.

- Despite having finite action, this singularity alone in the energy density from the three-forms should be considered an unacceptable singularity.

- However, it could be an artifact of the singularity in the energy density of the curvature and five form due to the smearing

Numerical Analysis

Bena, Graña, N.H.
work in progress

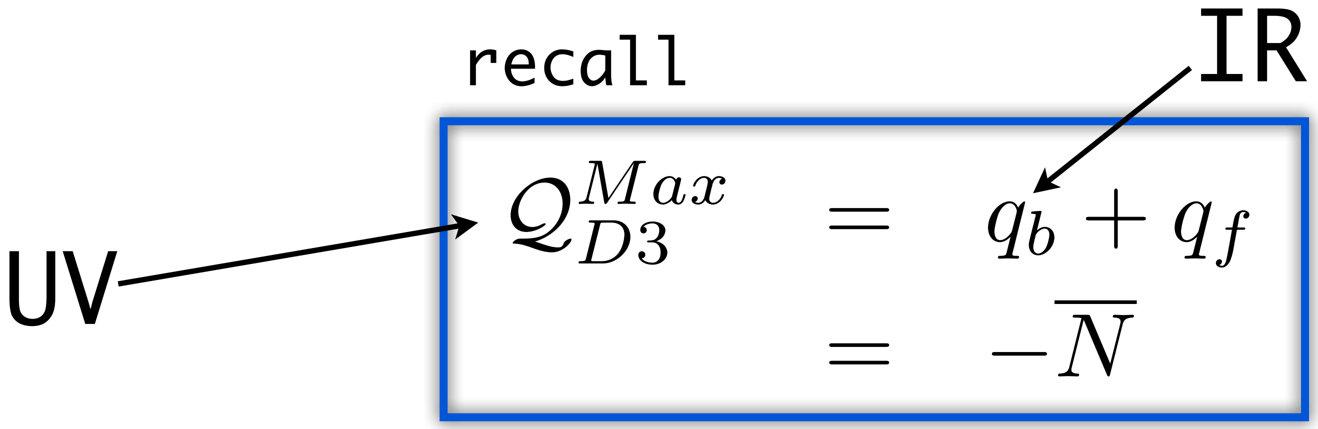
- The superpotential approach is a nice organizing principle for non-SUSY backgrounds which are first order perturbations around a SUSY background

  Papadopoulos, Tseytlin 2000
  Borokhov,Gubser 2002

- We have two sets of eight coupled first order O.D.E.'s. The bulk mass of these modes is known numerically Berg,Haack,Muck 2006 but we need the actual modes.

Numerical Analysis...

- Numerically integrating the field equations will allow us to relate IR and UV integration constants.



recall

$$\begin{aligned} \mathcal{Q}_{D3}^{Max} &= q_b + q_f \\ &= -\overline{N} \end{aligned}$$

- We will compute (q_b, q_f) in terms of $\overline{N}$

- We will also compute X_1^{UV} the coefficient of the force on a probe D3, in terms of $\overline{N}$

Summary

- Breaking supersymmetry by adding anti-D3 branes has been common practice and thus understanding the UV behaviour is a vital problem.
- Supergravity is our best tool since the field theory is strongly coupled everywhere.
- The IR singularities in our linear order analysis around KS suggest that the UV boundary conditions cannot be that of KS
  - This seems to imply that the supersymmetry breaking is explicit. However more work needs to be done:

Future Directions

- Unsmearing the brane
- Beyond perturbation theory
- Examine stability of our solution