The Randall-Sundrum Model in string theory and throat field mediated SUSY breaking

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based on hep-th/0510113 and hep-th/0605232
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Motivation and overview

The Randall-Sundrum 1 model: $ds^2 = e^{2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$
— a "slice of AdS_5" between two 4d branes: ($\rightarrow$ Randall/Sundrum '99)

- Interesting for particle physics and cosmology model building: Hierarchy problem / Compositeness / Sequestering / . . .
- How can such models be realized in string compactifications?
- Type IIB compactifications with branes and fluxes may develop a "warped throat" which looks like a RS background (plus 5 compact extra dimensions) $\rightarrow$ Verlinde '99, Giddings/Kachru/Polchinski '01

In this context, we will investigate:

1. the 5d description of 10d hierarchy stabilization by fluxes
2. the role of the universal unstabilized Kähler modulus in 5d
3. how SUSY breaking can be mediated from the IR to the UV brane

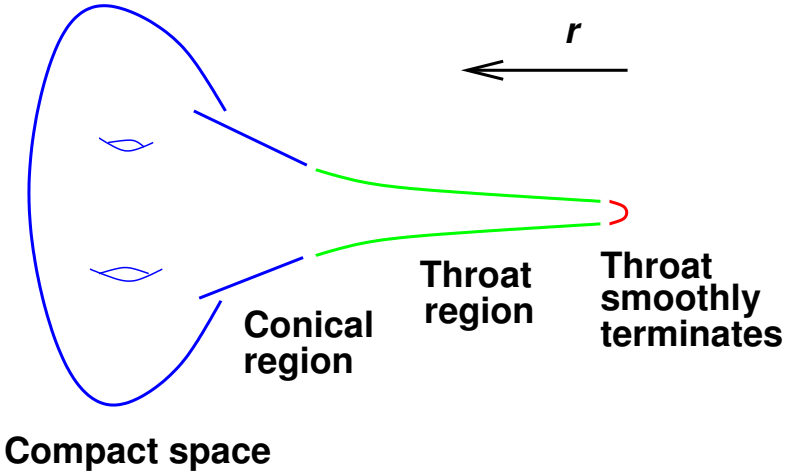
Review: The warped deformed conifold

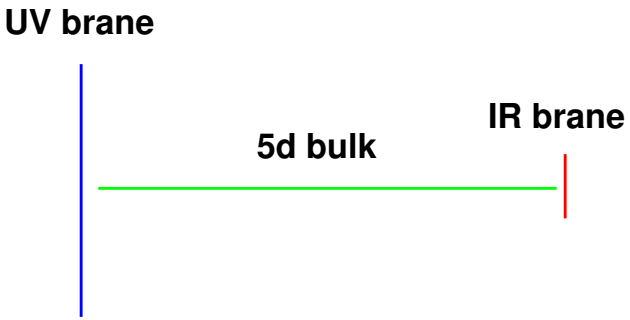
Example of a warped compactification of 10d IIB supergravity with fluxes $\rightarrow$ Klebanov/Strassler '00, GKP:

- spacetime is warped product of 4d Minkowski space with 6d CY manifold (actually CY orientifold or F theory base)
- in some "warped throat" region geometry is approximately $AdS_5 \times T^{1,1}$ (where $T^{1,1} \simeq S^2 \times S^3$ is a 5d Einstein space)
- have M units of RR 3-form flux on the S^3
- Radius R of $T^{1,1}$ and AdS varying slowly along AdS radial direction r:
- $R_{\text{eff}}(r)^4 \sim (\alpha')^2 g_s N_{\text{eff}}(r)$
- $N_{\text{eff}}(r) \sim g_s M^2 \log \frac{r}{r_s}$
- have $N_{\text{eff}}(r)$ units of $\tilde{F}_{(5)}$ flux through $T^{1,1}$ at r, where $\tilde{F}_{(5)} = F_{(3)} \wedge B_{(2)} + \ldots$ (compare this with D3 brane metric!)

10d vs. 5d geometry

This "warped throat" is part of some compact CY space:





- throat terminates smoothly at small r: RS IR brane
- throat becomes conical for large r. Compact CY + conical region: RS UV brane
- throat itself: RS bulk, approximately AdS_5 ($\times T^{1,1}$)

1. 10d vs. 5d radius stabilization

Fluxes can stabilize complex structure moduli, governing the hierarchy between IR and UV end. 5d mechanism?
Recall that interval length/hierarchy is modulus in pure RS 1!
Deviation from AdS geometry in throat: parametrized by one scalar degree of freedom, $N_{\text{eff}}(r) \sim \int_{T^{1,1}\text{ at } r} \tilde{F}_{(5)}$, with fixed boundary values N_{UV}, N_{IR}:

- N_{UV} fixed by branes and fluxes on UV manifold (tadpole condition)
- $N_{\text{IR}} = g_s M^2$

Compare this with Goldberger-Wise mechanism for radius stabilization in RS I:

- field content = gravity + 1 scalar H with boundary values fixed by steep potentials on boundaries $\rightarrow$ Goldberger/Wise '99
- Bulk profile + boundary values determine interval length.
- Here: Can determine bulk potential from requiring that backreaction gives rise to correct deformation of AdS background.
- Result: $V_{\text{bulk}}(H) \sim M_5^7 R_{\text{eff}}(r_s)^{-2} H^{-8/3}$

2. The universal Kähler modulus

- Complex structure moduli can be stabilized by fluxes
- but Kähler moduli remain massless (at this stage...)
- $\exists$ always at least a "universal" Kähler modulus which in unwarped compactifications governs the size of the internal manifold.

Geometrical significance of the UKM? (see also $\rightarrow$ S. Giddings' talk)
Throat metric:

$$ds^2 = h(r)^{-1/2}\eta_{\mu\nu}dx^\mu dx^\nu + h(r)^{1/2}(dr^2 + r^2 ds^2_{T^{1,1}}), \quad h(r) = 1 + \frac{R_{\text{eff}}(r)^4}{r^4}$$

UKM : can change $h(r) \rightarrow T + R_{\text{eff}}(r)^4/r^4$ ($\rightarrow$ Giddings/Maharana '05)

- For large T (T dominant in h):
  - $T \leftrightarrow$ overall rescaling of internal manifold as in unwarped case
  - 5d picture not valid (no throat)
- For small T:
  - T rescales only UV manifold + conical region
  - throat length and shape unaffected
  - T is a UV brane field in the 5d picture

3. SUSY breaking mediation by throat fields

Assume now ($\rightarrow$ KKLT '04):

- T is stabilized nonperturbatively
- SUSY is broken in the IR (e.g. by $\overline{\text{D3}}$s), vacuum dS or Minkowski

and

- Standard Model fields Q live somewhere on the UV manifold

No direct coupling between ~~SUSY~~ sector and SM sector: sequestering ($\rightarrow$ Randall/Sundrum '98)

How can ~~SUSY~~ be mediated from the IR to the UV?

- Dominant in this framework: mixed modulus-anomaly mediation ($\rightarrow$ Choi/Falkowski/Nilles/Olechowski '05, H.-P. Nilles' talk)
- Other equally important contributions? (see also $\rightarrow$ Choi/Jeong '06)

3. SUSY breaking mediation by throat fields

Effective 4d theory: Model ~~SUSY~~ sector as F term breaking by chiral superfield X. All heavy (flux-stablized) moduli integrated out.

Minimal scenario (modulus-anomaly mediation):

$$\mathcal{L} \supset \int d^4\theta\, \overline{\varphi}\varphi\, \Omega + \int d^2\theta\, \varphi^3\, W + \text{h.c.}$$

$$\Omega = -(T+\overline{T}) + \omega^2 \tilde{\Omega}(X,\overline{X}), \qquad W = W_0 + e^{-T} + \omega^3 \tilde{W}(X)$$

- $\omega \ll 1$ is the warp factor in the IR
- T is UV brane field $\Rightarrow$ sequestering in Ω
- e^{-T} term from nonperturbative stabilization, W_0 from heavy fields

For Minkowski (or dS with small Λ) uplift: need $W_0 \sim \omega^2, F_X \sim \omega$
$\Rightarrow F_\varphi \sim \omega^2$

- Add visible sector in the UV:
- $\Rightarrow$ soft scalar masses $m^2 \sim \omega^4$ for visible sector fields.

3. SUSY breaking mediation by throat fields

Warped deformed conifold scenario:

More fields!
In particular have vector superfields V from SO(4) symmetry of Klebanov-Strassler throat.

- SO(4) broken by UV manifold $\Rightarrow$ V gets UV-scale mass.
- expect X to be charged under V (e.g. $\overline{\text{D3}}$s at tip of throat break SO(4), hence they must couple to V)

$$\Omega = -(T+\overline{T}) + \omega^2\tilde{\Omega}(X, e^V\overline{X}) \qquad W = W_0 + e^{-T} + \omega^3\tilde{W}(X) + V^2$$

This gives a D term for V, $D \sim \omega^4$.

- Add visible sector fields Q with coupling $Qe^V\overline{Q}$
- $\Rightarrow$ scalar soft mass $m^2 \sim \omega^4$ induced.
- Comparable with modulus-anomaly mediation.

Summary and outlook

- The throat looks like a RS 1 model with extra fields from the 5d perspective.
- Radius stabilization by fluxes in 10d becomes Goldberger-Wise stabilization in 5d. The potential of the Goldberger-Wise scalar can be inferred from its backreaction on the geometry.
- The universal Kähler modulus is a brane field in the 5d picture.
- Sequestering between the IR and UV ends may be violated by massive vector fields coming from broken isometries of the throat.
- Next steps:

  Apply:
  - Build a model in which throat field mediation is realized.

  Understand:
  - Find the 5d SUGRA theory that describes the Klebanov-Strasser throat.
  - Find its coupling to the X sector and to fields on the UV manifold.