The Randall-Sundrum Model in String Theory and SUSY Breaking Mediation by Throat Fields

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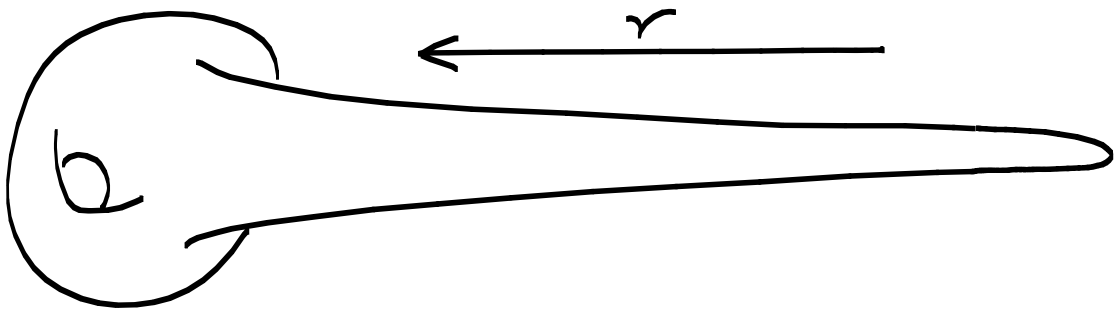
Outline:

- Klebanov-Strassler Throat as a Goldberger-Wise stabilized Randall-Sundrum Model
- The universal Kähler modulus as a UV-brane field
- Uplift by F-terms at the bottom of the throat
- Vector fields in the throat from the SO(4) isometry of the Klebanov-Strassler solution
- SUSY breaking mediation by throat vector fields

Compact Manifold with Klebanov-Strassler Throat ($\to$ GKP)



UV-brane — Calabi-Yau (orientifold)

effective 5d bulk — (Klebanov-Tseytlin)

IR-brane — (Klebanov-Strassler)

$\to$ Randall-Sundrum-picture

transverse $T^{1,1} \sim S^3 \times S^2$; $\int_{S^3} F_3 = M$

D3 brane flux equiv. $T^{1,1}$-radius equiv. B_2-flux

$N_{eff}(r) = \int_{T^{1,1}} \tilde{F}_5$ $\qquad$ $R_{eff}(r)$ $\qquad$ $\left(\int_{S^2} B_2\right)(r)$

Goldberger - Wise - Interpretation

$$N_{eff}(r) \quad \text{or} \quad R_{eff}(r) \quad \text{or} \quad \left(\int B_2\right)(r) \longrightarrow H(r)$$

(single scalar field)

① Identify coordinate y of 5d Einstein frame

② Identify potential $V(H)$ such that

$$\mathcal{L}_5 = \frac{1}{2} M_5^3 \mathcal{R} - \frac{1}{2}(\partial H)^2 - V(H) \Rightarrow H = H(y)$$

corresponding to

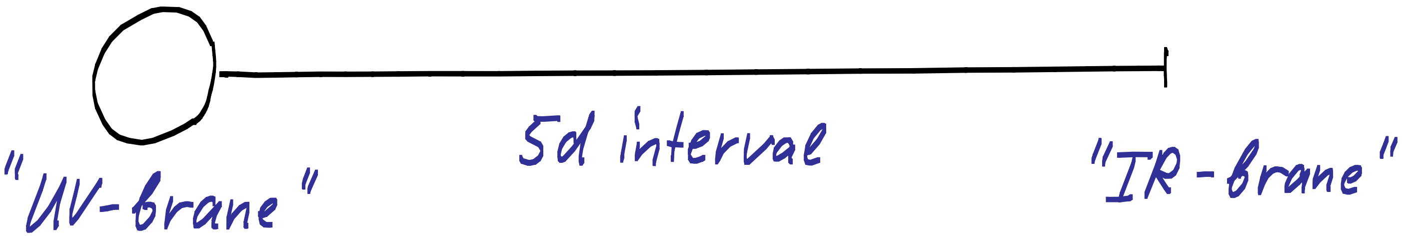
$$N_{eff}(r) \sim g_s M^2 \ln(r/r_s)$$

③ Identify boundary conditions on H at UV & IR end of the throat corresponding to

- $N_{eff}(r_{UV}) \sim N = M \cdot K$
- $N_{eff}(r_{IR}) \sim g_s M^2$

flux on dual cycle

The equivalent 5d model



- 5d Einstein frame metric:

$$ds_5^2 = e^{2A(y)} dx^2 + dy^2 \qquad ; \qquad A(y) \sim y^{3/5}$$

- Potential for Goldberger-Wise scalar:

$$V(H) \sim -M_5^9 \left(g_s^2 M^2 H\right)^{-8/3}$$

- Identification of H with N_{eff}:

$$H \sim M_5^{3/2} \left(N_{eff} / g_s M^2\right)^{1/2}$$

Geometric interpretation of the universal Kähler modulus

Throat metric: $$ds^2 = h(r)^{-1/2} dx^2 + h(r)^{1/2} \big(\underbrace{dr^2 + r^2 ds^2_{T^{1,1}}}_{\text{becomes CY metric in UV}} \big)$$

$$h(r) = 1 + \frac{g_s M^2 \ln(r/r_s)}{r^4}$$

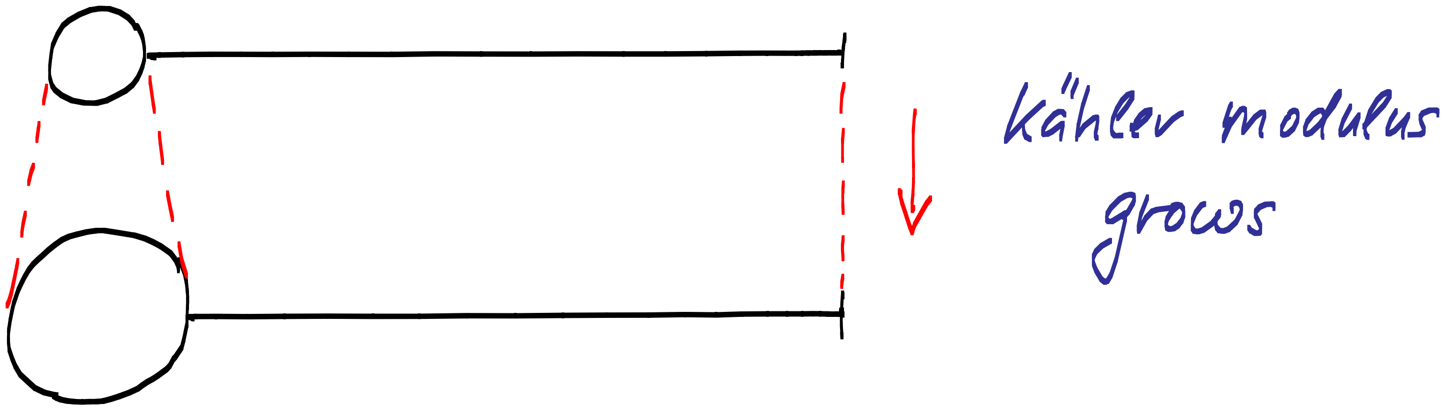
Changing the universal Kähler modulus corresponds to

$$h(r) \to \underset{\substack{\uparrow \\ \text{dominates} \\ \text{in UV space}}}{c} + \underset{\substack{\uparrow \\ \text{dominates in throat}}}{\frac{g_s M^2 \ln(r/r_s)}{r^4}}$$

(→ Giddings, Maharana, '05)

Question: How does the throat length change if the universal Kähler modulus grows?

Answer: The throat length shrinks by less than the UV-brane thickness increases.



$\Rightarrow$ Kähler modulus has to be interpreted as a UV-brane field.

(The shrinking of the throat is "negligible within the errors".)

F-term uplift of KKLT

(⋯ Arkani-Hamed, Dimopoulos, '04 ⋯ Lebedev, Nilles, Ratz, '06)

KKLT: $$\int d^4\theta \underbrace{-(T+\bar{T})}_{\Omega} \varphi\bar{\varphi} + \int d^2\theta \underbrace{(W_0 + e^{-T})}_{W} \varphi^3 + h.c.$$

(All of this is UV-brane-dynamics from the Randall-Sundrum model perspective.)

EOMs $\Rightarrow$ $$F_T \sim F_\varphi \sim e^{-T} \sim W_0$$

(small parameter)

Note: This solution does not yet describe a proper vacuum since $\mathcal{L} \supset \Omega \cdot \mathcal{R}$ and $\mathcal{R} \neq 0$.

F-term uplift (continued)

Uplifting sector: $\int d^4\theta \, \varphi\bar{\varphi} \, \omega^2 \Delta\Omega(X,\bar{X}) + \int d^2\theta \, \varphi^3 \omega^3 \Delta W(X) + h.c.$

(sequestered, since T at UV-brane)

ω^2, ω^3: warp factor (since X localized at the bottom of the throat)

$F_{\bar{X}}$ - EOM: $\quad \omega^2 \Delta\Omega_{X\bar{X}} F_X + \omega^3 \Delta\overline{W}_{\bar{X}} = 0$

$$\Rightarrow \quad F_X \sim \omega \quad ; \quad \text{uplift} \sim \omega^4 \quad \Rightarrow \quad \omega^4 \sim W_0^{\,2}$$

Final (almost-Minkowski) vacuum:

$$\underbrace{F_T \sim F_\varphi \sim W_0 \sim \omega^2}_{\text{precisely as above}} \quad ; \quad F_X \sim \omega$$

Interpretation of X-sector:

- model for $\overline{D3}$ branes

or

- new dynamics (yet to be realized in explicit throat construction)

Question:

Which fields couple X-sector to visible sector on UV brane?

(except, of course, φ (and hence T) as analyzed by Choi, Falkowski, Nilles, Olechowski, '05)

Isometry vector fields

Klebanov-Strassler solution: $SU_2 \times SU_2$ isometry

(left from $SU_2 \times SU_2 \times U_1$ isometry of $T^{1,1}$)

$\Rightarrow$ 6 massless 5d vectors ($\rightarrow$ Herzog, Klebanov, Ouyang, '01
Ceresole, Dall'Agata, '00)

Vector mediation

$$\mathcal{L} \supset \int d^2\theta \, W_\alpha W^\alpha + h.c. \; + \int d^4\theta \left(V^2 + \bar{Q} e^V Q + \omega^2 \bar{X} e^V X \right)$$

isometry broken by CY at UV end

visible sector at UV end

~~SUSY~~ sector at IR end

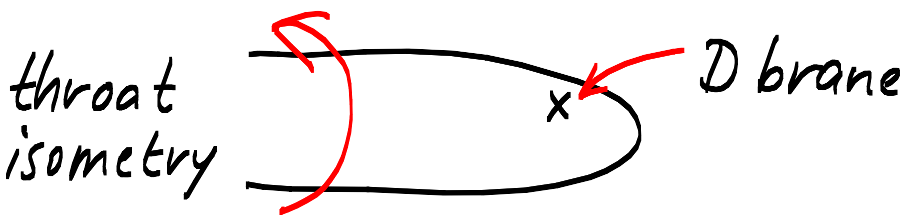
$$V = C + \theta^2 \bar{\theta}^2 D + \cdots \quad \Rightarrow \quad \mathcal{L} \supset CD + \omega^2 |F_X|^2 C$$

(cf. also Choi, Jeong, '06)

$$\Rightarrow \quad D \sim \omega^2 |F_X|^2 \sim \omega^4$$

$\Rightarrow$ soft scalar masses $\sim \omega^4$

Motivation for coupling of V with X and Q:



Isometry non-linearly realized on brane-scalars.

Conclusions and Outlook

- Randall-Sundrum interpretation of GKP / KKLT / Throat:
  - flux stabilization $\Rightarrow$ Goldberger-Wise stabilization
  - Kähler modulus $\Rightarrow$ UV-brane-localized no-scale field

    (same spirit as Ghergetta, Giedt, '06)
- Uplift by F-term of "X sector" on IR brane
- Natural ingredient: massless 5d vectors from isometries

  $\Rightarrow$ expect "vector mediation" of SUSY breaking

  (induced soft scalar masses can compete with "mixed modulus-anomaly mediation")
- Explicit brane construction / derivation of $N=1$ eff. theory needed!