Hierarchies

from

WARPED String

Compactifications

w/ Kachru & Polchinski

hep-th/0105097

Motivation

- New idea on hierarchies:

  different location ⇝ different 4d scales

- New and interesting phenomenology; string experiments?!

  — KK modes
  — string scale effects
  — black holes
  (μgrav x)

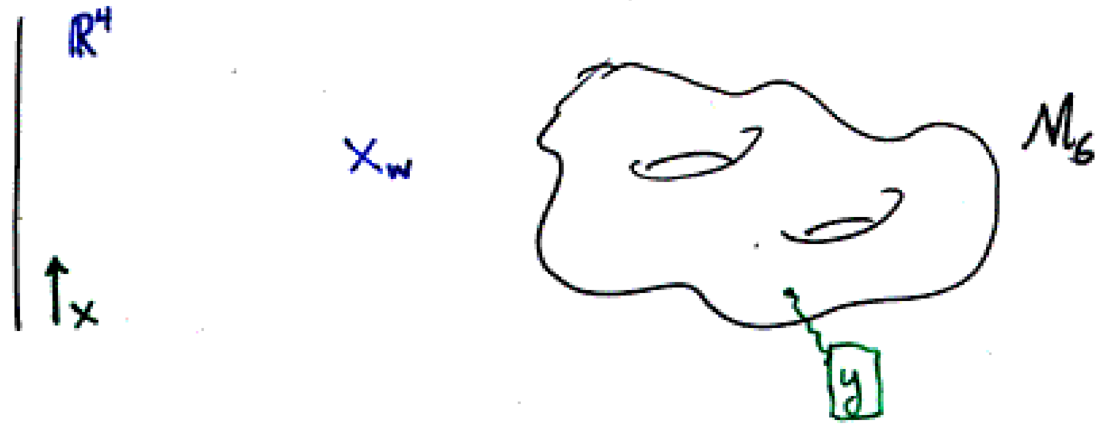
- Abstract: examples of broad & rich classes of string compactifications

  ... other possibilities to explore

Outline

1. Warped compactifications: generalities
2. Evading a no-go theorem
3. String solutions with hierarchies
4. Towards phenomenology
5. Conclusions and questions

1. Warped compactifications: generalities



Poincaré symmetry

$$ds^2 = e^{2A(y)} dx^2 + g_{mn}(y)\, dy^m dy^n$$

redshift: varying scale for 4d physics

4d gravity:

$$ds^2 = e^{2A(y)} \tilde{g}_{\mu\nu}(x)\, dx^\mu dx^\nu + g_{mn}\, dy^m dy^n$$

fluctuates

$$S_{10} \sim M_P^8 \int d^{10}x \sqrt{-g}\, R \sim M_P^8 \int d^6y \sqrt{g_6}\, e^{2A} \int d^4x \sqrt{-\tilde{g}}\, \tilde{R}(x)$$

- Measure 4d distances: $ds^2 = \tilde{g}_{\mu\nu} dx^\mu dx^\nu$
- $M_4^2 = M_P^8 \int d^6y \sqrt{g_6}\, e^{2A}$

$\Longleftrightarrow$ Define 4d Planck scale, 4d energies w.r.t. 10d observer at $A = 0$

Consider scattering on a brane elsewhere

$A = 0$

E_{10d}

$\longrightarrow \; \longleftarrow$

$A(y_0)$

redshift: $$E_{4d} = e^{A(y_0)} E_{10d}$$

measure at LHC — "true" scale for physics

TeV — M_{s6}, $M_{P\ell}$

- mechanism for generating hierarchy:

$$m_{10} \sim M_{P\ell} \longrightarrow m_4 \sim e^{A(y_0)} M_{P\ell}$$

- window to interesting physics @ ~ TeV
  - KK modes
  - string effects
  - black hole creation (cf SG & Katz, th/0009176)

2. Evading a no go theorem

e.g. IIB (similarly IIA, ...)

Fields: g_{MN}, $\tau = C_0 + i e^{-\phi}$, $G_3 = F_3 - \tau H_3$, $\tilde{F}_5 = dC_4 + \cdots$

Action:

$$S_{IIB} = \frac{1}{2\kappa_{10}^2}\int d^{10}x\sqrt{-g}\left(R - \frac{\partial_M\tau\,\partial^M\bar{\tau}}{2(\mathrm{Im}\,\tau)^2} - \frac{G_3\cdot\bar{G}_3}{12\,\mathrm{Im}\,\tau} - \frac{\tilde{F}_5^2}{4\cdot 5!}\right)$$

$$+ S_{CS} + S_{loc}$$

$\leftarrow$ branes

Ansatz: (Poincaré)

$$ds^2 = e^{2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + e^{-2A(y)}\tilde{g}_{mn}dy^m dy^n$$

$$\tau = \tau(y)$$

$$G_{(3)mnp} \neq 0$$

$$\tilde{F}_5 = (1+*)\left[d\alpha(y)\wedge dx^0\wedge dx^1\wedge dx^2\wedge dx^3\right]$$

"No go" (Maldacena - Nuñez)

Einstein's eqn:

$$R_{MN} = \kappa_{10}^2 \left(T_{MN} - \frac{1}{8} g_{MN} T \right)$$

$\mu\nu$ (4d):

$$\tilde{\nabla}_6^2 A = \underset{\geq 0}{\frac{e^{-2A} G \cdot \bar{G}}{48\, \mathrm{Im}\,\tau}} + \underset{\geq 0}{\frac{e^{-6A} (\nabla\alpha)^2}{4}} + \underset{\geq 0}{\frac{\kappa_{10}^2}{8} e^{-2A} \left(T_m^m - T_\mu^\mu \right)_{loc}}$$

positive tens $p \leq 7$

$\int_{M_6}$:

$$0 = \int_{M_6} \mathrm{RHS} \geq 0$$

$\Rightarrow$ each term $= 0$,

$A = \text{const}$

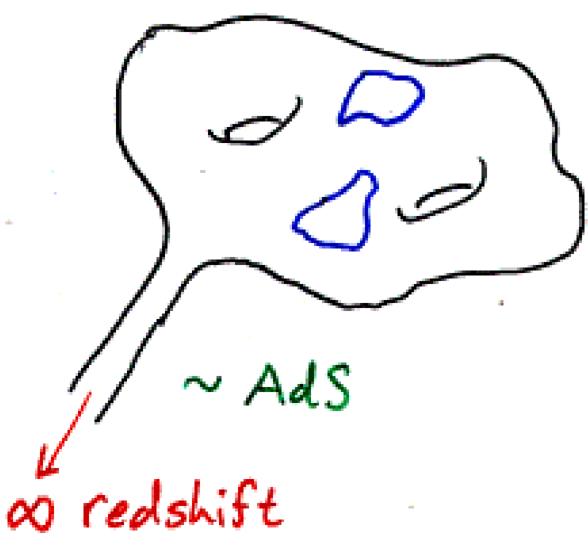
Evasion: String theory has negative tension objects

- orientifold planes
- induced −ve D3 tension in F thy.

E.g. Chan, Paul, H. Verlinde

F-theory:

$$S_{D7} = S_{DBI} + \cdots - \mu_7(\text{const}) \int_{C_4 \times \mathbb{R}^4} d^8x \sqrt{-g}\, Tr(R \wedge * R)$$

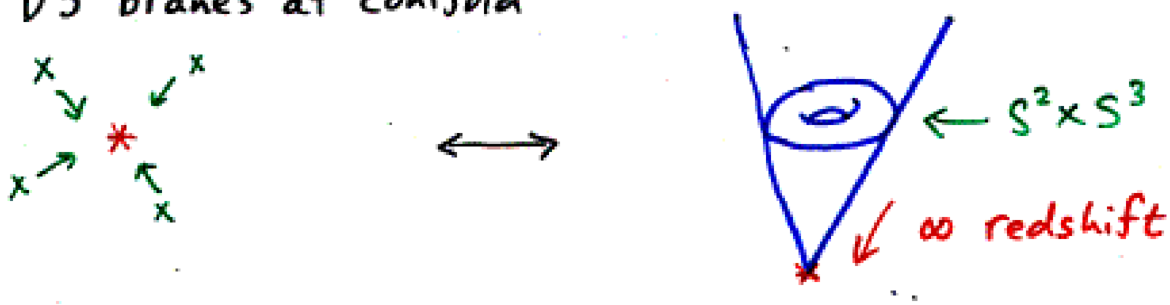


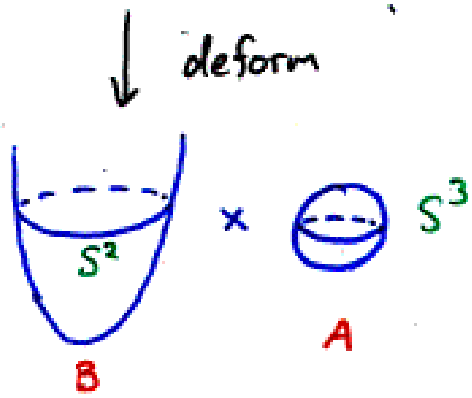
hierarchy –
but <u>arbitrary</u>

3. String solutions with hierarchies

Klebanov-Strassler:

D3 branes at conifold





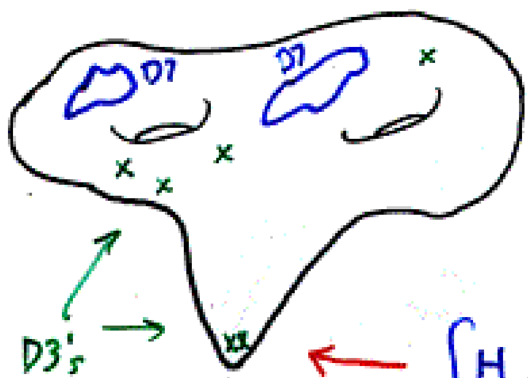
+ Fract. branes

- smooth
- finite & determined redshift
- fluxes replace branes

$$\int_B H_3 = -4\pi^2\alpha' K \qquad \int_A F_3 = 4\pi^2\alpha' M$$

Branes + fluxes in <u>compact</u> setting?

F-theory (or orientifold):



$$\int_A H \propto -K, \quad \int_B F \propto M$$

Constraints:

$$d\tilde{F}_5 = H_3 \wedge F_3 + 2\kappa_{10}^2 T_3 \rho_3^{loc}$$

$$\longleftrightarrow \qquad MK + N_{D3} = \frac{\chi(X_8)}{24}$$

Tension ✓

A general class of solutions

(generalizes Graña - Polchinski)

$$ds^2 = e^{2A} dx_4^2 + e^{-2A} \tilde{g}_{mn} dy^m dy^n$$

$$\tilde{F}_5 = (1 + *)\, d\alpha \wedge dx^0 \wedge dx^1 \wedge dx^2 \wedge dx^3$$

Einstein + Bianchi:

$$\tilde{\nabla}_6^2 \left(e^{4A} - \alpha\right) = \frac{e^{2A}}{6\,\mathrm{Im}\,\tau} \left|iG_3 - *G_3\right|^2 + e^{-6A} \left|\partial\left(e^{4A} - \alpha\right)\right|^2$$

$$+ \frac{\kappa_{10}^2 e^{2A}}{2} \underbrace{\left[\left(T^m_m - T^\mu_\mu\right)^{loc} - 4 T_3 \rho_3^{loc}\right]}_{\geq 0}$$

Therefore, if (~ BPS)

then:

- $= 0$
- $\alpha = e^{4A}$
- $* G_3 = i G_3$

Remaining IIB EOM solved w/

- $\tau(y)$, $\tilde{g}_{mn}(y)$ determined by F-thy

- $$\tilde{\nabla}_6^2 e^{-4A} = -e^{2A}\left[\frac{G\cdot\bar{G}}{12\,\mathrm{Im}\,\tau} + \frac{\kappa_{10}^2}{2}\left(T^m_m - T^\mu_\mu\right)^{loc}\right]$$

$*G_3 = iG_3$: $\epsilon_{123}{}^{123} = -i$

- implies G_3 is $(0,3)$ or $(2,1)$
- for given $\int_A F \propto M$ $\int_B H \propto -K$

<u>fixes</u> moduli

in particular, $\Rightarrow$ deformation away from conifold ~ KS

4d, N=1 SUSY thy

- gravity
- gauge thy. on branes
- light scalar superfields:
  - $h_{1,1}$ Kähler moduli ρ_i
    (e.g. take = 1 : scale of M_6)
  - $h_{2,1}$ Complex moduli z^α
  - τ (in orientifold case)

Action : dim. red.

Kähler potential:

$$K = -3\ln(\rho-\bar{\rho}) - \ln(\tau-\bar{\tau}) - \ln\int_{M_6} \Omega_3 \wedge \bar{\Omega}_3 + \text{const}$$

Ω_3: (3,0) on CY

Superpotential:

$$W(z^\alpha, \tau) = \int \Omega_3 \wedge G_3$$

(Gukov, Vafa, Witten)

note: ρ indep.

Check :

$$0 = D_\alpha W = \partial_\alpha W + \partial_\alpha \mathcal{K}\, W \overset{ex.}{=} \int_{M_6} G_3 \wedge \chi_\alpha$$

(2,1) forms

$$0 = D_\tau W = \partial_\tau W + \partial_\tau \mathcal{K}\, W \overset{ex.}{\propto} \int_{M_6} \bar{G}_3 \wedge \Omega$$

$$\Rightarrow \quad G_3 = (2,1) + (0,3) \quad \checkmark$$

F- theory generalization

$$K = -\ln \int_{X_8} \Omega_4 \wedge \bar{\Omega}_4$$

$$W = \int_{X_8} \Omega_4 \wedge G_4$$

Fiber coord

w/ (locally) $\quad G_4 = -\dfrac{G_3\, d\bar{w}}{\tau - \bar{\tau}} + h.c.$

Can now generate hierarchy:

Near conifold:

$$w_1^2 + w_2^2 + w_3^2 + w_4^2 = z$$

$$\int_A \Omega = z$$

$$\int_B \Omega = \mathcal{G}(z) = \frac{z \ln z}{2\pi i} + \text{holo.}$$

Fluxes: $\int_A F \propto +M \quad \int_B H \propto -K$

$$(G_3 = F_3 - \tau H_3)$$

ex $\rightsquigarrow$

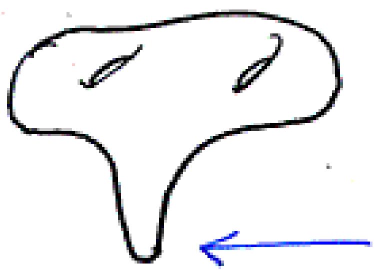
$$W = \int \Omega \wedge G_3 \propto M\mathcal{G}(z) - K\tau z$$

$$0 = D_z W \sim \frac{M \ln z}{2\pi} + \frac{K}{g_s}$$

this implies: $\boxed{z \sim e^{-\frac{2\pi K}{M g_s}}}$

(also need to fix τ; other fluxes $\rightsquigarrow$ $W \to W + \tilde{W}(\tau)$)

What this means:



$$e^{A_{min}} \sim z^{1/3} \sim e^{-\frac{2\pi K}{3 M g_s}}$$

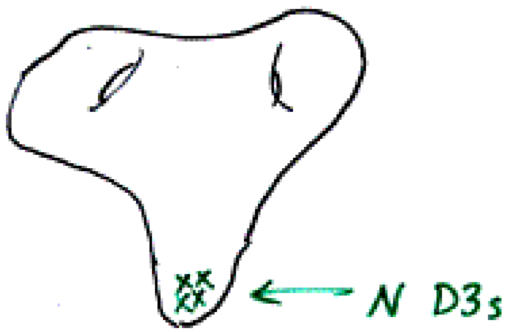
so, by a (discrete!) choice of fluxes,

e.g. $M = 1, \quad \frac{K}{g_s} \sim 8$

can generate TeV from $M_{P\ell}$

4. Towards phenomenology

Gauge dynamics from mobile D3's (generically required)



4d fields:
- $g_{\mu\nu}$
- A_μ^I $\quad SU(N)$
- z^α, τ $\quad$ fixed by flux/pot.
- ρ, X_m $\quad$ not fixed

brane positions

Indeed,

$$\partial_\rho W = 0 , \qquad \mathcal{K} = -3 \ln(\rho - \bar{\rho})$$

gives

$$V = e^{\mathcal{K}} \left(\mathcal{K}^{i\bar{j}} D_i W \overline{D_j W} + \mathcal{K}^{\rho\bar{\rho}} |D_\rho W|^2 - 3|W|^2 \right)$$

z, τ

cancel

$= 0$ indep. of ρ.

"No scale" (e.g. also Het, ...)

SUSY broken:

$$0 \neq e^{\mathcal{K}/2} W = m_{3/2} \propto \frac{1}{\rho^{3/2}}$$

- α', g_s corrections should fix ρ, x_m
- other branes/fluxes might classically fix <u>all</u> moduli

  (SG, SK, & JP in progress)

Conclusion & open questions

Have constructed a class of classical string solutions corresponding to warped compactifications

- large hierarchies generated by moderate discrete fluxes
- $N=1 \longrightarrow N=0$ SUSY
- $\Lambda = 0$

Questions:

- can we fix remaining moduli? (W.I.P.)
- can we build the standard model?
- understanding phenomenological consequences
  - KK, etc. prod
  - (– μ grav)
  - string scale effects
  - black hole production