D-BRANE MODELS AND FLUX SUPERSYMMETRY BREAKING

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IFT, MADRID

BASED ON : P.G. CAMARA, L. IBAÑEZ, A.U. TH/0311241, AND IN PROGRESS

RELATED WORKS :

M. GRAÑA, TH/0209200

GRAÑA, GRIMM, JOCKERS, LOUIS, TH/0312232

LAWRENCE, MCGREEVY, TH/0401034

LÜST, REFFERT, STIEBERGER, TH/0406092

OUTLINE OF THE TALK

- MOTIVATION
- D-BRANE MODELS
- FLUX CONFIGURATIONS
- SOFT TERMS ON D BRANES FROM FLUXES
  - LOCAL 10D SUGRA BACKGROUND
  - 4D EFFECTIVE THEORY
- CONCLUSIONS

MOTIVATION

- GENERAL PROBLEM OF UNDERSTANDING PHYSICS OF DBRANES IN STRING THEORY BACKGROUNDS WITH NSNS/RR FIELD STRENGTH FLUXES
  - ADS/CFT,
  - COMPACTIFICATIONS TO 4D WITH FLUXES AND DBRANES
- CENTER ON THE LATTER, WITH [POSSIBLE, BUT NOT ONLY!] APPLICATION TO PHENOMENOLOGICAL MODEL BUILDING
- PUT TOGETHER TWO RECENCT ADVANCES IN STRING COMPACTIFS.
  - DBRANE CONFIGURATIONS WITH NONABELIAN GAUGE SYMMETRIES AND CHARGED CHIRAL FERMIONS [E.G. MSSM-LIKE]
  - COMPACTIFICATIONS WITH FLUXES [MODULI STABILIZATION, WARPED GEOMETRIES, SUSY BREAKING, ...]

(Q) WHAT IS THE EFFECT OF [SUSY OR NOT] FLUXES ON THE GAUGE THEORY ON THE DBRANE WORLDVOLUME?

THE DBRANE CONFIGURATIONS

LOTS OF RECENT WORK ON MODEL BUILDING WITH DBRANES

↝ LOTS OF EXPLICIT MODELS

LESSON: PATTERN IN WHICH STRING TH. MAY REPRODUCE S.M.

- GAUGE FACTORS ASSOCIATED TO DBRANE STACKS "$\otimes_a U(N_a)$"
- A-BRANES: DG'S ON SPECIAL LAGRANGIAN 3CYCLES → INTERSECTING BRANE WORLDS
- B-BRANES: DBRANES ON HOLOMORPHIC CYCLES & CARRYING HOLOMORPHIC GAUGE BUNDLES

MIRROR

- SPECTRUM OF CHIRAL FERMIONS IN BI-FUNDAMENTALS "$I_{ab}(N_a, \bar{N}_b)$" WITH TOPOLOGICAL MULTIPLICITY

  A ↦ INTERSECTION NUMBER ; B → INDEX OF DIRAC OPERATOR

OBS: OF COURSE, DBRANES NOT MORE FUNDAMENTAL THAN, BUT DUAL TO, OTHER SETUPS [MTH ON G_2, HET ON CY_3, ...]

BUT MORE TRACTABLE IN SOME RESPECTS

LOCALITY: DBRANE FEELS ONLY LOCAL BACKND AROUND IT

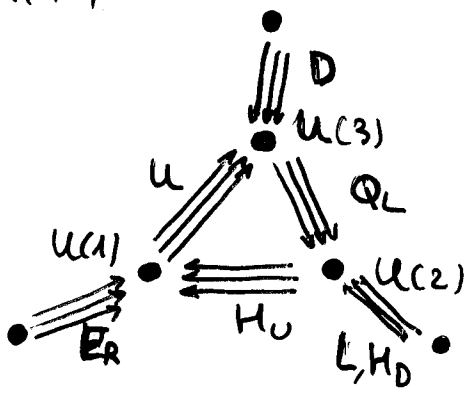
USE MODELS OF DBRANES TO LEARN MORE & GO BEYOND

WE CENTER ON TYPE IIB STRING THEORY ON CY_3 [EQ. FTH. ON CY_4]

→ B-TYPE BRANES

TWO VERY TRACTABLE CLASSES OF CONFIGURATIONS:

- MAGNETISED DBRANES [WITTEN; BACHAS; ANGELANTONI, ANTONIADIS, DUDAS, SAGNOTTI; BLUMENHAGEN, GORLICH, KORS, LUST; ...]
  [SEE DIETER'S TALK]
  DBRANES WRAPPED ON PRODUCTS OF T^2's IN T^6, WITH CONSTANT WORLDVOLUME MAGNETIC FIELD $\int_{T^2} F = m$
- DBRANES AT SINGULARITIES [DOUGLAS, MOORE; DOUGLAS, GREENE, MORRISON; ...]
  DBRANES WRAPPED ON CYCLES COLLAPSED AT SINGULARITY
  - MSSM-LIKE EXAMPLES EXIST, E.G. INVOLVING
    D3/D7 SYSTEMS AT $\mathbb{C}^3/\mathbb{Z}_3$ SINGULARITIES
    [ALDAZABAL, IBAÑEZ, QUEVEDO, A.U; BERENSTEIN, LEIGH]
  - PHYSICS OF QUOTIENT PARTIALLY INHERITED FROM PARENT FLAT SPACE
    → WORK IN FLAT SPACE, QUOTIENT AT LAST STAGE
    RESULTS IN FLAT SPACE USEFUL IN APPLICATIONS WHERE CHIRALITY IS NOT ESSENTIAL [FLAVOURED MASS DEFORMED N=4 SYM] [KÄHLER MODULI STAB]



CONSISTENCY CONDITIONS

+ - RR TADPOLE CANCELLATION

SM MODEL BUILDING

[ALDAZABAL, IBAÑEZ, QUEVEDO, A.U.]

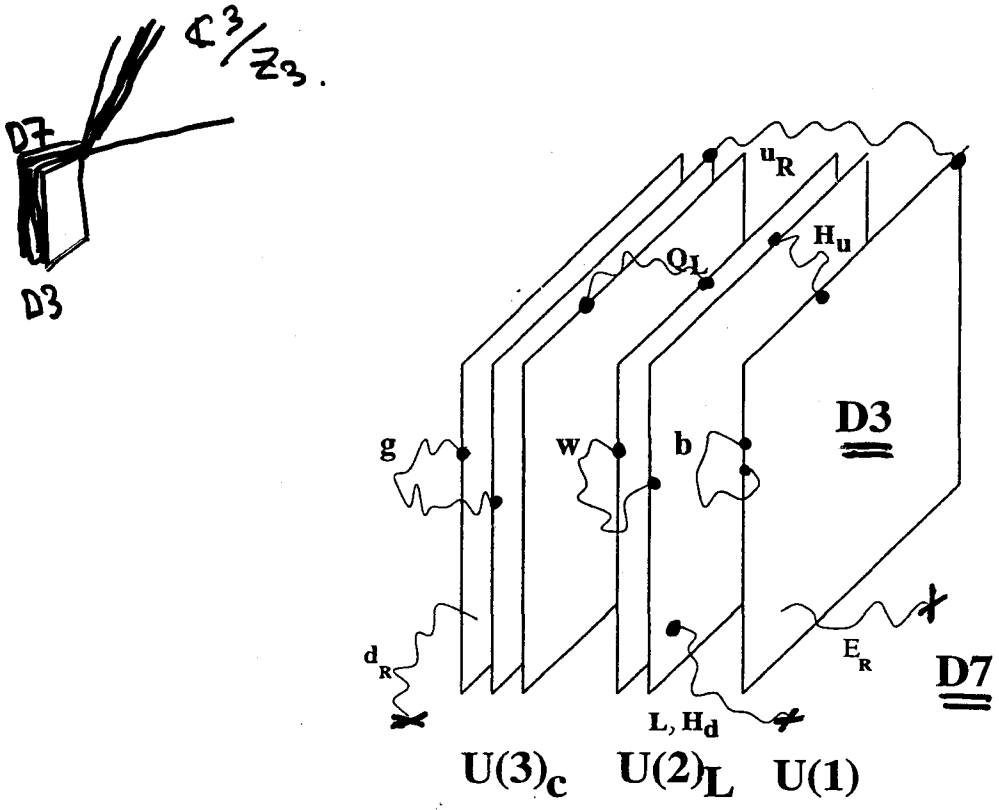
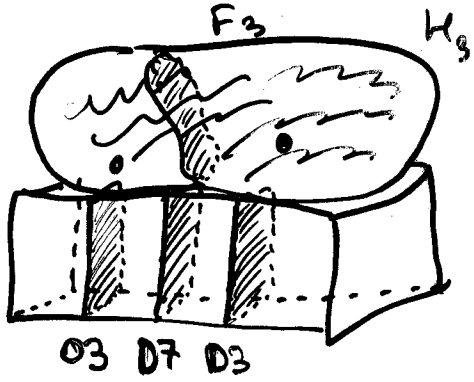


Figure 3: D-brane configuration of a SM $\mathbb{Z}_3$ orbifold mode.. Six D3-branes (with worldvolume spanning Minkowski space) are located on a $\mathbb{Z}_3$ singularity and the symmetry is broken to $U(3) \times U(2) \times U(1)$. For the sake of visualization the D3-branes are depicted at different locations, even though they are in fact on top of each other. Open strings starting and ending on the same sets of D3-branes give rise to gauge bosons; those starting in one set and ending on different sets originate the left-handed quarks, right-handed U-quarks and one set of Higgs fields. Leptons, and right-handed D-quarks correspond to open strings starting on some D3-branes and ending on the D7-branes (with world-volume filling the whole figure).

TYPE IIB ON CY_3 MOD ΩR WITH 3-FORM FLUXES

MUCH RECENT ACTIVITY, SEE TALKS BY SEVERAL OTHER SPEAKERS

- CONSIDER IIB ON CY_3 MOD ΩR [$R: x^m \to -x^m$] AND INTRODUCE NSNS/RR 3FORM FLUXES H_3, F_3 [EG. F THEORY ON ELLIPTIC CY_4 AND "G_4" FLUX]



- MAIN FEATURES [BECKERS; DASGUPTA, RAJESH, SETHI; GIDDINGS, KACHRU, POLCHINSKI; ...]

- SCALAR POTENTIAL & MODULI STABILIZATION

  $W = \int G_3 \wedge \Omega$ WITH $G_3 = F_3 - \tau H_3$ [GUKOV, VAFA, WITTEN]

  USUALLY $G_3 = i *_{6d} G_3$ [ISD], UNLESS FURTHER INGREDIENTS

- SUPERSYMMETRY

  N=1 SUSY FOR G_3 (2,1) & PRIMITIVE

  FOR (0,3) G_3, NONSUSY BUT ISD, $V(\Phi) = 0$.

  FOR IASD G_3, NONSUSY AND $V(\Phi) \neq 0$

- WARPING

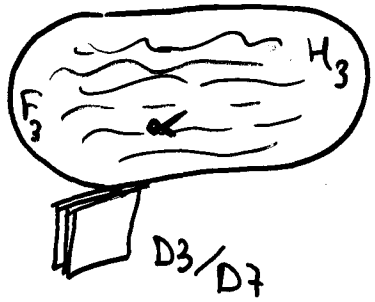
  FLUXES BACKREACT ON CY_3 BACKGROUND.

  E.G. $ds^2 = Z(x^m)^{-1/2}\, ds_{4d}^2 + Z(x^m)^{1/2}\, ds_{CY}^2$, ETC...

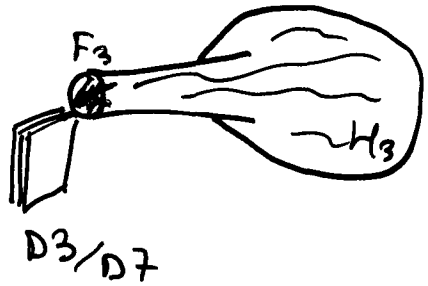
- NATURALLY INCLUDE D3/D7 BRANE SECTORS [OR ALSO $\bar{D3}$'S, ...]

NATURAL SETUP FOR MODEL BUILDING. TWO PICTORIAL REGIMES

HOMOG. BACKREACTION



STRONGLY WARPED THROATS



MODELS WITH FLUXES AND CHIRAL DBRANE SECTORS → [BLUMENHAGEN, LUST, TAYLOR; CASCALES, A.U.]

T^6 AND ORBIFOLDS

Z_3 QUOTIENT OF LOCAL CY_3 CONTAINING S^3'S [CASCALES, GARCIA DEL MORAL, QUEVEDO, A.U.]

- WE WOULD LIKE TO COMPUTE THE EFFECT OF FLUXES ON [SUSY] SECTORS OF D3- AND D7-BRANES

CONCRETELY, FLUX INDUCED TERMS IN THE ACTION FOR DBRANE WORLDVOLUME FIELDS [N=1 SUSY SUPERPOTENTIAL TERMS, SOFT ~~SUSY~~ TERMS]

TWO APPROACHES: • COUPLE DBRANE DBI+CS ACTION TO LOCAL BACKND

• USE EFFECTIVE 4D ACTION

LOCAL ANALYSIS

CONSIDER SETS OF D3/D7 BRANES IN [SUITABLY BACKREACTED] FLAT SPACE

[POSTPONE ORBIFOLDING TO THE END]

CENTER ON D3-BRANES TO START [NICE INTERPLAY WITH ADS/CFT ...]

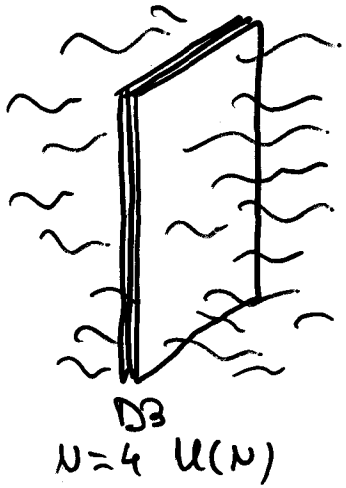
CONSIDER LOCAL BACKGROUND NEAR LOCATION x^m OF D3'S IN $\mathbb{R}^6$

USE DBI+CS D3 ACTION IN GENERAL SUGRA BACKGROUND [...; MYERS; ...]

$$S' = -\mu_3 \int d^4x \; Tr\left\{ e^{-\phi} \sqrt{\det\left(P[E_{\mu\nu} + E_{\mu m}(Q^{-1}-\delta)^{mn} E_{n\nu}\right) \det(Q^m_n)} \right\} +$$

$$+\mu_3 \int Tr\left\{ P\left[e^{i 2\pi\alpha' i_\phi i_\phi} \left(\sum_n C^{(n)} + \frac{1}{2} B_2 \wedge C_2 \right) e^{-B} \right] e^{2\pi\alpha' F} \right\} + \text{FERM}$$

$$E_{MN} = G_{MN} - B_{MN} \; ; \; Q^m_n = \delta^m_n + i 2\pi\alpha' [\phi^m, \phi^p] E_{pn} \; ; \; i_\phi C_{p+1} = C_{\mu_1 \ldots \mu_{p+1}} \phi^{\mu_{p+1}} dx^{\mu_1} \ldots dx^{\mu_p} \ldots$$



TAYLOR EXPANSION OF BACKGROUND IN x^m AROUND FLAT SOLUTION $\quad x^m \sim \phi^m$ $\quad$ EXPANSION OF D3 ACTION IN HIGHER DIM. OPERATORS IN ϕ^m ETC, AROUND $N=4$ $U(N)$ SYM

→ <u>SOFT TERMS</u>

INTERESTED IN MOST RELEVANT TERMS (DIM ≤ 3)

A FAIRLY GENERAL ANSATZ

$$ds^2 = Z_1(x^m)^{-1/2}\, ds_{4d}^2 + Z_2(x^m)^{1/2}\, dx^m dx^m$$

$$\tau = \tau(x^m)$$

$$G_3 = \frac{1}{3!}\, G_{lmn}(x^m)\, dx^l dx^m dx^n$$

$$\chi_4 = \chi(x^m)\, dx^0 dx^1 dx^2 dx^3$$

$$F_5 = (1 + *_{10})\, d\chi_4$$

EXPAND TO ENOUGH ORDER

$$Z_1^{-1/2} = 1 + \frac{1}{2} K_{mn}\, x^m x^n + \dots$$

$$Z_2^{1/2} = 1 + \dots$$

$$\tau = \tau_0 + \frac{1}{2} \tau_{mn}\, x^m x^n + \dots$$

$$\chi_4 = \text{const.} + \frac{1}{2} \chi_{mn}\, x^m x^n$$

USEFUL TO SPLIT G_3 IN IRREPS OF SO(6) LOCAL GEOM. SYMMETRY

$20 = 10 + \overline{10}$ $\qquad *G^{\pm} = \pm i G^{\pm}$

RESULTS [ASSUMING FLUX IS ONLY SOURCE IN EQS. OF MOTION]

SCALAR MASSES $\quad tr\, m^2 = g_s/2\, [\, |G^-|^2 - Re(G^+ G^-)\,]$ BRANE MOTION

SCALAR TRILINEARS $\quad G^-_{lmn}\, \phi^l \phi^m \phi^n + h.c.$ DIELECTRIC EFFECT

FERMION MASSES $\quad G^-_{lmn}\, \psi\, \Gamma^{lmn}\, \psi + h.c.$ $\qquad \psi$ = SO(6) 4-PLET

OBS ONLY G^- COUPLES [AT THIS ORDER]

→ ISD FLUX COMPACTIFICATIONS GIVE NO D3 SOFT TERMS [AT THIS ORDER]
[BUT NONTRIVIAL ON $\overline{D3}$'S]

OBS: VERY GENERAL FORMALISM: E.G. APPLY TO DISTANT $\overline{D3}$ BRANE ~~SUSY~~

EFFECT ON 7-7 FIELDS [IN PROGRESS]

QUALITATIVELY MORE INVOLVED : D7'S WRAP 4 CYCLES

- LOCAL GEOMETRICAL SYMMETRY IS $SO(4) \times SO(2)$

G_3 : ISD $10 = \underbrace{(3,1)_+}_{G} + \underbrace{(1,3)_-}_{G'} + (2,2)_0$; IASD $\overline{10} = \underbrace{(3,1)_-}_{g} + \underbrace{(1,3)_+}_{g'} + (2,2)_0$

- NON TRIVIAL CONSISTENCY CONDITIONS

  FREED, WITTEN $H|_{D7} = 0$. AVOIDED IF $(2,2)_0$ ARE ABSENT

- 4D PHYSICS DEPENDS DRASTICALLY ON 4 CYCLE [E.G. # D7 MODULI]

- EVEN 8D ACTION IS MORE INVOLVED [10^2 DERIVATIVE TERMS]

ASSUME D7 ON T^4, TRANSLATIONAL INVARIANCE.

TRACTABLE YET INTERESTING

RESULTS

TRANSVERSE POSITION MODULI MASSES

$$-g_s/_{18}\left\{\left[(G^*)^2 + (G'^*)^2\right] \Phi^3 \Phi^3 + \text{h.c.} + \frac{1}{2}\left(|G^a|^2 + |G'|^2\right) \Phi^3 \Phi^{\bar{3}}\right\}$$

MODULI TRILINEARS

$$-g_s/_{18}\left\{(\Phi^{\bar{1}}, \Phi^{\bar{2}})\,(\vec{G}^* \vec{\tau})\begin{pmatrix}\Phi^1 \\ \Phi^2\end{pmatrix} + (\Phi^{\bar{1}}, \Phi^{\bar{2}})\,\vec{G}' \vec{\tau}\begin{pmatrix}\Phi^1 \\ \Phi^{\bar{2}}\end{pmatrix} + \dots\right\} \cdot \Phi^3 + \text{H.C.}$$

FERMION MASSES

$$-g_s/_{6\sqrt{2}}\left\{(\lambda, \Psi_3)\,(G' \cdot \vec{\tau})\begin{pmatrix}\lambda \\ \Psi_3\end{pmatrix} + (\psi_1, \psi_2)\,(G \cdot \vec{\tau})\begin{pmatrix}\psi_1 \\ \psi_2\end{pmatrix} + \text{h.c.}\right\}$$

- ANALYZED ALSO THE 37 SECTOR [D7 INSTANTON MODULI] → FAR TRICKIER!
  VANISHING FERMION AND SCALAR MASSES, NONZERO TRILINEARS

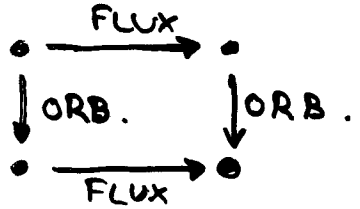
COMMENTS

- NONTRIVIAL SOFT TERMS EVEN FOR ISD [OR EVEN SUSY] FLUX
  → SUSY BREAKING, SOFT TERMS, CONSISTENTLY WITH ZERO VAC. POT.
- D7-BRANE POSITION MODULI ARE STABILIZED
  → ALSO VERY PLAUSIBLE FOR 4 CYCLES WITH SEVERAL SUCH MODULI
  [ALSO, EXPECTED FROM F-THEORY ON CY_4]
- D7-BRANE BUNDLE MODULI NOT STABILIZED IN OUR CASE
  → TOO SIMPLISTIC : 8D GAUGE INV. FORBIDS MASS TERMS
  kk REDUCTION ON T^4 IS TOO TRIVIAL
  EXPECT STABILIZATION IN GENERAL SITUATION [EX: ORBIFOLDS]
- RESULTS RELEVANT FOR KAHLER MODULI STABILIZATION VIA
  GAUGINO CONDENSATION [KACHRU, KALLOSH, LINDE, TRIVEDI]
  FLUX-INDUCED MASS FOR 77 FIELDS HELPS IN GETTING
  PURE N=1 SYM AND GAUGINO CONDENSATION

DBRANES AT ORBIFOLDS

FIELD THEORY ON DBRANES AT ORBIFOLDS $\mathbb{C}^3/\Gamma$ IS SIMPLY THE Γ-INVARIANT PROJECTION OF PARENT THEORY OF DBRANES IN FLAT SPACE

$\Rightarrow$ SOFT TERMS ON DBRANES AT ORBIFOLDS ARE SOFT TERMS IN FLAT SPACE INDUCED BY Γ-INVARIANT FLUXES



OBS SO(6) & SO(4)×SO(2) INVARIANT COUPLINGS GUARANTEE CONSISTENT ACTION OF Γ ON FIELDS & FLUXES

EXAMPLE MSSM-LIKE AT $\mathbb{C}^3/\mathbb{Z}_3$ [OR $(T^4 \times \mathbb{C})/\mathbb{Z}_3$]

$\mathbb{Z}_3$ INVARIANCE LEAVES $K_{i\bar{j}}, \tau_{ij}, \chi_{ij}, G_{ijk}, G_{\bar{i}\bar{j}\bar{k}} \longrightarrow (0,3)$ AND $(3,0)$ FLUX

SM ON D3'S : UNIVERSAL U SQUARK MASSES (33)
NO D SQUARK, SLEPTON MASSES (37)
SPECIFIC SET OF TRILINEARS & GAUGINO MASSES (33;37)

SM ON D7'S : MODULO THE ISSUE OF OUR LIMITED ANSATZ,
SIMILAR, BUT DIFFERENCE IN 1st, 2nd VS. 3rd FAMILY.

COMMENT: SOFT TERMS ENCODE BACKGROUND DATA AROUND SM BRANES
[AGAIN, BRANE LOCALITY]

4D EFFECTIVE THEORY APPROACH

USE 4D EFFECTIVE ACTION, INCLUDING CLOSED MODULI & OPEN FIELDS

$f_{D3} = S$; $f_{D7} = T_3^3$

$W = \int G_3 \wedge \Omega + W_{matter}$

$$K = -\log(S+S^* - |\Phi_{77}^3|^2) - \log(T_3+T_3^* - |\phi_{33}^3|^2) - (T_1+T_1^*)^{-1/2}(T_2+T_2^*)\,|\phi_{37}|^2$$
$$- \log(T_2+T_2^* - |\Phi_{33}^2|^2 - |\Phi_{77}^1|^2) - \log(T_1+T_1^* - |\Phi_{33}^1|^2 - |\Phi_{77}^2|^2)$$

FLUX COMPONENTS CORRESPOND TO VEVS FOR AUXILIARY FIELDS OF CLOSED MODULI

$G_3\ (0,3) \to \langle F_T \rangle \neq 0$; $G_3\ (3,0) \to \langle F_S \rangle \neq 0$

USE STANDARD 4D $N=1$ SUGRA FMLAE. TO READ OFF SOFT TERMS

[IBAÑEZ, LÜST ; KAPLUNOVSKY, LOUIS ; BRIGNOLE, IBAÑEZ, MUÑOZ ; ...]

FULL AGREEMENT WITH PREVIOUS RESULTS, BUT AVERAGE VALUE OF G_3 ALSO

- SOME LOCAL BACKGROUNDS DO NOT EXIST IN GLOBAL MODELS
  [E.G. NONPRIMITIVE G_3 COMPONENTS]
- DISAGREEMENT IN SCALAR MASSES IN LASD FLUX CASES
  → 4D APPROACH YIELDS $V \neq 0$, AND HENCE INCOMPATIBLE WITH M_4
  [USED IN LOCAL APPROACH]

CONCLUSIONS

- INTERPLAY OF BRANES & FLUXES IS RICH AND INTERESTING
- SATISFACTORY THAT THE GENERIC IIB/F-THEORY COMPACTIFICATION CONTAINS ALL INGREDIENTS FOR REALISTIC MODELS
  - ENOUGH D BRANES FOR CHIRAL GAUGE SECTORS
  - MODULI STABILIZATION
  - SUSY BREAKING & SOFT TERMS

  → EXPECT SIMILAR RESULTS IN OTHER SETUPS
- WE HAVE COMPUTED THE EFFECT OF FLUXES ON THE WORLDVOLUME ACTION OF CERTAIN D-BRANE CONFIGURATIONS
  - APPLICATION TO PHENOMENOLOGICAL MODEL BUILDING
  - BUT ALSO E.G. TO KÄHLER MODULI STABILIZATION
- SOFT TERM SCALE $\sim \alpha'/R^3$

  M_s^2/M_P FOR HOMOGENEOUS FLUXES → PICK $M_s \sim 10^{11}$ GeV

  LOCAL STRING SCALE FOR THROATS → CHOOSE WARPING TO YIELD TeV
- SOFT TERMS ENCODE GEOMETRY/BACKGROUND AROUND D-BRANES [AGAIN, BRANE LOCALITY] → BOTTOM UP RECONSTRUCTION OF GEOMETRY FROM SOFT TERMS