Title: Moduli fixing and MSSM-like vacua in Type II String Theory

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Abstract:

Moduli fixing and MSSM-like vacua in Type II String Theory

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Based on:

P.G.C., L. E. Ibáñez and A. Font. hep-th/0506066

P.G.C., L. E. Ibáñez and A. Uranga. hep-th/0408036 and hep-th/0311241

Related work on moduli fixing in Type IIA orientifolds:

Derendinger et al. (2004); Kachru et al. (2004); Louis et al. (2004); Zwirner et al. (2005); De Wolf et al. (2005)

Related work on flux induced soft-SUSY breaking:

Graña (2002); Louis et al. (2004); Lawrence and McGreevy (2004); Lust et al. (2004)

Outline

- Motivation
- Type IIA orientifolds with fluxes and twisted tori
- D6-branes and MSSM-like vacua
- Soft SUSY-breaking
- Final comments

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- The vacuum problem: arbitrariness of compactifications to 4d

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  - **SM, MSSM?** $\Longrightarrow$ It would provide a proof that string theory may be a unified theory of all particles and interactions

- In our way we may identify general low energy patterns of String Theory (e.g. soft-susy breaking patterns) $\Longrightarrow$ LHC?

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- In our way we may identify general low energy patterns of String Theory (e.g. soft-susy breaking patterns) $\Longrightarrow$ LHC?
- Bottom-up approach to String Theory by exploring its vacuum structure

Motivation

Heterotic on CY

SM or GUT group + hidden sector

$Z_2 \times Z_2$, Z_3, Z_6 orbifolds

Ross et al., Ibañez et al., Casas et al., Antoniadis et al., Faraggi et al., Lykken et al.

1986–1996

Type I on CY

Magnetic fluxes

Blumenhagen et al., Uranga et al.

Type IIB on CY

D3/D7–branes at singularities

Z_3 orbifolds. MSSM–like spectra + extra U(1)'s

Aldazabal et al., Leigh et al., Verlinde

2000–2005

Type IIA on CY

Intersecting D6–branes

MSSM–like spectra + $U(1)_{B-L}$

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M–theory on G_2 structure

Motivation

But: moduli unstabilized $\Longrightarrow$ massless scalars in the spectrum

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Flux backgrounds of RR and NSNS fields induce non-trivial superpotentials

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- Moreover, from the point of view of the effective supergravity, the fluxes are related to the F-auxiliary fields of the moduli

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may lead to soft SUSY-breaking

- Stringy realization of the Randall-Sundrum scenario **[Giddings et al.]**

$\Downarrow$

hierarchy of masses

Motivation

Type IIA with O6's	Type IIB with O3/O7's
$\overline{F}_{\alpha i\beta j\gamma k}$	$\overline{F}_{ijk}$
$\overline{F}_{\alpha i\beta j}$	$\overline{F}_{ij\gamma}$
$\overline{F}_{\alpha i}$	$\overline{F}_{i\beta\gamma}$
$F^{(0)}$	$\overline{F}_{\alpha\beta\gamma}$
$\overline{H}_{ijk}$	$\overline{H}_{ijk}$
$\overline{H}_{\alpha\beta k}$	$Q_k^{\alpha\beta}$
ω_{jk}^{α}	$\overline{H}_{\alpha jk}$
$\omega_{k\alpha}^{j}, \omega_{\beta k}^{i}, \omega_{\beta\gamma}^{\alpha}$	$Q_k^{\alpha j}, Q_k^{i\beta}, Q_{\alpha}^{\beta\gamma}$
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$Q_{\beta}^{\gamma i}, Q_{\gamma}^{i\beta}, Q_k^{ij}$	$Q_{\gamma}^{i\beta}, Q_{\beta}^{\gamma i}, Q_k^{ij}$
$R^{\alpha\beta\gamma}$	$\overline{H}_{\alpha\beta\gamma}$
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[Shelton, Taylor, Wecht. hep-th/0508133]

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Gukov-Vafa-Witten superpotential

$$W = \int_{CY} G_3 \wedge \Omega \quad ; \quad G_3 = F_3 - \tau H_3$$

G_3 ISD

$(2,1)$-primitive form $\Rightarrow$ SUSY

- No-scale models $\Rightarrow$ null c.c., Kähler moduli unfixed

$$V = \frac{1}{2} e^K (D_a W \overline{D^a W} - 3|W|^2) \rightarrow$$

$$\rightarrow \frac{1}{2} e^K (D_i W \overline{D^i W})$$

- Contribute to the tadpoles as D3's
- Non-perturbative effects $\Rightarrow$ KKLT (Kähler moduli, dS vacua)

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Fluxes in Type IIA orientifolds

perturbative Kähler fixing,

metric fluxes...

2. Type IIA orientifolds with fluxes and twisted tori

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IIA orientifolds

We will concentrate on the IIA orientifold $\otimes_{j=1}^{3} T_j^2/\Omega_P(-1)^{F_L}\sigma$ with

$$\sigma(\Omega) = \Omega^* \quad ; \quad \sigma(J) = -J$$

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The moduli space is better understood in terms of the complexified forms [Grimm, Louis. hep-th/0412277]

$$J_c = B + iJ \quad ; \quad \Omega_c = C_3 + i\mathrm{Re}(C\Omega)$$

with

$$C = e^{-\phi_4}\left[\frac{1}{8i}\int \Omega \wedge \Omega^*\right]^{-1/2}$$

IIA orientifolds

- Moduli space:

	dim.	form	dual form	moduli
Kähler	$h^-_{(1,1)}$	ω_A	$\widetilde{\omega}_A$	$T_A = -i\int J_c \wedge \widetilde{\omega}_A$
c.s + dilaton	$1 + h_{(1,2)}$	α_L	β_L	$U_L = i\int \Omega_c \wedge \beta_L \quad (S \equiv -U_0)$

IIA orientifolds

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	dim.	form	dual form	moduli
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c.s + dilaton	$1 + h_{(1,2)}$	α_L	β_L	$U_L = i\int \Omega_c \wedge \beta_L \quad (S \equiv -U_0)$

- Metric:

$$K = -\log\left[\frac{4}{3}\int J\wedge J\wedge J\right] - \log e^{-4\phi_4} =$$

$$= -\log(S+S^*) - \sum_{i=1}^{3}\log(U_i+U_i^*) - \sum_{i=1}^{3}\log(T_i+T_i^*)$$

Metric fluxes and twisted tori

- Turning on metric fluxes on the initial torus

$$ds^2 = \sum_k (dx^k + \omega^k_{pq} x^q dx^p)^2$$

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Twisted torus $\longrightarrow$ Parallelizable manifold with a well defined nowhere vanishing basis of vielbeins $d\eta^p = -\frac{1}{2}\omega^p_{mn}\eta^m \wedge \eta^n$ $\Rightarrow$ Reduced homology

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- The metric fluxes are the structure constants of the Lie algebra generated by the isometry generators [Scherk,Schwarz; Kaloper,Myers]

$$[Z_m, Z_n] = \omega^p_{mn} Z_p$$

Constraint from the algebra: $\omega^p_{[mn}\omega^s_{r]p} = 0$

Superpotentials

Switching on background fluxes:

$$\overline{F}_0 = -m \quad ; \quad \overline{F}_2 = \sum_{A=1}^{h_{11}^-} q_A \omega_A \quad ; \quad \overline{F}_4 = \sum_{A=1}^{h_{11}^-} e_A \widetilde{\omega}_A \quad ; \quad \overline{F}_6 = e_0 dVol_6$$

$$\overline{H}_3 = \sum_{L=0}^{h_{12}} h_L \beta_L \quad ; \quad \begin{pmatrix} \omega_{23}^1 & \omega_{53}^4 & \omega_{26}^4 \\ \omega_{34}^5 & \omega_{31}^2 & \omega_{61}^5 \\ \omega_{42}^6 & \omega_{15}^6 & \omega_{12}^3 \end{pmatrix} = \begin{pmatrix} -b_{11} & b_{12} & b_{13} \\ b_{21} & -b_{22} & b_{23} \\ b_{31} & b_{32} & -b_{33} \end{pmatrix}$$

$$\begin{pmatrix} \omega_{56}^1 \\ \omega_{64}^2 \\ \omega_{45}^3 \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} \quad ; \quad \begin{cases} b_{ij} + b_{jj} a_i = 0 & i \neq j \\ b_{ik} b_{kj} + b_{kk} b_{ij} = 0 & i \neq j \neq k \end{cases}$$

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...induces the superpotential: [Derendinger et al.; Grimm et al.; Villadoro et al.]

$$W = \int_{CY} [e^{J_c} \wedge \overline{F}_{RR} + \Omega_c \wedge (\overline{H}_3 + dJ_c)] = \sum_{i=1}^{3} [(ie_i - a_i S - \sum_{j=1}^{3} b_{ij} U_j) T_i - i h_i U_i] +$$

$$+ e_0 + i h_0 S - q_1 T_2 T_3 - q_2 T_1 T_3 - q_3 T_1 T_2 + i m T_1 T_2 T_3$$

Tadpoles

- Moreover the fluxes can contribute to the RR tadpoles [Villadoro et al.]

$$\int_{M_4\times Y}[C_7\wedge dF_2+C_7\wedge(m\overline{H}_3+d\overline{F}_2)]+\sum_a N_a\int_{M_4\times\Pi_a}C_7$$

[Stacks of N_a D6-branes wrapping $\Pi_a=(n_a^1,m_a^1)\otimes(n_a^2,m_a^2)\otimes(n_a^3,m_a^3)$].

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$$\sum_a N_a n_a^1 n_a^2 n_a^3+\frac{1}{2}(mh_0+q_1a_1+q_2a_2+q_3a_3)=16$$

$$\sum_a N_a n_a^1 m_a^2 m_a^3+\frac{1}{2}(mh_1-q_1b_{11}-q_2b_{21}-q_3b_{31})=0$$

$$\sum_a N_a m_a^1 n_a^2 m_a^3+\frac{1}{2}(mh_2-q_1b_{12}-q_2b_{22}-q_3b_{32})=0$$

$$\sum_a N_a m_a^1 m_a^2 n_a^3+\frac{1}{2}(mh_3-q_1b_{13}-q_2b_{23}-q_3b_{33})=0$$

Vacuum structure

- We want to look for critical points of the scalar potential

$$V = e^K \left(\sum_{\Phi=S,T_i,U_i} (\Phi + \Phi^*)^2 |D_\Phi W|^2 - 3|W|^2 \right)$$

- Broad landscape:
  - Supersymmetric Minkowski vacua
  - No-scale Minkowski vacua
  - Supersymmetric AdS vacua
  - Non-supersymmetric AdS vacua
- Superpotentials $W = W(S, T_1, T_2, T_3)$ are mirrors of the GVW superpotential.

Vacuum structure

Supersymmetric Minkowski vacua

- It requires $m = 0$ and non-null metric fluxes
- Fix at most 3 complex linear combinations of moduli
- Contribute to the tadpoles as D6-branes or do not contribute!

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- Contribute to the tadpoles as D6-branes or do not contribute!

No-scale Minkowski vacua

- Superpotential independent of three moduli so the form of the Kähler potential guarantees a cancellation of the c.c.
- Up to 4 complex moduli fixed
- Contribute to the tadpoles as D6-branes

Vacuum structure

Supersymmetric AdS vacua

- Superpotential depending on all seven moduli.
- All moduli fixed but some combinations of the axions $\mathrm{Im}S$ and $\mathrm{Im}U_i$.

  [Required for gauge anomaly cancellation on the worldvolume of D6-branes]
- Different cases:
  - No metric fluxes $\Longrightarrow$ contribute to the tadpoles as D6-branes
  - Metric fluxes $\Longrightarrow$ contribute to the tadpoles as D6 branes, O6-planes or do not contribute!

$\Downarrow$

Metric fluxes gives new possibilities for model building

Some examples

Example 1. Supersymmetric Minkowski with metric fluxes and $m = 0$

- Superpotential:

$$W = -T_2(a_2 S + b_{21} U_1) - T_3(a_3 S + b_{31} U_1) + e_0 + i h_0 S - i h_1 U_1 + i e_2 T_2 + i e_3 T_3$$

- Minimization constraints:

$$a_2 b_{31} = a_3 b_{21} \quad ; \quad e_2 a_3 = e_3 a_2 \quad ; \quad h_0 b_{31} = -a_3 h_1 \quad ; \quad h_0 e_2 = e_0 a_2$$

- Moduli fixing:

$$a_2 \mathrm{Im}\, T_2 + a_3 \mathrm{Im}\, T_3 = h_0 \qquad a_2 \mathrm{Im}\, S + b_{21} \mathrm{Im}\, U_1 = e_2$$

$$b_{31} \mathrm{Re}\, T_3 + b_{21} \mathrm{Re}\, T_2 = 0 \qquad a_2 \mathrm{Re}\, S + b_{21} \mathrm{Re}\, U_1 = 0$$

$\Downarrow$

No contribution to the RR tadpoles

Some examples

Example 2. Supersymmetric AdS with metric fluxes and $m \neq 0$

- Superpotential:

$$W = e_0 + 3ic_1 T + 3c_2 T^2 + imT^3 + ih_0 S - 3aST - \sum_{k=0}^{3} (ih_k + b_k T) U_k$$

- Minimization constraints: $3h_k a + h_0 b_k = 0 \quad k = 1, 2, 3$
- Moduli fixing:

$$a\,\mathrm{Re}\, S = 2\,\mathrm{Re}\, T(c_2 - m\,\mathrm{Im}\, T) \quad ; \quad 3a\,\mathrm{Re}\, S = b_k\,\mathrm{Re}\, U_k$$

$$3a\,\mathrm{Im}\, S + \sum_{k=1}^{3} b_k\,\mathrm{Im}\, U_k = 3c_1 + \frac{3c_2}{a}(3h_0 - 7a\,\mathrm{Im}\, T) - \frac{3m}{a}\,\mathrm{Im}\, T(3h_0 - 8a\,\mathrm{Im}\, T)$$

$$\mathrm{Im}\, T = (\lambda + \lambda_0)\frac{h_0}{3a} \quad ; \quad 3a^2(\mathrm{Re}\, T)^2 = 5h_0^2\lambda(\lambda + \lambda_0 - 1) \quad ; \quad \lambda_0 = \frac{3c_2 a}{mh_0}$$

$$160\lambda^3 + 186(\lambda_0 - 1)\lambda^2 + 27(\lambda_0 - 1)^2\lambda + \lambda_0^2(\lambda_0 - 3) + \frac{27a^2}{mh_0^3}(e_0 a - c_1 h_0) = 0$$

Some examples

Example 2. Supersymmetric AdS with metric fluxes and $m \neq 0$

- Tadpole contributions:

$$\sum_a N_a n_a^1 n_a^2 n_a^3 + \frac{1}{2} m h_0 (1 - \lambda_0) = 16$$

$$\sum_a N_a n_a^1 m_a^2 m_a^3 + \frac{1}{2} m h_1 (1 - \lambda_0) = 0$$

$$\sum_a N_a m_a^1 n_a^2 m_a^3 + \frac{1}{2} m h_2 (1 - \lambda_0) = 0$$

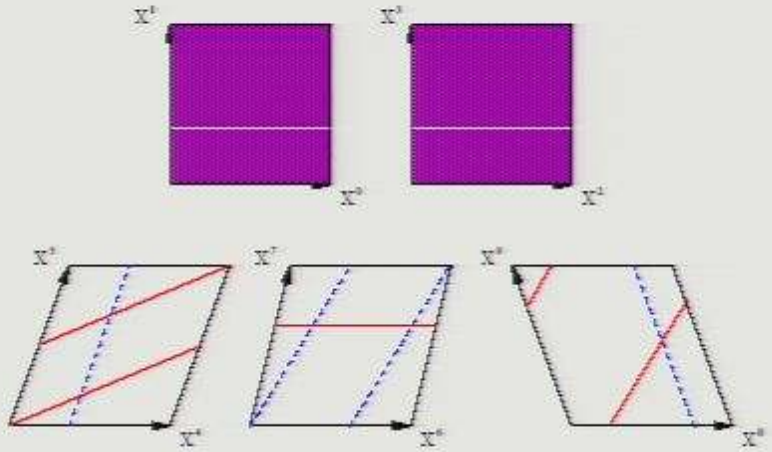
$$\sum_a N_a m_a^1 m_a^2 n_a^3 + \frac{1}{2} m h_3 (1 - \lambda_0) = 0$$

- Moduli can be fixed at perturbative regions

3. D6-branes and MSSM-like vacua

Intersecting D6-branes

Consider stacks of D6-branes filling M_4 and wrapping 3-cycles on $(T^2)^3$



$$[\Pi_a] = (n_a^1, m_a^1) \times (n_a^2, m_a^2) \times (n_a^3, m_a^3)$$

Intersection num.: $I_{ab} = \prod_{i=1}^{3} (n_a^i m_b^i - m_a^i n_b^i)$

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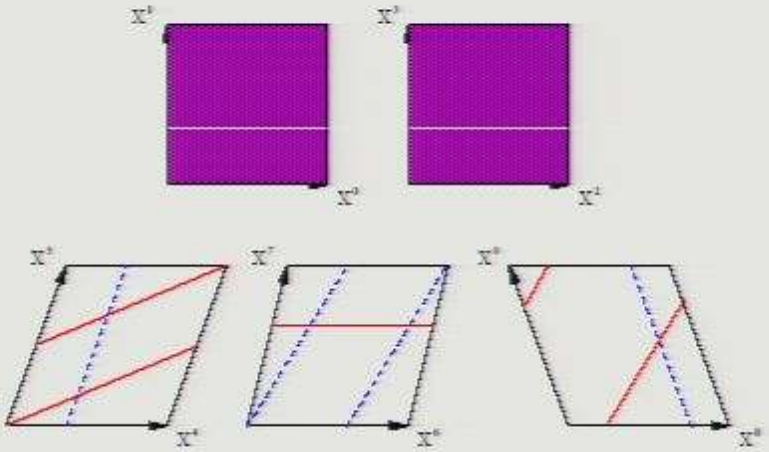

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- Mirror branes $D6_a^*$ under the orientifold should be added
- Bifundamental chiral representations $I_{ab}(N_a, \overline{N}_b) + I_{ab*}(N_a, N_b)$ living at the $D6_a D6_b$ and $D6_a D6_b^*$ intersections
- For all branes preserving the same $N = 1$ SUSY one must have

$$\sum_i \frac{m_i^a}{n_i^a} \tau_i = \frac{m_1^a m_2^a m_3^a}{n_1^a n_2^a n_3^a} \tau_1 \tau_2 \tau_3$$

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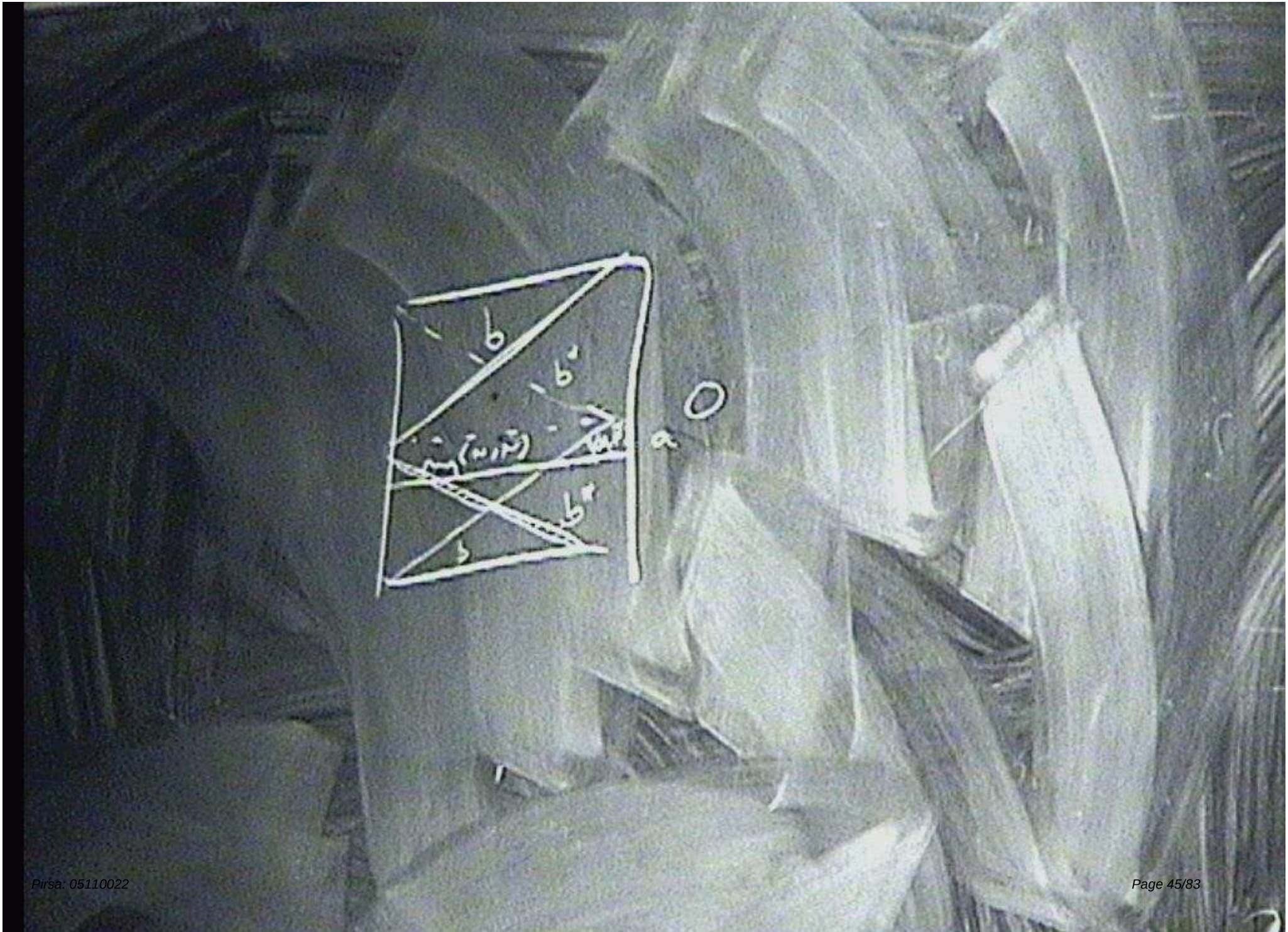
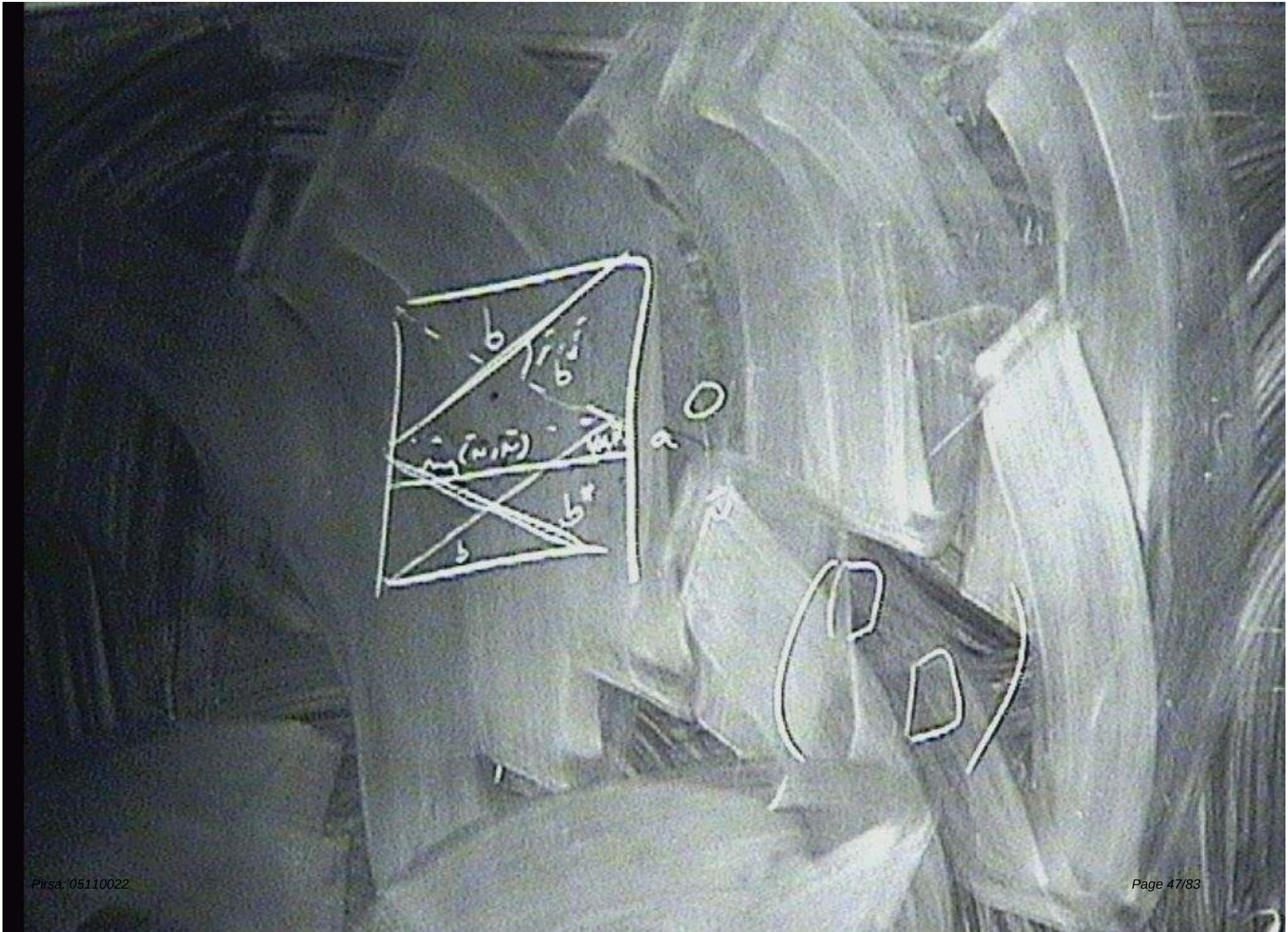
O





D6-branes and fluxes

- Couplings of the gauge fields to the c.s. axions:

$$\int_{D6}(C_3\wedge F_a\wedge F_a + C_5\wedge F_a) = \sum_I \int_{M_4}\left[p_I^a(\mathrm{Im}\,U_I)F_a\wedge F_a + N_a c_I^a C_I^{(2)}\wedge F^a\right]$$

with $U_I = \{S, U_i\}$ and

$$c_0^a = m_a^1 m_a^2 m_a^3 \qquad c_1^a = m_a^1 n_a^2 n_a^3 \qquad c_2^a = n_a^1 m_a^2 n_a^3 \qquad c_3^a = n_a^1 n_a^2 m_a^3$$
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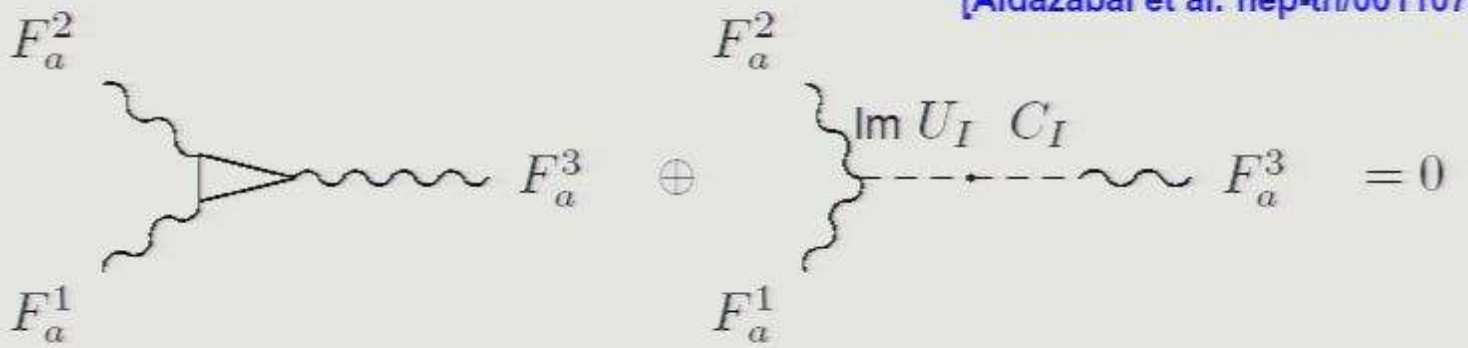
- The mixed $U(1)$ gauge anomalies are cancelled through:

[Aldazabal et al. hep-th/0011073]



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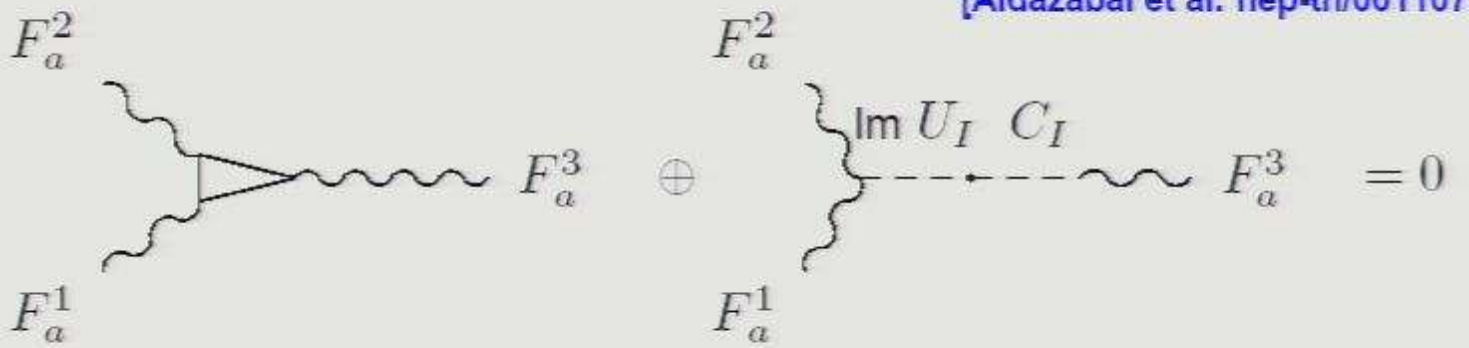

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- The scalars $\phi^a \equiv c_0^a \mathrm{Im}\, S - c_1^a \mathrm{Im}\, U_1 - c_2^a \mathrm{Im}\, U_2 - c_3^a \mathrm{Im}\, U_3$ behave like Goldstone bosons giving masses to the corresponding U(1)'s

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- It can be viewed as a generalization of the Freed-Witten anomaly constrains in presence of metric fluxes

MSSM-like vacua

- Brane content: (extension of [Cremades et al. hep-th/0302105])

N_i	(n_i^1, m_i^1)	(n_i^2, m_i^2)	(n_i^3, m_i^3)
$N_a = 4$	$(1,0)$	$(3,1)$	$(3,-1)$
$N_b = 1$	$(0,1)$	$(1,0)$	$(0,-1)$
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- Final gauge group: $SU(3) \times SU(2)_L \times U(1)_R \times U(1)_{B-L} \times [U(1) \times SU(3)^2]$

MSSM-like vacua

Intersection	Matter fields	Rep.	Q_{3B+L}	Q_1	Q_2
$a-b$	F_L	$3(4,2_L)$	1	0	0
$a-c$	F_R	$3(\bar{4},2_R)$	-1	0	0
$b-c$	H	$(2_L,2_R)$	0	0	0
$a-h_1$	T_1	$(4,\bar{3}_1)$	1	-1	0
$a-h_1'$	T_1'	$5(4,3_1)$	1	1	0
$a-h_2$	T_2	$5(\bar{4},\bar{3}_2)$	-1	0	1
$a-h_2'$	T_2'	$(\bar{4},\bar{3}_2)$	-1	0	-1
$b-h_2$	D_2	$2(2_L,\bar{3}_2)$	0	0	-1
$c-h_1$	D_1	$2(2_R,\bar{3}_1)$	0	-1	0
h_1-h_2'	X	$4(\bar{3}_1,3_2)$	0	-1	1

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- Fluxes (Supersymmetric AdS; 1 free parameter h_0):

$$q_i = h_i - 2 \quad ; \quad h_0 = -12h_i \quad ; \quad a_i = 16 \quad ; \quad m = b_{ij} = -b_{ii} = 4$$

- $\int_{\Pi_a} (\overline{H}_3 + \omega J_c) = 0 \Rightarrow$ **D6's on sLag cycles $\Rightarrow$ null FI, SUSY dynamically imposed!!**

MSSM-like vacua

- Flux contribute to tadpoles as $\overline{D6}$-charges $\Rightarrow$ tadpoles cancelled without orbifold twist!!
- All real moduli fixed by the fluxes:

$$\text{Re}\, S = -\frac{h_0\lambda}{96}\text{Re}\, T \quad ; \quad \text{Re}\, U_k = -\frac{h_0\lambda}{8}\text{Re}\, T \quad ; \quad \text{Re}\, T = \sqrt{\frac{5}{3}}\frac{|h_0|}{16}\lambda^{1/2}\left(\lambda + \frac{24}{h_0}\right)^{1/2}$$

with $\lambda_0 = 1 + (24/h_0)$ and

$$160\lambda^3 + 186(\lambda_0 - 1)\lambda^2 + 27(\lambda_0 - 1)^2\lambda + \lambda_0^2(\lambda_0 - 3) + \frac{27\cdot 4^3}{h_0^3}(16e_0 - c_1 h_0) = 0$$

- For large h_0 one can fix all the moduli in perturbative regions. E.g.

$$h_0 \gg 1, e_0 = c_1 = 0 \Longrightarrow e^{\phi_4} \simeq h_0^{-2} \quad ; \quad e^{\phi} \simeq h_0^{-1/2} \quad ; \quad \lambda_0 \simeq 1 \quad ; \quad V_0 \simeq -h_0^{-5}$$

- All Kähler axions are fixed whereas only the combination $12\text{Im}\, S + \sum_{k=1}^{3}\text{Im}\, U_k$ of c.s. axions is fixed.
- Two of the initial $U(1)$'s become massive through the Green-Schwarz mechanism

4. Soft SUSY-breaking

Flux induced soft SUSY-breaking

- The soft SUSY-breaking terms are crucial in the MSSM

$$\mathcal{L}_{soft} = -(m^2)_{ij}\phi_i\phi_j^* - \frac{1}{3!}A^{ijk}\phi_i\phi_j\phi_k + \frac{1}{2}B^{ij}\phi_i\phi_j - \frac{1}{2}M^a\lambda_a\lambda_a + h.c.$$

$$\mathcal{L}^{(2)}_{soft} = -\frac{1}{2}\mu^{ij}\psi_i\psi_j + \frac{1}{2}C^{ijk}\phi_i\phi_j^*\phi_k^* + M_g^{ia}\psi_i\lambda_a + h.c.$$

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We would like to compute the flux induced soft SUSY-breaking patterns from a microscopical point of view $\Rightarrow$ relations could be tested at LHC!

Flux induced soft SUSY-breaking

- We will center on Type IIA superpotentials of the form

$$W = W(S, T_1, T_2, T_3)$$

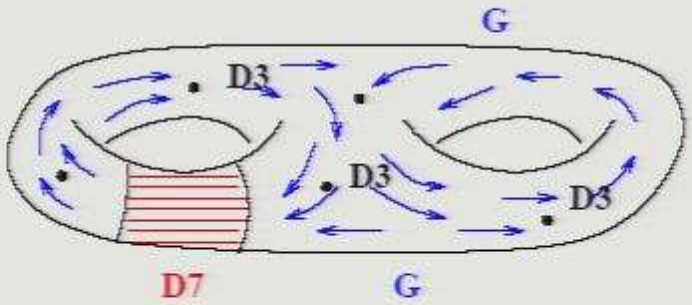
- In the Type IIB picture this corresponds to D3/D7-branes with RR and NSNS fluxes (GVW scenarios)

$$ds^2 = Z(x^m)^{-1/2}\eta_{\mu\nu}dx^\mu dx^\nu + Z(x^m)^{1/2}ds^2_{CY}$$

$$G_3 = F_3 - \tau H_3 = \frac{1}{3}G_{lmn}(x^m)dx^l \wedge dx^m \wedge dx^n$$

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

$$F_5 = d\chi_4 + *_{10}d\chi_4$$



At the minima G_3 is an ISD form (a $(2,1)_P$ form if $N \geq 1$ susy)

Soft-terms on D3-branes

- Local expansion of the six transverse coordinates $\Rightarrow$ diluted fluxes

$$Z^{-1/2} = 1 + \frac{1}{2} K_{mn} x^m x^n + \dots \qquad \tau = \tau_0 + \frac{1}{2} \tau_{mn} x^m x^n$$

$$G_{lmn}(x^m) = G_{lmn} + \dots \qquad \chi(x^m) = \text{const.} + \frac{1}{2} \chi_{mn} x^m x^n + \dots$$

This corresponds to an expansion on the worldvolume transverse scalar fields (open string moduli) $x^m = 2\pi\alpha' < \phi^m >$

- We plug it into the Myers action for a stack of D3-branes

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

$$+ \mu_3 \int \mathrm{Tr}\left(P\left[e^{i i_\phi i_\phi} \sum_n C^{(n)} e^{-B} \right] e^F \right)$$

Soft-terms on D3-branes

...and we obtain the low energy action for the D3-brane worldvolume fields

$$\mathcal{L} = \mathrm{Tr}\left[-(2K_{i\bar{j}} - \chi_{i\bar{j}} + g_s(\mathrm{Im}\,\tau)_{i\bar{j}})\Phi^i\Phi^{\bar{j}} - \frac{1}{2}(2K_{ij} - \chi_{ij} + g_s(\mathrm{Im}\,\tau)_{ij})\Phi^i\Phi^j + \mathrm{h.c.}\right.$$
$$+ g_s\sqrt{2\pi}\left[\frac{1}{3}G_{123}\epsilon_{ijk}\Phi^i\Phi^j\Phi^k + \frac{1}{2}\epsilon_{\bar{i}\bar{j}\bar{l}}(S_{lk} - (A_{\bar{l}\bar{k}})^*)\Phi^{\bar{i}}\Phi^{\bar{j}}\Phi^k + \mathrm{h.c.}\right] +$$
$$\left. + \frac{g_s^{1/2}}{2\sqrt{2}}\left[G_{123}\lambda\lambda + \frac{1}{2}\epsilon_{ijk}A_{\bar{j}\bar{k}}\Psi^i\lambda + \frac{1}{2}S_{ij}\Psi^i\Psi^j + \mathrm{h.c.}\right]\right]$$

	ISD			IASD	
$SU(3)$ rep.	Form	Tensor	$SU(3)$ rep.	Form	Tensor
$\overline{1}$	$(0,3)$	$G_{\bar{1}\bar{2}\bar{3}}$	1	$(3,0)$	G_{123}
$\overline{6}$	$(2,1)_P$	$S_{\bar{i}\bar{j}}$	6	$(1,2)_P$	S_{ij}
$\overline{3}$	$(1,2)_{NP}$	A_{ij}	3	$(2,1)_{NP}$	$A_{\bar{i}\bar{j}}$

Soft-terms on D3-branes

- In addition, the supergravity eqs. of motion impose

$$m_1^2 + m_2^2 + m_3^2 = \frac{g_s}{2}\left[|G_{123}|^2 + \frac{1}{4}\sum_{ij}(|S_{ij}|^2 + |A_{\bar{i}\bar{j}}|^2) - \right.$$
$$\left. -\mathrm{Re}\,(G_{123}G_{\bar{1}\bar{2}\bar{3}} + \frac{1}{4}S_{lk}S_{\bar{l}\bar{k}} + \frac{1}{4}A_{lk}A_{\bar{l}\bar{k}})\right]$$

There is a cancellation between DBI and CS depending on the relative sign between the background and the brane charges (BPS-like condition)

For ISD fluxes all the soft terms vanish

(The D3-brane open string moduli remain unfixed in GVW scenarios)

Soft-terms on D7-branes

- For D7-branes one proceeds analogously, but:
  - One expands the 2 transverse coordinates around a tubular neighborhood of the 4-cycle
  - One performs a KK reduction on the 4-cycle
- For a trivial normal bundle $T^4 \times C$ one gets

$$m^2_{1\bar{1}} = m^2_{2\bar{2}} = 0 \quad ; \quad B_{ij} = 0 \quad i,j \neq 3 \quad ; \quad A^{ijk} = -h^{ijk}\frac{g_s^{1/2}}{3\sqrt{2}}(G_{\bar{1}\bar{2}\bar{3}})^*$$

$$m^2_{3\bar{3}} = \frac{g_s}{18}\left(|G_{\bar{1}\bar{2}\bar{3}}|^2 + \frac{1}{4}|S_{\bar{3}\bar{3}}|^2 + \frac{1}{4}\sum_{i,j=1,2}(|S_{ij}|^2 + |A_{ij}|^2)\right)$$

$$B_{33} = \frac{g_s}{9}\left(\frac{1}{4}(S_{12})^{*2} + \frac{1}{4}(A_{12})^{*2} - \frac{1}{2}(G_{\bar{1}\bar{2}\bar{3}})^*(S_{\bar{3}\bar{3}})^* - \frac{1}{4}(S_{22})^*(S_{11})^*\right)$$

$$C^{ijk} = -\frac{g_s^{1/2}}{6\sqrt{2}}\left[\sum_{l=1,2} h^{jkl}(S_{li} + A_{li}) - h^{jk3}(S_{\bar{3}\bar{3}})^*\right] \quad ; \quad M^a = \frac{g_s^{1/2}}{3\sqrt{2}}(G_{\bar{1}\bar{2}\bar{3}})^*$$

$$\mu_{33} = -\frac{g_s^{1/2}}{6\sqrt{2}}(S_{\bar{3}\bar{3}})^* \quad ; \quad \mu_{ij} = -\frac{g_s^{1/2}}{6\sqrt{2}}S_{ij} \quad i,j = 1,2 \quad ; \quad M_g^{3a} = \frac{g_s^{1/2}}{6\sqrt{2}}(A_{12})^*$$

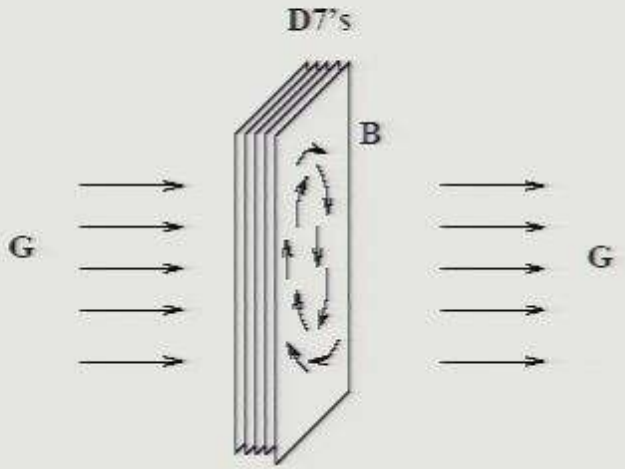
Soft-terms on D7-branes

- The soft lagrangian do not vanish for ISD fluxes [Kachru et al; Gomis et al]

D7-brane moduli fixed $\Rightarrow$ relevant for KKLT

- Local symmetry $SO(3,1) \times [SO(4) \times SO(2) \simeq SU(2) \times SU(2) \times U(1)]$

Rep.	ISD/IASD	SD/ASD in Σ_4
$(1,3)_+$	IASD	SD
$(3,1)_-$	IASD	ASD
$(1,3)_-$	ISD	SD
$(3,1)_+$	ISD	ASD



Soft-terms on D7-branes

- There are relations between the soft terms

$$ISD \begin{cases} (0,3) \begin{cases} A^{ijk} = -h^{ijk} M \\ (m^2)_{3\bar{3}} = |M|^2 \end{cases} & \Longrightarrow \quad \text{Kahler-domination } F_T \\ (2,1)_P \begin{cases} (m^2)_{ij} = |\mu_{ij}|^2 \\ C^{ijk} = -(h^{jkl})^* \mu_{il} \end{cases} & \Longrightarrow \quad \text{N=1 compatible} \end{cases}$$

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- The total scalar potential thus can be codified as

$$V_{ISD} = |\partial_i W - M^* \Phi_i^*|^2 \quad \Longrightarrow \quad \textbf{2 parameters!!}$$

MSSM on geometric moduli of D7-branes + ISD fluxes gives phenomenologically viable patterns of SUSY breaking

SUSY-breaking scale

Hierarchy of masses $\Longrightarrow$ $M_{\text{string}} \sim 10^{10} GeV$

(uniform fluxes)

$$m_{\text{soft}} = \frac{g_s^{1/2}}{\sqrt{2}} G_3 = \frac{f g_s^{1/2}}{\sqrt{2}} \frac{\alpha'}{R^3} = \frac{f M_s^2}{M_P} \quad ; \quad g_s^{1/2} \frac{\alpha'}{R^3}(\text{fluxes}) \ll \frac{1}{R}(\text{KK}) \ll M_s$$

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However, the soft terms depend on the local density of fluxes

$\Downarrow$

Further suppresion at regions with diluted fluxes

decoupling of the susy-breaking scale and the gravitino mass

- Additional suppression from the warping [Conlon,Quevedo,Suruliz]

5. Final comments

Final comments

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- Metric fluxes may contribute with any sign to RR-tadpoles giving rise to new model-building possibilities

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- Metric fluxes may contribute with any sign to RR-tadpoles giving rise to new model-building possibilities
- One can fix all the moduli in AdS vacua but some linear combinations of complex structure axions required for consistency. In this case, supersymmetry on the branes is dynamically forced by the fluxes
- We have presented a semi-realistic N=1 model in AdS with all closed string moduli stabilized in a perturbative regime

Final comments

- Moreover, the fluxes provide a microscopic source for supersymmetry breaking
- ISD fluxes + D7-branes constitute phenomenologically viable scenarios which may address the main problems of the MSSM
- Although the natural scale of SUSY-breaking continue being the gravitino mass, there is a decoupling between both scales

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- Although the natural scale of SUSY-breaking continue being the gravitino mass, there is a decoupling between both scales
- Lot of work to be done: SUSY-breaking patterns and open string moduli landscape in presence of metric fluxes, to explore other flux configurations, etc.
- Hopefully one day we will have a complete perturbative picture of the 4d vacuum structure of String Theory and perhaps... signatures at LHC?

Soft-terms on D7-branes

- There are relations between the soft terms

$$ISD \begin{cases} (0,3) \begin{cases} A^{ijk} = -h^{ijk} M \\ (m^2)_{3\bar{3}} = |M|^2 \end{cases} & \Longrightarrow \quad \text{Kahler-domination } F_T \\ (2,1)_P \begin{cases} (m^2)_{ij} = |\mu_{ij}|^2 \\ C^{ijk} = -(h^{jkl})^* \mu_{il} \end{cases} & \Longrightarrow \quad \text{N=1 compatible} \end{cases}$$

- The total scalar potential thus can be codified as

$$V_{ISD} = |\partial_i W - M^* \Phi_i^*|^2 \quad \Longrightarrow \quad \textbf{2 parameters!!}$$

MSSM on geometric moduli of D7-branes + ISD fluxes gives phenomenologically viable patterns of SUSY breaking