Title: Brane Transmutation by Internal Magnetic Fields and New Supersymmetric Orientifolds

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Abstract:

INTERNAL MAGNETIC FIELDS AND SUPERSYMMETRY IN ORIENTIFOLDS

based on E.D. & C. Timirgaziu, hep-th/0502085,
Nucl. Phys. B, to appear

1) Exotic orientifold planes and SUSY (breaking)
2) BPS branes $\longleftrightarrow$ non-BPS branes equivalence in Type I with internal magnetic fields
3) Negative induced tensions and SUSY in orientifolds
4) New SUSY orientifolds: examples
5) Prospects

Workshop "String Phenomenology"
Perimeter Institute
march 28, 2005

1. Exotic O-planes and SUSY (breaking)

Type IIB/IIA orientifolds contain different type of BPS objects, with various tensions and RR charges

Ex:

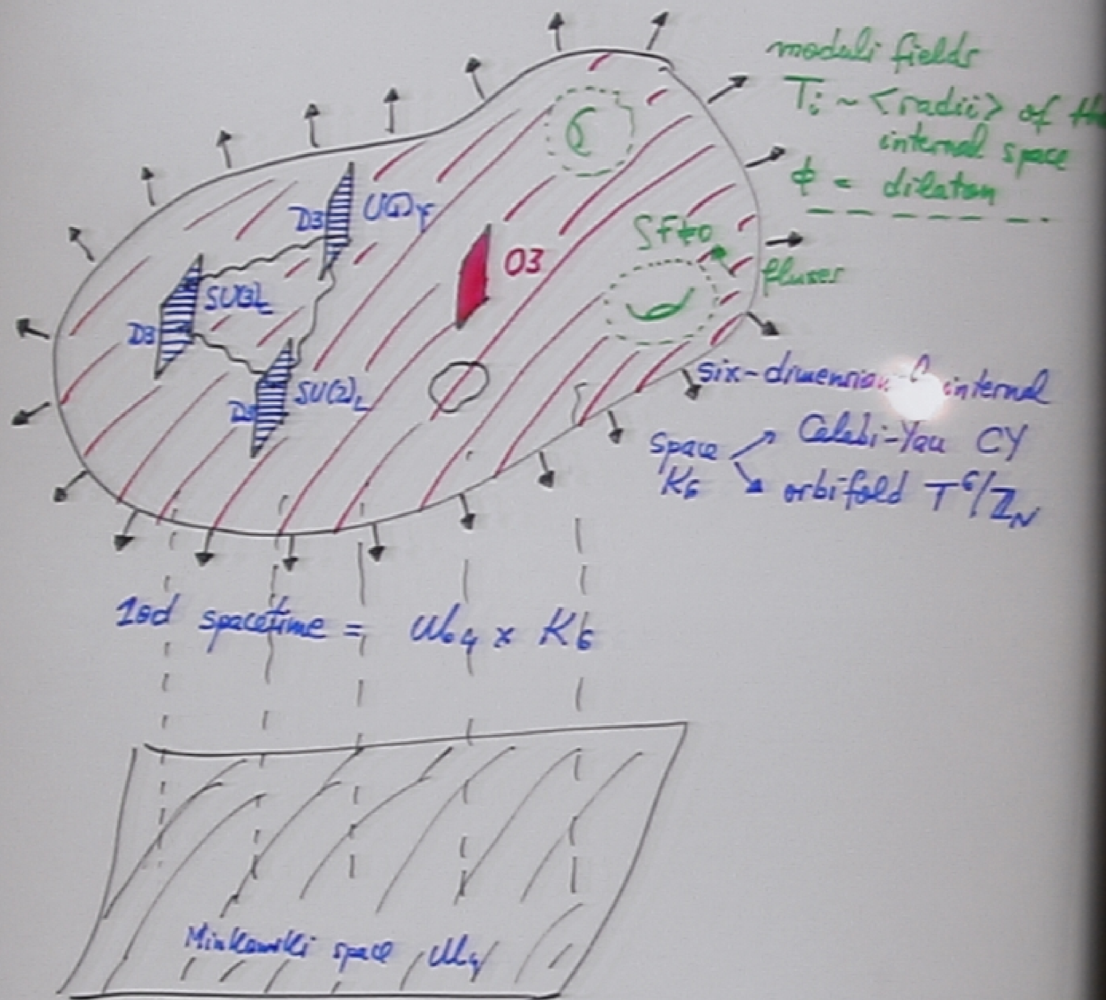
IIB orbifolds/orientifolds	tension	RR charge	SUSY
$D9$, $D5_i$	+	+	1/2
$\overline{D9}$, $\overline{D5_i}$	+	−	1/2
$O9_+$, $O5_{i+}$	−	−	1/2
$\overline{O9_+}$, $\overline{O5_{i+}}$	−	+	1/2
$O9_-$, $O5_{i-}$	+	+	1/2
$\overline{O9_-}$, $\overline{O5_{i-}}$	+	−	1/2

Certain configurations break completely SUSY with no tachyons:

$\overline{Dp} - Oq_\pm$ and $Dp - \overline{Oq_\pm}$ $\Rightarrow$

- SUSY in the closed sector
- ~~SUSY~~ (non-linear SUSY) in the open sector

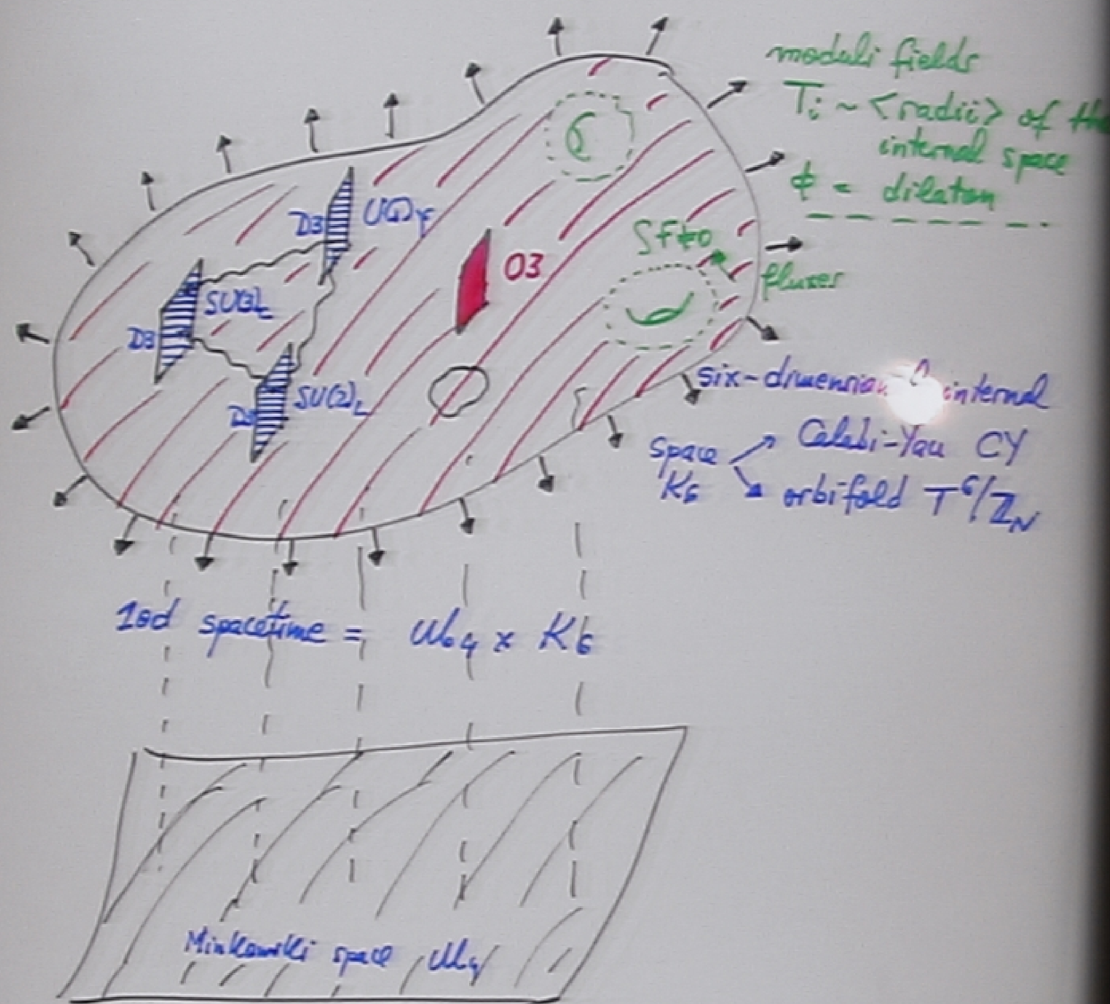
Cartoon of a string model



Gauss law in a compact space

$$\boxed{\sum_p q_{Dp} + \sum_p q_{Op} = 0}$$

Cartoon of a string model



Gauss law in a compact space

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Examples of exotic O-plane constructions with ~~SUSY~~

IIB/Ω'	objects	gauge group
$\Omega' = \Omega(-1)^F$ spacetime fermion # (Sugimoto, 99)	$O9, \overline{D9}$	$USp(32)$
$T^4/\mathbb{Z}_2$ orbifold $\Omega' = \Omega \cdot P$, $P \to 1$, untwisted; $P \to -1$, twisted (Antoniadis, Dudas & Sagnotti; Aldazabal & Uranga, 99)	$O9_+, D9$ $O5_-, \overline{D5}$	$[SO(16)\times SO(16)]_9 \times [USp(16)\times USp(16)]_5$
$T^6/\mathbb{Z}_2\times\mathbb{Z}_2$ orbifold with "discrete torsion" * $\Omega' = \Omega P'$, $P'^2 = \mathbb{1}$ (Antoniadis, Angelantonj, d'Appollonio, E.D. & Sagnotti, 99) $\varepsilon_1 \cdot \varepsilon_2 \cdot \varepsilon_3 = \varepsilon$: 1, no discrete torsion; -1, discrete torsion	$O9_+, D9$ $O5_{\varepsilon_i}, D5_i (\varepsilon_i = 1)$ $\overline{D5}_i (\varepsilon_i = -1)$	- - - - -

- Is ~~SUSY~~ unavoidable in orientifolds with exotic O-planes ?

* recent work: Blumenhagen, Lüst & Taylor
Marchesano & Shiu
Blumenhagen, Cvetič, Marchesano & Shiu

Examples of exotic O-plane constructions with $\not{S}USY$

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$T^4/\mathbb{Z}_2$ orbifold $\Omega' = \Omega \times P$; P: 1, untwisted; -1, twisted (Antoniadis, Dudas & Sagnotti; Aldazabal & Uranga: 99)	$O9_+$, $D9$ $O5_-$, $\overline{D5}$	$[SO(16) \times SO(16)]_9 \times$ $[USp(16) \times USp(16)]_5$
$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold with "discrete torsion" * $\Omega' = \Omega P'$, $P'^2 = \mathbb{1}$ (Antoniadis, Angelantonj, d'Appollonio, E.D. & Sagnotti, 99) $\varepsilon_1 \cdot \varepsilon_2 \cdot \varepsilon_3 = \varepsilon$: 1, no discrete torsion; -1, discrete torsion	$O9_+$, $D9$ $O5_{\varepsilon_i}$, $D5_i\,(\varepsilon_i = 1)$ $\overline{D5}_i\,(\varepsilon_i = -1)$	- - - - - -

- Is $\not{S}USY$ unavoidable in orientifolds with exotic O-planes ?

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2) INTERSECTING BRANE MODELS

(Bachas; Berkooz, Douglas & Leigh, Blumenhagen, Görlich, Körs & Lüst; Angelantonj, Antoniadis, E.D. & Sagnotti; Ibanez, Uranga & coll.; Cvetic, Shiu & Uranga.

Talks: Antoniadis, Cvetic, Marchesano

Type II B orientifold models with internal magnetic fields

$\updownarrow$ T-dual version

Type II A orientifolds with D-branes intersecting at angles

(IIB) compact coordinates

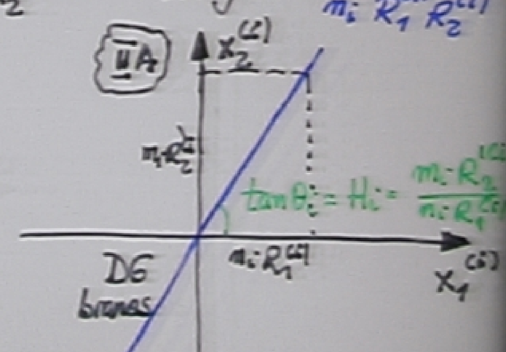
$T_2^{(1)}$	$T_2^{(2)}$	$T_2^{(3)}$
$x_1^{(1)}\, x_2^{(1)}$	$x_1^{(2)}\, x_2^{(2)}$	$x_1^{(3)}\, x_2^{(3)}$
H_1	H_2	H_3

Internal magnetic fields $\rightarrow$ H_1, H_2, H_3

Landau levels

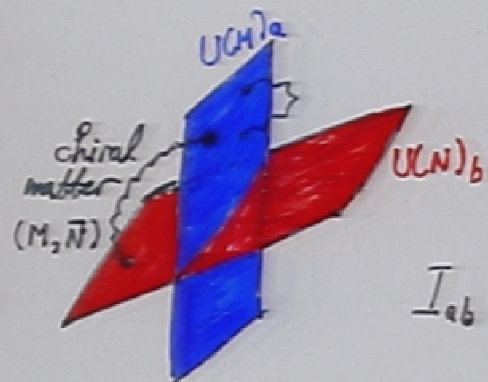
Dirac quantization condition
$$H_i = \frac{k_i}{R_1^{(i)} R_2^{(i)}} \xrightarrow[\text{theory}]{\text{string}} \frac{m_i}{n_i\, R_1^{(i)} R_2^{(i)}}$$

$$\xleftrightarrow{T_2^{(i)}\text{-dualities}}$$
$$R_2^{(i)} \rightarrow \frac{\alpha'}{R_2^{(i)}}$$



$$\begin{cases} m_i = \text{wrapping numbers along } X_2^{(i)} \\ n_i = \quad \text{---}\,"\text{---} \quad "\text{---} \quad "\text{---} \quad X_1^{(i)} \end{cases}$$

2-stacks of branes configuration



$\#$ generations

$\|$

intersection number

$\|$

$$I_{ab} = \prod_{i=1}^{3} \left(n_a^i m_b^i - m_a^i n_b^i \right)$$

Generic configuration breaks SUSY completely.

Particular configurations:

- $\frac{1}{2}$ BPS ($\mathcal{N}=4$ SUSY) : $\theta_1 = \theta_2 = \theta_3 = 0$
- $\frac{1}{4}$ BPS ($\mathcal{N}=2$ SUSY) : $\theta_1 \pm \theta_2 = 0$, $\theta_3 = 0$
- $\frac{1}{8}$ BPS ($\mathcal{N}=1$ SUSY) : $\theta_1 \pm \theta_2 \pm \theta_3 = 0$
- non-SUSY : $\theta_1 \pm \theta_2 \pm \theta_3 \neq 0$

BPS branes $\leftrightarrow$ non-BPS branes equivalence with internal magnetic fields in Type I

- BPS branes in internal magnetic fields

Ex: D9 branes ($\frac{1}{2}s_i = \pm\frac{1}{2}$ are internal helicities)

$$S_{WZ} = \frac{m_1 m_2 m_3}{2}\, q_9 \int_{\mathcal{M}_{10}} C \wedge \left(e^{s_1 H_1 + s_2 H_2 + s_3 H_3} + e^{-s_1 H_1 - s_2 H_2 - s_3 H_3} \right)$$

$$= m_1 m_2 m_3\, q_9 \int_{\mathcal{M}_{10}} C_{10} + \underbrace{\sum_{i<j} m_1 m_2 m_3\, q_9 \int_{\mathcal{M}_{10}} C_6 \wedge s_i s_j\, H_i \wedge H_j}_{\displaystyle q_5 \sum_{i\neq j\neq k} s_j s_k\, m_i\, m_j\, m_k \int_{\mathcal{M}_6^{(i)}} C_6^{(i)}}$$

induced $D5_i$ type RR charges

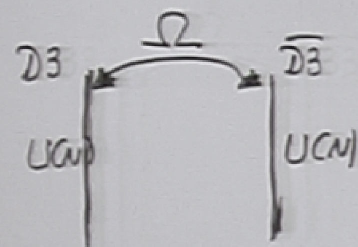
SUSY case $\Rightarrow$ effective tension has a similar interpretation

$$T_{\rm eff} = |n_1 n_2 n_3|\, T_9 \sqrt{\det(g_{\alpha\beta} + F_{\alpha\beta})} =$$

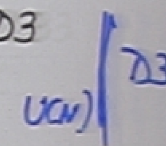
$$| m_1 m_2 m_3\, T_9 - T_5 (m_1 m_2 m_3 + m_1 m_2 m_3 + m_1 m_2 m_3)\, \mathrm{sgn}(n_1 n_2 n_3) |$$

- SUSY case $\Rightarrow$ $q_{\rm eff}$ matches perfectly $T_{\rm eff}$

- non-BPS D3/D7 in Type I with internal magnetic fluxes



$\Longrightarrow$ non-BPS D3 in Type I



since the RR 4-form is Ω-odd.

Add magnetic fluxes on the T-dual D9-branes

$$\mathcal{H}_i : \ \tan\varphi_i = \frac{m_i^1}{n_i^1 v_i}$$

$$S_{WZ} = \frac{n_1^1 n_2^1 n_3^1}{2}\, q_9 \int_{\mathcal{M}_{10}} C \wedge \left(e^{\sum_i s_i \mathcal{H}_i} - e^{-\sum_i s_i \mathcal{H}_i} \right) =$$

$$= \prod_{i=1}^{3} (s_i m_i^1)\, q_3 \int_{\mathcal{M}_4} C_4 + q_7 \sum_{i \neq j \neq k} s_i m_i^1 n_j^1 n_k^1 \int_{\mathcal{M}_8} C_8^{(i)}$$

$\xrightarrow[\text{back}]{\text{T-dualize}}$ ((induced D9 & $D5_i$ charges from non-BPS D3 branes

SUSY condition $\boxed{\varphi_1 + \varphi_2 + \varphi_3 = \frac{\pi}{2}}$

The equivalence

	flux	wrapping #	angles
D9	H_i	$(m_i; n_i)$	θ_i
D3	$\mathcal{H}_i = \frac{1}{H_i}$	$(m_i^1; n_i^1)$	

3) Negative induced tensions and SUSY in orientifolds

- use only BPS branes from now on. N_a stacks of D9 branes with fluxes

$$H_i^{(a)} = \tan\theta_i^{(a)} = \frac{m_i^{(a)}}{n_i^{(a)} v_i}$$

- SUSY conditions on each stack

$$\sum_i \theta_i^{(a)} = 0 \quad \Rightarrow \quad H_1^{(a)} + H_2^{(a)} + H_3^{(a)} = H_1^{(a)} H_2^{(a)} H_3^{(a)}$$

$\rightsquigarrow$ at least one magnetic field is negative $\Rightarrow$ one induced $D5_i$-type tension is negative

Ex: (+ permutation of tori + $H_i^{(a)} \to -H_i^{(a)}$)

D9 with fluxes	T_1	T_2	T_3
Magnetic fields	$H_1(+)$	$H_2(+)$	$H_3(-)$
Induced tension	$+$	$+$	$-$

$\Rightarrow$ possibility of compensating exotic O-plane tensions/charges by magnetic-induced ones, but tadpole conditions + SUSY put severe restrictions

Define $n^{(a)} \equiv n_1^{(a)} n_2^{(a)} n_3^{(a)}$ $\Rightarrow$ untwisted tadpole conditions

$$
\begin{cases}
\sum_a M_a n^{(a)} = 16 & D9/O9 \\
\sum_a M_a n^{(a)} H_2^{(a)} H_3^{(a)} = -\dfrac{16\,\varepsilon_1}{v_2 v_3} & D5_1/O5_1 \\
\sum_a M_a n^{(a)} H_1^{(a)} H_3^{(a)} = -\dfrac{16\,\varepsilon_2}{v_1 v_3} & D5_2/O5_2 \\
\sum_a M_a n^{(a)} H_1^{(a)} H_2^{(a)} = -\dfrac{16\,\varepsilon_3}{v_1 v_2} & D5_3/O5_3
\end{cases}
$$

in a condensed notation

$(\varepsilon_1, \varepsilon_2, \varepsilon_3) =$
- $\to (0,0,0)$, toroidal comp.
- $\to (\pm 1, 0, 0)$, $\mathbb{Z}_2$ orbifold
- $\to (\pm 1, \pm 1, \pm 1)$, $\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold

- Small magnetic fields $\quad 1 - \sum_{i<j} H_i^{(a)} H_j^{(a)} > 1 \Rightarrow$

$$\frac{\varepsilon_1}{v_2 v_3} + \frac{\varepsilon_2}{v_1 v_3} + \frac{\varepsilon_3}{v_1 v_2} > 0$$

- SUSY toroidal comp.; $T^4/\mathbb{Z}_2$ with exotic $T^4/\mathbb{Z}_2$; $T^6/\mathbb{Z}_2$ with $\varepsilon_i = -1$ $\Big\}$ impossible (generalized case (Antoniadis + Maillard) $\to$ possible)

- $\varepsilon_i = (1, 1, -1)$ possible if $v_1 > v_2, v_3$, etc

- For large magnetic fields similar constraints (toroidal + SUSY forbidden)

- Magnetic fields induce lower-dim. coupl...

New SUSY orientifolds: $\mathbb{Z}_2 \times \mathbb{Z}_2$ with exotic O-planes

- magnetic fields induce tadpoles for twisted RR 4-forms

Ex: helicities $s_i = (-\frac{1}{2}, \frac{1}{2}, 0, 0) \Rightarrow$

$$m_i^{(a)} M_a \int_{\mathcal{M}_6} C_T \wedge \left(e^{s_i H_i^{(a)}} - e^{-s_i H_i^{(a)}} \right)$$

$$\rightarrow \quad s_i M_a m_i^{(a)} \int_{\mathcal{M}_4} C_{4,T}$$

$$\Rightarrow \boxed{\sum_a m_i^{(a)} M_a = 0}$$

- write complete string propagation, spin-statistics, open-closed duality

Define intersection numbers

$$I^{ab} \equiv \prod_{i=1}^{3} I_i^{ab} = \prod_{i=1}^{3} \left(m_i^{(b)} n_i^{(a)} - n_i^{(b)} m_i^{(a)} \right)$$

$$I^{ab'} \equiv \prod_{i=1}^{3} I_i^{ab'} = \prod_{i=1}^{3} \left(m_i^{(a)} n_i^{(b)} + n_i^{(a)} m_i^{(b)} \right)$$

$$I^{aO} = 8 \left[m_1^{(a)} m_2^{(a)} m_3^{(a)} - \varepsilon_1 m_1^{(a)} n_2^{(a)} n_3^{(a)} - \varepsilon_2 n_1^{(a)} m_2^{(a)} n_3^{(a)} - \varepsilon_3 n_1^{(a)} n_2^{(a)} m_3^{(a)} \right)$$

Massless spectrum

Gauge group $\prod_a U(p_a)\times U(q_a)$

$(p_a=q_a)$

Multiplicity	Representation
1	$(p_a,\bar{q}_a)+(\bar{p}_a,q_a)$
$\frac{1}{8}\left(I^{aa'}+I^{aO}-4I_1^{aa'}-4I_2^{aa'}+4I_3^{aa'}\right)$	$\left(\frac{p_a(p_a-1)}{2},1\right)+\left(1,\frac{q_a(q_a-1)}{2}\right)$
$\frac{1}{8}\left(I^{aa'}-I^{aO}-4I_1^{aa'}-4I_2^{aa'}+4I_3^{aa'}\right)$	$\left(\frac{p_a(p_a+1)}{2},1\right)+\left(1,\frac{q_a(q_a+1)}{2}\right)$
$\frac{1}{4}\left(I^{aa'}-4I_1^{aa'}+4I_2^{aa'}-4I_3^{aa'}\right)$	(p_a,q_a)
$\frac{1}{4}\left(I^{ab'}-4I_1^{ab'}-4I_2^{ab'}+4I_3^{ab'}\right)$	$(p_a,p_b)+(q_a,q_b)$
$\frac{1}{4}\left(I^{ab'}-4I_1^{ab'}+4I_2^{ab'}-4I_3^{ab'}\right)$	(p_a,q_b)
$\frac{1}{4}\left(I^{ab}+4I_1^{ab}+4I_2^{ab}+4I_3^{ab}\right)$	$(p_a,\bar{p}_b)+(q_a,\bar{q}_b)$
$\frac{1}{4}\left(I^{ab}+4I_1^{ab}-4I_2^{ab}-4I_3^{ab}\right)$	$(p_a,\bar{q}_b)$

A chiral example

- 3 stacks $M_1 = 6$, $M_2 = 4$, $M_3 = 2$

with fluxes

$$(m_i^{(1)}, n_i^{(1)}) = (1,1), (1,1), (-1,1)$$

$$(m_i^{(2)}, n_i^{(2)}) = (-1,1), (-2,2), (1,1)$$

$$(m_i^{(3)}, n_i^{(3)}) = (-1,1), (-1,1), (1,1)$$

satisfy SUSY + untwisted tadpoles + twisted tadpoles

Gauge group $[U(3) \times U(2) \times U(1)]^2$ with

four generations of quarks & leptons

eight Higgs doublets

- There are byfundamental fields which, if given a vev, breaks the gauge group down to the Standard Model gauge group

PROSPECTS

- The new SUSY orientifolds have some nice features: no chirals in adjoint repres., avoids strong coupling regime for SM gauge couplings
- More constructions of this type desirable for quasi-realistic models (other orbifolds, different negative induced tensions)
- Possible heterotic duals
- Combine with 3-form fluxes (talk Marchesano; Blumenhagen, Cvetic, Marchesano & Shiu)
- Is there is a continuous connection between the SUSY and the non-SUSY solutions ?