TWISTS AND SHIFTS

Massimo BIANCHI

CERN Theory Division
Università di Roma "Tor Vergata" - INFN
Talk at String Pheno '08

June 1, 2008

Foreword

- The combined effect of twists and shifts has not been systematically explored in the context of unoriented strings
- Basic idea: chiral twists freeze untwisted moduli, non-geometric shifts prevent massless twisted moduli [Dabholkar, Hull; Dine, Silverstein; Kumar, Vafa; ...M.B., Morales, Pradisi]
- Various approaches: non-geometric and freely acting L-R (a)symmetric orbifolds [Narain, Sarmadi, Vafa; Ferrara, Kounnas, Porrati, Zwirner; Kiritsis, Petropoulos, Rizos; ...], free fermions [Antoniadis, Bachas, Kounnas; Kawai, Lewellen, Tye; ...], rational CFT's [Lerche, Lüst, Schellekens, Warner; Gepner; ...], ...
- Expect duality between (D-branes in) non-geometric vacua and (D-branes in) flux compactifications, at least for extended susy ($\mathcal{N} \geq 3$)

Plan

Part I: Unoriented twists and shifts

- Unoriented T-folds with few T's [Anastasopoulos, MB, Morales, Pradisi (w.i.p.)]
- B-field and bundles without vector structure [Bachas, MB, Blumenhagen, Lüst, Weigand]
- *Intermezzo*: Magic $\mathcal{N} = 2$ supergravities [MB, Ferrara; Kounnas, Dolivet, Julia]

Part II: Bound-states of D-branes in L-R asymmetric vacua with extended susy [MB]

- Residual susy and R-R couplings
- $\mathcal{N} = 6 = 2_L + 4_R$ and other extended susy cases
- Open string excitations

Outlook and Announcements

Part I: Unoriented twists and shifts

Unoriented T-folds with few T's

CDMP model [Camara, Dudas, Maillard, Pradisi; Vafa, Witten]: standard geometric freely acting orbifold $T^6/Z_2 \times Z_2$, Type I / Heterotic dual pairs
All twisted moduli are massive. Only untwisted moduli T_I, U_I,
Combine with gaugino condensate(s) in open string sector and/or 3-form fluxes to partially stabilize dilaton and other moduli.
DJK 'minimal' model [Dolivet, Julia, Kounnas]: (non-magic) hyper-free model, fermionic construction

$$G = \psi^\mu \partial X_\mu + \chi^i y^i w^i$$

Fermionic basis sets [Antoniadis, Ellis, Hagelin, Nanopoulos; ... Faraggi, Kounnas; ...] :
$F, S, \bar{S},\ \bar{b}_1,\ b_1 = \{\psi^\mu, \chi^{1,2}; y^{3,4,5,6}, y^1 w^1 | \bar{y}^5 \bar{w}^5\}$,
$b_2 = \{\psi^\mu, \chi^{3,4}; y^{1,2}, w^{5,6} y^3 w^3 | \bar{y}^6 \bar{w}^6\}$,
$b_3 = \{\psi^\mu, \chi^{5,6}; w^{1,2,3,4} y^6 w^6 | \bar{y}^6 \bar{w}^6\}$
Only dilaton vector-multiplet survives. $\mathcal{N}_L = 0$, L-R asymmetric $(-)^{F_L}\sigma$ freely acting orbifold of $T^6_{SO(12)}$, $y^i w^i \approx$ shifts.

Combining DJK and CDMP

Replace $\bar{b}_3$ with b_2, get a L-R symmetric asymmetric orbifold.
Geometric (freely acting) projections associated to $b_1\bar{b}_1$ and $b_2\bar{b}_2$.
Non geometric (freely acting) projections associated to $b_1, b_2, ...b_1\bar{b}_2$.
All untwisted moduli except dilaton hypermultiplet are projected out ($\mathcal{N}_L = \mathcal{N}_R = 1, \mathcal{N}_{tot} = 2$).
Massless multiplets only from $b_1 b_2\bar{b}_1\bar{b}_2$ twisted sector: one hypers and one vector, "h_{11}" = "h_{21}" $= 1$ ($\mathcal{HOLY}\,\mathcal{GRAIL}$ [Szendroi, Gross])
Unoriented projection produces $1_u + 2_t - n$ chiral-plets and n vector-plets ($n = 0, 1$)
Open string spectrum: non chiral, rank reduction from B-field.
Systematic study under way. For MSSM embeddings [Kiritsis's talk]
Combine with (non) anomalous $U(1)$'s, fluxes [McOrist's, Schulz's talks], (non)geometric D-brane instantons (gaugino condensation, ADS-like superpotentials, ...) [Blumenhagen's, Dudas's, Marchesano's talks]

$T^6/(Z_{2L} \times Z'_{2L} \times Z_{2R} \times Z'_{2R})$: 1-twisted sector

Generators of the orbifold group specified by the fermionic sets

$$
\begin{array}{rcl}
g_1 &=& \{\chi_{3456} \; ; \; y_{13456} \; ; \; w_1 \; | \; ; \; \tilde{y}_5 \; ; \; \tilde{w}_5 \} \\
g_2 &=& \{\chi_{1256} \; ; \; y_{123} \; ; \; w_{356} \; | \; ; \; \tilde{y}_6 \; ; \; \tilde{w}_6 \} \\
\tilde{g}_1 &=& \{ \; ; \; y_5 \; ; \; w_{15} \; | \tilde{\chi}_{3456} \; ; \; \tilde{y}_{13456} \; ; \; \tilde{w}_1 \} \\
\tilde{g}_2 &=& \{ \; ; \; y_6 \; ; \; w_6 \; | \tilde{\chi}_{1256} \; ; \; \tilde{y}_{123} \; ; \; \tilde{w}_{356} \}
\end{array}
$$

Introducing

$$
\begin{array}{rcl}
g_3 &=& g_1 g_2 = \{\chi_{1234} \; ; \; y_{2456} \; ; \; w_{1356} \; | \; ; \; \tilde{y}_{56} \; ; \; \tilde{w}_{56} \} \\
\tilde{g}_3 &=& \tilde{g}_1 \tilde{g}_2 = \{ \; ; \; y_{56} \; ; \; w_{56} \; | \tilde{\chi}_{1234} \; ; \; \tilde{y}_{2456} \; ; \; \tilde{w}_{1356} \}
\end{array}
$$

the generic orbifold group element can be written as $g_m^a \tilde{g}_n^b$ with $m, n = 1, 2, 3, \; a, b = 0, 1$.

Torus partition function

$$\mathcal{T} = \tfrac{1}{16}\{ \sum_{c,d=0}^{3} \rho_{0c}\, \bar\rho_{0d}\, \mathbf{\Lambda}_{00,cd} + \sum_{a,b=0}^{3} (\rho_{a0}\, \bar\rho_{b0}\, \mathbf{\Lambda}_{ab,00} + \rho_{aa}\, \bar\rho_{bb}\, \mathbf{\Lambda}_{ab,ab})$$
$$+ \sum_{a=1}^{3} \sum_{b\neq a}^{3} \epsilon_{\mathbf{ab}}\, \rho_{ab}\, \bar\rho_{ab}\, \mathbf{\Lambda}_{aa,bb} \}$$

where

$$\rho_{00} = \frac{1}{\eta^8} (Q_o + Q_v) \qquad \rho_{0h} = \frac{1}{\eta^8} (Q_o^{(h)} - Q_v^{(h)})$$
$$\rho_{h0} = \frac{1}{\eta^8} (Q_s^{(h)} + Q_c^{(h)}) \qquad \rho_{hh} = -\frac{i}{\eta^8} (Q_s^{(h)} - Q_c^{(h)})$$
$$\rho_{hh'} = -\frac{i}{\eta^8} (Q_{s-'}^{(h)} - Q_{c-'}^{(h)})$$

where $h \neq h'$ and $h = 1, 2, 3$

The lattice for $h = 1, 2$ and separately for 3 gives:

$$
\begin{aligned}
\Lambda_{00,00} &= \tfrac{1}{2}(|\vartheta_2|^{12} + |\vartheta_3|^{12} + |\vartheta_4|^{12}) \\
\Lambda_{00,h0} &= \Lambda^*_{00,0h} = \tfrac{1}{2}\left(\vartheta_3^3\vartheta_4^3\bar\vartheta_3^5\bar\vartheta_4 + \vartheta_3^3\vartheta_4^3\bar\vartheta_3\bar\vartheta_4^5\right) \\
\Lambda_{h0,00} &= \Lambda^*_{0h,00} = \tfrac{1}{2}\left(\vartheta_3^3\vartheta_2^3\bar\vartheta_3^5\bar\vartheta_2 + \vartheta_3^3\vartheta_2^3\bar\vartheta_3\bar\vartheta_2^5\right) \\
\Lambda_{h0,h0} &= \Lambda^*_{0h,0h} = \tfrac{i}{2}\left(\vartheta_4^3\vartheta_2^3\bar\vartheta_2^5\bar\vartheta_4 - \vartheta_2^3\vartheta_4^3\bar\vartheta_2\bar\vartheta_4^5\right) \\
\Lambda_{00,30} &= \Lambda^*_{00,03} = \tfrac{1}{2}\left(\vartheta_3^2\vartheta_4^4\bar\vartheta_3^4\bar\vartheta_4^2 + \vartheta_3^4\vartheta_4^2\bar\vartheta_3^2\bar\vartheta_4^4\right) \\
\Lambda_{30,00} &= \Lambda^*_{03,00} = \tfrac{1}{2}\left(\vartheta_3^2\vartheta_2^4\bar\vartheta_3^4\bar\vartheta_4^2 + \vartheta_3^4\vartheta_2^2\bar\vartheta_3^2\bar\vartheta_2^4\right) \\
\Lambda_{30,30} &= \Lambda^*_{03,03} = \tfrac{i}{2}\left(\vartheta_4^2\vartheta_2^4\bar\vartheta_4^4\bar\vartheta_4^2 - \vartheta_4^4\vartheta_2^2\bar\vartheta_4^2\bar\vartheta_2^4\right) \\
\Lambda_{other} &= 0
\end{aligned}
$$

Only massless states come from the $g_3\tilde{g}_3$-twisted sector:

$$
\mathcal{T} = |V - S - C|^2 + |2O - S - C|^2 + \dots
$$

$\mathcal{N} = 2$ supergravity coupled to 1+1 hypers and 1 vector
"h_{11}" = "h_{21}" $= 1$!!

B-field and no vector structure

Most 'rational' models allow/require discrete non zero values for the 'frozen' moduli

B-field in Type I, odd under Ω, $B = 1/2$ allowed, rank reduction in toroidal compactifications with flat bdles (susy) $N = 32 \times 2^{-r_B/2}$ [MB, Sagnotti; MB, Pradisi, Sagnotti]

Heterotic dual description: CHL strings [Chaudhuri, Hockney, Lykken]

Compactifications without vector structure $B = \tilde{w}_2$, non commuting Wilson lines [Sen, Sethi; Berkooz et al; MB; Witten; Dijkgraaf et al]

For non-susy (non-tachyonic) toroidal models with magnetic fields and 't Hooft fluxes, rank reduction not necessary

Model C [Bachas] $G = U(5) \times U(3) \times U(4) \times U(4)'$ with $(5^*, 3)$ and 3 copies of 10. Non susy. Magnetic field without vector structure, requires non zero B-field for consistency [Bachas, MB, Blumenhagen, Lüst, Weigand]

Figure 1

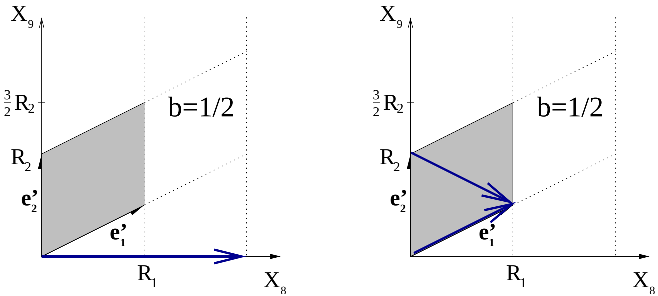

Figure: Two configurations of D8-branes cancelling the tadpole with the branes indicated by the blue arrows.

Figure 2

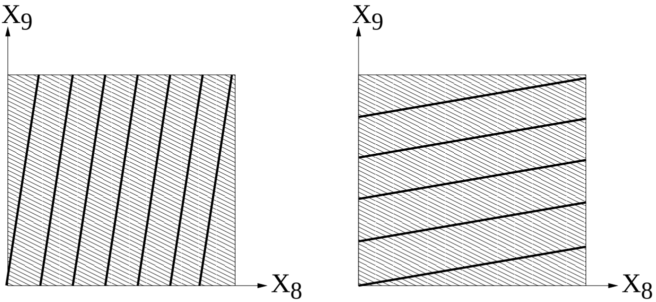

Figure: The left figure shows the T-dual of an abelian bundle $(n, m) = (1, 7)$ and the right image the T-dual of a 't Hooft bundle $(n, m) = (5, 1)$.

T-dual description

Tilt in the geometry $b = 0, 1/2$ [Angelantonj, Blumenhagen, Gaberdiel; Blumenhagen, Gorlich, Kors, Lüst; Cvetic, Shiu, Uranga; ....]

Intersecting D6's with 'half-integer' wrapping numbers
$\hat{m} = m + bn$ such that $\mathcal{R}(n, \hat{m}) = (n, -\hat{m})$, eg Model C
$U(5) : (1, 3/2; 1, 1/2; 1, 1/2)$, $U(3) : (1, -5/2; 1, 1/2; 1, 1/2)$,
$U(4) : (1, 1/2; 1, -1/2; 1, 1/2)$, $U(4)' : (1, -1/2; 1, -1/2; 1, 1/2)$

Tadpole cancellation OK, no susy, no tachyons for separated branes

Alternative: pairwise susy branes [Axenides, Floratos, Kokorelis; Emparan, Horowitz]

Unoriented strings on smooth CY manifolds, new perspectives from non-trivial bdles without vector structure

Quintic Gepner model $B = 1/2$, gauge group $SO(20) \times SO(12)$

Many different models depending on the choice of $B = 0, 1/2$ and other 'discrete' moduli (eg RR), exotic Ω-planes [Sugimoto; Bergman, Gimon, Sugimoto; Witten; Dudas, Mourad, Sagnotti; Keurentijs; ...]

Intermezzo: Magic $\mathcal{N} = 2$ supergravities

Related to magic square of Freudenthal, Rozenfeld and Tits of the division algebras R, C, H, O [Gunaydin, Sierra, Townsend]

Only octonionic model is not a truncation of $\mathcal{N} = 8$ SG: 27 vector-plets $\mathcal{M}_V = E_{7(-25)}/E_6 \times U(1)$ AND 28 hypers $\mathcal{M}_H = E_{8(-24)}/E_7 \times SU(2)$

Type I description[1]: start from $D = 6$ on T^4/Z_2 with $n_T = 1 + 8$ and 16 $D9$ OR 16 $D5$ (twist and shift!) and reduce to $D = 4$ on T^2 [MB, Ferrara]

Doubly magic $n_H = n_v$, no quantum corrections to geometry (two-derivative effective action)

Potential corrections to higher derivative F-terms (for FHSV: Type II - Heterotic - Type I - Type II' tetrality), black hole attractors ...

Other magic hyper-free supergravities [Dolivet, Julia, Kounnas]

[1] Closely related to Type I FHSV-like model without open strings

Part II: Bound-states of D-branes in L-R asymmetric vacua

Type II superstring vacua with extended susy

[Ferrara, Kounnas; Dabholkar, Harvey]

$$\mathcal{N} = 8 \quad \leftrightarrow \quad \mathcal{N}_L = 4 \; , \; \mathcal{N}_R = 4$$
$$\mathcal{N} = 6 \quad \leftrightarrow \quad \mathcal{N}_L = 2 \; , \; \mathcal{N}_R = 4$$
$$\mathcal{N} = 5 \quad \leftrightarrow \quad \mathcal{N}_L = 1 \; , \; \mathcal{N}_R = 4$$
$$\mathcal{N} = 4 \quad \leftrightarrow \quad \mathcal{N}_L = 2 \; , \; \mathcal{N}_R = 2 \quad \textbf{or} \quad \mathcal{N}_L = 0 \; , \; \mathcal{N}_R = 4$$
$$\mathcal{N} = 3 \quad \leftrightarrow \quad \mathcal{N}_L = 1 \; , \; \mathcal{N}_R = 2$$
$$\mathcal{N} = 2 \quad \leftrightarrow \quad \mathcal{N}_L = 1 \; , \; \mathcal{N}_R = 1 \quad \textbf{or} \quad \mathcal{N}_L = 0 \; , \; \mathcal{N}_R = 2$$

Generically, L-R asymmetric and thus non-geometric but ‘exact’ vacuum configurations based on (rational) CFT’s

When massless R-R states (eg graviphotons) survive there MUST be bound-states of D-branes they couple to

Some fraction of extended susy is preserved, BPS condition

Use boundary states to determine open string excitations

$\mathcal{N} = 6 = 2_L + 4_R$ case

Spontaneous breaking $\mathcal{N} = 8 \rightarrow \mathcal{N} = 6$ via chiral Z_2 twist of the L-movers ('T-duality' on four internal directions, T^4_t)

$$X^i_L \rightarrow -X^i_L \quad , \quad \Psi^i_L \rightarrow -\Psi^i_L \quad , \quad i = 6, 7, 8, 9$$

accompanied by an order two shift along untwisted T^2_s
Unbroken susy's satisfy

$$\mathcal{Q}_L = \Gamma_{6789} \mathcal{Q}_L$$

no conditions on $\mathcal{Q}_R$.
After dualizing all masseless 2-forms into axions, the $30 = 2_{NS-NS} + 12_{NS-NS} + 16_{R-R}$ scalar moduli parameterize the space $\mathcal{M}^{D=4}_{\mathcal{N}=6} = SO^*(12)/U(6)$. The $16 = 8_{NS-NS} + 8_{R-R}$ vectors together with their magnetic duals transform according to the **32** dimensional chiral spinor representation of $SO^*(12)$.

$\mathcal{N} = 6$ BPS branes, susy

Surviving $16_{R-R} = 2_{(1|5)} + 4_{(1|3)} + 6_{(3|3)} + 4_{(5|3)}$ R-R charges carried by D-brane bound-states invariant under twist and shift

$$q_1^a + \frac{1}{4!}\varepsilon_{ijkl} q_5^{aijkl} \quad , \quad q_1^i + \frac{1}{3!}\varepsilon^i{}_{jkl} q_3^{jkl} \quad ,$$

$$q_3^{aij} + \frac{1}{2!}\varepsilon^{ij}{}_{kl} q_3^{akl} \quad , \quad q_5^{abijk} + \varepsilon^{ijk}{}_l q_3^{abl}$$

Eg 1/3 BPS state: D5 wrapped along twisted $T_t^4 \times S_s^1$ and D1 along same S_s^1,

$$\mathcal{Q}_R = \Gamma_{04}\Gamma_{6789}\mathcal{Q}_L = \Gamma_{04}\mathcal{Q}_L$$

Different analysis for BPS states carrying NS-NS charges eg two massive gravitini and superpartners form a complex 1/2 BPS multiplet

D-branes in T-folds [Brunner, Rajaraman, Rozali; Gutperle; MB, Morales, Pradisi; Gaberdiel, Schafer-Nameki; Lawrence, Schulz, Wecht; Kawai, Sugawara]

Other $\mathcal{N} = 6$ cases

- Z_n chiral projection acting on 4 super-coordinates as

  $$(Z^1, Z^2)_L \to (\omega Z^1, \omega^{-1} Z^2)_L \quad , \quad (\Psi^1, \Psi^2)_L \to (\omega \Psi^1, \omega^{-1} \Psi^2)_L$$

  with $\omega^n = 1$. In order to avoid massless twisted states, combine with an order n shift along the 'untwisted' directions $(Z^3_L; Z^i_R)$
- maximal torus of $SU(3)^3$ with chiral Z_3 projection and no shift. $\mathcal{N} = 5$ supergravity in untwisted sector. Twisted sector produces the extra massless gravitino multiplet to complete the spectrum of $\mathcal{N} = 6$ supergravity [Dabholkar, Harvery]

Other extended susy cases with L$\neq$R

- $\mathcal{N}=5=1_L+4_R$, unique massless spectrum, non-geometric, uncorrected LEEA (as for $\mathcal{N}=6,8$)
- $\mathcal{N}=4=2_L+2_R$ uncorrected LEEA, (non)geometric, $SL(2)\times SO(6,N_v)$ symmetry
- $\mathcal{N}=3=1_L+2_R$ uncorrected LEEA, non-geometric / fuxes, $U(3,N_v)$ symmetry
- $\mathcal{N}=2=1_L+1_R$, (non) geometric, quantum corrections absent in special cases ($\chi=0$, eg FHSV, octonionic magic)
- $\mathcal{N}=4=0_L+1_R$, $\mathcal{N}=4=0_L+2_R$, $\mathcal{N}=1=0_L+1_R$ NO massless R-R graviphotons, NO BPS D-branes

Focus on $\mathcal{N}=5,3$

$\mathcal{N} = 5 = 1_L + 4_R$ case

Simple(st) realization [Ferrara, Kounnas] $Z_2^L \times Z_2^L$ which acts by T-duality along T^4_{6789} and T^4_{4589} combined with order two shifts
1/5 BPS bound states of D-branes carrying
$8_{R-R} = 6_{(1533)} + 2_{(3333)}$ R-R charges (invariant orbits)

$$q^I_{(1335)} = q^I_1 + \frac{1}{4!}\varepsilon_{i_I j_I k_I l_I} q_5^{I i_I j_I k_I l_I} + \frac{1}{3!}\varepsilon^I{}_{J,K'L'} q_3^{JK'L'} + \frac{1}{3!}\varepsilon^I{}_{J,K''L''} q_3^{JK''L''}$$

where i_I, j_I, k_I, l_I run over the four directions orthogonal to T^2_I while K', L' and K'', L'' run over the two sets of two directions orthogonal to T^2_I and

$$q^{I_1 I_2 I_3}_{(3333)} = q_3^{I_1 I_2 I_3} + \frac{1}{2!}\varepsilon^{I_2 I_3}{}_{J_2 J_3} q_3^{I_1 J_2 J_3} + \frac{1}{2!}\varepsilon^{I_3 I_1}{}_{J_3 J_1} q_3^{J_1 I_2 J_3} + \frac{1}{2!}\varepsilon^{I_1 I_2}{}_{J_1 J_2} q_3^{J_1 J_2 I_3}$$

Other realizations of $\mathcal{N} = 5 = 1_L + 4_R$

Uniqueness of $\mathcal{N} = 5$ supergravity massless spectrum and LEEA: graviton $g_{\mu\nu}$ and 5 gravitini ψ_μ, 10 graviphotons A_μ, 11 dilatini χ and 10 scalars ϕ. The latter parameterize $\mathcal{M}^{D=4}_{\mathcal{N}=5} = SU(5,1)/U(5)$. $10_e + 10_m$ graviphotons in **20** of $SU(5,1)$ (3-index anti-symmetric tensor)

- "Minimal" $\mathcal{N} = 5$ superstring solutions classified into four classes [Ferrara, Kounnas]

Two alternative superstring constructions [Dabholkar, Harvey]

- Z_7 asymmetric orbifold of $SU(7)$ torus $\theta_L = (\omega_7, \omega_7^2, \omega_7^4)$ and $7\sigma_R = (1, 2, -3, 0, 0, 0, 0)$
- Z_3 asymmetric orbifold of $SU(3)^3$ torus; $\theta_L = (\omega_3, \omega_3, \omega_3)$ and $3\sigma_R = (1, -1, 0; 1, -1, 0; 1, -1, 0)$

$\mathcal{N} = 3 = 1_L + 2_R$ case

The simplest $\mathcal{N} = 3$ model with 3 matter vector-plets. Two steps

- 'geometric' Z_2 freely acting orbifold (locally equivalent to $K3 \times T^2$). The Z_2 action combines a twist breaking $\mathcal{N} = 8 = 4_L + 4_R$ to $\mathcal{N} = 4 = 2_L + 2_R$ and a shift preventing massless twisted states
- non geometric chiral (say Left-) projection combined with a shift along the orthogonal directions $a = 4, 5$

Surviving NS-NS charges: p_R^a and their magnetic duals $\hat{P}_R^a$.
Surviving R-R charges: T-duality invariant combinations

$$q_1^a + \frac{1}{3!}\varepsilon^a_{bij} q_3^{bij} \quad , \quad q_3^{aij} + \frac{1}{3!}\varepsilon^a_{bkl} q_5^{bijkl}$$

One can consider 1/3 BPS states.
Massive gravitino in $\mathcal{N} = 4 \to \mathcal{N} = 3$ long multiplet.
No 1/2 BPS states

Other $\mathcal{N} = 3 = 1_L + 2_R$ cases

Complete classification of "minimal" $Z_2 \times Z_2^L$ $\mathcal{N} = 3$ superstring solutions Ferrara, Kounnas. Four classes with $3 + 4K$ matter vector multiplets, with $K = 0, 1, 2$, eleven sub-classes.

Extra chiral projection (ie splitting geometric Z_2 into two chiral Z_2) get models with $1 + 2K$ matter vector multiplets, with $K = 0, 1, 2$. In particular a model with only one vector multiplet, containing three complex scalars

Another construction [Narain]: asymmetric Z_3 projection with $\theta = (\omega_3, \omega_3, \omega_3; 1, \omega_3, \omega_3^{-1})$ acting on the lattice of $SU(3)^3$.

Boundary states for L-R asymmetric branes

[Abouelsaood, Callan, Lovelace, Nappi, Yost; Billò, Di Vecchia, Frau, Lerda, Pesando].

Bosonic coordinates

$$|B_a\rangle^{(X)} = \sqrt{\det(\mathcal{G}_a + \mathcal{F}_a)}\, \exp(-\sum_{n>o} a^i_{-n} R_{ij}(F_a) \tilde{a}^j_{-n}) |0_a\rangle$$

where $R_a = (1 - F_a)/(1 + F_a)$ and $|0_a\rangle \leftrightarrow p_L = -R_a p_R$

NS-NS sector (no fermionic zero-modes)

$$|B_a, \pm\rangle^{(\psi)}_{NS-NS} = \exp(\pm i \sum_{n\geq 1/2} \psi^i_{-n} R_{ij}(F_a) \tilde{\psi}^j_{-n}) |\pm\rangle$$

R-R sector

$$|B_a, \pm\rangle^{(\psi)}_{R-R} = \frac{1}{\sqrt{\det(\mathcal{G}_a + \mathcal{F}_a)}} \exp(i \pm \sum_{n>0} \psi^i_{-n} R_{ij}(F_a) \tilde{\psi}^j_{-n}) \mathcal{U}^{\pm}_{A\tilde{B}}(F_a) |A, \tilde{B}\rangle$$

$$\mathcal{U}^{\pm}_{A\tilde{B}}(F_a) = \left[\mathrm{AExp}(-F^a_{ij} \Gamma^{ij}/2) C \Gamma_{11} \frac{1 \pm i\Gamma_{11}}{1 \pm i} \right]_{A\tilde{B}} \quad .$$

Partition functions and tree channel

Magnetized / Intersecting D-branes in L-R symmetric orbifolds

[Angelantonj, Sagnotti; Blumenhagen, Cvetic, Langacker, Shiu; Blumenhagen, Körs, Lüst, Stieberger]

Generalize to $Z^L_{N_L} \times Z^R_{N_R}$ action, invariant boundary states would then be of the form

$$|B,F\rangle_g = \frac{1}{\sqrt{N_L N_R}}\left(1 + g_L + g_R + ... + g_L^{N_L-1} g_R^{N_R-1}\right)|B,F\rangle = = \frac{1}{\sqrt{N_L N_R}}\sum_{l,r}|B,F_{(l,r)}\rangle$$

where the 'induced' magnetic field $F_{(l,r)}$ is determined by the condition

$$R(F_{(l,r)}) = R(g_L^l) R(F) R^t(g_R^r)$$

$$\mathcal{A}_{g,h} = \Lambda(g,h)\mathcal{I}(g,h)\sum_\alpha c_\alpha^{GSO}\frac{\vartheta_\alpha(0)}{\eta^3}\prod_I \frac{\vartheta_\alpha(\epsilon_I(g,h)\tau)}{\vartheta_1(\epsilon(g,h)\tau)}$$

Example: $\mathcal{N} = 5$ model on T^6/Z_3^L torus of $SU(3)^3$

Prior to twists and shifts, 27 boundary states

$$\mathcal{A}_{\vec{r},\vec{s}} = N_{\vec{r},\vec{s}}^{\vec{t}} \mathcal{X}_{\vec{t}}$$

where $\mathcal{X}_{\vec{t}} = (V_8 - S_8)\chi_{t_1}\chi_{t_2}\chi_{t_3}$ correspond to branes with magnetic quantum number $(n, m) = (1, 0), (-1, 1), (0, -1)$
After twist and shift: branes rotated and displaced wrt one another

$$\mathcal{A}_{Z_3^{L\neq R}} = \frac{1}{6} \sum_{a,b\in Z_3} \Lambda_{(a,b)} \mathcal{I}_{(a,b)} \sum_{\alpha} c_{\alpha}^{GSO} \frac{\vartheta_\alpha(0)}{\eta^3} \prod_I \frac{\vartheta_\alpha(a\tau + b)}{\vartheta_1(a\tau + b)}$$

Both 'untwisted' and 'twisted' strings are present [MB, Morales, Pradisi; Blumehagen, Gorlich, Kors, Lüst; ...], yet non chiral spectra

Phenomenological applications

Generalize to branes extending along flat space-time directions
Similarity between crosscap and boundary states one might be tempted to simply consider g invariant combinations of Ω-planes.
A particularly interesting class of models $\mathcal{N} = 0_L + 1_R$
One can perturbatively stabilize all moduli except axio-dilaton in a controllable perturbative manner and then add L-R asymmetric D-branes that can
a) account for matter and gauge fields
b) help stabilizing the dilaton and breaking susy
c) offer a dual description to some not-fully controllable fluxes
Some tension between moduli stabilization and chirality

Outlook

Twists and shifts can conveniently combine with other mechanisms, *e.g.* open and closed string fluxes, non-anomalous $U(1)$'s, instanton effects, ... of moduli stabilization.

Explicit computations are feasible. Model with only 1+1 twisted moduli ... some tension with chirality ($\chi = 0$)

Discrete 'deformations' (B-field etc) can widen phenomenological perspectives of interesecting / magnetized branes in CY's: 3 generation Model C [Bachas] *docet*

D-branes in L-R asymmetric vacua, very promising ... yet relation with (non) geometric fluxes [Lawrence, Schulz, Wecht], [Hull, ...], [Berman, ...], [Villadoro, Zwirner], ... to be understood and interacting CFT's (WZW, Gepner or alike) to be worked out [Kawai, Sugawara]

Announcements

- *Strings '09*

  Rome, 22-26 June 2009

  Angelicum - Pontificia Università S. Tommaso
  http://people.roma2.infn.it/ strings2009/
- *New Perspectives in String Theory*

  GGI, Arcetri (Florence), 6 April - 19 June 2009
  http://ggi-www.fi.infn.it/index.php?p=events.inc&id=25