VACUUM CONFIGURATIONS OF OPEN AND UNORIENTED STRINGS

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PLAN

- Some pre-history in a nutshell
- Unoriented D-brane worlds
- Couplings, scales, dualities
- Anomaly related couplings
- $\mathcal{N}=1$ effective supergravity
- Adding D-branes & fluxes
- Embedding the (MS)SM
- Open & unoriented problems

SOME PRE-HISTORY

1968 Veneziano amplitude

1976 GSO projection susy!

1984 GS Mechanism $SO(32)$ $E_8 \times E_8$

- $SO(32)$ Type I & Heterotic
- $E_8 \times E_8$ Heterotic only

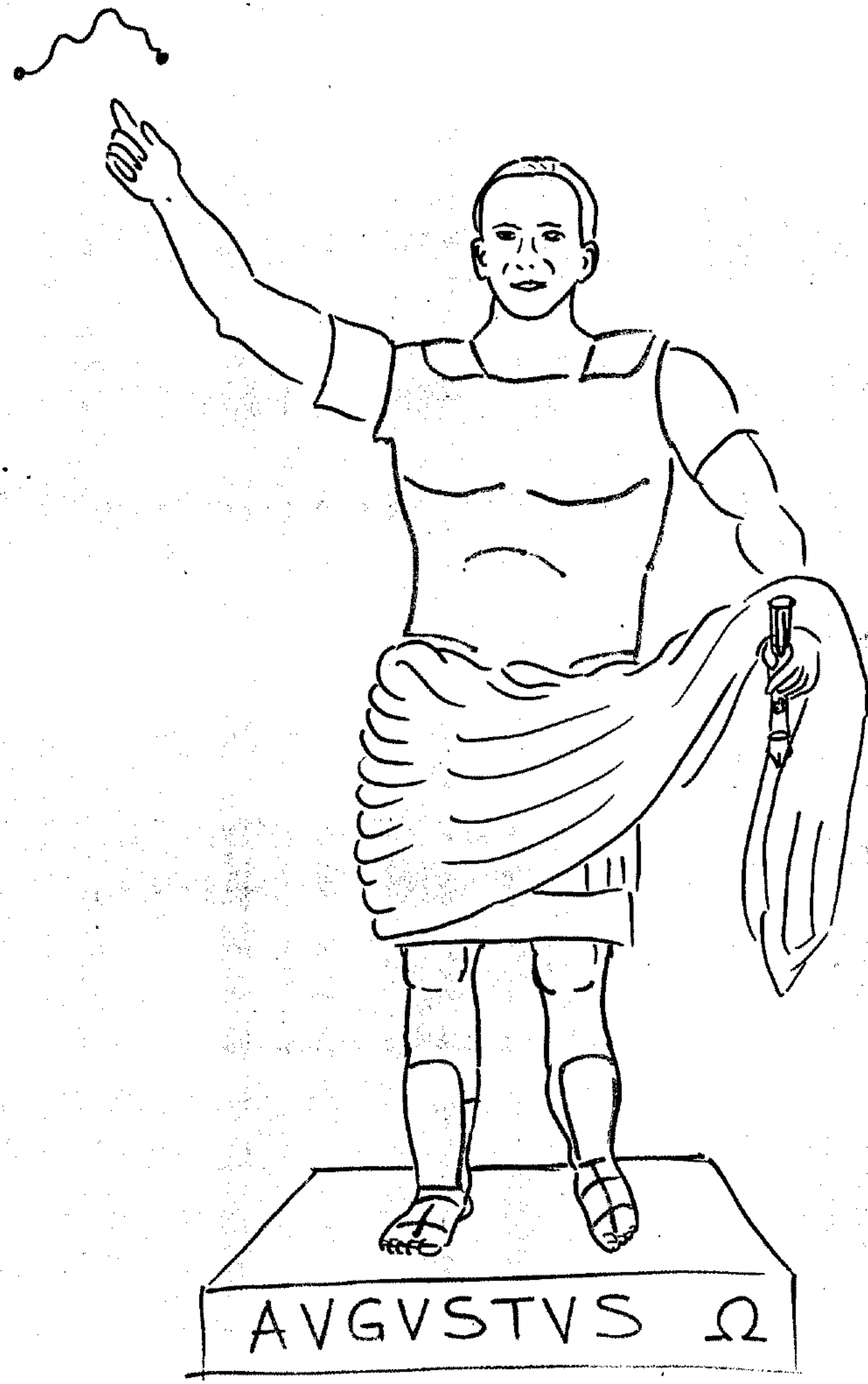
Calabi-Yau compactifications '84-'95

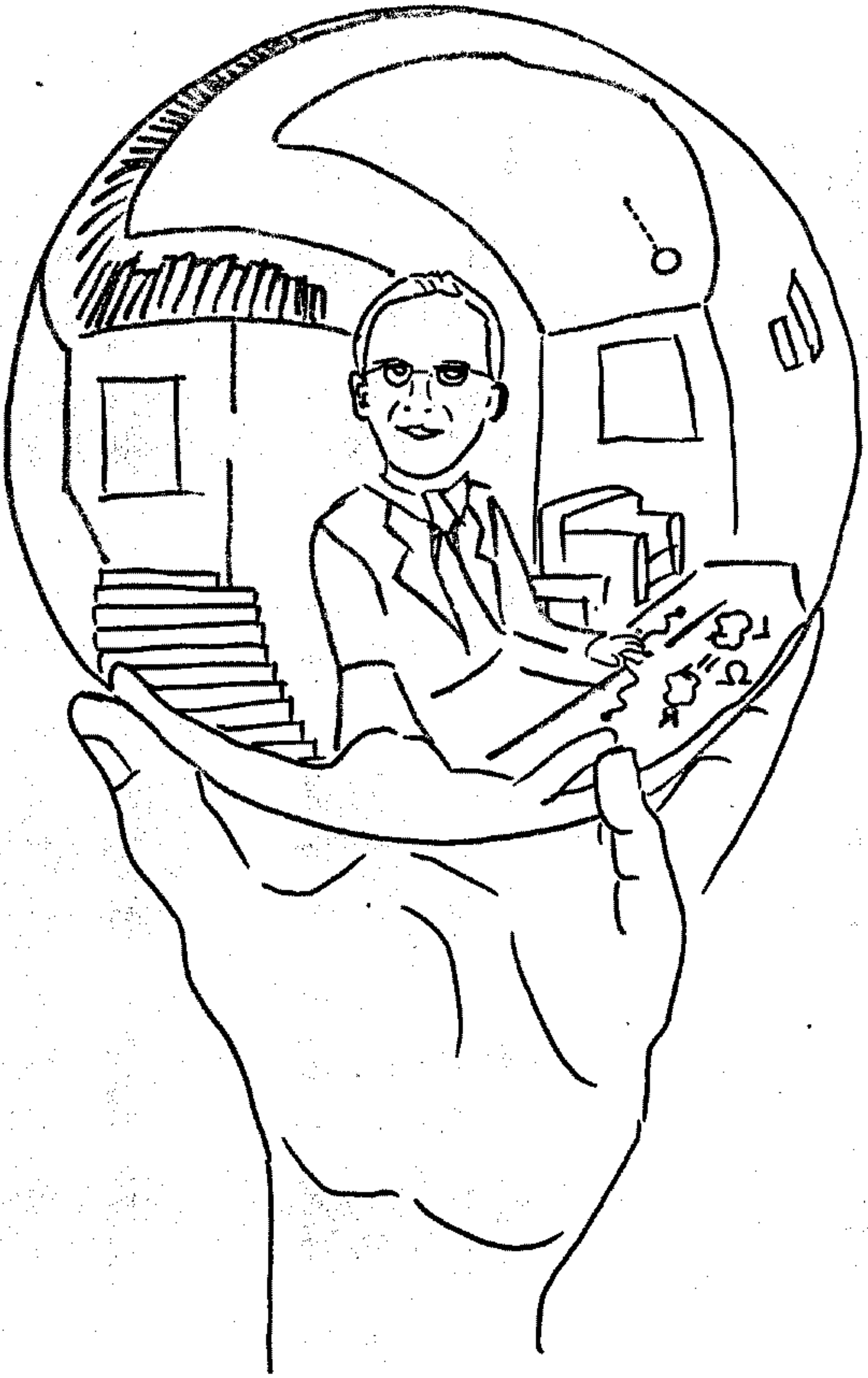
standard embedding $SU(3)_H \subset E_8 \to E_6$

$\#$ families $(27) = \frac{1}{2} \chi(CY)$

Almost nobody was working

on open & unoriented strings

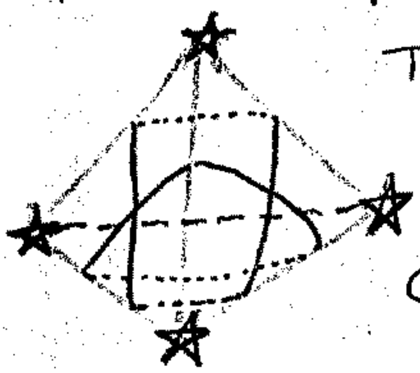

AVGVSTVS Ω

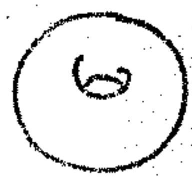


UNΩRIENTI-WORLDS

Sagnotti, Pradisi
MB Stanev
Dai Leigh Polchinski
... Berkooz Douglas

- Start with L↔R symmetric "compactification" of type II strings: $\mathcal{T}$





- Add intersecting / magnetized D-branes supporting (chiral) open strings: $\mathcal{A}$

- Include Ω-planes for consistency ~ RR-tadpole cancellation, unoriented strings: $\mathcal{K}$

- Add images of D-branes under Ω, unoriented open strings: $\mathcal{M}$

* Choose supersymmetric configurations for simplicity, stability, ... phenomenology

* Add fluxes / warping to stabilize "moduli"

OPEN STRING DESCENDANTS

- Left-Right symmetric closed string "parent"

$$\mathcal{T} = \frac{1}{2} \mathrm{Tr}_{cl}\, q^{H_L} \bar{q}^{H_R} = \frac{1}{2} \sum_{I,J} \tau_{IJ} \chi_I \bar{\chi}_J$$

- Ω-projection of the closed string spectrum

$$K = \frac{1}{2} \mathrm{Tr}_{cl}\, \Omega (q\bar{q})^{H_{L/R}} = \frac{1}{2} \sum_{I} K_I \chi_I(2it)$$

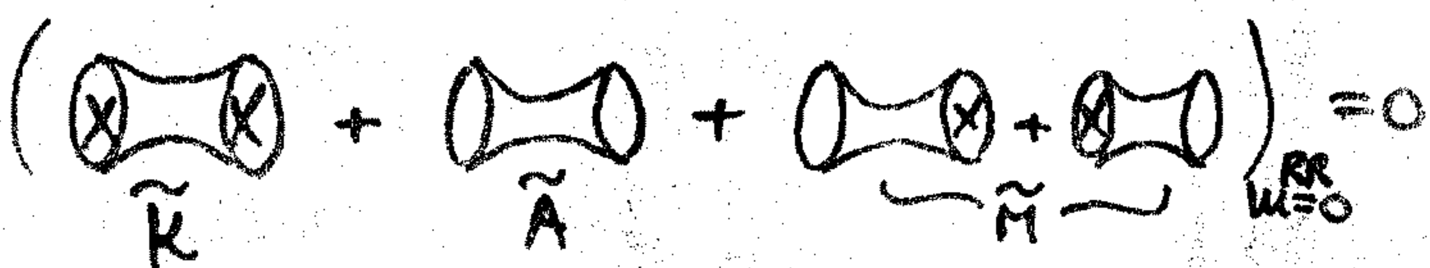
- Add D-branes and their open string excitations

$$A = \frac{1}{2} \sum_{I,a,b} A^I_{ab} n^a n^b \chi_I(it/2)$$

$$M = \frac{1}{2} \sum_{I,a} M^I_a n^a \hat{\chi}_I\left(\tfrac{it}{2} + \tfrac{1}{2}\right)$$

Consistency conditions $K_I = \tau_{II} \pmod 2$ $M^I_a = A^I_{aa}$ (mod

RR tadpole cancellation ($\sim$ anomaly canc. $\mathrm{Tr}(-)^F \neq 0$)



COUPLINGS & SCALES

Planck mass ~ closed strings ~ sphere

$$M_P^{8-d} = \frac{V_d M_S^8}{g_s^2} \qquad M_S^2 = \frac{1}{\alpha'} = T_s$$

Yang-Mills ~ open strings ~ disk

$$\frac{1}{g_{YM}^2} = \frac{V_d M_S^6}{g_s} \quad \text{(D9-branes} \sim \text{Type I strings!)}$$

Eliminating V_d for $d=6$ i.e. $D=4$

$$\frac{M_P^2}{M_S^2} = \frac{1}{g_s g_{YM}^2} \gg 1 \quad \text{if } g_s \text{ small}$$

[For heterotic $M_P^2 = g_{YM}^{-2} M_S^2$ independent of V_6, g_s !]

Type I

$$V_6 M_S^6 = \frac{g_s}{g_{YM}^2} = \frac{1}{g_{YM}^4}\left(\frac{M_S^2}{M_P^2}\right) \ll 1 \quad \text{if } M_S \ll M_P$$

T-dual description D9-branes $\xrightarrow{T_{1\dots6}}$ D3-branes

$$\tilde{V}_6 M_S^6 = \frac{1}{V_6 M_S^6} \gg 1 \qquad \text{Large Extra Dimensions}$$

→ quasi continuous spectrum of KK modes

→ low string tension (Antoniadis, Bachas, Dudas ..)

ANOMALY RELATED COUPLINGS

Anomaly cancellation in $D=10$ (Green-Schwarz)

$$\Delta S_{GS} = C_1 \int B \wedge \mathrm{Tr}(F^4) + C_2 \int \omega_3^{CS} \wedge \omega_7^{CS}$$

Non linear gauge tranformation of B_2 / C_2

$$\delta B_2 = \omega_2^{(1)} = \mathrm{Tr}(\alpha F_2) + \ldots \qquad H_3 = dB_2 + \omega_3^{CS}$$

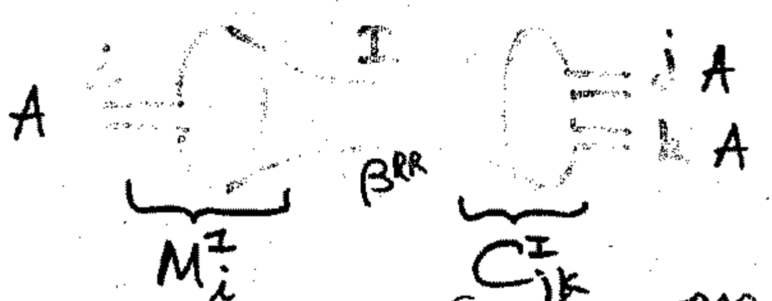
Heterotic $B_2 \in NS$ 1-loop $\leftrightarrow$ Type I $C_2 \in RR$ disk

In $D=4$ anomalous $U(1)$'s

Dine Seiberg Witten
Angelantonj MB Pradisi
Sagnotti Stanev, ...

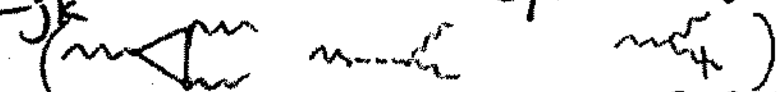
$H_3 = * d\beta$ axions $\sim$ Stückelberg fields

$$S_{ax} = \int \frac{1}{2} (\partial\beta - MA)^2 + c\, \beta F\tilde{F}$$



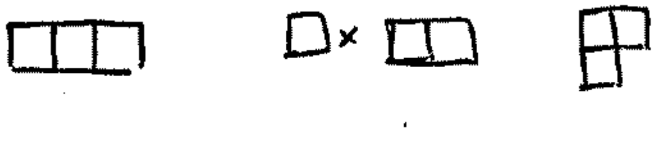
$$\delta A_\mu^i = \partial_\mu \alpha^i$$

$$\delta \beta^I = M_i^I \alpha^i$$

$\delta\Big($  $\Big) = 0$

$$\delta S_{tot} = 0 \qquad \mathrm{Tr}_f(Q_i Q_j Q_k) + M_i^I C_{jk}^I + E_{ijk}^{GCS} = 0$$

t_{ijk}



[illegible] (... Dudas Kiritsis)

Several axions $a^I \quad I = 1, \dots n_{ax}$

Several vectors $A^i_\mu \quad i = 1, \dots n_{U(1)}$

Axionic Lagrangian

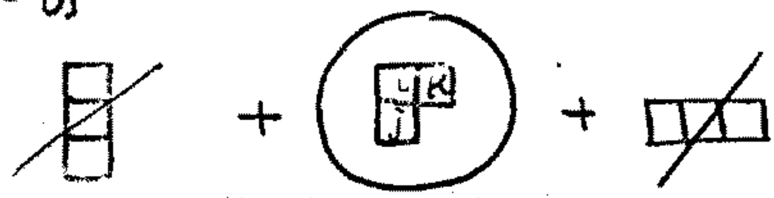
$$\mathcal{L}_{ax} = \frac{1}{2} G_{IJ} (\partial_\mu a^I - M^I_i A^i_\mu)(\partial^\mu a^J - M^J_j A^{\mu j})$$

$$+ C_{Ijk} a^I F^j \wedge F^k + C_{I(a)} a^I \, tr(G_{(a)} \wedge G_{(a)})$$

Generalized CS terms $\quad t_{ijk} = Tr_f(Q_i Q_j Q_k)$

$$\mathcal{L}_{CS} = E_{[ij]k} A^i \wedge A^j \wedge F^k \qquad E_{ijk} \equiv E_{[ij]k}$$

E_{ijk} :



total derivative   impossible

$$\delta \mathcal{L}_{CS} = -2 E_{[ij]k} \Lambda^i F^j \wedge F^k \qquad \delta A^i_\mu = \partial_\mu \Lambda^i$$

$$\delta \mathcal{L}_{ax} = M^I_i C_{Ijk} \Lambda^i F^j \wedge F^k \qquad \delta a^I = M^I_i \Lambda^i$$

$$\delta \mathcal{L}_{1\text{-loop}} = t_{ijk} \Lambda^i F^j \wedge F^k + t_{i(a)} \Lambda^i \, tr(G_{(a)} \wedge G_{(a)})$$

Gauge invariance

$$M^I_i C_{Ijk} - 2E_{[ij]k} + t_{ijk} = 0 \quad \begin{cases} M^I_{(i} C_{Ijk)} + t_{ijk} = 0 \\ M^I_{[i} C_{Ij]k} = 2E_{[ij]k} \end{cases}$$

$$M^I_i C_{I(a)} + t_{i(a)} = 0$$

(Andrianopoli, D'Auria, Ferrara, Lledó)

e.g. $t_{ijk} = 0$ (no chiral fermions) $\quad \begin{cases} M^I_{(i} C^I_{jk)} = 0 \quad \text{"cocycle"} \\ M^I_{[i} C_{Ij]k} = 2E_{[ij]k} \end{cases}$

Experimental signatures

- Mixing $\underbrace{W^3, Y}_{\mathcal{O}(1)}, \underbrace{\,, A_{PQ}}_{\mathcal{O}(M_Z/M_S)} \longleftrightarrow A, Z^0, Z'$

$$\rho = \frac{M_W^2}{M_Z^2 \sin^2\theta_W} \neq \rho_{SM} \qquad \frac{\Delta\rho}{\rho} \sim \frac{M_Z}{M_S} \overset{exp}{<} 6\cdot 10^{-4}$$

- B, L gauge bosons not affected by Higgsing but only by axioning $M_{B,L} \sim M_S$

- (a) typical decays $Z_0 \to \gamma\gamma^*$ $\qquad \mathcal{O}(M_Z/M_S)$

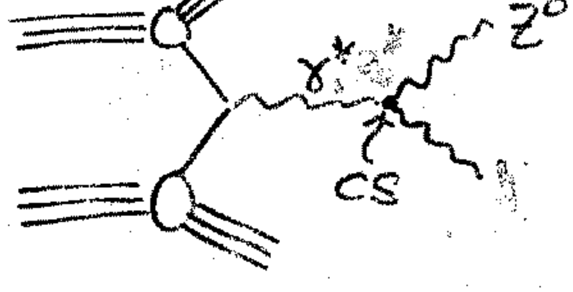
  $\Gamma(Z^0 \to \gamma\gamma^*)/M_{Z^0} < 5\cdot 10^{-7} \to$ limit on M_S

- Z' (PQ, B, L) $\longrightarrow Z^0\gamma$ $\qquad \mathcal{O}(1)$

  "visible" at LHC if $M_{Z'} < 5\,\text{TeV}$

  $\hookrightarrow$ ("spectacular") $\longleftrightarrow$ $E_\gamma = (M_{Z'}^2 - M_Z^2)/2M_{Z'} \pm \ldots$ width

- DY processes $\qquad p\,p \to \text{jets} + \gamma^* \xrightarrow[CS]{} Z^0\gamma$



(Corianò, Irges, Kiritsis)

LOW ENERGY E.F.T.

Toroidal orbifold / CY $\to$ susy + fluxes

$\mathcal{N}=1$ supergravity Cremmer Ferrara Girardello Van Proeyen

- Kähler potential $K(\phi,\phi^{+})$

ϕ chiral multiplets

closed string $\Phi = \phi^{NSNS} + i\,\beta^{RR}$ Kähler

$\phi_1^{NS\text{-}NS} + i\,\phi_2^{NS\text{-}NS}$ complex

open strings $A = A_1 + i A_2$ "neutral"

$C =$ charged wrt CP

- Superpotential $W = W(\phi)$

$$W = W_{tree} + W_{flux} + W_{pert} + W_{nonpert}$$

- Gauge kinetic functions $f_a = f_a(\phi)$

$$f_a = f_a^{tree} + f_a^{1\text{-}loop}$$ ← "threshold corrections"

- D-terms $D^a(\phi,\phi^{+})$ ← gaugings

"Kähler moment maps"

CLOSED STRING SECTOR

Truncation of "parent" type II theory

e.g. Type IIB on $CY_3 \to N=2$ $\mathcal{K}^{Vect}_{h_{21}} \times \mathcal{Q}^{Hyper}_{h_{11}+1}$

$$K^{Vect}_{h_{21}} = -\log \| \omega_3^{CY} \|^2 \qquad \mathcal{Q}_{h_{11}+1} \supset K_{h_{11}} = -\log V^{CY}$$

- $\Omega \to$ Type I on CY_3
- $\Omega' = \Omega \cdot \sigma \qquad h_{11} \to h_{11}^{+}, h_{11}^{-} \qquad h_{21} \to h_{21}^{+}, h_{21}^{-}$

h_{11}^{+} : $C^{RR}_{i\bar{j}}, g^{NS\text{-}NS}_{i\bar{j}}$ $\qquad$ h_{11}^{-} : $b^{NS\text{-}NS}_{i\bar{j}}$ $a^{RR}_{\mu\nu i\bar{j}}$

h_{21}^{+} $g^{NS\text{-}NS}_{ij}, g^{NS\text{-}NS}_{\bar{I}\bar{J}}$ $\qquad$ h_{21}^{-} : $A^{RR}_{\mu ij\bar{k}}$

Heterotic / Type I duality

$$D=10 \qquad \phi_H = -\phi_I \qquad \alpha'_H = g_I \alpha'_I$$

in $D=4$ $\quad S_H = \phi_H^{(4)} + i\, b_H$ factorizes

in Type I field redefinition $S'_I = S_H(\phi_I, C_I, \ldots)$

ANNULUS VACUUM AMPLITUDES

$\mathcal{N}=4$ susy sectors ~ toroidal compactifications

$$A_{ab}^{\mathcal{N}=4} = \Lambda_{ab}^{(6)} \sum_{\alpha} C_{\alpha}^{GSO} \frac{\vartheta_{\alpha}^{4}(0)}{\eta^{12}}$$

GSO projection ↓ SUSY

$\Lambda_{ab}^{(6)}$ sum over generalized KK momenta/windings

$\mathcal{N}=2$ susy sectors ~ SU(2) holonomy

$$A_{ab}^{\mathcal{N}=2} = I_{ab}^{(4)} \Lambda_{ab}^{(2)} \sum_{\alpha} C_{\alpha}^{GSO} \frac{\vartheta_{\alpha}^{2}(0)}{\eta^{6}} \frac{\vartheta_{\alpha}^{2}(u_{ab})}{\vartheta_{1}^{2}(u_{ab})}$$

$I_{ab}^{(4)}$ discrete multiplicity (fixed pts, # intersections, Landau levels, ..)

$u_{ab} = k\, v_{ab} + \varepsilon_{ab} \tau_{A}$

orbifold projection (eg $\mathbb{Z}_n$) mass-shift → magnetic fluxes, intersecting angles

$\Lambda_{ab}^{(2)}$ KK sum along un-magnetized, un-twisted dims

$\mathcal{N}=1$ susy sectors ~ SU(3) holonomy

$$A_{ab}^{\mathcal{N}=1} = I_{ab}^{(6)} \sum_{\alpha} C_{\alpha}^{GSO} \frac{\vartheta_{\alpha}(0)}{\eta^{3}} \prod_{I=1}^{3} \frac{\vartheta_{\alpha}(u_{ab}^{I})}{\vartheta_{1}(u_{ab}^{I})}$$

$u_{ab}^{I} \neq 0$: $\sum_{I=1}^{3} u_{ab}^{I} = 0 \pmod 1$ susy

EMBEDDING THE (MS)SM

No perturbative GUT's (Berenstein) (Antebi, Nir, Volansky)

~~$SO(10)$~~ NO $\underline{16}$! ~~E_6~~ (Marcus Sagnotti)

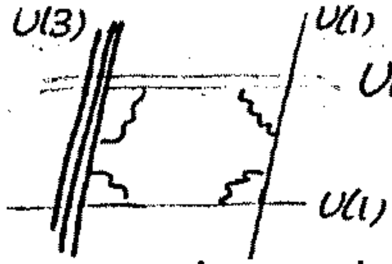
$SU(5) \hookrightarrow U(5)$ $\quad 5_{+1} + 10^*_{-2}$ Yukawa's ?

$5_{+1} \times 5_{+1} \times 10^*_{-2}$ ✓ (Cvetic, Papadimitriou, ... Cremades, Ibáñez Marchesano Blumenhagen, Kors, Lüst, Stieberger)

NO $5^*_{\cancel{+1}} \times 10^*_{-2} \times 10^*_{-2}$ → violates $U(1)$! ; → $\varepsilon^{pqrst} \neq$ (CP)

Local embeddings of $SU(3) \times SU(2) \times U(1) \times \ldots$

e.g. Madrid quiver



→ $U(1)_a \times U(1)_b \times U(1)_c \times U(1)_d \ldots$

Aldabazal, Ibanez, Uranga, Marchesano ; -- Antoniadis, Kiritsis Tomaras

- Need extra (anti) branes for consistency

  ~ RR tadpole cancelation

- Various $U(1)_Y$ embeddings — Dijkstra Huiszoon Schellekens + Anastasopoulos Kiritsis

- Problems with NS-NS tadpoles (non susy)

QUASI-SUSY MODELS

All brane intersections (D6 picture)

preserve some susy but $(N=1)_{a,b} \neq (N=1)'_{(c,d)}$

(Floratos, Kokorelis; ... Emparan Horowitz, ...)

	N	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)	
a, d:	$3+1$	$(1,0)$	$(1/\rho, 3\rho)$	$(1/\rho, -3\rho)$	$\to SU(4) \times U(1)$
b:	1	$(0,1)$	$(1,0)$	$(0,-1)$	$\to Sp(2)_L$
c:	1	$(1,0)$	$(0,-1)$	$(0,1)$	$\to Sp(2)_R$

$\rho = 1/3 \to$ 3 generation Pati-Salam susy

$+ \cancel{4}/\beta_1\beta_2$ Higgs $(1;2;2)_0 \in (b,c)$ $N=2$

$\beta_1 = \beta_2 = 1/2, 1$ quantized NS-NS background

(MB Pradisi Sagnotti)

$$4 \to 3_a + 1_d \qquad G \to U(3)_a \times Sp(2)_L^b \times \underset{\substack{\downarrow \\ U(1)_c}}{Sp(2)_R^c} \times U(1)_d$$

$$Y = \frac{1}{6} Q_a - \frac{1}{2} Q_b - \frac{1}{2} Q_d$$

Consistency $\sim$ RR <u>and</u> NS-NS tadpole cancellation $\to$ "Hidden" sector

+ vector-like "messangers" of susy breaking

OPEN STRING FLUXES

Internal Magnetic fields

$$V_A^{(0)} = \int_{\partial\Sigma} ds\; T^a F_{ij}^a \left(X^i \partial X^j + \psi^i \psi^j\right)$$

Change of boundary conditions

$$\partial_L X^i = R_a{}^i{}_j\, \partial_R X^j \qquad R_a{}^i{}_j = \left(\frac{1-q_a F_a}{1+q_a F_a}\right)^i{}_j$$

$$\psi_L^i = \eta\, R_a{}^i{}_j\, \psi_R^j \qquad F \to 0 \text{ Neumann} \qquad F \to \infty \text{ Dirichlet}$$

Mode shift (Callan, Lovelace, Nappi, Yost ; Tseytlin ; Bachas Porrati)

$$n^{(I)} = n^{(I)} + \varepsilon_{ab}^{(I)} \qquad R_{ab} = R_a^{q_a} R_b^{q_b} \to \left(e^{2\pi i \varepsilon_{ab}^I}, e^{-2\pi i \varepsilon_{ab}^I}\right)$$

"Parallel" fluxes $[R_a, R_b] = 0 \quad \varepsilon_{ab}^I = \varepsilon_a^I + \varepsilon_b^I$

"Oblique" fluxes $[R_a, R_b] \neq 0 \quad \varepsilon_{ab}^I \neq \varepsilon_a^I + \varepsilon_b^I$

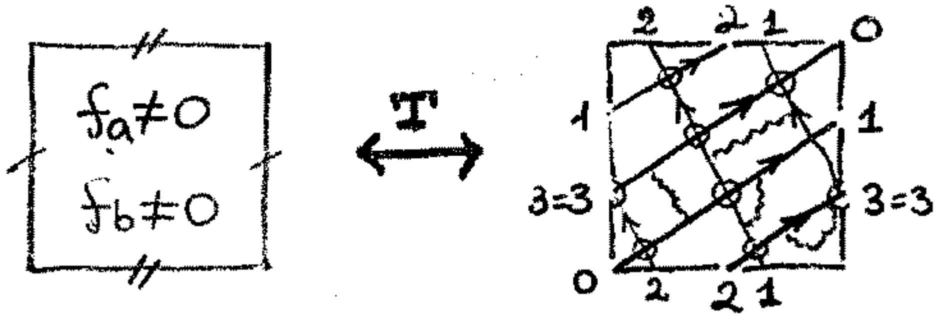
(Antoniadis, Maillard ; MB Trevigne ; Kumar, ...)

Susy $\quad I_{ab} \neq \prod_I I_{ab}^{(I)}$

$R_{ab} \in SU(3) \;\; \forall a,b \to \mathcal{N}=1 \qquad R_{ab} \in SU(2) \longrightarrow \mathcal{N}=2$

T-DUALITY $\rightarrow$ BRANES AT ANGLES

$$\tilde{r}_2 = \alpha'/r_2 \qquad \tan\beta_a = q_a f_a = q_a \frac{m_a}{n_a}\frac{\tilde{r}_2}{r_1}$$



Balasubramanian
Leigh
Berkooz Douglas

Fermionic zero modes at intersections

Charge sectors : (e.g. Angelantonj Sagnotti Pradisi Larosa, ...)

$Q = 0$ no magnetic shifts

- neutral strings : standard KK momenta
- dipole strings : $q_a = -q_b$ $(a=b)$ $N_a N_a^*$

$$p_i = k_i / n_i r_i \sqrt{1+f_a^2} \qquad \text{(Born-Infeld)}$$

$Q = \pm 2$ doubly charged strings (unoriented)

$$\tfrac{1}{2}(N_a^2 \pm N_a) \qquad \varepsilon_{a\tilde{a}} = \frac{2}{\pi}\beta_a = 2\varepsilon_{a0}$$

$Q = \pm 1$ singly charged $N_0 N_a$, $N_0 N_a^*$

$$\varepsilon_{0a} = \frac{1}{\pi}\beta_a \qquad I_{0a} = C_1(q_a \mathcal{F}_a)$$

$Q = (\pm 1, \pm 1)$ dy-charged strings $N_a N_b^*$ $N_a N_b$

$$\varepsilon_{ab} = \varepsilon_a + \varepsilon_b \qquad \text{(abelian!)}$$

T-DUALITY (~~OBLIQUE~~ FLUXES) → COISOTROPIC BRANES

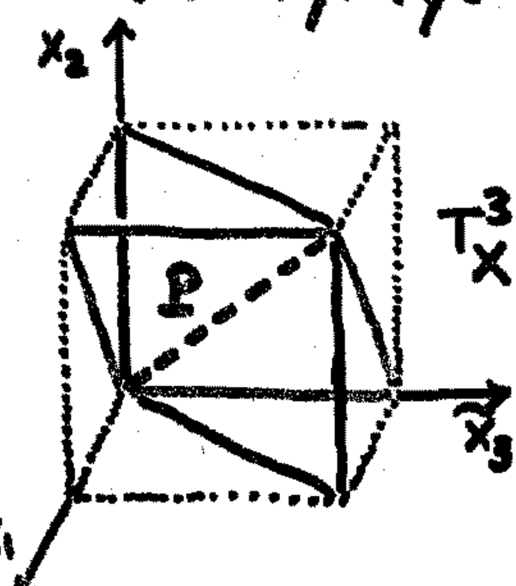
For a given pair of branes with oblique fluxes there is a T-duality mapping the pair into intersecting branes.

T depends on the choice of a and b so a configuration with many stacks cannot be mapped into a configurations of intersecting branes!

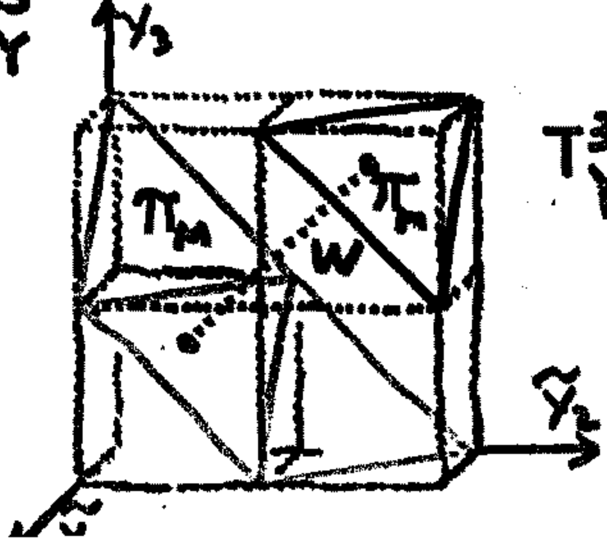
E.g. 4–5 sector of AM model

$$F_5 = -dx^1 \wedge dx^3 - dy^1 \wedge dy^3 \quad F_4 = -dx^2 \wedge dx^3 - dy^2 \wedge dy^3$$

$$T = T_{y^1} T_{y^2} T_{x^3} \longrightarrow D6_4,\ D6_5$$



$T^6 = T^3_X \times T^3_Y$



SCALAR POTENTIAL (FOR $\langle \varphi_{op} \rangle = 0$!)

In $d=6$ $\quad H^a_{\hat{i}\hat{j}} = E^i_{\hat{i}} E^j_{\hat{j}} F^a_{ij}$ (frame components)

$$\frac{\sqrt{\det(G_a + F_a)}}{\sqrt{\det(G_a)}} = 1 - \frac{1}{2}\operatorname{tr} H_a^2 + \frac{1}{4}(\operatorname{tr} H_a^2)^2 - \frac{1}{4}\operatorname{tr} H_a^4$$

$$\underbrace{- \frac{1}{6}\operatorname{tr}(H_a^6) + \frac{1}{8}\operatorname{tr}(H_a^2)\operatorname{tr}(H_a^4) - \frac{1}{48}\left[\operatorname{tr}(H_a^2)\right]^3}_{\frac{1}{8(3!)^2}(\varepsilon H_a H_a H_a)^2}$$

Skew diagonalizing H_a:

$$\sqrt{\det(1+H_a)} = \sqrt{\prod_1^3{}_i(1+h_i^2)} = \sqrt{(1-h_1h_2-h_2h_3-h_3h_1)^2 + (\underbrace{h_1h_2h_3-h_1-h_2-h_3}_{\text{susy}})^2}$$

Marchesano, Shiu, A-M, Dudas Timirgaziu NEGATIVE INDUCED TENSIONS! RR CHARGES

- For holomorphic bdles $\quad F^a_{(2,0)} = 0 \ \forall a$

$$\to \frac{|W|}{3!}\sqrt{\left(\int J\wedge J\wedge J - 3\int F^a\wedge F^a\wedge J\right)^2 + \left(\int F^a\wedge F^a\wedge F^a - 3\int J\wedge J\wedge F^a\right)^2}$$

Susy $\quad h_1^a h_2^a h_3^a = h_1^a + h_2^a + h_3^a \quad h_i = \tan\beta_i$

Super-magnetic triangle 

- Susy preserving moduli stabilization

$dz^I = dx^I + \tau^I{}_J dy^J$: $\quad F^a_{20} = 0 \leftrightarrow \tau^T f_{xx} \tau - \tau^T f_{xy} - f_{xy}^T \tau_y = f_{yy}$

Need 6 stacks of branes $\to$ e.g. $\tau^I{}_J = i\,\delta^I{}_J$

$F^a\wedge F^a\wedge F^a = 3\, J\wedge J\wedge F^a$ fix Kähler class J

Need 3 more stacks Antoniadis, Maillard

$+ \langle \phi \rangle \neq 0$ or $F_{ij}^{\text{non-abelian}}$ + Kumar + Mukhopadhyay Ray

GAUGE COUPLINGS (OBLIQUE CASE) → COISOTROPIC

- Tree level   Blumenhagen, Görlich, Stieberger, ...

$$\frac{1}{g_a^2} = |W_a| e^{-\phi} \sqrt{\det(G + F_a)}$$

á la Bachas, Fabre; Antoniadis, Bachas, Dudas

- one-loop running and thresholds:

Character valued partition function

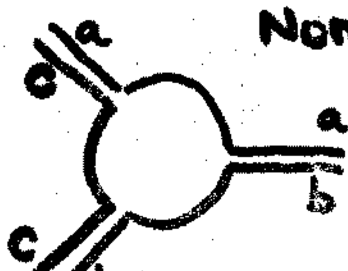
$$K(0) \sum_\alpha C_\alpha \frac{\vartheta_\alpha^4(0)}{\eta^{12}} \to K(\varepsilon) \sum_\alpha C_\alpha \prod_{i=1}^{4} \frac{\vartheta_\alpha(\varepsilon_{ab}^i \tau)}{\vartheta_1(\varepsilon_{ab}^i \tau)}$$

zero mode contributions

$\varepsilon_{ab}^{sp.t.}$ small and arbitrary (M_4 non compact)

ε_{ab}^{int} "quantized" (← mode shift, ...)

- Yukawa couplings & triangle:



Non-abelian!

Twist field correlator:

$$\varepsilon_{ab}^{(i)} \varepsilon_{bc}^{(i)} \varepsilon_{ca}^{(i)} = \varepsilon_{ab}^{(i)} + \varepsilon_{bc}^{(i)} + \varepsilon_{ca}^{(i)}$$

mass hierarchy?

- **T-dual to ~~intersecting~~ coisotropic branes <u>with</u> fluxes**

Ibanez, Uranga, Marchesano, Shiu, Cvetic, Langacker, Papadimitriou

Antoniadis, Kiritsis, Tomaras; Blumenhagen, Görlich, Lüst, ...

ONE-LOOP THRESHOLDS

Background field method — Bachas, Fabre, Antoniadis, Dudas, ...

$$F_{\mu\nu} = f\, \delta^2_{[\mu} \delta^3_{\nu]}\, Q \qquad Q \in CP$$

$$\mathrm{Tr}(Q) = 0 \qquad \mathrm{tr}(Q^2) = \tfrac{1}{2} \quad \text{(non anomalous!)}$$

$$\frac{4\pi}{g_Q^2} = \left.\frac{4\pi^2}{g_Q^2}\right|_{\text{tree}} + \frac{b_Q}{4\pi} \log \frac{M_s^2}{\mu^2} + \Delta_Q$$

Δ_Q UV_{op} (IR_{cl}) finite

$\mathcal{N}=4$ sectors: do not contribute (Kiritsis rev)

$\mathcal{N}=2$ sectors $\rightarrow \frac{1}{2}$ BPS States (")

$\mathcal{N}=1$ sectors: also massive oscillator modes!

$$\Delta_Q = \int \frac{dt}{4t}\, B_Q(t)$$

$$\left.B_Q^A\right|_{\mathcal{N}=1} = \frac{i}{\pi} \sum_{ab} I_{ab}\, \mathrm{Tr}_{N_a N_b} (Q_a + Q_b)^2 \sum_I \frac{\theta_1'(\epsilon^I_{ab} \tau_A | \tau_A)}{\theta_1(\epsilon^I_{ab} \tau_A | \tau_A)}$$

(similarly for $\hat{B}_Q^M$)

$$\left.B_Q^A\right|_{\mathcal{N}=2} = \frac{1}{2} \sum_{ab} I_{ab}^{\perp}\, \mathrm{Tr}_{N_a N_b} (Q_a + Q_b)^2\, \Lambda^u_{ab}(it)$$

ONE-LOO THRESHOLDS ('CTD)

In arbitrary susy compactification

$\mathcal{N}=1 \rightarrow \mathcal{N}=2$ on the worldsheet

Banks
Dixon
Friedan
Martinec
Shenker

Supersymmetric characters

$$\chi_I = \mathrm{Str}_{\mathcal{H}^I}\left(q^{L_0 - c/24}\, e^{2\pi i z J^0_{12}}\, e^{2\pi i \frac{z}{3} J^0_R} \right)$$

$$= 0 \qquad \forall z\ !$$

(Anastasopoulos MB Sarkissian Stanev)*

$$B_I(z) = \sum_\alpha C_\alpha \frac{\theta''_\alpha(z)}{\eta^5}\, \Omega^I_\alpha\left(\frac{z}{3}\right)$$

internal

$$= \sum_\alpha C_\alpha \frac{\theta'_\alpha(z)}{\eta^5} \cdot \Omega^{I\prime}_\alpha(z/3) \xrightarrow{z=0} \frac{2\pi}{3} \Omega^{I\prime}_R(0)$$

Quasi topological index (Bershadski Cecotti Vafa)

Thresholds in Gepner models with

(coisotropic) D-branes (in preparation*)

D-TERMS

In $N=1$ sugra $\sim$ gauging of holomorphic isometries

$$\delta_a Z^I = M_a^I(Z,\bar{Z}) \qquad D_\mu Z^I = \partial_\mu Z^I - M_a^I A_\mu^a$$

Invariance of Kähler form

$$M_a^I \frac{\partial^2 K}{\partial Z^I \partial \bar{Z}^J} = -i \frac{\partial D_a}{\partial \bar{Z}^J} \rightarrow D_a = i \frac{\partial K}{\partial Z^I} M_a^I + \zeta_a$$

$$\delta_a K = M_a^I \frac{\partial K}{\partial Z^I} + \bar{M}_a^{\bar{I}} \frac{\partial K}{\partial \bar{Z}^{\bar{I}}} = 0 \qquad \delta_a W = M_a^I \frac{\partial W}{\partial Z^I} = -i \zeta_a^W W$$

Equivariance $[\delta_a, \delta_b] = \delta_{[a,b]} \rightarrow \zeta_a = 0$ unless a central

No pure D-term uplift $-i D_a = M_a^I G_I$ (Villadoro Zwirner)

For D6-branes $\Pi_3^{(a)} = p_I^{(a)} \alpha^I - q^I_{(a)} \beta_I \in H_3$

$$\tilde{w}_\pi = i \int_\pi e^{-\phi} \omega_3^{cr} \qquad \mathrm{Re} f_a = N_a T_6 \,\mathrm{Re}\, w_\pi^{(a)}$$

$$V_6 = \sum_a N_a T_6 e^{-K} v_6^{cr} \Big[\overbrace{\mathrm{Re}\tilde{w}_\pi^a}^{F} + \overbrace{\Big(\sqrt{(\mathrm{Re}\tilde{w}_\pi^a)^2 + (\mathrm{Im}\,\tilde{w}_\pi^a)^2} - \mathrm{Re}\tilde{w}_\pi^a \Big)}^{D} \Big]$$

Compatibility with standard $N=1$ sugra

$$\left| \frac{\mathrm{Im}\,\tilde{w}_\pi^a}{\mathrm{Re}\,\tilde{w}_\pi^a} \right| \ll 1 \quad \text{for all branes!}$$

Similar conditions for D3/D7 D9/D5

CLOSED STRING FLUXES (A)

Giddings Kachru Polchinki ; Derendinger Kounnas Petropoulos Zwirner + Villadoro ; DeWolfe Gyrlawets Kachru

Type IIA (geometrical fluxes)

$$W_{flux} = \frac{1}{4} \int G^{RR}_{(ev)} e^{iJ_c} - i\left(H_3^{NS\text{-}NS} - i\gamma J_c\right)\Omega_3^c$$

$$G^{RR}_{(ev)} = \sum_n G^{(2n)}_{RR} = G^{RR}_{(0)} + G^{RR}_{(2)} + G^{RR}_{(4)} + G^{(6)}_{RR}$$

$$J_c = J + i B^{NS\text{-}NS} \qquad \Omega_3^c = \mathrm{Re}\left(i e^{-\phi}\Omega_3\right) + i C_3^{RR}$$

γ^k_{ij} torsion à la Scherk Schwarz

Consistency conditions ~ integrability, Bianchi ids

$$\gamma^k_{[ij}\gamma^m_{\ell]k} = 0 \qquad \gamma^k_{[ij} G^{(2)}_{\ell]k} + H^{(3)}_{ij\ell} G^{(0)} = \text{sources}$$

F-term potential depends on all moduli !

$$V_F = e^{\mathcal{G}}\left(\mathcal{G}^{i\bar{j}}\mathcal{G}_i\mathcal{G}^*_{\bar{j}} - 3\right) \qquad \mathcal{G} = K + \log|W|^2$$

Compatibility with $\Omega' = \Omega(-)^{F_L}\sigma_3$ $\quad \sigma_3\Omega_3 = -\Omega_3^*$

→ restriction on allowed fluxes

CLOSED STRING FLUXES (B)

Type IIB with Ωg, ΩS ~ Type I

$$W_{flux} = \int (G^{RR}_{(3)} - i\,\gamma\, J^c) \wedge \Omega^c_3$$

(for $h^-_{11} = 0 = h^-_{21}$)

Non geometric fluxes (Shelton Taylor Wecht, Zwirner Villadoro)

$$H_{ijk} \xrightarrow{T} \gamma^k_{ij} \xrightarrow{T} Q^{jk}_i \xrightarrow{T} R^{ijk}$$

Localized Bianchi identities

$$\cancel{H_3} \overset{\Omega}{+} \gamma^{\cdot} F_{2\cdot} + \tfrac{1}{2} \cancel{Q^{\cdot\cdot}} \overset{\Omega}{F_\cdot} F_\cdot + \tfrac{1}{3} R^{\cdots} F_\cdot F_\cdot F_\cdot = 0$$

For $\Omega' = \Omega\sigma$ → modified projection/truncation

(~ Heterotic) including non geometric fluxes

$$W = \int (G^{RR}_{(3)} - i\,\gamma\, J^c - i\, R\, \tilde{S}) \wedge \Omega^c$$

$$\tilde{S} = *_6 S$$

CLOSED STRING FLUXES (B')

Type IIB with $\Omega 3, \Omega 7$ $\quad \Omega' = \Omega(-)^{F_L}\cdot\sigma_{2,6}$

(Gukov, Vafa, Witten; Taylor Vafa)

$$W^{B'}_{flux} = \int \left(G^{(3)}_{RR} - i S H^{(3)}_{NS\text{-}NS}\right) \wedge \Omega^c_3$$

only dilaton and complex structure moduli

including non-geometric fluxes

$$\Delta W^{non\text{-}geo} = -i \int Q J^c \wedge \Omega_c$$

- KKLT scenario $\quad AdS \to DS$

  Use W_{flux} to stabilize complex structure and dilaton, use $W_{nonpert}$ (ED3) to stabilize Kähler moduli; add $\overline{D3}$ or something else to uplift to DS

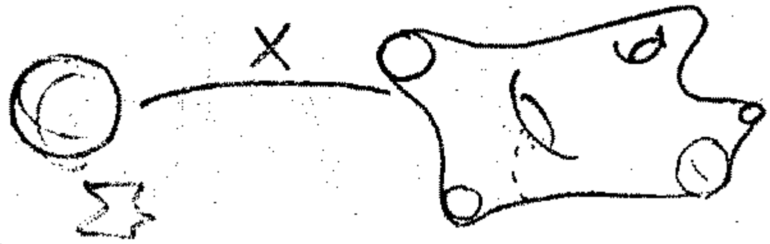
- Alternatively mirror of a rigid ($h_{21} = 0$) CY_3

  $\to$ no Kähler moduli (Becker² Vafa Walcher)

NON - PERTURBATIVE EFFECTS

In oriented closed strings

worldsheet instantons $\bar{\partial} X^i = 0$



$$e^{-S} \sim e^{-\kappa\left(\frac{R^2}{\alpha'} - i b\right)}$$

Type IIA $\rightarrow$ corrections to $K^{S.K.}_{h_{11}} = -\log V_{CY_3}$

Heterotic $\rightarrow$ corrections to $K_{h_{11}}$ and to Yukawa's

Type IIB $\rightarrow$ corrections to $\mathcal{Q}^{Hyper}_{h_{11}+1}$

Becker Becker Strominger

Brane-instantons ~ "Euclidean" worldvolumes

Heterotic ENS5 ~ gauge/gravitational instantons

Type II ENS5 + D-brane instantons

IIA $\cancel{ED0}$ (CY_3 $b_1=0$) ED2 $\cancel{ED4}$ (CY_3 $b_5=0$)

IIB ED(-1) $\cancel{ED3}$ (Ω) ED5 $\cancel{ED(-1)}$ (Ω)

D-BRANE INSTANTONS

D(p-4) inside Dp ~ instanton (Douglas)

$$S_{WZ} = \int C_{p+1} + C_{p-1} F + C_{p-3} F \wedge F + \cdots$$

- Dp - Dp strings gauge theory + ...
- Dp - D(p-4) strings $(w_{\dot\alpha i}^{u})_{N\times k}$
- D(p-3)-D(p-4) strings $(a_\mu)_{k\times k}$ $(\chi_I)_{k\times k}$

$\Big\}$ ADHM data #ND=4

If Dp wraps $\Sigma_{p-3} \subset \mathcal{M}_6$

ED(p-4) wrapping <u>same</u> Σ_{p-3} ~ instanton

$$S_{EDp-4} \equiv f_{Dp} \quad \text{gauge kinetic function}$$

Other extreme (#ND=8) Dp D(p-8)

eg D-string instantons in Type I

only massless fermions $\lambda^A_{Dp/Dp-8} \sim \lambda^A_{Het}$!

Intermediate EDp' on $\Sigma_{p'}$ with fluxes

+ susy conditions / # fermionic zero modes

Blumenhagen Cvetic Weigand Ibanez Uranga Kachru ...

COMPATIBILITY

Gauging of axionic shifts

$$\delta Z = c \longrightarrow \delta Z = M\,\alpha(x)$$

incompatible with non-perturbative effects

eg $W_{\text{non-pert}} \sim e^{-S_E} \sim e^{-b\cdot Z + \dots}$

Solution : gauging $\sim$ fluxes

$$\delta\beta^{I}_{RR}(x) = \alpha^{a}(x) \int_{\Sigma_2^I} F_a = \alpha^{a}(x)\, M^{I}_{a}$$

Fluxes obstruct brane wrappings eg ED1:

$$\int_{\Sigma} dG_1 = \int_{\Sigma} F_2 \neq 0 \quad \text{not (gauge invariant)}$$

consistent

For ED3 : Freed Witten anomaly for $H_3 \neq 0$

- Only "bona fidoe" axions not eaten by "anomalous" $U(1)$'s can appear in (super)potential
- Need $\chi(D) = 1$ for zero-mode counting (Witten, ...)

OPEN AND UNORIENTED PROBLEMS

- Only diluted (RR) fluxes
  ~ small warping

  No fullfledged string description
  for (arbitrary) closed string fluxes

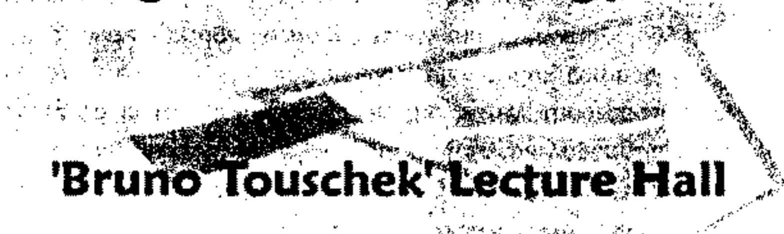
- Non-abelian magnetic fluxes
  (open string) non-abelian Born-Infeld
  [Brane recombination]

- Non-perturbative effects
  D-brane instantons largely unexplored

- Meta-stabilization in DS $\overset{?}{\leftarrow}$ Inclusion
  of all terms in $V(\phi, \phi^{+})$!

Istituto Nazionale di Fisica Nucleare

String Phenomenology 2007



'Bruno Touschek' Lecture Hall

INFN Frascati National Laboratories
June 4-8, 2007

E. Prampolini "Forms-forces in the space"

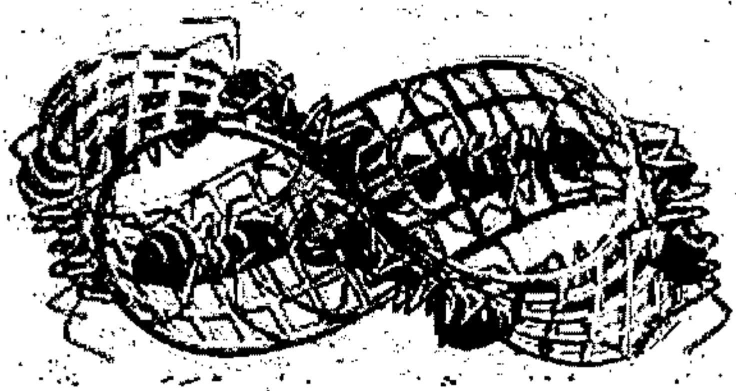
HOME PROGRAM INFO HOW TO REACH REGISTRATION CORRECTION SUBMIT TALK PARTICIPANTS

Foreword

The **6th edition of the String Phenomenology Conference** will take place at the **INFN Frascati National Laboratories**, Frascati (Rome), Italy, on **June 4-8 2007**. The Conference Venue is the 'Bruno Touschek Lecture Hall', inside the INFN Frascati National Laboratories.

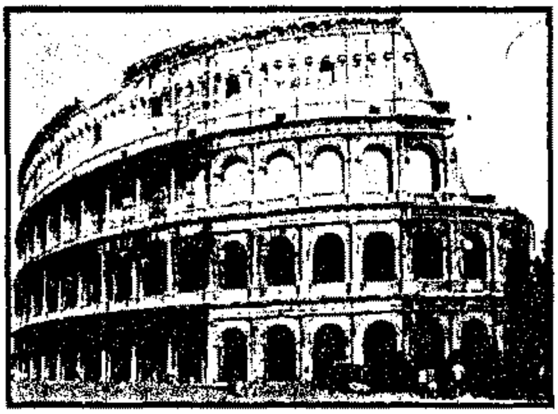
Structure and target of the Conference

Phenomenological aspects of String Theory have received renewed attention in recent years and many problems like hierarchy, supersymmetry breaking and electroweak symmetry breaking, gauge coupling unification, inflation, neutrino physics, dark matter, baryogenesis and flavour physics, have been properly incorporated in this framework. On the purely theoretical side, explorations of the space of string vacua (the "landscape"), and in particular of flux compactifications and intersecting brane world scenarios, provide a bridge between theory and phenomenology and are waiting for tests in the near future (for instance at the CERN LHC). Together with data from cosmology, they have the potential to drive new and important discoveries in the forthcoming years.
The conference aim at bringing together experts in String Theory, Particle Physics, Cosmology and Mathematical Physics, thus providing an occasion of very fruitful interactions that can spur

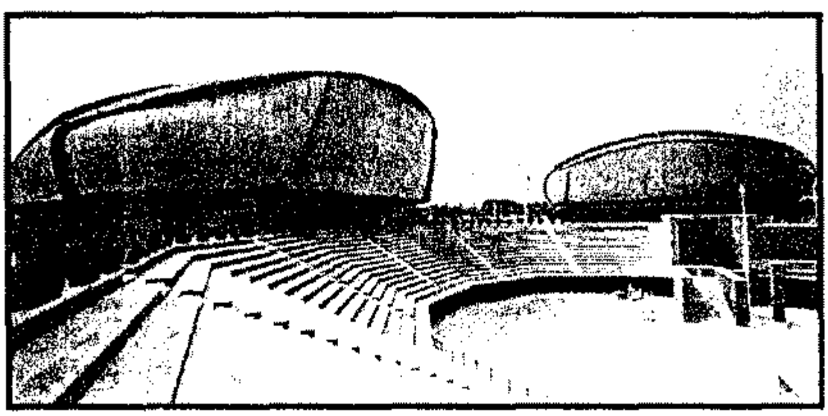


STRINGS '09

ROMAE, Idibus Juniis, MMIX



University of Rome "*Tor Vergata*"



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