Instanton induced Yukawa couplings in MSSM-like orientifold models

based on:

M. Cvetič, J. Halverson, R.R. arXiv:0905.3379

related earlier work:

L. E. Ibáñez, R.R. arXiv:0811.1583

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Motivation

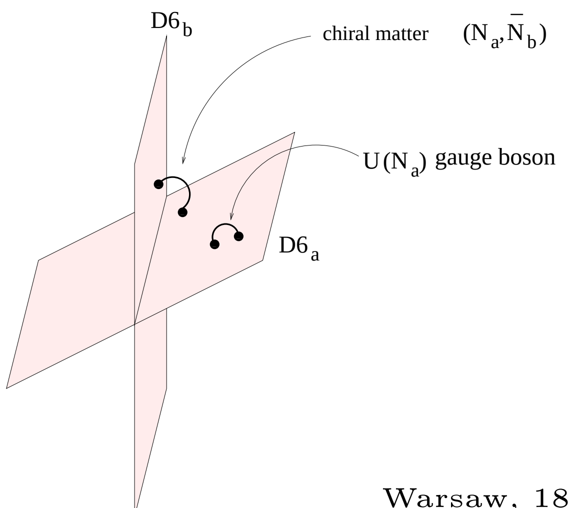
Intersecting Brane worlds provide geometrically appealing model building framework

(1) gauge group: each stack of N_a D6-branes carries $U(N_a) = SU(N_a) \times U(1)_a$ gauge theory

(2) chirality: two intersecting branes give rise to chiral fermions

(3) replication: in the compact manifold two branes might intersect several times

Many realization of globsl MSSM-like three family models



Motivation

What about superpotential?

computation string amplitudes

suppressed by world-sheet instantons $\rightsquigarrow$ hierarchy

Global U(1)'s forbid various desired couplings !

$E2$-instantons induce couplings: $e^{-S_{E2}} \prod_I \Phi_I$ $\rightsquigarrow$ hierarchy

Blumenhagen,Cvetic,Weigand hep-th/0609191, Ibanez, Uranga hep-th/0609213

- Majorana mass term for righthanded Neutrinos
- μ-term
- $\mathbf{10}\,\mathbf{10}\,\mathbf{5}$ Yukawa coupling in SU(5) GUT-like models

Blumenhagen, Cvetic, Weigand hep-th/0609191, Ibanez, Uranga hep-th/0609213, Cvetic, Weigand, R.R. hep-th/0703028, Ibanez, Schellekens, Uranga arXiv:0704.1079, Blumenhagen, Cvetic, Lüst, Weigand, R.R. arXiv:0707.1871, Cvetic, Weigand arXiv:0711.0209

Motivation

Missing couplings in realistic D-brane-quivers?

previous work:

- Madrid quiver

  Ibanez, R.R. arXiv:0811.1583

- specific three-stack quiver

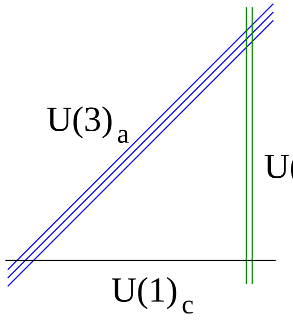
  Leontaris arXiv:0903.3691

- mass hierarchies in Madrid quiver

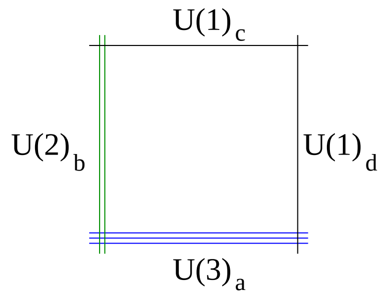
  Anastasopoulos, Kiritsis, Lionetto arXiv:0905.3044

Here: systematic bottom-up analysis of multi-stack MSSM quivers

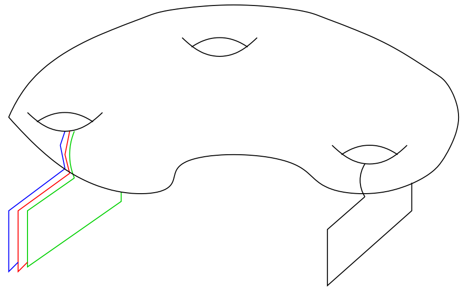
3- and 4-stack quivers



$U(3)_a \times U(2)_b \times U(1)_c$



$U(3)_a \times U(2)_b \times U(1)_c \times U(1)_d$



anomalous $U(1)$'s become massive via GS-mechanism

massless $U(1)_Y$ puts constraints on cycles the D-branes wrap

resulting gauge theory in 4D: $SU(3) \times SU(2) \times U(1)_Y$

global embedding $\rightsquigarrow$ Hidden sector

Top-down constraints

Tadpole cancellation: $\sum_x N_x\,(\pi_x + \pi'_x) - 4\pi_{O6} = 0$

$\rightsquigarrow$ constraints on transformation behavior of chiral matter

$$\#(a) - \#(\overline{a}) + (N_a - 4)\#(\text{antisym}_a) + (N_a + 4)\#(\text{sym}_a) = 0$$

usual anomaly cancellation for $N_a \geq 3$ also true for $N_a = 2$

$N_a = 1$ condition is relaxed

$$\#(a) - \#(\overline{a}) + 5\#(\text{sym}_a) = 0 \qquad \text{mod}\, 3$$

Massless $U(1)$: $\sum_x q_x\, N_x(\pi_x - \pi'_x) = 0$

$\rightsquigarrow$ constraints on transformation behavior of chiral matter

$$q_a\, N_a \left(\#(\text{sym}_a) + \#(\text{antisym}_a)\right) = \sum_{x \neq a} q_x\, N_x\,(\#(a, \overline{x}) - \#(a, x))$$

for $N_a = 1$ condition takes a slightly different form

Only necessary conditions, not sufficient!

Bottom-up constraints

- Spectrum: exact MSSM + 3 N_R

no chiral exotics charged under the MSSM D-branes

all MSSM + 3 N_R only charged under the MSSM D-branes

$\rightsquigarrow$ top-down constraints are satisfied within the MSSM-branes

righthanded quarks can transform as $\begin{smallmatrix}\square\\\square\end{smallmatrix}_a$

righthanded leptons can transform as $\begin{smallmatrix}\square\\\square\end{smallmatrix}_b$, $\square\square_c$, $\square\square_d$

- MSSM Superpotential: MSSM superpotential is realized

    perturbatively or non-perturbatively

    Yukawa couplings for all three families

- Top Yukawa: require the presence of top Yukawa coupling
- R-parity: No R-parity violating couplings

neither on perturbative nor non-perturbative level

$\rightsquigarrow$ a large class of quivers are ruled out

Bottom-up constraints

• Neutrino masses: Setup must allow for mechanism which explains the smallness of neutrino masses

Seesaw or non-pert. Dirac neutrino mass

Seesaw mechanism

$$M_{N_R}\, N_R\, N_R \qquad L\, H_u\, N_R$$

non-pert. Dirac neutrino mass

Langacker, Cvetič arXiv:0803.2876

$$e^{-S_{E2}}\, L\, H_u\, N_R \qquad \text{suppr. factor } e^{-S_{E2}} \sim 10^{-13}$$

• μ-term: instanton generating desired Yukawa must not induce μ-term $\rightsquigarrow$ otherwise too large μ term

allowing for a second Higgs pair might relax this condition

Ibanez, R.R. arXiv:0811.1583

Stick to the exact MSSM $\rightsquigarrow$ large class of quivers ruled out

Results

Classify all possible hypercharge embeddings

Anastosopoulos,Dijkstra,Kiritsis,Schellekens hep-th/0605226

Top-down constraints give of order 10000 D-brane quiver with exact MSSM $+$ 3 N_R

around 50 models satisfy all the bottom-up constraints

different origins for different families are unfavorable due to absence of R-parity and realistic μ-term

Bad news for mass hierarchies! See later!

Potential problem: Presence of additional massless $U(1)$'s

$\rightsquigarrow$ various couplings cannot induced non-perturbatively

(non-chiral) singlets under SM-gauge groups can induce Yukawas via higher order couplings

Anastasopoulos, Kiritsis, Lionetto arXiv:0905.3044

Madrid embedding most promising quiver

Results

Solution #	q_L		d_R			u_R		L			E_R			N_R				H_u				H_d
	(a,b)	$(a,\overline{b})$	$(\overline{a},c)$	$(\overline{a},\overline{d})$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_a$	$(\overline{a},\overline{c})$	$(\overline{a},d)$	$(b,\overline{c})$	(b,d)	$(\overline{b},d)$	$(c,\overline{d})$	$\Box\!\Box_c$	$\overline{\Box\!\Box}_d$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$	(c,d)	$(\overline{c},\overline{d})$	(b,c)	$(\overline{b},c)$	$(b,\overline{d})$	$(\overline{b},\overline{d})$	$(\overline{b},\overline{c})$
1	3	0	3	0	0	0	3	0	0	3	0	0	3	2	0	0	1	0	0	0	1	1
2	3	0	2	0	1	0	3	0	0	3	0	0	3	2	0	0	1	0	0	0	1	1
3	3	0	1	0	2	0	3	0	0	3	0	0	3	2	0	0	1	0	0	0	1	1
4	3	0	0	0	3	0	3	0	0	3	0	0	3	2	0	0	1	0	0	0	1	1
5	3	0	0	0	3	0	3	0	0	3	0	0	3	3	0	0	0	1	0	0	0	1
6	3	0	3	0	0	2	1	0	0	3	0	2	1	2	0	1	0	0	0	0	1	1
7	3	0	3	0	0	3	0	0	0	3	2	1	0	2	0	0	1	0	1	0	0	1
8	3	0	3	0	0	3	0	0	0	3	0	2	1	2	0	0	1	0	1	0	0	1
9	3	0	3	0	0	3	0	0	0	3	1	2	0	2	0	1	0	0	1	0	0	1
10	2	1	3	0	0	1	2	0	0	3	0	0	3	0	0	0	3	1	0	0	0	1
11	2	1	3	0	0	1	2	0	0	3	3	0	0	0	0	3	0	1	0	0	0	1
12	2	1	3	0	0	3	0	0	0	3	3	0	0	0	0	0	3	1	0	0	0	1
13	2	1	3	0	0	3	0	0	1	2	3	0	0	0	0	0	3	0	1	0	0	1
14	1	2	3	0	0	3	0	0	3	0	3	0	0	0	0	0	3	1	0	0	0	1
15	0	3	0	3	0	0	3	3	0	0	0	1	2	0	3	0	0	0	0	1	0	1
16	0	3	0	0	3	0	3	0	3	0	0	0	3	0	3	0	0	1	0	0	0	1
17	0	3	0	0	3	0	3	1	2	0	1	0	2	0	3	0	0	0	0	1	0	1
18	0	3	0	0	3	0	3	3	0	0	2	0	1	0	3	0	0	0	0	1	0	1
19	0	3	0	0	3	0	3	3	0	0	0	1	2	0	3	0	0	0	0	1	0	1
20	0	3	0	0	3	1	2	1	2	0	2	0	1	0	3	0	0	1	0	0	0	1
21	0	3	0	0	3	1	2	1	2	0	0	1	2	0	3	0	0	1	0	0	0	1
22	0	3	0	0	3	1	2	3	0	0	3	0	0	0	3	0	0	1	0	0	0	1
23	0	3	0	0	3	1	2	3	0	0	1	1	1	0	3	0	0	1	0	0	0	1
24	0	3	0	0	3	2	1	0	3	0	3	0	0	0	3	0	0	1	0	0	0	1
25	0	3	0	0	3	2	1	0	3	0	1	1	1	0	3	0	0	1	0	0	0	1
26	0	3	0	0	3	2	1	2	1	0	2	1	0	0	3	0	0	1	0	0	0	1
27	0	3	0	0	3	2	1	2	1	0	0	2	1	0	3	0	0	1	0	0	0	1
28	0	3	0	3	0	3	0	3	0	0	0	3	0	0	3	0	0	1	0	0	0	1
29	0	3	0	2	1	3	0	3	0	0	0	3	0	0	3	0	0	1	0	0	0	1
30	0	3	0	1	2	3	0	3	0	0	0	3	0	0	3	0	0	1	0	0	0	1
31	0	3	0	0	3	3	0	1	2	0	1	2	0	0	3	0	0	1	0	0	0	1

Solutions for hypercharge $U(1)_Y = \frac{1}{6}U(1)_a + \frac{1}{2}U(1)_c - \frac{1}{2}U(1)_d$

Results - Yukawa textures

- different origins for different families

Kiritsis Talk, Anastasopoulos, Kiritsis, Lionetto arXiv:0905.3044

e.g. q_L: $2 \times (3, \overline{2})\ \ 1 \times (3, 2)$ $\qquad$ u_R: $2 \times (\overline{3}, 1_c)\ \ 1 \times (\overline{3}, 1_d)$

$$\begin{pmatrix} A & B & B \\ C & D & D \\ C & D & D \end{pmatrix} \begin{pmatrix} A & B & C \\ A & B & C \\ A & B & C \end{pmatrix} \begin{pmatrix} A & B & C \\ D & E & F \\ D & E & F \end{pmatrix} \begin{pmatrix} A & B & C \\ D & E & F \\ G & H & I \end{pmatrix}$$

different entries induced by different instantons $\rightsquigarrow$ hierarchy

Splitting not favorable! $\rightsquigarrow$ higher-stack models?

- instanton induced Yukawa matrix factorizes

$Y^{IJ} \sim Y^I Y^J$ $\rightsquigarrow$ needs 3 instantons $\rightsquigarrow$ hierarchy

quarks: if realized as antisymmetric $\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_a$

leptons: (1) if E_R realized as $\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$ or $\Box\Box_c$

(2) if instanton exhibits vector-like modes

Summary and Outlook

classified and analyzed (local) MSSM D-brane quiver

pert. missing couplings are induced via D-instantons

large class of quivers exhibit R-parity violating couplings or a too large μ-term

order 10000 globally consistent quivers

$\rightsquigarrow$ only 50 quiver survive bottom up constraints

Quest for global embedding!

splitting of families not favorable higher stack models ?

but D-instanton effects lead to factorizable Yukawa matrices

$\rightsquigarrow$ can explain mass hierarchies within families

- increase number of stacks $\rightsquigarrow$ mass hierarchies!
- allowing for additional fields doubled Higgs sector or singlets
- relaxing R-parity