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STRINGY INSTANTONS ON RIGID MAGNETISED BRANES

work in collaboration with
Cezar Condeescu, Emilian Dudas and Michael Lennek

NPB 818 (2009) 52 [arXiv:0902.1694]

$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2'$ orientifolds with discrete torsion

- O-plane geography
- Non-Supersymmetric BSB vacua
- Supersymmetric vacua with magnetised branes (or, alternatively, branes at angles)
- Rigid instantons
- Examples
- Conclusions & speculations

related talks: Bianchi, Uranga, Weigand, Richter, Cvetic, ...

Why are stringy instantons interesting?

If they exist in a given theory, they will play a role!
Therefore, their role is worth to be studied.

Why are stringy instantons interesting?

Phenomenologically

they may induce non-perturbative corrections to low-energy couplings. Although these corrections are typically negligible in a perturbative framework, they may nevertheless represent leading contributions to given quantities if symmetries forbid classical and quantum operators.

$$\mathscr{W} = e^{-S_{\text{inst}}} \prod_i \Phi_i$$

where, chiral fields have charges Q_i wrt anomalous U(1)'s, and

$$S_{\text{inst}} \to S_{\text{inst}} + \Lambda \sum_i Q_i$$

Why are stringy instantons interesting?

Phenomenologically

- Generation of perturbatively forbidden couplings
  - generation of Majorana neutrino masses;
  - Higgs term in MSSM;
  - top Yukawa coupligs in SU(5) GUT's;
- Moduli stabilisation
- Supersymmetry breaking;
- ....

[Ibanez, Uranga, Blumenhagen, Cvetic, Weigand, Richter, Bianchi, Fucito, Morales, Lerda, Frau, Billò, Pesando, Ferro, Gallot, Dudas, Camara, Argurio, Ferretti, Bertolini, Kachru, Maillard, Pradisi, Schmidt-Sommerfeld, Akerblom, Petersson, Halverson, Garcia-Extebarria, ...]

Why are stringy instantons interesting?

Theoretically

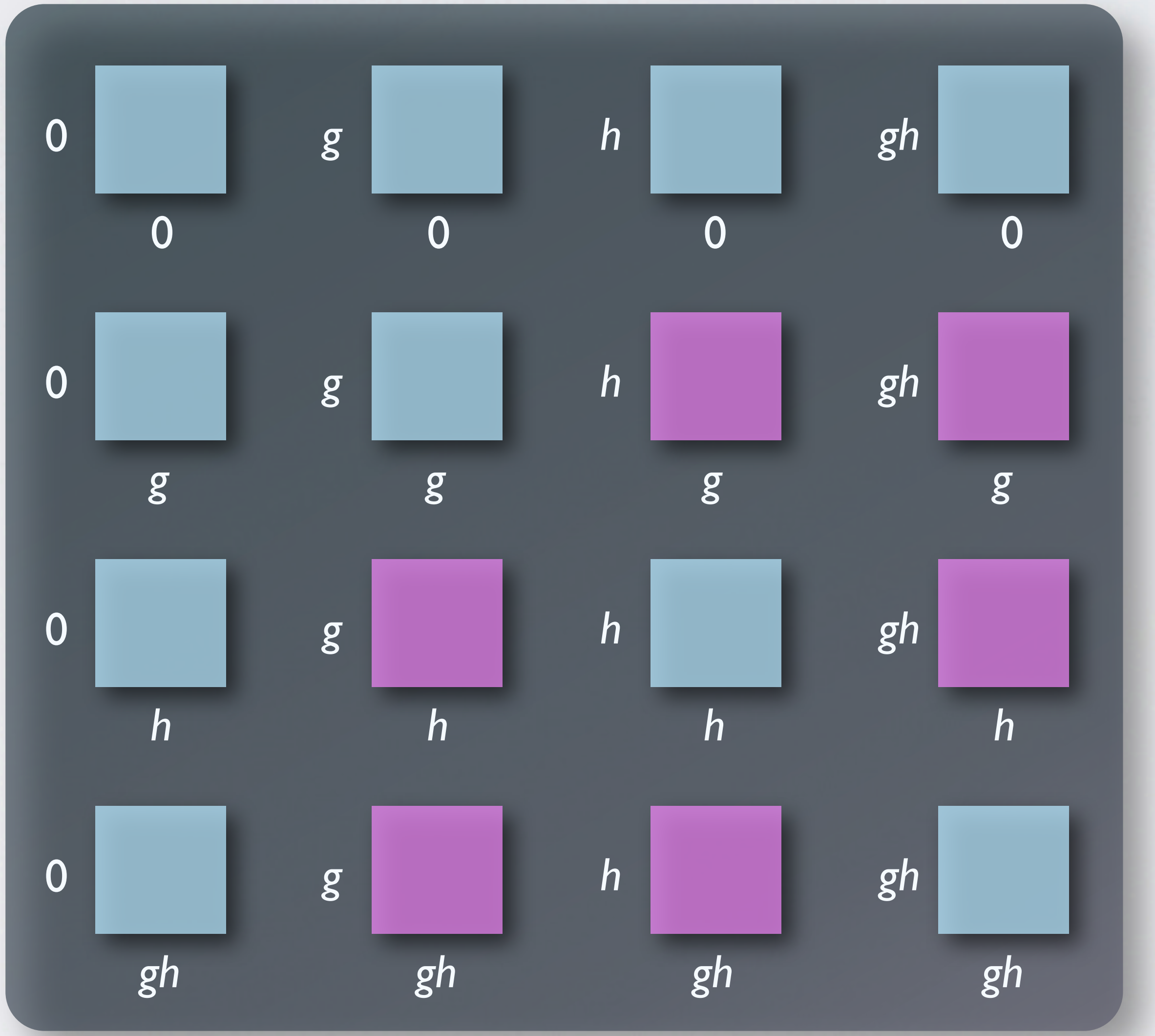
test of heterotic SO(32) - type I duality

heterotic	type I
α' corrections	E1 branes
NS5 branes	E5 branes

[Camara, Dudas, Maillard, Pradisi]

$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2'$ IIB orientifolds

$$\mathbb{Z}_2 \ni g \,:\, (z_1,\, z_2,\, z_3) \rightarrow (z_1,\, -z_2,\, -z_3) \qquad \mathbb{Z}_2' \ni h \,:\, (z_1,\, z_2,\, z_3) \rightarrow (-z_1,\, -z_2,\, z_3)$$



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$$\mathscr{Z} = \sum_{\alpha,\beta} {}^{\alpha}\square_{\beta} + \epsilon \sum_{\gamma,\delta} {}^{\gamma}\blacksquare_{\delta}$$

$\epsilon = \pm 1$ is related to discrete torsion and, clearly, affects massless and massive spectra

$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2'$ IIB orientifolds

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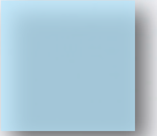
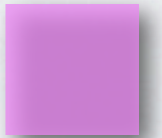
$\mathscr{Z} = \sum_{\alpha,\beta}$ α  β $+\,\epsilon \sum_{\gamma,\delta}$ γ  δ

$\epsilon = \pm 1$ is related to discrete torsion and, clearly, affects massless and massive spectra

1. changing the GSO projection of the oriented IIB string $(h_{1,1} \leftrightarrow h_{2,1})$
2. determining the type of orientifold planes introduced

In fact, in the presence of discrete torsion $(\epsilon = -1)$ ....

	space time	z_1	z_2	z_3
O9$_-$ planes	▬	▬	▬	▬
O5$^1_-$ planes	▬	▬	●	●
O5$^2_-$ planes	▬	●	▬	●
O5$^3_+$ planes	▬	●	●	▬

In fact, in the presence of discrete torsion $(\epsilon = -1)$ ....

	tension	charge
O_- planes	-	-
O_+ planes	+	+

In fact, in the presence of discrete torsion $(\epsilon = -1)$ ....

	space time	z_1	z_2	z_3
$O9_-$ planes	▬	▬	▬	▬
$O5^1_-$ planes	▬	▬	•	•
$O5^2_-$ planes	▬	•	▬	•
$O5^3_+$ planes	▬	•	•	▬

In fact, in the presence of discrete torsion $(\epsilon = -1)$ ....

	space time	z_1	z_2	z_3
$O9_-$ planes	▬	▬	▬	▬
$O5^1{}_-$ planes	▬	▬	•	•
$O5^2{}_-$ planes	▬	•	▬	•
$O5^3{}_+$ planes	▬	•	•	▬

	space time	z_1	z_2	z_3
D9 branes	▬	▬	▬	▬
$D5^1$ branes	▬	▬	•	•
$D5^2$ branes	▬	•	▬	•
$\overline{D5}^3$ branes	▬	•	•	▬

Stable Brane Supersymmetry Breaking Vacuum Configuration

[C.A, Antoniadis, D'Appollonio, Dudas, Sagnotti]

In fact, in the presence of discrete torsion $(\epsilon = -1)$ ....

	space time	z_1	z_2	z_3
$O9_-$ planes	▬	▬	▬	▬
$O5^1_-$ planes	▬	▬	•	•
$O5^2_-$ planes	▬	•	▬	•
$O5^3_+$ planes	▬	•	•	▬

	space time	z_1	z_2	z_3
D9 branes	▬	H_1	H_2	H_3

Supersymmetry condition: $H_1 + H_2 + H_3 = H_1 \, H_2 \, H_3$

$$T_{\rm eff} = T_{\rm D9} \int (1 - H_2 H_3 - H_3 H_1 - H_1 H_2)$$

$H_1 \, , \, H_2 > 0 \, , \; H_3 < 0$ Stable Supersymmetry Vacuum Configuration

[Dudas, Timirgaziu; Blumenhagen, Cvetic, Marchesano, Shiu]

Using standard techniques one can compute the spectrum of open-string excitations on the magnetised D9 branes

$$G_{\mathrm{CP}} = \prod_a \mathrm{U}(p_a) \times \prod_\alpha \mathrm{U}(q_\alpha)$$

together with varying families of chiral matter in bi-fundamental and rank-2 (anti)symmetric representations but NO adjoint chiral multiplets

$\mathbf{Z}_2\times\mathbf{Z}_2'$ orbifold with discret torsion have Hodge numbers $(h_{11},h_{21})=(3,51)$

Eight 3-cycles are inherited from the covering six-torus. The remaining 3-cycles originate from the twisted sectors and have the topology of $S^1\times S^2$ where S^1 is a 1-cycle of the fixed torus while S^2 corresponds to the 2-cycle of the blown-up orbifold singularities.

The twised 3-cycles (*aka* rigid cycles) are localised on orbifold singularities and thus cannot be deformed

Euclidean-brane instantons

	s.t.	z_1	z_2	z_3	G_{CP}	minimal z.m.
E5	●	▬	▬	▬	U(n)	4
$E1_1$	●	▬	●	●	U(n)	4
$E1_2$	●	●	▬	●	U(n)	4
$E1_3$	●	●	●	▬	SO(n)	2

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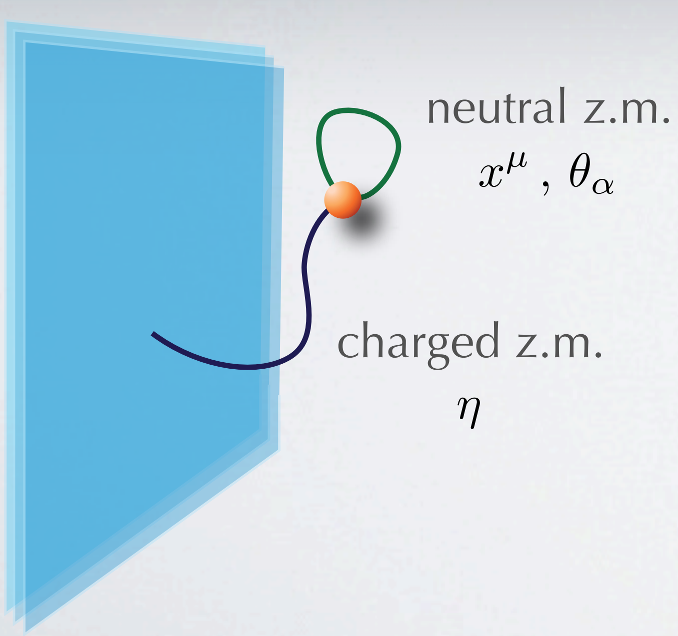
$E1_3$	●	●	●	▬	SO(n)	2



$$\mathscr{S}_{\rm inst} = \mathscr{S}_{\rm neutral}(\mathrm{vol}) + \mathscr{S}_{\rm charged}(\eta\,, \varPhi_o)$$

$$\int [d\eta] e^{-\mathscr{S}_{\rm inst}} \;\Rightarrow\; \mathscr{W}_{\rm np} \sim e^{-\mathscr{S}_{\rm neutral}} \prod_i \varPhi_o^i$$

Example ❶

4 stacks of magnetised branes			
	"wrapping" numbers		
stack 1	(2,1)	(1,1)	(-1,1)
stack 2	(-2,1)	(-1,1)	(1,1)
stack 3	(0,1)	(0,1)	(0,1)
stack 4	(0,1)	(1,0)	(-1,0)

Example ❶

$G_{CP} = U(2)^2 \times U(2)^2 \times USp(4)^2 \times USp(4)^2$		
mult	reps	field
1	$(\mathbf{2},\mathbf{2}^*,1,1;1,1,1,1)$	$\Phi_{1\bar{2}}$
1	$(\mathbf{2}^*,\mathbf{2},1,1;1,1,1,1)$	$\Phi_{\bar{1}2}$
12	$(\mathbf{1}^*,1,1,1;1,1,1,1)$	A^1
12	$(1,\mathbf{1}^*,1,1;1,1,1,1)$	A^2
4	$(\mathbf{2}^*,\mathbf{2}^*,1,1;1,1,1,1)$	$\Phi_{\bar{1}\bar{2}}$
1	$(1,1,\mathbf{2},\mathbf{2}^*;1,1,1,1)$	$\Phi_{3\bar{4}}$
1	$(1,1,\mathbf{2}^*,\mathbf{2};1,1,1,1)$	$\Phi_{\bar{3}4}$
12	$(1,1,\mathbf{1},1;1,1,1,1)$	A^3
12	$(1,1,1,\mathbf{1};1,1,1,1)$	A^4
4	$(1,1,\mathbf{2},\mathbf{2};1,1,1,1)$	Φ_{34}
2	$(\mathbf{2}^*,1,1,1;\mathbf{4},1,1,1)$	
2	$(1,\mathbf{2}^*,1,1;1,\mathbf{4},1,1)$	

....

Example ❶

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....

Euclidean instantons with 2 neutral z.m.		
	reps	field
$E1_o$	$(\mathbf{1},\mathbf{2},1,1;1,1,1,1)$	η_i^o
$E1_g$	$(\mathbf{2},1,1,1;1,1,1,1)$	η_i^g
$E1_f$	$(1,1,\mathbf{2}^*,1;1,1,1,1)$	η_i^f
$E1_h$	$(1,1,1,\mathbf{2}^*;1,1,1,1)$	η_i^h

Example ❶

$$\mathscr{S}_{\text{neutral}} = T_3 + \sum_{a=1}^{3} \alpha_a M_a$$

volume of the third T[2] — twisted moduli

$$\mathscr{S}_{\text{charged}} = \sum_{i.j} \eta_i^o A_{ij}^2 \eta_j^o + \sum_{i,j,k=1}^{2} \eta_i^o \,\Phi_{1\bar{2}}^{ki}\,\Phi_{1\bar{2}}^{kj}\,\eta_j^o$$

Upon integration over charged zero modes

$$\mathscr{W}_{\text{np}} = e^{-\mathscr{S}_{\text{neutral}}} \sum_{i,j=1,2} \epsilon_{ij} \left[A_{ij}^2 + \sum_{k=1,2} \Phi_{1\bar{2}}^{ki}\,\Phi_{1\bar{2}}^{kj} \right]$$

Linear terms in the superpotential may induce O'Raifeartaigh/Polony supersymmetry breaking, gauge mediation supersymmetry breaking, moduli stabilisation, ...

$G_{CP} = U(2)^2 \times U(2)^2 \times USp(4)^2 \times USp(4)^2$		
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Example ❶

$$\mathscr{S}_{\text{neutral}} = T_3 + \sum_{a=1}^{3} \alpha_a M_a$$

volume of the third T^2 → T_3; twisted moduli → M_a

$$\mathscr{S}_{\text{charged}} = \sum_{i.j} \eta_i^o A_{ij}^2 \eta_j^o + \sum_{i,j,k=1}^{2} \eta_i^o \Phi_{1\bar{2}}^{ki} \Phi_{1\bar{2}}^{kj} \eta_j^o$$

Upon integration over charged zero modes

$$\delta \mathscr{S}_{\text{neutral}} = 2\Lambda_2$$

$$\mathscr{W}_{\text{np}} = e^{-\mathscr{S}_{\text{neutral}}} \sum_{i,j=1,2} \epsilon_{ij} \left[A_{ij}^2 + \sum_{k=1,2} \Phi_{1\bar{2}}^{ki} \Phi_{1\bar{2}}^{kj} \right]$$

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Example ❶

$$\mathscr{S}_{\text{neutral}} = T_3 + \sum_{a=1}^{3} \alpha_a M_a$$

volume of the third T[2] — twisted moduli

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Upon integration over charged zero modes

$$\mathscr{W}_{\text{np}} = e^{-\mathscr{S}_{\text{neutral}}} \sum_{i,j=1,2} \epsilon_{ij} \left[A^2_{ij} + \sum_{k=1,2} \Phi^{ki}_{1\bar{2}} \, \Phi^{kj}_{\bar{1}2} \right]$$

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$E1_h$	(1,1,1,**2***;1,1,1,1)	η_i^h

Example ❷

2 stacks of magnetised branes			
	"wrapping" numbers		
stack 1	(1,1)	(1,1)	(-1,1)
stack 2	(-1,1)	(-1,1)	(1,1)

η_i^o

η_i^g

η_i^f

η_i^h

Example ❷

$G_{CP} = U(4)^2 \times U(4)^2$		
mult	reps	field
1	$(\mathbf{4}^*,\mathbf{4},1,1)$	
1	$(\mathbf{4},\mathbf{4}^*,1,1)$	
1	$(1,1,\mathbf{4}^*,\mathbf{4})$	
1	$(1,1,\mathbf{4},\mathbf{4}^*)$	
8	$(\mathbf{6}^*,1,1,1)$	A^1
8	$(1,\mathbf{6}^*,1,1)$	A^2
8	$(1,1,\mathbf{6},1)$	A^3
8	$(1,1,1,\mathbf{6})$	A^4

η_i^o

η_i^g

η_i^f

η_i^h

Example ❷

G_{CP} = U(4)²×U(4)²		
mult	reps	field
1	($\mathbf{4}^*$,$\mathbf{4}$,1,1)	
1	($\mathbf{4}$,$\mathbf{4}^*$,1,1)	
1	(1,1,$\mathbf{4}^*$,$\mathbf{4}$)	
1	(1,1,$\mathbf{4}$,$\mathbf{4}^*$)	
8	($\mathbf{6}^*$,1,1,1)	A^1
8	(1,$\mathbf{6}^*$,1,1)	A^2
8	(1,1,$\mathbf{6}$,1)	A^3
8	(1,1,1,$\mathbf{6}$)	A^4

Euclidean instantons with 2 neutral z.m.		
	reps	field
$E1_o$	(1,$\mathbf{4}$,1,1)	η_i^o
$E1_g$	($\mathbf{4}$,1,1,1)	η_i^g
$E1_f$	(1,1,$\mathbf{4}^*$,1)	η_i^f
$E1_h$	(1,1,1,$\mathbf{4}^*$)	η_i^h

Example ❷

$$\mathscr{S}_{\text{neutral}} = T_3 + \sum_{a=1}^{3} \alpha_a M_a$$

volume of the third T^2 — twisted moduli

$$\mathscr{S}_{\text{charged}} = \sum_{i.j=1}^{4} \eta_i^o A_{ij}^2 \eta_j^o$$

Upon integration over charged zero modes

$$\mathscr{W}_{\text{np}} = e^{-\mathscr{S}_{\text{neutral}}} \sum_{i,j,k,l=1}^{4} \epsilon_{ijkl}\, A_{ij}^2\, A_{kl}^2$$

non-perturbative mass term for the *A*'s

$G_{CP} = U(4)^2 \times U(4)^2$		
mult	reps	field
1	$(\mathbf{4}^*,\mathbf{4},1,1)$	
1	$(\mathbf{4},\mathbf{4}^*,1,1)$	
1	$(1,1,\mathbf{4}^*,\mathbf{4})$	
1	$(1,1,\mathbf{4},\mathbf{4}^*)$	
8	$(\mathbf{6}^*,1,1,1)$	A^1
8	$(1,\mathbf{6}^*,1,1)$	A^2
8	$(1,1,\mathbf{6},1)$	A^3
8	$(1,1,1,\mathbf{6})$	A^4

Euclidean instantons with 2 neutral z.m.		
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$E1_h$	$(1,1,1,\mathbf{4}^*)$	η_i^h

Example ❷

The gauge theory on the D9 branes, actually divides into two non-interacting sectors.
The beta functions for the non-Abelian couplings are vanishing at one loop and it is tempting to speculate about the existence of an IR conformal fixed point.

[Leigh, Strassler]

$G_{CP} = U(4)^2 \times U(4)^2$		
mult	reps	field
1	$(\mathbf{4}^*,\mathbf{4},1,1)$	
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8	$(\mathbf{6}^*,1,1,1)$	A^1
8	$(1,\mathbf{6}^*,1,1)$	A^2
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8	$(1,1,1,\mathbf{6})$	A^4

Conformal invariance would then be broken by non-perturbative effects mAA at a hierarchically small energy scale, thus offering an alternative solution to the hierarchy problem.

[Frampton, Vafa]

CONCLUSIONS

Stringy instantons play a crucial role in generating
hierarchically small masses,
low-energy supersymmetry breaking,
conformal symmetry breaking,
....

They are also crucial for testing string dualities,
....

SPECULATIONS

Our driving motivation was trying to connect non-tachyonic non-supersymmetric vacua with N=1 supersymmetric vacua with magnetised D9 branes. In fact, both configurations share the same supersymmetric closed-string spectrum, with identical O-plane structure.

It is reasonable to believe that, though classically stable, the non-supersymmetric vacuum is actually metastable and will quantum mechanically decay to the supersymmetric solution.

This is actually what happens in similar N=2 set-ups

[C.A., Dudas]

SPECULATIONS

The non-supersymmetric model contains stacks of $D5_{1,2}$ branes and $D5_3$ branes in addition to D9 ones. All D5 branes can actually be seen as zero-size gauge instantons on the D9 branes.

[Witten]

Instantons would energetically prefer to expand to their maximal size within the D9 branes, and because of conservation of topological charges, the original D5 (anti)branes are actually converted into diluted magnetic fluxes on the D9's.

It is tempting to believe that this (highly non-trivial) dynamical process is triggered by E-brane instantons