Intersecting branes in the $\mathbb{Z}_6'$ orientifold

Alex Love[a] & David Bailin[b]

[a] Royal Holloway, London

[b] Department of Physics & Astronomy

University of Sussex

d.bailin@sussex.ac.uk

University of Sussex

Outline

- Background
- $\mathbb{Z}_6$ orientifold (Honecker & Ott)
- $\mathbb{Z}_6'$ orientifold
- Summary & conclusions

Background

- Open strings that begin and end on a stack a of N_a D6-branes wrapping a 3-cycle of $T^6 = T_1^2 \otimes T_2^2 \otimes T_3^2$ give the (massless) gauge bosons of $U(N_a) = U(1)_a \otimes SU(N_a)$.

- At the intersections of two stacks a and b there is chiral matter in the bi-fundamental $(\mathbf{N}_a, \overline{\mathbf{N}}_b)$ representation of $U(N_a) \otimes U(N_b)$, where $\mathbf{N}_a$ and $\overline{\mathbf{N}}_b$ respectively have charges $Q_a = +1$ and $Q_b = -1$ with respect to $U(1)_a$ and $U(1)_b$.

- To get the standard model, we start with $N_a = 3$ and $N_b = 2$ and then arrange that there are $a \circ b = 3$ intersections. However $3(\mathbf{3}, \overline{\mathbf{2}})$ has $Q_b = -9$, so with 3 lepton doublets $(\mathbf{1}, \mathbf{2})$ we require $Q_b = 6$ units of doublet charge from another source to cancel Q_b overall (as required by tadpole cancellation.) This requires additional (vector-like) non-standard model matter from other intersections.

- If instead we wrap an orientifold T^6/Ω, where Ω is the world-sheet parity operator, then at the intersections of a and the orientifold image b' of b the chiral matter is in the $(\mathbf{N}_a, \mathbf{N}_b) = (\mathbf{3}, \mathbf{2})$ representation. Then $2(\mathbf{3}, \overline{\mathbf{2}}) + 1(\mathbf{3}, \mathbf{2})$ has $Q_b = -3$ which can be cancelled by 3 lepton doublets.

- To get just the standard model we require that $(|a \circ b|, |a \circ b'|) = (2, 1)$ or $(1, 2)$.

  Ibáñez, Marchesano & Rabadán

- D6-branes wrapping 3-cycles of T^6/Ω generally give a non-supersymmetric spectrum. This requires a low (TeV-scale) unification/string scale to avoid the hierarchy problem. Such low-scale models have unacceptable levels of flavour changing neutral currents induced by world-sheet instantons.

  Abel, Lebedev & Santiago

- Non-susy theories generally have uncancelled NSNS tadpoles, which reflect the instability of the complex structure moduli of T^6. We can stabilise (some of) these moduli using an orbifold $T^6/\mathbb{Z}_N$ or $T^6/\mathbb{Z}_M \times \mathbb{Z}_N$ instead, and if the embedding is supersymmetric, RR tadpole cancellation ensures NSNS tadpole cancellation too.

  Cvetič, Shiu & Uranga

$\mathbb{Z}_6$ orientifold

- The $\mathbb{Z}_6$ orbifold has a twist vector $\mathbf{v} = \frac{1}{6}(1, 1, -2)$ that can be realised using an $SU(3)$ root lattice in each of the tori $T_k^2,\ k = 1, 2, 3$. The point group generator acts as $\theta z_k = e^{2\pi i v_k} z_k$. The embedding $\mathcal{R}$ of Ω acts as $\mathcal{R} z_k = \overline{z}_k$ and for this to be an automorphism (each) lattice must be in either the **A** or **B** configuration.

- Since $b_3(T^6/\mathbb{Z}_6) = 2$ there are 2 independent (invariant, untwisted) bulk 3-cycles $\rho_{1,2}$, and the only non-zero intersection is even: $\rho_1 \circ \rho_2 = -2$.

- There is one $\mathcal{R}$-invariant combination for each lattice, and in all cases it is supersymmetric.

- To get odd intersection numbers you have to use fractional branes

$$a = \frac{1}{2}\left[\Pi_a^{\rm bulk} + \Pi_a^{\rm exceptional}\right]$$

where $\Pi_a^{\rm exceptional}$ consists of a collapsed 2-cycle stuck at a ($\mathbb{Z}_2$) fixed point in $T_1^2 \otimes T_2^2$ times a 1-cycle in T_3^2.

- They occur only in the θ^3 twisted sector. There are 10 independent exceptional cycles $\epsilon_i, \tilde{\epsilon}_i,\ (i = 1, 2...5)$ with non-zero intersection numbers $\epsilon_i \circ \tilde{\epsilon}_j = -2\delta_{ij}$. The pairs of fixed points to be used are determined by the wrapping numbers in $T^2_{1,2}$ of the bulk part.

- To avoid symmetric and antisymmetric representations of the (non-abelian) gauge groups we require that $a \circ a' = 0 = b \circ b'$. Honecker & Ott have shown that it is then impossible for $(|a \circ b|, |a \circ b'|) = (2, 1)$ or $(1, 2)$.

$\mathbb{Z}'_6$ orientifold

- Can we get the required intersection numbers using the $\mathbb{Z}'_6$ orientifold? The twist vector is $\mathbf{v} = \frac{1}{6}(1, 2, -3)$. On $T^2_{1,2}$ the point group can again be realised using an $SU(3)$ root lattice. On T^2_3 the point group acts as a reflection, so the complex structure U_3 is unconstrained. There are still two ($\mathcal{R}$-invariant) orientations of the torus: $\mathrm{Re}\, U_3 = 0$ in **A**, and $\mathrm{Re}\, U_3 = \frac{1}{2}$ in **B**.
- $b_3(T^6/\mathbb{Z}'_6) = 4$, so there are 4 independent (invariant, untwisted) bulk 3-cycles $\rho_{1,3,4,6}$ and the general bulk 3-cycle is

$$\Pi_a^{\mathrm{bulk}} = \sum_{i=1,3,4,6} A_i \rho_i$$

with the coefficients $A_i(n^a_k, m^a_k)$ determined by the wrapping numbers $(n^a_k, m^a_k),\ k = 1, 2, 3$ on the three tori. For example,

$$A_1 = (n^a_1 n^a_2 + n^a_1 m^a_2 + m^a_1 n^a_2) n^a_3$$

The intersections $\rho_i \circ \rho_j$ are even, so again we must use fractional branes to get the standard model.

- Supersymmetry gives a single constraint on $\Pi_a^{\rm bulk}$ in terms of U_3. On the **AAB**-lattice

$$\sqrt{3}(2A_3 + A_6) = (A_6 - 2A_4)2{\rm Im}\, U_3$$

There are two independent $\mathcal{R}$-invariant combinations for each lattice. On the **AAB**-lattice

$$2A_3 + A_6 = 0 = A_6 - 2A_4$$

Both are supersymmetric. In this case there are supersymmetric combinations that are not $\mathcal{R}$-invariant.

- Exceptional cycles occur in the $\theta^{2,4}$ and θ^3 twisted sectors. The latter generates 8 independent cycles $\epsilon_i, \tilde{\epsilon}_i,\ (i = 1,4,5,6)$ with $\epsilon_i \circ \tilde{\epsilon}_j = -2\delta_{ij}$. Only this sector looks rich enough to generate the required intersection numbers.

- In the $\mathbb{Z}_6$ case, the (5) stacks had an $\mathcal{R}$-invariant bulk part, so that all intersection numbers derive from the exceptional parts. If we assume that the same applies here, then you can get

$$(|a \circ b|, |a \circ b'|) = (2,1)$$

Unfortunately, No-go theorem 1: the required exceptional parts use fixed points that are inconsistent with the wrapping numbers needed for the $\mathcal{R}$-invariant bulk part.

- The (assumed) common bulk part must be supersymmetric, but not $\mathcal{R}$-invariant. A "generic" way to get a common bulk part for two stacks is to interchange the wrapping numbers on $T^2_{1,2}$ so that

$$(n^b_1, m^b_1; n^b_2, m^b_2; n^b_3, m^b_3) = (n^a_2, m^a_2; n^a_1, m^a_1; n^a_3, m^a_3)$$

No-go theorem 2: Generic stacks a, b satisfying $a \circ a' = 0 = b \circ b'$ (on the **AAB**-lattice) always have $(|a \circ b|, |a \circ b'|) \neq (\underline{2, 1})$. Other lattices will also be studied.

- Finally we must do a computer search to see whether non-generic stacks can provide the required intersections.

Summary & conclusions

The most direct route to just the (supersymmetric) standard model is to find stacks a, b with $N_a = 3$ and $N_b = 2$ satisfying $a \circ a' = 0 = b \circ b'$ and $(|a \circ b|, |a \circ b'|) = (2, 1)$. This cannot be done using the $\mathbb{Z}_6$ orientifold, and so far not with the $\mathbb{Z}'_6$ either.

Result is unaffected by Wilson lines.

In both cases we could instead use the G_2 lattice on one or more of the tori T^2_k.

The Kähler moduli and dilaton could perhaps be stabilised using flux compactifications and the "rigid corset" of Cámara, Font & Ibáñez .