TOURING AMONG ORIENTIFOLD VACUA

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Orientifold constructions admit several different vacua associated to different D-brane geometries and to different solutions of the tadpole equations

Are these vacua a *discretuum* or are they part of a more general *landscape*?

Are orientifold vacua connected by some (non-)perturbative effect?

Clearly, this is the case of
(unstable) non-supersymmetric vacua

What about supersymmetric configurations?

The transition among different vacua could involve changes in the background geometry and/or D-brane configurations

It is well known that D5 branes can be described as zero-size instantons on the world-volume of the D9 branes

Hence, blowing-up the instanton one could imagine that vacua with D9/D5 branes could be connected to configurations with magnetised D9-branes

PLAN OF THE TALK

- Brane recombination
- (limitation of) the Higgs description
- A field theory analysis

Orientifold vacua are characterised by a background closed-string geometry (orbifold fixed points + O-planes) plus a collection of D-branes wrapping internal cycles

$$\boldsymbol{\Pi}_a = \boldsymbol{\Pi}_a^u + \boldsymbol{\Pi}_a^t$$

Consistency of the construction requires the introduction of image branes

$$\tilde{\boldsymbol{\Pi}}_a = \Omega \cdot \boldsymbol{\Pi}_a$$

so that the invariant cycle is

$$\hat{\boldsymbol{\Pi}}_a = \boldsymbol{\Pi}_a + \tilde{\boldsymbol{\Pi}}_a$$

The set of cycles $\boldsymbol{\Pi}_a$ determines the gauge group and the chiral spectrum of the vacuum

Different vacua correspond to different solutions to the tadpole conditions

$$\sum_a N_a \left(\boldsymbol{\Pi}_a + \tilde{\boldsymbol{\Pi}}_a \right) + \boldsymbol{\Pi}_{\mathrm{O}} = 0$$

The question is whether the different solutions can be connected by some (non-perturbative) effect

BRANE RECOMBINATION

(RR charge conservation)

$$N_c(\boldsymbol{\Pi}_c + \tilde{\boldsymbol{\Pi}}_c) \equiv [N_a(\boldsymbol{\Pi}_a + \tilde{\boldsymbol{\Pi}}_a)] \cup [N_b(\boldsymbol{\Pi}_b + \tilde{\boldsymbol{\Pi}}_b)]$$

If the invariant cycles of the original branes *are not* rigid,

$$\boldsymbol{\Pi}_a + \tilde{\boldsymbol{\Pi}}_a = \boldsymbol{\Pi}_a^u + \tilde{\boldsymbol{\Pi}}_a^u$$

$$\boldsymbol{\Pi}_a^t + \tilde{\boldsymbol{\Pi}}_a^t = 0$$

recombination is straightforward and well understood.

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$$\boldsymbol{\Pi}_a + \tilde{\boldsymbol{\Pi}}_a = \boldsymbol{\Pi}_a^u + \tilde{\boldsymbol{\Pi}}_a^u + \boldsymbol{\Pi}_a^t + \tilde{\boldsymbol{\Pi}}_a^t$$

recombination is non-trivial, since the bulk (or untwisted) cycles determine the exceptional (or twisted) ones and they have to do it in a consistent way!

The amazing result is that ***all*** supersymmetric (and non-supersymmetric) orientifold vacua with the same background closed-string geometry are ***all*** in the same moduli space and can be connected via ***brane recombination***

Example. SUSY vacua in D=6

In this case $\boldsymbol{\Pi}^t_a + \tilde{\boldsymbol{\Pi}}^t_a = 0$

All solutions are connected to the mother $\mathrm{U}(16) \times \mathrm{U}(16)$ theory with hyper's in 2(**120**,1)+2(1,**120**)+(**16**,**16**)

The original vacuum involves 16 copies of

$$\mathrm{D7} \ : \ \boldsymbol{\Pi}_7 = \boldsymbol{a}_1 \otimes \boldsymbol{a}_2 \, , \qquad \mathrm{D7}' \ : \ \boldsymbol{\Pi}_{7'} = \boldsymbol{b}_1 \otimes \boldsymbol{b}_2 \, ,$$

Tadpole conditions

$$\sum_e N_e m_e^1 m_e^2 = 16\,, \qquad \sum_e N_e n_e^1 n_e^2 = 16$$

Brane recombination

$$N_c m_c^1 m_c^2 = N_a m_a^1 m_a^2 + N_b m_b^1 m_b^2$$
$$N_c n_c^1 n_c^2 = N_a n_a^1 n_a^2 + N_b n_b^1 n_b^2$$

$$\boldsymbol{\Pi}_a = \bigotimes_{i=1,2} (m_a^i\, \boldsymbol{a}_i + n_a^i\, \boldsymbol{b}_i)$$

Example a. U(16)

diagonal recombination

$$16\boldsymbol{\Pi}_7 \cup 16\boldsymbol{\Pi}_{7'} = 16\boldsymbol{\Pi}_{\text{diag}}$$

$(1,1;1,1)$

massless spectrum

$$4 \times \mathbf{120}$$

Example b. U(12)xU(4)

partial recombination

$$12\boldsymbol{\Pi}_7 + [4\boldsymbol{\Pi}_7 \cup 16\boldsymbol{\Pi}_{7'}] = 12\boldsymbol{\Pi}_7 + 4\boldsymbol{\Pi}_{\text{rec}}$$

$(1,2;1,2)$

massless spectrum

$$2 \times (\mathbf{66}, 1) + 10(1, \mathbf{6}) + 4(\mathbf{12}, \mathbf{4})$$

Similar results also in 6d models with
Brane Supersymmetry Breaking

A Higgs mechanism description

It is argued that *brane recombination* (and its T-dual *brane transmutation*) can be described in terms of a conventional Higgs-like mechanism in the low-energy action

Although, this is quite obvious in 6d SUSY vacua, it is less straightforward when SUSY is broken and in 4d

Anyhow, in general the Higgs description is not very efficient

Example a. U(16)

straightforward!

$$\boxed{U(16) \times U(16) \to U(16)_{\mathrm{diag}}}$$

by giving a *vev* to the **(16,16)**

The charged spectrum follows

Example b. U(12)xU(4)

convoluted!

First break

$$\boxed{U(16) \times U(16) \to U(12) \times U(4)^5}$$

by giving a *vev* to the **(120,1)**+ **(1,120)**

Then break

$$\boxed{U(4)^5 \to U(4)_{\mathrm{diag}}}$$

The charged spectrum finally follows

The non-SUSY case is more complicated since after the Higgs breaking the charged spectra do not match!

One must then postulate the existence of new (higher-order) couplings that give masses to un-matched states

$$\Phi\,\psi\,\psi \qquad\qquad \Phi\,\Phi\,\phi\,\phi$$

In d=4, brane recombination connects non-SUSY and SUSY vacua

In some cases, brane recombination implies the (spontaneous) nucleation of brane-antibrane pairs

In these cases, a Higgs-like mechanisms seems non to capture the transition

$$\boxed{H_1 + H_2 + H_3 = (\alpha')^2 \, H_1 H_2 H_3}$$

A FIELD THEORY ANALYSIS

Can field theory capture the process of brane recombination (or brane transmutation) and show the appearance of the magnetic field background when D5 branes disappear?

Our assumption is that the Higgs *vev* can be parameterised by a FI term in the effective Lagrangian

$$\bar{F} = -\frac{1}{\sqrt{2}}(\partial_1 \Phi_2 - \partial_2 \Phi_1)$$

$$D = -\frac{1}{2}\sum_{i=1}^{2}(\partial_i \bar{\Phi}^i + \bar{\partial}^i \Phi_i) + \xi\delta^{(4)}$$

$$\Phi_1 = A_5 + iA_4$$
$$\Phi_2 = A_7 + iA_6$$

The equations of motion read

$$\bar{\partial}^i D - \sqrt{2}\epsilon^{ij}\partial_j F = 0$$

A convenient Ansatz is

$$\Phi_1 = k_1\,\partial_1 G_4\,, \quad \Phi_2 = k_2\,\partial_2 G_4$$

where $(\partial_1\bar{\partial}^1 + \partial_2\bar{\partial}^2)G_4 = \delta^{(4)} - V_4^{-1}$

$$\bar{F} = \frac{1}{\sqrt{2}}(k_1 - k_2)\partial_1\partial_2 G_4 \,,$$

$$\bar{F} = 0 \;\Leftrightarrow\; k_1 = k_2$$

For the D-term, after plugging-in the F-term solution,

$$D = -k(\partial_1\bar{\partial}^1 + \partial_2\bar{\partial}^2)G_4 + \xi\,\delta^{(4)} = -k(\delta^{(4)} - V_4^{-1}) + \xi\,\delta^{(4)}$$

so that regularity of the solution $k = \xi$

implies indeed that a magnetic field is generated

$$D \equiv -(F_{45} + F_{67}) = \frac{\xi}{V_4}$$

What kind of non-perturbative effect is responsible for brane transmutation?

$$\tilde{F}_{\rho\sigma} = -F_{\rho\sigma} - kJ_{\rho\sigma}\Delta G_4$$

The compactness of space violates anti-self-duality. Moreover

$$\int d^4x\, F_{\rho\sigma}\tilde{F}^{\rho\sigma} = -8\pi^2 \int_0^\infty dr\, \frac{d}{dr}\left(r^2\left(G_4'(r)\right)^2\right) = +\infty$$

Born-Infled non-linearities do not regulate the singularity

Perhaps higher-derivative terms?

The transition from D5 branes to magnetic background on the D9 branes is induced by an ***Abelian configuration*** and not by the SU(2) instanton of Witten

The Abelian part of the SU(2) instanton cannot be the magnetic field

In 4d vacua D5 branes have Sp(2n) gauge groups while D9 have U(n)'s!