Dynamical Supersymmetry Breaking from Simple Quivers

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We construct a simple local model of dynamical supersymmetry breaking. The model is a one generation SU(5) that arises from a IIB ZN orientifold. It does not admit a runaway direction and is argued to stabilize the blowup mode related to the corresponding U(1) factor. The theory demonstrates the existence of a new class of “blowup” fractional branes.

INTRODUCTION

Dynamical supersymmetry breaking (DSB) [1] is an intriguing solution to the hierarchy problem. Examples of such models were first presented more than twenty years ago [2], and the idea has been extensively studied both from the theoretical and phenomenological points of view (for a review see e.g. [3]).

For string theory to make contact with reality, some mechanism to break supersymmetry must be employed. In recent years, following the understanding of flux compactifications and moduli stabilization [4, 5], the problem of breaking supersymmetry has attracted a vast amount of attention. Many models have been presented, employing various stringy mechanisms, however only very few break supersymmetry dynamically. The reason for the lack of DSB models in string theory is twofold. On the one hand, models with completely stable DSB vacua are non-generic at the field theory level. On the other hand, compactifying such models and taking care of the stabilization of all moduli and in particular Kähler moduli, is very laborious [6].

Constructions of local models were attempted on D-branes [7]. In [8, 9, 10], a classification of the gauge dynamics on fractional branes was introduced, where it was argued that the corresponding quiver theories typically break supersymmetry dynamically. However, as was stressed in [11], these brane configurations generally posses a runaway direction which corresponds to a blowup of the singular geometry. This problem can be ameliorated in compact models by stabilizing the runaway directions through some non-perturbative effects [12, 13].

Recently it was suggested that meta-stable vacua that exhibit DSB may be more generic [14]. While indeed true at the field theory level, such constructions in string theory still lack a good explanation for the origin of small mass terms which appear in most theories. There have been several attempts to realize such models in string theory, however most do not address the above issue [15, 16, 17] and cannot be compactified in a direct manner.

It is therefore worthwhile to construct new local models of DSB which are simple enough to allow for a straightforward embedding in a compact background. In this note we report on progress in this direction. Here we concentrate on a simple local construction, while the details of the compact model will be given in [18]. The local construction is a type IIB ZN orientifold. Specifically, we construct an SU(5) gauge theory with one generation of 10 + 5 [19]. After imposing the orientifold projection, only one anomalous U(1) is present. We argue that the corresponding closed string Kähler blowup mode that shows up as a Fayet-Iliopoulos (FI) term is stabilized close to the origin. As opposed to the generic quiver, this (bi-directional) quiver does not suffer from a runaway behaviour and demonstrates the existence of a new class of fractional branes which we call blowup fractional branes.

While this work was being completed, we became aware of [20] which partially overlaps with the local construction of our model.

LOCAL MODELS

As a first step towards writing a complete compact solution, one must specify a local quiver model which exhibits DSB. Here we concentrate on the non-calculable SU(5) gauge theory with one generation of 10 and 5. This model is known to break supersymmetry dynamically [19]. The construction is based on fractional branes located at fixed points of C3/ZN orientifolds. Quiver models that arise from placing D-branes at such singularities have been extensively studied. The reader is referred to [21, 22] and references therein for more details.

Formalism. We begin by setting up our notations, closely following [22]. Consider a C3/ZN singularity. The ZN generator θ acts on the three complex coordinates as θ : (z1, z2, z3) → (ωb1z1, ωb2z2, ωb3z3) where ω = e2πi/N is the Nth root of unity. To preserve N = 1 supersymmetry, the ZN must be a subgroup of SU(3) which translates into taking b1 + b2 + b3 = 0 (mod N). The action on the Chan-Paton indices is

\[ A^a \rightarrow \gamma(\theta)A^a\gamma(\theta)^{-1}, \]
\[ Z^i \rightarrow \omega^{b_i}\gamma(\theta)Z^i\gamma(\theta)^{-1}, \]

where \( \gamma(\theta) \) is a representation of \( Z_N \). Since \( Z_N \) is abelian, all its irreducible representations are one dimensional,
and without loss of generality we may take \( \gamma(\theta) \) to be

\[
\gamma(\theta) = \text{diag}(1_{n_0}, \omega 1_{n_1}, \ldots, \omega^{N-1} 1_{n_{N-1}})
\]  

(3)

where \( \sum_n n_a = n \) is the number of fractional branes. The invariant spectrum at the singularity is described by a \( U(n_0) \times U(n_1) \times \cdots \times U(n_{N-1}) \) theory with matter multiplets transforming as \((n_a, \tilde{n}_{a+b_i})\) for \( i = 1, 2, 3 \) and \( a + b_i \) is taken mod \( N \). Such a field theory can be efficiently described by a quiver diagram, where each node denotes a \( U(n) \) factor and the bi-fundamental chiral fields are represented by directed lines connecting two such nodes. A line originating and ending on the same node describes a field in the adjoint representation of the corresponding \( U(n) \) factor.

Next we would like to consider the spectrum of D-branes located on top of orientifold planes. As usual, to preserve the same supersymmetry as D3-branes, only O3- or O7-planes may be included, located on the fixed locus of the orientifold action, \( \Omega R(-1)^{F_L} \) (where \( R \) is the \( Z_2 \) geometric involution and \( (-1)^{F_L} \) is the left-handed world-sheet fermion number). In terms of the open string modes, the effect of the orientifold action is to identify each \( U(n_a) \) gauge group with \( U(n-a) \) while identifying the representation \((n_a, \tilde{n}_{a+b_i})\) with \((n_{-a-b_i}, \tilde{n}_{-a})\). In particular, the \( U(n_0) \) and \( U(N/2) \) gauge factors (if exist) are projected onto themselves, resulting in an \( Sp(SO) \) gauge group, depending on the exact orientifold action. Similarly chiral fields transforming in the \((n_a, \tilde{n}_{-a})\) are projected into the symmetric representation of \( SU(n_a) \).

Finally, the quiver diagrams must be extended to accommodate these unoriented theories. Since each end of the string can independently be in either the fundamental or the antifundamental, it must be represented as a bi-directed line with an arrow at each of the two ends, indicating the representation of the string under each of the two gauge group factors. In such a bidirected quiver (biquiver for short), a symmetric or an antisymmetric field is represented by a line with both ends coming out of the same set of branes.

**DSB Quivers.** It is now a simple matter to construct the desired \( SU(5) \) model. As an example, consider a \( Z_6 \) orientifold with the orbifold action \((b_1, b_2, b_3) = (1, 2, -3)\) and orientifold \( R = (-1, -1, -1) \). Furthermore, we take the action on the Chan-Paton indices to be,

\[
\text{diag}(1, \omega^2 1_5, \omega^4 1_5), \quad \omega = e^{i\pi/3},
\]  

(4)

so altogether we have eleven fractional branes. There is a single orbifold fixed point and an O3-plane at the origin. The biquiver is shown in Fig. 1. As required, the theory is \( SO(1) \times U(5) \) with one generation of 10 + \( \bar{5} \). The \( U(1) \) corresponding to the \( SU(5) \) is anomalous and becomes massive through the generalized Green-Schwarz mechanism \([23, 25]\). Hence it remains as a global symmetry and has no effect on the low-energy dynamics.

It is also possible to construct this biquiver on other singularities, as we (non-exhaustively) list in table I.

**Blowup Fractional Branes.** Such DSB biquivers exhibit a new class of fractional brane models. In [8] fractional branes were classified as follows:

1. \( N=2 \) fractional branes: These exhibit flat directions along which the dynamics are those of \( N = 2 \). They typically arise at non-isolated \( \mathbb{C}^2/Z_N \) singularities.

2. Deformation fractional branes: The theory exhibits confining dynamics which translates into (partial) complex structure deformation of the geometry.

3. Runaway (DSB) fractional branes: This is the generic case. In general, the gauge factors have different ranks and the dynamics lead to a runaway behaviour through a non-perturbative superpotential.

It is clear that the DSB biquiver described above does not fit into any of the above classes but instead demonstrates the existence of a new class of fractional branes:

4. Blowup fractional branes: These are fractional branes which do not have flat or runaway directions and are associated with the stabilization of Kähler moduli, corresponding to the possible (partial) blowup of the singularity. In accordance with the classification above we expect blowup fractional branes to be related to unoriented singularities.

In our example the singularity indeed blows up, as we now explain. Ignoring for the moment the non-perturbative dynamics, the \( SU(5) \) model has a classical supersymmetric minimum at the origin of field space. Turning on a FI term \( \xi^2 \) for the corresponding \( U(1) \),

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\(^1\) We thank Angel Uranga for drawing our attention to this point.
breaks supersymmetry due to the incompatibility between the $SU(5)$ and $U(1)$ D-terms. At large $\xi^2$ where the classical theory is reliable, a potential

$$V \sim |\xi|^4$$

is generated, driving the dynamical FI field to zero. Taking the non-perturbative effects into account, one cannot determine the exact location of the minimum, and on dimensional grounds we expect $\xi^2$ to stabilize near the origin at $\xi^2 \sim \Lambda^2_{\text{pl}}$. Such stabilization corresponds to blowing up a 2-cycle in the geometry.

This is in contrast to the case of the runaway class, for which the D-term of a massive anomalous $U(1)$ is necessary in order to stabilize a classical flat direction that becomes unstable quantum mechanically. However, as was already noted in [8] and stressed in [11], such D-term equations should not be imposed, as the massive $U(1)$ is not exhibited at low energy. Imposing the massive D-terms comes at the expense of introducing a new runaway direction of a blowup mode which appears as a FI term. For the model at hand, the field theory does not have a runaway direction and this, in turn, translates into having a stabilized Kähler modulus.

For the specific $SU(5)$ local model, one encounters at the field theory level a single FI blowup mode. In order to embed this quiver in a compact model (away from the decoupling limit), one must worry about other Kähler moduli which must be stabilized without changing the theory at the singularity. There are two mechanisms: First, for the specific $\mathbb{Z}_6$ orbifold, the local geometry consists of four exceptional divisors (arising from one fixed-point and two fixed-curves) out of which only one is compact. Thus, out of the four twisted Kähler moduli, one is stabilized as seen through the gauge dynamics, while the others may be stabilized away from the orbifold fixed-point without affecting the quiver. Second, it is not at all clear which (if any) of the Kähler moduli remain after the orientifold projection. It is possibly misleading to understand the geometry by first resolving the singularity and then orientifolding. Still, the analysis of [20] suggests that at least some of these moduli might be projected out. More details of the Kähler stabilization will appear in [18].

Finally, let us remark that at this stage it is still not clear how generic the blowup class is or whether examples exist where the Kähler moduli are stabilized exactly at the origin, corresponding to the orbifold limit. Furthermore, it would be very interesting to understand whether such quivers exhibit a large-$N$ limit with DSB and Kähler stabilization at the bottom of a duality cascade. We postpone the investigation of this question to future work.

In this letter, a novel realization of the one generation $SU(5)$ DSB model in string theory was introduced. The model arises in a simple type IIB $\mathbb{Z}_N$ orientifold with fractional branes at the singular locus. The corresponding biquiver model is easily extracted from the geometry. At the field theory level the model has no flat directions, which translates into a stabilization of the Kähler modulus. The latter appears as a dynamical FI term related to the anomalous $U(1)$. The dynamics are therefore in a new class of fractional branes, which (partially) blow up the geometry.

Such models are very simple and are generated from singularities that appear generically on the moduli space of Calabi-Yau manifolds. Therefore it should be easy to construct a compactify version of our construction embedding it in a CY 3-fold. It will be interesting to further study such constructions as they will allow for complex-structure moduli stabilization by turning on fluxes. Such a setup is a step forward in constructing realistic models of particle physics and may allow one to address issues of DSB in the landscape.

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SUMMARY

$SU(5)$ DSB model in string theory was introduced. The model arises in a simple type IIB $\mathbb{Z}_N$ orientifold with fractional branes at the singular locus. The corresponding biquiver model is easily extracted from the geometry. At the field theory level the model has no flat directions, which translates into a stabilization of the Kähler modulus. The latter appears as a dynamical FI term related to the anomalous $U(1)$. The dynamics are therefore in a new class of fractional branes, which (partially) blow up the geometry.
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