Dynamical Supersymmetry breaking

from D-branes at singularities

– Why, Where and How –

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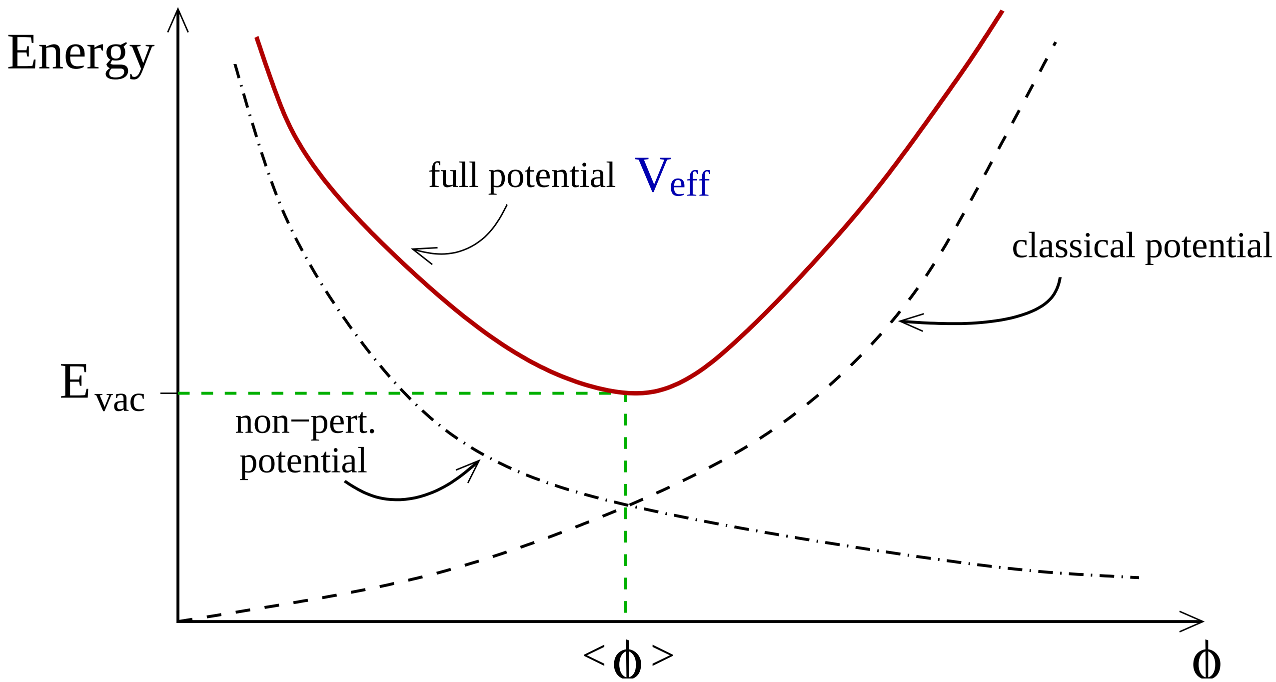
(and some previous works with Francesco Bigazzi and Aldo Cotrone)

Why?

Dynamical SUSY breaking (DSB) is an elegant mechanism for breaking SUSY.

$$M_s \sim \Lambda \sim M_x \exp\left(-\frac{8\pi^2}{g^2(M_x)}\right) << M_x$$



$$V_{\text{eff}} = \left[\frac{\partial^2 K_{\text{eff}}\left(\phi, \bar{\phi}\right)}{\partial\phi\, \partial\bar{\phi}}\right]^{-1} \left|\frac{\partial W_{\text{eff}}(\phi)}{\partial\phi}\right|^2$$

Since middle 80's/early 90's, we have several (field theory) tools to understand the low energy, strongly coupled dynamics of supersymmetric gauge theories.

These are powerful to get information about *holomorphic* quantities (i.e. F-terms), like the number of isolated vacua or the quantum moduli space of vacua, the existence of necessary conditions for supersymmetry breaking, ... Difficult to get quantitative information about low-energy physics around these vacua, like the spectrum and the interactions (i.e. D-terms, Kähler potential).

This is why the gauge/string duality is interesting to us: in principle, this approach gives full access to D-terms and can provide quantitative information on gauge theory IR dynamics. Today I will report on some recent progress on how to embed DSB in D-brane/string theory models.

Note: having well-defined settings where to embed dynamical supersymmetry breaking into string models is of extreme interest both in the context of the gauge/string duality as well as in string compactifications.

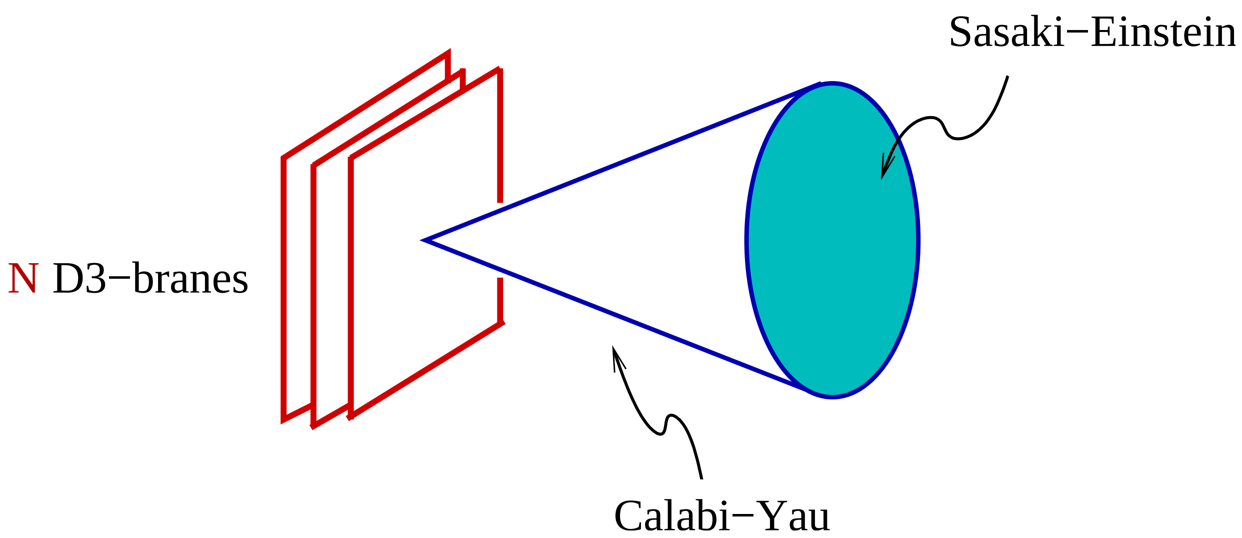
Where?

The AdS/CFT correspondence is an equivalence between a string theory in 10d and a superconformal field theory in 4d

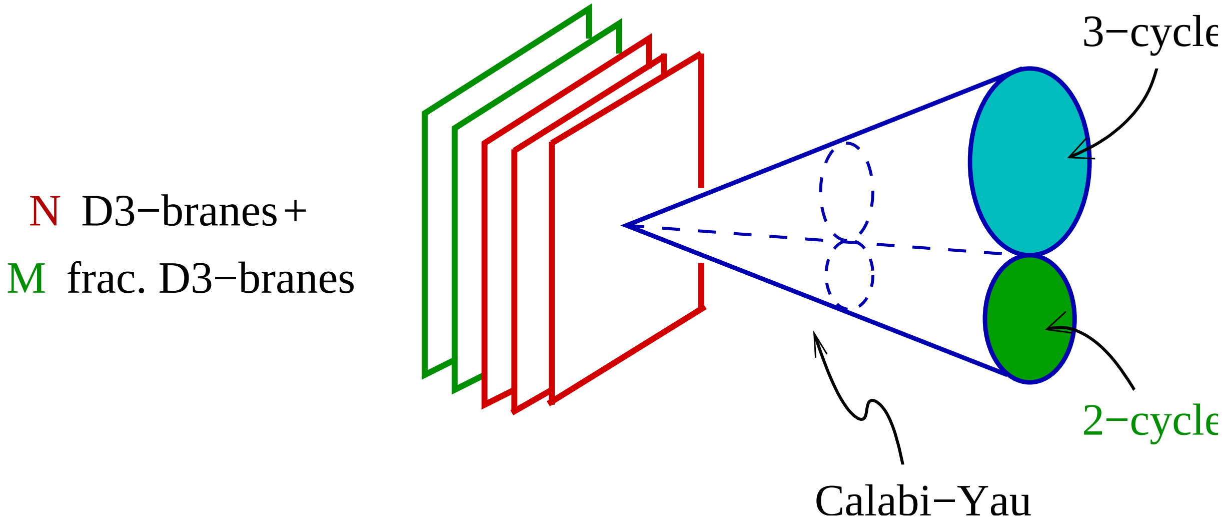
Type IIB string theory on $AdS_5 \times X^5$ + F_5—flux $\Longleftrightarrow$ $\mathcal{N}=1$ 4-dimensional SCFT

X^5 is a Sasaki-Einstein manifold, i.e. the cone over X^5 is a Calabi-Yau manifold

$$ds^2 = dr^2 + r^2 ds^2(X^5)$$



If X^5 has non-trivial topology possible to add fractional branes, which are higher dimensional branes wrapped on non-trivial cycles of the internal manifold



They have the properties of *breaking* conformal invariance $\longrightarrow$ move towards more realistic (*i.e.* QCD-like) theories.

Note: for $\mathcal{N} = 1$ dualities, fractional branes generically trigger duality cascades. At the *bottom* of the cascade (deep IR) the theory looks as if regular branes have disappeared and only fractional branes have survived $\longrightarrow$ *the IR dynamics of the theory is determined by the fractional branes*.

There exist three different classes of fractional branes, according to the low energy IR dynamics they trigger:

1. $\mathcal{N} = 2$ fractional branes: give rise to SW-like dynamics. The singularity at the tip is not isolated, there is a curve singularity.

2. deformation fractional branes: give rise to supersymmetric (confining) vacua. Geometrically they induce a complex structure deformation of the CY cone.

3. supersymmetry breaking fractional branes: give rise to ADS superpotential and may induce either *dynamical supersymmetry breaking* (DSB) to a stable non-susy vacuum, or a *runaway behaviour*.

$\longrightarrow$ Supersymmetry breaking (SB) branes are interesting objects to look at!

The nice thing is that SB branes are generically present in string models... the most frequent type of fractional branes to arise, in fact!

The bad thing is that SB branes of known models induce runaway and not DSB... It is difficult not to have flat directions in string theory!

Question:

Is it possible to (minimally) *deform* these theories in some way so to stabilize the otherwise runaway direction and get stable non-susy vacua?

Answer:

Yes... and a specific pattern seems to emerge.

How?

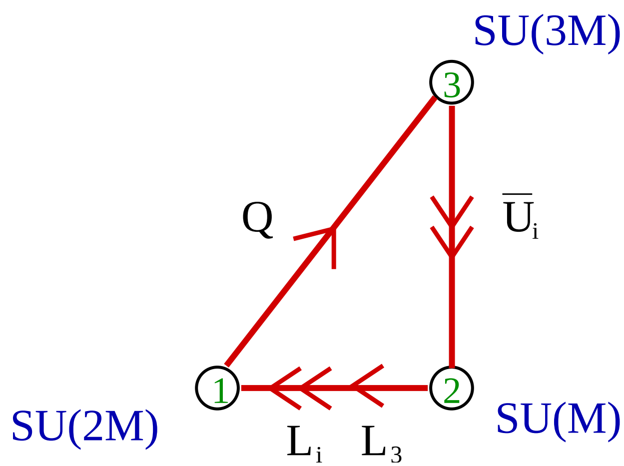
We focus on some explicit examples: branes at the complex CY cone over del Pezzo surfaces, $\mathbf{dP_k}$.

The super-conformal dual gauge theories are known, as well as the type of fractional branes one can add to break conformal invariance.

One can show that adding fractional branes a duality cascade always occurs: we will always focus on the dynamics at the bottom of the cascade, where only fractional branes are present.

Important to us: all del Pezzo's admit SB fractional branes.

The $\mathbf{dP_1}$ theory admits only one type of fractional branes, which are SB branes. The theory for M of them is as follows



with $W_{tree} = Q\, \bar{U}_i L_j\, \varepsilon^{ij}$ i,j=1,2

F-flatness conditions set all invariants involving Q and $\bar{U}_i$ to zero, but there are several *baryonic* flat directions

$$\mathcal{B}_{i_1 \ldots i_k} = \epsilon_{2M} \epsilon_M \epsilon_M (L_i)^{2M-k} (L_3)^k \equiv \mathcal{B}_{[k]} \qquad \text{with} \qquad k = 0, \ldots, M$$

Non-perturbative dynamics (for node 3 we have $N_F < N_C$) makes $\mathcal{B}_{[0]}$ a runaway direction.

Can we deform the theory so to lift all classical flat directions and get true DSB?

For $M = 1$ one can define the following deformed superpotential

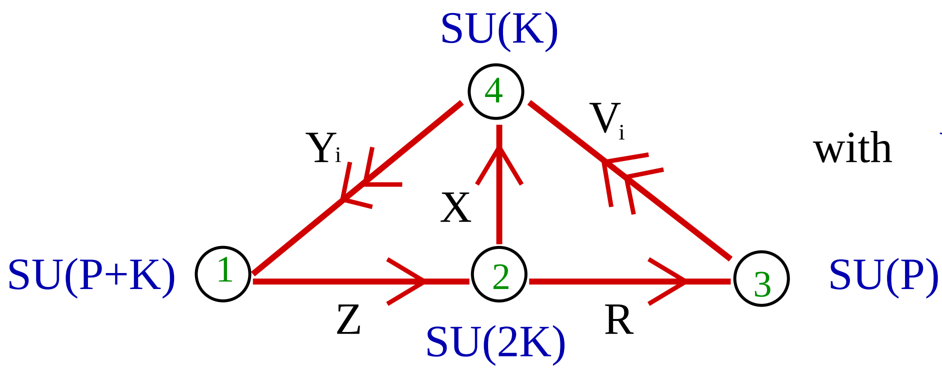
$$W_{\rm def} = W_{\rm tree} + \alpha \mathcal{B}_1 = Q\,\bar{U}_i L_j\,\epsilon^{ij} + \alpha L_1 L_3$$

After integrating out massive fields, this reduces exactly to the well known 3-2 model, which has no classical flat directions and does display DSB into a stable non-susy vacuum!

$\star$ Surprising (?) result: for $M > 1$ one gets instead either susy vacua or (still) runaway. No way of stabilizing the runaway direction!

Main lesson: *only* for $M = 1$ it is possible to cure the runaway and get a stable non-susy vacuum $\rightarrow$ problems for a possible supergravity *dual* description.

The $\mathbf{dP_2}$ theory admits *two* types of fractional branes (SB and deformation)



For generic values of P and K the theory is runaway and cannot be cured. A unique possibility is singled out: P generic and $K = 1$.

The moduli space has dimension 3 and is described by the invariants

$$d_i = X^\alpha R^\beta_m V^m_i \epsilon_{\alpha\beta} \quad , \quad e = R^\alpha_m R^\beta_n V^m_i V^n_j \epsilon_{\alpha\beta} \epsilon^{ij}$$

At a generic point in the moduli space the theory is broken to SU(P+1)×SU(P-2) and non-perturbative dynamics shows that it is runaway both in d_1 and e.

Note: in terms of matter content and gauge structure this model is essentially the same as two copies of the SU(N)-SU(2) model, sharing the same SU(2) node.

Can we cure the runaway? Also in this case one can add a simple deformation which does the job

$$W_{\rm def} = -Y_1 Z X + Y_2 Z R V_1 + X R V_2$$

This lifts all classical flat directions and effectively reduces the theory to a (double) SU(N)-SU(2) model. The F-flatness conditions derived from the full effective superpotential are *not* satisfied anymore, even at infinite field VEV's, leading to a stable non-susy vacuum.

Note: this might be amenable to a probe analysis in a weakly curved dual supergravity background, since P may be taken to be large.

$\star$ What happens for higher del Pezzo's? The theories look more complicated but it turns out the only possibility for a DSB deformation is reducing (and this is always possible!) to the same IR theory working for $\mathbf{dP_2}$ $\rightarrow$ a *unifying picture* seems to emerge.

Conclusions ...

First message: ADS-like superpotentials are naturally generated in string theory, when considering (fractional) D-branes at singularities. Conventional fractional brane configurations, however, always induce a runaway behavior.

Second message: in some cases, it is possible to get true DSB in a stable vacuum by adding suitable operators (either quadratic or cubic) to the superpotential.

Third message: except for $\mathbf{dP_1}$, one could treat the SB branes in the probe approximation in a well-behaved, weakly curved KS-like background and a specific model seems to emerge. This is a slightly modified version of the SU(N)-SU(2) model.

... and open questions

⋆ What is the interpretation of the deformation terms up in the cascade, i.e. their origin, where a large (effective) number of regular branes is present?

⋆ What is the nature of low energy spectrum and its supergravity dual description? The goldstino should *not* correspond to a bulk mode, but to a mode in the probe brane-world theory. Other massless modes, as Goldstone modes, should still be bulk modes (together with their supersymmetric partners, in the probe approximation).

⋆ How to generate the deformation terms in the superpotential? These should come considering wrapped Euclidean D-branes. The corresponding massless strings stretching between the latter and quiver D-branes provide a coupling to quiver fields, which after integration over collective coordinates of the instanton, generates an effective (weighted) field theory operator

$$\Delta W \sim \mathcal{F}(X_i)\, Exp(-V)$$