



**The Abdus Salam
International Centre for Theoretical Physics**



1935-9

Spring School on Superstring Theory and Related Topics

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Stringy Avatars of Dynamical SUSY Breaking - Lecture 1

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Trieste '08, Lecture I

SUSY relevant @ weak scale \Rightarrow

$$\Lambda_{\text{SUSY}} \lesssim 10^{11} \text{ GeV} \ll M_{\text{Pl}}$$

How does this come about?

1d $N=1$ SUSY $L_{\text{eff}} \rightarrow$ at 2 derivative [v]

$$L = \int d^4\theta \, d^4x \, k(\bar{\Phi}^+, \bar{\Phi}) +$$

$$\int d^2\theta \, d^4x \, W(\bar{\Phi}) + \text{c.c.}$$

$$+ \int d^2\theta \, d^4x \, f(\bar{\Phi}) W_\alpha W^\alpha + \text{c.c.}$$

$$\bar{\Phi} = \phi + \theta^\alpha \psi_\alpha + \theta\bar{\theta} F$$

$$W_\alpha = \lambda_\alpha + \dots$$

$f \rightarrow \frac{1}{g^2}$ of gauge group

1d Idea: (Witten '81)

$$W = W_{\text{tree}} + O(e^{-1/g^2})$$

by non-renormalization theorems

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$$\frac{\partial^2 k}{\partial \phi^i \partial \phi^j}$$

$$V(\Phi, \bar{\Phi}) = \sum g^{i\bar{j}} \frac{\partial W}{\partial \phi^i} \frac{\partial \bar{W}}{\partial \bar{\phi}^j} + (\text{D-term})$$

\Rightarrow - SUSY unbroken if $dW = 0$

- SUSY if $F_i \neq 0$ for any ϕ_i

$$(F_i \sim \frac{\partial W}{\partial \phi_i})$$

So suppose W_{tree} admits only SUSY vacua

but \bullet the $O(e^{-1/g^2})$ effects \rightarrow SUSY

Then expect $F \sim e^{-1/g^2} \Rightarrow$ SUSY is

naturally at a scale $\ll M_P$.

Historical evolution of subject:

Simple models of classical breaking

(Polonyi, Fayet, ...) \Rightarrow Models w/ intricate

gauge dynamics in non-Abelian hidden sector

(Affleck, Dine, Seiberg; ...) to implement DSB

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Here, we ask:

Are there natural, simple ways to get DSB in string theory which aren't same as geometrically engineering field theoretic DSB models? (No non-Abelian gauge dynamics.)

OUTLINE:

I. Simple classical models

II. Stringy Instantons (hep-th [0708.0493])
w/ Bhattacharyya + Silverstein

II - Geometric transitions & fluxes:

summing the instantons (hep-th [0709.4277])
w/ Aganagic + Be

I. Classical SUSY models

Here, we write down IR free QFTs that break SUSY.

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A. Polonyi Model

(Consider the theory of a single chiral)

superfield X .

$$K = X^+ X$$

$$W = M^2 X$$

$$F_X = M^2 \Rightarrow \text{SUSY}$$

$$V = |F_X|^2 = M^4 \Rightarrow \exists \text{ classical moduli}$$

space of SUSY vacua

Note: $M_X = 0, M_{\psi_X} = 0$ (it's the Goldstino)

\rightarrow SUSY w/o mass splittings here ...

The (pseudo) moduli-space is very suspicious in a non-SUSY theory; expect any higher corrections to lift it. Examples:

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$$\Delta W = \epsilon x^n$$

$$W = M^2 X + \epsilon x^n$$

$$\frac{\partial W}{\partial X} = M^2 + n \epsilon x^{n-1} = 0 \quad \left. \begin{array}{l} \\ \end{array} \right\} \begin{array}{l} n-1 \\ \text{SWY vacuum} \end{array}$$

$$\Delta K = \frac{c}{M^2} (X^+ X)^2$$

think of M as scale
where massive fields were integrated out

$$W = M^2 X$$

$$K = X^+ X + \frac{c}{M^2} (X^+ X)^2$$

$$\Rightarrow g_{X\bar{X}} = 1 + 4 \frac{c}{M^2} |X|^2$$

So at small $|X|$

$$\begin{aligned} V &= g_{X\bar{X}} \frac{\partial X}{\partial \bar{X}} W \frac{\partial \bar{X}}{\partial \bar{X}} \\ &\sim \left(1 - \frac{4c}{M^2} |X|^2 \right) \times M^4 \end{aligned}$$

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- For $c > 0$, roll off to large $X \not\models$ must re-expand theory
- For $c < 0$, \exists stable SUSY vacuum at $X = 0$

$$M_x^2 \sim -c \cdot \frac{\mu^4}{M^2}$$

Ψ_x still Goldstone $\Rightarrow \exists$ mass splitting now ✓

NOTE: In QFT, can set $M^2 \ll M_p^2$ by hand and it is "technically natural." Of course in the IR free theory, tiny μ^2 is NOT generated dynamically.

B. Fayet model

Now, consider a simple IR free gauge theory

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$$G = U(1)$$

Charged matter: ϕ_+, ϕ_-

$$W = m \phi_+ \phi_-$$

\exists also possibility of Fayet - Iliopoulos D-term

$$\int d^4x \quad r \quad D_{U(1)} \quad \left. \right\} \quad \begin{array}{l} \text{gauge not only} \\ \text{for } G = U(1) \end{array}$$

\Rightarrow with

k = (canonical) one

$$V = |m\phi_+|^2 + |m\phi_-|^2 + e^2 (|\phi_+|^2 - |\phi_-|^2 - r)^2$$

$$\left. \begin{array}{l} \text{SUSY eqns: } \quad m\phi_+ = 0 \\ \quad m\phi_- = 0 \\ \quad |\phi_+|^2 - |\phi_-|^2 = r \end{array} \right\} \quad \begin{array}{l} r \neq 0 \Rightarrow \\ \text{cannot be} \\ \text{satisfied} \end{array}$$

E.g. for r large ($r \gg \frac{m^2}{e^2}$), the vacuum is at

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$$|\phi_+|^2 = r - \frac{m^2}{2e^2} \simeq r, \quad \phi_- = 0$$

+ dominant SUSY is from $F_{\phi_-} \simeq m\sqrt{r}$.

NOTES:

1) Coupling of FI terms to SUGRA & string

theory is subtle (anomalies aside, "r" is dynamical?) etc.).

2) Consider limit $r \rightarrow \infty$ with

$$m\sqrt{r} = M^2 \quad \underline{\text{fixed}}$$

Renaming $X = \phi_-$, we have

$$\langle \phi_+ \rangle \simeq \sqrt{r} \Rightarrow$$

$$W = M^2 X$$

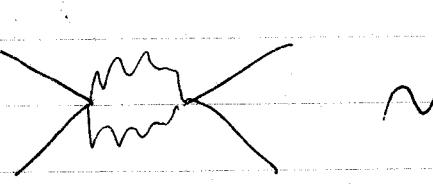
$U(\phi)$ very massive, ϕ_+ saturates D-term

\Rightarrow this is Polonyi model, w/ stable minimum

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In fact, we can relate the stability here to our discussion of ΔK in Polonyi case.

- Integrate out massive $U(1)$ gauge mult.



$$\sim \frac{g_{U(1)}^2}{M_{U(1)}^2} (x^+ x)^2$$

- $U(1)$ mass is $M_{U(1)} \sim g_{U(1)} \sqrt{r} \Rightarrow$

$$\boxed{\Delta K \simeq -\frac{1}{r} (x^+ x)^2}$$

In our earlier notation, $C = -\frac{1}{r} < 0$ + 3 stable vacuum ✓.

Like Polonyi, can eg set $M \ll M_p$ to get low SUSY scale, but no DSB in this IR free theory -- dynamics doesn't explain small M .

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C. susy by rank condition

Consider a theory with $SU(N) \times SU(M)$ global

symmetry, with fields:

$Q (N, M)$

$\tilde{Q} (\bar{N}, \bar{M})$

$\Phi (1, M^2)$

$$\text{Say } W = \mu^2 \text{Tr } \Phi - \text{Tr } \tilde{Q} \Phi Q$$

Computing $F_\Phi \Rightarrow$

* 1st term has rank M contribution

* 2nd term has rank N , at most

So if $N < M$, $F_\Phi \neq 0 \Rightarrow$ susy.

Much more care is required to see if 3 stab.

susy vacuum [Coleman-Weinberg analysis];

c.f. ISS paper. susy is at low scale

for small μ^2 ; again, need to explain.

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II Stringy Instantons & DSB

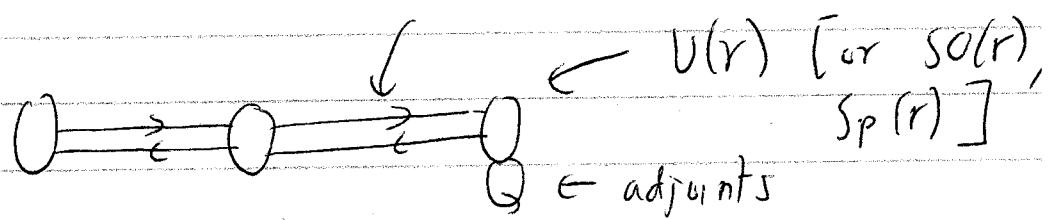
A. Basic Idea

D-branes at singularities in (non-compact)

CY manifolds \rightarrow 4d $N=1$ quiver gauge

theories.
bi-fundamentals

c.f. Douglas/
Moore



• Get SO or Sp if the given quiver "node" \cap

an orientifold plane.

Rough intuition: Each node \rightarrow collapsed cycle

in the geometry; D-branes wrapping that
cycle + filling $\mathbb{R}^4 \rightarrow$ gauge group.

The quiver:

$$\begin{array}{c} (2) \xrightarrow{\quad} (3) \\ r_2=1 \qquad r_3=1 \end{array} \Rightarrow \begin{array}{c} U(1) \times U(1) \\ + - \\ - + \end{array}$$

(2)

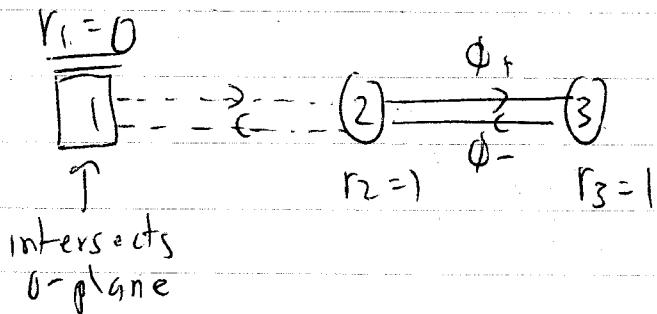
\Rightarrow a decoupled $U(1)$ + a $U(1)$ w/ chiral s

$$\phi \pm$$

This is the Fayet model.

- At quiver pt $m = 0$
- FI term $r \longleftrightarrow$ (non-normalizable mode of) closed strings

Now, imagine a slightly larger quiver



$r_1 = 0$ -- so no change to theory, right?

WRONG.

Can still consider (t must) D-instantons
wrapping node 1.

(2) (3)

Suppose we're in IIB theory, $I \hookrightarrow$ collapsed curve C . Then:

- If there was a stack of D5s on C ,

the coupling $\int_{D5} C_2 \wedge F \wedge F = D$

Euclidean D1 on C = gauge instanton

in D5 stack

- But no D5s on $C \rightarrow$ the Euclidean D1 is NOT a gauge theory effect in the low-energy theory; "stringy" effect.

Next time: We give simple examples where stringy instantons induce "DSB" in IR for simple theories. No non-Abelian gauge dynamics!