D3-brane model building and the supertrace rule

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String Phenomenology

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Work with I. Bena, M. Graña, S. Kuperstein and M. Petrini

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Outline

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Motivation

Open string excitations on a stack of N $D3$-branes (at a regular point of M_{int}):

$\Longrightarrow$Effective field theory of massless modes

- (1/2) of supersymmetry preserved
- gauge group $U(N)$
- matter content:
  - 4 fermions in the adjoint of $U(N)$
  - 6 scalars in the adjoint of $U(N)$

$\Longrightarrow \quad \mathcal{N} = 4$ super Yang-Mills (SYM)

$\rightarrow$Place $D3$-branes at singularities of $\mathbb{C}^3/\mathbb{Z}_p$

$\Longrightarrow \quad U(N) \rightarrow U(pN) \xrightarrow{\text{split}}$ subgroups (quiver diagrams):*

- SM- or GUT-like gauge groups
- matter fields in bi-fundamental reps.

$\rightarrow$Fluxes on $M_{\text{int}} \Longrightarrow$

- susy-preserving masses
- susy-breaking terms (softly)†

Explicit susy-breaking $\stackrel{?}{\rightarrow}$ avoid very light susy particles

*Douglas, Moore '96

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→ Deform it:

- $\mathcal{N} = 4 \longrightarrow \mathcal{N} = 1: \quad \delta W = (1/2)m_{ij}\Phi^i\Phi^j$
- $\mathcal{N} = 1 \xrightarrow{\text{softly}} \mathcal{N} = 0: \quad \delta\mathcal{L} = \mathcal{L}_{\text{soft}}(m^2_{\text{soft}}, b_{ij}, \hat{m}_i, \tilde{m}, c^k_{ij}, a_{ijk})$

$$\mathcal{L}_{\text{susy}} + \mathcal{L}_{\text{soft}} = -(mm^\dagger)_i^j\phi^i\bar{\phi}_j - \left(\frac{1}{2}m_{ij}\psi^i\psi^j + h.c\right)$$
$$-(m^2_{\text{soft}})_i^j\phi^i\bar{\phi}_j - \left(\frac{1}{2}b_{ij}\phi^i\phi^j + \hat{m}_i\psi^i\lambda + \frac{1}{2}\tilde{m}\lambda\lambda + h.c.\right)$$
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→Good UV behaviour (absence of quadratic divergences)

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$\rightarrow$Good UV behaviour (absence of quadratic divergences)

→ Descends from $\mathcal{N} = 4$ SYM $\Longrightarrow$ memory of $SU(4)$ R-symmetry

Fermions:

$$M^{\text{ferm}}_{IJ} = \begin{pmatrix} m_{ij} & \hat{m}_i \\ \hat{m}_i^T & \tilde{m} \end{pmatrix} \quad \text{in} \quad \mathbf{10} = \mathbf{6} + \mathbf{3} + \mathbf{1} \quad \text{of} \quad SU(4)_R \supset \underbrace{SU(3)}_{\text{Comp.Str.}} \times U(1)_R$$

→ But $SU(4) \cong SO(6)/\mathbb{Z}_2 \quad \Longrightarrow \quad$ **10** encoded in T_3 with $\star T_3 = -iT_3$

$$m_{ij} = \tfrac{1}{2} T_{i\,\overline{kl}} \epsilon^{\overline{kl}}{}_j \quad \to \quad \text{(1,2) primitive} \quad 6$$

$$\hat{m}_i = -\tfrac{i}{2} T_{ij\bar{k}} J^{j\bar{k}} \quad \to \quad \text{(2,1) non-prim.} \quad \mathbf{3}$$

$$\tilde{m} = \tfrac{1}{6} T_{ijk} \epsilon^{ijk} \quad \to \quad \text{(3,0)} \quad \mathbf{1}$$

Bosons:

$$(M^2)^{\text{bos}}_{AB} = \left\{ \begin{array}{c} (mm^\dagger + m^2_{\text{soft}})_{i\bar{j}} \\ \text{Tr}(mm^\dagger + m^2_{\text{soft}}) \\ b_{ij} \\ \bar{b}_{\bar{i}\bar{j}} \end{array} \right\} \quad \text{in} \quad \mathbf{21} = (\mathbf{8} + \mathbf{1})_{+\text{soft}} + \mathbf{6} + \bar{\mathbf{6}}$$

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Fermion masses and boson trilinear couplings

IIB sugra background:

→Metric: $ds_{10}^2 = e^{2\alpha(y)} \underbrace{ds_4^2(x)}_{D3-\text{brane}} + \underbrace{ds_6^2(y)}_{M_{\text{int}}} \leftarrow SO(6)$

→5-form flux: $F_5 = (1 + *_{10})\, d\mathcal{C}(y) \wedge \text{vol}_4$

→3-form flux: $G_3 = F_3 - ie^{-\phi}H_3 \quad \longrightarrow \quad T_3 = e^{4\alpha}(\star_6 G_3 - iG_3)$

$\Longrightarrow$ T_3 position independent!*

T_3 couplings to D-brane bosons and fermions determine

- Boson trilinear couplings†: $T_{ij\bar{k}} = c^k{}_{ij}$ and $T_{ijk} = a_{ijk}$
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Boson masses

→ Probe D3-brane in equilibrium at y^0 with potential:

$$V = V_0 + 0 + \frac{1}{2}(\partial^2_{AB}V)(\delta y)^A(\delta y)^B + \dots$$
$$\sim \frac{1}{2}(M^2)^{\text{bos}}_{AB} \ \phi^A \ \ \phi^B$$

with $\quad V = e^{4\alpha} - \mathcal{C}$

→ Recall: $\quad M^2_{\text{bos}} \in \mathbf{20} + \mathbf{1}$

- The **20** is determined by the geometry near the brane, but..
- The trace is fixed by equations of motion*: $\quad \mathrm{Tr}(M^2_{\text{bos}}) \propto |T_3|^2$

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The supertrace rule

Collecting the results:

- $|T_3|^2 = \mathrm{Tr}(mm^\dagger + m^2_{\text{soft}}) = \mathrm{Tr}(M^2_{\text{bos}})$
- $|T_3|^2 = \mathrm{Tr}(mm^\dagger + 2\,\hat{m}_i\bar{\hat{m}}^i + \tilde{m}^2) = \mathrm{Tr}(M_{\text{ferm}}M^\dagger_{\text{ferm}})$

$\Longrightarrow$

$$\mathrm{Tr}[\text{boson masses}^2] = \mathrm{Tr}[\text{fermion masses}^2]$$

$\longrightarrow$ Soft-susy-breaking terms cannot avoid the supertrace rule

Quantum corrections

→Beta-functions for all couplings of $\mathcal{L}_{\text{susy}} + \mathcal{L}_{\text{soft}} \quad \longrightarrow \quad \beta_i(\text{susy}; \text{soft})^*$

→In general (arbitrary couplings): $\beta_i \neq 0$ but..

→For theories on D3-branes (sugra constraints): $\beta_i = 0$ at 1 and 2 loops

(checked also on orbifold singularities ($\mathbb{C}^3/\mathbb{Z}_2$,$\mathbb{C}^3/\mathbb{Z}_3$)

In particular this means:

$\Longrightarrow \text{Tr}(M^2_{\text{bos}}) = \text{Tr}(M^2_{\text{ferm}})$ up to two loops

$\text{Tr}(M^2_{\text{ferm}})$ does not run (dual to constant T_3):

⇝Expect $\text{Tr}(M^2_{\text{bos}})$ not to run as well

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Summary

- D3-branes carry on their world-volume susy gauge theories
- Fluxes induce terms that break susy softly
- Explicitly breaking susy seems to avoid light superpartners

- However, string theory eom require $\mathrm{Tr}(M^2_{\mathrm{bos}}) = \mathrm{Tr}(M^2_{\mathrm{ferm}})$
- D3-brane model building problematic for phenomenology

Thank you for your attention!