FIVE-BRANE CONFIGURATIONS, CFT's and the STRONG-COUPLING PROBLEM

Marios Petropoulos   KOΛYMBAPION 2003

(with C. Bachas, A. Fotopoulos, D. Israël, E. Kiritsis, C. Kounnas, S. Ribault, I. Rizos)

1. General context

- string theory ∋ gauge interactions & gravity

↳ tradition → string phenomenology → SM and beyond

→ string gravity → search for backgrounds

string cosmology ← time-dependent ↵

quantum effects, singularities, bh ← short-distance behaviour ↵

- Branes → new landscape of interests

Fundamental objects : F1 NS5 DP

→ • conceptual achievement • → understand the string spectrum beyond perturbation theory

• → unify the string vacua (dualities), introduce M-theory ∋ M2 & M5

→ • merging of phenomenology and gravity motivations and methods

branes act like "impurities"

⇓

alter the string spectrum ← → modify the background

Use exact CFT approaches (orbifold, fermionic, ...) → SM

find $O(\alpha')$ σ-models and interpret them geometrically → GRAVITY

↘ ↙

Find brane configurations, their spectrum, their geometry and CFT interpretation

concrete and celebrated example: the Randall - Sundrum scenari

→ • other drawback: DECOUPLING LIMITS ≠ low-energy

• string spectrum is highly constrained (GSO, modular invariance, ...) and contains gravity and gauge interactions in an intricate way

• much like orbifold fixed points, branes carry part of the spectrum i.e. one among many sectors, all necessary (see exact CFT's)

however . . .

. . . there are limits where

- the spectrum is dominated by excitations leaving on the brane, not described by QFT
- gravitational sector decouples
- holography is at work

. . . occuring in regions of space-time where g_{string} diverges!

- **motivation:** illustrate these issues in the celebrated example of **5-branes** and show how to overcome the strong-coupling problem within exact CFT framework.

2. The 5-brane solutions in type II [the original CHS 91]

- $$S^{\text{Low-energy}}_{\text{II}\ \text{10-dim}} = \frac{1}{2\kappa_{10}^2}\int d^{10}x\,\sqrt{-g^{(10)}}\left(R^{(10)} - \frac{1}{2}(\partial\phi_\gamma)^2 - \frac{1}{12}e^{-\gamma\phi_\gamma}H^2\right)$$

→ $H = dB$ $\quad \gamma = 1$ NS-NS ; $\gamma = -1$ R-R (IIB)

→ string coupling $\quad g_s = \exp\phi_\gamma$

- $\beta = 0$ $[O(\alpha')]$ → five-brane type of solutions:

$$\frac{ds^2}{\alpha'} = h(r)^{-1/4}\underbrace{\left(-dt^2 + d\vec{x}^2\right)}_{5+1} + h(r)^{3/4}\underbrace{\left(dr^2 + r^2 d\Omega_3^2\right)}_{4}$$

world volume ∥ — 6+1 - Poincaré

transverse ⊥ — SO(4)

→ $H = -r^3 h' \times$ volume form of S^3

→ $\phi_\gamma = \frac{\gamma}{2} \log h$

$\Box_{(4)} h = 0$

Q_5 5-branes at $r=0$ ← $h = h_0 + Q_5/r^2$

$\frac{1}{2}$ SUSY

generic h_0, Q_5: $r \to \infty$ / $r \to 0$

* if $Q_5 = 0$ flat space exact CFT (trivial)

* if $h_0 = 0$ { 6+1 flat space ⊕ S^3 rad $= \sqrt{Q_5}$; linear dilaton in one direction }

($\gamma=1$) EXACT CFT

↳ $\mathcal{N}=4$ superconformal: $SU(2)_{Q_5-2}$ WZW $\times U_Q(1) \times Flat_{5+1}$

↳ spectrum known (combination of characters of SU(2) and Liouville)

[Antoniadis, Ferrara, Kounnas '94; Kiritsis Kounnas '95]

- discrete → short $\mathcal{N}=4$
- continuous → long (massive)

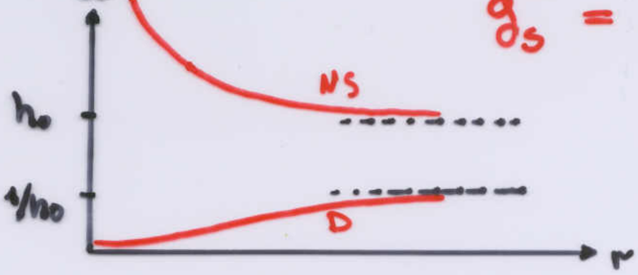
«brane» — «bulk» → at large k

«brane» → survive in the decoupling limit: LST

[Aharony, Berkooz, Kutasov, Seiberg '98]
[Giveon, Kutasov, Seiberg]

- The string coupling :

$g_s^2 = h^\gamma$



NS → strong coupling at $r \sim 0$

D → If $h_0 = 0$, strong coupling at $r \to \infty$

- this behaviour is **not** pathological: consistent with LST

→ type IIB $r \to 0$ $\equiv$ IR in the LST of NS5

$\equiv$ SYM $(1,1)_{6D}$ ~ free

dual by holography

D5-brane background at $g_s \to 0$ >S-dual< string theory in the above background at $g_s \to \infty$

↳ no exact CFT techniques

→ type IIA LST in IR $\equiv$ superconformal $(2,0)_{6d}$ fixed-point

dual by holography

M5-spread over $AdS_7 \times S^4$

3. Scanning the web of NS5 (or D5)

idea: distribute the branes in the transverse space

↳ new backgrounds

better understanding of the strong-coupling ↳ new decoupling limits

↳ new web of CFT's

well known example: 5-branes on a circle [Sfetsos '98, Giveon et al '99, Bakas et al '00]

$Q_5 = N \times k$

- in the LST higgs $\to \mathbb{Z}_N$
- simpler setup: continuous distribution in the NH limit (decoupling)

- geometry

$$ds^2 = Q_5 \left\{ d\rho^2 + d\vartheta^2 + \frac{\tan^2\vartheta \, d\psi^2 + \tanh^2\rho \, d\tau^2}{1 + \tanh^2\rho \, \tan^2\vartheta} \right\} ; \quad H = dB$$

$$g_s^{-2} = e^{-2\phi} = e^{-2\phi_0} \left(\cosh^2\rho \cos^2\vartheta + \sinh^2\rho \sin^2\vartheta \right) \quad \text{for NS5}$$

- rich content in terms of exact CFT's (NS 5's)

→ $\rho =$ cons. squashed sphere $J\bar{J}$-deformed $SU(2)_{Q_5-2}$
↳ dynamical deformation

↳ $\rho \to 0$ Bell × $U(1)$

$$\frac{SU(2)}{U(1)} \equiv$$

↳ $\rho \to \infty$ $SU(2)_{Q_5-2}$ undeformed

→ $\vartheta =$ cons.

↳ $\vartheta = 0$ cigar × $U(1)$

$$\frac{SL(2,\mathbb{R})}{U(1)_{axial}} \equiv$$

↳ $\vartheta = \pi/2$ trumpet × $U(1)$

$$\frac{SL(2,\mathbb{R})}{U(1)_{vector}} \equiv$$

- strong coupling avoided by chain of T-dualities + $\mathbb{Z}_{Q_5}$

$\hookrightarrow \mathbb{Z}_{Q_5}^{\tau} \longrightarrow T^{\tau} \longrightarrow \mathbb{Z}_{Q_5}^{\psi} \longrightarrow T^{\psi}$ ↴

N=4 superconformal world-sheet $\left\{ \begin{array}{c} \text{cigar} \times \text{bell} \\ \dfrac{SL(2,\mathbb{R})_{Q_5+2}}{U(1)_{\text{axial}}} \times \dfrac{SU(2)_{Q_5-2}}{U(1)} \end{array} \right\}$ no strong coupling

- which is also T-dual to the original $SU(2)_k \times U(1)_Q$

→ needs further investigation

4. Adding F1 (or D1) & null deformation

(see talk by Dan Israël)

- NS5/F1 (IIA, B) ⟵ S ⟶ D5/D1 (IIB)

N=2 backgrounds (N=4 in the NHG)

$AdS_3 \times S^3 \times T^4$ ← decoupling limit: $\alpha' \to 0$, $U \equiv r/\alpha'$ fixed, v fixed

$M^2 \to \infty$ ↑ $\qquad V \sim \alpha'^2 v$

↓ marginal null deformation $(J_1+J_3)(\bar{J}_1+\bar{J}_3)$ ↓

← another decoupling limit: $\alpha' \to 0$, $u^{-1} = U \equiv r/\alpha'$ fixed; dilution of D1's: $g_s \cdot \alpha'$ fixed, $v\,\alpha'^2$ fixed

$$M^2 = \frac{g_s N_1}{\alpha' v}$$

$$ds^2 = Q_5\left(\frac{du^2}{u^2} + \frac{dx^2 - dt^2}{u^2 + 1/M^2} + d\Omega_3^2\right) + d(T^4)^2$$

$$g_s^2 = e^{2\phi} = \frac{1}{g_{10}^2}\,\frac{u^2}{u^2 + 1/M^2} \qquad (NS5/F1)$$

- at $M^2 \to 0$ (F1 ∞ly diluted): $SU(2)_k \times U(1)_Q$

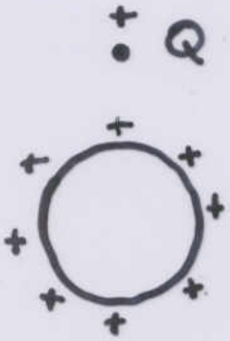
  g_s^2 diverges at $u \to \infty$ (horizon)

- at finite M^2: no divergence

[Israël, Kounnas, Petropoulos]

5. Spreading the NS5 or D5 over an S^3

- the guide: electrostatic analogue



$V = Q/r$ divergent

$V = Q/r$ outside
$V = Q/r_0$ inside
finite

- translated in our brane system: distribute the Q_5 branes over an S^3, at radius $r=1$ instead of having them all at $r=0$

[Kiritsis, Kounnas, Petropoulos, Rizos '02]

- Eq. $\partial_z^2 h + 2\partial_z h = 0 \qquad (r = \exp z)$

  becomes $\partial_z^2 h + 2\partial_z h = -2\,\frac{Q_5}{\alpha'}\,\delta(z)$

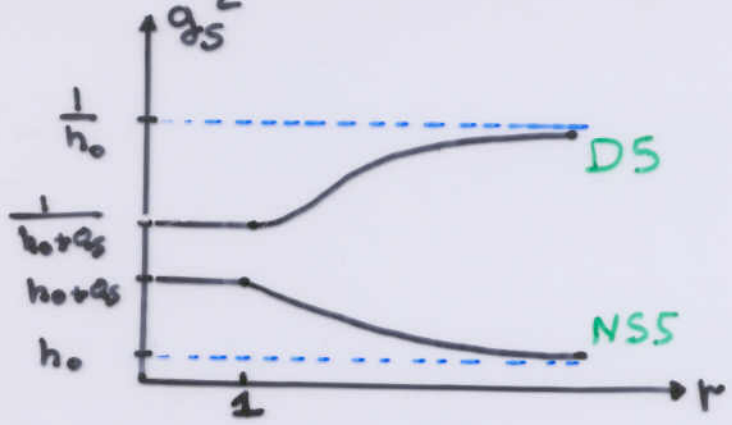
  ↳ source at finite z

  from $S = S^{\text{low-energy}}_{\text{II 10-d}} + S^{\text{distr}}_{5\text{-brane}}$

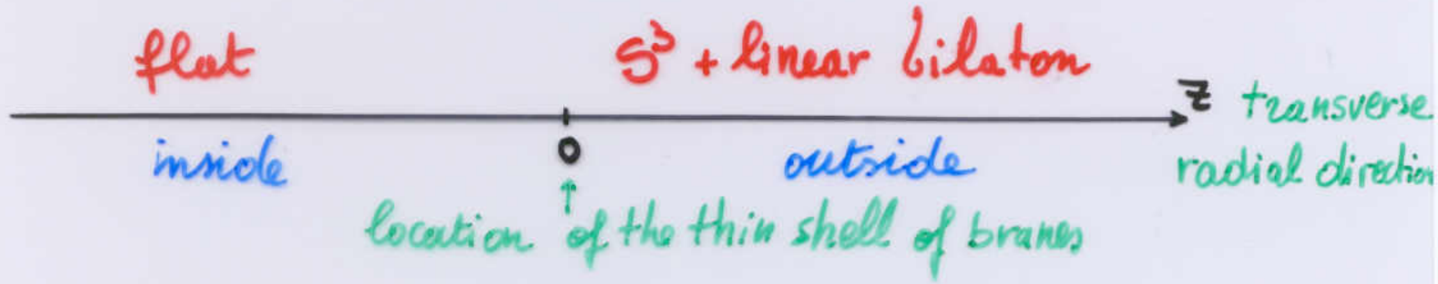
$$S^{\text{distr}}_{5b} = -\frac{Q_5 T_5}{2\pi^2}\int d^{10}x\, \sin^2\vartheta\, \sin\varphi\, \delta(z)\, \sqrt{-G_{(6)}}\, e^{-\frac{\gamma\Phi}{2}}$$

$\gamma = \pm 1$ (NS / D)

- solution $h = h_0 + Q_5 \exp(-z - |z|)$
  - → $z < 0$ $(0 < r < 1)$ $h = h_0 + Q_5$ flat
  - → $z > 0$ $(r > 1)$ previous solution
- → antisym. tens. $H = 2Q_5\, \Theta(z) \times$ volume form of S^3
- → dilaton → string coupling



- for $h_0 = 0$ → the above solution "interpolate" between two exact CFT's (NS5) in two regions of the target space



→ it solves the strong-coupling problem for NS branes; not for D.

- this pattern is quite generic:

6. Extensions and generalizations

- another electrostatic analogue: the screening

$V = Q/r$ inside

$V = Q/r_0$ outside

- This is achieved in our framework by using orientifold planes ($\gamma = -1$) or orbifold planes ($\gamma = 1$)
  - D5 (orientifold), NS5 (orbifold)

  Both are negative-tension objects allowing for new type II configurations

  → we can obtain flat space outside the S^3
  ↳ solve the strong-coupling problem for D5

  → we can have various exotic configuration of brane-shells with alternating flat and curved domains or D5 & NS5 (→ dyons)

- New kind of "CFT": → Target space made of several patches

  → Each patch is a piece of the target space of a 2-d conformal σ-model

→ needs further investigation
→ low-energy spectrum by studying the fluctuations in the eff. field th.
↳ gravitational K-K sector
non-localized states with a mass gap
↳ massless states and moduli

7. Summary

standard 5-brane configuration

NHG

decoupling limit & LST — target space of σ-model (NS: exact CFT)

↓

"strong-coupling region"

* embed the original configuration in a "web of T-dualities"
* regularize by adding F- or D-strings: marginal deformations of $AdS_3 \times S^3 \times T^4$
* distribute the branes over S^3

→ further investigation is needed in all cases

* incorporate the full geometry including the asymptotic region
* control of T-dualities in curved space
* recast the decoupling limit for spread sources
* analyse the "patchwork CFT's": spectra, ...