Superstrings on NS5 backgrounds, deformed AdS_3 and holography

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Based on work with C. Kounnas and M. Petropoulos, hep-th/0306053

Outline of the talk

1. Introduction and motivations
2. Decoupling limits of D1/D5
3. Partition function for $SL(2,\mathbb{R})$
4. Marginal deformations of $SL(2,\mathbb{R})$
5. Comments on holography
6. Conclusions and open problems

Introduction

1. String theory on AdS_3 backgrounds

- Exact description: WZW model $SL(2,\mathbb{R}) \Rightarrow$ simplest non-trivial spacetime in string theory
- Configuration of NS5/F1 branes in near-horizon limit $\Rightarrow$ background $AdS_3 \times S^3 \times (T^4$ or $K3)$

Antoniadis, Bachas, Sagnotti, Phys. Lett. **B235**

Horowitz, Maldacena, Strominger, hep-th/9603109

- Starting point for other interesting string backgrounds: black holes, cosmological models...

Witten, Phys. Rev. **D44**

Kounnas, Lüst, hep-th/9205046

- Non-unitary worldsheet CFT based on the non-compact affine algebra $\widehat{SL(2,\mathbb{R})}_L \times \widehat{SL(2,\mathbb{R})}_R$

Balog, O'Raifeartaigh, Forgacs, Wipf, Nucl. Phys. **B325**

- To obtain a consistent theory $\Rightarrow$ new representations by spectral flow

Maldacena, Ooguri, hep-th/0001053

- The one loop partition function was not known up to now $\Rightarrow$ new proposal

Israël, Kounnas, Petropoulos, hep-th/0306053

2. Holography

- D1/D5-branes theory in the decoupling limit
  $\Rightarrow AdS_3/CFT_2$ correspondence

Maldacena hep-th/9711200

- NS5-branes worldvolume theory in the decoupling limit: "Little String Theory" (LST). Conjectured holography with the near-horizon limit of the NS5-branes background: $SU(2) \times U(1)_Q$

Seiberg hep-th/9705221

Aharony, Berkooz, Kutasov, Seiberg, hep-th/9808149

- RG flow between these two theories?
  $\Rightarrow$ exact string background:

  $\{\text{null} - \text{deformed } SL(2,\mathbb{R})\} \times SU(2) \times U(1)^4$

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3. Marginal deformations of $SL(2,\mathbb{R})$

- WZW models can be deformed marginally with bilinears of currents of the Cartan subalgebra

Chaudhuri, Schwartz, Phys. Lett. **B219**

- In $SL(2,\mathbb{R})$, three possibilites: two inequivalent choices of Cartan subalgebra, and the *null* subalgebra.

Förste, hep-th/9407198

$\Rightarrow$ Derivation of the spectrum for these deformations

& superconformal structure of the null deformation

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The D1/D5 background

- Solution of type IIB supergravity:

$$
\begin{aligned}
d\tilde{s}^2_\sigma &= \frac{-dt^2 + dx^2}{\sqrt{H_1 H_5}} + \sqrt{H_1 H_5}\left(dr^2 + r^2 d\Omega_3^2\right) + \sqrt{\frac{H_1}{H_5}} \sum_{i=6}^{9} (dx^i)^2 \\
e^{2\tilde{\phi}} &= g_s^2 \frac{H_1}{H_5}
\end{aligned}
$$

$$
\text{with} \quad H_1 = 1 + \frac{g_s \alpha' N_1}{v r^2}\,, \quad H_5 = 1 + \frac{g_s \alpha' N_5}{r^2}.
$$

- Standard decoupling limit: $\alpha' \to 0$, $u \equiv \alpha'/r$ fixed, v fixed

  $\star$ The geometry is $AdS_3 \times S^3 \times T^4$:

$$
ds^2 = \alpha' g_s \sqrt{\frac{N_1 N_5}{v}} \left\{ \frac{du^2 + dX^2 - dT^2}{u^2} + d\Omega_3^2 \right\} + \sqrt{\frac{N_1}{v N_5}} \sum_{i=1}^{6} (dx^i)^2
$$

Maldacena, hep-th/9711200

- New decoupling limit: partial near-horizon geometry

$$
\left\{
\begin{array}{l}
\alpha' \to 0, \\
u = \alpha'/r \text{ fixed}, \\
g_s \alpha' \text{ fixed (i.e. } g_s \to \infty), \\
\alpha'^2 v \text{ fixed (i.e. \textit{decompactification})}
\end{array}
\right.
$$

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⋆ S-dual background ($\phi = -\tilde{\phi}$, $F_{[3]} \to H_{[3]}$):

$$\{\text{null} - \text{deformed } SL(2,\mathbb{R})\} \times SU(2) \times T^4$$

$$\boxed{\begin{aligned} ds^2_\sigma &= \alpha' N_5 \left\{ \tfrac{du^2}{u^2} + \tfrac{dX^2 - dT^2}{u^2 + 1/M^2} + d\Omega_3^2 \right\} + \tfrac{1}{g_s} \sum_{i=6}^{9} (dx^i)^2 \\ e^{2\phi} &= g^2_{max}\, \tfrac{u^2}{u^2+1/M^2} \end{aligned}}$$

With the mass scale $\boxed{M^2 = \frac{g_s N_1}{\alpha' v}}$

String coupling constant bounded from above:

$$g_{max} = \sqrt{\frac{v N_5}{g_s^2 N_1}}$$

⋆ Asymptotic geometries:

1. $u \to 0$: linear dilaton (weakly coupled region)
2. $u \to \infty$: AdS_3 geometry (central region)

- Supersymmetry

  Type IIB supergravity in partial near-horizon geometry

  ⋆ Condition for unbroken susy:

$$\boxed{\delta\lambda = \delta\psi_\mu = 0.}$$

⇒ Preserves 1/4 of supersymmetry

- Sigma-model description

$SL(2,\mathbb{R})$ WZW model in Poincaré coordinates :

$$S = \frac{k}{2\pi}\int d^2z \left(\frac{\partial u \bar\partial u}{u^2} + \frac{\partial x^+ \bar\partial x^-}{u^2}\right).$$

The following null isometries are linearly realized :

$$J = J^1 + J^3 = \frac{\partial x^+}{u^2}\,, \quad \bar J = \bar J^1 + \bar J^3 = \frac{\bar\partial x^-}{u^2}.$$

⋆ Deform the model with truly marginal operator $J\bar J$:

$$\boxed{S_M = \frac{k}{2\pi}\int d^2z \left(\frac{\partial u \bar\partial u}{u^2} + \frac{\partial x^+ \bar\partial x^-}{u^2+1/M^2}\right)}$$

Affine symmetry $\widehat{SL}(2,\mathbb{R})_L \times \widehat{SL}(2,\mathbb{R})_R$ broken down to $\widehat{U}(1)_L \times \widehat{U}(1)_R$.

Förste, hep-th/9407198

⋆ Alternatively: $O(2,2,\mathbb{R})$ transformation of the background

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THE $SL(2,\mathbb{R})$ CONFORMAL FIELD THEORY

- Algebraic description: non-compact affine $SL(2,\mathbb{R})$ algebra:

$$\begin{aligned}\left[J^3_n, J^3_m\right] &= -\frac{k}{2} n \delta_{m,-n},\\ \left[J^3_n, J^\pm_m\right] &= \pm J^\pm_{n+m},\\ \left[J^+_n, J^-_m\right] &= -2J^3_{n+m} + kn\delta_{m,-n}.\end{aligned}$$

- Physical spectrum

  Physical spectrum built from unitary representations of the horizontal algebra:

  Principal discrete representations $\mathcal{D}^\pm_j$, with $m = \pm j, \pm(j+1), \cdots, j \in \mathbb{R}^+$;

  Principal continuous representations $\mathcal{C}^\alpha_j$, with $m = \alpha, \alpha \pm 1, \cdots, 0 \leq \alpha < 1, j = 1/2 + i\mathbb{R}$.

  Non-unitary affine representations $\Rightarrow$ unitary physical spectrum if : $0 < j < k/2$ (discrete representations).

Petropoulos, Phys. Lett. **B236**

Mohammedi, Int. J. Mod. Phys. **A5**

- Spectral flow: to obtain a closed and physically sensible spectrum (with an infinite tower of massive states) $\Rightarrow$ inclusion of new sectors obtained by *spectral flow*:

$$\begin{aligned}\tilde{J}^3_n &= J^3_n - \frac{k}{2} w \; \delta_{n,0}\\ \tilde{J}^\pm_n &= J^\pm_{n\pm w}\end{aligned}$$

Maldacena, Ooguri, hep-th/0001053

⋆ Partition function? $\Rightarrow$ divergent affine characters.

- The coset theory $SL(2,\mathbb{R})/U(1)_A$

  Axial gauging of $SL(2,\mathbb{R})$: $g \to hgh$ with $h = e^{i\lambda\sigma_2/2}$

  $\Rightarrow$ non-compact parafermions.

  Unitary CFT with the partition function:

$$Z_A = 4\sqrt{k(k-2)}\,\eta\bar{\eta}\int d^2s \frac{\mathrm{e}^{\frac{2\pi}{\tau_2}(\mathrm{Im}(s_1\tau - s_2))^2}}{|\vartheta_1(s_1\tau - s_2|\tau)|^2}\sum_{m,w=-\infty}^{+\infty} \mathrm{e}^{-\frac{k\pi}{\tau_2}|(s_1+w)\tau-(s_2+m)|^2}$$

Hanany, Prezas, Troost, hep-th/0202129

  1. Freely acting orbifold structure
  2. Obvious divergence for $s_1 = s_2 = 0$

- The $SL(2,\mathbb{R})$ partition function from the coset

  1. States of the coset :
     $J^3_{n>0}|\Phi\rangle = \bar{J}^3_{n>0}|\Phi\rangle = 0$
     and $J^3_0 + \bar{J}^3_0 = -wk$, $J^3_0 - \bar{J}^3_0 = n$.
  2. No-ghost theorem for $SL(2,\mathbb{R}) \Rightarrow$ physical states obey:
     $J^3_{n>0}|\Phi\rangle = \bar{J}^3_{n>0}|\Phi\rangle = 0$
  3. To reconstruct the $SL(2,\mathbb{R})$ partition function $\Rightarrow$ couple the coset theory with an appropriate lattice
  4. non-compact parafermions: $\mathbb{Z}$ symmetry
     $\Rightarrow$ *continuous orbifold*

$$SL(2,\mathbb{R}) \sim \left(\frac{SL(2,\mathbb{R})}{U(1)} \times U(1)_t\right) / \;\mathbb{Z}$$

⋆ Partition function for $SL(2,\mathbb{R})$:

$$Z_{SL(2,R)} = 4k(k-2)^{3/2} \int d^2s\ d^2t\ \frac{\mathrm{e}^{\frac{2\pi}{\tau_2}(\mathrm{Im}(s_1\tau - s_2))^2}}{|\vartheta_1(s_1\tau - s_2|\tau)|^2} \times$$

$$\times \sum_{m,w} \mathrm{e}^{-\frac{k\pi}{\tau_2}|(s_1-t_1+w)\tau-(s_2-t_2+m)|^2} \sum_{m',w'} \mathrm{e}^{+\frac{k\pi}{\tau_2}\left|(t_1+w')\tau-(t_2+m')\right|^2}$$

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- Structure of the partition function

1. Structure of a $\mathbb{Z}_{twist} \times \mathbb{Z}_{shift}$ orbifold $\Rightarrow$ modular invariant
2. Zero modes structure:

$$P^+_{\mathrm{L,R}} = \frac{n^+}{\sqrt{2k}} \pm \sqrt{\frac{k}{2}}(w_- - 2t_1)\ ,\quad P^-_{\mathrm{L,R}} = \pm\sqrt{\frac{k}{2}}w_+.$$

$\Rightarrow$ X^- is compact, X^+ at "radius" zero (i.e. non-compact)

$\Rightarrow$ "Shifted winding" $\sqrt{\frac{k}{2}}(w_- - 2t_1)$ defines a *lightcone energy*

3. Free-field representation:

$$J^3 = i\sqrt{\frac{k}{2}}\partial T\ ,\quad J^\pm = -\left(\sqrt{\frac{k}{2}}\partial X \pm i\sqrt{\frac{k-2}{2}}\partial\rho\right)\mathrm{e}^{\pm i\sqrt{\frac{2}{k}}(X-T)}$$

with a linear dilaton: $Q_\rho = 1/\sqrt{2(k-2)}$

⋆ Structure of the zero modes: integration over t_1, t_2

⋆ Correlation with oscillators: integration over s_1, s_2

4. Integration over the lightcone energy : after regulating the partition function and analytic continuation, one find:

$$Z_{SL(2,\mathbb{R})} = 4\frac{(k-2)^{3/2}}{k\sqrt{\tau_2}} \frac{\mathrm{e}^{\frac{2\pi}{\tau_2}(\mathrm{Im}\theta)^2}}{|\vartheta_1(\theta|\tau)|^2}.$$

Gawedzki, hep-th/91100796

Petropoulos, hep-th/9908189

- Uncovering the spectrum

Integration of the Lagrange multipliers s_1, s_2 and t_2:

⋆ *Discrete representations* in the range $\frac{1}{2} < j < \frac{k-1}{2}$

$$L_0 = -\frac{j(j-1)}{k-2} + w_+\left(-\tilde{m} - \frac{k}{4}w_+\right) + N,$$
$$\bar{L}_0 = -\frac{j(j-1)}{k-2} + w_+\left(-\bar{\tilde{m}} - \frac{k}{4}w_+\right) + \bar{N},$$

⋆ *Continuous representations*

$$L_0 = \frac{s^2+1/4}{k-2} + w_+\left(-\tilde{m} - \frac{k}{4}w_+\right) + N,$$
$$\bar{L}_0 = \frac{s^2+1/4}{k-2} + w_+\left(-\bar{\tilde{m}} - \frac{k}{4}w_+\right) + \bar{N},$$

with $\tilde{m} + \bar{\tilde{m}} = -k(w - t_1)$ and $\tilde{m} - \bar{\tilde{m}} = n$.

Maldacena, Ooguri, hep-th/0001053

- Superconformal structure
  The $\hat{c}=6$ worldsheet SCFT $SL(2,\mathbb{R})\times SU(2)$ factorizes into a first $\hat{c}=2$, $N=2$ superconformal algebra, with $N=2$ R-current:
  $$J_2 = \psi^3\chi^3$$
  And a "would be" N=4 algebra, with $N=2$ R-current:
  $$\begin{aligned} J_4 &= i\sqrt{2}\partial H^+ \\ &= \chi^+\chi^- + \psi^+\psi^- \\ &\quad + \frac{2}{k+2}\Big[\underbrace{J^3+\chi^+\chi^-}_{\text{total } SL(2,R)\ J^3 \text{ current}} - \Big(\underbrace{I^3+\psi^+\psi^-}_{\text{total } SU(2)\ I^3 \text{ current}}\Big)\Big] \end{aligned}$$
  Cartan currents coupled to their respective coset theories $\Rightarrow H^+$ is not a free boson at self-dual radius
- Spacetime supersymmetry ?
  $N=2$ current $J=J_2+J_4$ not appropriate to define spacetime supercharges:
  1. Physical states have non-integer charges w.r.t. J
  2. Target space symmetries not respected

$\Rightarrow$ Use directly the bosonized free fermions:

$$\Theta_\varepsilon(z) = \exp\left\{\frac{i}{2}\left(\varepsilon_0 H_0 + \varepsilon_1 H_1 + \varepsilon_2 H_2 + \varepsilon_3 H_3 + \varepsilon_4 H_4\right)\right\}$$

physical, provided that $\varepsilon_0\varepsilon_1\varepsilon_2 = 1$ (i.e. choice of 6D chirality for $AdS_3 \times S^3$ fermions)

Giveon, Kutasov, Seiberg, hep-th/9806194

For type IIB: we realize instead the projection on the four-torus fermions $\Rightarrow$ $T^4/\mathbb{Z}_2$ orbifold. The five-branes are wrapped on K3.

⋆ Partition function (type IIB):

$$Z_{\mathrm{IIB}} = \frac{\mathrm{Im}\tau}{\eta^2\bar\eta^2} Z_{SU(2)}\, Z_{SL(2,\mathbb{R})}\, \frac{1}{2}\sum_{h,g=0}^{1} Z^{\text{twisted}}_{T^4/\mathbb{Z}_2}\begin{bmatrix}h\\g\end{bmatrix}$$
$$\times \frac{1}{2}\sum_{a,b=0}^{1}(-)^{a+b}\,\vartheta^2\begin{bmatrix}a\\b\end{bmatrix}\vartheta\begin{bmatrix}a+h\\b+g\end{bmatrix}\vartheta\begin{bmatrix}a-h\\b-g\end{bmatrix}$$
$$\times \frac{1}{2}\sum_{\bar a,\bar b=0}^{1}(-)^{\bar a+\bar b}\,\bar\vartheta^2\begin{bmatrix}\bar a\\\bar b\end{bmatrix}\bar\vartheta\begin{bmatrix}\bar a+h\\\bar b+g\end{bmatrix}\bar\vartheta\begin{bmatrix}\bar a-h\\\bar b-g\end{bmatrix}$$

Marginal deformations of $SL(2,\mathbb{R})$

Bilinears of affine Cartan currents in WZW models $\Rightarrow$ exactly marginal deformations $\Rightarrow$ continuous lines of CFT's

- The $J^3\bar{J}^3$ deformation

  Standard choice : timelike Cartan generator
  $\Rightarrow$ geometry of the deformed CFT:

$$ds^2 = dr^2 + \frac{-\cosh^2 r\, dt^2 + \mathcal{R}^2 \sinh^2 r\, d\phi^2}{\mathcal{R}^2 \cosh^2 r - \sinh^2 r}$$
$$e^{2\Phi} = e^{2\Phi_0} \frac{\mathcal{R}^2 - 1}{\mathcal{R}^2 \cosh^2 r - \sinh^2 r}$$

$\star$ Spectrum of the theory: change the radius of the J^3, $\bar{J}^3$ timelike lattice:

$$Z_{3\bar{3}}(\mathcal{R}) = 4\mathcal{R}k\sqrt{k-2}\int d^2s\, d^2t\, \frac{e^{\frac{2\pi}{\tau_2}(\mathrm{Im}(s_1\tau - s_2))^2}}{|\vartheta_1(s_1\tau - s_2|\tau)|^2} \times$$
$$\times \sum_{m,w} e^{-\frac{k\pi}{\tau_2}|(s_1 - t_1 + w)\tau - (s_2 - t_2 + m)|^2} \sum_{m',w'} e^{\mathcal{R}^2 \frac{k\pi}{\tau_2}\left|(t_1 + w')\tau - (t_2 + m')\right|^2}$$

At first order (i.e. $\mathcal{R}^2 = 1 + \varepsilon$) :

$$\delta L_0 = \delta \bar{L}_0 = -\frac{\varepsilon}{k}\left(\tilde{m} + \frac{k}{2}w_+\right)\left(\tilde{\bar{m}} + \frac{k}{2}w_+\right)$$

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CIGAR/TRUMPET DUALITY ?

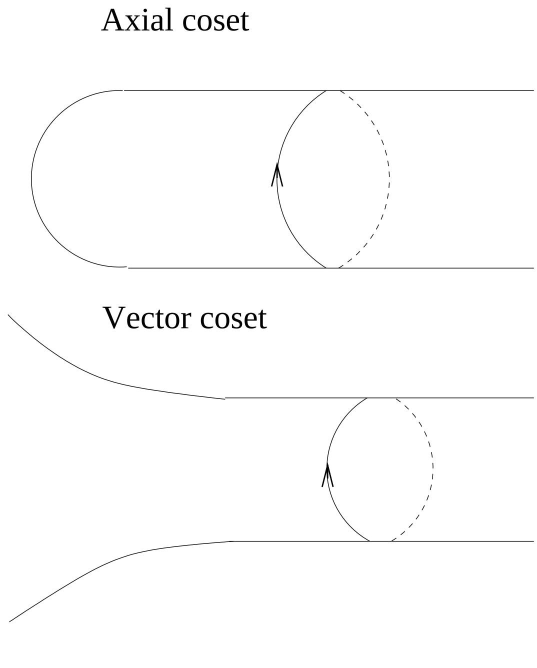
⇒ Infinite deformation ($\mathcal{R} \to \infty$): *axial coset*, cigar geometry

⋆ Spectrum: $L_0^{axial} = -\frac{j(j-1)}{k-2} + \frac{(n/2-kw/2)^2}{k}$

⇒ Opposite limit ($\mathcal{R} \to 0$): *vector coset*, trumpet geometry

⋆ Spectrum: $L_0^{vector} = -\frac{j(j-1)}{k-2} + \frac{\mu^2}{k}$, with $\mu \in \mathbb{R}$.

Mismatch: choice of the *universal cover* of $SL(2,\mathbb{R})$



- The $J^2\bar{J}^2$ deformation
  Inequivalent choice of Cartan subalgebra: spacelike current J^2
  $\Rightarrow$ change the radius of the spacelike lattice in the partition function
  Infinite deformation: *Minkowskian 2D black hole*

- Null deformation
  In $SL(2,\mathbb{R})$, another inequivalent subalgebra: *null subalgebra* (currents $J = J^1 + J^3$, $\bar{J} = \bar{J}^1 + \bar{J}^3$)
  $\Rightarrow$ deform with the exactly marginal operator $J\bar{J}$

  ⋆ Partition function: change the radii of both lattices

  $\Rightarrow$ first order spectrum (continuous repr.):

$$L_0 = \frac{s^2 + 1/4}{k-2} - w_+[m + \frac{\varepsilon}{2}(m + \bar{m})] - \frac{k}{4}(1+\varepsilon)w_+^2$$

  Deformation acts on *spectral flow*

  ⋆ Infinite deformation limit: $U(1)_Q \times \mathbb{R}^{1,1}$

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- The supersymmetric null deformation

Continuous line of N=2 algebras interpolating between $SL(2,\mathbb{R})\times SU(2)$ and $U(1)_Q\times\mathbb{R}^{1,1}\times SU(2)$ (parametrized by p) :

$$\begin{aligned}
\sqrt{2}G^{\pm} &= \left[s_0(I^3+i\partial H_2)\mp i(c\,\partial T + s\,\partial H_1)\right]e^{\pm iH_0} + s_0 I^{\mp} e^{\pm iH_2} \\
&\quad + i\left[c\,\partial X - (s_0 - s)\left(\partial H_1 - t\,\partial X^-\right)\mp i\partial\rho\right]\mathrm{e}^{\pm i[H_1 - tX^-]} \\
J &= i\partial H_0 + i\partial H_2 + i\partial H_1 + ips^2\left[\tfrac{1}{t}\partial T + \partial H_1\right] - s_0^2\,\mathcal{I}^3 \\
&\quad + (p-1)t\; i\partial X^-
\end{aligned}$$

where $c=\cosh(\sigma),\ s=\sinh(\sigma)=s_0/p,$ with $s_0=\sqrt{\frac{2}{k+2}}$ and $p\geq 1$

⋆Limit $s\to s_0$: undeformed theory

⋆Limit $s\to 0$: $U(1)_Q\times\mathbb{R}^{1,1}\times SU(2)$, nonstandard complex structure.

⋆ New physical spin fields (same projections) :

$$\Theta^d_{\varepsilon}(z)=\exp\left\{\frac{i}{2}\left[\varepsilon_0 H_0+\varepsilon_1\left(H_1+(p-1)t\;X^-\right)+\sum_{\ell=2}^{4}\varepsilon_\ell H_\ell\right]\right\}$$

⋆ Locality w.r.t to the spectrum ⇒ quantization of the deformation parameter:

$$\boxed{p\in 2\mathbb{Z}+1}$$

Right-moving sector: replace $\bar{X}^-\to\bar{X}^+$

⇒ flip of chirality for the anti-holomorphic spin fields

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Some comments about holography

- AdS_3 holography
  Low energy limit of the D1/D5 theory ($\alpha' \to 0$)
  $\Rightarrow$ (full) near-horizon geometry: $AdS_3 \times S^3 \times T^4$ or $K3$
  $\star$ Dual theory: Dynamics of string-like instantons in D=6 SYM (Higgs branch) $\Rightarrow \mathcal{N} = (4,4)$ SCFT in 2D on a deformation of the symmetric product $Sym(T^4 \text{ or } K3)^k$.

Maldacena, hep-th/9711200

- Linear dilaton holography
  "Decoupling" limit of the NS5-branes: $\tilde{g}_s \to 0$, $\tilde{\alpha}'$ fixed.
  $\Rightarrow$ near-horizon limit of the NS5 background:

$$\begin{aligned} ds^2 &= dx^\mu dx^\nu \eta_{\mu\nu} + \tilde{\alpha}' N_5 (d\rho^2 + d{\Omega_3}^2) \\ \Phi &= \Phi_0 - \rho \\ H &= 2\tilde{\alpha}' N_5 \, \epsilon(\Omega_3) \end{aligned}$$

$\star$ Dual theory (type IIB): $\mathcal{N} = (1,1)$ "gauge" theory in D=6. In the UV, new string-like degrees of freedom $\Rightarrow$ Little String Theory

$\star$ At low energies: Super-Yang-Mills, gauge group $U(N_5)$.

Aharony, Berkooz, Kutasov, Seiberg, hep-th/9808149

$\star$ Free fixed point in the IR (type IIB)
$\Rightarrow$ strong coupling problem: distribute the five-branes on a circle or a three-sphere

Giveon, Kutasov, hep-th/9909110

Kiritsis, Kounnas, Petropoulos, Rizos, hep-th/0204201

- Null-deformed theory
From AdS_3/CFT_2 point of view : deform with (infra-red) irrelevant operator + decompactification limit
$\Rightarrow$ Best described as an infrared regularization of LST

$\star$ Worldsheet perspective: marginal deformation of linear dilaton CFT

$$\delta S_{worldsheet} \sim M^2 \int d^2z \, e^{-\sqrt{\frac{2}{k+2}}\,\rho} \, \partial X^+ \bar{\partial} X^-$$

$\Rightarrow$ Liouville potential with nontrivial $B_{\mu\nu}$, singlet of $\widehat{SU(2)}_L \times \widehat{SU(2)}_R$.

$\star$ D5-branes perspective: add RR flux $\Rightarrow$ generates imaginary "theta-like" term

$$S_{gauge} = \frac{1}{\alpha' g_s} \int \mathrm{Tr}\,(F \wedge *F) - dt \wedge dx \wedge \mathrm{Tr}\,(F \wedge F)$$

$\Rightarrow$ "instanton-like" solutions contribute:

$$*_6 F = F \wedge dt \wedge dx$$

Infra-red fixed point: SCFT of AdS_3/CFT_2 correspondence
$\Rightarrow$ dilaton stops running

$\star$ Null-deformed AdS_3: RG flow between linear dilaton and AdS_3 holographic theories

Israel, Kounnas, Petropoulos

Conclusions

- Partition function for Minkowskian $SL(2,\mathbb{R})$, including flowed representations
- Spectra of marginal deformations of $SL(2,\mathbb{R})$: three left-right symmetric deformations ⇒ asymmetric ones?
- New decoupling limit of D1/D5 theory, S-dual to an exact SCFT: $\{\text{null-deformed } SL(2,\mathbb{R})\} \times SU(2) \times U(1)^4$
- Realization of worldsheet and target space supersymmetry for these theories
- Holographic interpretation: infra-red regularization of LST with "condensate" of fundamental strings

- Open problems:
  1. Other realizations of spacetime supersymmetry?
  2. Brane interpretation of other deformations?
  3. Explicit holography calculations...