New susy type II AdS$_4$ vacua

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Ko$\lambda\upsilon\mu\pi\grave{\alpha}\rho\iota$, *K*$\rho\grave{\eta}\tau\eta$

Outline

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Motivation

AdS_4/CFT_3 duality

- Nonperturbative definition of String Theory
- Multiple M2 branes

Deviation from CY-ness

- Flux$\neq 0 \Longrightarrow AdS_4 \times_w \mathcal{M}_6$

Flux Vacua

- Moduli stabilization
- Starting point for de Sitter
- Susy breaking, ...

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The result

- New $\mathcal{N} = 2$ IIA and $\mathcal{N} = 1$ IIB pure-flux vacua

Ten-dimensional spacetime

$AdS_4 \times_w \mathcal{M}_6$ with:

$$ds^2(\mathcal{M}_6) = dt^2 + ds_t{}^2(\mathcal{M}_5)$$

where $\mathcal{M}_5$ admits a Sasaki-Einstein structure

$$ds_t{}^2(\mathcal{M}_5) = e^{2B(t)} ds^2_{KE} + \xi^2(t)(d\psi + A)^2$$

Lüst, DT, JHEP 0904

Lüst, DT, arXiv:0906

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$$ds^2_{SE}(\mathcal{M}_5) = ds^2_{KE} + (d\psi + A)^2$$

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Outline

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- $AdS_4 \times \mathcal{M}_6$ vacua: generalities
- New explicit vacua

Outline

SU(3) structure

Flux$=0$, $\mathcal{M}_6 =$CY

- SUSY: $\nabla\eta = 0$
- Bilinears: $J_{mn}:=\eta^\dagger\gamma_{mn}\eta;\qquad \Omega_{mnp}:=\eta\gamma_{mnp}\eta$
- Differential conditions: $d\Omega = 0;\qquad dJ = 0$

SU(3) structure

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SU(3) structure

[hep-th]

$$(\eta, g_{mn})$$

SU(3) structure

[math.DG]

$$(J, \Omega)$$

SU(3) structure

Definition

$$\Omega \wedge \overline{\Omega} = \frac{1}{3!} J^3$$

$$J \wedge \Omega = 0$$

$$Sp(6, \mathbb{R}) \cap SL(3, \mathbb{C}) = SU(3)$$

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Spinor ansatz

Two susy parameters

$$\epsilon_i = \zeta \otimes \theta_i + \text{c.c.} \, ; \qquad i = 1, 2$$

$$|\theta_1|^2 = |\theta_2|^2 \propto e^A$$

Two unimodular spinors

$$\theta_1 = a \, \eta_1 ; \qquad \theta_2 = \begin{cases} b \, \eta_2^* + c^* \eta_1^* & \text{IIA} \\ b \, \eta_2 + c \, \eta_1 & \text{IIB} \end{cases}$$

$$a^2 = b^2 + |c|^2$$

SU(3)×SU(3) structure

Local SU(2)=SU(3)∩SU(3) structure

$$\widetilde{J} \wedge \omega = 0$$
$$2\widetilde{J} \wedge \widetilde{J} = \omega \wedge \omega^* \neq 0$$
$$\iota_K \widetilde{J} = \iota_K \mathrm{Re}\,\omega = \iota_K \mathrm{Im}\,\omega = 0$$

SU(3)×SU(3) structure

$$J^{(1)} = \frac{i}{2} K \wedge K^* + \widetilde{J} \; ; \qquad J^{(2)} = \frac{i}{2} K \wedge K^* - \widetilde{J}$$
$$\Omega^{(1)} = -i\omega \wedge K \; ; \qquad \Omega^{(2)} = i\omega^* \wedge K$$

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The scalar ansatz

Provided certain conditions are obeyed by $(K, \widetilde{J}, \omega)$
the scalar ansatz solves the susy equations of IIA/IIB

Lüst, DT, JHEP 0904

The scalar ansatz

Metric

$$ds^2 = e^{2A} ds^2(AdS_4) + ds^2(\mathcal{M}_6)$$

Three-form

$$H = \frac{1}{24}\left(h_1 \omega^* + h_2 \omega + 2 h_3 \widetilde{J}\right) \wedge K + \text{c.c.}$$

The scalar ansatz

RR fluxes IIA

$$e^{\phi} F_0 = f_0$$

$$e^{\phi} F_2 = \frac{1}{8}\left(f_2\,\omega^* + f_3\widetilde{J} + 2if_1\,K \wedge K^*\right) + \mathrm{c.c.}$$

$$e^{\phi} F_4 = \frac{1}{16} g_1 \widetilde{J} \wedge \widetilde{J} + \frac{i}{96}\left(g_2\,\omega^* + g_2^*\,\omega + 2g_3\widetilde{J}\right) \wedge K \wedge K^*$$

$$e^{\phi} F_6 = f\, vol_6$$

The scalar ansatz

RR fluxes IIB

$$e^{\phi} F_1 = g_1 K + \text{c.c.}$$

$$e^{\phi} F_3 = \frac{1}{24}\left(f_1 \omega^* + f_2 \omega + 2 f_3 \widetilde{J}\right) \wedge K + \text{c.c.}$$

$$e^{\phi} F_5 = g_2 \star_6 K + \text{c.c.}$$

Equations of motion

- SUSY$\oplus$(generalized) Bianchi ids $\Longrightarrow$ All EOM's
- Also in the presence of calibrated sources

Koerber, DT, JHEP 0708

Outline

Construction of vacua

IIA Strict SU(3)

- Until recently all known (massive) vacua were of rigid-SU(3) type
- All can be described in a unifying framework: left-invariant SU(3) structures on groups, cosets
- Many more should be possible!

Lüst, DT, JHEP 0502

Koerber, Lüst, DT, JHEP 0807

Explicit vacua

IIA Strict SU(3)

- Nilsson, Pope, CQG 1984
- Sorokin, Tkach, Volkov PLB 1985
- Behrndt, Cvetič, NPB 2005
- Lüst, DT, JHEP 0502
- Graña, Minasian, Petrini, Tomasiello JHEP 0705
- Aldazabal, Font, JHEP 0802
- Tomasiello, hep-th 0712
- Koerber, Lüst, DT, JHEP 0807

Explicit vacua

IIA SU(3)×SU(3)

- Gaiotto, Tomasiello, arXiv:0904
- Petrini, Zaffaroni, arXiv:0904
- Lüst, DT, arXiv:0906

Outline

New $\mathcal{N} = 2$ IIA vacua

$\mathcal{M}_5$ admits a S-E SU(2) structure

$$\iota_u \alpha = \iota_u \beta = \iota_u \gamma = 0$$
$$\alpha \wedge \beta = \beta \wedge \gamma = \gamma \wedge \alpha = 0$$
$$\alpha \wedge \alpha = \beta \wedge \beta = \gamma \wedge \gamma \neq 0$$
$$du = -2\gamma \; ; \quad d(\alpha + i\beta) = -3iu \wedge (\alpha + i\beta) \; ; \quad d\gamma = 0$$

5d Sasaki-Einstein

Killing spinor

$$\nabla_m \eta = \pm \frac{i}{2} \Gamma_m \eta$$
$$R_{mn} = 4 g_{mn}$$

The SU(2) structure

$$\begin{aligned} u_m &:= (\eta^\dagger \Gamma_m \eta) \\ \alpha_{mn} + i\beta_{mn} &:= (\eta \Gamma_{mn} \eta) \\ \gamma_{mn} &:= i(\eta^\dagger \Gamma_{mn} \eta) \end{aligned}$$

New $\mathcal{N} = 2$ IIA vacua

Local SU(2) structure

$$K = e^{B(t)}\left(dt - i\xi(t)u\right)$$

$$\begin{pmatrix} \widetilde{J} \\ \mathrm{Re}\,\omega \\ \mathrm{Im}\,\omega \end{pmatrix} = e^{2C(t)}\mathcal{R}(\theta(t), \chi(t)) \begin{pmatrix} \alpha \\ \beta \\ \gamma \end{pmatrix}$$

Metric on $\mathcal{M}_6$

$$ds^2(\mathcal{M}_6) = e^{2B}\left(\frac{3}{W}e^{2(C-B)}ds^2_{KE} + \xi^2\, u \otimes u + dt^2\right)$$

- $\mathcal{M}_6$ is locally a smooth S^2 bundle over 4D K-E base.

New $\mathcal{N} = 2$ IIA vacua

- All conditions of the scalar ansatz are satisfied
- All BI's and EOM's are satisfied
- All fields are determined

The solution

$$
\begin{aligned}
\tan\theta &= \frac{\tan\varphi}{\sin\varepsilon} = \sqrt{2}\tan(\sqrt{2}t) \\
f &= -3We^{-A}\cos\varepsilon\cos\varphi \\
f_0 &= -We^{-A}(\cos\varphi\sin\varepsilon + \csc\varepsilon\sin\varphi\tan\varphi) \\
f_1 &= -\cos\varepsilon\cos\varphi\left(We^{-A} + 4e^{-B}A'\cot\varphi\sin\varepsilon\right) \\
f_2 &= -8e^{-B}A'\cos\varepsilon\cos\varphi
\end{aligned}
$$

New $\mathcal{N} = 2$ IIA vacua

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The solution

$$g_1 = -8\left(\cos\varphi \sin\varepsilon + \sin\varphi \csc\varepsilon \tan\varphi\right)\left(We^{-A} - 4e^{-B}A' \cot\varphi \sin\varepsilon\right)$$

$$g_2 = 48 \sin\varphi \left(We^{-A} + e^{-B}A' \cot\varphi \sin\varepsilon\right)$$

$$h_1 = -6\sin^2\varphi \cot\varepsilon \left(We^{-A} - 2e^{-B}A' \sin\varepsilon \cot\varphi\right)$$

$$\frac{h_1}{h_3} = \frac{h_2}{h_3} = \frac{f_2}{f_3} = \frac{g_2}{g_3} = -\tan\theta\ .$$

New $\mathcal{N} = 2$ IIA vacua

- All conditions of the scalar ansatz are satisfied
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The solution

$$
\begin{aligned}
e^{4A} &= \frac{1}{\cos^2\theta}\tan\varepsilon \\
e^{B-A} &= -\frac{1}{2W}\cot\theta\,(\log\tan\varepsilon)' \\
e^{\phi-3A} &= \cos\varphi\cos\varepsilon \\
\xi &= \frac{3}{2W}e^{A-B}\sin\theta
\end{aligned}
$$

New $\mathcal{N} = 2$ IIA vacua

- All conditions of the scalar ansatz are satisfied
- All BI's and EOM's are satisfied
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The solution

$$\zeta' = \frac{1}{2W} e^{2(A-C)} \cos\theta \cot\varepsilon \sin^2\varphi (\log\tan\varepsilon)'$$

$$\theta' = \cot\theta \left(\frac{1}{2W} e^{2(A-C)} \sin^2\theta - 1 \right) (\log\tan\varepsilon)'$$

$$C' = -\frac{1}{4W} e^{2(A-C)} (\sin^2\varphi + \cos^2\theta)(\log\tan\varepsilon)'$$

Outline

New susy IIB vacua

Local SU(2) structure

$$K = e^{A(t)}\,(i dt - 3u)$$

$$\begin{pmatrix} \tilde{J} \\ \mathrm{Re}\,\omega \\ \mathrm{Im}\,\omega \end{pmatrix} = e^{2A(t)}\mathcal{R}(\theta(t)) \begin{pmatrix} \alpha \\ \beta \\ \gamma \end{pmatrix}$$

Metric on $\mathcal{M}_6$

$$ds_E^2 = ds^2(AdS_4) + \frac{6}{5W^2} ds_{KE}^2 + 9\,u \otimes u + dt^2$$

- $\mathcal{M}_6$ is the product of squashed 5D S-E and S^1 or $\mathbb{R}$.

New susy IIB vacua

- All conditions of the scalar ansatz are satisfied
- All BI's and EOM's are satisfied
- All fields are determined

The solution

$$\begin{aligned} H &= \frac{1}{2} W \mathrm{Re}\omega \wedge dt - \left(2A'\widetilde{J} + ce^{-4A}\mathrm{Re}\omega\right) \wedge u \\ e^{\phi} F_1 &= -2ce^{-4A} dt \\ e^{\phi} F_3 &= -\frac{1}{2} W\widetilde{J} \wedge dt + \left(2A'\mathrm{Re}\omega - ce^{-4A}\widetilde{J}\right) \wedge u \\ e^{\phi} F_5 &= \frac{3}{2} W\widetilde{J} \wedge \widetilde{J} \wedge u \end{aligned}$$

New susy IIB vacua

- All conditions of the scalar ansatz are satisfied
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The solution

$$\phi = 4A$$

$$e^{\phi} = \begin{cases} \frac{2}{\sqrt{5}} \left|\frac{c}{W}\right| \cosh\left[\sqrt{5}W(t-t_0)\right] , & c \neq 0 \\ \exp\left[\sqrt{5}W(t-t_0)\right] , & c = 0 \end{cases}$$

$$\tan(\theta-\theta_0) = \begin{cases} \tanh\left[\frac{\sqrt{5}}{2}W(t-t_0)\right] , & c \neq 0 \\ 0 , & c = 0 \end{cases}$$

Outline

Conclusions

Summary

- Given any 5D S-E manifold we have constructed corresponding families of new explicit IIA/IIB AdS_4 vacua
- Infinite number of families
- Pure flux
- Given any 4D K-E manifold we have constructed corresponding families of vacua

Outline

Conclusions

Open problems

- Implications for AdS_4/CFT_3 (specific models)
- Many more vacua? $\mathcal{N}=3$? (more CFT_3's than AdS_4's)
- General properties of flux vacua?
- Phenomenological applications

Thank You