Multi-scale Dynamics on the Baryonic Branch of Klebanov-Strassler

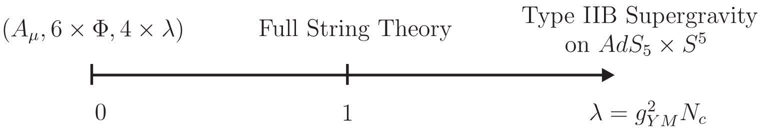
Daniel Elander

Tata Institute of Fundamental Research

arXiv:1104.3963 [hep-th]
(with Jérôme Gaillard, Carlos Núñez, and Maurizio Piai)
arXiv:0908.2808 [hep-th]
(with Carlos Núñez and Maurizio Piai)

Holography:

- The most familiar and simple example is AdS/CFT where $\mathcal{N} = 4$ SYM is dual to Type IIB String Theory on $AdS_5 \times S^5$:



- Many generalizations, for example based on the conifold and its variations, and deformations of $\mathcal{N} = 4$ SYM
- It is interesting to look at backgrounds with less supersymmetry, and for which conformal invariance is broken

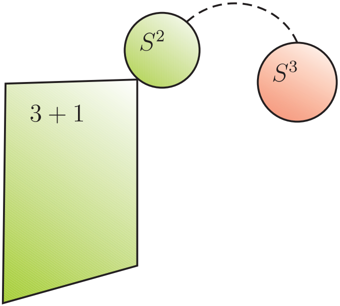
Introduction

Outline of talk:

- D5 System
- Walking Dynamics
- Rotated Solutions and Klebanov-Strassler
- Summary and Outlook

D5 System

Set-up:



- D5-branes wrapped on S^2
- This gives us an $\mathcal{N}=1$ SUSY field theory

D5 System

- Type IIB supergravity ansatz (ds^2, F_3, ϕ):

$$
\begin{aligned}
ds^2 =& e^{\frac{\phi}{2}}\Big[dx_{1,3}^2 + e^{2k}d\rho^2 + e^{2h}(d\theta^2 + \sin^2\theta d\varphi^2) + \\
& \frac{e^{2g}}{4}\Big((\tilde\omega_1 + ad\theta)^2 + (\tilde\omega_2 - a\sin\theta d\varphi)^2\Big) + \frac{e^{2k}}{4}(\tilde\omega_3 + \cos\theta d\varphi)^2\Big], \\
F_3 =& \frac{N_c}{4}\Big[-(\tilde\omega_1 + bd\theta)\wedge(\tilde\omega_2 - b\sin\theta d\varphi)\wedge(\tilde\omega_3 + \cos\theta d\varphi) + \\
& d\rho\wedge(b'(-d\theta\wedge\tilde\omega_1 + \sin\theta d\varphi\wedge\tilde\omega_2)) + (1-b^2)\sin\theta d\theta\wedge d\varphi\wedge\tilde\omega_3\Big],
\end{aligned}
$$

with

$$
\begin{aligned}
\tilde\omega_1 =& \cos\psi d\tilde\theta + \sin\psi\sin\tilde\theta d\tilde\varphi, \\
\tilde\omega_2 =& -\sin\psi d\tilde\theta + \cos\psi\sin\tilde\theta d\tilde\varphi, \\
\tilde\omega_3 =& d\psi + \cos\tilde\theta d\tilde\varphi.
\end{aligned}
$$

D5 System

Finding solutions:

- Write down BPS equations for the background fields $\{g, k, h, \phi, a, b\}$
- These can be repackaged into a single second order differential equation (Hoyos, Nunez, Papadimitriou 2008):

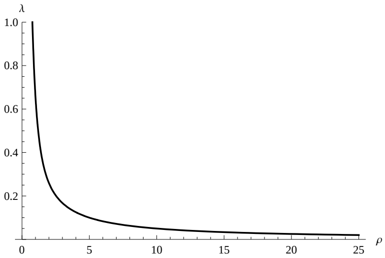
$$P'' + P'\left[\frac{P'+Q'}{P-Q} + \frac{P'-Q'}{P+Q} - 4\coth(2\rho)\right] = 0,$$
$$Q(\rho) = N_c(2\rho\coth(2\rho) - 1)$$

- Map from P to solutions in Type IIB supergravity: $P \to \{g, k, h, \phi, a, b\}$

D5 System

Example: Maldacena-Nunez ($P = 2N_c\rho$)

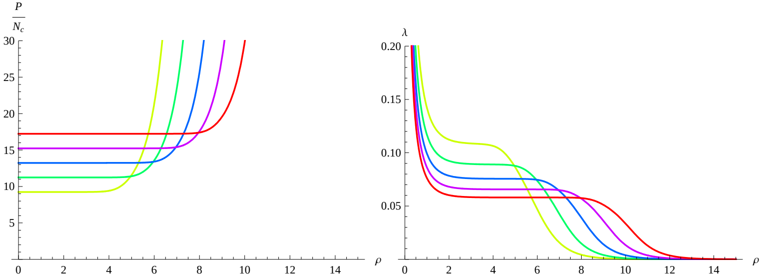
- Non-singular: in the IR, S^2 shrinks to zero size, while the size of S^3 stays finite (like the deformed conifold)
- 4d gauge coupling constant $\lambda = \frac{g^2 N_c}{8\pi^2} = \frac{N_c \coth\rho}{P}$



- One scale: set by gaugino condensate

Walking Dynamics

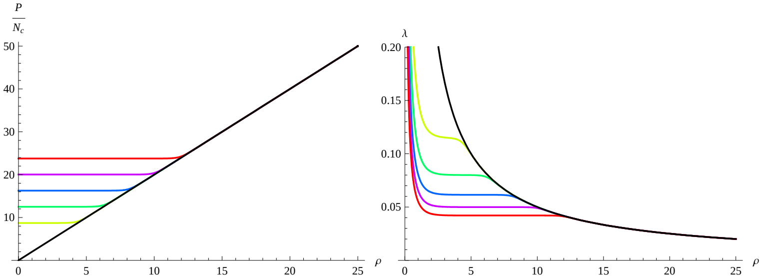
Walking backgrounds (UV behaviour: $P \sim e^{4\rho/3}$):
(Nunez, Papadimitriou, Piai 2008)



Two scales: gaugino condensate and end of walking region ρ_*

Walking Dynamics

Walking backgrounds (UV behaviour: Maldacena-Nunez): (DE, Nunez, Piai 2009)



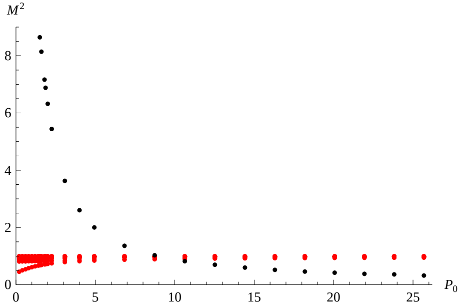
Two scales: gaugino condensate and end of walking region ρ_*

Walking Dynamics

Why is the walking dynamics interesting?

- These models have similarities with Walking Technicolor
- Because of the strongly coupled dynamics, holography is a natural framework
- Question: do we have spontaneous breaking of approximate scale invariance implying a light scalar (the dilaton, pseudo-Goldstone boson of dilatations)?

Spectrum of scalar glueballs for different values of $P_0 \simeq 2\rho_*$ (in units of $g_s\alpha' N_c$):



Light scalar whose mass is suppressed by the length of the walking region

Walking Dynamics

UV behaviour of the walking backgrounds:

- Not asymptotically AdS (either MN or dim-8 operator)
- The dictionary is less well-defined
- It is not easy to identify the QFT that is dual to a particular geometry

Rotated Solutions and Klebanov-Strassler

Solution generating technique (Maldacena, Martelli 2009):

- Start with a solution to the D5 system (ds^2, F_3, ϕ)
- Generate a new (rotated) solution $(ds^{(r)2}, F_3^{(r)}, H_3^{(r)}, F_5^{(r)}, \phi^{(r)})$:

$$
\begin{aligned}
ds^{(r)2} &= e^{\phi/2}\Big[\left(1-\kappa^2 e^{2\phi}\right)^{-1/2} dx_{1,3}^2 + \left(1-\kappa^2 e^{2\phi}\right)^{1/2} ds_6^2\Big],\\
\phi^{(r)} &= \phi,\\
F_3^{(r)} &= F_3,\\
H_3^{(r)} &= -\kappa e^{2\phi} *_6 F_3,\\
F_5^{(r)} &= -\kappa(1+*_{10})\mathrm{vol}_{(4)} \wedge d\left(e^{-2\phi}-\kappa^2\right)^{-1}
\end{aligned}
$$

- D5 system $\rightarrow$ D5/D3 system
- Preserves SUSY

Rotated Solutions and Klebanov-Strassler

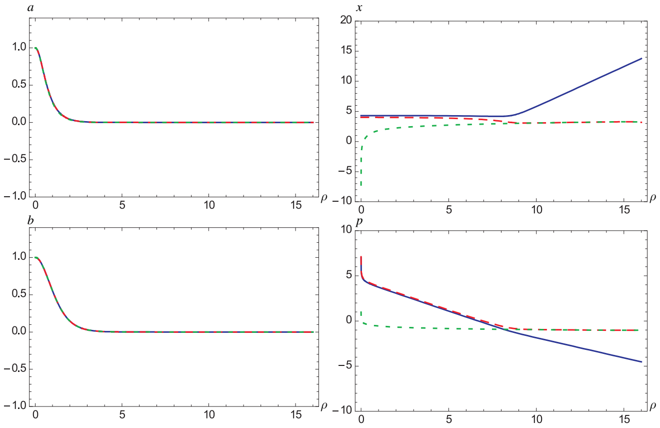
- Apply to the walking backgrounds with $P \sim e^{4\rho/3}$ in the UV (dim-8 operator)
- For $\kappa = e^{-\phi_{UV}}$, the rotated backgrounds behave asymptotically like Klebanov-Strassler in the UV
- The field theory dual to KS is more well-understood: $SU(N+M) \times SU(N)$ gauge group, bifundamental matter A_i and B_i ($i = 1, 2$) in representations $(N+M, \overline{N})$ and $(\overline{N+M}, N)$, superpotential $\mathcal{W} = \lambda_1 \mathrm{Tr}(A_i B_j A_k B_l) \epsilon^{ik} \epsilon^{jl}$

Rotated Solutions and Klebanov-Strassler

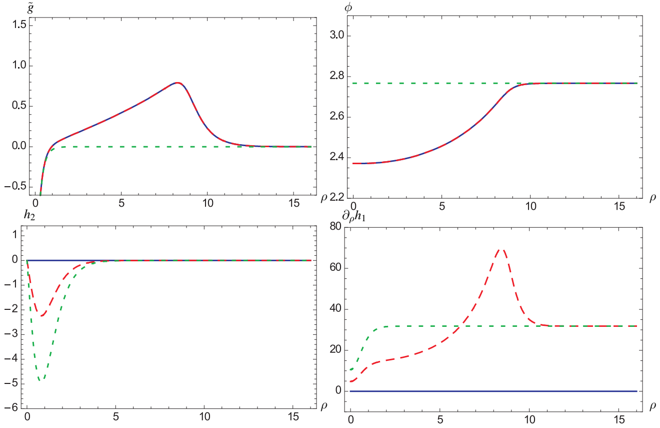
Properties of the rotated solutions $(\kappa = e^{-\phi_{UV}})$:

- The dim-8 operator is no longer present, making the UV well-defined
- There is a dim-3 VEV, the gaugino condensate
- There is a dim-2 VEV, $\langle \mathrm{Tr}(A\bar{A} - B\bar{B}) \rangle \neq 0$, signalling that we are on the baryonic branch of Klebanov-Strassler
- There is a dim-6 VEV, $\langle \mathrm{Tr} W^2 \bar{W}^2 \rangle \neq 0$
- Compute Wilson loops $\Rightarrow$ confinement

Background functions (Unrotated, Rotated, KS):



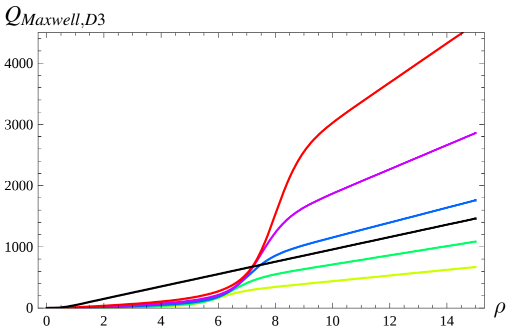
Background functions (Unrotated, Rotated, KS):



Rotated Solutions and Klebanov-Strassler

- The scale of both the dim-2 and dim-6 VEVs is at ρ_*
- Below this scale, the rotated and unrotated solutions are almost the same
- This suggests that the unrotated solution is an <u>effective</u> description of the rotated solution, valid at scales below ρ_*

Maxwell charge ($Q_{Maxwell,D3} \sim \int_{\Sigma_5} F_5$):



Sudden drop in the number of degrees of freedom at scale ρ_*

Rotated Solutions and Klebanov-Strassler

Picture (suggested from gravity solution):

- Flowing from the UV, the theory undergoes a duality cascade $SU(N+M)\times SU(N)\to SU(N)\times SU(N-M)\to\dots$
- This proceeds until the scale ρ_* where, being on the baryonic branch, the gauge group is Higgsed: $SU(\tilde{N}+\tilde{M})\times SU(\tilde{N})\to SU(\tilde{N})$
- Consistent with 1. the sudden drop in the number of degrees of freedom at ρ_*, and 2. that below ρ_* the theory is described by the D5 system which has a <u>single</u> gauge group
- Integrating out heavy modes generates the dim-8 operator of the (effective) unrotated theory

Summary

- We have described a system of wrapped D5-branes with solutions that have walking dynamics
- Applying a solution generating technique to these, we have found new Type IIB SUGRA solutions whose UV is similar to Klebanov-Strassler
- We have proposed the interpretation that these 'rotated' solutions are the UV completion of the 'unrotated' ones, which should be thought of as effective descriptions valid below the scale ρ_*

Outlook

- Compute spectrum
- There is (mild) singularity in the IR — can it be resolved?
- More general backgrounds in which the scales of the dim-2 and dim-6 VEVs are not the same