

AdS₃ vacua and surface defects in massive IIA

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We summarize the results and the ideas in [1–3] where new warped AdS₃ backgrounds are derived in massive IIA string theory by uplifting exact solutions in $\mathcal{N} = 1, d = 7$ and $\mathcal{N} = (1, 1), d = 6$ gauged supergravities. These solutions are respectively asymptotically AdS₇ and AdS₆ and they are related to the D2-D4-NS5-D6-D8 brane intersection. We provide a particular supergravity solution in 10d describing this bound state and we discuss the relations between its near-horizon geometry and the uplifts from 6d and 7d. Then we give the holographic interpretations of these AdS₃ warped backgrounds in terms of $\mathcal{N} = (0, 4)$ defect SCFT₂ within the $\mathcal{N} = (1, 0)$ SCFT₆ and the $\mathcal{N} = 2$ SCFT₅.

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1. Introduction

In this proceeding we will consider two particular realizations of defect conformal field theories realized in massive IIA string theory [1–3].

A defect CFT is defined by degrees of freedom localized on a boundary embedded in the background of a higher-dimensional CFT [4]. From the point of view of this higher-dimensional theory, the defect is described by a deformation related to a position-dependent coupling. This deformation breaks partially the conformal isometries in the bulk and, as a consequence, the 1-point functions are no longer vanishing. Moreover a non-trivial displacement operator appears and this is due to the fact of that the energy-momentum tensor is not conserved anymore.

The first examples¹ of defect in string theory were given in [25]. The idea is to look at the emerging of defect CFTs as the result of the interesection of some “defect branes” ending on a given brane system, with an AdS vacuum at the near-horizon. The defect branes break partially the isometries of the AdS vacuum of the original brane setup producing a lower-dimensional warped AdS background. The degrees of freedom of the defect CFT are related to the boundary conditions of the intersection and the warping of the corresponding supergravity background is associated to the backreaction of the defect branes onto the bulk. This is the supergravity interpretation of the position-dependent deformation of the SCFT, holographically dual to the original higher-dimensional AdS near-horizon.

More explicitly, let’s consider a supersymmetric AdS_d vacuum associated to the near-horizon of a brane system and let’s assume the existence of a compactification linking the 10d (or 11d) physics to a solution in a d -dimensional gauged supergravity. The interesection with defect branes ending on the system will be given by a bound state with a $(p + 1)$ -dimensional worldvolume described by a d -dimensional spacetime background of the type

$$ds_d^2 = e^{2U(r)} ds_{\text{AdS}_{p+2}}^2 + e^{2V(r)} dr^2 + e^{2W(r)} ds_{d-p-3}^2. \quad (1.1)$$

This background is characterized by a AdS_{p+2} foliation and an asymptotic behavior locally given by the AdS_d vacuum of the theory. Moreover (1.1) can be uplifted and it reproduces a warped geometry of the type AdS_{p+2} × \mathcal{M}_{d-p-2} × Σ_{D-d} , where \mathcal{M}_{d-p-2} is given by a fibration of the $(d - p - 3)$ -dimensional internal manifold over the interval I_r and Σ_{D-d} is the internal manifold characterizing the particular truncation. The holographic picture of this supergravity configuration is that of a defect SCFT_{p+1} within the SCFT_{d-1} dual to AdS_d vacuum.

In this proceeding we summarize the ideas and the main results of [1–3] where new warped AdS₃ backgrounds are constructed explicitly from $\mathcal{N} = 1$, 7d and $\mathcal{N} = (1, 1)$, 6d gauged supergravities. These backgrounds are interpreted in massive IIA string theory as 2d defect superconformal field theories within the $\mathcal{N} = (1, 0)$ SCFT₆ and the $\mathcal{N} = 2$ SCFT₅ respectively dual to the AdS₇ and AdS₆ vacua describing the asymptotics of our solutions. In order to construct the holographic interpretation in terms of conformal defects, we will consider two particular brane systems in massive IIA string theory, namely the NS5-D6-D8 interesection [26] and the D4-D8 system [27]. The supergravity solutions describing these intersections are described at the horizon respectively by AdS₇ × S³ and AdS₆ × S⁴ warped gemoetries. We will present a general 10d background reproducing the interesection of these two bound states with some new defect branes, respectively

¹For a non-exhaustive list of references on conformal defects in string theory and holography see [5–24].

D2-D4 and D2-NS5-D6. The effect of these new branes will be that of break some of the isometries of the AdS₇ and AdS₆ vacua in a way that the near-horizon will be now given by a background of the type AdS₃ × S³ × S² × I². Up to a change of coordinate, this near-horizon geometry reproduces the uplifts of the 6d and 7d solutions with whom we started our analysis. Starting from this we will give the holographic interpretation of these AdS₃ slicings found in 6d and 7d supergravities in terms of a defect $\mathcal{N} = (0, 4)$ SCFT₂ within $\mathcal{N} = (1, 0)$ SCFT₆ and $\mathcal{N} = 2$ SCFT₅. Then we will conclude by discussing the derivation of the 1-point functions of these defects by using holographic methods and conformal perturbation expansion.

2. The Setup

In this section we review the main properties of the NS5-D6-D8 and D4-D8 brane setups in massive IIA string theory. These brane setups give rise to the warped vacua AdS₇ × S³ and AdS₆ × S⁴, and to their dual² descriptions respectively given in terms of $\mathcal{N} = (1, 0)$ SCFT₆ and $\mathcal{N} = 2$ SCFT₅. Moreover massive IIA admits two consistent truncations around the above vacua reproducing respectively $d = 7$, $\mathcal{N} = 1$ and $d = 6$, $\mathcal{N} = (1, 1)$ gauged supergravities. These two supergravities will constitute the playground used to generate warped AdS₃ solutions describing conformal surface defects in the brane setups considered.

Let's firstly consider the construction originally proposed in [26]. This brane system involves D6 branes stretched along D8 branes with NS5 branes completely inside the D6s. The NS5 describe the interface between the D6 and the D8 and their mutual distance defines the gauge coupling of the 6d worldvolume theory of the brane intersection. This brane setup is described, in the low-

branes	t	y^1	y^2	y^3	y^4	y^5	z	r	θ^1	θ^2
NS5	×	×	×	×	×	×	—	—	—	—
D6	×	×	×	×	×	×	×	—	—	—
D8	×	×	×	×	×	×	—	×	×	×

Table 1: The brane picture of the $\mathcal{N} = (1, 0)$ SCFT₆ described by a NS5-D6-D8 system. This system is BPS/4. Note that the radial coordinate realizing to the AdS₇ geometry is given by a combination of z and r .

energy regime, by an infinite class of warped AdS₇ × S³ vacua at the horizon preserving 16 real supercharges and a SO(3) symmetry (as hinted in [31] and clarified in [45]). These string vacua were originally found in [30] as BPS solutions of massive type IIA supergravity by using the pure spinor formalism (see also [32, 33, 46] for further details). The internal 3-sphere is squashed and it is described locally as a S²-fibration over a segment. From the point of view of the brane picture the D6-branes fill AdS₇ and are completely localized at the poles of the 3-sphere. Finally the D8-branes wrap the S². In [31] the dual interpretation of the AdS₇ vacua in massive IIA is formulated in terms of linear quivers realizing a $\mathcal{N} = (1, 0)$ SCFT₆ emerging as a fixed point of the 6d Yang-Mills worldvolume theory.

These AdS₇ solutions define a warped compactification on the squashed S³ [46]. This dimensional reduction implies that the physics of massive IIA string theory around the AdS₇ × S³ vacua is

²For a non-exhaustive list on AdS₇/CFT₆ and AdS₆/CFT₅ correspondences see [26, 28–32, 32–44].

captured by the minimal³ realization of $\mathcal{N} = 1$, 7d gauged supergravity. In particular the bosonic fields involved into the 7d supergravity multiplet are

$$g_{\mu\nu}, \quad X, \quad \mathcal{B}_{(3)\mu\nu\rho}, \quad A_\mu^i, \quad (2.1)$$

where X is a real scalar, $\mathcal{B}_{(3)}$ is a 3-form gauge potential and A_μ^i an $SU(2)$ -triplet of gauge vectors. The theory is driven by a scalar potential for X depending on the coupling g associated to the gauging of the R-symmetry group $SU(2)_R$ and on a topological mass h for the 3-form. This 7d supergravity realization will constitute the main setup used to find massive IIA solutions describing conformal defects within the $\mathcal{N} = (1,0)$ SCFT₆.

The other brane setup that we consider is the well-known D4-D8 system where N D4 branes are completely localized on D8 branes with O8 planes on top [27, 47]. The supergravity solution describing the low-energy regime of this system is related to an $AdS_6 \times S^4$ geometry at the horizon [27, 48, 49]. The holographic interpretation of this vacuum was constructed in [27, 47, 50] in terms

branes	t	y^1	y^2	y^3	y^4	z	ρ	θ^1	θ^2	θ^3
D8	×	×	×	×	×	—	×	×	×	×
D4	×	×	×	×	×	—	—	—	—	—

Table 2: The brane picture underlying the 5d $\mathcal{N} = 2$ SCFT defined by the D4-D8 system. The system is BPS/4 and the $AdS_6 \times S^4$ vacuum is realized by a combination of ρ and z .

of a $\mathcal{N} = 2$ SCFT₅ with a $Usp(N)$ gauge group and couplings to fundamental and antisymmetric hypermultiplets.

This vacuum preserves 16 supercharges and $SO(4)$ symmetry. It induces a warped compactification [51] of massive IIA on the 4-sphere to the so-called Romans supergravity [52], namely the minimal realization of $\mathcal{N} = (1,1)$, 6d gauged supergravity. The bosonic content of the supergravity multiplet of this theory is given by

$$g_{\mu\nu}, \quad X, \quad \mathcal{B}_{(2)\mu\nu}, \quad A_\mu^0, \quad A_\mu^i, \quad (2.2)$$

where X is a real scalar, $\mathcal{B}_{(2)}$ is a 2-form gauge potential, A_μ^0 is an abelian vector and A_μ^i an $SU(2)$ -triplet of gauge vectors. The gauging of the theory is very similar to the above 7d case. The theory is driven by a scalar potential for X depending on a coupling g associated to the gauging of the R-symmetry group $SU(2)_R$ and on a topological mass m for the 2-form. This 6d supergravity will constitute the main setup used to find solutions associated to conformal defects within the $\mathcal{N} = 2$ SCFT₅.

3. Warped $AdS_3 \times S^3 \times S^2 \times I^2$ Backgrounds

Let's consider now the two lower-dimensional supergravities introduced in the previous section, namely $\mathcal{N} = 1$, 7d and $\mathcal{N} = (1,1)$, 6d gauged supergravities in their minimal realization.

³Only the supergravity multiplet is retained in the compactification.

For the bosonic field content given respectively in (2.2) and (2.1), we will consider the following backgrounds [1, 3],

$$ds_{6,7}^2 = e^{2U(r)} ds_{\text{AdS}_3}^2 + e^{2V(r)} dr^2 + e^{2W(r)} ds_{\Sigma_{2,3}}^2, \quad (3.1)$$

with $\Sigma_{2,3} = \{S^2, S^3\}$ respectively for the 6d and 7d cases. As far it regards the scalar we will suppose in both cases that $X = X(r)$. Furthermore for simplicity we will consider all the vectors vanishing, while for the p -form gauge potential we will require that

$$\begin{aligned} 7d: \quad \mathcal{B}_{(3)} &= k(r) \text{vol}_{\text{AdS}_3} + l(r) \text{vol}_{S^3}, \\ 6d: \quad \mathcal{B}_{(2)} &= b(r) \text{vol}_{S^2}. \end{aligned} \quad (3.2)$$

In [1, 3], the BPS equations for (3.1) are derived and solved for the cases of two independent warp factors U and W , and for the case of one single warp factor $U = W$.

Let consider the second case. The assumption $U = W$ implies that $k = l$ for the 7d 3-form (3.2). The BPS equations become in this case very simple and their solution in the 7d case is given by

$$\begin{aligned} e^{2U} &= \frac{2^{-1/4}}{g^{1/2}} \left(\frac{r}{1-r^5} \right)^{1/2}, \quad e^{2V} = \frac{25}{2g^2} \frac{r^6}{(1-r^5)^2}, \\ k &= -\frac{2^{1/4}L}{g^{3/2}} \left(\frac{r^5}{1-r^5} \right)^{1/2}, \quad X = r, \end{aligned} \quad (3.3)$$

where r ranges from 0 to 1 and the two gauge coupling g and h satisfy the relation $h = \frac{g}{2\sqrt{2}}$. In the 6d case the solution of the BPS equation takes the following form

$$\begin{aligned} e^{2U} &= \frac{2^{-1/3}}{g^{2/3}} \left(\frac{r'}{1-r'^5} \right)^{2/3}, \quad e^{2V} = \frac{8}{g^2} \frac{r'^4}{(1-r'^4)^2}, \\ b &= -\frac{2^{1/3}3L}{g^{4/3}} \left(\frac{r'^4}{1-r'^4} \right)^{1/3}, \quad X = r', \end{aligned} \quad (3.4)$$

where also in this case r' ranges from 0 to 1 and the gauge coupling g and m satisfy the relation $m = \frac{\sqrt{2}g}{3}$. For $r \& r' \rightarrow 1$, these solutions are locally described by AdS₇ and AdS₆ geometries, while, for $r \& r' \rightarrow 0$, they manifest singular behaviors.

The goal is to interpret the singularities appearing in the $r \rightarrow 0$ and $r' \rightarrow 0$ limits in terms of some brane sources. If one consider the uplifts of the asymptotic regime of the solutions (3.3) and (3.4), one obtains the AdS₇ \times S^3 and AdS₆ \times S^4 vacua, while for other value of r and r' one obtains two AdS₃ \times $S^3 \times S^2 \times I^2$ warped background that are very similar for their geometric properties. In particular

$$\begin{aligned} 7d: \quad \text{AdS}_3 \times S^3 \times I_r &\longrightarrow 10d: \quad \text{AdS}_3 \times S^3 \times I_r \times S^2 \times I_\xi \\ 6d: \quad \text{AdS}_3 \times S^2 \times I_{r'} &\longrightarrow 10d: \quad \text{AdS}_3 \times S^2 \times I_{r'} \times S^3 \times I_{\xi'}, \end{aligned} \quad (3.5)$$

where the coordinates ξ and ξ' respectively describes the fibrations coordinates of the warped compactifications of massive IIA on the squashed 3-sphere and 4-sphere. The structure of the fluxes and the same number of supersymmetries preserved hints that the 10d backgrounds obtained by

uplifting from 6d and 7d could be the same background up to a change of coordinates, namely $(r, \xi) \rightarrow (r', \xi')$. Unfortunately it is very complicated to derive the explicit form of this change of coordinate because of the highly non-linear dependence of the warp factors in the uplift expressions.

4. The D2-D4-NS5-D6-D8 System and Conformal Defects

The two solutions in 6d and 7d written in (3.3) and (3.4) are asymptotically locally AdS₇ and AdS₆. As we said in the previous section, from the 10d point of view these are the two warped vacua AdS₇ × S³ and AdS₆ × S⁴. This means that, if we want to search for a brane setup described by a AdS₃ near-horizon of the type of (3.5), we have to consider supergravity solutions including as particular limits the solutions of the bound states NS5-D6-D8 and D4-D8 with some new defect branes breaking the isometries of the above vacua.

For the 7d case this solution can be derived exactly and it describes the intersection of a D2-D4 bound state with the NS5-D6-D8 one. The brane solution of the general intersection is given by [2]

branes	t	y	ρ	φ^1	φ^2	φ^3	z	r	θ^1	θ^2
NS5	×	×	×	×	×	×	—	—	—	—
D6	×	×	×	×	×	×	×	—	—	—
D8	×	×	×	×	×	×	—	×	×	×
D2	×	×	—	—	—	—	×	—	—	—
D4	×	×	—	—	—	—	—	×	×	×

Table 3: The brane picture of the $\mathcal{N} = (0, 4)$ defect SCFT₂ associated to D2- and D4-branes ending on an NS5-D6-D8 intersection. The above system is BPS/8.

$$\begin{aligned}
ds_{10}^2 &= S^{-1/2} H_{D2}^{-1/2} H_{D4}^{-1/2} ds_{\text{Mkw}_2}^2 + S^{-1/2} H_{D2}^{1/2} H_{D4}^{1/2} \left(d\rho^2 + \rho^2 d\Omega_{(3)}^2 \right) + \\
&\quad + K S^{-1/2} H_{D2}^{-1/2} H_{D4}^{1/2} dz^2 + K S^{1/2} H_{D2}^{1/2} H_{D4}^{-1/2} \left(dr^2 + r^2 d\Omega_{(2)}^2 \right) , \\
e^\Phi &= g_s K^{1/2} S^{-3/4} H_{D2}^{1/4} H_{D4}^{-1/4} , \\
H_{(3)} &= \frac{\partial}{\partial z} (KS) \text{vol}_{(3)} - dz \wedge *_{(3)}(dK) , \\
F_{(0)} &= m , \\
F_{(2)} &= -g_s^{-1} *_{(3)}(dS) , \\
F_{(4)} &= g_s^{-1} \text{vol}_{(1,1)} \wedge dz \wedge dH_{D2}^{-1} + *_{(10)} \left(\text{vol}_{(1,1)} \wedge \text{vol}_{(3)} \wedge dH_{D4}^{-1} \right) ,
\end{aligned} \tag{4.1}$$

where the functions $K(z, r)$ and $S(z, r)$ satisfy [49]

$$\begin{cases} mg_s K - \frac{\partial S}{\partial z} = 0 , \\ \Delta_{(3)} S + \frac{1}{2} \frac{\partial^2}{\partial z^2} S^2 = 0 , \end{cases} \tag{4.2}$$

while

$$H_{D2}(\rho, r) = \left(1 + \frac{q_{D4}}{\rho^2}\right) \left(1 + \frac{q_{D6}}{r}\right), \quad H_{D4}(\rho) = \left(1 + \frac{q_{D4}}{\rho^2}\right). \quad (4.3)$$

As it has been showed in [2], the solution (4.1) reproduces the near-horizon geometry AdS₃ × S³ × S² × I². Moreover by comparing the fluxes and the supersymmetries preserved the conclusion is that, up to a change of the fibration-coordinates, this near-horizon reproduces the uplift of the 7d solution (3.3).

The 6d case is analogous, but now the isometries of the AdS₆ vacuum are broken by the intersections of the defect branes D2-NS5-D6 [3]. The general form of the 10d solution is the

branes	t	y	ρ	φ^1	φ^2	φ^3	z	r	θ^1	θ^2
D8	×	×	×	×	×	×	—	×	×	×
D4	×	×	—	—	—	—	—	×	×	×
D2	×	×	—	—	—	—	×	—	—	—
NS5	×	×	×	×	×	×	—	—	—	—
D6	×	×	×	×	×	×	×	—	—	—

Table 4: The brane picture of the $\mathcal{N} = (0, 4)$ defect SCFT₂ produced by D2-NS5-D6 branes ending on an D4-D8 bound state. The system is BPS/8.

same of (4.1), but clearly now the explicit form of the warp factors appearing in (4.1) is different, i.e. the parametrization of the AdS₃ near-horizon is different respect to that one obtained from the solution (4.3). Unfortunately we don't have an explicit form of the warp factors in this case, but the structure of fluxes and the supersymmetry preserved by the uplift of the 6d AdS₃ solution in (3.5) are the same of the near-horizon obtained from (4.3).

The holographic interpretation of these AdS₃ solution is given in terms of a $\mathcal{N} = (0, 4)$ SCFT₂ realizing a surface defect respectively within the $\mathcal{N} = (1, 0)$ SCFT₆ and $\mathcal{N} = 2$ SCFT₅. In order to show that the 2d defect SCFTs corresponding to the 6d and 7d cases are actually the same, one should provide an explicit change of coordinates within the two uplifts (3.5), but the above arguments there is a quite strong evidence on their equivalence.

Finally we checked this holographic interpretation by sketching the calculation of the 1-point functions. The presence of the defect breaks some of the conformal isometries so as a first check it is interesting to see if the position-dependence of the coupling of the deformation describing the defect is the same when it is calculated using the standard holographic dictionary on one side (extracting the 1-point functions from the asymptotic expansion of the supergravity background) and on the other side by considering a conformal perturbation expansion of the correlation functions [8]. Supposing that the deformation is driven in both cases by the scalar X , we obtain the same behaviors in both case 6d and 5d cases, namely [2, 3]

$$\begin{aligned} \langle \mathcal{O}_X \rangle_{6d} &\sim x^{-4}, \\ \langle \mathcal{O}_X \rangle_{5d} &\sim x^{-3}, \end{aligned} \quad (4.4)$$

where x is the radial coordinate of the AdS₃ slicings of (3.3) and (3.4).

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