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AdS_5 Superalgebras with Brane Charges

S. Ferrara[a], M. Porrati[a,b1]

(a) *Theory Division CERN, Ch 1211 Geneva 23, Switzerland*

(b) *Department of Physics, NYU, 4 Washington Pl., New York, NY 10003, USA*[2]

ABSTRACT

We consider the inclusion of brane charges in AdS_5 superalgebras that contain the maximal central extension of the super-Poincaré algebra on ∂AdS_5. For theories with N supersymmetries on the boundary, the maximal extension is $OSp(1/8N)$, which contains the group $Sp(8N, R) \supset U(2N, 2N) \supset SU(2, 2) \times U(N)$ as extension of the conformal group. An "intermediate" extension to $U(2N, 2N/1)$ is also discussed. BPS conditions on boundary states are studied in some details.

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[1]e-mail: sergio.ferrara@cern.ch, massimo.porrati@nyu.edu
[2]Permanent Address

1 Introduction

It is well known that the classification of superalgebras, containing the anti-de Sitter –i.e. conformal– superalgebra has a barrier at dimension $D = 7$ [1]. This result is based on the assumption that the bosonic subalgebra of the superalgebra is the "direct product" of the conformal algebra $O(D-1, 2)$ with an internal symmetry group G. This classification can be viewed, essentially, as an extension of the Haag-Lopuszanski-Sohnius theorem [2] for $D > 4$.

On the other hand, in dynamical theories with extended objects, it is already known that the super-Poincaré algebras do include, in any dimension, "central" charges [3, 4, 5, 6, 7] which at first sight violate the above assumption.

It is then natural to consider the same generalization when such charges of rank p are introduced in the AdS superalgebra rather than in its Poincaré counterpart. Such extension has been studied in the literature with the goal of constructing an eleven-dimensional theory in AdS space [8, 9], or a conformal theory in ten dimensions [6].

The result of these investigations is that the conformal extension of the $D = 10$ $N = 1$ Poincaré superalgebra is $OSp(1/32)$, in which $Sp(32) \supset O(10, 2)$.

In the present paper, we consider a similar extension in the context of AdS_5 supergravity. The difference here is that AdS_5 superalgebras already exist. In the absence of p-brane charge, they correspond to the usual superconformal algebras $U(2, 2/N)$, which occur in the classification of Haag, Lopuszanski and Sohnius (HLS) [2]. We consider here the AdS_5 superalgebra in the presence of AdS p-branes, and we show that, for any N-extended supergravity, such algebra is $OSp(1/8N)$, with the conformal group $O(4, 2) \sim SU(2, 2)$ embedded as follows in the real symplectic group $Sp(8N, R)$ [10]:

$$Sp(8N, R) \supset U(2N, 2N) \supset SU(2, 2) \times U(N). \tag{1}$$

Extensions of conformal superalgebras in $D = 5$ have been considered also in ref. [11], where worldsheet superalgebras for $D5$-branes in an AdS_5 background were proposed. Ref. [11] shows, among other things, that, in the presence of p-brane charges, the world-sheet superconformal group of a $D3$-brane in AdS_5, $U(2, 2/4)$, is extended to $OSp(1/32)$.

This paper is organized as follows: in Section 2, we consider the standard superalgebras in the 5-D Minkowski space, M_5, and in AdS_5, and view them as the starting blocks for further investigations. In Section 3 we consider the $OSp(1/8N)$ algebras as algebras in AdS_5 in the presence of AdS p-branes. In Section 4 we give a general, algebraic analysis of the BPS condition in AdS_5, and, in particular, we study the pattern of R-parity breaking induced by BPS p-branes. Section 5 contains a brief description of an additional "intermediate" conformal extension of the super-Poincaré algebra, and a comment on the uniqueness of such extensions.

2 Maximal Central Extensions of Poincaré Superalgebras

The maximal central extension of the Poincaré superalgebra with n spinorial components of the supersymmetry charges gives an algebra with $n(n+1)/2$ bosonic central charges [3], including the space-time translations. Examples of such extensions are the $N=1$ superalgebra in $D=11$ dimensions, in the presence of two- and five-brane charges, and the IIA and IIB algebras in ten dimensions, in the presence of NS and R brane charges [3, 4, 5, 6].

When the space-time dimension is sufficiently low, the maximal central extensions include also BPS domain walls and BPS instantons, as it becomes obvious if one regards such algebras obtained by dimensional reduction. It is relevant to this paper to recall the central extensions in dimensions $D=4,5$, because they will play an important role when the analogous five-dimensional superalgebra will be considered in AdS_5, and M_4 will be interpreted as its boundary.

The N-extended Poincaré superalgebra in $D=5$, with maximal central extension, has a $USp(2N)$ R-symmetry [12], and it reads

$$\{Q^A_\alpha, Q^B_\beta\} = (\gamma^\mu C)_{\alpha\beta} P_\mu \Omega^{AB} + (\gamma^\mu C)_{\alpha\beta} Z^{o\,[AB]}_\mu + C_{\alpha\beta} Z^{[AB]} + (\gamma^{\mu\nu} C)_{\alpha\beta} Z^{(AB)}_{\mu\nu}, \tag{2}$$

where $Z^{o\,[AB]}_\mu$, $Z^{[AB]}$ are in the antisymmetric of $USp(2N)$ ($Z^{o\,[AB]}_\mu$ is also symplectic-traceless: $\Omega_{AB} Z^{o\,[AB]}_\mu = 0$) and $Z^{(AB)}_{\mu\nu}$ is in the adjoint of $USp(2N)$.

The standard HLS [2] algebra is obtained by setting $Z^{o\,[AB]}_\mu = Z^{(AB)}_{\mu\nu} = 0$. These charges come from strings and membranes.

3 Anti-de Sitter and Conformal Superalgebras

The Anti-de Sitter superalgebra is a modification of the Poincaré superalgebra given in Eq. (2), where P_μ, $M_{\mu\nu}$ span the algebra of $O(4,2)$, and generators of $U(N)$ are included.

This is the AdS_5 superalgebra $U(2,2/N)$. This superalgebra can be formally obtained by decomposing $USp(2N) \rightarrow SU(N) \times U(1)$ in the former algebra:

$$\{Q^A_\alpha, Q_{B\,\beta}\} = (\gamma^\mu C)_{\alpha\beta} P_\mu \delta^A_B + (\gamma^{\mu\nu} C)_{\alpha\beta} M_{\mu\nu} \delta^A_B + (\gamma^{\mu\nu} C)_{\alpha\beta} Z^{o\,A}_{\mu\nu\,B} + (\gamma^\mu C)_{\alpha\beta} Z^{o\,A}_{\mu\,B} + C_{\alpha\beta} U^A_B, \tag{3}$$

$$\{Q^A_\alpha, Q^B_\beta\} = (\gamma^\mu C)_{\alpha\beta} Z^{[AB]}_\mu + C_{\alpha\beta} Z^{[AB]} + (\gamma^{\mu\nu} C)_{\alpha\beta} Z^{(AB)}_{\mu\nu}, \quad c.c., \quad \mu,\nu = 0,..,4. \tag{4}$$

Setting to zero all bosonic generators except P_μ, $M_{\mu\nu}$ and U^A_B, and promoting them to the (non-commutative) generators of the $SU(2,2) \times U(N)$ Lie algebra, with the fermionic generators in

[3] More precisely, they are bosonic central charges of the supertranslation algebra, which is a subalgebra of the super-Poincaré algebra.

the $(4,N)+(\bar{4},\bar{N})$ representation, the algebra becomes

$$\{Q^A_\alpha, Q_{B\,\beta}\} = (\gamma^\mu C)_{\alpha\beta} P_\mu \delta^A_B + (\gamma^{\mu\nu} C)_{\alpha\beta} M_{\mu\nu} + C_{\alpha\beta} U^A_B, \quad (5)$$

$$\{Q^A_\alpha, Q^B_\beta\} = \{Q^\alpha_A, Q^\beta_B\} = 0. \quad (6)$$

This is the standard AdS_5 superalgebra considered in the literature. If realized on the four-dimensional boundary, it corresponds to the HLS superconformal algebra in $D=4$, which is the conformal extension of the Poincaré superalgebra without central charges.

Let us now consider whether an AdS_5 superalgebra exists with non-vanishing Z generators. The Z should correspond somehow to brane charges in AdS_5.

The AdS_5 extension of the Poincaré superalgebra with charges given in Eqs. (3,4) is immediate. Namely, the Z generators in Eqs. (3,4) complete the superalgebra $OSp(1/8N,R)$. The $SU(2,2)\times U(N)$ generators are embedded as follows in $Sp(8N,R)$:

$$Sp(8N,R) \to U(2N,2N) \to SU(2,2)\times U(N). \quad (7)$$

As it is well known, the $Sp(8N,R)$ algebra has a three-grading with respect to the "dilation" generator, R in the decomposition $SU(2,2)\to SL(2,C)\times R$. Here, $SL(2,C)$ is the Lorentz group of the boundary of AdS_5. Indeed,

$$\mathcal{L}_{Sp(8N)} = \mathcal{L}^1 + \mathcal{L}^0 + \mathcal{L}^{-1}, \quad (8)$$

where $\mathcal{L}^1$ contains P_μ and all (dimension-1) central charges of the 4-D super-Poincaré algebra. $\mathcal{L}^{-1}$ contains K_μ and all (dimension -1) special-conformal central charges, while

$$\mathcal{L}^0 = SL(4N,R)\times R \quad (9)$$

is the Lie algebra which contains, among others, the generators of the Lorentz group on ∂AdS_5, and $U(N)$ [10]:

$$SL(4N,R) \to SL(2N,C)\times U(1) \to SL(2,C)\times SU(N)\times U(1). \quad (10)$$

The $OSp(1/8N)$ superalgebra has a 5-grading [9, 13, 14], in which the $\mathcal{L}^{\pm 1}$ subalgebras, in the symmetric representation of $SL(4N)$, are completed with the $8N$-dimensional fundamental representation of $Sp(8N,R)$, which splits under $SL(2,C)\times SU(N)\times U(1)$ as:

$$8N \to (1/2,0,N)^{1/2} + (0,1/2,N)^{-1/2} + (0,1/2,\bar{N})^{1/2} + (1/2,0,\bar{N})^{-1/2}. \quad (11)$$

This splitting corresponds to writing the AdS_5 spinor Q^A_α as $(Q^A_\alpha, \bar{S}^A_{\dot\alpha})$, and $Q_{\alpha\,A}$ as $(\bar{Q}_{\dot\alpha\,A}, S_{\alpha\,A})$. The spinor charges $(Q^A_\alpha, \bar{Q}_{\dot\alpha\,A})$, together with $\mathcal{L}^1$, form the maximal central extension of the super-Poincaré algebra in $D=4$, as found in ref. [7]. The $(S_{\beta\,A}, \bar{S}^A_{\dot\beta})$, together with $\mathcal{L}^{-1}$, form an isomorphic algebra, with the substitution $P_\mu \to K_\mu$ and $Z \to Z_S$. The generators in $\mathcal{L}^0$ appear in the mixed anti-commutators $\{Q, S\}$, as it follows from the general structure of the grading:

$$
\begin{array}{lcrcl}
 & & \{Q^A_\alpha, \bar{Q}_{\dot\beta\, B}\} & = & \sigma^\mu_{\alpha\dot\beta} P_\mu \delta^A_B + Z^A_{\alpha\dot\beta\, B}, \quad (Z^A_{\alpha\dot\beta\, A} = 0), \quad \mu = 0, ..3, \\
\mathcal{SP}^+ & : & \{Q^A_\alpha, Q^B_\beta\} & = & \epsilon_{\alpha\beta} Z^{[AB]} + Z^{(AB)}_{\alpha\beta}, \\
 & & & & c.c., \\
 & & \{S_{\alpha\, A}, \bar{S}^B_{\dot\beta}\} & = & \sigma^\mu_{\alpha\dot\beta} K_\mu \delta^B_A + Z^B_{S\,\alpha\dot\beta\, A}, \quad (Z^A_{S\,\alpha\dot\beta\, A} = 0), \\
\mathcal{SC}^- & : & \{S_{\alpha\, A}, S_{\beta\, B}\} & = & \epsilon_{\alpha\beta} Z_{S\,[AB]} + Z_{S\,\alpha\beta\,(AB)}, \\
 & & & & c.c., \\
 & & \{Q^A_\alpha, S_{\beta\, B}\} & = & [\epsilon_{\alpha\beta}(D + iU) + M_{\alpha\beta}]\delta^A_B + \epsilon_{\alpha\beta} U^{o\,A}_B + U^{o\,A}_{\alpha\beta\, B} \quad \text{(traceless)}, \\
\mathcal{L}^0 & : & \{Q^A_\alpha, \bar{S}^B_{\dot\beta}\} & = & W^{[AB]}_{\alpha\dot\beta} + W^{(AB)}_{\alpha\dot\beta}, \\
 & & & & c.c.,
\end{array}
$$

$$
\mathcal{L}_{OSp(1/8N)} = \mathcal{SP}^+ + \mathcal{L}^0 + \mathcal{SC}^-. \tag{12}
$$

The total number of generators of $Sp(8N, R)$ is $4N(8N+1)$, which splits, in this decomposition, as

$$
(\mathrm{Sym}\, GL(4N))^+ + (\mathrm{Adj}\, GL(4N)) + (\mathrm{Sym}\, GL(4N))^- \tag{13}
$$

$$
\dim \mathcal{P}^+ = \dim \mathcal{C}^- = 8N^2 + 2N, \tag{14}
$$

$$
\dim \mathcal{L}^0 = 16N^2. \tag{15}
$$

Note that in the usual conformal extension of the non-centrally extended $\mathcal{SP}$, that we call $\mathcal{P}_0$,

$$
\mathcal{L}_{U(2,2/N)} = \mathcal{SP}^+_0 + \mathcal{L}^0_0 + \mathcal{SC}^-_0, \tag{16}
$$

where $\dim \mathcal{P}^+_0 = \dim \mathcal{C}^-_0 = 4$, $\dim \mathcal{L}^0_0 = 15 + N^2$.

4 BPS States in AdS_5 and R-Symmetry Breaking

States that preserve some of the supersymmetries of the $D = 4$ N-extended super-Poincaré algebra $\mathcal{SP}^+$ can be point-like or extended. These states preserve only subgroups of the R-symmetry $U(N)$, and their breaking pattern can be analyzed in pure algebraic terms. This analysis agrees with previous studies of branes in AdS_5 [11, 15] in all known cases, but also predicts general patterns of R-symmetry breaking.

The identification of brane charges with the central charges of the super-Poincaré algebra in Eq. (2) is well established in flat space. The corresponding identification of brane charges with some bosonic genrators of $OSp(1/8N)$ should hold in AdS_5 [11, 15]. This correspondence was established explicitly in [11] for a brane charge appearing in the world-volume superalgebra of a $D5$-brane in AdS_5.

Let us consider, in particular, the case $N = 4$, and let us start our analysis with point-like states (monopoles and dyons). They are associated with a scalar central charge, that we called $Z^{[AB]}$. It can always be put in the form

$$Z^{[AB]} = \begin{pmatrix} \lambda_1 \epsilon & \\ & \lambda_2 \epsilon \end{pmatrix}, \tag{17}$$

with ϵ the 2×2 antisymmetric matrix. When $\lambda_1 = \lambda_2$ we have a 1/2 BPS state, and the R-symmetry $SU(4)$ is broken to $USp(4) \sim O(5)$. When $\lambda_1 \neq \lambda_2$ one has 1/4 BPS states, and $SU(4) \to USp(2) \times USp(2) \sim O(3) \times O(3)$.

String BPS states are charged under the vector charge $Z^A_{\mu\, B}$. Let us consider a string oriented along one of the cooridante axis. The only nonzero component of $Z^A_{\mu\, B}$ is, say $Z^A_{1\, B}$ that can be brought to the standard form:

$$Z^A_{\mu\, B} = \begin{pmatrix} \lambda_1 & & & \\ & \lambda_2 & & \\ & & \lambda_3 & \\ & & & -\lambda_1 - \lambda_2 - \lambda_3 \end{pmatrix}. \tag{18}$$

By looking at the $SU(4) \sim O(6)$ subgroup left invariant by this matrix one can easily find all possible R-symmetry breaking patterns. Specifically, 1/2 BPS states have $\lambda_1 = \lambda_2 = -\lambda_3$; this means that the R-symmetry is broken to $SU(2) \times SU(2) \times U(1)$, or

$$O(6) \to O(4) \times O(2). \tag{19}$$

1/4 BPS states have $\lambda_1 = \lambda_2$, $\lambda_3 \neq \lambda_1$. The R-symmetry breaking is in this case

$$O(6) \to SU(2) \times U(1)^2. \tag{20}$$

When $\lambda_1 = \lambda_2 = \lambda_3$ the string preserves 3/8 of the original supersymmetries, while

$$O(6) \to SU(3) \times U(1). \tag{21}$$

Finally, for generic λ_i, one finds a 1/8 BPS state preserving only a $U(1)^3$ subgroup of the R-symmetry.

Finally, 2-branes are sources for the antisymmetric-tensor charge $Z^{(AB)}_{\mu\nu}$, belonging to the symmetric representation of $SU(4)$. By choosing a 2-brane configuration oriented along two coordinate axis, the only nonzero charge is, say, $Z^{(AB)}_{12}$. It can be brought into the standard form

$$Z^{(AB)}_{12} = \begin{pmatrix} \lambda_1 \delta & \\ & \lambda_2 \delta \end{pmatrix}, \tag{22}$$

with δ the 2×2 identity matrix. In this case, 1/2 BPS states correspond to $\lambda_1 = \lambda_2$, and the R-symmetry breaking pattern is $SU(4) \to O(4) = O(3) \times O(3)$. 1/4 BPS states correspond to $\lambda_1 \neq \lambda_2$; the residual R-symmetry is, in this case $SU(4) \to O(2) \times O(2)$.

The BPS states on the boundary can be thought of as "singletons" since they have multiplicity 2^N ($N = 4$ in our case), if regarded as N-extended 4-D Poincaré multiplets.

We call s-singleton the usual singleton associated to a massless particle on the boundary, while we call p-singleton a state associated to a p-brane on the boundary. Thus, "photons" are s-singletons, monopoles or dyons are 0-singletons etc. BPS states propagating in the bulk are "bound states" of p-singletons, since they have multiplicity 2^{2N}.

To summarize, a p-singleton breaks the original $O(6)$ R-symmetry to $O(5-p) \times O(p+1)$, while the s-singleton corresponds to $p = -1$ in this formula.

5 Other Algebras and Uniqueness of the Extension

Let us conclude with a few additional remarks.

First, let us point out that here is a superalgebra that is intermediate between that in Eqs. (3,4) and that in Eqs. (5,6). This is the $U(2N, 2N/1)$ superalgebra. It is obtained by setting to zero the right-hand side of Eq. (4), but keeping all terms in the r.h.s. of Eq. (3).

All these algebras can be written in a manifestly $O(4,2)$-invariant notation using the following decompostition, where A and S denote symmetrization and antisymmetrization, respectively ($\mu, \nu = 0, ..5$):

$$\begin{aligned}
[(4,N) \times (4,N)]_S &= [6, (N \times N)_A] + [10, (N \times N)_S], \\
(4,N) \times (\bar{4}, \bar{N}) &= (1,1) + (15,1) + (15, N^2-1) + (1, N^2-1), \\
\{Q^A, Q^B\} &= (\gamma^\mu C)^+ T_\mu^{[AB]} + (\gamma^{\mu\nu\rho} C)^+ T_{\mu\nu\rho}^{(AB)}, \quad c.c. \\
\{Q^A, Q_B\} &= (\gamma^{\mu\nu} C) M_{\mu\nu} \delta_B^A + C T_B^A + (\gamma^{\mu\nu} C) T^{o\,A}_{\mu\nu\,B}.
\end{aligned} \tag{23}$$

Here $+$ is the 6-D chiral projection. The space-time conformal spinors are identified here with the $(4, \bar{4})$ of $SU(2,2)$. The $U(2N, 2N/1)$ superalgebra is obtained by setting $\{Q^A, Q^B\} = 0$, while the $U(2, 2/N)$ superalgebra is obtained by setting $\{Q^A, Q^B\} = 0$ and $T^{o\,A}_{\mu\nu\,B} = 0$.

We must also point out that AdS_5 algebras with brane charges clearly violate the Coleman-Mandula theorem [18]. This should imply that they cannot be realized as symmetries of a local world-sheet theory. In spite of this, the brane charges studied in ref. [11] are topological charges appearing in the (local) Born-Infeld action of the D-brane. The meaning of this result is not yet clear to us.

Finally, let us comment on the uniqueness of AdS_5 extensions of the super-Poincaré algebra with central charges. For N-extended supersymmetry, $OSp(1/8N)$ is the unique extension of the super-Poincaré algebra in Eq. (2) with the following properties: a) all right-hand sides of the fermionic anticommutators are nonzero, and form a simple Lie algebra; b) it contains the group $O(4,2) \times U(N)$; c) it has the same number of fermionic charges as the superconformal algebra $U(2,2/N)$. This follows from the classification of all superalgebras based on simple Lie algebras given in ref. [16]. Likewise, the "intermediate" algebra $U(2N,2N/1)$ is the unique superconformal extension of algebra (2) where all chiral Poincaré anticommutators are set to zero. For $N=1$ one can say more. In that case, indeed, it was shown in ref. [17] that only two extensions of the super-Poincaré algebra exist. One, in which all central charges are set to zero, is the usual $U(2,2/1)$; the other is, necessarily, $OSp(1/8)$. Notice that in this case the "intemediate" algebra is also $U(2,2,/1)$. In this case $\mathcal{SP}^+$ is just the $N=1$ supertranslational algebra considered in [19, 20], while [10]

$$\mathcal{L}^0 = R \times SO(3,3), \tag{24}$$

since $SL(4,R) \sim SO(3,3)$. The standard Lorentz transformations and $U(1)$ R-symmetry correspond to the subgroup $SO(3,1) \times SO(2) \subset SO(3,3)$.

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