BPS Preons and generalized AdS supersymmetry

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Abstract

We introduce the notion of *AdS preons* as the AdS version of BPS preons, the conjectured fundamental constituents of M-theory. The AdS preon definition is given by a deformation of its 'M-algebraic' version. This leads to a non-commutative deformation of the original M-algebra, which we call the *AdS-M-algebra* and which turns out to be $osp(1|32)$. This is also supported by the fact that the $D = 4, 6, 10$ counterparts of the $D = 11$ BPS preon may be identified with wavefunctions which describe a tower of free, massless, conformal higher spin fields.

1 Introduction

Preons were introduced [1] as the possible fundamental constituents of M-theory. They are defined as BPS states that preserve all supersymmetries but one. For D=11, this means 31 supersymmetries out of 32, and hence a preon is labelled as

$$|BPS\ ,\ preon>=|BPS\ ,\ 31/32> \ . \tag{1}$$

As it was shown in [1], a $k/32$-BPS state for $k < 32$ may be considered as a composite of $n = 32 - k$ preons. Fully supersymmetric BPS states ($k = 32$) do not contain any preons and, hence, they are *preonic vacua* ('vacua of vacua', since all the supersymmetric BPS states are stable and are considered themselves as different M-theory vacua); a preon is the simplest excitation over such a fully supersymmetric vacuum. At the other extreme, a non-supersymmetric (and, hence, non BPS) state, breaking all 32 supersymmetries, is a composite of the maximal number, 32, of independent BPS-preons.

The preon definition [1] also applies to arbitrary D [2]. In D= 4,6,10 BPS preons can be associated [2,3] with an infinite tower of free higher spin fields (see [4,5]). This identification can be established through the quantization [3,6] of the generalized superparticle [7] which provides a dynamical model for a point-like or 0-brane preon [2].

The standard realization of M-theory BPS states is provided by supersymmetric solutions of the equations of motion for the D=11 or type II D=10 supergravities, which are the low energy limits of M-theory[1]. A $k/32$-BPS state corresponds to a solution preserving k of the 32 supersymmetries. The k-supersymmetric *bosonic* solutions are characterized

[1] We will not consider here the N=1, D=10 supergravity-SYM interacting systems describing the low energy limits of the two heterotic string and type I 'corners' of M-theory.

by k bosonic *Killing spinors* associated with the preserved supersymmetries. These obey the generalized Killing spinor equations

$$\mathcal{D}\epsilon_I{}^\alpha := d\epsilon_I{}^\alpha + \tfrac{1}{4}\epsilon_I{}^\beta\,\Gamma_{ab\beta}{}^\alpha\omega^{ab} - \epsilon_I{}^\beta\, t_\beta{}^\alpha = 0\ , \ (a) \qquad \epsilon_I{}^\alpha \mathcal{M}_{\alpha\beta} = 0\ , \ (b) \quad I = 1,\ldots,k\ . \quad (2)$$

In eq. (2a), $\mathcal{D} = d - w = d - \omega - t$ is the generalized covariant derivative involving the generalized connection $w_\beta{}^\alpha = \omega_{L\beta}{}^\alpha + t_\beta{}^\alpha$, where $\omega_{L\beta}{}^\alpha = \frac{1}{4}\omega_L{}^{ab}\Gamma_{ab\beta}{}^\alpha$ is the spin connection and $t_\beta{}^\alpha$ is a tensorial contribution which, as the matrix $\mathcal{M}_{\alpha\beta}$ in the *algebraic* equation (2b), is constructed from the fluxes (the field strengths of the gauge fields) and scalars in the supergravity multiplets. In D=11 supergravity [8] eq. (2b) is absent and the tensorial contribution in (2a) reads $t_\beta{}^\alpha = \frac{i}{18}e^a F_{ab_1b_2b_3}\Gamma^{b_1b_2b_3}{}_\beta{}^\alpha + \frac{i}{144}e^a\Gamma_{ab_1b_2b_3b_4\beta}{}^\alpha F^{b_1b_2b_3b_4}$, where $F_4 = dC_3 = \frac{1}{4}e^{c_4}\wedge\ldots\wedge e^{c_1}F_{c_1\ldots c_4}$ is the field strength of the three-form gauge field C_3.

A hypothetical preonic supergravity solution would have 31 Killing spinors, $\epsilon_I{}^\alpha$. Since there is only one bosonic spinor λ_α orthogonal to all of them,

$$\epsilon_I{}^\alpha\lambda_\alpha = 0\ , \qquad I = 1,\ldots,31\ , \qquad \alpha = 1,\ldots,32\ , \qquad (3)$$

a preonic solution may also be characterized by such a *preonic spinor* λ_α.

Algebraically, any $k/32$ is allowed for a BPS state [9,10]. However, only solutions for the following number of preserved supersymmetries have been found at present

$$k = 0,1,2,3,4,5,6,\ 8,\ 10,\ 12,\ 14,\ 16,\ 18,\ 20,\ 22,\ 24,\ 26,\ 28, \qquad 32$$

(see *e.g.* [11]); the preonic solution is conspicuously missing in this list.

The interest on the possible existence of 31/32-supersymmetric *i.e.* preonic solutions, began around 2003 [12–14]. Recently, a series of no-go results have been obtained for the 'free', classical D=11 and D=10 type II supergravities [15–18] (see [19] for a review and further references[2]). However, for supergravity with quantum (α') corrections and/or brane sources the existence of preonic solutions is still open (see [16] and [19] for further discussion). Moreover, even the possible absence of preonic *solutions* in the presence of quantum corrections and sources from superbranes would not preclude the preon hypothesis, as such a 'preon conspiracy' would still allow us to consider all supersymmetric BPS states as composites of preons (in the same way as, by way of an analogy, quark confinement does not prevent the existence of quarks). However, a dynamical mechanism to construct k/32-BPS states out of 31/32-preons is not known. A further study of the formal, algebraic properties of preons might shed light in this direction. With this in mind, we consider here the AdS version of the BPS preon.

To motivate the problem, let us begin by noting that the supergravity solutions that describe fully supersymmetric BPS states include [21], besides the Minkowski vacuum of superPoincaré symmetry, the $AdS_{(p+2)} \times S^{(D-p-2)}$ spaces, $(D,p) = (11,2), (11,5), (10,3)$, and the *pp*-wave spaces which will not be considered here. Thus, preons may correspond to the simplest excitations over the Minkowski vacuum or over an $AdS \times S$ vacuum. However, their original definition was based on the M-algebra [22], which is associated with a generalized superPoincaré supersymmetry[3]. Although the M-algebraic language is

[2] A very recent [20] paper states that the maximal fraction ($\neq 1$) of supersymmetries preserved by a solution of the (again, free and classical) type IIB supergravity is 28/32.

[3] This generalization of the superPoincaré algebra is given by the semidirect sum of the M-algebra [22] and $so(1,10)$ (alternatively, one may take $GL(32,\mathbb{R})$ as the M-algebra automorphism group [24]), which can be shown to be an *expansion* [25] of the $osp(1|32)$ superalgebra. The (32+528)-dimensional M-algebra itself, which is the maximal *central extension* of the abelian {Q,Q}=0 algebra of 32 fermionic generators (see [26]), is a *contraction* of the $osp(1|32)$ superalgebra. Such a contraction is possible because the M-algebra and $osp(1|32)$ have the same dimension.

meant to be universal (as suggested *i.e.* by the study of M- and D-brane systems), and thus the preon notion [1] is not restricted to considering excitations over the Minkowski vacuum, it is natural to ask ourselves whether preons can be defined in terms of an AdS-based generalization of the M-algebra, which we call the *AdS-M-algebra*. Our conclusion, which follows from the AdS preon generalization to be presented below, is that the AdS-M-algebra is identified with $osp(1|32)$, which in our preonic context appears naturally as a *deformation* of the M-algebra (see [23] for pp-wave related superalgebras). The case for $osp(1|32)$ as a generalized AdS superalgebra in D=11 had been made in [27–29] (see also [30–34] for related considerations). The $osp(1|32)$ superalgebra had already been singled out in the original D=11 supergravity paper [8], and also used as a starting point for a discussion of the gauge structure of D=11 supergravity [35, 36]; its relevance in M-theory was put forward in [37].

Not surprisingly, our AdS preon is related to the description of free massless conformal AdS higher spin theories [38, 39] in the generalized AdS superspaces given by the OSp supergroup manifolds [40–42].

2 BPS preons, preonic supermultiplet and the M-algebra

As a hypothetical preonic supergravity solution, an abstract BPS preonic state may be characterized by one bosonic preonic spinor λ_α

$$|BPS\ ,\ preon>=|\ \lambda>\ , \tag{4}$$

orthogonal ($\epsilon_I{}^\alpha\lambda_\alpha = 0$, *cf.* eq. (3)) to the 31 bosonic $\epsilon_I{}^\alpha$ spinors that characterize the supersymmetries preserved by the BPS preon,

$$\epsilon_I{}^\alpha Q_\alpha|\ \lambda>=0\ , \qquad I=1,\ldots,31\ . \tag{5}$$

Due to eq. (3), eq. (5) implies that $Q_\alpha|\ \lambda> \propto \lambda_\alpha$. This may be expressed as

$$Q_\alpha|\ \lambda>=\lambda_\alpha|\ \lambda^f>\ , \tag{6}$$

where $|\ \lambda^f>$ is a fermionic state (assuming that the original preonic state $|\ \lambda>$ is bosonic, as befits a state corresponding to a purely bosonic solution of supergravity). The simplest preonic supermultiplet contains only two states, $|\ \lambda>$ and $|\ \lambda^f>$,

$$||\lambda^{super}>>:=\begin{pmatrix}|\lambda>\\ |\lambda^f>\end{pmatrix}\ . \tag{7}$$

The action of the supersymmetry generator on $|\ \lambda^f>$ can be defined in terms of the same bosonic spinor λ_α so that

$$Q_\alpha|\ \lambda>=\lambda_\alpha|\ \lambda^f>\ , \qquad Q_\alpha|\ \lambda^f>=\lambda_\alpha|\ \lambda>\ . \tag{8}$$

These supersymmetry transformations may be collected in one compact equation

$$Q_\alpha||\lambda^{super}>>=\chi\lambda_\alpha||\lambda^{super}>>\ , \qquad \chi\chi=1 \qquad \left(\chi=\begin{pmatrix}0&1\\1&0\end{pmatrix}\right)\ , \tag{9}$$

in terms of the preonic supermultiplet $||\lambda^{super}>>$ (7) and a Clifford algebra variable χ.

Now, assuming that λ_α is a c-number which, in particular, implies that λ_α commutes with the supersymmetry charges,

$$Q_\beta \lambda_\alpha = \lambda_\alpha Q_\beta \ , \tag{10}$$

we conclude that the supersymmetry transformations generate the M-algebra,

$$\{Q_\alpha \, , \, Q_\beta\} = P_{\alpha\beta} \ , \qquad [\, P_{\alpha\beta} \, , \, Q_\gamma] = 0 \ , \qquad [\, P_{\alpha\beta} \, , \, P_{\gamma\delta}] = 0 \ . \tag{11}$$

Indeed, using (10) we find from (8) that both the BPS preon and its superpartner are eigenstates of the generalized momentum $P_{\alpha\beta}$ (here characterized as the most general *r.h.s.* for the $\{Q_\alpha \, , \, Q_\beta\}$ anticommutator). The common eigenvalue matrix of $|\lambda>$ and $|\lambda^f>$ is given by the tensor product $\lambda_\alpha\lambda_\beta$ of two copies of the bosonic preonic spinor λ,

$$\begin{cases} P_{\alpha\beta}|\lambda >= \lambda_\alpha\lambda_\beta|\lambda > \ , \\ P_{\alpha\beta}|\lambda^f >= \lambda_\alpha\lambda_\beta|\lambda^f > \ , \end{cases} \qquad \Leftrightarrow \qquad P_{\alpha\beta}||\lambda^{super} >>= \lambda_\alpha\lambda_\beta||\lambda^{super} >> \ . \tag{12}$$

As λ_α is a c-number (eq. (10) also implies $P_{\alpha\beta}\lambda_\gamma = \lambda_\gamma P_{\alpha\beta}$), one easily finds that the $[P,P]$ commutator on a preonic state or on the preonic supermultiplet is zero ($[P,P]||\lambda >>= 0$). We then conclude, if we do not allow the presence of further generators, that $[P,P] = 0$ since the possibility $[P,P] = cP$, allowed by Grassmann parity conservation, is ruled out because the preonic spinor is nonvanishing and $[P,P]|\lambda >= c\lambda\lambda|\lambda >= 0$ requires $c = 0$.

Thus, as we have shown, the original definition of the BPS preon [1] is related to the M-algebra (11). This generalizes the superPoincaré algebra (see footnote 3) by involving the general spin-tensorial generator $P_{\alpha\beta} = P_{\beta\alpha}$ which includes, in addition to the standard translation generator P_m (through $\not{P}_{\alpha\beta} = P_m\Gamma^m_{\alpha\beta}$), a set of tensorial central charges that reflect the existence of extended objects in M-theory: they can be realized as topological charges for various branes [43] (see also [26, 44]).

3 AdS preons

The previous discussion indicates that to find an AdS generalization of the BPS preon notion one needs dropping the commutative character (eq. (10)) of the preonic spinor. Indeed, it was using this property that we arrived at a realization of the M-algebra (11) on the preonic supermultiplet.

When looking for the AdS generalization of the BPS preon it is convenient to introduce the radius R of the AdS space to require that in the 'flat' $R \to \infty$ limit the AdS preonic supermultiplet becomes the M-algebraic one. Further, we shall assume that the supersymmetry generators transform the AdS preon and its superpartner among themselves as in (6), but with a noncommuting but still Grassmann even preonic spinor Λ_α which replaces the c-number λ_α,

$$Q_\alpha|\lambda >= \Lambda_\alpha|\lambda^f > \ , \qquad Q_\alpha|\lambda^f >= \Lambda_\alpha|\lambda > \ , \qquad [\Lambda_\alpha \, , \, \Lambda_\beta] \neq 0 \ . \tag{13}$$

To have a suitable $R \to \infty$ limit we conclude that $[\Lambda_\alpha \, , \, \Lambda_\beta] \propto \frac{1}{R}$. As the required coefficient is a dimensionless antisymmetric spin-tensor, it is natural to identify it with $C_{\alpha\beta}$. In such a way we find the following algebra and explicit realization of the Λ_α spinors:

$$[\Lambda_\alpha \, , \, \Lambda_\beta] = -\frac{i}{2R} C_{\alpha\beta} \ , \qquad \Lambda_\alpha = \lambda_\alpha - \frac{i}{4R} C_{\alpha\beta} \frac{\partial}{\partial\lambda^\beta} \ . \tag{14}$$

Notice that the replacement $\lambda_\alpha \to \Lambda_\alpha$ can be treated as passing to the Moyal star product,

$$\lambda_\alpha \cdot \to \Lambda_\alpha \cdot = \lambda_\alpha * \quad , \tag{15}$$

see [41]. Eqs. (14), (15) determine a *deformation*, the result of which is the non-commutativity of the Λ_α. In the $R \to \infty$ limit, the spinor Λ_α becomes the commutative preonic spinor λ_α. Thus, the flat limit of the AdS preon reproduces the original M-algebraic BPS preon definition [1], of which the AdS preon is a deformation.

Denoting the AdS preonic supermultiplet also by $||\lambda^{super} >>$, as in eq. (7), the two equations in eq. (13) are collected in a single equation (*cf.* (9)),

$$Q_\alpha||\lambda^{super} >>= \chi\Lambda_\alpha||\lambda^{super} >> \ (a) \ , \quad \chi\chi = 1 \ (b) \ , \quad \Lambda_\alpha = \lambda_\alpha - \frac{i}{4R}C_{\alpha\beta}\frac{\partial}{\partial\lambda^\beta} \ (c) \ . \tag{16}$$

which involves the Clifford algebra element χ (see eq. (9)) and the non-commutative preonic spinor Λ_α, eq. (14).

4 AdS preons and $osp(1|32)$ as the AdS-M-algebra

Our definition of AdS preon suggests that the proper AdS generalization of the M-algebra, the AdS-M-algebra, is given by $osp(1|32)$.

Indeed, on the preonic supermultiplet the AdS supersymmetry generators are represented by $Q_\alpha = \chi\Lambda_\alpha$, Eq. (16a). Computing the anticommutator of two charges, one easily finds that it gives a noncommutative set of generators, $M_{\alpha\beta} := \{Q_\alpha \, , \, Q_\beta\} = 2\Lambda_{(\alpha}\Lambda_{\beta)}$, the commutation relations of which determine the $sp(n)$ algebra.

Thus the AdS preonic supermultiplet is associated with the following representation

$$Q_\alpha = \chi\Lambda_\alpha \ , \qquad M_{\alpha\beta} = 2\Lambda_{(\alpha}\Lambda_{\beta)} \tag{17}$$

of the generators of $osp(1|32)$,

$$\begin{aligned} \{Q_\alpha \, , \, Q_\beta\} &= M_{\alpha\beta} \ , \qquad [\, M_{\alpha\beta} \, , \, Q_\gamma] = \frac{2}{R}C_{\gamma(\alpha}Q_{\beta)} \ , \\ [\, M_{\alpha\beta} \, , \, M_{\gamma\delta}] &= \frac{2}{R}(C_{\gamma(\alpha}M_{\beta)\delta} + C_{\delta(\alpha}M_{\beta)\gamma}) \ . \end{aligned} \tag{18}$$

Now, the special rôle of the BPS preon in the classification of the M-theory BPS states [1] indicates that the the appropriate AdS generalization of the M-algebra, the *AdS-M-algebra*, is the orthosymplectic $osp(1|32)$ superalgebra, Eq. (18), as also argued in [27–29, 37] from various points of view.

Notice that our guiding principle has been the existence of an AdS counterpart of the M-algebraic definition of the BPS preon, rather than the presence of central charges[4]. Since the AdS preon turns out to be a noncommutative deformation of the BPS one, it is natural that the associated AdS-M-algebra be a non-commutative deformation of the M-algebra. Indeed, the the M-algebra (11) is obtained by a contraction of $osp(1|32)$ (18)

[4] This last point of view was adopted in [33] to look for a possible AdS generalization of the M-algebra by trying to incorporate the tensorial central charges (treated as topological charges of superbranes) into the $AdS_p \times S^{D-p}$ superalgebra (*i.e.* the superalgebra associated with the supersymmetry of superspaces with bosonic bodies given by $AdS_p \times S^{D-p}$ for fixed D and p), but this leads to an infinite dimensional superalgebra.

(see footnote 3). Reciprocally, $osp(1|32)$ is a deformation of the M-algebra characterized by the radius deformation parameter R in (18).

In matrix form, the preonic representation of the $osp(1|32)$ generators it written as

$$Q_\alpha = \begin{pmatrix} 0 & \Lambda_\alpha \\ \Lambda_\alpha & 0 \end{pmatrix} , \qquad M_{\alpha\beta} = \begin{pmatrix} 2\Lambda_{(\alpha}\Lambda_{\beta)} & 0 \\ 0 & 2\Lambda_{(\alpha}\Lambda_{\beta)} \end{pmatrix} . \qquad (19)$$

The basic commutation relations of Λ_α together with the $M_{\alpha\beta}$ representation in (17) are collected in the multiplication rule

$$\Lambda_\alpha\Lambda_\beta = -\frac{i}{4R}C_{\alpha\beta} + \frac{1}{2}M_{\alpha\beta} . \qquad (20)$$

The AdS preon may be described by a scalar superfield on the $OSp(1|32)$ supergroup manifold. We will discuss this elsewhere [49], and only mention here that this superfield is the $n = 32$ ($D = 11$) element of a family of scalar field theories on $OSp(1|n)$ manifolds, the $n = 4$ representative of which, $OSp(1|4)$, describes the higher spin theory in AdS_4 spacetime; the $n = 8$ and $n = 16$ cases, $OSp(1|8)$ and $OSp(1|16)$, likely describe the corresponding massless conformal higher spin theories on the AdS_6 and AdS_{10} spaces[5].

5 Conclusions and discussion

In this contribution we have presented the AdS version of the M-algebraic definition of the BPS preon. Although the M-algebra language is supposed to be universal, and so it is the preon concept [1], the question of the AdS generalization arises naturally when a preon is considered as an excitation over a completely supersymmetric AdS vacuum.

Our AdS preon is described by a non-commutative deformation of the M-algebra BPS preon definition in [1] (eq. (16) is a deformation of (9), see also (15)). This is supported by the observation that the $D = 4, 6, 10$ counterparts of the BPS preon can be identified [2,46] with the tower of all the free massless, conformal higher spin fields in the corresponding flat Minkowski spaces [3,6,45]. Then, as far as the AdS generalization of the tensorial superspace higher spin equations is also known [41,42,46], we may identify the wavefunction of AdS preon state with the $OSp(1|32)$ counterpart of the scalar superfield on the $OSp(1|4)$ supermanifold which describes [41,42,46] all the conformal higher spin fields in AdS_4 space. As the generalized AdS geometry of the free AdS higher spin fields is formulated on the $OSp(1|n)$ supergroup manifolds (see footnote 5), our construction indicates that the *AdS-M-algebra* is given by $osp(1|32)$ [27–29,37]. This $osp(1|32)$ appears as a deformation of M-algebra associated with the non-commutative AdS deformation of the M-algebraic definition of the BPS preon [1].

The absence of tensorial charges and the appearance of the non-commutative $sp(32)$ part $M_{\alpha\beta}$ in $osp(1|32)$ (eq. (18)), replacing the abelian $P_{\alpha\beta}$ of the M-algebra (11), makes now not obvious how to describe algebraically the fraction of AdS supersymmetry preserved by an AdS preon; in contrast, the supersymmetry preservation is typical of a BPS

[5]Specifically, free conformal higher spin theories in D=4,6,10 flat, Minkowski spaces may be described by means of scalar superfields on flat n=4,8,16 tensorial superspaces [3,6,45]. In the AdS case, the D=4 massless higher spin theory may be described by a scalar superfield on the $OSp(1|4)$ group manifold [41,42]. However, the possibility of describing conformal higher spin theories in the $D = 6, 10$ AdS spacetimes by means of scalar superfields on $OSp(1|8)$, $OSp(1|16)$, albeit likely, has still to be proven by methods similar to those used in [3] for the flat case.

state when studied in the M-algebra language. To clarify this point one can look at the dynamical preonic 0-brane model on the $OSp(1|n)$ supergroup manifold [40], whose quantization in the $D = 4 = n$ case leads to a scalar superfield on $OSp(1|4)$ describing the AdS higher spin fields [42]. The supersymmetry preserved by the ground state of this model is 31-parametric, related to its 31-parametric κ-symmetry, and thus this ground state is a BPS preon (the AdS preon). However, the action of this preserved part of the AdS supersymmetry on this preonic state is $(X^{\alpha\beta}, \theta^{\beta})$- dependent (as it is the generalized AdS supersymmetry acting on $OSp(1|n)$ supergroup manifold). Thus, this preservation is difficult to see in the abstract (bra-ket) quantum mechanical language. This explains why the preonic representation of the OSp supersymmetry generators (6) cannot be obviously translated in terms of *preserved* supersymmetries. Instead, the AdS preon definition appears as a *deformation* of the statement that a preon *breaks* just one supersymmetry, which provides an equivalent definition of a BPS preon in the M-algebraic language.

The notion of AdS preon introduced here suggests that the search for a dynamical mechanism to build $k/32$-BPS states out of BPS preons may be related to the problem of finding a consistent interaction theory of a tower of massless conformal higher spin fields. Interacting, massless conformal higher spin theories were constructed in [38]. However in our preonic context we need to have such an *interacting* higher spin theory formulated on (curved) tensorial superspaces (see [3, 6, 45, 46] for the free, flat case). This is still unknown, although some progress in this direction has been made [50] by introducing higher spin gauge potentials in the description of free AdS higher spin theories on OSp supermanifolds.

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