Title: BPS preons and M-theory

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Abstract: \'BPS preons were conjectured (PRL 86, 4451 (2001), hep-th/0101113) as the basic constituents of M-theory; they are states preserving 31/32 supersymmetries. We discuss the absence of preonic solutions in D=10,11 supergravities and its possible implications. The AdS generalization of the BPS preons, the AdS preons defined over an AdS vacuum, will also be discussed. This leads to the {it AdS-M-algebra}, a deformation of the M-algebra which is identifed as $osp(1|32)$.\'

BPS PREONS AND M-THEORY

J. A. de Azcárraga

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[a short review of work with I. A. Bandos, J. M. Izquierdo, J. Lukierski, M. Picón and O. Varela]

PASCOS '08 (June 2-6, 2008)
Perimeter Institute, Waterloo, June 3

BPS states have partially broken supersymmetry. They saturate Bogomol'ny Prasad-Sommerfield-like bounds, and are the carriers of p-form charges that show up in the {Q,Q} supersymmetry algebra

The simplest ones are (p+1)-hyperplanes *i.e., **super-p-branes.***

A BPS state preserving ***all*** supersymmetries ***but one*** is called ***preonic***.

Why the 'preon' name? ***Because any other BPS state/supergravity solution breaking n supersymmetries may be considered as a composite of n basic, preonic states.***

How to describe these hypothetical BPS preonic states?

Algebraically:

by looking at the (D=11 ***M***)-***superalgebra*** and its 'central' charges structure → ***rank*** of the generalized momentum matrix, ***preonic spinors***, ***susy spinors***

Geometrically:

by looking at the geometry of ***supergravity solutions*** → ***Killing spinors***, holonomy and ***generalized holonomy*** (but caution: geometrical Killing spinor analysis is ***local***)

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Summary

(1) BPS STATES: M-ALGEBRAIC, THEORETIC CONSIDERATIONS

**(2) BPS SUPERGRAVITY(ies) SOLUTIONS:
HOLONOMY ANALYSIS**

**(3) NO PREONS IN
D=11 CREMMER-JULIA-SCHERK AND D=10 IIA, IIB SUPERGRAVITIES**

**(4) CONCLUSIONS AND FURTHER EXTENSIONS:
AdS-preons and the AdS-M-algebra**

(1) BPS STATES: M-ALGEBRAIC, THEORETIC CONSIDERATIONS

The 'M-theory superalgebra'

In D=11, the {Q,Q} anticommutator has 32×33/2= 528 = 11+ 55 + 462 components,

$$\{Q_\alpha, Q_\beta\} = P_{\alpha\beta}\ , \quad P_{\alpha\beta} = P_{\beta\alpha}\ , \quad [Q_\alpha, P_{\beta\gamma}] = 0$$

$$\alpha, \beta, \gamma = 1, 2, \ldots 32 \quad ,$$

$$P_{\alpha\beta} = p_\mu \Gamma^\mu_{\alpha\beta} + p_{\mu\nu}\Gamma^{\mu\nu}_{\alpha\beta} + p_{\mu_1\ldots\mu_5}\Gamma^{\mu_1\ldots\mu_5}_{\alpha\beta}\ ,$$

$$\Sigma^{(\frac{\tilde{n}(\tilde{n}+1)}{2}|\tilde{n})} = \left\{\mathcal{Z}^\Sigma = (\theta^\alpha, X^{\alpha\beta})\right\}\ ,$$
$$\alpha, \beta = 1, 2, \ldots, \tilde{n}(= 32)$$

$$\Sigma^{(\frac{\tilde{n}(\tilde{n}+1)}{2}|\tilde{n})} \otimes GL(\tilde{n} = 32)\ ;$$

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The above defines the ***‘M-algebra’*** [P.K. Townsend,hep-th/9712004; see also J.W. van Holten and A. van Proeyen, JPA **15**, 3763 (1982)]; the 517 components characterize the ***topological charges*** of the M2 and M5 branes [J.A. de A., J.M. Izquierdo, J. Gauntlett and P.K. Townsend, Phys.Rev.Lett.**63**, 2443 (1989); see also D. Sorokin+P.K. Townsend, PLB **412**, 265 (1997) [hep-th/9708003]]

The coordinates of its supersym. group define ***tensorial superspace*** $\Sigma^{(\frac{\tilde{n}(\tilde{n}+1)}{2}|\tilde{n})}$.

The ***P's*** may be looked at as ***SO(1,10)-tensorial, supersymmetry-central charges***. In terms of the ***abelian generalized momenta*** $P_{\alpha\beta}$, dual to the ***bosonic tensorial space coordinates*** $X^{\alpha\beta}$, the algebra presents an obvious $GL(32,R)$ automorphism symmetry (I. Bärwald and P. West, PLB **476**, 157 (2000) [hep-th/9912226; J. Gauntlett, G.W.Gibbons. C.M. Hull and P. K. Townsend, CMP **216**, 431 (2001) [hep-th/0001024]. See also J. Molins and J. Simón, PRD **62** , 125019 (2000) [hep.th/0007253]).

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If spinors 'are first', then standard D-superspace and its superalgebra, $\{Q,Q\} \sim \Gamma^\mu P_\mu$, ***follows*** as a D-vector-valued ***'central' extension***, ***but*** it is ***not*** the ***maximal*** one: in fact,

the maximal Q-central extension of the D=11 spinorial abelian odd algebra, {Q,Q}=0, is the above 'M-algebra'.

For enlarged superspaces, extensions and branes, see C. Chryssomalakos, J.A. de A., J.M. Izquierdo and J.C. Pérez Bueno, NPB **567**, 293 (2000) [hep-th/9904137] ;

(k/32-) Supersymmetric BPS states and preons

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A *BPS state* $|BPS\,,\,k\rangle$ preserving ***k*** supersymmetries satisfies

$$\epsilon_J{}^\alpha Q_\alpha|BPS\,,\,k\rangle = 0\,, \quad J=1,\ldots,k\;,\; k\leq 32$$

where the ***k*** *bosonic spinors* $\boxed{\epsilon_J{}^\alpha}$ (*Killing spinors* in *sugra solutions*, see later) determine the Grasmann parameters of the supersymmetries by $\varepsilon^\alpha = \varepsilon^J \epsilon_J{}^\alpha$, ε^Jodd.

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$$|BPS\,,\,31\rangle \;\Rightarrow\; \epsilon_J{}^\alpha Q_\alpha |BPS\,, preon\rangle = 0\,,\; J=1,\ldots,31\,.$$

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Then, introducing a ***preonic spinor*** λ_α by the condition $\epsilon_J{}^{\alpha}\lambda_\alpha = 0$ we see that *a preonic state may equally be characterized* as

$$|BPS\,, preon\rangle \;=\; |BPS\,,\,31\rangle \;=\; |BPS\,,\,\lambda\rangle \quad \text{or, for short,} \quad |\lambda\rangle\,.$$

This emphasizes the *alternative view*: ***a preon breaks just one supersymmetry.***

Since $\epsilon_J^{\alpha} Q_\alpha |\lambda> = 0$, this means (with $|\lambda>$ bosonic) that $Q_\alpha |\lambda> = \lambda_\alpha |\lambda^f>$. Thus, the pair

$$\{|\lambda>, |\lambda^f>\}$$

determines a ***BPS preonic supermultiplet*** on which the action of the supersymmetry generators reads

$$Q_\alpha |\lambda> = \lambda_\alpha |\lambda^f> \quad , \quad Q_\alpha |\lambda^f> = \lambda_\alpha |\lambda>$$

or

$$Q_\alpha ||\lambda^{super}>> = \chi \lambda_\alpha ||\lambda^{super}>> \,, \;\; \chi = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \,, \;\; ||\lambda^{super}>> := \begin{pmatrix} |\lambda> \\ |\lambda^f> \end{pmatrix} \,.$$

Since $\epsilon_J^\alpha Q_\alpha | \lambda >= 0$, this means (with $| \lambda >$ bosonic) that $Q_\alpha | \lambda >= \lambda_\alpha | \lambda^f >$. Thus, the pair

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Thus, *since bosonic ($|\lambda\rangle$) and fermionic ($|\lambda^f\rangle$) preonic states enter symmetrically,*

one might also think of considering *fermionic preonic states* .

[I.A. Bandos and J.A. de A., hep-th/0612277; Fortschr. Phys. 55, 5 (2007) [hep-th/070299]].

k/32-BPS states

In general, when $k \leq 31$ we may introduce $n = 32\text{-}k$ linearly independent bosonic spinors $\boxed{\lambda_\alpha{}^r}$ orthogonal to the set of k bosonic spinors $\epsilon_J{}^\alpha$,

$$\epsilon_J{}^\alpha \lambda_\alpha{}^r = 0\,, \quad \alpha = 1, \ldots, 32\,,\ J = 1, \ldots, k\,,\ r = 1, \ldots, n = (32 - k)\,.$$

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Thus, a general BPS state $|BPS\,,\, k\rangle$ preserving k supersymmetries may be characterized either by

k supersymmetry spinors $\boxed{\epsilon_J{}^\alpha}$

associated with the k supersymmetries preserved by the BPS state, or by

n=32-k preonic spinors $\boxed{\lambda_\alpha{}^r}$,

orthogonal to the k supersymmetry spinors (n will determine the compositeness degree of the BPS state).

The use in supergravity solutions of both Killing and preonic spinors leads to the 'G-frame method'.

[I.A. Bandos, J.A. de A., J.M. Izquierdo, M. Picón and O. Varela, PRD **69**, 105010 (2004) [hep-th/0312266]]

BPS preons as constituents:
An equivalent definition of $k/32$ -supersymmetric BPS states

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A $k/32$-BPS state may also be defined as an eigenstate of the generalized momentum operator whose eigenvalue matrix is singular, of rank n=32-k, and positive (semi)definite,

$$P_{\alpha\beta}|BPS,\, k\rangle = p_{\alpha\beta}|BPS,\, k\rangle \ , \ \text{det} p_{\alpha\beta} = 0 \text{ if } \ 1 \leq k \leq 32 \ .$$

$$\frac{k}{32}\text{−BPS state :} \qquad \{\text{rank}\, p_{\alpha\beta} \equiv n = 32 - k \ , \ k \leq 32\} \ .$$

(For a discussion of the 'eigenvalue problem' and branes see I. Bars, PR **D55**, 2373 (1997) [hep-th/9607112] and P.K. Townsend hep-th/9712004; see also J. Molins and J. Simón, PR **D62**, 125019 (2000) [hep-th/0007253])

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Rank *1* is obtained when the matrix is given in terms of one spinor by the *generalized Penrose relation* $\boxed{p_{\alpha\beta} = \lambda_\alpha \lambda_\beta}$, $\alpha, \beta = 1, \ldots, 32$. This will correspond to a *preonic state* *(rank n=1; k=31)*; the case of a *general k-BPS* state will then correspond to the generalized momenta eigenvalues matrix

$$p_{\alpha\beta} = \Sigma_{r=1}^{n} \lambda_\alpha^r \lambda_\beta^r \ , \quad r = 1, \ldots, n = 32 - k \ , \quad 32 > k \geq 1 \ .$$

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To see it, notice that this matrix can be diagonalized by the $GL(32,R)$ automorphism symmetry. Further, *all its eigenvalues are positive or zero*, since in a suitable diagonal basis, $P_{\alpha\beta} = \{Q_\alpha, Q_\beta\}$ and $p_{11} = -1$, say, would imply $(Q_1)^2|BPS, k\rangle = -|BPS, k\rangle$, contradicting positivity. Hence, in that basis, $p_{(\gamma)(\delta)} = diag(\underbrace{1, \ldots, 1}_{n=32-k}, \underbrace{0, \ldots, 0}_{k})$.

Now, since the 1's in the diagonal may be obtained by multiplying one-component elementary spinors, in the original basis we may also write the eigenvalues

$$P_{\alpha\beta}|BPS,k\rangle = \sum_{r=1}^{n=32-k} \lambda_\alpha{}^r \lambda_\beta{}^r |BPS,k\rangle \equiv$$

$$\equiv \quad \left(\lambda_\alpha{}^1 \lambda_\beta{}^1 + \ldots + \lambda_\alpha{}^{32-k} \lambda_\beta{}^{32-k}\right) |BPS,k\rangle = p_{\alpha\beta}|BPS,k\rangle \; .$$

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$\{\epsilon_J{}^\alpha Q_\alpha, \epsilon_K{}^\beta Q_\beta\} = \epsilon_J{}^\alpha \epsilon_K{}^\beta P_{\alpha\beta}$ implies that

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and ***k=32-n***. The case ***k=31***, ***n=1*** corresponds to a ***BPS preon***.

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It then follows that we may look at the equation at the top as a manifestation of th composite structure of a k/32-BPS state, since it allows us to write it as

$$\boxed{|BPS,k\rangle = |\lambda^1\rangle \otimes \ldots \otimes |\lambda^{(32-k)}\rangle \equiv \otimes_{r=1}^{32-k} |\lambda^{(r)} >}$$

*where the $|\lambda^1\rangle, \ldots, |\lambda^n\rangle$ are **n elementary, BPS-preonic states** characterized by the **n** linearly independent **preonic spinors** $\lambda_\alpha{}^1$, ..., $\lambda_\alpha{}^n$, **n=32-k**.* Further, we check

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$$Q_\alpha|BPS,k >= \lambda^1_\alpha|f^1 > + \ldots + \lambda^n_\alpha|f^n >= \bigoplus_{r=1}^{32-k} \lambda^r_\alpha|f^r > \ , \ Q_{(\beta} \bigoplus_{r=1}^{32-k} \lambda^r_{\alpha)}|f^r >= p_{\alpha\beta}|BPS,k\rangle$$

$$|f^r >:= |\lambda^{(1)} > \otimes|\lambda^{(2)} > \otimes \ldots \otimes|\lambda^{(r)f} > \otimes \ldots \otimes|\lambda^{(32-k)} > \ .$$

Thus, on the preonic state, we recover the **{Q,Q}=P** *'M-theory' superalgebra.*

Thus, *for a k/32-BPS state*, with $n = rank(p_{\alpha\beta})$, we see that

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Clearly, *the above arguments do not depend on the dimension of spacetime D*, and hold for general *tensorial superalgebras*. These are associated with rigid, *D-tensorial superspace manifolds* parametrized by

$$\Sigma^{(\frac{\tilde{n}(\tilde{n}+1)}{2}|\tilde{n})} \; ; \; \{(X^{\alpha\beta}, \theta^{\alpha})\} \, , \; X^{\alpha\beta} = X^{\beta\alpha} \, , \, \alpha, \beta = 1, 2, \ldots \tilde{n} \; .$$

$$\{Q_\alpha, Q_\beta\} = P_{\alpha\beta} \; , \; P_{\alpha\beta} = P_{\beta\alpha} \; , \; [Q_\alpha, P_{\beta\gamma}] = 0 \; .$$

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$$p_{\alpha\beta} = \lambda_\alpha \lambda_\beta \;\Rightarrow\; p_\mu \propto \lambda_\alpha \Gamma_{\mu\,\alpha\beta} \lambda_\beta \,, \;\; p_{\mu\nu} \propto \lambda_\alpha \Gamma_{\mu\nu\,\alpha\beta} \lambda_\beta \,, \;\; p_{\mu_1 \ldots \mu_5} \propto \lambda_\alpha \Gamma_{\mu_1 \ldots \mu_5\,\alpha\beta} \lambda_\beta \,.$$

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In the rest frame of ***a BPS massive state***, $p_\mu = m(1, 0, \ldots, 0)$. A *M2 brane* has the ıve index charge equal to zero. Assume for the moment that it is a certain ***k/32=(32-)/32*** BPS state. Then,

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ˌet the space slice of the M2 worldvol. be in the $\{12\}$-plane, $p_{\mu\nu} = \delta^1_{[\mu}\delta^2_{\nu]} z$, $z = 2p_{12}$ Ve may use now a $Spin(1,2) \otimes Spin(8)$ covariant splitting of Dirac matrices. Then,

$$\lambda^i_\alpha = \begin{pmatrix} \lambda^i_{aq} \\ \lambda^{ia}_{\dot q} \end{pmatrix} \ (a = 1, 2\,; q, \dot q = 1, \ldots, 8\,; \ i = 1, \ldots, n) \quad ; \quad \Gamma_{12} = \begin{pmatrix} I_{16} & 0 \\ 0 & -I_{16} \end{pmatrix}$$

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...he expression of $p_{\alpha\beta}$ justifies the name 'BPS states'. We see that the matrix $p_{\alpha\beta}$ ...as either rank *32* (for $m \neq \pm z$, not BPS) , or *16* (for $m = \pm z$, which saturates the ...*BPS bound*); the above system has solutions only if the rank *n*=32 or 16.

Assuming z>0 we conclude that the M2 brane BPS state corresponds to m = z (rank 16) and that it preserves one-half (=16) of the target space supersym...

There are also n=16 preonic spinors: the BPS M2 is a composite of 16 preons

(2) BPS SUPERGRAVITY(IES) SOLUTIONS: HOLONOMY ANALYSIS

Generalized curvature and gen. holonomy

Generalized curvature and gen. holonomy

Consider a ***bosonic*** solution of CJS supergravity. Since $\delta_\varepsilon e \propto \psi = 0$, $\delta_\varepsilon A_3 \propto \psi = 0$

he invariance under supersymmetry of a bosonic solution is guaranteed if

$$\delta_\varepsilon \psi^\alpha := \mathcal{D}\varepsilon^\alpha = 0 \quad \boxed{\mathcal{D}\epsilon_J{}^\alpha = 0} ,$$

where $\varepsilon = \varepsilon^J \epsilon_J{}^\alpha$, ε^J constant and Grassmann odd, and $\epsilon_J{}^\alpha$ is bosonic.

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Killing spinors should also satisfy the integrability or consistency equation

$$\mathcal{D}\mathcal{D}\epsilon_J{}^\alpha = 0 \quad \boxed{\epsilon_J{}^\beta \mathcal{R}_\beta{}^\alpha = 0} \ ,$$

which is given in terms of the *generalized curvature* of the *generalized connection*

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The *curvature R* of a connection takes values in the algebra $\mathcal{H} \subset \mathcal{G}$ of the holonomy group $H \subset G$, $R_\beta{}^\alpha \in \mathcal{H}$ $(\omega_\beta{}^\alpha \in \mathcal{G})$. It is natural to introduce the notion of *generalized holonomy group* for the *generalized curvature* [M.J. Duff and K.S. Stelle, PLB **253**, 113 (1991); J. Figueroa-O'Farrill, G. Papadopoulos, JHEP **0303**, 048 (2003) [hep-th/0211089]; M. Duff and J.T. Liu, NPB **674**, 217 (2003); hep-th/0303140, C. Hull hep th/0305039, G. Papadopoulos and D. Tsimpsis hep-th/0306117; M. Duff, hep-th/0201062 (updated '06), hep/0403160].

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The generalized curvature $\mathcal{R}_\beta{}^\alpha$ takes values in the *generalized holonomy algebra*, hol(ω); for the D=11 and type II supergravities it is known that [C. Hull hep th/0305039, G. Papadopoulos and D. Tsimpsis hep-th/0306117]

$$\text{hol}(\omega) \subset sl(32, R) \ .$$

Furthermore, the 32 of sl(32,R) is reducible under hol(ω). *Killing spinors are invariant singlets in this decomposition.*

Generalized holonomy and Killing spinors

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The possible supersymmetric bosonic solutions of supergravity can be analized in terms of the generalized holonomies: the necessary condition for the existence of k Killing spinors,

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can be looked at as a restriction of the generalized holonomy group H.

If the field strength of the bosonic solution is also zero, *F*=0, the generalized connection reduces to the true, *spin(1,10)*-valued connection ω_L . We thus have:

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(1) $\psi = 0$, *F=0: supersymmetry and Riemannian holonomy:*

- the only non-vanishing field is the metric;
- the generalized connection reduces to the true, Levi-Civita spin connection ω_L;
- the Killing equation reduces to $D\epsilon_J{}^{\alpha} = 0$ where D is the ordinary covariant derivative; $[D_a, D_b]\epsilon^{\alpha} \propto R_{ab}{}^{cd}\Gamma_{cd}{}^{\alpha}{}_{\beta}\epsilon^{\beta} = 0$
- the integrability/consistency condition involves the ordinary Riemann tensor,
- if Killing spinors exist, $\mathrm{hol}(\omega) \subset so(1,10)$ strictly, the **32** of *spin*(1,10) is reducible under the $\mathrm{hol}(\omega)$ subalgebra; Killing sp. and invariant singlets in this decomposition are in one-to-one correspondence.
- in euclidean signature all holonomies are known [M. Berger, Bull. Soc. Math. France, 83, 225 (1995)]; for the Lorentz case, the *Spin*(1,10) subgroups leaving invariant spinors have been given [R.L. Bryant, Sémin. Congr., 4, Soc. Math. France, Paris, 2000, 53-94 [math.DG/0004073]; see DG/9910059 for a review]
- in this $F=0$ case, *the # k of preserved supersymmetries is either 32 or k ≤ 16* (1,2,3,4,6,8,16) [see J. Figueroa O'Farrill, CQG 17, 2925 (2000) [hep-th/9904124] and refs. therein.]

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[C.Hull, hep-th/0305039 ; Papadopoulos and Tsimpis, CQG **20**, L253 (2003) [hep-th/0307127], JHEP **0307**, 018 (2003) [hep-th/0306117] : see also, in the G-frame method context I.A. Bandos, J.A. de A., J.M. Izquierdo, M. Picón and O. Varela, PRD **69**, 105010 (2004) [hep-th/0212347]]

$$\mathrm{hol}(\omega) \subset sl(32-k, R) \;\subset\!\!\!\!+\; R^{\oplus k(32-k)} \equiv$$
$$sl(32-k, R) \;\subset\!\!\!\!+\; (R^{(32-k)} \oplus \cdots \oplus R^{(32-k)})$$

In particular, for a hypothetical *preonic* state, ***k*=31**, and thus

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In general, the ***generalized holonomy permits fractions k>16 of preserved*** 16

k/32-supersym. sugra solutions (D=11,10 present list)

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k=32, n=0 : vacuum, *Mink. flat superspace*, also the D=11 $AdS_{4,7} \times S^{7,4}$ and the IIB-r
supergravity solutions $AdS_5 \times S^5$, $AdS_{p+2} \times S^{D-p-2}$, $(D,p) = (11,2), (11,5), (10,3)$.
[P.T. Chrusciel and J. Kowalski-Glikman, PLB **149**, 107 (1984); J. Figueroa O'Farrill, G. Papadopoulos, JHEP **0108**,036 (2002) [hep-th/0105308]; M. Blau, J. Figueroa O'Farrill, G. Papadopoulos, CQG **19**, 4753 (2002) [hep-th/0202111]]

k=n=16 : 'standard' BPS states, solutions of D=11 supergravity, as the
M0 (M-wave), *M2, M5, M-KK* (D=11 Kaluza-Klein monopole), *M9* branes
[see M.J. Duff, R.R. Khuri and J.X. Lu, Phys. Rep. **259**, 213 (1995) [hep-th/9412184]; K.S. Stelle, hep-th/9803116; C. Hull, NPB **509**, 216 (1998) [hep th/9705162]

$k \leq 16$, $n \geq 16$: $k/32 \leq 1/2$ states can be treated as superspposition of *½* states
(intersecting branes) [P.K. Townsend, Cargèse lectures [hep-th/9712004]; see also J. Molins and J. Simon, PRD **62**, 125019 (2000) [hep- th/0007253]; A. Batrachenko, M.J. Duff, J.T. Liu and W.Y. Wen, hep-th/0312165 ; ……]

$k > 16$, $n < 16$: various 'exotic', *$k/32 > 1/2$* states also have been found (from 2002)
[see *refs. above* plus Cvetic+Lu+Pope [0203229]; Mickelsson [0206204]; Lu+Vazquez-Poritz [0204001]; Bena+R. Roiban,[0206195]; Sakaguchi [0306009]…….]

At present the list of k-supersym. states is (bracketed numbers = *missing (k)*-solutions)

k/32-supersym. sugra solutions (D=11,10 present list)

All fractions k/32 of preserved supersymmetries are allowed by the M-algebra.

Bandos and J. Lukierski, XIIth Max Born, LNP (1999) [hep-th/9812074] ; J.P. Gauntlett and C.M Hull, JHEP **0001**, 001 (2000) [hep-th/9909098]]. Further, all
?-central charges are on the same footing and mixed by the $GL(32,R)$ symmetry. Thus,

there is no reason, a priori, for not finding backgrounds for all possibilities.

But, *can we actually find a configuration for any k in D=10, 11 supergravities?*

k=32, n=0 : vacuum, *Mink. flat superspace*, also the D=11 $AdS_{4,7} \times S^{7,4}$ and the IIB-r
supergravity solutions $AdS_5 \times S^5$, $AdS_{p+2} \times S^{D-p-2}$, $(D,p) = (11,2), (11,5), (10,3)$.
[P.T. Chrusciel and J. Kowalski-Glikman, PLB **149**, 107 (1984); J. Figueroa O'Farrill, G. Papadopoulos, JHEP **0108**,036 (2002) [hep-th/0105308]; M. Blau, J. Figueroa O'Farrill, G. Papadopoulos, CQG **19**, 4753 (2002) [hep-th/0202111]]

k=n=16 : 'standard' BPS states, solutions of D=11 supergravity, as the
M0 (M-wave), *M2*, *M5*, *M-KK* (D=11 Kaluza-Klein monopole), *M9* branes
[see M.J. Duff, R.R. Khuri and J.X. Lu, Phys. Rep. **259**, 213 (1995) [hep-th/9412184]; K.S. Stelle, hep-th/9803116; C. Hull, NPB **509**, 216 (1998) [hep th/9705162]

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At present the list of k-supersym. states is (bracketed numbers = *missing (k)*-solutions)

k **= 0, 1, 2, 3, 4, 5, 6, *(7)*, 8, *(9)*, 10, *(11)*, 12, *(13)*, 14, *(15)*, 16, *(17)*,**
18, *(19)*, 20, *(21)*, 22, *(23)*, 24, *(25)*, 26, *(27)*, 28, *(29)*, *(30)*, *(31)*, 32

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(3) NO PREONS IN D=11 CREMMER-JULIA-SCHERK AND D=10 IIA, IIB SUPERGRAVITIES

No preonic solutions in standard CJS supergravity

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Some indications for the absence of preons in CJS supergravity were given early using the G-frame method [I.A. Bandos, J.A. de A., J.M. Izquierdo, M. Picón and O. Varela, PRD **69**, 105010 (2004) [hep-th/0212347]]

[*Parenthetical remark*: ***there always exist preonic solutions in Chern-Simons-type supergravities*** I.A. Bandos, J.A. de A., J.M. Izquierdo, M. Picón and O. Varela, PR **D69** , 105010 (2004) [hep-th/hep-th/0312266]]

But preonic solutions in CJS have been ruled out, both for simply connected manifolds [U. Gran, J. Gutowski, G. Papadopoulos and D. Roest, JHEP **0702**, 043 (2007) [hep-th/0610331] Fortschr. Phys. **55**, 736-74 (2007) [hep-th/0611150]]

as well as for their non-simply connected quotients [J. Figueroa O'Farrill and S. Gadhia, JHEP **0706**, 043 (2007) [hep-th/0702055]] (it is seen that if a solution admits 31 Killing spinors, it also admits an additional one and hence it is fully supersymmetric).

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However, all the above negative results correspond to 'pure' CJS supergravity. They do not yet exclude possible preonic solutions if e.g., 'higher order' $(\alpha')^3$-corrections, of third order in the Riemannian curvature are considered [see P. Candelas, M. Freeman, C.N. Pope, M. Sohnius and K. Stelle, PL **B177**, 341 (1986); K. Peeters, P. Vanhove and A. Westerberg, CQG **18**, 843 (2001) [hep-th/0010167, hep-th/0010182]; P.S. Howe and D. Tsimpis, JHEP **0309**, 038 (2003) [hep-th/0305129]; B. Zwiebach, PLB **156**, 315 (1985); H. Lu, C.N. Pope and K.S. Stelle, NP **B741**, 17 (2006) hep-th/0509057]]
and/or non-zero r.h.s's for the equations of motion (D=11 sugra interacting with branes, also not considered here).

No preonic solutions in standard IIA, IIB supergravities

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In both type II supergravities, a ***bosonic*** *solution* $\breve{\psi} = 0 = \breve{\chi}$ *stable under* k *supersymmetry transformations satisfies a differential (Killing) equation (as for CJS), plus an additional algebraic equation (coming from the dilatini transformations, M):*

$$\delta_\varepsilon \breve{\psi}_a^{\breve{\alpha}} = 0 \quad \Rightarrow \quad \mathcal{D}\breve{\epsilon}_I := D\breve{\epsilon}_I - \breve{\epsilon}_I \breve{t} = 0 \, ,$$

$$\delta_\varepsilon \breve{\chi} = 0 \quad \Rightarrow \quad \breve{\epsilon}_I \, M \; = 0 \qquad (I = 1, \ldots, k)$$

These two equations guarantee that the ***bosonic*** *solution is* k*-supersymmetric.* Then,

$$\breve{\epsilon}_I{}^{\alpha} \breve{\lambda}_{\breve{\alpha}} = 0 \, , \; I = 1, \ldots, 31 \Rightarrow \quad M = \breve{\lambda} \otimes \breve{s} \quad i.e. \begin{cases} IIA \; : \; M_{\breve{\beta}}{}^{\breve{\alpha}} = \breve{\lambda}_{\breve{\beta}} \, \breve{s}^{\breve{\alpha}} \\ IIB \; : \; M_{\breve{\beta}\breve{\alpha}} = \breve{\lambda}_{\breve{\beta}} \, \breve{s}_{\breve{\alpha}} \end{cases}$$

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For IIA either the preonic spinor is zero (→ no preons) or the matrix M itself is also zero and s *all* IIA fluxes are also zero. This means that the differential Killing spinor equation involves the ordinary connection and so there may be 32 or k=16 or less supersymmetries, but not 31 → *there are no IIA supergravity preons* (again, this result might change if stringy corrections, which modify the fluxes matrix M, are considered)

[I.A. Bandos, J.A. de A. and O. Varela, JHEP **09**, 009 (2006) [hep-th/0607060]

For IIB a similar analysis shows that only *even* numbers of preserved supersymmetries are possible, and hence that *there are no IIB supergravity preons* either, recovering the earlier negative result of [U. Gran, J. Gutowski, G. Papadopoulos and D.Roest, JHEP **0702**, 044 (2007) [hep-th/0606049]]

(4) SUMMARY/CONCLUSIONS

ll *BPS states of M-theory preserving k supersymmetries can be looked at as composites of* ı*=32-k primary constituents or BPS preons.*

[a similar statement holds in any *D* with *32* replaced by the corresponding spinor dimension $\tilde{n}$].

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Way out: if preonic solutions were found only when corrections are considered, this would indicate that preons are intrinsically quantum objects that cannot be seen in the low energy approximation to M-theory. Since preons are truly M-theory objects, a conclusive analysis of supergravities with 'stringy' corrections remains to be done.

If, nevertheless, preons were then not found, a natural question would be to know the degree of the '***preon conspiracy/confinement***' determining the ***minimal number of preons of a supergravity solution.***

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***Final remark:* it has been shown recently that, in D=4 and D=5 supergravities there exist sugra preonic (ν=3/4) BPS backgrounds obtained by quotients**

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This is a first example of preons (albeit in lower dim. supergravity).

A cautionary signal for local holonomy analyses?

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Thus, concerning the existence of M-theory preon states, perhaps we may conclude by saying that the jury is still out…