Supersymmetric version of the 3D Virasoro-like algebra and supersymmetrization of SU(∞)

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Extended supersymmetric versions of the Virasoro-like generalization of a 3D conformal algebra constructed previously by us are obtained. They contain supersymmetric versions of SU(∞) as subsuperalgebras.

1. Introduction

In the present paper we continue our investigation of the possible infinite-dimensional analogues of the Virasoro algebra in $D>2$ space–time initiated in refs. [1,2]. Using the symplectic structure on the twistor space, in ref. [1] we have constructed a certain infinite-dimensional algebra which contains a 3D conformal algebra (so(3, 2) or so (4, 1)) as its finite-dimensional subalgebra. It has a structure somewhat like the Virasoro one. Our goal in this paper consists in constructing N-extended supersymmetric versions of the algebra PAC(so(3, 2)) of ref. [1]. Such superalgebras may play the role of straightforward algebraical counterparts of the Neveu–Schwarz and SO(N)-extended [3] conformal superalgebras in $D=3$. They contain osp(N|4) as their finite-dimensional subsuperalgebras. Higher spin generalizations of these superalgebras looking like SO(N)-extended higher spin conformal superalgebras in $D=2$ [4,5] are also obtained. In the course of our consideration we shall also construct N-extended supersymmetric versions of SU(∞) in a rather simple way [#1]. Our method will be based on the Poisson superbrackets on the extended supertwistor superspace.

We will follow the notations and conventions of ref. [1] and sometimes refer to the formulae therein as e.g. (I.3).

2. SO(N)-extended 2D higher spin conformal superalgebras

To begin with, let us consider the simpler case of the SO(N)-extended 2D conformal superalgebra [3] and its higher spin version [4,5].

First, let us introduce a pair of canonical variables (p, q) and N Grassmann variables ψ_i, $i=1, ..., N$, and define the Poisson superbrackets as usual,

$$\{f, g\}_{PB}=\frac{\partial f}{\partial q}\frac{\partial g}{\partial p}-\frac{\partial f}{\partial p}\frac{\partial g}{\partial q}+2\frac{\partial_r f}{\partial \psi_i}\frac{\partial_\ell g}{\partial \psi^i}. \tag{1}$$

We will be concerned with a Poisson superbracket algebra of the Laurent polynomials of p and q and usual polynomials of ψ_i generated by the basis

[#1] In this paper su(∞) is just the Poisson bracket (area-preserving diffeomorphisms) algebra on the sphere S^2 [12].

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$$L^s_{n,i_1\ldots i_k}=\tfrac{1}{2}(p)^{s+n}(q)^{s-n}\psi_{i_1}\ldots\psi_{i_k}\,, \tag{2}$$

where $k=0, 1, \ldots, N$; $s\in\mathbf{Z}$ and $n\in\mathbf{Z}$, or $s\in\mathbf{Z}+\frac{1}{2}$ and $n\in\mathbf{Z}+\frac{1}{2}$ (we consider the Neveu–Schwarz sector) and the following conditions are supposed to be satisfied: $k+2s\geqslant 2$ and $k+2s$ is even. The Grassmann parity for such functions is defined as usual: $L^s_{n,i_1\ldots i_k}$ is Grassmann even when s is integer and k is even, and it is odd when s is half-integer and k is odd (note that we require $k+2s$ to be even for the right connection between spin and statistics for (2)). Calculating the Poisson brackets (1) for the basis elements (2), we obtain the composition law in the superalgebra, which we denoted shsc$^{*E}(N|1)$ in refs. [4,5] (shsc means super higher spin conformal, E (even) for $k+2s$ even, * for the Poisson brackets)

$$[L^s_{n,i_1\ldots i_k}, L^{s'}_{n',j_1\ldots j_{k'}}\}_{\mathrm{PB}}=(sn'-s'n)L^{s+s'-1}_{n+n',i_1\ldots i_k j_1\ldots j_{k'}}+kk'\ \mathrm{Alt}(\delta_{i_k j_1}L^{s+s'}_{n+n',i_1\ldots i_{k-1}j_2\ldots j_{k'}}), \tag{3}$$

where Alt means antisymmetrization in all i- and j-indices separately ($\mathrm{Alt}(A_{i_1}B_{i_2})=\frac{1}{2}(A_{i_1}B_{i_2}-A_{i_2}B_{i_1})$). The superalgebra shsc$^{*E}(N|1)$ (3) contains the SO(N)-extended conformal superalgebra [3] as a subsuperalgebra generated by the monomials (2) with $2s+k=2$ (only spins $s\leqslant 1$ may appear)

$$L^1_n,\ L^{1/2}_{n,i},\ \ldots,\ L^{1-N/2}_{n,i_1\ldots i_N}\quad (k+2s=2)\,. \tag{4}$$

When $N=0$ this is the usual (centreless) Virasoro algebra and when $N=1$ it is the Neveu–Schwarz superalgebra. An important feature of the SO(N)-superconformal algebra and its higher spin generalization (3) consists in the presence of negative spins ($s<0$) when $N>2$. Also when $N>4$ [6] there is no non-trivial central extension. In refs. [4,5] we also calculated the conformal anomalies (from the nilpotency condition $\Omega^2=0$) for these extended higher spin conformal superalgebras and the results were $C=-\frac{1}{6}$ ($N=0$), $-\frac{5}{24}$ ($N=1$), $-\frac{1}{4}$ ($N=2$), and 0 (for all $N>2$). To obtain the first three non-zero anomalies the ζ-regularization is needed, while the conformal anomalies for $N>2$ are cancelled out separately for each osp($N|2$) supermultiplet [#2].

Another interesting subsuperalgebra of (3) is extracted when the restrictions $s\geqslant 0$ and $|n|\leqslant s$ are supposed to be satisfied (i.e. the generators contain only non-negative powers of p and q). In fact this is a higher spin superalgebra shs$^{*E}(N|2)$ of ref. [7], where the extended versions of the higher spin algebras originally appeared in ref. [8] were constructed. It generalizes osp($N|2$) which is contained in shs$^{*E}(N|1)$ as a maximal finite-dimensional subsuperalgebra generated by $\{L^1_{\pm 1,0}, L^{1/2}_{\pm 1/2,i}, L^0_{0,ij}\}$. On the other hand, in the terminology of refs. [1,2], shsc$^{*E}(N|1)$ is an analytic continuation of shs$^{*E}(N|1)$ and is obtained from the latter after abolishing the restrictions $|n|\leqslant s$, $s\geqslant 0$. (In such a terminology the SO(N)-extended conformal superalgebra [3] is an analytic continuation of osp($N|2$) along the sp(2) roots [2].)

3. Virasoro-like extension of 3D conformal superalgebra osp($N|4$) and its higher spin version

Now let us pass to the main subject of the present paper, the 3D conformal superalgebra. Along with the spinorial generating elements a_α, b_α as in (1.9) we introduce also Grassmann variables ψ_i, $i=1, \ldots, N$ to obtain an extended supersymmetric version of the results of ref. [1]. (This is a general method of constructing extended higher spin superalgebras [8–10]. For finite-dimensional superalgebras such oscillator-like realizations were studied in ref. [11].) The Poisson superbracket for two functions of a_α, b_α and ψ_i is defined according to

$$[f, g\}_{\mathrm{PB}}=f\overleftrightarrow{\Delta}g,\quad \overleftrightarrow{\Delta}=\frac{\overleftarrow{\partial}}{\partial a_\alpha}\varepsilon_{\alpha\beta}\frac{\overrightarrow{\partial}}{\partial b_\beta}+\frac{\overleftarrow{\partial}}{\partial b_\alpha}\varepsilon_{\alpha\beta}\frac{\overrightarrow{\partial}}{\partial a_\beta}+2\frac{\overleftarrow{\partial}_r}{\partial\psi_i}\frac{\overrightarrow{\partial}_l}{\partial\psi^i}\,. \tag{5}$$

An algebra of all second order polynomials of (a_α, b_α, ψ_i) with respect to the Poisson bracket (5) is iso-

[#2] For comparison we give the conformal anomalies for usual conformal superalgebras without higher spins: $\frac{13}{6}$($N=0$), $\frac{5}{4}$($N=1$), $\frac{1}{2}$($N=2$) and 0 (for all $N>2$).

morphic to osp$(N|4)$. An infinite-dimensional algebra shsc*$(N|3)$ [9] of all order polynomials, so that

$$P(-a_\alpha, -b_\alpha, -\psi_i)=P(a_\alpha, b_\alpha, \psi_i)\ , \tag{6}$$

generalizes the 3D conformal superalgebra osp $(N|4)$ to the case of all higher spins. shsc*$(N|3)$ (N-extended higher spin 3D conformal Poisson-bracket superalgebra) is isomorphic to shs$^{*E}(N|4)$ [8] (higher-spin superalgebra in 4D anti-de Sitter space) due to the isomorphism between the usual 3D conformal and 4D anti-de Sitter superalgebras.

The generators of shsc*$(N|3)$ have a form [9] (for all our notations and conventions see section 4 in ref. [1])

$$T^{(s,c)}_{\alpha(2l),i_1\dots i_k}=\tfrac{1}{2}\sqrt{\frac{(2\ell)!}{(\ell+c)!(\ell-c)!}}\,\underbrace{a_\alpha\dots a_\alpha}_{\ell-c}\,\underbrace{b_\alpha\dots b_\alpha}_{\ell+c}\,\psi_{i_1}\dots\psi_{i_k}(a^\gamma b_\gamma)^{s-\ell}\ , \tag{7}$$

where the indices have the following range of definition:

$$s=0,\tfrac{1}{2},1,\dots,\quad \ell=0,\tfrac{1}{2},1,\dots,\quad \ell\leqslant s\ , \tag{8}$$

$c=-\ell, -\ell+1, \dots, \ell$; s, ℓ and c are simultaneously integer or half-integer; $k=0, 1, \dots, N$, $k+2s\geqslant 2$, and $k+2s$ is an even number.

The new element here in comparison with (I.12) consists in introducing the Grassmann variables ψ_i (each generator now is an anti-symmetric tensor with respect to its internal indices), and now s, ℓ and c may be integer and half-integer (Bose and Fermi generators are presented).

The second-order monomials (7) with $k+2s=2$ form a maximal finite-dimensional subalgebra isomorphic to osp $(N|4)$.

The superalgebra shsc*$(N|3)$ is a 3D analogue of the *little* higher spin conformal subsuperalgebra of shsc*$(N|1)$ given in (3) (note that "little" means that the restrictions $s\geqslant 0$, $|n|\leqslant s$ are supposed to be satisfied).

To pass to the 3D counterpart of the SO(N)-extended Virasoro superalgebra and its higher spin version, one has to abolish the restrictions

$$s\geqslant 0,\quad \ell\leqslant s \tag{9}$$

in (7), (8) (all the others remain true). This is similar to abolishing the restrictions $s\geqslant 0$, $|n|\leqslant s$ that has to be done to pass to the Virasoro superalgebra from the little superalgebra. Such a general procedure was named analytic continuation in refs. [2,1].

Calculating the Poisson brackets of two basis monomials (7), we obtain a manifest expression for the N-extended supersymmetric version of the algebra (I.13):

$$[T^{(s,c)}_{\alpha(2\ell),i_1\dots i_k}, T^{(s',c')}_{\beta(2\ell'),j_1\dots j_{k'}}]_{\rm PB}$$
$$=\sum_{\ell'',c''} C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')}[f^{\ell\ell'\ell''}_{cc'c''}(s,s')T^{(s+s'-1,c'')}_{\gamma(2\ell''),i_1\dots i_kj_1\dots j_{k'}}+kk'C^{\ell\ell'\ell''}_{cc'c''}\,\mathrm{Alt}(\delta_{i_kj_1}T^{(s+s',c'')}_{\gamma(2\ell''),i_1\dots i_{k-1}j_2\dots j_{k'}})] \tag{10}$$

(see (I.13)–(I.16)). The quantities $f^{\ell\ell'\ell''}_{cc'c''}(s,s')$ are given in (I.16)).

The generators with $k+2s=2$ form a basis in the subsuperalgebra which is a 3D counterpart of the SO(N)-superconformal algebra [3]. In particular we present as evidence the manifest expressions for the 3D counterpart of the $N=1$ Neveu–Schwarz superalgebra PAC(osp(1/4)) ($L^c_{\alpha(2\ell)}=T^{(1,c)}_{\alpha(2\ell)}$, $Q^c_{\alpha(2\ell)}=T^{(1/2,c)}_{\alpha(2\ell)}\psi$),

$$[L^c_{\alpha(2\ell)}, L^{c'}_{\beta(2\ell')}]_{\rm PB}=\sum_{\ell'',c''} f^{\ell\ell'\ell''}_{cc'c''}(1,1)C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')}L^{c''}_{\gamma(2\ell'')}\ ,$$

$$[L^c_{\alpha(2\ell)}Q^{c'}_{\beta(2\ell')}]_{\rm PB}=\sum_{\ell'',c''} f^{\ell\ell'\ell''}_{cc'c''}(1,\tfrac{1}{2})C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')}Q^{c''}_{\gamma(2\ell'')}\ , \tag{11}$$

$$\{Q^{c}_{\alpha(2\ell)}, Q^{c'}_{\beta(2\ell')}\}_{PB} = \sum_{\ell'',c''} C^{\ell\ell'\ell''}_{cc'c''} C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')} L^{c''}_{\gamma(2\ell'')} . \qquad (11\text{ cont'd})$$

Here the generators

$$P_{\alpha(2)} \sim L^{-1}_{\alpha(2)}, \quad K_{\alpha(2)} \sim L^{1}_{\alpha(2)}, \quad M_{\alpha(2)} \sim L^{0}_{\alpha(2)}, \quad D \sim L^0, \quad Q_\alpha \sim Q^{-1/2}_{\alpha}, \quad S_\alpha \sim Q^{1/2}_{\alpha} \qquad (12)$$

form a basis in osp $(1|4)$, which is contained as a maximal finite-dimensional subalgebra in PAC(osp$1|4$)), its analytic continuation beyond the boundaries $\ell \leqslant s$ ($s=1$ for $L^{c}_{\alpha(2\ell)}$, $s=\frac{1}{2}$ for $Q^{c}_{\alpha(2\ell)}$).

The higher spin extension of (11), counterpart of the Poisson-bracket higher spin extension of the Neveu–Schwarz superalgebra, is given by

$$[T^{(s,c)}_{\alpha(2\ell)}, T^{(s',c')}_{\beta(2\ell')}]_{PB} = \sum_{\ell'',c''} f^{\ell\ell'\ell''}_{cc'c''}(s,s') C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')} T^{(s+s'-1,c'')}_{\gamma(2\ell'')} ,$$

$$[T^{(s,c)}_{\alpha(2\ell)}, Q^{(s',c')}_{\beta(2\ell')}]_{PB} = \sum_{\ell'',c''} f^{\ell\ell'\ell''}_{cc'c''}(s,s') C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')} Q^{(s+s'-1,c'')}_{\gamma(2\ell'')} ,$$

$$\{Q^{(s,c)}_{\alpha(2\ell)}, Q^{(s',c')}_{\beta(2\ell')}\}_{PB} = \sum_{\ell'',c''} C^{\ell\ell'\ell''}_{cc'c''} C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')} T^{(s+s',c'')}_{\gamma(2\ell'')} . \qquad (13)$$

4. Extended supersymmetric versions of SU(∞)

As was shown in ref. [1], the algebra AC(so(4,1)) contains SU(∞), the Poisson bracket algebra on the sphere S^2 [12], as its zero-conformal weight subalgebra. It is constituted by the generators having zero Poisson brackets with the dilatation generator D. Similar $2N$-extended supersymmetric versions of PAC(so(3,2)) constructed in the previous section contain extended supersymmetric versions of SU(∞, ∞) (non-compact form of SU(∞) related with $S^{1,1}$ in place of S^2) as their special subalgebras.

To describe these subsuperalgebras, let us consider the $2N$-extended case and choose $2N$ new Grassmann variables ξ_i, η^j with the Poisson brackets

$$\{\xi_i, \eta^j\}_{PB} = \delta^j_i \qquad (14)$$

instead of the old variables ψ. Now we can introduce the following quantity:

$$S = \tfrac{1}{2}(\alpha_\gamma b^\gamma + \xi_i \eta^i) , \qquad (15)$$

which in the twistor theory is usually called a superspirality operator ((15) is its classical version exactly). It is easy to see that the condition

$$[s, f]_{PB} = 0 \qquad (16)$$

for $f \in$ osp$(2N|4)$ extracts the subsuperalgebra SU$(1, 1|N) \subset$ osp$(2N|4)$ (we have excluded S itself) (see ref. [10]). Requiring the condition (16) to be satisfied after the analytic continuation, we arrive at the infinite-dimensional superalgebra with basis polynomials

$$T_{\alpha(2\ell),i_1\ldots i_p}{}^{j_1\ldots j_q} = \frac{1}{2}\sqrt{\frac{(2\ell)!}{[\ell+(q-p)/2]!\,[\ell-(q-p)/2]!}}\ \underbrace{a_\alpha\ldots a_\alpha}_{\ell-(q-p)/2}\ \underbrace{b_\alpha\ldots b_\alpha}_{\ell+(q-p)/2}\ \underbrace{\xi_{i_1}\ldots\xi_{i_p}}_{p}\ \underbrace{\eta_{j_1}\ldots\eta_{j_q}}_{q}\ (a^\gamma b_\gamma)^{1-\ell-(q+p)/2} , \qquad (17)$$

where

$$\ell = 0, \tfrac{1}{2}, 1, \ldots, \quad q, p = 0, 1, \ldots, N, \quad |(q-p)/2| \leqslant \ell , \qquad (18)$$

$|(q-p)/2|$ and ℓ are simultaneously integers or half-integers.

Supercommutation relations can be calculated straightforwardly,

$$[T_{\alpha(2\ell),i_1\dots i_p,}{}^{j_1\dots j_q}, T_{\beta(2\ell'),i'_1\dots i'_{p'},}{}^{j'_1\dots j'_{q'}}\}_{\rm PB} = \sum_{\ell''} (-1)^{qp'} C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')}$$
$$\times [f^{\ell,\ell',\ell''}_{(q-p)/2,(q'-p')/2,(q+q'-p-p')/2}(1-(q+p)/2, 1-(q'+p'/2))\, T_{\gamma(2\ell''),i_1\dots i_p i'_1\dots i'_{p'},}{}^{j_1\dots j_q j'_1\dots j'_{q'}}$$
$$+\tfrac{1}{2}(-1)^{q+p'} C^{\ell,\ell',\ell''}_{(q-p)/2,\,(q'-p')/2,\,(q+q'-p-p')/2}$$
$$\times \mathrm{Alt}(q'p\delta^{j'_1}_{i_p} T_{\gamma(2\ell''),i_1\dots i_{p-1}i'_1\dots i'_{p'},}{}^{j_1\dots j_q j'_2\dots j'_{q'}} - qp'\delta^{j_q}_{i'_1} T_{\gamma(2\ell''),i_1\dots i_p i'_2\dots i'_{p'},}{}^{j_1\dots j_{q-1} j'_1\dots j'_{q'}})] , \tag{19}$$

where $f^{\ell\ell'\ell''}_{cc'c''}(s, s')$ have been given in (I.16) and Alt means the same as in (3).

The above superalgebra as a matter of fact is an N-extended supersymmetric version of the Poisson bracket algebra on the hyperboloid $S^{1,1}$. The latter is a subalgebra and formed by the subset of the basis elements (17) without ξ and η (simply $T_{\alpha(2\ell)}$) (as it was shown in ref. [1], (I.25)). On the other hand the superalgebra (19) contains a maximal finite-dimensional subalgebra SU(1,1|N) (when $2\ell+p+q=2$ in (17)), N-extended supersymmetrization of the isometry algebra of $S^{1,1}$. Note that transformation from the usual coordinates X_μ of $S^{1,1}$ ($X_\mu X^\mu = R^2$) to our spinorial coordinates a_α, b_α as a matter of fact is a twistor-type transformation for 3D space–time (see appendix C in ref. [5])

$$x_\mu = \sigma^{\alpha(2)}_\mu a_\alpha b_\alpha \tag{20}$$

($\sigma_\mu = (I, \sigma_1, \sigma_3)$, σ_1, σ_3 are the symmetric Pauli matrices). As is known, in many cases the twistor transformation allows one to simplify considerably various non-linear structures. In the case in question it reduces the non-canonical Poisson brackets $[X_\mu, X_\nu]_{\rm PB} = \epsilon_{\mu\nu\rho}X^\rho$ to the usual canonical ones $[a_\alpha, b_\beta]_{\rm PB} = \varepsilon_{\alpha\beta}$. Realization (17) in fact gives a generalization to supertwistors.

Now let us pass to the euclidean case. Instead of the spinorial basis the weight basis can be used with the euclidean hermitian conjugation

$$(T^{\ell}_{m,i_1\dots i_p,}{}^{j_1\dots j_q})^\dagger = (-1)^{m+(q-p)/2} T^{\ell}_{-m,j_1\dots j_q,}{}^{i_1\dots i_p} \tag{21}$$

and the supercommutation relations read as in (19) with the usual Clebsch–Gordan coefficients $C^{\ell\ell'\ell''}_{mm'm''}$ in place of the spinorial $C_{\alpha(2\ell),\beta(2\ell'),}{}^{\gamma(2\ell'')}$. This is an N-extended supersymmetrization of SU(∞) [12]. It contains su(∞) itself (the generators T^{ℓ}_m ($p=q=0$)) as well as the maximal finite-dimensional subalgebra SU(2|N) (the generators with $2\ell+p+q=2$).

The case of the $N=1$ superalgebra, SU($\infty+1|\infty$), was obtained by us also in essentially another way as the large-M limit of the finite-dimensional matrix superalgebras SU($M+1|M$) [13].

5. Summary

To summarize the results of the present paper, first, infinite-dimensional superalgebras generalizing 3D conformal superalgebras osp(N|4) are constructed. They are 3D algebraical analogues of the Neveu–Schwarz and the SO(N)-extended 2D superconformal algebras. Second, their higher spin generalizations are obtained. Third, from the SO($2N$)-extended 3D Virasoro-like superalgebra we have extracted a special subalgebra which can be considered as an N-extended supersymmetric version of SU(∞) (in the euclidean case).

The complete expressions for the structure constants of the above algebras are obtained. Note also that calculations of the structure constants (which are rather complicated themselves) are especially simple in the approach presented, based on the Poisson brackets for 3D supertwistors.

References

[1] E.S. Fradkin and V.Ya. Linetsky, Phys. Lett. B., 253 (1990) 97.
[2] E.S. Fradkin and V.Ya. Linetsky, Mod. Phys. Lett. A 5 (1990) 1167.
[3] M. Ademollo et al., Phys. Lett. B 62 (1976) 105; Nucl. Phys. B 111 (1976) 77.
[4] E.S. Fradkin and V.Ya. Linetsky, Mod. Phys. Lett. A 4 (1989) 2649.
[5] E.S. Fradkin and V.Ya. Linetsky, in: Proc. Trieste Conf. on Supermembranes and physics in 2+1 dimensions (World Scientific, Singapore, 1990).
[6] V.G. Kac and J.W. van der Leur, in: Strings'88, eds. S.J. Gates Jr., C.R. Preitschopf and W. Siegel (World Scientific, Singapore, 1989).
[7] E.S. Fradkin and M.A. Vasiliev, Ann. Phys. (NY) 177 (1987) 63.
[8] M.A. Vasiliev, Fortschr. Phys. 36 (1988) 33.
[9] E.S. Fradkin and V.Ya. Linetsky, Mod. Phys. Lett. A 4 (1989) 731; Ann. Phys. 198 (1990) 293.
[10] E.S. Fradkin and V.Ya. Linetsky, Mod. Phys. lett. A 4 (1989) 2363; Ann. Phys. 198 (1990) 252.
[11] I. Bars and M. Günaydin, Commun. Math. Phys. 91 (1983) 31;
M. Günaydin, Lecture Notes in Physics, Vol. 180 (Springer, Berlin, 1982), p. 192.
[12] J. Hoppe, MIT Ph.D. thesis (1982); and Florence 1986 Workshop on Constraint theory and relativistic dynamics, eds. G. Longhi and L. Lusanna (World Scientific, Singapore).
[13] E.S. Fradkin and V.Ya. Linetsky, Mod. Phys. Lett. A, in press.