Super Galilean conformal algebra in AdS/CFT

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Abstract

Galilean conformal algebra (GCA) is an Inönü-Wigner (IW) contraction of a conformal algebra, while Newton-Hooke string algebra is an IW contraction of an AdS algebra which is the isometry of an AdS space. It is shown that the GCA is a boundary realization of the Newton-Hooke string algebra in the bulk AdS. The string lies along the direction transverse to the boundary, and the worldsheet is AdS$_2$. The one-dimensional conformal symmetry so(2,1) and rotational symmetry so($d$) contained in the GCA are realized as the symmetry on the AdS$_2$ string worldsheet and rotational symmetry in the space transverse to the AdS$_2$ in AdS$_{d+2}$, respectively. It follows from this correspondence that 32 supersymmetric GCAs can be derived as IW contractions of superconformal algebras, psu(2,2|4), osp(8|4) and osp(8$^*$|4). We also derive less supersymmetric GCAs from su(2,2|2), osp(4|4), osp(2|4) and osp(8$^*$|2).
1 Introduction

The AdS/CFT conjecture [1, 2] has attracted much interest in studies of fundamental aspects of strings and in its applications to actual experiments.

One of the main difficulties to rigorously prove this conjecture is to explicitly quantize the type IIB superstring on AdS$_5 \times$S$^5$ [3] (AdS superstring). So it is still important to look for a limit which extracts a solvable subsector of the full AdS superstring. One such limit is the Penrose limit [4], which corresponds to taking a close-up of a null geodesic. Under the limit [5], the AdS$_5 \times$S$^5$ background reduces to the pp-wave background [6]. The superstring on this background was exactly solved in the light-cone gauge fixing [7], and the BMN operator correspondence was found [8]. The symmetry of the latter theory, the super pp-wave algebra, is an Inönü-Wigner (IW) contraction [9] of the super-isometry of the AdS$_5 \times$S$^5$ background, the super-AdS$_5 \times$S$^5$ algebra [10].

Another limit is the non-relativistic (NR) limit [11, 12] \footnote{The NR string theory in flat space was studied in [13] [14].}, which corresponds to taking a close-up of an AdS$_2$ string worldsheet. The string theory reduces to a free theory of three
massive scalars, five massless scalars and eight massive fermions propagating on AdS$_2$ in the static gauge [11]. These modes correspond to fluctuations of the string worldsheet [17]. The non-normalizable modes which correspond to fluctuations reaching the boundary deform the Wilson loop on the boundary, and result in operator insertions in the Wilson loop. The symmetry of the NR string theory is the super Newton-Hooke string algebra which is an IW contraction of the super AdS$_5 \times S^5$ algebra [11]. The analysis was extended to supersymmetric branes in AdS$_5 \times S^5$, AdS$_4 \times S^7$ and AdS$_7 \times S^4$ in [18].

More recently, there have been considerable activities in studies of strongly coupled systems. The NR conformal field theory (CFT) which has Schrödinger symmetry [19] is discussed in [20, 21], and is relevant to studies of ultracold atoms at unitarity. The holographic dual description was proposed in [22, 23] [24,25]. The Schrödinger symmetry is a non-relativistic analog of the conformal symmetry with dynamical exponent $z = 2$. The Schrödinger symmetry in $d$ spacial dimensions, sch($d$), is the extension of the Galilean symmetry generated by time translation $H$, space translation $P_i$, space rotation $J_{ij}$ and Galilean boost $G_i$, to include dilatation $D$, Galilean special conformal $K$, and a center $M$, where $i = 1, \cdots, d$. The sch($d$) is a subalgebra of the conformal algebra in $(d + 2)$-dimensions, so($d + 2, 2$), and thus of the AdS algebra in $(d + 3)$-dimensions. From this, super Schrödinger algebras were derived as subalgebras of superconformal algebras, psu(2,2$|$4) and osp(8($^*$)$|$4) in [26, 27]. Super Schrödinger-invariant field theories are obtained as non-relativistic limits of relativistic field theories in [70–72].

Galilean conformal algebra (GCA) [73], which is the main subject in the present paper, is another non-relativistic analog of the conformal symmetry with dynamical exponent $z = 1$. Recent studies on this issue includes [74]– [77] [66]– [68]. It is the extension of the Galilean algebra with dilatation $D$, Galilean special conformal $K$ and acceleration $K_i$. It is known that the GCA is an IW contraction of the conformal algebra. The conformal algebra in $(d + 1)$-dimensions is the AdS$_{d+2}$ algebra. So the GCA on the boundary should be related to a certain IW contraction of the AdS$_{d+2}$ algebra. In fact, it is shown that the Newton-Hooke string algebra [11, 12] is the bulk realization of the GCA on the boundary. The string lies along the direction transverse to the boundary. The GCA has so(1,2) times so($d$) as a subalgebra. The one-dimensional conformal algebra so(1,2) $\cong$ sl(2) is the symmetry of the AdS$_2$ worldsheet. The so($d$) is rotational symmetry in the space transverse to the AdS$_2$ in AdS$_{d+2}$. Taking a close-up of AdS$_2$ in AdS$_{d+2}$ corresponds the IW contraction of the conformal algebra to the GCA.

From this observation, we derive super GCAs from superconformal algebras in this paper. Firstly, we derive super GCAs in (1 + 3)-dimensions as IW contractions of the four-dimensional superconformal algebras, psu(2,2$|$4) and su(2,2$|$2). This corresponds to taking a close-up of

\footnote{The physical spectrum was obtained in [15], and the semiclassical partition function was evaluated in [16].}

\footnote{Further studies along this line includes [26]– [68]. See [69] for a review.}
an AdS$_2$ string in AdS$_5 \times $S$^5$. Secondly, super GCAs in (1 + 2)-dimensions are derived as IW contractions of the three-dimensional superconformal algebras, osp(8|4), osp(4|4) and osp(2|4). This corresponds to taking a close-up of an AdS$_2 \times $S$^1$ M2-brane in AdS$_4 \times $S$^7$. Thirdly, we derive super semi-GCAs in (1 + 5)-dimensions as IW contractions of six-dimensional superconformal algebras, osp(8$^*$|4) and osp(8$^*$|2). This corresponds to taking a close-up of an AdS$_3$ M2-brane in AdS$_7 \times $S$^4$. The resulting 32 supersymmetric GCAs are boundary realizations of the super Newton-Hooke algebras of a brane derived in [11], [18]. Less supersymmetric (semi-)GCAs obtained in this paper give new super Newton-Hooke algebras of a brane. Various supersymmetric (semi-)GCAs can be derived by considering 1/2 BPS brane configurations in [18], but we will not complete them here.

This paper is organized as follows. First, we show that GCA is the boundary realization of the Newton-Hooke string algebra, and that the Newton-Hooke brane algebra is realized as the semi-GCA on the boundary. In section 3, super GCAs are derived from the four-dimensional $\mathcal{N} = 4$ and 2 superconformal algebras psu(2,2|4) and su(2,2|2), respectively. In section 4, we derive super GCAs from the three-dimensional $\mathcal{N} = 8$, 4 and 2 superconformal algebras osp(8|4), osp(4|4) and osp(2|4), respectively. We also derive super GCAs from the six-dimensional $\mathcal{N} = 4$ and 2 superconformal algebras osp(8$^*$|4) and osp(8$^*$|2), in section 5. The last section is devoted to a summary and discussions.

2 GCA from Conformal algebra

Conformal algebra in $(d+1)$-dimensions is generated by translation $\tilde{P}_\mu$, special conformal transformation $\tilde{K}_\mu$, dilatation $\tilde{D}$ and Lorentz rotation $\tilde{J}_{\mu \nu}$, where $\mu = 0, 1, \cdots, d$. The commutation relation is given by

\[
\begin{align*}
[\tilde{J}_{\mu \nu}, \tilde{J}_{\rho \sigma}] &= \eta_{\nu \rho} \tilde{J}_{\mu \sigma} + 3\text{-terms}, \\
[\tilde{J}_{\mu \nu}, \tilde{P}_\rho] &= \eta_{\nu \rho} \tilde{P}_\mu - \eta_{\mu \rho} \tilde{P}_\nu, \\
[\tilde{J}_{\mu \nu}, \tilde{K}_\rho] &= \eta_{\nu \rho} \tilde{K}_\mu - \eta_{\mu \rho} \tilde{K}_\nu, \\
[\tilde{D}, \tilde{P}_\mu] &= \tilde{P}_\mu, \\
[\tilde{D}, \tilde{K}_\mu] &= -\tilde{K}_\mu, \\
[\tilde{P}_\mu, \tilde{K}_\nu] &= \frac{1}{2} \tilde{J}_{\mu \nu} + \frac{1}{2} \eta_{\mu \nu} \tilde{D}, \\
\end{align*}
\]

where $\eta_{\mu \nu} = \text{diag}(-1, +1, \cdots, +1)$.

Let us rename and scale generators as

\[
\begin{align*}
\tilde{P}_0 &= H, \\
\tilde{K}_0 &= K, \\
\tilde{D} &= D, \\
\tilde{J}_{ij} &= J_{ij}, \\
\tilde{P}_i &= \omega P_i, \\
\tilde{K}_i &= \omega K_i, \\
\tilde{J}_{0i} &= \omega G_i
\end{align*}
\]

We suppress trivial commutators in this paper.

The contraction used in [73]

\[
\begin{align*}
\tilde{P}_0 &= \frac{1}{c} H, \\
\tilde{P}_i &= P_i, \\
\tilde{K}_0 &= c K, \\
\tilde{K}_i &= c^2 F_i, \\
\tilde{D} &= D, \\
\tilde{J}_{0i} &= c K_i, \\
\tilde{J}_{ij} &= J_{ij}, \\
\end{align*}
\]

and $c \to \infty$ leads to the same result.
where $\mu = (0, i)$ and $i = 1, \cdots, d$. Substituting these into (2.1), one sees that the limit $\omega \to \infty$ is non-singular. This implies that, under a contraction $\omega \to \infty$, the conformal algebra (2.1) reduces to

$$[D, H] = H, \quad [D, K] = -K, \quad [H, K] = -\frac{1}{2} D,$$

$$[D, P_i] = P_i, \quad [D, K_i] = -K_i, \quad [H, K_i] = -\frac{1}{2} G_i,$$

$$[H, G_i] = P_i, \quad [K, G_i] = K_i, \quad [K, P_i] = -\frac{1}{2} G_i,$$

$$[J_{ij}, J_{kl}] = \delta_{jk} J_{il} + \text{3-terms}, \quad [J_{ij}, F_i] = \delta_{jk} F_j - \delta_{ik} F_j, \quad F_i = \{P_i, K_i, G_i\}. \quad (2.3)$$

The resulting algebra

$$\{H, K, D, J_{ij}, P_i, K_i, G_i\} \quad (2.4)$$

is the GCA. The set of generators $\{H, K, D\}$ generates $\text{sl}(2, R) \cong \text{so}(2, 1)$ while $\{J_{ij}\}$ generates $\text{so}(d)$.

### 2.1 GCA and Newton-Hooke string algebra

On the other hand, the conformal algebra in $(d+1)$-dimensions is equivalent to the AdS algebra in $(d + 2)$-dimensions

$$[P_a, P_b] = J_{ab}, \quad [J_{ab}, P_c] = \eta_{bc} P_a - \eta_{ac} P_b, \quad [J_{ab}, J_{cd}] = \eta_{bc} J_{ad} + \text{3-terms}, \quad (2.5)$$

where $a = 0, 1, \cdots, d + 1$. It reduces to the conformal algebra (2.1) by

$$P_\mu = \tilde{P}_\mu + \tilde{K}_\mu, \quad P_{d+1} = \tilde{D}, \quad J_{\mu \nu} = \tilde{J}_{\mu \nu}, \quad J_{\mu d+1} = \tilde{K}_\mu - \tilde{P}_\mu. \quad (2.6)$$

It is easy to see that the scaling (2.2) corresponds to

$$P_{\bar{a}} \to P_{\bar{a}}, \quad J_{ij} \to J_{ij}, \quad J_{\bar{a}b} \to J_{\bar{a}b}, \quad P_i \to \omega P_i, \quad J_{i\bar{a}} \to \omega J_{i\bar{a}}. \quad (2.7)$$

where $\bar{a} = 0, d + 1$. This is nothing but the contraction which leads to the Newton-Hooke string algebra [12] [11](see also [18]). The string lies along $(d + 1)$-th direction. By the contraction, the AdS algebra reduces to the Newton-Hooke string algebra

$$[P_{\bar{a}}, P_{\bar{b}}] = J_{\bar{a}b}, \quad [J_{\bar{a}b}, P_c] = \eta_{bc} P_{\bar{a}} - \eta_{\bar{a}c} P_{\bar{b}}, \quad [J_{\bar{a}b}, J_{\bar{c}d}] = \eta_{bc} J_{\bar{a}d} + \text{3-tems}, \quad (2.8)$$

The first three commutation relations represent $\text{AdS}_2$ symmetry $\text{sl}(2, R)$. This is the symmetry on the string worldsheet extending along $(0, d+1)$-th directions. The last commutation relation
is so(d) which is the rotation in the space transverse to the AdS in AdS_{d+2}. The Newton-Hooke string algebra \(^{(2.8)}\) is equivalent to the GCA \(^{(2.3)}\). So the GCA on the boundary is realized as the Newton-Hooke string algebra in the bulk. The limit corresponds to taking a close-up of the AdS_{2} string worldsheet. Thus the GCA can be interpreted as the symmetry of the non-relativistic string in AdS space.

The Newton-Hooke brane algebra \([12]\) is a generalization of the Newton-Hooke string algebra to the case that \(a\) spans a \(p\)-dimensional brane worldvolume. Let \(a\) be \(a = (\alpha, d + 1)\), where \(\alpha\) spans a \((p - 1)\)-dimensional spacetime. The Newton-Hooke string algebra is the case with \(p = 2\). The scaling \(^{(2.7)}\) means

\[
\bar{P}_\alpha = P_\alpha, \quad \bar{K}_\alpha = K_\alpha, \quad \bar{D} = D, \quad \bar{J}_{ij} = J_{ij}, \quad \bar{J}_{\alpha\beta} = J_{\alpha\beta},
\]

\[
\bar{P}_i = \omega P_i, \quad \bar{K}_i = \omega K_i, \quad \bar{J}_{i\alpha} = \omega G_{i\alpha}.
\]  

The Newton-Hooke brane algebra is expressed on the boundary as

\[
[D, P_\alpha] = P_\alpha, \quad [D, K_\alpha] = -K_\alpha, \quad [D, P_i] = P_i, \quad [D, K_i] = -K_i,
\]

\[
[P_\alpha, K_\beta] = \frac{1}{2} J_{\alpha\beta} + \frac{1}{2} \eta_{\alpha\beta} D, \quad [P_\alpha, K_\alpha] = \frac{1}{2} G_{i\alpha}, \quad [P_\alpha, K_i] = -\frac{1}{2} G_{i\alpha},
\]

\[
[J_{\alpha\beta}, P_\gamma] = \eta_{\beta\gamma} P_\alpha - \eta_{\alpha\gamma} P_\beta, \quad [J_{\alpha\beta}, K_\gamma] = \eta_{\beta\gamma} K_\alpha - \eta_{\alpha\gamma} K_\beta, \quad [J_{\alpha\beta}, G_{i\gamma}] = \eta_{\alpha\gamma} G_{i\beta} - \eta_{\beta\gamma} G_{i\alpha},
\]

\[
[J_{ij}, P_k] = \delta_{jk} P_i - \delta_{ik} P_j, \quad [J_{ij}, K_k] = \delta_{jk} K_i - \eta_{ik} K_j, \quad [J_{ij}, G_{ka}] = \delta_{jk} G_{ia} - \delta_{ik} G_{ja},
\]

\[
[J_{ij}, J_{kl}] = \delta_{jk} J_{id} + 3\text{-terms}, \quad [J_{\alpha\beta}, J_{\gamma\delta}] = \delta_{\beta\gamma} J_{\alpha\delta} + 3\text{-terms}.
\]  

This is called as semi-GCA in \([75]\). It reduces to the GCA \(^{(2.3)}\) when \(\alpha = 0\).

In the subsequent sections, we will derive super GCAs from superconformal algebras.

### 3 Super GCA from four-dimensional superconformal algebra

In this section, we derive super GCAs from the four-dimensional superconformal algebras, psu(2,2|4) and su(2,2|2).

The bosonic part of psu(2,2|4) is the four-dimensional conformal algebra so(2,4) given in \(^{(2.1)}\) with \(\mu = 0, 1, 2, 3\), and the R-symmetry so(6) \(\cong su(4)\)

\[
[\bar{P}_{a'}, \bar{P}_{b'}] = -\bar{J}_{a'b'}, \quad [\bar{J}_{a'd'}, \bar{J}_{c'd'}] = \delta_{b'c'} \bar{J}_{a'd'} + 3\text{-terms}, \quad [\bar{J}_{a'd'}, \bar{P}_{c'}] = \delta_{b'c'} \bar{P}_{a'} - \delta_{a'd'} \bar{P}_{b'},
\]

where \(a', b' = 5, \ldots, 9\). The fermionic part of the (anti-)commutation relation is

\[
[\bar{P}_{\mu}, Q] = -\frac{1}{2} \Omega \Gamma_{\mu 4} p_+, \quad [\bar{K}_\mu, Q] = +\frac{1}{2} \Omega \Gamma_{\mu 4} p_-, \quad [\bar{D}, Q] = -\frac{1}{2} \Omega \Gamma_4 \bar{I} \bar{\sigma}_2,\]

\(^6\)We follow the notation given in \([26]\).
\[ [\tilde{J}_{\mu\nu}, Q] = \frac{1}{2} Q \Gamma_{\mu\nu}, \quad [\tilde{P}_{a'}, Q] = \frac{1}{2} Q \Gamma_a J i \sigma_2, \quad [\tilde{J}_{a'\nu}, Q] = \frac{1}{2} Q \Gamma_{a'\nu}, \]

\[ \{Q^T, Q\} = 4i C T^\mu h_+ (p_- \tilde{P}_\mu + p_+ \tilde{K}_\mu) + 2i C T^4 h_+ \tilde{D} + i C T^\mu\nu J i \sigma_2 h_+ J_{\mu\nu} + 2i C T^{a'} h_+ \tilde{P}_{a'} - i C T^{a'\nu} J i \sigma_2 h_+ J_{a'\nu}, \]

(3.2)

where \( \mathcal{I} = \Gamma^{01234}, \ \mathcal{J} = \Gamma^{56789} \) and

\[ p_\pm = \frac{1}{2} (1 \pm \Gamma^{01234} i \sigma_2) . \]

(3.3)

The supercharge \( Q = (Q_1, Q_2) \) is a pair of 16 component Majorana-Weyl spinors in \((1 + 9)\)-dimensions with the same chirality \( Q_{1,2} = Q_{1,2} h_+ \), where \( h_+ \) is the chirality projector. The \( \tilde{Q} = Q p_- \) and \( \tilde{S} = Q p_+ \) correspond to the supercharge and the superconformal charge of the \( N = 4 \) superconformal algebra, respectively.

### 3.1 32 supersymmetric GCA from psu(2, 2|4)

We introduce a pair of projectors defined by

\[ \ell_\pm = \frac{1}{2} (1 \pm \Gamma^{04}) \]

(3.4)

where \( \sigma = \sigma_1, \sigma_3 \). Note that \( \ell_\pm \) commute with \( h_+, p_+ \) and \( p_- \). Decomposing \( Q \) by using \( \ell_\pm \) as

\[ \tilde{Q}_\pm = Q \ell_\pm, \]

(3.5)

we rewrite (3.2)

\[ [\tilde{P}_0, \tilde{Q}_\pm] = -\frac{1}{2} \tilde{Q}_\pm \Gamma_{04} p_+, \quad [\tilde{K}_0, \tilde{Q}_\pm] = +\frac{1}{2} \tilde{Q}_\pm \Gamma_{04} p_-, \quad [\tilde{D}, \tilde{Q}_\pm] = -\frac{1}{2} \tilde{Q}_\pm \Gamma_{4} J i \sigma_2, \]

\[ [\tilde{P}_i, \tilde{Q}_\pm] = -\frac{1}{2} \tilde{Q}_\pm \Gamma_{i4} p_+, \quad [\tilde{K}_i, \tilde{Q}_\pm] = +\frac{1}{2} \tilde{Q}_\pm \Gamma_{i4} p_-, \quad [\tilde{J}_{ij}, \tilde{Q}_\pm] = +\frac{1}{2} \tilde{Q}_\pm \Gamma_{ij} J \ell_\pm, \]

\[ \{\tilde{Q}_\pm^T, \tilde{Q}_\pm\} = 4i C T^0 h_+ \ell_\pm (p_- \tilde{P}_0 + p_+ \tilde{K}_0) + 2i C T^4 h_+ \ell_\pm \tilde{D} + i C T^i J i \sigma_2 h_+ \ell_\pm \tilde{J}_{ij}, \]

\[ \{\tilde{Q}_+^T, \tilde{Q}_-\} = 4i C T^i h_+ \ell_\pm (p_- \tilde{P}_i + p_+ \tilde{K}_i) + 2i C T^0 J i \sigma_2 h_+ \ell_- \tilde{J}_{i0} + 2i C T^{a'} h_+ \ell_- \tilde{P}_{a'}, \]

(3.6)

where \( i = 1, 2, 3 \). \( \tilde{Q}_\pm \) are a pair of 16 component spinors which are independent of each other.

In addition to (2.2), we scale generators as

\[ \tilde{Q}_+ = Q_+, \quad \tilde{Q}_- = \omega Q_- , \quad \tilde{P}_{a'} = \omega P_{a'}, \quad \tilde{J}_{a'\nu} = J_{a'\nu}. \]

(3.7)
Substituting these into the above (anti-)commutation relation and taking the limit $\omega \to \infty$, we obtain
\[
[H, Q_{\pm}] = -\frac{1}{2} Q_{\pm} \Gamma_{04} p_+ , \quad [K, Q_{\pm}] = +\frac{1}{2} Q_{\pm} \Gamma_{04} p_- , \quad [D, Q_{\pm}] = -\frac{1}{2} Q_{\pm} \Gamma_4 i\sigma_2 , \\
[P_i, Q_+] = -\frac{1}{2} Q_- \Gamma_{i4} p_+ , \quad [K_i, Q_+] = +\frac{1}{2} Q_- \Gamma_{i4} p_- , \quad [G_i, Q_+] = \frac{1}{2} Q_- \Gamma_{i0} , \\
[J_{ij}, Q_{\pm}] = \frac{1}{2} Q_{\pm} \Gamma_{ij} , \quad (3.8)
\]
and
\[
[J_{a'b'}, J_{c'd'}] = \delta_{b'c'} J_{a'd'} + 3\text{-terms} , \quad [J_{a'b'}, P_{c'}] = \delta_{b'c'} P_{a'} - \delta_{a'c'} P_{b'} , \\
[P_{a'}, Q_+] = \frac{1}{2} Q_- \Gamma_{a'd'} i\sigma_2 , \quad [J_{a'b'}, Q_{\pm}] = \frac{1}{2} Q_{\pm} \Gamma_{a'b'} , \\
\{Q^T_+, Q_+\} = 4i C T_0 h_+ \ell_+ (p_- H + p_+ K) + 2i C T_4 h_+ \ell_+ D + i C T_4 i\sigma_2 h_+ \ell_+ J_{ij} \\
- i C T_4 i\sigma_2 h_+ \ell_+ J_{a'b'} , \\
\{Q^T_+, Q_-\} = 4i C T_4 h_+ \ell_- (p_- P_i + p_+ K_i) + 2i C T_4 i\sigma_2 h_+ \ell_- G_i \\
+ 2i C T_4 h_+ \ell_- P_{a'} , \quad (3.9)
\]
in addition to (2.3). This is a 32 supersymmetric GCA. The bosonic subalgebra is the GCA and iso(5). By construction, the super GCA obtained above
\[
\{H, K, D, J_{ij}, J_{a'b'}, Q_+, Q_-\} \quad (3.10)
\]
coincides with the super Newton-Hooke algebra of a string in AdS$_5 \times S^5$ [11] [18]. The string lies along the 4-th direction which is transverse to the boundary of AdS$_5$ and the worldsheet is AdS$_2$. Thus the super GCA obtained above is a boundary realization of the super Newton-Hooke algebra of the AdS$_2$ string.

We note that the set of generators
\[
\{H, K, D, J_{ij}, J_{a'b'}, Q_+\} \quad (3.11)
\]
forms a 16 supersymmetric subalgebra. \{H, K, D\} corresponds to the symmetry of the AdS$_2$. $J_{ij}$ and $J_{a'b'}$ are the rotational symmetry in the space transverse to AdS$_2$ in AdS$_5 \times S^5$. The subalgebra (3.11) is the residual symmetry in the presence of a 1/2 BPS string. It is seen from the superalgebra that the string is F(D)-string for $\sigma = \sigma_3(\sigma_1, \text{respectively}).$

### 3.2 16 supersymmetric GCA from su(2, 2|2)

Firstly, we derive the $\mathcal{N} = 2$ superconformal algebra su(2, 2|2) from the $\mathcal{N} = 4$ superconformal algebra psu(2, 2|4). For this, we introduce a projector [27]
\[
q_+ = \frac{1}{2} (1 + \Gamma^{5678}) , \quad (3.12)
\]
and require that

\[ Q \equiv Q_+ . \]  \hspace{1cm} (3.13)

We note that \( q_+ \) commutes with \( h_+ \) and \( p_\pm \). The fermionic part of \( \text{psu}(2, 2|4) \) reduces to

\[
\begin{align*}
[\tilde{P}_\mu, Q] &= -\frac{1}{2} \Omega_{\mu 4} p_+ , \\
[\tilde{K}_\mu, Q] &= +\frac{1}{2} \Omega_{\mu 4} p_- \\
[\tilde{D}, Q] &= -\frac{1}{2} \Omega_{4} i\sigma_2 \\
[\tilde{J}_{\mu \nu}, Q] &= \frac{1}{2} \Omega_{\mu \nu} , \\
[\tilde{P}_9, Q] &= \frac{1}{2} \Omega_9 J i\sigma_2 , \\
[\tilde{J}_{mn}, Q] &= \frac{1}{2} \Omega_{mn} , \\
\{Q^T, Q\} &= 4iC T^\mu h_+ q_+ (p_- \tilde{P}_\mu + p_+ \tilde{K}_\mu) + 2iC T^4 h_+ q_+ \tilde{D} + iC T^{\mu \nu} i\sigma_2 h_+ q_+ \tilde{J}_{\mu \nu} \\
&\quad + 2iC T^9 h_+ q_+ \tilde{P}_9 - iC T^{mn} J i\sigma_2 h_+ q_+ \tilde{J}_{mn} ,
\end{align*}
\]

(3.14)

where \( m = 5, 6, 7, 8 \). The bosonic part is \( (2.1) \) and \( \text{su}(2) \times \text{u}(1) \) generated by \( \{\tilde{P}_9, \tilde{J}_{mn}\} \)

\[ [\tilde{J}_{mn}, \tilde{J}_{pq}] = \delta_{np}\tilde{J}_{mq} + 3\text{-terms} . \]  \hspace{1cm} (3.15)

Only the \( \text{su}(2) \times \text{u}(1) \) part in \( \text{su}(2)^2 \times \text{u}(1) \) acts non-trivially on the supercharge \( Q \). To see this, we note that the commutation relations containing \( \tilde{J}_{mn} \) can be rewritten as

\[
\begin{align*}
[\tilde{J}_{I}^{(\pm)}, \tilde{J}_{J}^{(\pm)}] &= \epsilon_{IJ K} \tilde{J}_{K}^{(\pm)} , \\
[\tilde{J}_{I}^{(+)}, Q] &= \frac{1}{2} Q \rho_I , \\
[\tilde{J}_{I}^{(-)}, Q] &= 0 , \\
\{Q^T, Q\} &= \cdots - 4iC J i\sigma_2 h_+ q_+ \left( \rho_1 \tilde{J}_{I}^{(+)} + \rho_2 \tilde{J}_{I}^{(+)} + \rho_3 \tilde{J}_{I}^{(+)} \right) ,
\end{align*}
\]

(3.16)

which follow from the fact \( \Gamma^{5678} q_+ = q_+ \). We have defined

\[ \tilde{J}_{I}^{(\pm)} = \left( \frac{1}{2} (\tilde{J}_{56} \pm \tilde{J}_{78}) , \frac{1}{2} (\tilde{J}_{57} \pm \tilde{J}_{68}) , \frac{1}{2} (\pm \tilde{J}_{58} - \tilde{J}_{67}) \right) , \quad \rho_I \equiv (\Gamma^{56}, \Gamma^{57}, \Gamma^{58}) , \]  \hspace{1cm} (3.17)

and \( \epsilon_{123} = 1 \). The \( \mathcal{N} = 2 \) superconformal algebra,

\[ \{\tilde{P}_\mu, \tilde{K}_\mu, \tilde{D}, \tilde{J}_{\mu \nu}, \tilde{P}_9, \tilde{J}_{I}^{(+)} , Q\} , \]  \hspace{1cm} (3.18)

is \( \text{su}(2, 2|2) \). The set of generators \( \{\tilde{J}_{I}^{(+)} , \tilde{P}_9\} \) acts as the R-symmetry \( \text{su}(2) \times \text{u}(1) \).

Next, we introduce \( \ell_\pm \) in \( (3.4) \), which commute with \( q_+ \), and decompose \( Q \) as \( \tilde{Q}_\pm = Q \ell_\pm \). In addition to \( (2.2) \), we scale generators as

\[ \tilde{Q}_+ = Q_+ , \quad \tilde{Q}_- = \omega Q_- , \quad \tilde{J}_{I}^{(+)} = \tilde{J}_{I}^{(+)} , \quad \tilde{P}_9 = \omega P_9 . \]  \hspace{1cm} (3.19)

Under the contraction, we obtain a 16 supersymmetric GCA from \( \text{su}(2, 2|2) \)

\[ \{H, K, D, J_{ij}, P_i, K_i, G_i, P_9, J_{I}^{(+)} , Q_+, Q_-\} , \]  \hspace{1cm} (3.20)

with the (anti-)commutation relations, \( (2.3) \), \( (3.8) \) and

\[
\begin{align*}
[J_{I}^{(+)} , J_{J}^{(+)}] &= \epsilon_{IJK} J_{K}^{(+)} , \\
[P_9, Q_+] &= \frac{1}{2} Q_- \Gamma_9 J i\sigma_2 , \\
[J_{I}^{(+)} , Q_\pm] &= \frac{1}{2} Q_\pm \rho_I ,
\end{align*}
\]
\[ \{Q^T_+, Q_+\} = 4iC\tilde{T}h_+\ell_+q_+(p_-H + p_+K) + 2iCT^4h_+\ell_+q_+D + iCT^{ij}\tilde{I}\sigma_2h_+\ell_+q_+J_{ij} \]
\[ -4iC\tilde{J}\sigma_2h_+\ell_+\left(\rho_1\tilde{J}^{(+)1} + \rho_2\tilde{J}^{(+)2} + \rho_3\tilde{J}^{(+)3}\right), \]
\[ \{Q^T_+, Q_-\} = 4iCT^i\tilde{h}_+\ell_-q_+(p_-P_i + p_+K_i) + 2iCT^{ij}\tilde{I}\sigma_2h_+\ell_-q_+G_i \]
\[ +2iCT^9h_+\ell_-q_+P_9. \] (3.21)

We note that the set of generators
\[ \{H, K, D, J_{ij}, J^{(+)i}, Q^T, Q\} \] (3.22)
forms a 8 supersymmetric subalgebra. \(J^{(+)i}\) acts as the R-symmetry \(\text{su}(2)\).

Introducing the 1/4 projector as in [27], \(q_+ = \frac{1}{2}(1 + \Gamma^{56}i\sigma_2)\frac{1}{2}(1 + \Gamma^{78}i\sigma_2)\), we can derive the \(\mathcal{N} = 1\) superconformal algebra \(\text{su}(2,2|\Gamma)\) by considering the diagonal \(u(1)\) in \(u(1)^3\). But the \(\ell_\pm\) does not commute with \(q_+\). This is because \(\mathcal{N} = 1\) is the minimal supersymmetry and to derive our super GCA we need at least two sets of supercharges, namely \(\mathcal{N} = 2\).

4 Super GCA from three-dimensional superconformal algebra

In this section, we derive super GCAs from the three-dimensional superconformal algebras \(\text{osp}(8|4), \text{osp}(4|4)\) and \(\text{osp}(2|4)\).

The super-\(\text{AdS}_4\times\mathbb{S}^7\) algebra \(\text{osp}(8|4)\) is the \(\mathcal{N} = 8\) superconformal algebra in three-dimensions. The bosonic part of the algebra is given in (2.1) with \(\mu = 0, 1, 2\) and (3.1) with \(a' = 4, \cdots, 9, \sharp\). The fermionic part is
\[ [\tilde{P}_\mu, Q] = -\frac{1}{2}Q\Gamma_{\mu3}p_+ , \quad [\tilde{K}_\mu, Q] = +\frac{1}{2}Q\Gamma_{\mu3}p_- , \quad [\tilde{D}, Q] = -\frac{1}{2}Q\tilde{I}3 , \quad [\tilde{J}_{\mu\nu}, Q] = \frac{1}{2}Q\Gamma_{\mu\nu} , \]
\[ [\tilde{P}_{a'}, Q] = -\frac{1}{2}Q\Gamma_{a'} , \quad [\tilde{J}_{a'\psi}, Q] = \frac{1}{2}Q\Gamma_{a'\psi} , \]
\[ \{Q^T, Q\} = -4C\Gamma^\mu(p_+\tilde{K}_\mu + p_-\tilde{P}_\mu) - 2CT^3\tilde{D} + C\Gamma^\mu\nu\tilde{J}_{\mu\nu} - CT^{a'}\tilde{P}_{a'} - \frac{1}{2}C\Gamma^{a'b'}\tilde{J}_{a'\psi} , \] (4.1)

where \(\tilde{I} = \Gamma^{0123}\) and
\[ p_+ = \frac{1}{2}(1 + \Gamma^{012}) . \] (4.2)

The supercharge \(Q\) is a 32 component Majorana spinor in \((1+10)\)-dimensions. \(\{\tilde{P}_{a'}, \tilde{J}_{a'\psi}\}\) generates the R-symmetry \(\text{so}(8)\).
4.1 32 supersymmetric GCA from \textit{osp}(8|4)

Let us decompose \( Q \) as \( \tilde{Q}_\pm = Q\ell_\pm \) by introducing a pair of projectors

\[
\ell_\pm = \frac{1}{2}(1 \pm \Gamma^{034}) ,
\]

which commute with \( p_\pm \), as \([\Gamma^{034}, p_\pm] = 0\). In addition to (2.2), we scale generators as

\[
\tilde{Q}_+ = Q_+ , \quad \tilde{Q}_- = \omega Q_- , \quad \tilde{P}_4 = P_4 , \quad \tilde{P}_m = \omega P_m , \quad \tilde{J}_{4m} = \omega J_{4m} , \quad \tilde{J}_{mn} = J_{mn} , \quad (4.4)
\]

where \( a' = (4, m) \) and \( m = 5, 6, 7, 8, 9, 10 \). Substituting these into the (anti-)commutation relation of the \( \mathcal{N} = 8 \) superconformal algebra and taking the limit \( \omega \to \infty \), we arrive at

\[
[H, Q_\pm] = -\frac{1}{2}Q_\pm \Gamma_{03}p_+ , \quad [K, Q_\pm] = +\frac{1}{2}Q_\pm \Gamma_{03}p_- , \quad [D, Q_\pm] = -\frac{1}{2}Q_\pm T\Gamma_3 ,
\]

\[
[P_i, Q_+] = -\frac{1}{2}Q_- \Gamma_{i3}p_+ , \quad [K_i, Q_+] = +\frac{1}{2}Q_- \Gamma_{i3}p_- , \quad [G_i, Q_+] = \frac{1}{2}Q_- \Gamma_{i0} ,
\]

\[
[J_{ij}, Q_\pm] = \frac{1}{2}Q_\pm \Gamma_{ij} , \quad (4.5)
\]

and

\[
[J_{mn}, J_{pq}] = \delta_{np}J_{mq} + 3\text{-terms} , \quad [J_{mn}, P_p] = \delta_{np}P_m - \delta_{mp}P_n ,
\]

\[
[J_{mn}, J_{4p}] = \delta_{mp}J_{n4} - \delta_{np}J_{m4} , \quad [J_{4m}, P_4] = -P_m ,
\]

\[
[J_{mn}, Q_+] = \frac{1}{2}Q_- \Gamma_{mn} , \quad [J_{4m}, Q_+] = \frac{1}{2}Q_- \Gamma_{4m} ,
\]

\[
\{Q_+^T, Q_+\} = -4\Gamma^0\ell_+(p_+H + p_+K) - 2\Gamma^3\ell_+D + C\Gamma^{ij}\ell_+J_{ij}
\]

\[
-\Gamma^4\ell_+P_4 - \frac{1}{2}C\Gamma^{mn}\ell_+J_{mn} ,
\]

\[
\{Q_+^T, Q_-\} = -4\Gamma^i\ell_-(p_-P_i + p_-K_i) + 2C\Gamma^{i0}\ell_-G_i - C\Gamma^m\ell_-P_m - C\Gamma^{4m}\ell_-J_{4m} , \quad (4.6)
\]

in addition to (2.3) with \( i = 1, 2 \). This is a 32 supersymmetric GCA. By construction, the super GCA

\[
\{H, K, D, P_i, K_i, G_i, J_{ij}, P_4, P_m, J_{mn}, J_{4m}, Q_+, Q_-\} \quad (4.7)
\]

is the super Newton-Hooke algebra of an M2-brane in \( \text{AdS}_4 \times S^7 \). The M2-brane worldvolume is \( \text{AdS}_2 \times S^1 \) extending along \((0, 3, 4)-\text{th directions}\). The M2-brane worldvolume extends along two directions in \( \text{AdS}_4 \) and so the GCA results. If a brane extends along more than two directions in \( \text{AdS} \), a semi-GCA emerges generally as seen in the next section. The super GCA obtained above contains a 16 supersymmetric subalgebra

\[
\{H, K, D, J_{ij}, P_4, J_{mn}, Q_+\} . \quad (4.8)
\]
The set of generators \( \{H, K, D, P_4\} \) generates the \( \text{AdS}_2 \times S^1 \) symmetry on the M2-brane world-volume, while \( \{J_{ij}, J_{mn}\} \) is the rotational symmetry \( \text{so}(2) \times \text{so}(6) \) in the space transverse to \( \text{AdS}_2 \times S^1 \) in \( \text{AdS}_4 \times S^7 \).

### 4.2 16 supersymmetric GCA from osp(4\(|4\))

We derive a 16 supersymmetric GCA from the \( \mathcal{N} = 4 \) superconformal algebra \( \text{osp}(4\|4) \).

Firstly, we derive \( \text{osp}(4\|4) \) from the \( \mathcal{N} = 8 \) superconformal algebra \( \text{osp}(8\|4) \). For this, we introduce a 1/2 projector in the \( \mathcal{N} = 8 \) superconformal algebra

\[
q_+ = \frac{1}{2}(1 + \Gamma^{789}) ,
\]

and require that \( Q \equiv Q q_+ \). We note \( q_+ \) commutes with \( p_\pm \). Then the \( \mathcal{N} = 8 \) superconformal algebra reduces to a \( \mathcal{N} = 4 \) superconformal algebra. The fermionic part of the algebra is

\[
\{ \tilde{P}_\mu, Q \} = -\frac{1}{2} \Gamma_{\mu3} p_+ , \quad [\tilde{K}_\mu, Q] = +\frac{1}{2} \Gamma_{\mu3} p_- , \quad [\tilde{D}, Q] = -\frac{1}{2} Q T_3 , \quad [\tilde{J}_{\mu
u}, Q] = \frac{1}{2} \Gamma_{\mu
u} ,
\]

\[
[P_m, Q] = -\frac{1}{2} Q T_{m} , \quad [J_{mn}, Q] = \frac{1}{2} Q \Gamma_{mn} , \quad [J_{m'n'}, Q] = \frac{1}{2} \Gamma_{m'n'} ,
\]

\[
\{ Q^T, Q \} = -4 C \Gamma^\mu q_+ (p_+ \tilde{K}_\mu + p_- \tilde{P}_\mu) - 2 C T_3 q_+ D + C T^\mu_\nu q_+ \tilde{J}_{\mu
u}
\]

\[
- C \Gamma^m q_+ \tilde{P}^m = \frac{1}{2} C T q_+ (\Gamma^{mn} \tilde{J}_{mn} + \Gamma^{m'n'} \tilde{J}_{m'n'}) ,
\]

where \( a' = (m, m') \), \( m = 4, 5, 6 \) and \( m' = 7, 8, 9, \xi \). The bosonic part is \[ \{ \tilde{P}_m, \tilde{J}_{mn} \} \] and \( \{ J_{m'n'} \} \).

As was done in section 3.2, we rewrite the commutation relations containing \( J_{m'n'} \) as

\[
\{ \tilde{J}_I^{(\pm)}, \tilde{J}_I^{(\pm)} \} = \epsilon_{IJK} \tilde{J}_K^{(\pm)} , \quad \{ \tilde{J}_I^{(\pm)}, Q \} = \frac{1}{2} Q \rho_I , \quad \{ \tilde{J}_I^{(-)}, Q \} = 0 ,
\]

\[
\{ Q^T, Q \} = \cdots - 2 C T q_+ \sum_{I=1,2,3} \rho_I \tilde{J}_I^{(\pm)},
\]

with

\[
\tilde{J}_I^{(\pm)} = \left( \frac{1}{2} (\tilde{J}_{89} \pm \tilde{J}_{78}), \frac{1}{2} (\tilde{J}_{79} \pm \tilde{J}_{82}), \frac{1}{2} (\tilde{J}_{78} \pm \tilde{J}_{82}) \right), \quad \rho_I = (\Gamma_{89}, \Gamma_{79}, \Gamma_{78}) .
\]

Similarly, the commutation relations containing \( \tilde{P}_m \) and \( \tilde{J}_{mn} \) can be rewritten as

\[
\{ \tilde{J}_I^{(\pm)}, \tilde{J}_I^{(\pm)} \} = \epsilon_{IJK} \tilde{J}_K^{(\pm)} , \quad \{ \tilde{J}_I^{(\pm)}, Q \} = \frac{1}{2} Q \rho_I , \quad \{ \tilde{J}_I^{(-)}, Q \} = 0 ,
\]

\[
\{ Q^T, Q \} = \cdots - 2 C T q_+ \sum_{I=1,2,3} \rho_I \tilde{J}_I^{(\pm)},
\]

with

\[
\tilde{J}_I^{(\pm)} = \left( \frac{1}{2} (\tilde{P}_5 \pm \tilde{J}_{45}), \frac{1}{2} (\tilde{P}_6 \pm \tilde{J}_{46}), \frac{1}{2} (\pm \tilde{P}_4 + \tilde{J}_{56}) \right), \quad \rho_I = (\Gamma_{45}, -\Gamma_{46}, \Gamma_{56}) .
\]
These follow from the fact $\Gamma^{789}q_+ = q_+$ and $\Gamma^2 = \Gamma^{0..9}$. Thus the set of generators
\[
\{ \tilde{P}_\mu, \tilde{K}_\mu, \tilde{D}, \tilde{J}_{\mu
u}, \tilde{J}_{I}^{(+)}, \tilde{J}_{J}^{(+)}, Q \}
\] (4.15)
forms a superconformal algebra, which is $\text{osp}(4|4)$. $\{\tilde{J}_{I}^{(+)}, \tilde{J}_{J}^{(+)}\}$ generates the R-symmetry $\text{su}(2) \times \text{su}(2) \cong \text{so}(4)$.

Next, we decompose $Q$ as $\tilde{Q}_\pm = Q\ell_\pm$ by introducing a pair of projectors $\ell_\pm$ in (4.3), which commute with $q_+$, and scale generators as (2.2) and
\[
\tilde{Q}_+ = Q_+ , \quad \tilde{Q}_- = \omega Q_- , \quad \tilde{J}_3^{(+)} = J_3^{(+)} , \quad \tilde{J}_{1,2}^{(+)} = \omega J_{1,2}^{(+)} , \quad \tilde{J}_{J}^{(+)} = J_{J}^{(+)} .
\] (4.16)
Substituting these into the (anti-)commutation relation of the $\mathcal{N} = 4$ superconformal algebra $\text{osp}(4|4)$ and taking the limit $\omega \to \infty$, we derive (2.3), (4.5) and
\[
\begin{align*}
[ J_3^{(+)} , J_I^{(+)} ] &= \epsilon_{3IJ} J_J^{(+)} , \\
[ J_3^{(+)} , Q_\pm ] &= -\frac{1}{2} Q_\pm I \rho_3 , \\
[ J_{1,2}^{(+)} , Q_\pm ] &= -\frac{1}{2} Q_\pm I \rho_{1,2} , \\
[ J_I^{(+)} , J_J^{(+)} ] &= \epsilon_{IJK} J_K^{(+)} , \\
[ J_I^{(+)} , Q_\pm ] &= \frac{1}{2} Q_\pm I \rho_I , \\
\{ Q_+ , Q_+ \} &= -4C\Gamma^0 \ell_+ q_+ (p_- H + p_+ K) - 2C\Gamma^3 \ell_+ q_+ D + C\Gamma^{ij} \ell_+ q_+ J_{ij} \\
&\quad - 2C\rho_3 \ell_+ q_+ J_3^{(+)} - 2C\ell_+ q_+ \sum_{I=1,2,3} \rho_I J_I^{(+)} , \\
\{ Q_+ , Q_- \} &= -4C\Gamma^i \ell_- q_+ (p_- P_i + p_+ K_i) + 2C\Gamma^{0i} \ell_- q_+ G_i \\
&\quad - 2C\ell q_+ (\rho_1 J_1^{(+)} + \rho_2 J_2^{(+)} ) \ell_- .
\end{align*}
\] (4.17)
This is a 16 supersymmetric GCA
\[
\{ H, K, D, J_{ij}, P_i, K_i, G_i, J_I^{(+)} , J_J^{(+)} , J_{1,2}^{(+)} , Q_+, Q_- \} .
\] (4.18)
The bosonic subalgebra is the GCA and $\text{so}(3) \times \text{iso}(2)$. The super GCA contains a 8 supersymmetric subalgebra
\[
\{ H, K, D, J_{ij}, J_3^{(+)} , J_I^{(+)} , J_J^{(+)} , Q_+ \} .
\] (4.19)
$\{ J_I^{(+)} , J_J^{(+)} \}$ generates the R-symmetry $\text{su}(2) \times \text{u}(1)$.

### 4.3 8 supersymmetric GCA from $\text{osp}(2|4)$

We derive a 8 supersymmetric GCA from the $\mathcal{N} = 2$ superconformal algebra $\text{osp}(2|4)$.

Firstly, we derive $\text{osp}(2|4)$ from the $\mathcal{N} = 8$ superconformal algebra $\text{osp}(8|4)$. We introduce a 1/4 projector
\[
q_+ = \frac{1}{2} (1 + \Gamma^{5678}) \frac{1}{2} (1 + \Gamma^{7895}) ,
\] (4.20)
which commutes with $p_{\pm}$, and require that $Q \equiv Q_+$. Then the $\mathcal{N} = 8$ superconformal algebra reduces to a $\mathcal{N} = 2$ superconformal algebra. The fermionic part of the algebra is

$$[P_4, Q] = -\frac{1}{2} Q IT_4, \quad [J_{56}, Q] = \frac{1}{2} Q \Gamma_{56}, \quad [J_{78}, Q] = \frac{1}{2} Q \Gamma_{78}, \quad [J_{9\ell}, Q] = \frac{1}{2} Q \Gamma_{9\ell},$$

$$\{Q^T, Q\} = -4CT^\mu q_+ (p_+ \tilde{K}_\mu + p_- \tilde{P}_\mu) - 2CT^3 q_+ \tilde{D} + C T \Gamma^{\mu
u} q_+ J_{\mu
u},$$

$$-CT^4 q_+ \tilde{P}_4 - CT q_+ (\Gamma^{56} \tilde{J}_{56} + \Gamma^{78} \tilde{J}_{78} + \Gamma^{9\ell} \tilde{J}_{9\ell}).$$

The bosonic part is (2.1) and $u(1)^4$ generated by $\{\tilde{P}_4, \tilde{J}_{56}, \tilde{J}_{78}, \tilde{J}_{9\ell}\}$. We note the commutation relations containing $u(1)^4$ generators are rewritten as

$$[\tilde{J}_I, Q] = -\frac{1}{2} Q IT_4, \quad \{Q^T, Q\} = \cdots - 4CT^4 q_+ \tilde{J},$$

with

$$\tilde{J}_I = (\tilde{P}_4, \tilde{J}_{56}, -\tilde{J}_{78}, \tilde{J}_{9\ell}), \quad \tilde{J} = \frac{1}{4} \sum_{I=1,2,3,4} \tilde{J}_I.$$

It follows that the set of generators

$$\{\tilde{P}_\mu, \tilde{K}_\mu, \tilde{D}, \tilde{J}_{\mu\nu}, \tilde{J}, Q\}$$

forms the $\mathcal{N} = 2$ superconformal algebra $\text{osp}(2|4)$. $\tilde{J}$ generates the R-symmetry $so(2)$.

Next, we decompose $Q$ as $\tilde{Q}_\pm = Q\ell_\pm$ by $\ell_\pm$ in (4.3), which commute with $q_+$, and scale generators as (2.2) and

$$\tilde{Q}_+ = Q_+, \quad \tilde{Q}_- = \omega Q_-, \quad \tilde{J} = J.$$

Substituting these into the above (anti-)commutation relation of $\text{osp}(2|4)$ and taking the limit $\omega \to \infty$, we derive (2.3), (4.5) and

$$[J, Q_\pm] = -\frac{1}{2} Q_\pm IT_4,$$

$$\{Q^T_+, Q_+\} = -4CT^0 \ell_+ q_+ (p_- H + p_+ K) - 2CT^3 \ell_+ q_+ D + C T \Gamma^{ij} \ell_+ q_+ J_{ij},$$

$$-4CT^4 q_+ \ell_+ J,$$

$$\{Q^T_+, Q_-\} = -4CT^4 \ell_- q_+ (p_- P_i + p_+ K_i) + 2CT \Gamma^{i0} \ell_- q_+ G_i.$$

This is a 8 supersymmetric GCA

$$\{H, K, D, J_{ij}, P_i, K_i, G_i, J, Q_+, Q_-\}.$$

It contains a 4 supersymmetric subalgebra

$$\{H, K, D, J_{ij}, J, Q_+\},$$

in which $J$ acts as the R-symmetry $so(2)$. 

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5 Super semi-GCA from six-dimensional superconformal algebra

In this section, we derive super GCAs from the six-dimensional superconformal algebras, osp(8*|4) and osp(8*|2).

The super-AdS$_7 \times$S$^4$ algebra osp(8*|4) is the $\mathcal{N} = 4$ superconformal algebra in six-dimensions. The bosonic part is (2.1) with $\mu = 0, 1, \cdots, 5$ and the R-symmetry sp(4) $\cong$ so(5) given in (3.1) with $a' = 7, 8, 9, 10$. The fermionic part is

$$\{\tilde{P}_\mu, Q\} = -\frac{1}{2} Q \Gamma^6 \tilde{p}_+ , \quad \{\tilde{K}_\mu, Q\} = \frac{1}{2} Q \Gamma^6 \tilde{p}_- , \quad \{\tilde{D}, Q\} = -\frac{1}{2} Q \Gamma^6 , \quad \{\tilde{J}_{\mu
u}, Q\} = \frac{1}{2} Q \Gamma^6 \tilde{p}_- ,$$

where $I = \Gamma^{78910}$ and

$$p_\pm = \frac{1}{2}(1 \pm \Gamma^{678910}) .$$

The supercharge $\tilde{Q} = Qp_-$ (and $\tilde{S} = Qp_+$ also) is composed of four sets of four-component Weyl spinors subject to the sp(4) Majorana condition. The sp(4) $\cong$ so(5) is generated by $\{P_{a'}, J_{a'b'}\}$.

5.1 32 supersymmetric semi-GCA from osp(8*|4)

Let us decompose $Q$ as $\tilde{Q}_\pm = Q\ell_\pm$ by introducing a pair of projectors

$$\ell_\pm = \frac{1}{2}(1 \pm \Gamma^{06}) ,$$

which commute with $p_\pm$, and scale generators as

$$\tilde{P}_a = P_a , \quad \tilde{K}_a = K_a , \quad \tilde{J}_{05} = J_{05} , \quad \tilde{J}_{ij} = J_{ij} , \quad \tilde{Q}_+ = Q_+ ,$$

$$\tilde{P}_i = \omega P_i , \quad \tilde{K}_i = \omega K_i , \quad \tilde{J}_{ia} = \omega G_{ia} , \quad \tilde{Q}_- = \omega Q_- ,$$

and

$$\tilde{P}_{a'} = \omega P_{a'} , \quad \tilde{J}_{a'b'} = J_{a'b'} ,$$

where $a = 0, 5$ and $i = 1, 2, 3, 4$. Substituting these into the (anti-)commutation relation of the $\mathcal{N} = 4$ superconformal algebra osp(8*|4) and taking the limit $\omega \rightarrow \infty$, we derive a 32 supersymmetric semi-GCA. The bosonic part is (2.10) and

$$[J_{a'b'}, J_{c'd'}] = \delta_{b',c'} J_{a'd'} + 3\text{-terms} , \quad [J_{a'b'}, P_{c'}] = \delta_{b',c'} P_{a'} - \delta_{a',c'} P_{b'} .$$
The fermionic part is

\[ [P_\alpha, Q_\pm] = -\frac{1}{2} Q_\pm \Gamma_{\alpha \pm} p_+ , \quad [K_\alpha, Q_\pm] = \frac{1}{2} Q_\pm \Gamma_{\alpha \pm} p_+ , \quad [D, Q_\pm] = -\frac{1}{2} Q_\pm \Gamma_6 , \]

\[ [P_i, Q_+] = -\frac{1}{2} Q_\pm \Gamma_{i \pm} p_+ , \quad [K_i, Q_+] = \frac{1}{2} Q_\pm \Gamma_{i \pm} p_+ , \quad [G_{i\alpha}, Q_+] = \frac{1}{2} Q_\pm \Gamma_{i \alpha} , \]

\[ [J_{ij}, Q_\pm] = \frac{1}{2} Q_\pm \Gamma_{ij} , \quad [J_{\alpha \beta}, Q_\pm] = \frac{1}{2} Q_\pm \Gamma_{\alpha \beta} , \quad [J_{ij}, Q_\pm] = \frac{1}{2} Q_\pm \Gamma_{ij} , \quad [J_{i\alpha}, Q_\pm] = \frac{1}{2} Q_\pm \Gamma_{i \alpha} , \quad [J_{ij}, Q_\pm] = \frac{1}{2} Q_\pm \Gamma_{ij} , \]

and

\[ [P_{a'}, Q_+] = -\frac{1}{2} Q_\pm \Gamma_{a' \pm} , \quad [J_{a'\nu}, Q_\pm] = \frac{1}{2} Q_\pm \Gamma_{a' \nu} , \]

\[ \{Q^T_+, Q_+\} = -4C\Gamma^\alpha \ell_+ (p_- P_\alpha + p_+ K_\alpha) - 2C\Gamma^6 \ell_+ D - C\Gamma^{\alpha \beta} \ell_+ J_{\alpha \beta} - C\Gamma^{ij} \ell_+ J_{ij} + 2C\Gamma^{a' \nu} \ell_+ J_{a' \nu} , \]

\[ \{Q^T_-, Q_-\} = -4C\Gamma^i \ell_- (p_- P_+ + p_+ K_\iota) - 2C\Gamma^{i \alpha} \ell_- G_{i \alpha} - 4C\Gamma^{a' \nu} \ell_- P_{a'} . \] (5.7)

By construction, the supersymmetric semi-GCA

\[ \{P_\alpha, K_\alpha, D, P_0, K_0, G_{i\alpha}, J_{ij}, J_{05}, P_{a'}, J_{a'\nu}, Q_+, Q_-\} \] (5.9)

is the super Newton-Hooke algebra of an M2-brane in \( \text{AdS}_7 \times S^4 \). The M2-brane worldvolume is \( \text{AdS}_3 \) extending along (0, 5, 6)-th directions in \( \text{AdS}_7 \). As the M2-brane worldvolume extends along more than two directions in AdS, a semi-GCA emerges. It contains a 16 supersymmetric subalgebra

\[ \{P_\alpha, K_\alpha, D, J_{05}, J_{ij}, J_{a'\nu}, Q_+\} . \] (5.10)

The set of generators \( \{H_\alpha, K_\alpha, D, J_{05}\} \) generates the AdS_3 symmetry so(2,2) on the M2-brane worldvolume. The generators \( \{J_{ij}, J_{a'\nu}\} \) represents the rotational symmetry so(4)^2 in the space transverse to AdS_3 in AdS_7 \times S^4.

### 5.2 16 supersymmetric semi-GCA from \( \text{osp}(8^*|2) \)

We derive a 16 supersymmetric GCA from the \( \mathcal{N} = 2 \) superconformal algebra \( \text{osp}(8^*|2) \).

Firstly, we derive \( \text{osp}(8^*|2) \) from the \( \mathcal{N} = 4 \) superconformal algebra \( \text{osp}(8^*|4) \). For this, we introduce a 1/2 projector

\[ q_+ = \frac{1}{2} (1 + \Gamma^{789}) , \] (5.11)

which commutes with \( p_{\pm} \), and require that \( Q \equiv Q q_+ \). Then the \( \mathcal{N} = 4 \) superconformal algebra reduces to a \( \mathcal{N} = 2 \) superconformal algebra. The fermionic part of the algebra is

\[ [\tilde{P}_\mu, Q] = -\frac{1}{2} \Omega \Gamma_{\mu 6} p_+ , \quad [\tilde{K}_\mu, Q] = +\frac{1}{2} \Omega \Gamma_{\mu 6} p_- , \quad [\tilde{D}, Q] = -\frac{1}{2} \Omega \Gamma_6 , \]

16
\[
[\tilde{J}_{\mu}, Q] = \frac{1}{2} Q \Gamma_{\mu}, \quad [\tilde{J}_{a'b'}, Q] = \frac{1}{2} Q \Gamma_{a'b'},
\]
\[
\{Q^T, Q\} = -4CT^a q_+ (p_+ \tilde{K}_\mu + p_- \bar{P}_\mu) - 2CT^6 q_+ \bar{D} - C T \Gamma^{\mu\nu} q_+ \tilde{J}_{\mu} + 2CT^{a'b'} q_+ \tilde{J}_{a'b'}.
\] (5.12)

The bosonic part is \((2,1)\) with \(\mu = 0, \ldots, 5\) and \(\text{so}(4)\) generated by \(\{\tilde{J}_{a'b'}\}\). We note that the commutation relations containing \(\tilde{J}_{a'b'}\) can be rewritten as
\[
[\tilde{j}^{(\pm)}_I, \tilde{j}^{(\pm)}_J] = \epsilon_{IJK} \tilde{j}^{(\pm)}_K, \quad [\tilde{j}^{(+)}_I, Q] = \frac{1}{2} Q \rho_I, \quad [\tilde{j}^{(-)}_I, Q] = 0,
\]
\[
\{Q^T, Q\} = \cdots + 8CT q_+ \sum_{l=1,2,3} \rho_I j^{(+)}_I,
\] (5.13)

with
\[
\tilde{j}^{(\pm)}_I = \left(\frac{1}{2} (\tilde{j}_{89} \pm \tilde{j}_{72}), \frac{1}{2} (\tilde{j}_{79} \pm \tilde{j}_{82}), \frac{1}{2} (\tilde{j}_{78} \pm \bar{j}_{92})\right), \quad \rho_I = (\Gamma^{89}, \Gamma^{79}, \Gamma^{78}).
\] (5.14)

It follows that the set of generators
\[
\{\tilde{P}_\mu, \tilde{K}_\mu, \tilde{D}, \tilde{J}_{\mu}, j^{(+)}_I, Q\}
\] (5.15)
forms the superconformal algebra \(\text{osp}(8^*|2)\). \(j^{(+)}_I\) generates the R-symmetry \(\text{su}(2) \cong \text{sp}(2)\).

As above, we decompose \(Q\) as \(Q_\pm = Q_{\ell_\pm}\) by introducing a pair of projectors \(\ell_\pm\) in (5.3) and scale generators as in (5.4) and
\[
j^{(+)}_I = j^{(+)}_I.
\] (5.16)

We note that \(q_+\) and \(\ell_\pm\) commute each other. Substituting these into the (anti-)commutation relation of the \(\mathcal{N} = 2\) superconformal algebra \(\text{osp}(8^*|2)\) and taking the limit \(\omega \to \infty\), we derive (2.10), (5.7) and
\[
[j^{(+)}_I, j^{(+)}_J] = \epsilon_{IJK} j^{(+)}_K, \quad [j^{(+)}_I, Q_\pm] = \frac{1}{2} Q_\pm \rho_I,
\]
\[
\{Q^T, Q_\pm\} = -4CT^a \ell_+ q_+(p_- P_\alpha + p_+ K_\alpha) - 2CT^6 \ell_+ q_+ D - C T \Gamma^{\alpha\beta} \ell_+ q_+ J_{\alpha\beta} - C T \Gamma^{ij} \ell_+ q_+ J_{ij} + 8CT q_+ \ell_+ \sum_{l=1,2,3} \rho_I j^{(+)}_I,
\]
\[
\{Q^T, Q_-\} = -4CT^i \ell_- q_+(p_- P_i + p_+ K_i) - 2CT \Gamma^{i\alpha} \ell_- q_+ G_{i\alpha}.
\] (5.17)

This is a 16 supersymmetric semi-GCA
\[
\{P_\alpha, K_\alpha, D, P_i, K_i, G_{i\alpha}, J_{ij}, J_{05}, j^{(+)}_I, Q_+, Q_-\}.
\] (5.18)

It contains a 8 supersymmetric subalgebra
\[
\{P_\alpha, K_\alpha, D, J_{\alpha\beta}, J_{ij}, j^{(+)}_I, Q_+, Q_-\}.
\] (5.19)

\(j^{(+)}_I\) acts as the R-symmetry \(\text{su}(2) \cong \text{sp}(2)\).
Summary and Discussions

Conformal algebra in \((d + 1)\)-dimensions is the \(\text{AdS}_{d+2}\) algebra. The IW contraction which derives a GCA from the conformal algebra in \((d + 1)\)-dimensions is equivalent to the IW contraction which derives a Newton-Hooke string algebra from the \(\text{AdS}_{d+2}\) algebra. The string lies along the direction transverse to the boundary. In other words, a GCA is a boundary realization of a Newton-Hooke string algebra. From this observation, we have derived 32 supersymmetric GCAs from superconformal algebras, \(\text{psu}(2,2|4)\), \(\text{osp}(8|4)\) and \(\text{osp}(8^∗|4)\). We have also derived less supersymmetric GCAs by considering less supersymmetric conformal algebras, \(\text{su}(2,2|2)\), \(\text{osp}(4|4)\), \(\text{osp}(2|4)\) and \(\text{osp}(8^∗|2)\).

In this paper we have considered an \(\text{AdS}_2\) string in \(\text{AdS}_5 \times S^5\), an \(\text{AdS}_2 \times S^1\) brane in \(\text{AdS}_4 \times S^7\) and an \(\text{AdS}_3\) brane in \(\text{AdS}_7 \times S^4\). There are many other 1/2 BPS brane configurations in AdS spaces as seen in [18]. We leave this issue for future studies. These branes are considered as a probe which does not affect the background. The Newton-Cartan-like geometry discussed recently in [74] [67] may have some connections to ours. It is interesting to clarify this point.

We have chosen the scaling of the supercharge so that the resulting super GCA has a 1/2 supersymmetric subalgebra, which is a supersymmetrization of the base \(\text{so}(2,1) \times \text{so}(d)\) of the bosonic GCA. As a consistent IW contraction, one may consider another scaling of the supercharges. In fact, one may scale the supercharges as \(Q \rightarrow \omega^{1/2} Q\). In this case, the anticommutator of two \(Q\)s contains only \(P_i, K_i, G_i\) and \(P_a'\) for the super GCA considered in section 3.1. So the dynamical supersymmetry disappears.

It is also interesting to look for NR systems which are invariant under the super GCAs obtained in this paper. The NR string action [11], which has the symmetry of the super Newton-Hooke algebra of a string, might give some hint for this.

In this paper, we have not discussed the central extensions of the GCA and the infinite-dimensional extensions of the GCA [74]. For the centrally extended GCA, the exotic GCA [73], we can derive it as an expansion [78, 79] of the conformal algebra. In addition, one may find non-central extensions of a (super) GCA by this method. We hope to report on this issue in future.

We hope that our results may be useful in the future studies in AdS/CFT.

Note added

The supersymmetric extensions of GCA derived in section 3 were found independently by J. A. de Azcarraga and J. Lukierski in [80].

\(^7\) See [18] for the NR brane actions.
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