Goldstone fields with spins higher than 1/2

Sukruti Bansal

University of Padua and INFN Padua, Italy

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Introduction

- Typically, higher-spin gauge theories are based on infinite-dimensional symmetries with infinite number of fields of increasing spin. Study of spontaneous symmetry breaking in these theories is highly non-trivial.

- We consider simple 3D models in which massless spin-1 and spin-3/2 fields play the role of the Goldstones of a spontaneously broken higher-spin generalization of supersymmetry algebra.

Higher Spin Algebras

Hietarinta Higher-Spin Algebra - FINITE

Fermionic Superalgebra:

$$\{Q_{\alpha}^{a_1 \ldots a_n}, Q_{\beta}^{b_1 \ldots b_m}\} = f_{\alpha\beta}^{a_1 \ldots a_n, b_1 \ldots b_m, c} P_c \,; \; [Q_{\alpha}^{a_1 \ldots a_n}, P_c] = 0.$$

Bosonic Algebra:

$$[S^{a_1 \ldots a_p}, S^{b_1 \ldots b_q}] = f^{a_1 \ldots a_n, b_1 \ldots b_m, c} P_c \,; \; [S^{a_1, \ldots a_n}, P_c] = 0.$$

Hietarinta

Conventional Higher-Spin Superalgebra - INFINITE

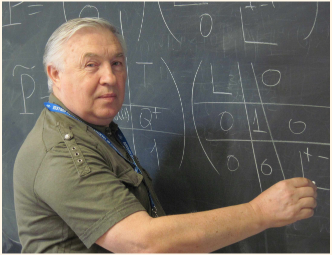
$$[T_{s_1}, T_{s_2}] = T_{s_1+s_2-2} + T_{s_1+s_2-4} + \ldots + T_{|s_1-s_2|+2}$$

Unlike the conventional HS superalgebra, Hietarinta superalgebra does not produce more HS generators of ever-increasing spin.

Volkov-Akulov Lagrangian

Dmitrij Vasilievich Volkov and **Vladimir P. Akulov** developed the **Volkov-Akulov Lagrangian** formalism. It realizes supersymmetry non-linearly.

Volkov



Akulov

Volkov-Akulov formalism enables the construction of the Lagrangian of the Goldstone field. It can be generalised for all higher-spin fields associated with Hietarinta algebra.

Chern-Simons Goldstone Model

Spin-1

Chern-Simons Goldstone Model

Bosonic algebra: $[S^a, S^b] = 2\,\varepsilon^{abc}\,P_c\,, \quad [S^a, P_b] = 0\,,$

where S^a is the bosonic vector operator.

$$\boxed{\begin{aligned} S_1 &= -f^2 \int d^3x\,(\det E^a_d - 1) \\ &= \int d^3x\,\Big(\underbrace{\varepsilon^{abc} A_a\,\partial_b A_c}_{\text{Chern-Simons}} - \frac{f^{-2}}{2}\,\varepsilon^{abc}\varepsilon^{def}\,A_a\,A_d\,\partial_e A_b\,\partial_f A_c\Big) \end{aligned}}$$

Stueckelberg Trick

$$A_a \to \hat{A}_a = A_a - f^{\frac{1}{2}}\,\partial_a \hat{\varphi}$$

$\hat{A}_a$ is invariant under $\delta A_a = \partial_a \lambda$ and $\delta\hat{\varphi} = f^{-\frac{1}{2}}\lambda$.

In the decoupling limit, the Steuckelberg Lagrangian reduces to

$$\boxed{\mathcal{L}_{f\to\infty} = \varepsilon^{abc} A_a \partial_b A_c - \hat{\varphi}\left((\Box\hat{\varphi})^3 - 3\,\Box\hat{\varphi}\,\partial_a\partial^b\hat{\varphi}\,\partial_b\partial^a\hat{\varphi} + 2\,\partial_a\partial^b\hat{\varphi}\,\partial_b\partial^c\hat{\varphi}\,\partial_c\partial^a\hat{\varphi}\right)}$$

This is the same as the quartic term in the Galileon Lagrangian in modified gravity.

Rarita Schwinger Goldstino Model

Spin-3/2

Rarita-Schwinger Goldstino Model

Spin 3/2 superalgebra: $\{Q^a_\alpha, Q^b_\beta\} = 2\, C_{\alpha\beta}\, \varepsilon^{abc} P_c\,, \quad [Q^a_\alpha, P_b] = 0$

The spin-3/2 goldstino action has the following form:

$$S_{3/2} = \int d^3x \Bigg(\overbrace{i\,\varepsilon^{abc}\,\chi_a\,\partial_b\chi_c}^{Rarita-Schwinger} + \frac{f^{-2}}{2}\left(\varepsilon^{abc}\varepsilon^{dfg} - \varepsilon^{afc}\varepsilon^{dbg}\right)\left(\chi_a\,\partial_b\chi_c\right)\left(\chi_d\,\partial_f\chi_g\right)$$
$$+\frac{i\,f^{-4}}{6}\,\varepsilon^{a'b'c'}\left(\varepsilon^{abc}\varepsilon^{def} - \varepsilon^{abf}\varepsilon^{dec}\right)\left(\chi_c\,\partial_{a'}\chi_f\right)\left(\chi_a\,\partial_{b'}\chi_b\right)\left(\chi_d\,\partial_{c'}\chi_e\right)\Bigg)$$

Stueckelberg Trick

$$\hat{\chi}_a = \chi_a + f^{\frac{2}{3}} \partial_a \psi$$

$\hat{\chi}_a$ is invariant under $\delta\chi_a = \partial_a \epsilon$ and $\delta\psi = -f^{-\frac{2}{3}} \epsilon$.

In the limit $f \to \infty$ the Stueckleberg Lagrangian reduces to

$$\boxed{\mathcal{L}_{f\to\infty} = i\,\varepsilon^{abc}\,\chi_a\,\partial_b\chi_c + 2\,\varepsilon^{abc}\varepsilon^{dfg}(\chi_a\,\partial_d\partial_c\psi)\,(\partial_f\psi\,\partial_b\partial_g\psi) - \frac{1}{3}\mathrm{tr}\,(M^3)}$$

where $M^a{}_d = i\,\varepsilon^{abc}\,\partial_b\psi\,\partial_d\partial_c\psi$.

Full Spin-3/2 Action as Rarita-Schwinger Action

The action reduces to the free Rarita-Schwinger action

$$S_{RS} = i \int d^3x\, \varepsilon^{abc}\, \hat{\chi}_a\, \partial_b \hat{\chi}_c$$

upon the following non-linear field redefinition:

$$\hat{\chi}_a^\alpha = \chi_a^\alpha + \frac{if^{-2}}{3}\, \varepsilon^{dfg}\, \chi_d^\alpha\, (\chi_f\, \partial_a \chi_g).$$

In contrast to the vector Goldstone case, this non-linear model retains gauge symmetry which is that of the Rarita-Schwinger action.

Conclusions and Outlook

- It would be interesting to consider the coupling of the vector Goldstone to a 3d gravity theory which is invariant under local symmetry associated with Hietarinta algebra.
- What kind of 3d massive gravity or bi-gravity will we obtain in that case?

Conclusions and Outlook

- One can couple the RS goldstino to conventional 3d (super)gravity and Hypergravity (with spin-2 and spin-5/2 gauge fields) and study the properties of these models.

- One can also consider the RS goldstino model in D=4 associated with the algebra

$$\{Q^a_\alpha, Q^b_\beta\} = 2\,\varepsilon^{abcd}\,(\Gamma_5\,\Gamma_c)_{\alpha\beta}\,P_d\,, \quad (\alpha,\beta = 1,\ldots,4) \quad (a,b,\ldots = 0,1,2,3)$$

  to see if it reduces to the free Rarita-Schwinger action and has gauge symmetry or not.

- Generalization to yet higher-spin Goldstone fields.

Thank you!