REVIEW ON HIGHER-SPIN THEORIES

Dmitry Ponomarev

PLAN

- Basic introduction
- Difficulties with interactions
- Most successful attempts
- Outlook and conclusion

BASIC INTRODUCTION

MOTIVATION

Explore possibilities to construct quantum theories with gravity

WHAT IS SPIN?

Spin is a property of perturbations around a symmetric background, e.g. the Minkowski space. These satisfy linear Poincare-invariant eom's of the form

$$\Box\phi^{\Omega} + \cdots = 0$$

These eom's define representations of the Poincare algebra. One can always decompose them into irreducible ones. In quantum field theory one requires them to be unitary.

So, we need to study unitary irreducible representations (UIR's) of the Poincare algebra.

WHAT IS SPIN?

UIR's of the Poincare algebra have been classified long ago. Most relevant for physics are massive and massless representations. They also carry an additional quantum number - spin, integer or half-integer (for simplicity d=4).

Massive UIR's $m^2 \neq 0, \qquad s = 0, \frac{1}{2}, 1, \frac{3}{2}, 2, \ldots$

Massless UIR's $m^2 = 0, \qquad s = 0, \frac{1}{2}, 1, \frac{3}{2}, 2, \ldots$

So, spin characterizes how the field transforms with respect to the Poincare algebra

[for details, see the QFT book of Weinberg]

WHAT IS SPIN?

It is convenient to make Lorentz symmetry manifest by employing Lorentz tensors. For massive integer spin-s UIR's we have

$$
\begin{aligned}
(\Box - m^2)\phi^{a_1 \dots a_s} &= 0, \\
\partial_b \phi^{b a_2 \dots a_s} &= 0, \\
\phi_b{}^{b a_3 \dots a_s} &= 0,
\end{aligned}
$$

where phi is a symmetric rank-s tensor.

WHAT IS SPIN?

Massless UIR's in terms of Lorentz tensors can be described as

$$\begin{aligned} \Box\phi^{a_1\dots a_s} &= 0, \\ \partial_b\phi^{ba_2\dots a_s} &= 0, \\ \phi_b{}^{ba_3\dots a_s} &= 0, \end{aligned}$$

where, in addition, one should quotient out <u>pure gauge</u> states

$$\delta\phi^{a_1\dots a_s} = \partial^{a_1}\varepsilon^{a_2\dots a_s} + \dots, \qquad \text{where} \qquad \begin{aligned} \Box\varepsilon^{a_1\dots a_{s-1}} &= 0, \\ \partial_b\varepsilon^{ba_2\dots a_{s-1}} &= 0, \\ \varepsilon_b{}^{ba_3\dots a_{s-1}} &= 0. \end{aligned}$$

Here epsilon is a symmetric rank-(s-1) tensor

From now on, I will discuss only massless fields. Gauge invariance is what makes them more interesting

ACTION

Minimal action

$$S = -\frac{1}{2}\int d^dx \left(\partial_b\phi_{a_1\ldots a_s}\partial^b\phi^{a_1\ldots a_s} - \frac{s(s-1)}{2}\partial_b\phi^c{}_{ca_3\ldots a_s}\partial^b\phi_d{}^{da_3\ldots a_s}\right.$$

$$+ s(s-1)\partial_b\phi^c{}_{ca_3\ldots a_s}\partial_d\phi^{bda_3\ldots a_s} - s\partial_b\phi^b{}_{a_2\ldots a_s}\partial_c\phi^{ca_2\ldots a_s}$$

$$\left. - \frac{s(s-1)(s-2)}{4}\partial_b\phi^{bc}{}_{ca_4\ldots a_s}\partial_d\phi_f{}^{dfa_4\ldots a_s}\right)$$

Gauge transformations

$$\delta\phi_{a_1\ldots a_s} = \partial_{a_1}\varepsilon_{a_2\ldots a_s} + \ldots$$

$$\phi_b{}^b{}_c{}^{ca_4\ldots a_s} = 0, \qquad \varepsilon_b{}^{ba_3\ldots a_{s-1}} = 0$$

[Fronsdal'78]

LIGHT-CONE APPROACH

Action

$$S = -\frac{1}{2}\int d^4x \partial_a \Phi^\lambda \partial^a \Phi^{-\lambda}$$

Poincare generators act by

$$P^a \Phi^\lambda = \partial^a \Phi^\lambda, \qquad J^{ab}\Phi^\lambda = (x^a \partial^b - x^b \partial^a + S^{ab})\Phi^\lambda$$

where

$$S^{+a}\Phi^\lambda = 0, \qquad S^{x\bar{x}}\Phi^\lambda = -\lambda \Phi^\lambda$$

$$S^{x-}\Phi^\lambda = \lambda \frac{\partial}{\partial^+}\Phi^\lambda, \qquad S^{\bar{x}-}\Phi^\lambda = -\lambda \frac{\bar{\partial}}{\partial^+}\Phi^\lambda \qquad x^a = \{x^-, x^+, x, \bar{x}\}$$

Action is much simpler, though, Lorentz invariance is not manifest

ADDING INTERACTIONS

We add higher-order terms to the action (cubic in fields and higher)

What to demand? Wightman axioms? Correlators, QFT.

Our requirements:

Poincare-invariant action

No extra degrees of freedom

Locality: not too many derivatives

LOWER-SPIN EXAMPLES

The Yang-Mills theory:

Quadratic part of the action is spin-1 action of Fronsdal ✓
Interactions: cubic and quartic terms ✓
Poincare invariance: manifest ✓
Gauge invariance: not broken at the non-linear level ✓
Derivatives: no more than two ✓

Good interacting massless theory of spin 1 ✓

LOWER-SPIN EXAMPLES

General relativity:

Expand around flat metric: $$g_{ab} = \eta_{ab} + h_{ab}$$

- Quadratic part of the action is spin-2 action of Fronsdal ✓
- Interactions: terms of all orders in h ✓
- Poincare invariance: manifest ✓
- Gauge invariance: not broken at the non-linear level ✓
- Derivatives: no more than two ✓

Good interacting massless theory of spin 2 ✓

HIGHER-SPIN PROBLEM

Construct a theory, that involves interacting massless field of spin > 2

APPROACHES TO HS INTERACTIONS

WHY IT WORKED FOR YM AND GR?

The key to success was that there existed non-linear deformations of Fronsdal's gauge transformations. Moreover, it was known how to build invariants of these symmetries.

These symmetries — diffemorphisms and local gauge transformations on the principal bundle — have geometric meaning. Then, the knowledge from Riemannian geometry and geometry of principal bundles was helpful for building an action.

In the higher-spin case, thus far, higher-spin symmetries do not have any other meaning than the result of the non-linear deformation of Fronsdal transformations. So, we do not have any tool to write out the higher-spin action as easily as for GR or the YM theory.

STANDARD TOOLS DO NOT WORK

One can try to couple a free higher-spin field to gravity in the standard way

$$S[\partial] \to S[\nabla], \qquad \delta[\partial]\phi \to \delta[\nabla]\phi$$

This does not work:

$$\delta[\nabla]S[\nabla] \propto R_{ab,cd}(\dots)$$

Moreover, this lack of gauge invariance cannot be compensated by allowing the metric transform with respect to HS gauge transformations

The same applies to coupling to the YM connection

[Aragone, Deser'79]

THE NOETHER PROCEDURE

Noether procedure: require gauge invariance order by order in fields

$$S = S_2 + S_3 + \ldots, \qquad \delta\phi = \delta_0\phi + \delta_1\phi + \ldots$$

$$S_2 \sim \phi \cdot \phi, \qquad S_3 \sim g\phi \cdot \phi \cdot \phi, \qquad \delta_0\phi \sim \varepsilon, \qquad \delta_1\phi \sim g\varepsilon \cdot \phi$$

Gauge invariance of the complete action then implies

$$\delta S = 0 \qquad \Rightarrow \qquad \begin{aligned} \delta_0 S_2 &= 0 \\ \delta_0 S_3 + \delta_1 S_2 &= 0 \\ \delta_0 S_4 + \delta_1 S_3 + \delta_2 S_2 &= 0 \\ &\ldots \end{aligned}$$

THE NOETHER PROCEDURE

First non-trivial order

$$\delta_0 S_3 + \delta_1 S_2 = 0 \tag{1}$$

$$\delta_1 S_2 = \delta_1 \phi \frac{\delta S_2}{\delta \phi} \approx 0$$

$$\delta_0 S_3 \approx 0$$

Note that

$$\frac{\delta S_2}{\delta \phi} \sim \Box \phi$$

If one allows

$$\delta_1 \phi = \frac{1}{\Box}(\dots)$$

then (1) is trivial as a constraint on S_3

THE NOETHER PROCEDURE

In other words, imposing locality is absolutely crucial in the Noether procedure. Otherwise, it becomes trivial.

More rigorous discussions of the relevance of the functional class issue:

[Barnich, Henneaux'93]

Analysis of the Noether procedure for massless higher spin fields

[Berends, Burgers, van Dam, Boulanger, Manvelyan, Mkrtchyan, Taronna, Joung,…]

THE LIGHT-CONE DEFORMATION PROCEDURE

What is different:

Only, physical degrees of freedom. No need to care about gauge invariance

However, Poincare symmetry has to be imposed

In practice: deform charges of the Poincare algebra and require that they commute properly

$$[P^-, J^{x-}] = 0 \qquad \Rightarrow \qquad \begin{aligned} [P_2^-, J_2^{x-}] &= 0, \\ [P_2^-, J_3^{x-}] + [P_3^-, J_2^{x-}] &= 0, \\ [P_2^-, J_4^{x-}] + [P_3^-, J_3^{x-}] + [P_4^-, J_2^{x-}] &= 0 \end{aligned}$$

It is also crucial to require locality

AMPLITUDES

Instead of studying constraints on the action, one can consider amplitudes

$$A_n(\epsilon_1, p_1; \ldots; \epsilon_n, p_n)$$

Gauge invariance leads to the Ward identities

$$p_i \frac{\partial}{\partial \epsilon_i} A_n(\epsilon_1, p_1; \ldots; \epsilon_n, p_n) = 0, \qquad \forall i$$

Again, study them order by order

AMPLITUDES

Leading order in g

$$p_i \frac{\partial}{\partial \epsilon_i} A_3(\epsilon_1, p_1; \epsilon_2, p_2; \epsilon_3, p_3) = 0, \qquad \forall i$$

Subleading order

$$p_i \frac{\partial}{\partial \epsilon_i} A_4(\epsilon_1, p_1; \ldots; \epsilon_4, p_4) = 0, \qquad \forall i$$

$$A_4 = A_{4|c} + A_{4|e}$$

For local contact interaction, the associated amplitude is polynomial in the Mandelstam variables. Exchanges have poles with the resides defined by A_3. So the goal is to find A_4 that solves the Ward identity and has fixed singularities. If locality is relaxed, any solution to the Ward identity works.

SPINOR-HELICITY AMPLITUDES

In 4d

$$p_a = -\frac{1}{2}(\sigma_a)^{\dot{\alpha}\alpha}\lambda_\alpha\bar{\lambda}_{\dot{\alpha}}$$

Amplitudes can be expressed in terms of spinor products

$$\langle ij\rangle \equiv \lambda^i_\alpha\lambda^j_\beta\varepsilon^{\alpha\beta}, \qquad [ij] \equiv \bar{\lambda}^i_{\dot{\alpha}}\bar{\lambda}^j_{\dot{\beta}}\varepsilon^{\dot{\alpha}\dot{\beta}}$$

No Ward identities. Helicity constraints

$$\frac{1}{2}\left(|i]\frac{\partial}{\partial|i]} - |i\rangle\frac{\partial}{\partial|i\rangle}\right)A = h_i A, \qquad \forall i$$

Here h is helicity

SUMMARY OF RESULTS

3-PT VERTICES AND AMPLITUDES

In any d, Noether procedure, tensor amplitudes:

For generic triplet of spins there are s1+1 different vertices, s1 is the minimal spin

In 4d, Noether procedure, tensor amplitudes:

For generic triplet of spins there are 2 different vertices

In 4d, light cone and spinor-helicity amplitudes:

For generic triplet of spins there are 4 different vertices

4-PT VERTICES AND AMPLITUDES

<u>All approaches: no solutions</u>

First result of this type: Weinberg's no-go theorem

[Weinberg'64]

VASILIEV THEORY

VASILIEV THEORY

First step: going to AdS space

What is special about AdS space? singleton representations

FLATO-FRONSDAL THEOREM

The AdS space isometry algebra SO(d,2) in d+1 dimensions is also the conformal isometry algebra of the Minkowski space in d dimensions. So,

$$\Box\phi = 0$$

in Minkowski d defines a representation of SO(d,2), called Rac. Moreover, the Flato-Fronsdal theorem states that the tensor product of two Rac's

$$|Rac\rangle \otimes |Rac\rangle = \sum_{s=0}^{\infty} |m^2 = 0, s\rangle$$

gives the sum of massless fields in AdS with integer spins.

[Flato, Fronsdal'78]

Flat-space limit of the FF theorem is singular (does not work). Singletons in the flat space limit become zero-momentum representations.

HIGHER-SPIN ALGEBRA

Consider symmetries of

$$\Box\phi = 0$$

These are differential operators L, such that

$$\Box\phi = 0 \qquad \Rightarrow \qquad \Box L\phi = 0.$$

They form an algebra, which for higher-spin fields in AdS plays a similar role to that of SU(N) for the Yang-Mills theory

[Eastwood'02, Vasiliev'03]

VASILIEV THEORY

Frame-like approach. In GR, instead of the metric, one can take the frame field and the spin-connection to be dynamical fields

$$g_{\mu\nu} \qquad \to \qquad e_\mu{}^a, \quad \omega_\mu{}^{a,b} = -\omega_\mu{}^{b,a}$$

The spin connection can be solved in terms of the frame field from the zero torsion constraint

$$T = 0 \qquad \Rightarrow \qquad \omega \sim \partial e.$$

The antisymmetric part of e can be set to zero by a Stueckelberg gauge symmetry

$$\delta e_{a|b} = \lambda_{a,b}, \qquad \lambda_{a,b} = -\lambda_{b,a}.$$

After that, e can be identified with the metric in GR

VASILIEV THEORY

Similarly, there exists the frame-like approach for Fronsdal fields

$$\phi_{\mu_1\dots\mu_s} \qquad \to \qquad e_\mu{}^{a_1\dots a_{s-1}}, \quad \omega_\mu{}^{a_1\dots a_{s-1},b}.$$

Again, eliminating auxiliary fields and fixing Stueckelberg gauge symmetries, one recovers Fronsdal's theory

VASILIEV THEORY

The Vasiliev theory is given by non-linear equations of motion for fields of spins from 0 to infinity. It is formulated in therms of master fields typically denoted W, C and S. In particular, W is a one-form that depends on the following variables

$$W = W(x|y_1, y_2; z_1, z_2)$$

To compare, Fronsdal fields of spins from 0 to infinity can be combined into a generating function

$$h(x|y) \equiv \sum_{s=0}^{\infty} h_{\mu_1 \dots \mu_s} y^{\mu_1} \dots y^{\mu_s} .$$

Once all auxiliary fields are eliminated and Stueckelberg symmetries fixed, the Vasiliev equations reproduce equations of Fronsdal. This makes it a promising candidate for an interacting higher-spin theory in AdS space

[Vasiliev'90, Vasiliev'03]

VASILIEV THEORY

Vasiliev theory was explored at the first non-linear level. By following the same procedure of elimination of auxiliary fields and fixing the gauges as at free level, it was found, that 3-pt amplitudes that it gives are infinite

[Giombi, Yin'09, Boulanger, Kessel, Skvortsov, Taronna'15]

Currently, there is an ongoing research exploring different schemes to eliminate auxiliary fields. There is some progress at leading orders (including checks with holography, see below)

[Vasiliev, Didenko, Gelfond, Misuna, Korybut '15-…]

HOLOGRAPHIC RECONSTRUCTION

HIGHER-SPIN HOLOGRAPHY

Higher-spin theory in AdS of (d+1) dimensions ⟷ Simple vector CFT's in d dimensions

[Sezgin, Sundell'02, Klebanov, Polyakov'02]

The simplest version of the boundary theory

$$S = \frac{1}{2} \int d^d x \phi^a \Box \phi_a$$

Here "a" is the O(N) index. The theory has infinitely many conserved currents

$$J_{\mu_1 \dots \mu_s} = \phi^a \partial_{\mu_1} \dots \partial_{\mu_s} \phi_a + \dots .$$

HIGHER-SPIN HOLOGRAPHY

Witten diagrams in AdS (AdS amplitudes) ⟷ Correlators of single-trace operators in CFT

Instead of trying to prove the duality, we can use it as a definition of the higher-spin theory in AdS. Then we can test its locality

HOLOGRAPHIC RECONSTRUCTION

More precisely,

$$A_3(s_1, s_2, s_3) \qquad = \qquad \langle J_{s_1} J_{s_2} J_{s_3} \rangle$$

This allows to reconstruct cubic couplings of the HS theory in AdS

Next,

$$\begin{aligned} A_4(s_1, s_2, s_3, s_4) \qquad &= \qquad \langle J_{s_1} J_{s_2} J_{s_3} J_{s_4} \rangle, \\ A_4 \qquad &= \qquad A_{4|c} + A_{4|e} \end{aligned}$$

Then, use analytic properties of Witten diagrams to see whether the contact interaction is local

HOLOGRAPHIC RECONSTRUCTION

In the Mellin representation, contact Witten diagrams are given by polynomials of the so-called Mellin variables, while Mellin amplitudes for exchanges have simple poles. This makes Mellin amplitudes similar to flat-space amplitudes, expressed in terms of the Mandelstam variables.

Higher-spin case: $\Delta \equiv d-2$

$$A_4(s,t) = \delta(s-\frac{\Delta}{2})\delta(t-\frac{\Delta}{2}) + \delta(s-\frac{\Delta}{2})\delta(t-\Delta) + \delta(s-\Delta)\delta(t-\frac{\Delta}{2})$$

Contact diagram has singularities of the same type.

Conclusion. Higher-spin amplitudes are very peculiar. They are not local in a conventional sense. Still, being dual to free theories, they, unlikely, have issues with, e.g. unitarity

[Bekaert, Erdmenger, DP, Sleight'15,'16, Sleight, Taronna'16'17, DP'17]

HIGHER SPIN THEORIES IN 3D

HS IN 3D

The 3d gravity in AdS can be presented as the Chern-Simons theory for

$$so(2,2) \sim so(1,2) \oplus so(1,2)$$

Consider connections

$$A = j_\mu{}^a J_a dx^\mu, \qquad \tilde{A} = \tilde{j}_\mu{}^a J_a dx^\mu$$

$$so(1,2) \sim sl(2,\mathbb{R}) : \qquad [J_a, J_b] = \epsilon_{abc} J^c \qquad \mathrm{tr}(J_a J_b) = \frac{1}{2}\eta_{ab}$$

Then

$$S_{CS}[A] = \frac{k}{4\pi}\int \mathrm{tr}\left(A \wedge dA + \frac{2}{3} A \wedge A \wedge A\right)$$

$$S_{EH} = S_{CS}[A] - S_{CS}[\tilde{A}], \qquad k = \frac{l}{4G} \qquad j_\mu{}^a = \omega_\mu{}^a + \frac{1}{l} e_\mu{}^a, \qquad \tilde{j}_\mu{}^a = \omega_\mu{}^a - \frac{1}{l} e_\mu{}^a$$

HS IN 3D

Replacing

$$sl(2,\mathbb{R}) \oplus sl(2,\mathbb{R}) \quad \rightarrow \quad sl(N,\mathbb{R}) \oplus sl(N,\mathbb{R})$$

we obtain an interacting theory of massless fields with spins 2,3,…,N (in the sense that its linearisation reduces to the sum of 3d Fronsdal actions in AdS). One can also use

$$hs(\lambda) \oplus hs(\lambda), \qquad \lambda \in \mathbb{R}$$

as a gauge group.

HS IN 3D

Comments

3d story is very different from that in 4d: massless fields with spin greater or equal to 2 do not propagate. This is the reason why no-go arguments do not apply here.

Still, the end result is very simple and higher spins appear on the same footing with lower-spin fields.

There are still some things to study, e.g. holography, black holes, etc.

Attempts to rewrite the Chern-Simons action in terms of Fronsdal fields leads to a mess with no obvious structure.

CONFORMAL HS THEORIES

FREE CONFORMAL HS FIELDS

At free level conformal higher spin fields are given by

$$S = \int d^d x \phi_s P_s \partial^{2s+d-4} \phi_s$$

where P is the transverse-traceless projector constructed from derivatives.

Gauge symmetry

$$\delta\phi_{\mu_1\dots\mu_s} = \partial_{(\mu_1}\varepsilon_{\mu_2\dots\mu_s)} + \eta_{(\mu_1\mu_2}\alpha_{\mu_3\dots\mu_s)}.$$

In d=4 for spin 1 it gives the Maxwell theory, for spin 2 — linearised conformal gravity. In general, these theories are non-unitary (have higher order derivatives)

CONFORMAL HS THEORIES

Consider an action

$$S = \int d^d x \phi^* \Box \phi + \sum_{s=0}^{\infty} \int d^d x J^{\mu_1 \dots \mu_s} h_{\mu_1 \dots \mu_s} .$$

Integrating out phi and focusing on the logΛ divergent part, we obtain a non-linear and local action for conformal higher spin fields

$$S[h] = \log \det(\Box + \sum_s h_s J_s)\big|_{log\Lambda}$$

[Tseytlin'02, Segal'02]

CONFORMAL HS THEORIES

Features:

This procedure implicitly gives the action to all orders in fields

All vertices involve finitely many derivatives once spins of fields are fixed

It has distributional amplitudes

$$A_4 \sim \delta\left(\frac{s}{t}\right) + \delta\left(\frac{s}{u}\right).$$

[Joung, Nakach, Tseytlin'15]

CHIRAL HS THEORIES

CHIRAL HS THEORIES

The action

$$S = -\sum_{\lambda} \int d^4x \partial_a \Phi^{-\lambda} \partial^a \Phi^{\lambda}$$

$$+ \sum_{\lambda_i} \int d^4x \frac{l^{\lambda_1+\lambda_2+\lambda_3-1}}{\Gamma(\lambda_1+\lambda_2+\lambda_3)} \frac{\bar{\mathbb{P}}^{\lambda_1+\lambda_2+\lambda_3}}{(\partial_1^+)^{\lambda_1}(\partial_2^+)^{\lambda_2}(\partial_3^+)^{\lambda_3}} \Phi^{\lambda_1}\Phi^{\lambda_2}\Phi^{\lambda_3}$$

$$+ \sum_{\lambda_i} \int d^4x \frac{l^{\lambda_1+\lambda_2+\lambda_3-1}}{\Gamma(\lambda_1+\lambda_2+\lambda_3)} \frac{\mathbb{P}^{\lambda_1+\lambda_2+\lambda_3}}{(\partial_1^+)^{\lambda_1}(\partial_2^+)^{\lambda_2}(\partial_3^+)^{\lambda_3}} \Phi^{-\lambda_1}\Phi^{-\lambda_2}\Phi^{-\lambda_3} + \dots$$

where

$$\mathbb{P} = \frac{1}{3}\left[(\partial_1^+ - \partial_2^+)\partial_3 + (\partial_2^+ - \partial_3^+)\partial_1 + (\partial_3^+ - \partial_1^+)\partial_2\right]$$

solves g-order and partially solves g^2-order consistency conditions

[Metsaev'90]

CHIRAL HS THEORIES

One can note that

$$S = -\sum_{\lambda} \int d^4x \partial_a \Phi^{-\lambda} \partial^a \Phi^{\lambda}$$
$$+ \sum_{\lambda_i} \int d^4x \frac{l^{\lambda_1+\lambda_2+\lambda_3-1}}{\Gamma(\lambda_1+\lambda_2+\lambda_3)} \frac{\bar{\mathbb{P}}^{\lambda_1+\lambda_2+\lambda_3}}{(\partial_1^+)^{\lambda_1}(\partial_2^+)^{\lambda_2}(\partial_3^+)^{\lambda_3}} \Phi^{\lambda_1}\Phi^{\lambda_2}\Phi^{\lambda_3}$$
$$+ \sum_{\lambda_i} \int d^4x \frac{l^{\lambda_1+\lambda_2+\lambda_3-1}}{\Gamma(\lambda_1+\lambda_2+\lambda_3)} \frac{\mathbb{P}^{\lambda_1+\lambda_2+\lambda_3}}{(\partial_1^+)^{\lambda_1}(\partial_2^+)^{\lambda_2}(\partial_3^+)^{\lambda_3}} \Phi^{-\lambda_1}\Phi^{-\lambda_2}\Phi^{-\lambda_3} + \dots$$

solves the consistency conditions to all orders. The resulting theory is called the chiral higher-spin theory

[DP, Skvortsov'16]

CHIRAL HS THEORIES

Properties:

Contains finitely many derivatives once helicities in the vertex are fixed

The action is not real

Can be rewritten as a self-dual Yang-Mills theory. Has similar properties

Infinite-dimensional symmetry algebra, integrability

All amplitudes vanish, including loops (QG?)

Amplitudes are expected to form a subsector of amplitudes for the parity-invariant extension

A version of BCJ relations holds

[DP'17, Skvortsov, Tran, Tsulaia'18]

CONCLUSION AND OUTLOOK

CONCLUSION

With the standard assumptions massless fields cannot interact. Different results, however, suggest that if some assumptions are relaxed, one can obtain consistent interacting theories. For example, consider distributional amplitudes

There is a couple of toy examples of higher-spin theories, which are rather simple and completely analogous to their lower-spin counterparts

FUTURE DIRECTIONS

Explore chiral higher-spin theories: instanton and black-hole solutions, test the geometry with the probe particles

It would be interesting to see whether the flat-space holography can be useful as a tool to generate higher-spin theories in flat space. Issue: no flat singleton

Application of amplitude techniques to generate higher-spin amplitudes in flat space: BCFW, color-kinematics duality, CHY formalism