Higher spins: from quantum gravity to black hole scattering

From Amplitudes to Gravitational Waves, Nordita

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July 28

European Research Council

Established by the European Commission

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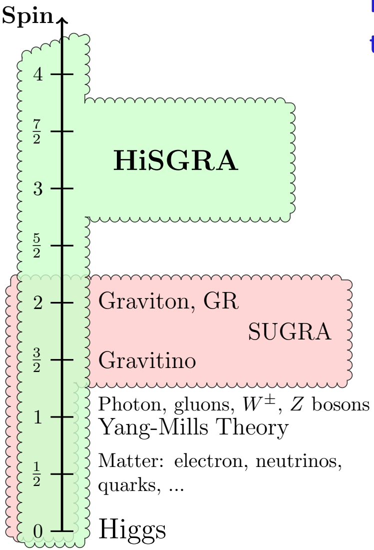
Plan/Keywords

- **Massless higher spins:**
  - quantum gravity via higher spin gravity (HiSGRA)
  - higher spin symmetry, AdS/CFT
  - some HiSGRAs, chiral HiSGRA
- **Massive higher spins:**
  - massive = $\bigoplus$ massless
  - chiral approach
  - black hole scattering

Spin by spin, where is higher spin?



Different spins lead to very different types of theories/physics:

- $s = 0$: Higgs
- $s = 1/2$: Matter

- $s = 1$: Yang-Mills, Lie algebras
- $s = 3/2$: SUGRA and supergeometry, graviton $\in$ spectrum
- $s = 2$ (graviton): GR and Riemann Geometry, no color

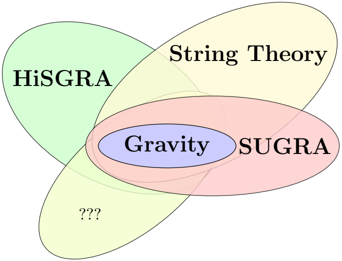
- $s > 2$: HiSGRA and String theory, ∞ states, graviton is there too!

Why massless higher spins?

- string theory
- acausality of higher der. corrections to gravity (Camanho et al.)
- divergences in (SU)GRA's
- Quantum Gravity via AdS/CFT

→ quantization of gravity →

- unbounded spin → ∞ many fields
- UV → massless



HiSGRA = the smallest extension of gravity by massless, i.e. gauge, higher spin fields. Vast gauge symmetry should render it finite (≈ SUGRA).

Quantizing Gravity via HiSGRA = Classical HiSGRA?

What Higher Spin Problem is: Field theory approach

A massless spin-s particle can be described by a rank-s tensor

$$\delta\Phi_{\mu_1\dots\mu_s} = \nabla_{\mu_1}\xi_{\mu_2\dots\mu_s} + \text{permutations}$$

which generalizes $\delta A_\mu = \partial_\mu \xi, \qquad \delta g_{\mu\nu} = \nabla_\mu \xi_\nu + \nabla_\nu \xi_\mu$

Fronsdal, Berends, Burgers, Van Dam, Bengtsson^2, Brink, ...

Problem: find a nonlinear completion (action, gauge symmetries)

$$S = \int (\nabla\Phi)^2 + \mathcal{O}(\Phi^3) + \dots \qquad\qquad \delta\Phi_{\dots} = \nabla_{.}\xi_{\dots} + \dots$$

and prove that it is UV-finite, hence a Quantum Gravity model

Warning: brute force does not seem to work! Bekaert, Boulanger, Leclerq; Taronna; Roiban, Tseytlin; Ponomarev; Taronna, Sleight; . . .

Power of higher spin symmetry
know your friend/enemy

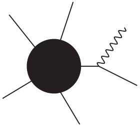
too small symmetry: nothing can be computed even with a theory
too big symmetry: everything is fixed even without a theory
higher spin symmetry: almost everything is fixed and very few theories

Higher spin symmetry constraints on S-matrix

Let's study **asymptotic higher spin symmetry** in Minkowski

$$\delta\Phi_{\mu_1\dots\mu_s}(x) = \partial_{\mu_1}\xi_{\mu_2\dots\mu_s}$$

Weinberg low energy theorem (similarly, Coleman-Mandula theorem):



$$\sum_i g_i\, p^i_{\mu_1}\dots p^i_{\mu_{s-1}} = 0$$

- $s = 1$, charge conservation $\sum g_i = 0$
- $s = 2$, equivalence principle $\sum g_i\, p^i_\mu = 0 \rightarrow g_i = g$
- $s > 2$, too many conservation laws and **HiSGRA** $\boldsymbol{S = 1}$

This is in '**tension**' with $V^{\lambda_1,\lambda_2,\lambda_3} \sim [12]^{\lambda_1+\lambda_2-\lambda_3}[23]^{\lambda_2+\lambda_3-\lambda_1}[13]^{\lambda_1+\lambda_3-\lambda_2}$

Higher spin symmetry constraints on holographic S-matrix

Let's study **asymptotic higher spin symmetry** in anti-de Sitter

$$\delta\Phi_{\mu_1\ldots\mu_s}(x)=\nabla_{\mu_1}\xi_{\mu_2\ldots\mu_s} \qquad \Longleftrightarrow \qquad \partial^m J_{ma_2\ldots a_s}=0$$

$$\Updownarrow$$

free CFT

Given a CFT in $d \geq 3$ with stress-tensor J_2 and at least one higher-spin current J_s, one can prove that it is a free CFT in disguise Maldacena, Zhiboedov; Boulanger, Ponomarev, E.S., Taronna; Alba, Diab, Stanev

This is a generalization of the Weinberg and Coleman-Mandula theorems to AdS/CFT: higher spin symmetry implies

holographic HiSGRA S = free CFT

Let's study **asymptotic** **slightly-broken** **higher spin symmetry** in AdS

$$\delta\Phi_{\mu_1\ldots\mu_s}(x) = \nabla_{\mu_1}\xi_{\mu_2\ldots\mu_s} \qquad \Longleftrightarrow \qquad \partial^m J_{ma_2\ldots a_s} = \frac{1}{N}[JJ] \neq 0$$

Large-N critical vector model (Wilson-Fisher)

$$S = \int d^3x \left((\partial\phi^i)^2 + \frac{\lambda}{4!}(\phi^i\phi^i)^2 \right)$$

should be dual to the same HiSGRA for $\Delta = 2$ boundary conditions on $\Phi(x)$ (Klebanov, Polyakov; Sezgin, Sundell; Leigh, Petkou)

holographic HiSGRA S = Large-N Ising

This can be extended to Chern-Simons Matter theories, (Chang, Minwalla, Sharma, Yin, Giombi, Prakash, Trivedi, Wadia; Aharony; Maldacena, Zhiboedov, ...)

New input: vector models have slightly-broken higher spin symmetry!

S-matrix summary

We see that **asymptotic higher spin symmetries** (HSS)

$$\delta\Phi_{\mu_1\dots\mu_s}(x) = \nabla_{\mu_1}\xi_{\mu_2\dots\mu_s}$$

seem to completely fix (holographic) S-matrix to be

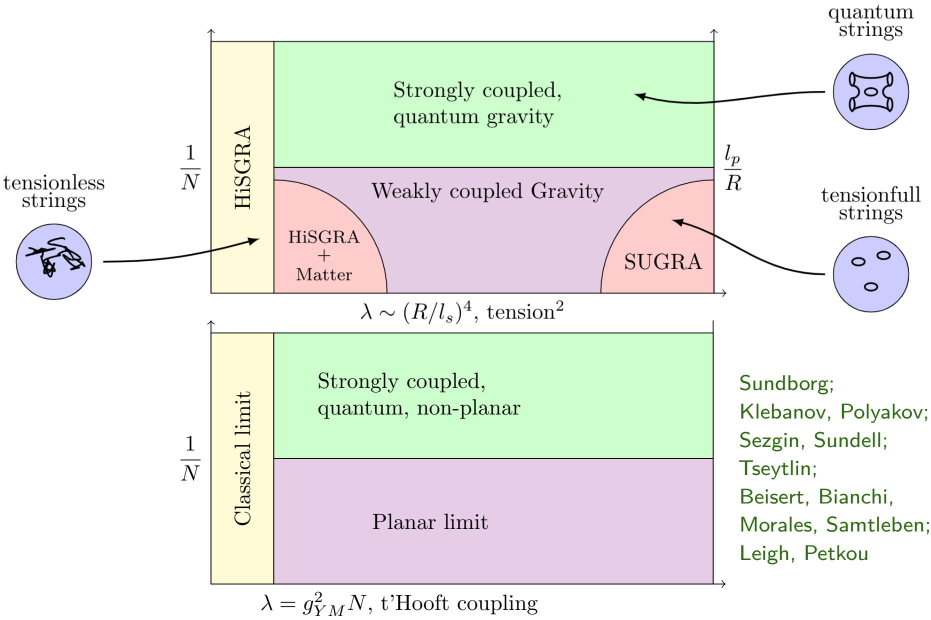
$$S_{\text{HiSGRA}} = \begin{cases} 1^{***}, & \text{flat space} \\ \text{free CFT}, & \text{asymptotic AdS, unbroken HSS} \\ \textbf{Chern-Simons Matter}, & \textbf{asymptotic AdS}_4\textbf{, SB HSS} \end{cases}$$

Trivial/known S-matrix can still be helpful for QG toy-models

The most interesting applications are for AdS_4/CFT_3 and three-dimensional dualities (power of HSS is underexplored)

Both Minkowski and AdS cases reveal certain non-localities to be tamed. HSS mixes ∞ spins and derivatives, invalidating the local QFT approach

HiSGRA from Tensionless Strings, duals of weakly coupled CFT's



Sundborg;
Klebanov, Polyakov;
Sezgin, Sundell;
Tseytlin;
Beisert, Bianchi, Morales, Samtleben;
Leigh, Petkou

HiSGRA that survived

Quantizing Gravity via HiSGRA = Constructing Classical HiSGRA

Therefore, HiSGRA can be good probes of the Quantum Gravity Problem

Local HiSGRA in 2023

3d massless, conformal and partially-massless (Blencowe; Bergshoeff, Stelle; Campoleoni, Fredenhagen, Pfenninger, Theisen; Henneaux, Rey; Gaberdiel, Gopakumar; Grumiller; Grigoriev, Mkrtchyan, E.S.; Pope, Townsend; Fradkin, Linetsky; Lovrekovic; ...), $S = S_{CS}$ for a HS extension of $sl_2 \oplus sl_2$ or $so(3,2)$

$$S = \int \omega\, d\omega + \tfrac{2}{3}\omega^3$$

4d conformal (Tseytlin, Segal; Bekaert, Joung, Mourad; Adamo, Tseytlin; Basile, Grigoriev, E.S.; ...), higher spin extension of Weyl gravity, local Weyl symmetry tames non-localities

$$S = \int \sqrt{g}\,(C_{\mu\nu,\lambda\rho})^2 + ...$$

4d massless chiral (Metsaev; Ponomarev, E.S.; Ponomarev; E.S., Tran, Tsulaia; ...). The smallest higher spin theory with propagating fields.

The theories avoid all no-go's. Surprisingly, all of them have simple actions and are clearly well-defined, as close to Field Theory as possible

Other ideas and proposals

- **Reconstruction**: invert AdS/CFT
  - Brute force (Bekaert, Erdmenger, Ponomarev, Sleight; Taronna, Sleight)
  - Collective Dipole (Jevicki, Mello Koch et al; Aharony et al)
  - Holographic RG (Leigh et al, Polchinski et al)
- **IKKT matrix model for fuzzy H_4** (Steinacker, Sperling, Fredenhagen, Tran)
- **Formal HiSGRA**: constructing L_∞-extension of HS algebras, i.e. a certain odd Q, $QQ = 0$, and write AKSZ sigma model (Barnich, Grigoriev)

$$d\Phi = Q(\Phi)$$

Warning: Boulanger, Kessel, E.S., Taronna

(Vasiliev; E.S., Sharapov, Bekaert, Grigoriev, E.S.; Grigoriev, E.S.; Tran; Bonezzi, Boulanger, Sezgin, Sundell; Neiman) AdS/CFT: (Sundborg, Sezgin, Sundell, Klebanov, Polyakov, Giombi, Yin, ...) Chiral HiSGRA (Sharapov, E.S., Sukhanov, Van Dongen)

Certain things do work, but the general rules are yet to be understood, e.g. non-locality, ... **More:** Snowmass paper, ArXiv: 2205.01567

Chiral Higher Spin Gravity

Self-dual Yang-Mills is a useful analogy

- the theory is non-unitary due to the interactions $(A_\mu \to \Phi^\pm)$

$$\mathcal{L}_{\text{YM}} = \text{tr}\, F_{\mu\nu} F^{\mu\nu}$$

$$\wr\wr$$

$$\mathcal{L}_{\text{(SD)YM}} = \Phi^- \Box \Phi^+ + V^{++-} + V^{--+} + V^{++--}$$

- tree-level amplitudes vanish, $A_{\text{tree}} = 0$
- one-loop amplitudes coincide with $(+ + ... +)$ of QCD
- **SD theories are consistent truncations**, so anything we can compute will be a legitimate observable in the full theory
- integrability, instantons, twistors, ...

Chiral HSGRA in Minkowski

Chiral HiSGRA (Metsaev; Ponomarev, E.S.) is a 'higher spin extension' of SDYM/SDGR. It has fields of all spins $s = 0, 1, 2, 3, ...$:

$$\mathcal{L} = \sum_{\lambda} \Phi^{-\lambda} \Box \Phi^{+\lambda} + \sum_{\lambda_i} \frac{\kappa\, l_{\text{Pl}}^{\lambda_1+\lambda_2+\lambda_3-1}}{\Gamma(\lambda_1+\lambda_2+\lambda_3)} V^{\lambda_1,\lambda_2,\lambda_3}$$

light-cone gauge is very close to the spinor-helicity language

$$V^{\lambda_1,\lambda_2,\lambda_3} \sim [12]^{\lambda_1+\lambda_2-\lambda_3}[23]^{\lambda_2+\lambda_3-\lambda_1}[13]^{\lambda_1+\lambda_3-\lambda_2}$$

Locality + Lorentz invariance + genuine higher spin interaction result in a unique completion

This is the smallest higher spin theory and it is unique.
Graviton and scalar field belong to the same multiplet

No UV Divergences! One-loop finiteness

Tree amplitudes vanish. The interactions are naively non-renormalizable, the higher the spin the more derivatives:

$$V^{\lambda_1,\lambda_2,\lambda_3} \sim \partial^{|\lambda_1+\lambda_2+\lambda_3|}\Phi^3$$

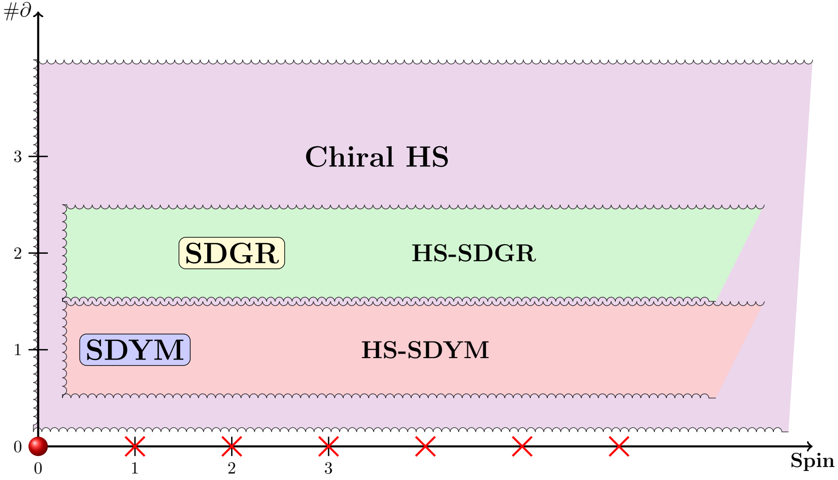
but there are **no UV divergences!** (E.S., Tsulaia, Tran). Some loop momenta eventually factor out, just as in $\mathcal{N}=4$ SYM, but ∞-many times.

At one loop we find three factors: (1) SDYM or all-plus 1-loop QCD; (2) higher spin dressing to account for λ_i; (3) total number of d.o.f.:

$$A^{\text{1-loop}}_{\text{Chiral}} = A^{++\ldots+}_{\text{QCD,1-loop}} \times D^{\text{HSG}}_{\lambda_1,\ldots,\lambda_n} \times \sum_\lambda 1$$

d.o.f.= $\sum_\lambda 1 = 1 + 2\sum_{\lambda>0} 1 = 1 + 2\zeta(0) = 0$ to comply with no-go's, (Beccaria, Tseytlin) and agrees with many results in AdS, where $\neq 0$

Russian doll of theories



Contractions (Ponomarev); Equations of motion of Chiral HiSGRA's are available in flat/(A)dS (Sharapov, E.S., Sukhanov, Van Dongen; Didenko).

Random massless comments

Random massless comments

HiSGRA in dS as well: prediction for R vs. R^3 corrections in cosmology, (Anninos et al,...; Neiman)

$$S = \int \sqrt{g}(R + \cos 2\theta(C_+^3 + C_-^3) + \sin 2\theta(C_+^3 - C_-^3) + \ldots$$

'Double copy' and integrability: YM and Gravitational interactions are sub-sectors of the same theory and $\mathbf{Mat}_N \otimes$ Moyal Weyl $\ni [\bullet, \bullet] + \hbar\{\bullet, \bullet\} + \ldots$, where Poisson $\{\bullet, \bullet\}$ is the same as same as $w_{1+\infty}$ (Ponomarev) → Nagy

HS-SDGR, HS-SDYM and twistors: (Adamo, Tran; Tran; Krasnov, E.S., Tran; Herfray, Krasnov, E.S.)

Celestial studies and flat holography: (Monteiro; Ren, Spradlin, Yelleshpur Srikant, Volovich; Ponomarev)

The day job: strong homotopy algebras (e.g., Sharapov, E.S., Sukhanov, Van Dongen), deformation quantization, Grassmannian → HS-hedron 

Massive Higher Spins

(massive non-elementary particles definitely exist,
but there is much less literature about them.
No no-go's, no challenge?)

Massive higher spins?

String's spectrum is full of massive higher spins as well ...

Massive "higher spins" are notoriously "more complicated": second class constraints, Boulware-Deser ghosts, actions are not easy (Singh, Hagen; Zinoviev)

$$(\Box - m^2)\Phi_{\mu_1 \dots \mu_s} = 0 \qquad\qquad \partial^\nu \Phi_{\nu\mu_2 \dots \mu_s} = 0$$

Interactions are very difficult to construct, (Buchbinder et al; Metsaev; Zinoviev et al)

Low spins success stories: $s = 1$ spontaneously broken Yang-Mills; $s = 3/2$; $s = 2$ massive (bi)-gravity (dRGT; Hassan, Rosen); $s = 5/2$ (Chiodaroli, Johansson, Pichini)

Zinoviev's approach

Instead of the tedious Hamiltonian analysis of (second class) constraints to make sure that interactions of $\Phi_{\mu_1 \ldots \mu_s}$ do not activate unphysical degrees of freedom, one can convert all second class to first class. The latter can be taken care of by gauge symmetries:

$$\text{massive spin} - s = \bigoplus_{k=0}^{k=s} \text{massless spin} - k$$

which leads to

$$\delta\Phi_k = \partial\xi_{k-1} + \xi_k + g\xi_{k-2} + \mathcal{O}(\Phi\xi)$$

For the steps along the Zinoviev approach see 'Kerr Black Holes Enjoy Massive Higher-Spin Gauge Symmetry', Cangemi, Chiodaroli, Johansson, Ochirov, Pichini, et al; arxiv: 2212.06120 & 2308.xxxx and the talk by Lucile Cangemi

Chiral approach

The problem is to embed physical degrees of freedom into a Lorentz covariant field

$$\text{degrees of freedom} \rightsquigarrow \text{Lorentz (spin-)tensor}\,, \Phi_{A_1\ldots A_n, A'_1\ldots A'_m}$$

In principle, any $\Phi_{A(n),A'(m)}$ of $sl(2,\mathbb{C})$ with $n+m=2s$ is good enough and

$$\Phi_{\mu_1\ldots\mu_s} \sim \Phi_{A(s),A'(s)} \sim (s,s)$$

Simple idea in $4d$ (Ochirov, E.S.): let's take

$$\Phi_{A_1\ldots A_{2s}} \sim (2s,0)$$

It does not have any longitudinal unphysical modes.

No auxiliary fields are needed. Parity is not easy ... but everything is a consistent interaction

Chiral approach: Massive low spins

Chalmers and Siegel, '97-98, mapped "Standard model" to its chiral version, i.e. "chiralized" massive $s = 1/2, 1$

For $s = 1/2$ we just integrate out half of the Majorana spinor $\psi_A, \psi_{A'}$:

$$\mathcal{L}_M = i\psi^A \nabla_{AA'} \psi^{A'} + \frac{1}{2} m(\psi_A \psi^A + \psi_{A'} \psi^{A'})$$

to get some **nonminimal interactions** as well

$$\mathcal{L} = \psi^A (\Box - m^2) \psi_A + \psi^A F_{AB} \psi^B + R \psi^A \psi_A$$

where F_{AB} is the self-dual part of the (non)-abelian gauge background field

$$F_{\mu\nu} = F_{AB} \epsilon_{A'B'} + \epsilon_{AB} F_{A'B'} = F_- + F_+$$

Chalmers and Siegel mapped "Standard model" to its chiral version, i.e. "chiralized" massive $s = 1/2, 1$

For $s = 1$ (abelian) Proca on a gravitational background

$$\mathcal{L}_P = \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{2} m^2 A_\mu A^\mu$$

we first introduce an auxiliary field Φ^{AB}:

$$\Phi^{BC} F_{BC}(A) + \frac{1}{2}\Phi^{BC}\Phi_{BC} + \frac{1}{2} m^2 A_{BB'} A^{BB'}$$

Integrating A out leads to

$$\Phi^{AB}(\Box - m^2 + R)\Phi_{AB} + C_{ABCD}\Phi^{AB}\Phi^{CD},$$

where C is the self-dual part of the Weyl tensor.

Chiral approach: Massive higher spins

Easy to introduce 'minimal' EM, YM and gravitational interactions

$$\mathcal{L} = \langle\Phi|(\Box - m^2)|\Phi\rangle \equiv \Phi_{A(2s)}(\Box - m^2)\Phi^{A(2s)}$$

Simple relation to massive spinor-helicity (Arkani-Hamed, Huang[2])

Anything is a consistent interaction → easy to classify non-minimal couplings

Wanted: Black hole Lagragian,

$$\mathcal{L}_{\text{BH}} = \langle\Phi|(\Box - m^2)|\Phi\rangle + \mathcal{L}_{\text{non-min}}$$

i.e. the simplest parity-invariant theory that couples HS to photons/gluons ($\sqrt{\textbf{Kerr}}$) or to gravitons (**Kerr**) that starts with (Arkani-Hamed, Huang^2; Guevara, Ochirov, Vines; Chung, Huang, Kim, Lee)

$$\mathcal{A}(s,s,+) \sim \langle\mathbf{1}\,\mathbf{2}\rangle^{2s}\mathcal{A}(0,0,+) \qquad \mathcal{A}(s,s,-) \sim [\mathbf{1}\,\mathbf{2}]^{2s}\mathcal{A}(0,0,-)$$

How far away are we?

Wanted: Black hole Lagragian,

$$\mathcal{L}_{\text{BH}} = \langle \Phi | (\Box - m^2) | \Phi \rangle + \mathcal{L}_{\text{non-min}}$$

that starts with (Arkani-Hamed, Huang^2; Guevara, Ochirov, Vines; Chung, Huang, Kim, Lee)

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The minimal coupling correctly reproduces all-plus amplitudes obtained from unitarity (Aoude, Haddad, Helset; Lazopoulos, Ochirov, Shi):

$$\mathcal{A}(s,s,+,\ldots,+) \sim \langle \mathbf{1}\,\mathbf{2} \rangle^{2s} \mathcal{A}(0,0,+,\ldots,+)$$

Wanted: Black hole Lagragian,

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The minimal coupling correctly reproduces all-plus amplitudes obtained from unitarity (Aoude, Haddad, Helset; Lazopoulos, Ochirov, Shi):

$$\mathcal{A}(s,s,+,\dots,+) \sim \langle \mathbf{1}\,\mathbf{2} \rangle^{2s} \mathcal{A}(0,0,+,\dots,+)$$

To restore parity at the cubic level we need

$$\mathcal{L}_{\text{non-min}} \sim \sum_{k=0}^{2s-1} \frac{1 \text{ or } (2s-k-1)}{m^{2k}} \langle \Phi | \left(\overleftarrow{D} \overrightarrow{D} \right)^k F_- \text{ or } R_- | \Phi \rangle$$

Massless higher spins:

Some HiSGRA do exist as local field theories, e.g. Chiral HSGRA — toy model with stringy features. Some quantum checks passed, no UV divergences thanks to higher spin symmetry. Relation to Chern-Simons vector models and $3d$ bosonization. Main challenge is to construct unitary ones, in particular, the dual to the CS-matter

Massive higher spins:

An open challenge to construct theories with massive higher spins, in particular, the minimal one that describes black hole scattering, all spins should be needed again. Chiral approach facilitates introduction of interactions, ...

Thank you for your attention!

may the higher spin force be with you!

... backup slides ...

Chiral HSGRA in Minkowski

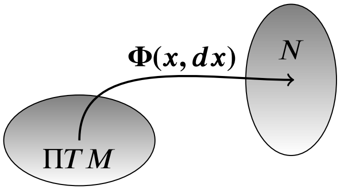
- **stringy 1**: the spectrum is infinite $s = 0, (1), 2, (3), 4, ...$
- **stringy 2**: admit Chan-Paton factors, $U(N)$, $O(N)$ and $USp(N)$
- **stringy 3**: we have to deal with spin sums $\sum_s$ (worldsheet takes care of this in string theory) and ζ-function helps
- **stringy 4**: the action contains parts of YM and Gravity
- **stringy 5**: higher spin fields soften amplitudes
- consistent with Weinberg etc. $S = 1^{***}$ (in Minkowski)
- gives all-plus QCD or SDYM amplitudes from a gravity

Apart from Minkowski space the theory exists also in (anti)-de Sitter space, where holographic S-matrix turns out to be nontrivial ... and related to Chern-Simons matter theories

Let us be given a Q-manifold (view it locally as an L_∞-algebra)

$\Phi\,, Q^2 = 0$

$\Omega^\bullet(M)\,, d^2 = 0$



then we can always write a sigma-model:

$$\boldsymbol{d\Phi = Q(\Phi)}$$

Any PDE can be cast into such a form ... (Barnich, Grigoriev)

Other names: Free Differential Algebras (Sullivan), in physics: (van Nieuwenhuizen; Fre, D' Auria); FDA=unfolding (Vasiliev), AKSZ (AKSZ)

Some 'tensionless pairs'/duals of weakly-coupled CFT's

- free SYM vs. ??HiSGRA+Matter (Sundborg; Sezgin, Sundell; Beisert, Bianchi, Morales, Samtleben);
- free SYM vs. tensionless strings on $AdS_5 \times S^5$ (Gaberdiel, Gopakumar);
- $\mathrm{Sym}^N(\mathbb{T}^4)$ vs. strings on $AdS_3{\times}S^3{\times}\mathbb{T}^4$ (Gaberdiel, Gopakumar; Eberhardt, Gaberdiel);
- Fishnet vs. ?? strings (Caetano, Kazakov; Gromov, Sever)
- free scalar/fermion CFT's, Wilson-Fisher/Gross-Neveu, Chern-Simons Matter theories up to ABJ vs. strings and ??HiSGRA (Klebanov, Polyakov, Sezgin, Sundell, Petkou, Leigh, Chang, Minwalla, Sharma, Yin, Giombi, Prakash, Trivedi, Wadia);
- ??subector of tensionless strings on $AdS_4 \times \mathbb{CP}^3$ vs. ??subsector of ABJ (Chern-Simons) vector models vs. Chiral HiSGRA (Ponomarev, E.S.; Sharapov, E.S., Van Dongen)

Covariantization, SDYM, SDGR

Chiral HiSGRA admits two contractions (Ponomarev) to higher spin extensions of SDYM and SDGR. These HS-SDYM and HS-SDGR can be covariantized (Krasnov, E.S., Tran). New (Hitchin) free action

$$S = \int \Psi^{A_1...A_{2s}} \wedge H_{A_1A_2} \wedge \nabla\omega_{A_3...A_{2s-2}}$$

$H^{AB} \equiv e^A{}_{C'} \wedge e^{BC'}$. Interactions can be introduced by taking sum over s and by replacing $\nabla\omega$ or both H and $\nabla\omega$ with

$$F = d\omega + \tfrac{1}{2}[\omega,\omega] \qquad\qquad S = \int \Psi\, F \wedge F$$

where $\omega \equiv \sum_k \omega_{A_1...A_k}\, y^{A_1}...y^{A_k}$ and the commutator is either due to Yang-Mills groups or due to Poisson bracket on $\mathbb{R}^2$ of $f(y)$, same as $w_{1+\infty}$.

Full covariant form of Chiral HiSGRA is available (Sharapov, E.S., Sukhanov, Van Dongen). Twistors (Tran)

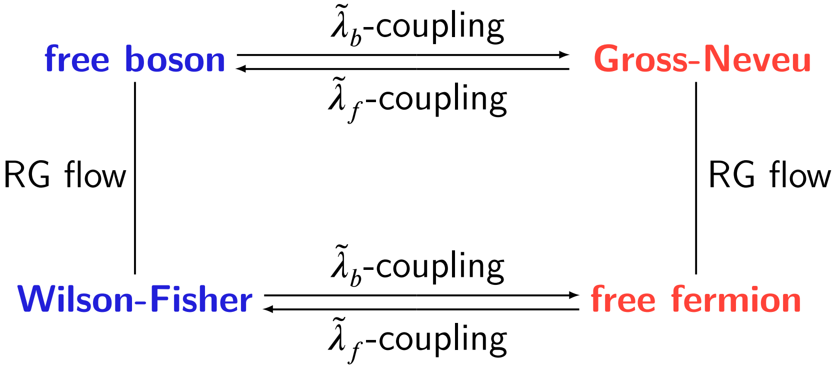
Chern-Simons Matter theories and dualities

In AdS_4/CFT_3 one can do much better — there exists a large class of models, Chern-Simons Matter theories (extends to ABJ(M))

$$\frac{k}{4\pi} S_{CS}(A) + \text{Matter} \begin{cases} (D\phi^i)^2 & \textbf{free boson} \\ (D\phi^i)^2 + g(\phi^i\phi^i)^2 & \textbf{Wilson-Fisher (Ising)} \\ \bar{\psi}\not{D}\psi & \textbf{free fermion} \\ \bar{\psi}\not{D}\psi + g(\bar{\psi}\psi)^2 & \textbf{Gross-Neveu} \end{cases}$$

- describe physics (Ising, quantum Hall, ...)
- break parity in general (Chern-Simons)
- two parameters $\lambda = N/k$, $1/N$ (λ continuous for N large)
- exhibit remarkable dualities, e.g. ***3d* bosonization duality** (Aharony, Alday, Bissi, Giombi, Karch, Maldacena, Minwalla, Prakash, Seiberg, Tong, Witten, Yacobi, Yin, Zhiboedov, ...)

Chern-Simons Matter theories and dualities

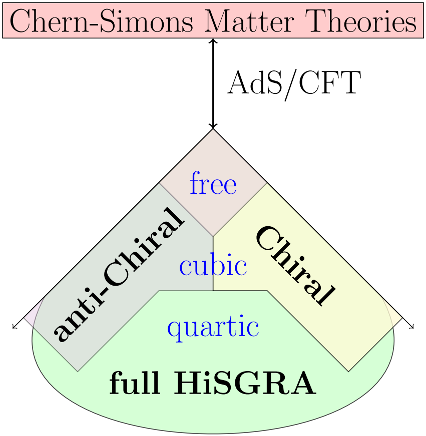


The simplest gauge-invariant operators are $J_s = \phi D ... D\phi$ or $J_s = \bar{\psi}\gamma D ... D\psi$, which are dual to higher spin fields.

Currents are slightly non-conserved $\partial \cdot J = \frac{1}{N}[JJ]$

$\gamma(J_s)$ at order $1/N$ (Giombi, Gurucharan, Kirillin, Prakash, E.S.) confirm the duality. Many other tests!

Chiral HiSGRA and Chern-Simons Matter



$\exists$ Chiral HiSGRA $\rightarrow$ $\exists$ closed subsector

(anti)-Chiral Theories are rigid, we need to learn how to glue them

gluing depends on one parameter, which is introduced via simple EM-duality rotation $\Phi_{\pm s} \rightarrow e^{\pm i\theta}\Phi_{\pm s}$

gives all 3-point correlators consistent with (Maldacena, Zhiboedov)

Bosonization is manifest! Concrete predictions from HiSGRA.

(anti)-Chiral Theories provide a complete base for 3-pt amplitudes

$$V_3 = V_{chiral} \oplus \bar{V}_{chiral} \quad \leftrightarrow \quad \langle JJJ \rangle$$