On higher-spin supertranslations and superrotations

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with: A. Campoleoni & C. Heissenberg

SCUOLA NORMALE SUPERIORE

INVITATION: THE HSP INFRARED PROBLEM

* LOW-SPINS: field theories first understood as MASSLESS theories with LOCAL SYMMETRY ($s \geq 1$)

  - MAXWELL
  - YANG-MILLS
  - (SUPER-)GRAVITY

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* HIGH-SPINS:

  - massive excitations observed since the 50's
  - massive hsp particles "predicted" by ST ('68)
  - BUT massless hsp theories long-assumed to $\nexists$
  - even Fradkin-Vasiliev's way out relies on the presence of an INFRARED REGULATOR: Λ

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→ the naive elimination of the IR cut-off appears to be singular both in String Theory (TENSIONLESS LIMIT) and in Vasiliev's theory (FLAT LIMIT)

→ in the $m=0$ case, even when $\Lambda \neq 0$, implementing the full hsp gauge symmetry forces some degree of non locality, whose full import is yet to be understood.

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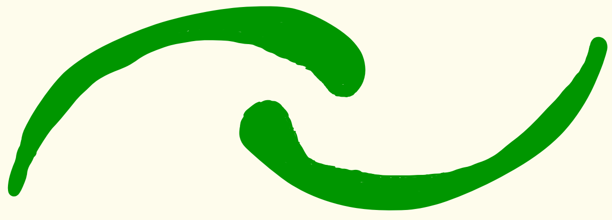
→ Interpret these inputs as an indication that relevant (if not crucial) features of hsp systems lie in the unusual long distance/flat behavior of the corresponding massless quanta, and try to envisage options to get at least some partial insight.



PROLOGUE

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∂ "THEORY = BULK + BOUNDARY"

∂ SYMMETRIES: LOCAL vs GLOBAL $\not\Longleftrightarrow$ REDUNDANCIES vs OBSERVABLES

∂ PHYSICAL RELEVANCE OF INFRARED EFFECTS

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- CONNECTION TO WEINBERG'S SOFT THEOREM
  (infrared)

Plan

§I. Lower spins

* asymptotic symmetries
* Weinberg's soft theorem

§II. Higher spins

* asymptotic symmetries
* Weinberg's soft theorem

§III. Remarks & Outlook

§I. LOWER SPINS

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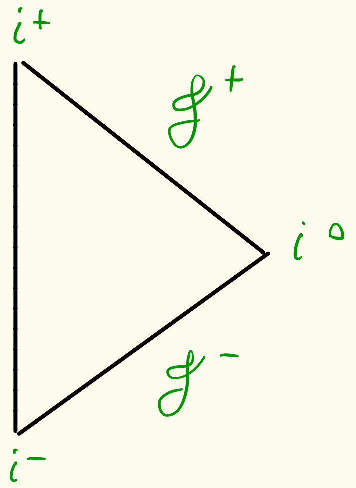
* ASYMPTOTIC SYMMETRIES

Asymptotically-flat space times

$$ds^2 = -du^2 - 2\,du\,dr + r^2 \gamma_{z\bar{z}}\,dz\,d\bar{z}$$

* Flat space



$$(t, r, \vartheta, \varphi) \longrightarrow (u, r, z, \bar{z})$$

$\mathscr{I}^+$: Retarded Bondi Coordinates

* $u = t - r$
* $z = e^{i\varphi} \cot \vartheta/2$
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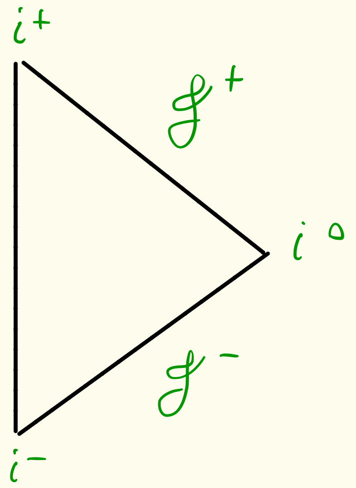

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(M, g) whose conformal compactification has a boundary "RESEMBLING" the boundary of the Carter-Penrose diagram of Minkowski space

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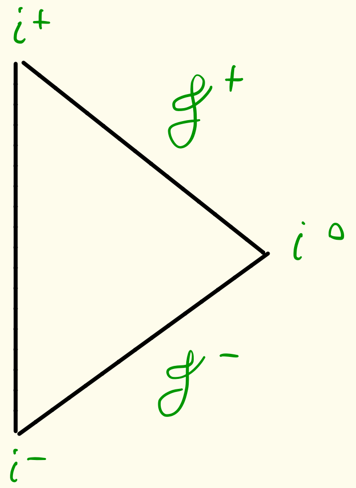

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BMS GROUP

* "RESEMBLING" THE BOUNDARY OF MINKOWSKI :

On the (null) boundary of the "unphysical" space time, all A.F. spaces share the same UNIVERSAL STRUCTURE :

EQUIVALENCE CLASS of conformally related triples

$$\underbrace{\left\{ \left(\mathscr{I} \, , \, \tilde{h}_{ab} \, , \, n^a \right) \right\}}$$

$\tilde{h}_{ab}$: DEGENERATE INDUCED METRIC ON $\mathscr{I}$

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* **BMS GROUP** : DIFFEOMORPHISMS on $\mathscr{I}$,

$$\psi : \mathscr{I} \longrightarrow \mathscr{I} \, ,$$

that PRESERVE THE UNIVERSAL STRUCTURE

$SO(3,1) \ltimes ST$

$\Rightarrow$ admit ψ's connecting EQUIVALENT, yet DIFFERENT METRICS

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$$g_{\mu\nu} \not\longrightarrow \eta_{\mu\nu} \quad \text{rather} \quad \text{"} g_{\mu\nu} \longrightarrow \{\eta_{\mu\nu}\} \text{"}$$

or, maybe more suggestively

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BMS ALGEBRA:

∞ - DIM ENHANCEMENT OF POINCARÉ

$P_\mu \longrightarrow$ SUPERTRANSLATIONS $T(z,\bar{z})$

[BONDI, METZNER, VAN DER BURG, SACHS]

$M_{\mu\nu} \longrightarrow$ SUPERROTATIONS $Y_z(z,\bar{z})$

[BARNICH AND TROESSAERT]

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MORE EXPLICITLY, SO AS TO GET CLOSER TO OUR HSP EXTENSION:

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

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* m_B, U_z and C_{zz} (and $z \leftrightarrow \bar{z}$) DO NOT DEPEND ON r;

* These conditions combine GAUGE FIXING and analysis of full, non-linear eom;

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SPIN-ONE LGT

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§I. LOWER SPINS

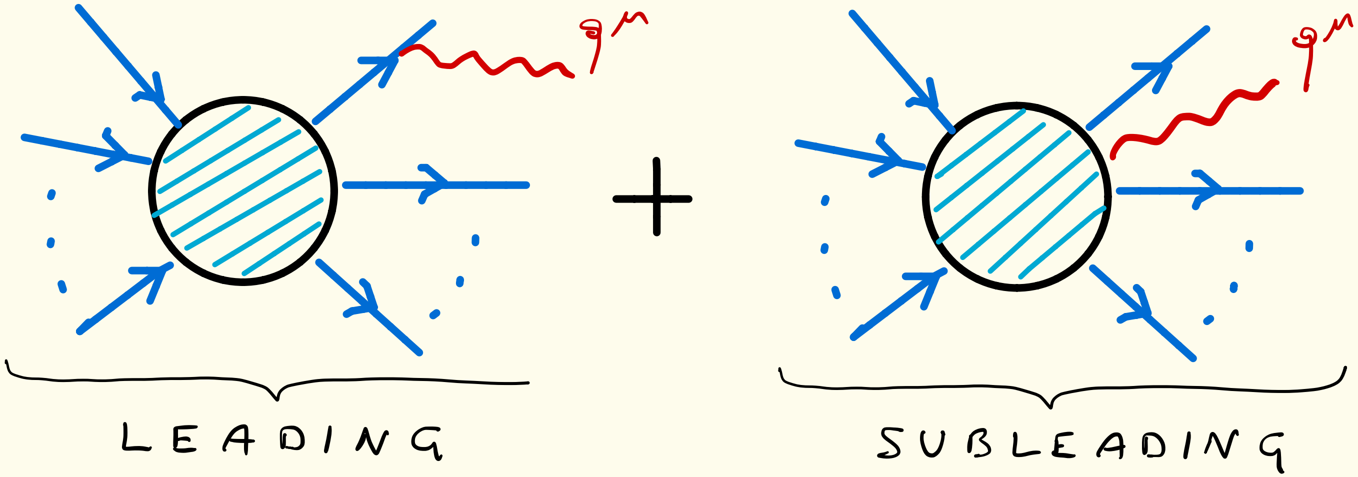
* SOFT THEOREMS

(leading order)

LGT & WEINBERG'S SOFT THEOREM

$$S_{\alpha\beta}(q) =$$

$q^2 = 0\,,\ q^\mu \to 0$



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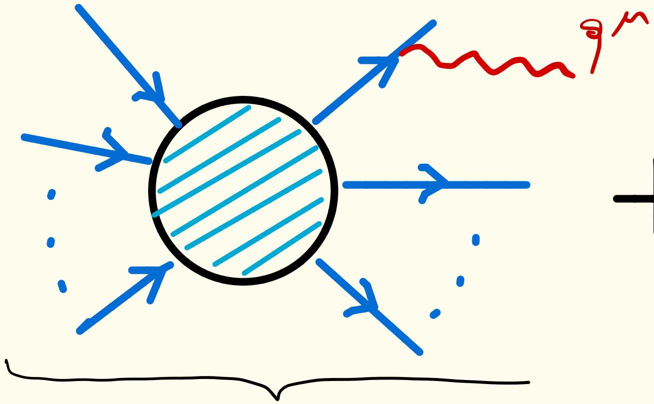
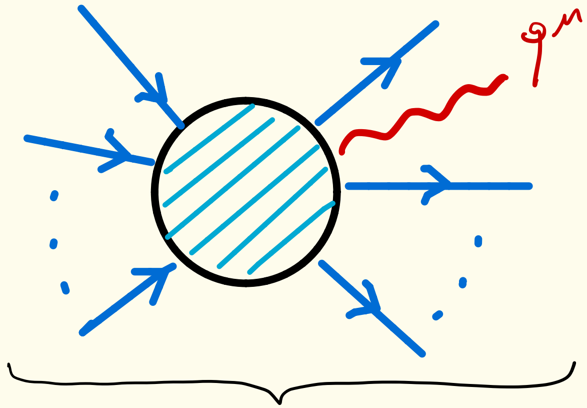


LEADING

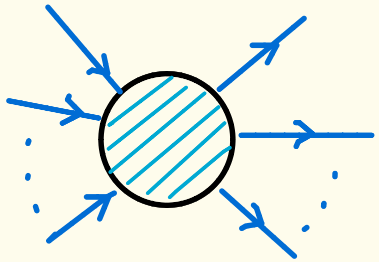
$$+$$



SUBLEADING

$$q^2 = 0 \,, \quad q^\mu \to 0$$

$$\left\{ \sum_{n \in \{in, out\}}' g_n^{(s)} \frac{\epsilon_{\mu_1 \dots \mu_s}(q)\, p_n^{\mu_1} \cdots p_n^{\mu_s}}{p_i \cdot q} \right\}$$



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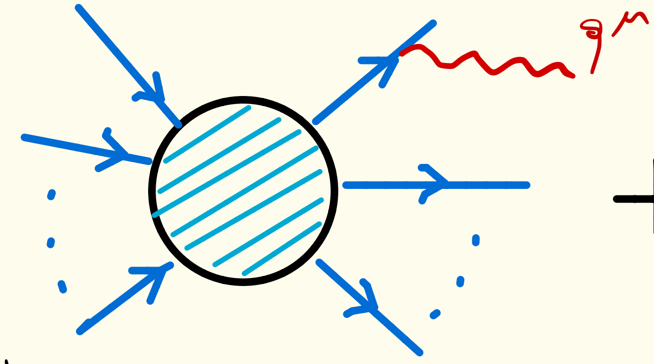

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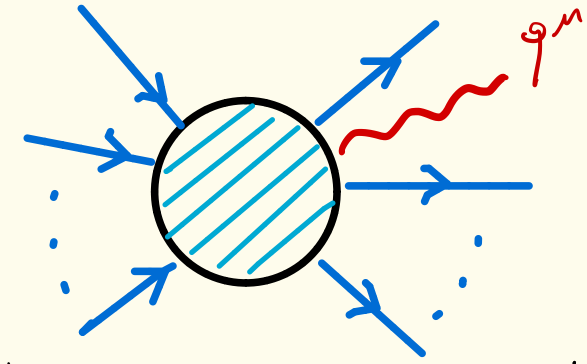

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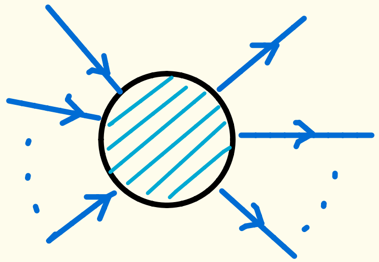

S-MATRIX LORENTZ INVARIANCE:

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* $s=2 \longrightarrow g_m^{(2)} = g$
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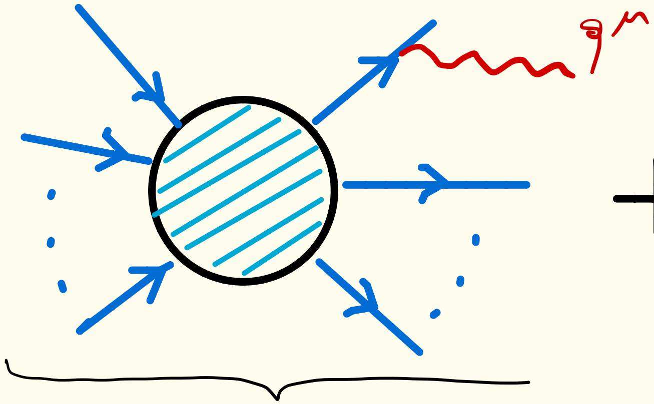

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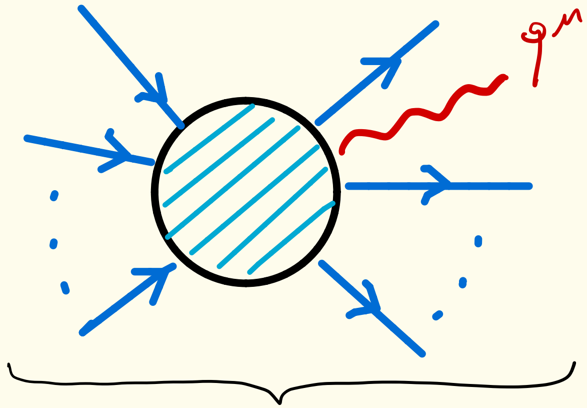

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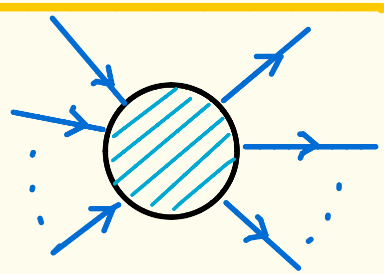

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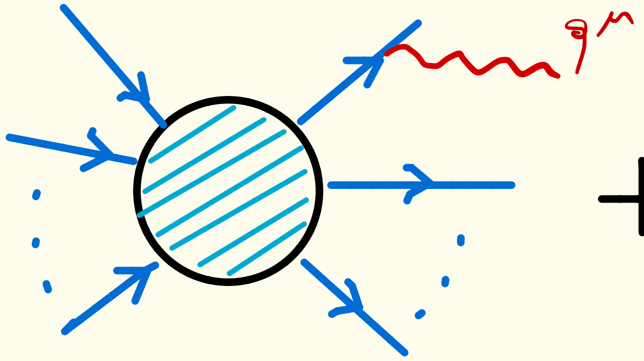
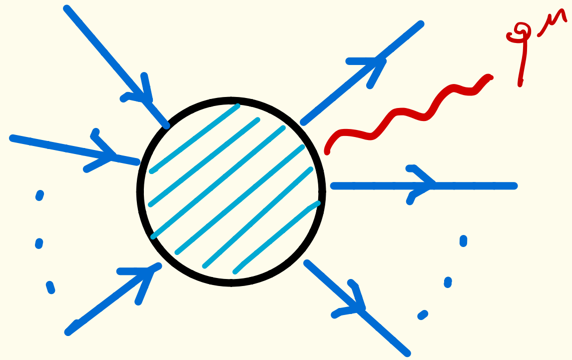
$$S_{\alpha\beta}(q) =$$  $+$ 

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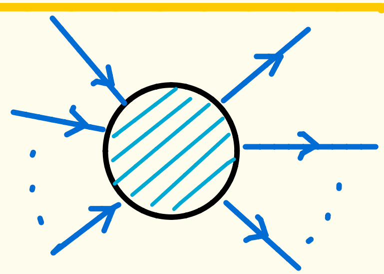
$$\left\{ \sum_{n \in \{in,out\}}' g_n^{(s)} \, \frac{\epsilon_{\mu_1 \dots \mu_s}(q)\, p_n^{\mu_1} \cdots p_n^{\mu_s}}{p_i \cdot q} \right\}$$ 

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STROMINGER et (many...) al.

WARD IDENTITY OF $\begin{cases} \text{MAXWELL'S LGT} & s = 1 \\ \text{BMS SUPERTRANSLATIONS} & s = 2 \end{cases}$

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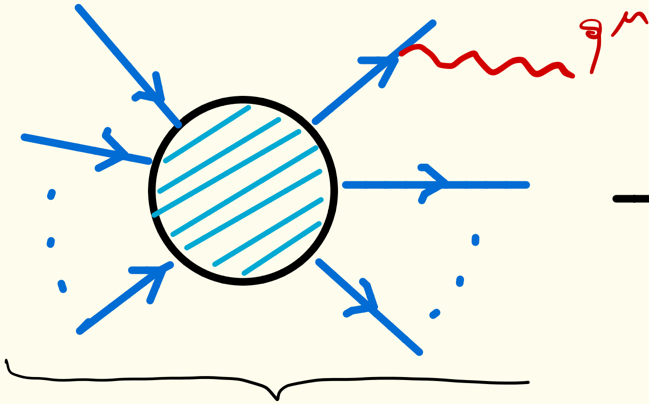

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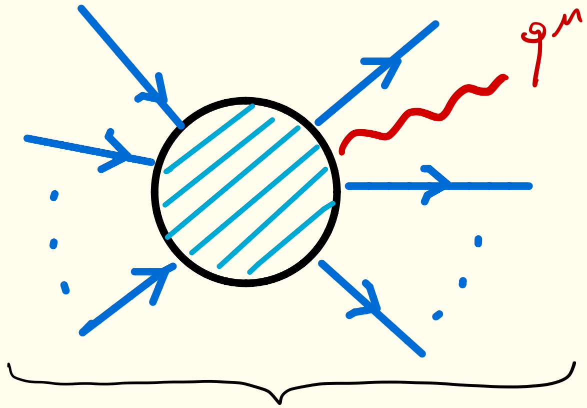

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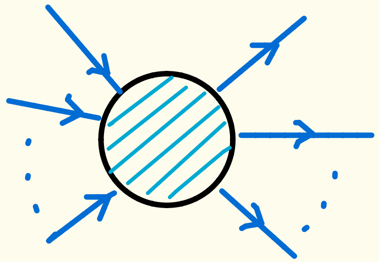

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FOR $S \geq 3$:

CAN ONE INTERPRET WEINBERG'S RESULT AS THE WARD IDENTITY STEMMING FROM SOME ASYMPTOTIC HIGHER-SPIN SYMMETRY?

§ II. HIGHER SPINS

§ II. Higher spins

* Asymptotic symmetries

FALL-OFFS & BONDI-LIKE GAUGE

CRUCIAL STEP: ASSIGN SPIN-S FALL-OFF CONDITIONS

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$(z \longleftrightarrow \bar{z})$

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* SPIN S: $\varphi_{\mu_1 \ldots \mu_{s-1} r} = 0$

$$\varphi_{\mu_1 \ldots \mu_{s-2} z\bar{z}} = 0$$

$$\varphi_{u \ldots u \underbrace{z \ldots z}_{k}} = O(r^{k-1})$$

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$\varphi_{\mu_1 \dots \mu_{s-2} z \bar{z}} = 0$

$\varphi_{u \dots u \underbrace{z \dots z}_{k}} = O(r^{k-1})$

* GUIDING LINES :

- ANALOGY WITH GRAVITY
- CONSISTENCY WITH FREE EOM

PROGRAM:

- COMPUTE THE RESIDUAL SYMMETRIES

$$\delta \varphi_{\mu_1 \ldots \mu_s} = \nabla_{(\mu_1} \epsilon_{\mu_2 \ldots \mu_s)}$$

  (IF ANY) THAT KEEP THE BONDI-LIKE "GAUGE"

- SEE WHETHER THEY BEAR ANY RELATION TO WEINBERG'S SOFT THEOREM

HIGHER-SPIN SUPERTRANSLATIONS

SIMPLIFYING ANSATZ: u-INDEPENDENT RESIDUAL SYMMETRY

→ The residual gauge symmetry gets determined by a set of recursive equations:

$$\epsilon_{\underbrace{u\dots u}_{p}\,\underbrace{z\dots z}_{k}\,\underbrace{z\bar{z}\dots z\bar{z}}_{c+1}}(z,\bar{z}) \sim \epsilon_{p,k,c} - 2\,\epsilon_{p+1,k,c}$$

$$\epsilon_{p,k,0} \sim r^{k} D_{z}^{k} T_{p}(z,\bar{z})$$

$$T_{p+1} \sim \alpha(s,p)\,T_{p} + \beta(s,p)\,D^{z}D_{z}\,T_{p}$$

→ Eventually, HIGHER-SPIN SUPERTRANSLATIONS are parametrised by a single arbitrary function $T(z,\bar{z})$

HIGHER-SPIN SUPERROTATIONS $(s=3)$

LOOK FOR THE GENERAL SOLUTION, FOR $\epsilon_{\mu\nu} = \epsilon_{\mu\nu}(u, z, \bar{z})$

BESIDES HSP SUPERTRANSLATIONS, PARAMETRISED BY $T(z,\bar{z})$

WE FIND:

→ $K_{ij}(z, \bar{z})$ CONFORMAL KILLING TENSORS ON THE CELESTIAL SPHERE $\left(K(z), \tilde{K}(\bar{z})\right)$

→ $\rho_i(z, \bar{z})$

$$\rho^z = \alpha(z) + \partial_z K(z,\bar{z}) + \beta(z)$$

$$\tilde{\rho}^{\bar{z}} = \tilde{\alpha}(\bar{z}) + \partial_{\bar{z}} K(z,\bar{z}) + \tilde{\beta}(\bar{z})$$

- i,j run over coordinates on the celestial sphere
- K_{ij} and ρ_i satisfy differential constraints.

ENHANCING WHAT ?

$$\mathfrak{bms}: \left\{ \begin{array}{lll} T \quad (ST) & \longleftrightarrow & P^\mu \\ & & \\ Y_z \quad (SR) & \longleftrightarrow & M^{\mu\nu} \end{array} \right\}$$

INFINITE - DIM
ENHANCEMENT OF
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INFINITE - DIM ENHANCEMENT OF POINCARÉ

$$\text{“}\mathfrak{ahs}_3\text{”} : \begin{cases} T & \longleftrightarrow \quad P^{(\mu}P^{\nu)} \\ K_{ij} & \longleftrightarrow \quad M^{\mu(\nu}M^{\rho)\sigma} \\ P_i & \longleftrightarrow \quad P^{(\mu}M^{\nu)\rho} \end{cases} \Bigg\} \; 1 \div 1 \text{ WITH SOLUTIONS OF } \partial_{(\mu}\epsilon_{\nu\rho)} = 0$$

INFINITE - DIM ENHANCEMENT OF $s=3$ KILLING

§ II. HIGHER SPINS

* SOFT THEOREMS

(leading order)

SUPERTRANSLATION WARD IDENTITY

→ LET US EXPLORE THE CONSEQUENCES OF $[Q = Q_{SOFT} + Q_{HARD}, S_{MATRIX}] = 0$

* $$Q_s^+ \sim \int_{\mathscr{I}^+} T(z,\bar z)\, \partial_u D_z^s B_{z\ldots z}(u,z,\bar z)\, \gamma_{z\bar z}\, dz\, d\bar z\, du$$

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where : → Q_s^+ is FINITE and $\neq 0$ (check on admissibility of fall-offs);

→ Analogous expression for Q_s^-;

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- → Analogous expression for Q_s^-;
- → Suitable bd conditions at $\mathcal{J}^{\pm}_{\mp}$ are assigned;

* $$[Q_H^+, \Phi] \sim i T(z,\bar{z})\, \partial_u^{s-1} \Phi$$

* $$\langle \mathrm{OUT} | Q_s^+ S - S Q_s^- | \mathrm{IN} \rangle \sim \sum_i g_i^{(s)}\, T(z,\bar{z})\, E_i^{s-1} \langle \mathrm{OUT} | S | \mathrm{IN} \rangle$$

REPRODUCING WEINBERG'S RESULT

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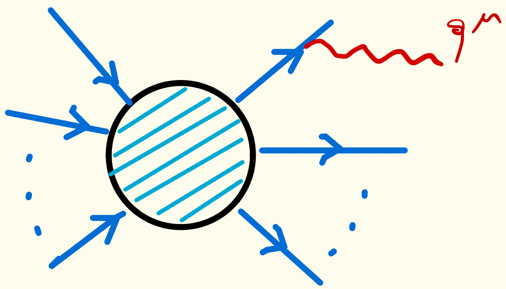
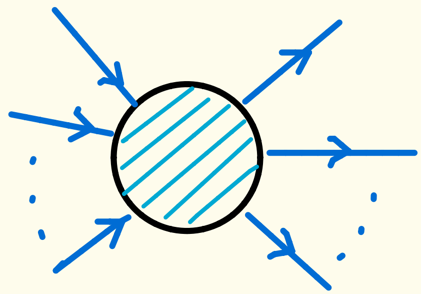


$$= \left\{ \sum_{n \in \{in, out\}}' g_n^{(s)} \frac{\epsilon_{\mu_1 \dots \mu_s}(q)\, p_n^{\mu_1} \dots p_n^{\mu_s}}{p_i \cdot q} \right\}$$



§III. Remarks & Outlook

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* HSP FLAT-SPACE SCATTERING ASSUMED TO BE TRIVIAL;

SO WHAT?

STILL ASYMPTOTIC SYMMETRIES EXPECTED TO LEAVE REMNANTS IN A (PUTATIVE) BROKEN MASSIVE PHASE.

OUTLOOK

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* MOST GENERAL CLASS OF SENSIBLE FALL-OFFS ;

* CHARGES & VERTICES ; UNDERLYING ALGEBRAIC STRUCTURE ;

* ASYMPTOTIC SYMM'S BEYOND SUBGROUPS OF BULK LOCAL SYMM'S

* AdS_4 ;

* $D > 4$ [Weinberg's result (apparently) valid in any D] ;

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* UNDERSTANDING THE IR PHYSICS OF HSP SYSTEM: CRUCIAL STEP TO THE GOAL OF ASSESSING THEIR ROLE AT A FUNDAMENTAL LEVEL;

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  WILL BE OF CENTRAL IMPORTANCE

→ ELABORATING ON ASYMPTOTIC SYMMETRIES IN $D \geq 4$ PROVIDES AN ALTERNATIVE ANGLE FROM WHICH ATTEMPTING TO GET SOME INSIGHTS, POSSIBLY CONNECTING TO THE EXPLORATIONS RELATED TO FLAT HOLOGRAPHY.