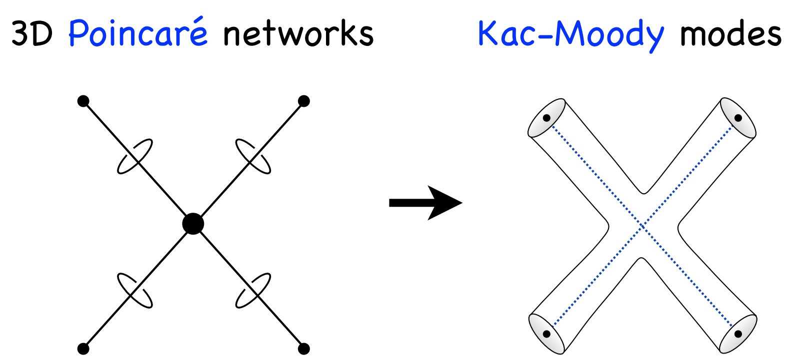
⭐ Goal: New description of quantum geometry by understanding the nature of the universal corner symmetry algebra $\mathfrak{g}_S \supset \mathfrak{su}(2)$ of any subregion of space

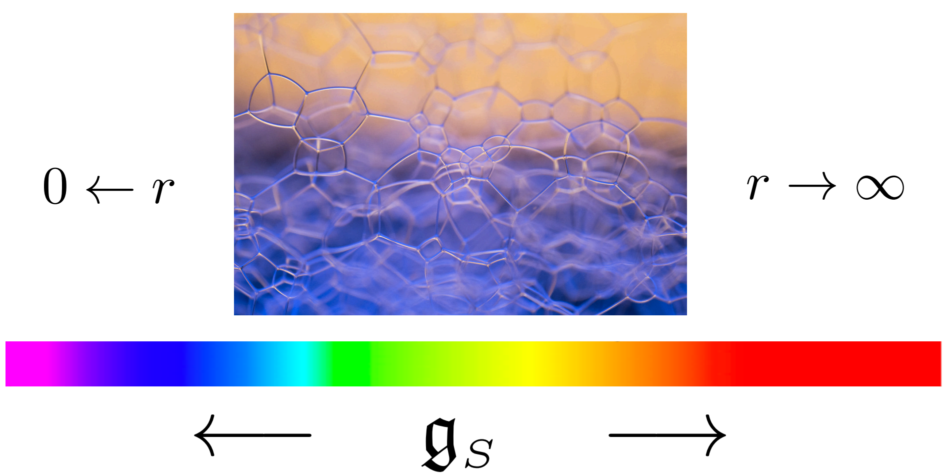
☞ Organizing principle for understanding quantum gravity

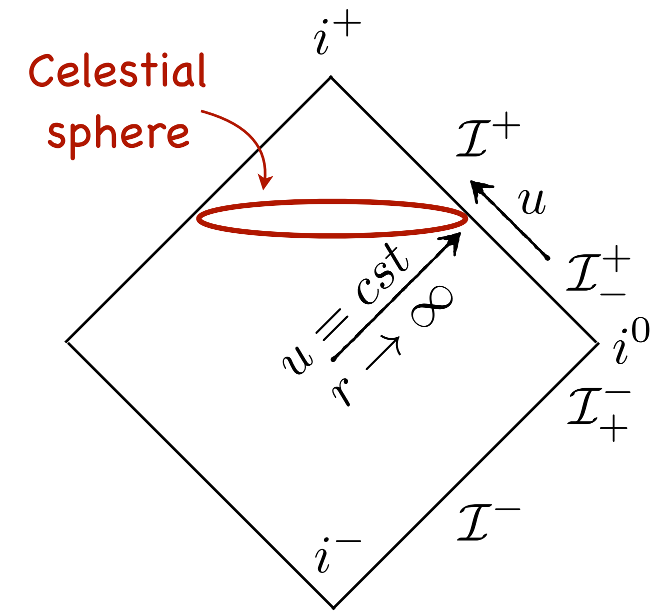
Space = network of "bubbles"

Corner symmetry charges = Coarse-grained information of geometrical DOF inside each region it encloses



LQGs: SU(2) -> SL(2,C) -> Poincaré





BMS group

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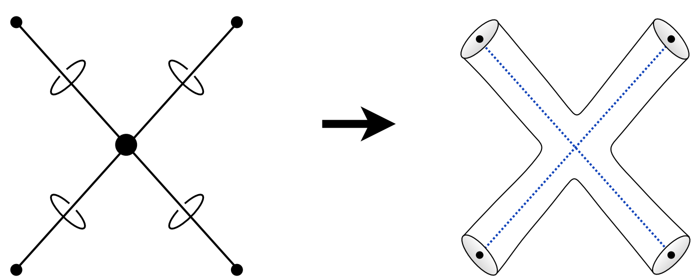
3D Poincaré networks → Kac-Moody modes



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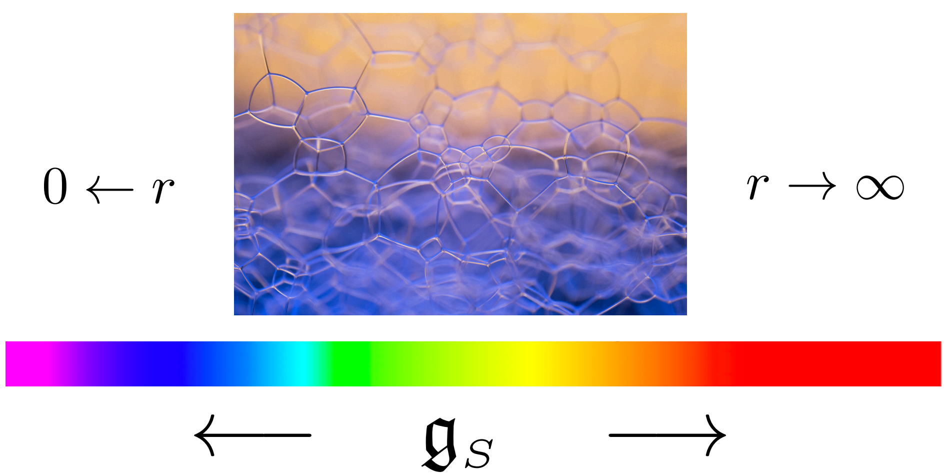
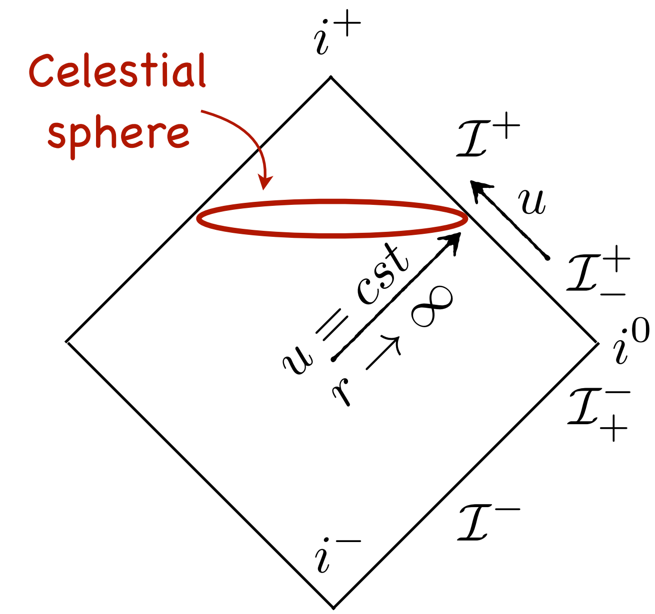
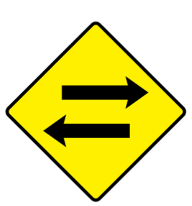




BMS group

- Symmetries of null infinity
- Properties of scattering amplitudes in the IR

Factorization properties of scattering amplitudes in the zero energy limit of an external graviton $\longleftrightarrow$ Conservation laws of an infinite number of charges associated to the asymptotic symmetry group of null infinity



- Possibility to apply LQG techniques to the asymptotic quantization program
- Symmetry constraints to test the correct implementation of quantum dynamics

Building on [Ashtekar, Streubel 1981], [Barnich, Troessaert 2010], [Campiglia, Laddha 2014]
and weakening boundary conditions to allow Bondi frame [Bondi, van der Burg, Metzner, Sachs 1962] to fluctuate:
2-sphere Conformal class and conformal scale allowed to vary

- Corner symmetry group $\longrightarrow$ Weyl BMS group = Group of asymptotic symmetry [Freidel, Oliveri, DP, Speziale 2021]

$$\mathrm{BMSW} = \underbrace{(\mathrm{Diff}(S) \ltimes \mathbb{R}^S_W)}_{:=H_S \text{ Kinematical subgroup}} \ltimes \mathbb{R}^S_T \subset G_S$$

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- Gravity from symmetry [Freidel, DP 2021]

Asymptotic Einstein's equations can be reconstructed by identifying the combinations of metric components and their derivatives that transform homogeneously under arbitrary BMSW transformations

Corner charges = Primary fields for the kinematical subgroup H_s

$$\delta_{(Y,W)} O_{(\Delta,s)} = (\mathcal{L}_Y + (\Delta - s)W) O_{(\Delta,s)} \qquad \Delta = \text{ Conformal dimension,} \quad s = \text{ Spin}$$

Asymptotic EEs in terms of primaries:

$$\boxed{\begin{aligned} \dot{\mathcal{J}} &= \tfrac{1}{2} D\mathcal{N}\,, \\ \dot{\mathcal{M}}_{\mathbb{C}} &= D\mathcal{J} + \tfrac{1}{4} C\mathcal{N}\,, \\ \dot{\mathcal{P}} &= D\mathcal{M}_{\mathbb{C}} + C\mathcal{J}\,, \\ \dot{\mathcal{T}} &= D\mathcal{P} + \tfrac{3}{2} C\mathcal{M}_{\mathbb{C}} \end{aligned}}$$

$\mathcal{J} =$ Covariant energy current

$\mathcal{N} = \ddot{C} =$ Radiative data

$\mathcal{M}_{\mathbb{C}} = \mathcal{M} + i\tilde{\mathcal{M}} \leftarrow$ Dual covariant mass

$\mathcal{P} =$ Covariant angular momentum

$\mathcal{T} =$ Spin-2 charge

Evolution Eq.s = Primary fields for the full BMSW

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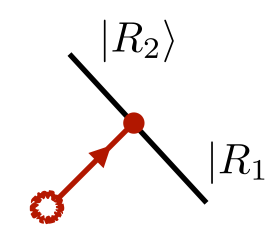
Evolution Eq.s = Primary fields for the full BMSW

Lessons from LQG

- Asymptotic non-perturbative quantum dynamics akin to the imposition of SU(2) invariance in LQG
  - Vacua labelled by representations $|R\rangle$ of the kinematical BMSW
  - Impulsive waves [Wieland 2019]; [Freidel, DP 2021] as a new basis for vacuum transitions at all orders in G_N

WORK IN PROGRESS

Notion of generalized intertwiner to fuse tensor products of irreducible representations associated to the non-radiative corner phase space at consecutive instants of time at $\mathcal{I}$?



- New memory effects: Inclusion of the dual mass in the leading soft theorem for a possible measurement of the Immirzi parameter ?

Charge action

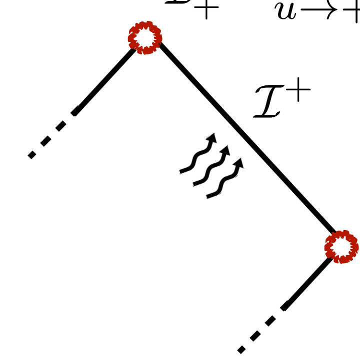
$$\boxed{\delta_{\tau_s} C(u,z) = \{Q_s(\tau), C(u,z)\}}$$

where $$Q_s(\tau) := \int_S \mathrm{d}^2 z\, \tau_s(z) q_s(z) \qquad s = 0,1,2$$

Renormalized charges: $$q_0 := \lim_{u\to-\infty} \mathcal{M}_{\mathbb{C}}\,, \qquad q_1 := \lim_{u\to-\infty} \mathcal{P} + \cdots\,, \qquad q_2 := \lim_{u\to-\infty} \mathcal{T} + \cdots$$

$q_s \overset{\text{EEs}}{=} q_s[C,N]$ $+$ Radiative phase space [Ashtekar 1981]: $$\{N(u,z), C(u',z')\} = \frac{\kappa}{2}\delta(u-u')\delta(z,z')$$

In order to integrate the recursion relation, we need to assume that



This allows us to define the charge aspects as integrals over their flux: $$q_s(z) = \int_{-\infty}^{\infty} \mathrm{d}u\, \dot{q}_s(u,z)$$

and to use basic bracket of the radiative phase space at null infinity to compute the symmetry action on C

Universal behaviour of scattering amplitudes

In the limit $\omega \to 0$: $\langle \mathrm{out}| a_{\pm}(\omega \hat{x}) \mathcal{S} |\mathrm{in}\rangle = \left(S_{\pm}^{(0)} + S_{\pm}^{(1)} + S_{\pm}^{(2)} \right) \langle \mathrm{out}|\mathcal{S}|\mathrm{in}\rangle + \mathcal{O}(\omega^2)$

Soft factors: Leading Subleading Sub-subleading

[Weinberg 1965] [Cachazo, Strominger 2014]

In order to have a well defined scattering problem in GR [Strominger 2013] :

$$q_s(z)|_{\mathcal{I}^+_-} = q_s(\epsilon(z))|_{\mathcal{I}^-_+} \qquad \longrightarrow \qquad \langle \mathrm{out}|\; q_s(z)|_{\mathcal{I}^+_-}\, \mathcal{S} - \mathcal{S}\; q_s(\epsilon(z))|_{\mathcal{I}^-_+}\, |\mathrm{in}\rangle = 0$$

antipodal match

Infinite number of Conservation laws = Symmetries of the S-matrix

Truncated Ward identities:

$$\langle \mathrm{out}|[q_s^1, \mathcal{S}]|\mathrm{in}\rangle = -\langle \mathrm{out}|[q_s^2, \mathcal{S}]|\mathrm{in}\rangle$$

☞

Leading, subleading, sub-subleading soft th.s

$s = 0 \qquad s = 1 \qquad s = 2$

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Asymptotic Einstein's eq.s $\longleftrightarrow$ Ward identities

[Strominger 2014]; [Kapec, Lysov, Pasterski, Strominger 2014]; [Campiglia, Laddha 2014]; [Freidel, DP, Raclariu 2021-I]

Lessons for LQG

- Mutual consistency of the loop and spin foam quantizations from symmetry constraints:

Asymptotic EEs $\leftrightarrow$ $\mathcal{S} \sim \lim_{t\to\infty} e^{iHt}$, $\langle \mathrm{out}|[q_s, \mathcal{S}]|\mathrm{in}\rangle = 0$ ☞ Quantum dynamics in a local subregion $\overset{?}{\leftrightarrow}$ $\mathcal{A}_v \sim e^{i\hat{H}_v t}$, $\langle \Gamma_1|[q_s, \mathcal{A}_v]|\Gamma_2\rangle = 0$

We are proposing to represent bulk constraints as conservation laws for the local corner charges

(as for SU(2) gauge invariance)

- Representation of local space-like translations [Freidel, Livine, DP 2019] and SL(2, C) [Freidel, Geiller, DP 2020]

Use the action of the symmetry charges to constraint the form of the spin foam amplitude by demanding it satisfies the Ward identities